Greenroads™

MANUAL

v1.5

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FOREWORD

Welcome to the new and improved *Greenroads Manual v1.5*! In our fourth year of research and development, we have plenty of news to report! We are happy to announce that we have made great progress toward refining this continually developing system and you will see many changes in this version of the document as a result of input from case studies, pilot projects, and thoughtful comments we've gathered in the last year. Plus, we are pleased to announce that Greenroads has commercialized and is now a pending trademark of the University of Washington (UW)! We have also formed the Greenroads Foundation, a third-party non-profit corporation, with a mission of benefiting communities by promoting sustainability in transportation practice and education.

This *Greenroads Manual* contains ALL of the finer details of each Project Requirement (PR) and Voluntary Credit (VC) currently included in the Greenroads Rating System. You can use this document as a reference guide while you proceed through the design and construction phases of your Greenroads projects. For each PR and VC, this *Manual* provides the goal, what needs to be done to meet that goal, the documentation to prove those things were done, benefits, sustainability components addressed (*Ecology, Economy, Equity, Extent, Expectations, Experience and Exposure*), strategies, helpful examples and a supporting body of research and references to help you along the way. For those of you who may not have the time to read hundreds of pages of roadway research, you may note that there is also a shorter version of this manual, the *Greenroads Abridged Manual v1.5,* which is also available for download on the Greenroads website (http://www.greenroads.us). It has a green cover image.

IMPORTANT STUFF

- All 11 Project Requirements must be met and completed in order to be considered for certification. *All* of them. No exceptions. They are designed not to be difficult to do, especially if you start thinking about them early.
- Current point ranges for the four available certification levels are listed in the Introduction to the Manual. The minimum level of "Certified" means that all 11 PRs have been completed and that a minimum of 32 points have been earned by completing a variety of Voluntary Credits (VC).
- Please do not use the Greenroads logo or "Greenroads" without written permission of UW.
- Please give credit where credit is due. If you are using Greenroads in an article or paper, please be sure to cite appropriately. Here is a sample, in APA format:

Muench, S.T., Anderson, J.L., Hatfield, J.P., Koester, J.R., & Söderlund, M. et al. (2011). *Greenroads Manual v1.5.* (J.L. Anderson, C.D. Weiland, and S.T. Muench, Eds.). Seattle, WA: University of Washington.

HOW TO SUBMIT YOUR COMMENTS

- Visit the Greenroads website: http://www.greenroads.us.
- Sign up to be a Reviewer by clicking the bottom grey and white button on the front page that says "Review the Manual" or by following this link directly: http://www.greenroads.us/312/register-to-review.html
- Fill in your contact information and you will receive a confirmation email with your login credentials.
- Navigate the online version of the *Manual,* which is in the orange box on the right hand side of your screen when you visit the website.

ADDITIONAL NOTES

- We fixed the pagination and have provided a table of contents in this edition.
- We have published a version 1.0.1 to v1.5 "Errata" which is downloadable from our Manual webpage. Errata have a blue cover image and show the date of publish in their titles.

We look forward to working with you on Greenroads!

Jeralee Anderson, Craig Weiland, and Steve Muench
Editors

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This updated version of the *Greenroads™ Manual* would not have been possible without the concerted effort of many smart individuals who are devoted to making roadway design and construction practice more sustainable. In particular, Greenroads would not have become what it is today without the initial concept from Martina Söderlund. Much credit is due to Martina. Her original master's thesis work, *Sustainable Roadway Design: a Model for an Environmental Rating System* (2007) is available at the University of Washington libraries.

AUTHORS & CONTRIBUTORS

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University of Washington

Stephen T. Muench, PhD., P.E.
Jeralee L. Anderson, P.E., LEED®AP
Craig Weiland
Jared Koester
Eric Peterson
Maleena Scarsella
Steven Lampert
Celeste Hoffman
Nicholas Jones
David Vichitthavong
Malissa Phok
Aaron Knight
Erika Ramirez
Martina Söderlund
Joshua Hatfield
Kari Watkins, P.E.
Yenyu Lin
Paul Prigge
Jin Woo Bae
Rachel Liberty
Adnan Shabir
Andrea Gagliano
Andrew Sahl
Katherine McIntyre
Juliette Peyroux
Manisa Veeravigrom

UNIVERSITY of WASHINGTON

CH2M HILL, Inc.

Timothy Bevan, P.E.
Sam Seskin
Marcy Schwartz
Kristin Hull
Joe Guenther
Scott Barber, R.L.A.
Daniel Pitzler
Robin Senner, Ph.D.
Chuck Blair, C.W.B.
Amy Elliott, P.E.
Anneke Davis, P.E.
Daniel Peterson, P.E.
Linda Cyra-Korsgaard, R.L.A.
Steve Mader, C.E.
Russell Mudgett
Donald Wagner, P.E.
Guy Caley, P.E.
Louise Brown
Loren Bloomberg, P.E.
Kathleen Penney, P.E.

CH2MHILL

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Oregon Department of Transportation

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University of Washington

Joe Mahoney, PhD.
Tim Larson, PhD.
Russell Torgesen, P.E., LEED®AP
Joyce Nuesca, M.D.
Sabine Eisma
Rosslyn Luke
Christopher Croft
Ancelmo McCarthy

CH2M HILL, Inc.

Tim Neuman, P.E.
Kirsten Pennington
Mark Bastasch, P.E.,
Mike Paddock, P.E., P.L.S.
Bill Derry
Canisius Chan, P.Eng.
Alex Chan, P.Eng.
John Willis, P.E.
Kevin Murphy, P.E.
Thomas Cahill, P.E.
Grahm Satterwhite

Others

Amit Armstrong, Ph.D., P.E., *Western Federal Lands Highway Division (WFLHD)*
Lyn Cornell, *ODOT*
Kim Willoughby, P.E., *Washington Department of Transportation (WSDOT)*
Jeff Uhlmeyer, P.E., *WSDOT*
Jim Weston, P.E., *WSDOT*
Freeman Anthony, *City of Bellingham, WA*
Maureen Jensen, *Minnesota Department of Transportation*
Angela Brady, P.E., PMP *Seattle Department of Transportation (SDOT)*
Mark Mazzola, *SDOT*
Erin Moxon, *British Columbia Ministry of Transportation*
Daniel Medina, Ph.D., P.E., *PBS&J*
Michael Booth, P.E., *Perteet, Inc.*
Jesse Thomsen, *Perteet, Inc.*
Travis Rauscher, *Perteet, Inc.*
Debra T. Johnson, *Eco-Edge, LLC*
Mike Hutchinson, *GeoEngineers, Inc.*
Kiva Lints, *AECOM, USA, Inc.*
Kara Swanson, *Parsons Brinckerhoff, Inc.*
Steve Carter, *TriCar, Ltd.*
Tom Wheeler, *Transportation Corridor Agencies*

Volunteer Manual Reviewers

Bob Gansauer, *National Park Service*
Bob Holzheimer, *National Park Service*
Darin Thacker, *National Park Service*
Dennis Nagao, *National Park Service*
Ginger Molitor, *National Park Service*
Jan Burton, *National Park Service*
Jesse Van Horne, *National Park Service*
Jessica Hendryx, *National Park Service*
Karen Vaage, *National Park Service*
Lee Terzis, *National Park Service*
Margaret McRoberts, *National Park Service*
Robin Gregory, *National Park Service*
Steven Culver, *National Park Service*
Treff Alexander, *National Park Service*
Dean Potts, *Caterpillar*
Gary Aamold, *Consultant*
Skip Stothert, *Green Roads Recycling, Ltd.*
Jonathan Braadvedt, *KOA Corporation*
Lionel Lemay, *National Ready Mixed Concrete Association*
Tarek Eweida, *Parsons International*
Ryan Westrom, *Patrick Engineering, Inc.*
Mike Hendrix, *Perteet, Inc.*
Fares Abdo, *Portland Cement Association*
Donna DeNinno, *UNI-GROUP, USA*
Judith Rochat, *US DOT / RITA / Volpe Center*

INTRODUCTION

INTRODUCTION

WHY GREENROADS™?

Did you know that in order to make one lane of road, one mile long, you would need to use the same amount of energy used in one year by about 50 average American households? In 2008, the United States had almost 8.5 million lane-miles of pavements and 600,000 bridges. So, the energy we have already used to make our transportation network is over 25% of that used by the entire U.S. in the entire year in 2005. With the national call to energy efficiency standards for our built environment, why not also look to improve how we get from place to place every day by rethinking what we use, how we use it, where it comes from, and how it all fits together?

Roads and bridges are a critical part of our nation's economic prosperity and local community well-being. It may be hard to believe that out of the total 100 hours Americans spend on the road commuting to work every year, almost one whole work week (36 hours) is lost just waiting for road construction projects to be finished. You might even be surprised to learn that construction delays cost regular Americans almost $80 billion in lost productivity, benefits, and wages annually. These delays also represent 2.9 billion gallons of wasted fuel and countless carbon dioxide emissions, as well as other harmful environmental exhausts that can cause acid rain and smog. In busy cities, many people may agree that their local congestion problems can be even worse (in some cases, they are)!

People obviously suffer frustrations, but our natural environment probably suffers even more. We all depend on how well the environment functions for our own health, livelihoods, and cultures. Sadly, even the convenient street to and from your local grocery store could be to blame for loss and destruction of sensitive habitats and wetlands, undrinkable water, collisions with innocent animals, and lots of loud noise and unpleasant odors.

The good news is that there is now a way to address and solve some of these problems, or at least a way to help us manage them better and to make the right decisions when we are thinking about building new roads in our communities: the Greenroads™ Rating System. Greenroads is a tool (http://www.greenroads.us) that can help road builders work to make better transportation projects every day, one project at a time.

Figure I.1: Greenroads Pilot Project at Northshore Drive in Bellingham, Washington. Photo by Freeman Anthony, City of Bellingham Public Works

WHAT IS GREENROADS™?

Greenroads is a voluntary third-party rating system for road projects. A rating system can be useful for many reasons. Ultimately, Greenroads seeks to recognize and reward roadway projects that exceed public expectations for environmental, economic and social performance.

Fundamentally, Greenroads helps quantify the sustainable attributes of a roadway project. This quantification can be used to:

- Define what features contribute to sustainability on the project.
- Provide accountability for sustainability on roadway projects.
- Measure and track specific sustainability goals over time.
- Manage and improve roadway sustainability.
- Encourage new and innovative practices.
- Promote competitive advantage and other economic or market incentives for sustainability.
- Communicate sustainable features to stakeholders in an understandable way, especially to the general public.

WHAT IS A GREENROAD?

A Greenroad is defined as a roadway project that has been designed and constructed to a level of sustainability that is substantially higher than current common practice.

Greenroads is an award-based, flexible rating system (sometimes called a "performance metric") that can be used to rank, score and compare different road projects for their overall performance toward being more sustainable than an average road project. Earning a Greenroads award, called "certification" is like winning the Olympic Games for roads: projects earn points for special activities. Upon successful completion, a distinctive sign can be used on road projects that go above and beyond current standards for environmental compliance, roadway design and construction practice. These projects demonstrate a level of excellence in sustainability beyond the average roadway project and communicate substantial achievement to project stakeholders.

Figure I.2: Yellowstone East Entrance Pilot Project, Western Federal Lands Highway Division. Photo by Chris Croft

A NOTE ON COPYRIGHT AND TRADEMARK USE

Greenroads is a publicly available system that can be used by anyone. However, the Greenroads logo and name remain the property of the University of Washington and may only be used with express permission of the UW or a licensed agent. Any use of ideas or references to Greenroads requires proper citation of Greenroads as the origin of these ideas and recognition that UW owns the trademark.

HOW GREENROADS™ WORKS

Greenroads is a collection of sustainability best practices that apply to roadway design and construction. These best practices are divided into two general types: required and voluntary. Greenroads activities are not intended to supersede local, state, or federal regulation or other jurisdictional ordinances.

WHAT IS REQUIRED

At minimum, every Greenroads project must complete 11 specific activities in order to qualify for any award. No exceptions. These activities are straightforwardly called Project Requirements (PRs) and are grouped together as the first category in the *Manual*.

The PRs are intended to capture some of the most critical ideas of sustainability for any roadway project from planning, design, construction and operations and maintenance, such as:

- Environmental and economic decision-making
- Public engagement
- Design for long-term environmental performance
- Construction planning
- Planning for lifetime monitoring and maintenance

Note that many, but not all, projects will meet several of the PR outright with little or no additional effort. This is because underlying many of these credits are ideas that are often regulated by both federal and state laws. However, because states carry a significant amount of autonomy for many laws, some of the standards in the PRs may be somewhat stricter or possibly less strict than the project's actual state laws. PRs carry no point value.

Figure I.3: Fernan Lake Road Pilot Project, Fernan Lake, ID. Western Federal Lands Highway Division. Photo by Chris Croft

WHAT IS OPTIONAL

Voluntary best practices are those that may optionally be included in a roadway project. These are called "Voluntary Credits". Each Voluntary Credit is assigned a point value (1-5 points) depending upon its impact on sustainability. Currently, there are 37 Voluntary Credits totaling 108 points. Greenroads also allows a project or organization to create and use its own Voluntary Credits (called "Custom Credits"), subject to approval of Greenroads, for a total of 10 more points, which brings the total available points to 118.

Project teams apply for points by submitting specific documentation in support of the Project Requirement or Voluntary Credit they are pursuing. These documents, which can range from project specifications to field documentation, are verified by an independent review team. Once a project is complete, the Greenroads team verifies the application and assigns a Greenroads score based on achieving all 11 of the Project Requirements and the number of points earned from the Voluntary Credits. This score may then be used at the owner's discretion and may also be translated to a standard achievement level or "certification" if so desired: the more points earned, the higher the recognition. If a project reaches a certification level it will be able to display the Greenroads logo and appropriate certification graphic once permission from the Greenroads team is given. The Greenroads certification levels are detailed in a subsequent section of this document.

Owner agencies, developers, design consultants and contractors may wish to pursue official certification or use Greenroads in other ways that are either voluntary or prescriptive. For instance, developers and designers may wish to use Greenroads as a list of potential ideas for improving the sustainability of a roadway project. Or, owners may wish to use Greenroads point values or certification levels as goals or benchmarks for new roadway projects or metrics by which they can measure and manage their roadway sustainability efforts.

IS GREENROADS RIGHT FOR ME?

There are a number of stakeholders who may have interest in a roadway sustainability rating system. Each stakeholder is likely to have opinions on how Greenroads should work; however it should be noted that not all points of view can be fully accommodated. Stakeholders include:

- Road owners: federal, state, county and city agencies as well as the general public.
- Funding agencies: federal, state, county, city and other regional authorities
- Design consultants: those involved with corridor, road or even parking lot design
- Contractors: heavy construction, road and paving contractors
- Regulatory agencies: U.S. Environmental Protection Agency
- Sustainability organizations: U.S. Green Building Council (USGBC), Green Highways Partnership, Sierra Club, etc.
- Research organizations: universities and other research organizations that participate in investigating transportation related sustainable technologies.

GENERAL PHILOSOPHY OF THE RATING SYSTEM

The fundamental tenets that guide the development and writing of Greenroads are:

- **Straightforward and understandable.** Non-experts should be able to understand the system. Simplicity is valued over excessive detail because it is more understandable. Project Requirements and Voluntary Credits are often simplistic interpretations of complex ideas; they are bound to contain some controversy however the interpretation should hold true to the fundamental idea.
- **Empirical evidence and existing evaluative techniques.** Project Requirements and Voluntary Credits are based on a preponderance of empirical evidence and, to the extent possible, should be evaluated using existing tools and techniques.
- **Points commensurate with impact.** Items that have high economic, environmental or social impact are assigned more points than low impact items.
- **Flexible.** Greenroads should be able to accommodate a broad range of both urban and rural roadway projects from preservation overlays to major new corridor development. Project Requirements and Voluntary Credits should be applicable anywhere in the U.S. International versions may need further development in the future.
- **Continual evolution.** Over time, better ideas, more complete knowledge and technology advances will require Greenroads to be updated and changed.
- **Minimal bureaucracy.** Pursuing certification requires documentation but documents should either come from existing documents (e.g. plans and specifications) or be simple and inexpensive to produce from existing documents.
- **Beyond minimum requirements.** Greenroads should spur innovation and encourage design and construction decisions based on sustainability considerations that go beyond regulatory requirements. While regulatory requirements and design standards contribute to sustainability, a rating system that awards credit for these items alone essentially becomes a marketing tool that is technically redundant and administratively burdensome.

WHO DEVELOPED GREENROADS?

Greenroads is a research project that originated at the University of Washington and has developed in several versions since the initial beginnings of research work in 2007. Version 0.95 (2009) was developed jointly by the University of Washington (UW) and CH2M HILL, with further work on v1.0, v1.0.1 and this version of the *Rating System* and *Manual* were managed through the University of Washington, with helpful collaboration from CH2M HILL and a number of other industry groups and consultants who have contributed data and commentary by means of pilot projects, case studies and public comments.

Current research at the University of Washington is headed by Steve Muench, an Associate Professor in the Department of Civil and Environmental Engineering. Work on the original 0.95 version of Greenroads at CH2M HILL was led by Tim Bevan, Mountain West Region Technology and Quality Manager, Transportation Business Group. Importantly, although UW and CH2M HILL are developing this system, the brand associated with any rated project will only be the Greenroads brand, which is a pending trademark of the University of Washington. The Greenroads Foundation, a third-party independent non-profit organization incorporated in 2010, is intended to be the sole licensee of the rating system and will manage future updates to maintain and continually improve Greenroads.

GREENROADS WEBSITE

All Greenroads work, including this *Manual* and all of its credits, is documented on the official website:

www.greenroads.us

Please visit this website to see the latest news, copies of presentations given, rated projects and other Greenroads related information. You can also contact Greenroads Foundation staff directly via the Contact Us form, register your projects or volunteer to review the *Manual*.

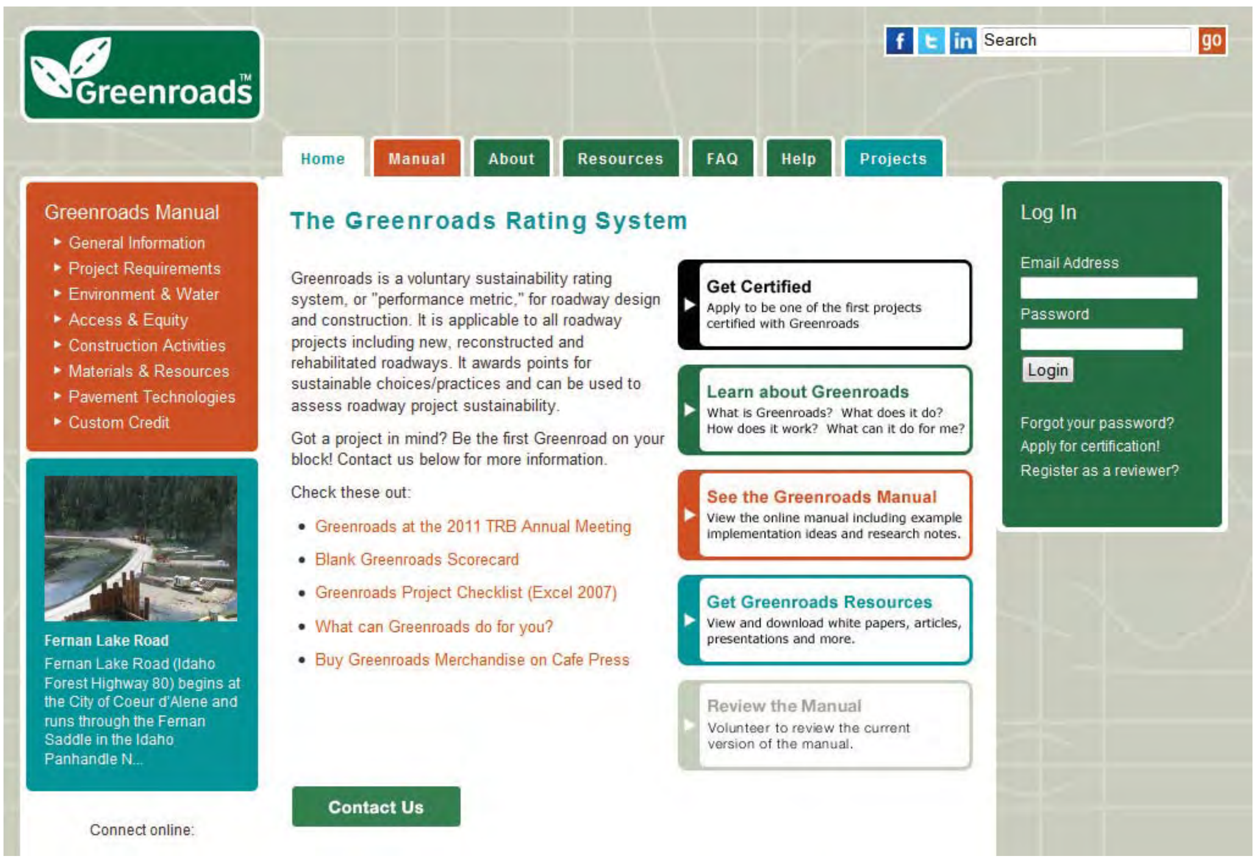

Figure I.4: Homepage of the Greenroads Website: http://www.greenroads.us

FUTURE CHANGES

Greenroads will change in the future as more information is gathered and new industry standard practices/rules are developed. This means that new credits could be added, old ones removed, point values changed, certification levels adjusted and more. No matter what the current Greenroads version is, we are already working on the next. Therefore, user comments are welcomed and might very well be incorporated into the next version. If you are getting pursuing certification under one version of the rating system while another comes out, you will be given the opportunity to upgrade to the latest version.

GREENROADS ESSENTIALS

This section describes the essentials of the Greenroads Rating System. These are items a project may want to know about when deciding whether or not to pursue Greenroads certification.

PROJECT REQUIREMENTS

Project Requirements are the minimum steps that must be completed in order to be considered a Greenroad. They can be thought of as characteristics common to all Greenroads. In order to achieve certification they must all be met and an additional number of Voluntary Credit points must also be earned. In other words, regardless of how many Voluntary Credit points are achieved, if a project does not meet all of the Project Requirements, a Greenroads certification level will NOT be awarded.

Project Requirements are listed in their own category at the front of the manual to distinguish them from the Voluntary Credit categories. The Project Requirements also consist of items or procedures that are often related to practices that can achieve points in one or more of the Voluntary Credit categories, which may strategically assist projects that are planning to pursue certification.

VOLUNTARY CREDITS

In addition to the Project Requirements, there is a wide selection of Voluntary Credits that a project can earn. Each Voluntary Credit is associated with a number of points (from 1 to 5) depending upon the impact the credit has on sustainability (as defined later in this document). A project chooses to pursue Voluntary Credits on a voluntary basis; none are required. Once those pursued Voluntary Credits are verified by the Greenroads team, the number of points achieved is tallied up and a certification level (see next section), if desired, is awarded.

Voluntary Credits span a wide spectrum of project actions from cultural outreach and multimodal access to safety to pavement materials. Therefore, it is likely that no project will be able to achieve all of the Voluntary Credits. However, the goal of Greenroads is to have enough choice in Voluntary Credits that any roadway project could find enough relevant credits to achieve at least a minimum certification level. This means that Greenroads should work for all roadway projects from basic preservation overlays to large, multi-billion dollar corridor projects.

ACHIEVEMENT/CERTIFICATION LEVELS

Greenroads may be used to “certify” a project based on total points achieved. Depending upon the appetite of the project, these levels can be called “achievement” or “certification” levels. Obtaining these levels is an official acknowledgement by Greenroads that a project has met all Project Requirements and achieved enough of the 118 possible Voluntary Credit points to surpass a predetermined certification level. There are four certification levels as shown below:

- Certified: All Project Requirements + 32-42 Voluntary Credit points (30-40% of total)
- Silver: All Project Requirements + 43-53 Voluntary Credit points (40-50% of total)
- Gold: All Project Requirements + 54-63 Voluntary Credit points (50-60% of total)
- Evergreen: All Project Requirements + 64+ Voluntary Credit points (>60% of total)

These levels are subject to revision with new versions of Greenroads and may change in the future as the system is updated. A certified roadway can be considered a Greenroad.

SCOPE OF THE GREENROADS RATING SYSTEM

This section describes the underlying ideas, scope and limits of Greenroads. It is expected that the basic system will grow and change as sustainability thought, technologies and regulations change. However, the fundamental concepts addressed here are expected to remain relatively constant.

HOW DOES GREENROADS FIT WITH REGULATORY STANDARDS?

Greenroads is designed to promote sustainability best practices within and beyond existing federal, state and local regulations. Specifically, Greenroads credits are designed to influence decisions regarding sustainability options where they are not precluded by regulation or where regulation allows a choice between options that could have sustainability impacts.

An important corollary to this is that Greenroads is not an absolute measure of sustainability because it does not include sustainability items that are covered by current U.S. regulation (e.g., Clean Water Act, Clean Air Act, National Historical Preservation Act, Americans with Disabilities Act, etc.). However, given that all U.S. agencies are governed by the same set of federal regulations, Greenroads can be considered a sustainability metric built on U.S. standard practice.

Greenroads is also meant to encourage organizations to include sustainable practices in their company-wide strategy and daily work practices. Importantly, Greenroads is not meant to dictate design or trade-off decisions. Rather it provides a tool to help with such decisions.

WHAT ARE THE SYSTEM BOUNDARIES?

Greenroads, in its current version, is a project-based rating system. This means that it is applicable to the design and construction of new or rehabilitated roadways, including expansion or redesign. There are shortcomings to a project-based system which are highlighted more briefly below. Specifically though, Greenroads best applies to the design process and construction activities within the workzone as well as material hauling activities, production of portland cement concrete (PCC) and hot mix asphalt (HMA).

If you are wondering if your project fits with a system like Greenroads, contact us directly or you can also browse the *Abridged Manual* with a checklist in hand to help you make that determination yourself. Chances are that you will be able to incorporate many of the ideas into your project. Actually, you may find that you are already thinking about many of them, but may have had trouble seeing how they would fit together, or help achieve your sustainability goals.

We also think transportation planners and public works agencies can use Greenroads as a handy tool during early project decision-making, internal accountability programs or even as a part of high-level planning or long-term maintenance and operations decisions. However, the majority of the credits in the Rating System do not address planning and operations in depth. We recognize the concern that this appears to create a piecemeal approach to sustainability but also that an enormous environmental impact happens immediately upon groundbreaking during roadway construction. Our long-term goal is to be able to develop project-specific credits that help roadway projects support and interconnect with many of the network-level decisions for sustainability at any owner-agency.

How Do Greenroads Projects Relate To Transportation Planning?

Decisions regarding the location, type, timing, feasibility or other planning level ideas for roadway projects are excluded. For example, Greenroads does not answer the question “should we build a road or not?” While planning is fundamental to roadway and community sustainability, these decisions are often too complex or political to be adequately defined by a point-based system. Project level planning however, in terms of project development and/or project delivery, is included and many of the Project Requirements and Voluntary Credits can be used during design and development to help shape decisions on the project.

How Does Greenroads Address Upstream Supply-Chain Processes?

Currently, no credits in the rating system explicitly address direct improvements in upstream supply-chain processes. This is because these upstream processes present a quantification problem that is fundamentally difficult to assign specifically enough to a roadway project. However, a handful of Greenroads credits do capture ideas that involve supply-chain processes, and also interconnect with each other to make a small contribution toward broader supply-chain goals.

An upstream supply-chain process is an activity that contributes only partly to a roadway project, such as petroleum refining or cement manufacturing. The reason this is difficult to quantify on a per-project basis is because these processes are multifunctional and have more than one product or result. Petroleum is used for a number of things beyond the gas that fuels vehicles, including the production of asphalt, which is actually a byproduct (waste) of the refining process. Also, cement and cement products are used in many applications beyond roadways, such as in buildings. Should a project be held responsible for all of the asphalt or cement in the batch, or just a portion of it?

Addressing the allocation of sustainability impacts to such industries or others that contribute to roadway design and construction would be a daunting task and we think it may also introduce unnecessary subjectivity to the rating system. Many upstream choices involve tradeoffs that are outside the control of a rating system tool like Greenroads. For this reason, multifunctional processes are a subject of hot debate and until there is established consensus on how to allocate responsibility, a project-level credit for such activities is not likely. Ultimately, it is not the primary goal or utility of a point-based rating system for roadway projects to address the sustainability of supply-chain management and this may be best left to experts in those fields.

We do try to improve awareness of these upstream activities and their impacts and tradeoffs through integration of lifecycle inventories (LCI) and assessments (LCA) through providing incentives to inform project decision-making. However, if there are suggestions on how to resolve some of these issues and integrate better with upstream goals, we would be glad to entertain them for future credits.

How Does Greenroads Address Structures?

Bridges, tunnels, walls and other structures are not explicitly considered in Greenroads, but they are not explicitly excluded either. In fact, several examples in the *Greenroads Manual* feature these types of structures. At this time though, no structurally-specific credits have been identified outside the pavement structure and bridges, but could easily be incorporated into future versions of Greenroads (i.e. via the Custom Credits). We think many of the existing Project Requirements and Voluntary Credits are appropriate to bridge and tunnel projects, because the credits are designed to be broadly applicable.

You may notice that in this edition of the *Manual* we have updated some of the pavement-specific credits to include alternatives for different types of structures. Many of these updates came out of our case study and pilot project research on a handful of bridge projects.

Non-pavement, non-bridge roadway structures, such as walls, luminaires and barriers, can be included in some credits conceptually as a lump of materials, but there are no credits exclusively for these road-related items. As always, comments are welcome regarding adjustments that would need to be made to be more reflective of sustainable activities for bridges, tunnels and other structures.

What about Operations & Maintenance Projects?

What Is Included. Overlays, rehabilitations, 2R, 3R, 4R, you name it. If pavement is being moved in a meaningful way, it is included (i.e. to and from site, around a site, etc.). A maintenance project intended to preserve the life of a roadway is a construction project for the purposes of Greenroads.

What Is Not Included. Activities that are performed as part of the Site Maintenance Plan (see PR-10), usually by Public Works Agencies and their contractors.

Maintenance and preservation activities are a key part in the long-term sustainability of a roadway, so there are a number of Project Requirements and Voluntary Credits that reflect these activities and require that a plan is in place for these to be performed sometime in the future. However, a rating system like Greenroads cannot be used to monitor these activities over the long-term effectively. This means that once the Greenroads score is calculated, essentially these maintenance and preservation plans become promises to perform.

The current review process for certification does not allow for ensuring that these promises are kept. Ideally, once a project becomes a Greenroad, the maintenance and preservation activities will also continue to follow this framework whether certification for these activities is pursued or not. We realize this is a weakness of the rating system in general and would appreciate feedback on how to incorporate these ideas in a meaningful, effective way. We have been thinking about this idea but have not been able to determine or identify a standardized, accepted way that currently meets all the requirements of our rating system philosophy. If you have ideas on how we can do this at a roadway project-level, we encourage you to submit for a Custom Credit on your project.

Does Greenroads Fit Pathway and Trail Projects?

Paths and trails may be able to use Greenroads too. We think that there is room for including these design and construction projects and that many of the ideas in Greenroads would work well. Some of the credits may require modification to be applicable though, and earning enough points to become Certified might be difficult depending on the size and scale of the project. However, if there is a pathway or trail directly associated with a roadway project, it is definitely included. If you have a pathway project that you want to test out with Greenroads, you can always contact Greenroads Foundation to inquire about pilot project opportunities.

GREENROADS RATING SYSTEM

LIST OF CREDITS (v1.5)

No.	Title	Pts.	Description
Project Requirements (PR) – Mandatory for all projects			
PR-1	Environmental Review Process	Req	Complete a comprehensive environmental review
PR-2	Lifecycle Cost Analysis (LCCA)	Req	Perform LCCA for pavement section
PR-3	Lifecycle Inventory (LCI)	Req	Perform LCI of pavement section
PR-4	Quality Control Plan	Req	Have a formal contractor quality control plan
PR-5	Noise Mitigation Plan	Req	Have a construction noise mitigation plan
PR-6	Waste Management Plan	Req	Have a plan to divert C&D waste from landfill
PR-7	Pollution Prevention Plan	Req	Have a TESC/SWPPP
PR-8	Low Impact Development (LID)	Req	Complete a LID feasibility study
PR-9	Pavement Management System	Req	Have a pavement management system
PR-10	Site Maintenance Plan	Req	Have a roadside maintenance plan
PR-11	Educational Outreach	Req	Publicize sustainability information for project
Environment & Water (EW) – Up to 21 Points			
EW-1	Environmental Management System	2	ISO 14001 certification for general contractor
EW-2	Runff Flow Control	1-3	Reduce runoff quantity
EW-3	Runoff Quality	1-3	Treat stormwater to a higher level of quality
EW-4	Stormwater Cost Analysis	1	Conduct an LCCA for stormwater elements
EW-5	Site Vegetation	1-3	Use native low/no water vegetation
EW-6	Habitat Restoration	3	Restore habitat beyond what is required
EW-7	Ecological Connectivity	1-3	Connect habitat across roadways
EW-8	Light Pollution	3	Discourage light pollution
Access & Equity (AE) – Up to 30 Points			
AE-1	Safety Audit	1-2	Perform roadway safety audit
AE-2	Intelligent Transportation Systems (ITS)	2-5	Implement ITS solutions
AE-3	Context Sensitive Solutions	5	Plan for context sensitive solutions
AE-4	Traffic Emissions Reduction	5	Reduce emissions with quantifiable methods
AE-5	Pedestrian Access	1-2	Provide/improve pedestrian accessibility
AE-6	Bicycle Access	1-2	Provide/improve bicycle accessibility
AE-7	Transit Access	1-5	Provide/improve transit accessibility
AE-8	Scenic Views	1-2	Provide views of scenery or vistas
AE-9	Cultural Outreach	1-2	Promote art/culture/community values
Construction Activities (CA) – Up to 14 Points			
CA-1	Quality Management System	2	ISO 9001 certification for general contractor
CA-2	Environmental Training	1	Provide environmental training
CA-3	Site Recycling Plan	1	Have a plan to divert waste from landfill
CA-4	Fossil Fuel Reduction	1-2	Use alternative fuels in construction equipment
CA-5	Equipment Emissions Reduction	1-2	Meet EPA Tier 4 standards for non-road equip.
CA-6	Paving Emissions Reduction	1	Use pavers that meet NIOSH requirements
CA-7	Water Tracking	2	Develop data on water use in construction
CA-8	Contractor Warranty	3	Warranty on the constructed pavement
Materials & Resources (MR) – Up to 23 Points			
MR-1	Life Cycle Assessment (LCA)	2	Conduct a detailed LCA of the entire project
MR-2	Pavement Reuse	1-5	Reuse existing pavement sections
MR-3	Earthwork Balance	1	Use native soil rather than import fill
MR-4	Recycled Materials	1-5	Use recycled materials for new pavement
MR-5	Regional Materials	1-5	Use regional materials to reduce transportation
MR-6	Energy Efficiency	1-5	Improve energy efficiency of operational systems
Pavement Technologies (PT) – Up to 20 Points			
PT-1	Long-Life Pavement	5	Design pavements for long-life
PT-2	Permeable Pavement	3	Use permeable pavement as a LID technique
PT-3	Warm Mix Asphalt (WMA)	3	Use WMA in place of HMA
PT-4	Cool Pavement	5	Contribute less to urban heat island effect (UHI)
PT-5	Quiet Pavement	2-3	Use a quiet pavement to reduce noise
PT-6	Pavement Performance Tracking	1	Relate construction to performance data
Custom Credits (CC) – Available for all projects based on context and innovation, subject to approval			
CC-1	Custom Credit 1	1-5	Design a new voluntary credit
CC-2	Custom Credit 2	1-5	Design a new voluntary credit
	Greenroads Total Points:	**118**	

BACKGROUND

WHAT WE MEAN BY "SUSTAINABILITY"

While many of the definitions offered by other authors or political groups address the three central and well-recognized themes of sustainability (ecology, economy and equity, a.k.a. the "triple bottom line"), none of these definitions are directly actionable at a project level and are of little utility when considering sustainability from the perspective of a transportation designer or contractor. This is for two particular reasons: 1) lack of project-level context and specific tangible constraints, and 2) lack of incentive or drivers to progress sustainability in a meaningful way.

However, three key broader ideas are consistent in most of the definitions: physical constraints or laws of Nature (**natural laws**), satisfaction of basic human needs and desires (**human values**), and the idea that roadway projects are best perceived as **systems** of varying degrees of complexity, interdependence, scale and context. These three terms are clarified in detail below.

A useful, implementable definition of sustainability for roadway projects must feature these three terms because these ideas are simple to understand and explain to project stakeholders. Importantly, how well a particular project fits these project-specific natural law and human value constraints is a characteristic or trait of that system that is *measurable* (in terms of quantity and/or quality). This means sustainability on one roadway project can be compared to other roadway projects, and ultimately, sustainability becomes manageable on both short- and long-term time scales. Therefore, sustainability is a characteristic of a system that reflects its capacity to support natural laws and human values.[1]

WHAT IS SUSTAINABILITY?

Sustainability is a characteristic of a system that reflects its capacity to support natural laws and human values.

This definition is essentially compatible with other definitions of sustainability or sustainable development, such as that provided by the Brundtland Commission[2] and ideas featured in reports and international policy documents such as the Millennium Ecosystem Assessment[3] and "Agenda 21"[4]. Note that **processes** (practices) are part of systems as well; that they are inclusive in the above definition of sustainability, but are not explicitly included in the definition for brevity and simplicity.

NATURAL LAWS

"Natural laws" encompass the essential idea of **Ecology,** which is the study of ecosystems. These concepts are illustrated by the simple, but oxymoronic idea that ecosystems are too complex to be fully controlled or understood by humans, and that our best control and understanding comes from basic sciences like physics, chemistry and biology. Effectively, mathematics and sciences are the tools by which we measure the limits and current status of our environment. These natural laws form the physical constraints within which all projects must fit, regardless of how much control we think we may have over our own environment as humans or how complete or certain the science is perceived to be.

[1] Anderson, J. L. (2008). Sustainability in civil engineering. Thesis (M.S.C.E.)--University of Washington, 2008.
[2] United Nations General Assembly, 42nd Session. (1987, August 4). Report of the World Commission on Environment and Development (WCED): "Our Common Future." (A/42/427). Annex to Official Record. Geneva, Switzerland, 1987. (Masthead).
[3] Millennium Ecosystem Assessment (MEA), (2005). Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC.
[4] United Nations Conference on Environment and Development (UNCED), Rio de Janeiro, 3-14 June 1992. (1993, January 1). Report on the United Nations Conference on Environment and Development: "Agenda 21." (A/CONF.151/26/REV.1[VOL.I] and Corrigendum). Vol. I., Annex II to Resolutions Adopted by the Conference. New York, 1993. (Masthead).

We must understand that our conventional understanding of natural laws is at best incomplete and at worst could be totally wrong. Humans live and operate within the context of ecosystems, not vice versa (as indicated by current trends in civil development). The paradigm in which we live, operate and behave must therefore shift to a more sustainable one under our best possible and most current understanding of ecology, such as that proposed by The Natural Step framework, which offers a system-based approach to sustainability guided by three basic principles[5,6] as follows:

- Substances should not be extracted from the Earth at a rate faster than they can be regenerated by natural processes.
- Substances (waste) should not be produced at rate faster than they can be decomposed and reintegrated into an ecosystem.
- Ecosystems should not be systematically degraded or otherwise disrupted from equilibrium by human activities.

Conventional roadway design and construction practices and systems do not support these three above principles consistently; however, a significant amount of academic and industry research in a variety of fields indicates that they can.

HUMAN VALUES

Similarly, "human values" (basically Robèrt's fourth principle) include both **equity** and **economy**. **Equity** can be broadly understood as seeking quality of life for all: ultimately this means satisfaction of basic human needs within a specific cultural context. Human needs have been well studied in psychology and social sciences. The most prevalent ideas regarding human needs can be defined by either a hierarchical model, such as that proposed by Maslow[7] or a taxonomic model. Maslow identified physiological needs, safety, belonging, esteem and self-actualization as tiers of needs. Max-Neef et al.[8] identified nine unique needs that vary according to the process by which they are satisfied (being, having, doing, and interacting): subsistence, protection, affection understanding, participation, leisure, creation, identity, and freedom. For the sustainability purposes, either psychological model is fitting to best illustrate the idea of human values. The basic idea is that all humans have the same needs, the value of these needs can change with time, and there is a wide variety and varying degree to which needs are satisfied and managed in different communities and cultures.[9]

There are a number of tradeoffs that occur when meeting more than one need simultaneously. These societal constraints, including regulations and policy, govern the idea of **Economy**, which means, simply, management of financial, natural, manufactured, and human capital resources.[10,11] The concept of economy can be scaled down to apply to project-level financial choices or scaled up to more broad practices of resource management such as sustainable forestry, waste management or carbon cap-and-trade arrangements. Again, however, conventional roadway design and construction practice does not support these needs, or address their dynamics and management, consistently on all projects.

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[5] Robèrt, K. -H. (2000). Tools and concepts for sustainable development, how do they relate to a general framework for sustainable development, and to each other? *Journal of Cleaner Production*. 8(3), 243-254.
[6] Robèrt, K. -H. (2002). *The natural step story: seeding a quiet revolution.* Gabriola Island, BC: New Society Publishers.
[7] Maslow, A.H. (1943). A theory of human motivations. *Psychological Review.* 50(4), 370-396.
[8] Max-Neef. M.A.; Elizalde, A. and Hopenhayn, H. (1991). Human scale development: conception, application and further reflections. New York: The Apex Press.
[9] Fisher, K.J. (2000). A wealth of notions: reflective engagement in the emancipator teaching and learning of economics. Unpublished doctoral dissertation, University of Western Sydney, Richmond.
[10] Hawken, P.; Lovins, A.B. and Lovins, L.H. (1999). Natural capitalism: creating the next industrial revolution (1st ed.). Boston, MA: Little Brown and Co.
[11] Goodland, R. (1993). International Association of Impact Assessment (IAIA) Newsletter 5 (2).

SYSTEMS AND SUSTAINABILITY

Clearly, a systems-based approach to sustainability renders a definition that includes only Ecology, Equity, and Economy incomplete. In addition to these components, sustainability is context-sensitive. Specifically, a roadway project system's context is sensitive to whatever human needs and values are defined by the management team and stakeholders and its environmental setting. These are the constraints, or boundaries, within which project decisions must be made. Therefore, two more critical sustainability components, **extent** and **expectations**, are identified.[12] These two components act as the system boundaries, providing scope and context to sustainability.

7 E'S OF SUSTAINABILITY

Ecology
Equity
Economy
Extent
Expectations
Experience
Exposure

Extent represents the idea that a project system has well-defined constraints and limits within which sustainability can be measured. Extent refers to spatial and temporal constraints of civil projects (such as centerline length, right of way dimensions, footprint, and service life, respectively) often explicitly defined by natural laws (such as how gravity ultimately defines load limits). Some other practical examples of extent are height restrictions and construction working hours.

Performance criteria, or **Expectations**, are the key human value constraints identified for the project. Expectations provide the equity and economic context within which the overall performance of the system is most effectively judged. Expectations vary by project and may include practical performance of the individual design elements, overall quality of the construction processes of a project, or system-wide outcomes like reduced accidents or improved worker productivity.

While the ideas of Extent and Expectations may be implicit (or presumed to be understood) in the preceding descriptions of natural laws and human values, there is no reason for them not to be explicitly stated in working definition of sustainability. In fact, without explicitly stating these components, it is more likely that misunderstandings of these critical limits, boundaries, and constraints would occur, or that their impacts and importance would be ignored or downplayed.

Furthermore, it is not enough to believe that the idea of sustainability will self-propagate and implement its own paradigm shift toward more sustainable systems and practices. Thus, the final two important components of sustainability, **Experience** and **Exposure**, translate the philosophical concept of sustainability into implementable practices. **Experience** represents both what has been learned and the learning process itself, which is ongoing. So, experience includes technical expertise, innovation, and knowledge of applicable historical information, which is critical in decision-making processes. For example, most successful project teams are comprised of interdisciplinary experts that can bring specialized experience to design or construction.

Finally, if the concept of sustainability is to cause a paradigm shift in individual, community and societal behavior then it must include an active educational component; or more specifically, a teaching or outreach component. **Exposure** represents the idea that implementing sustainability in practice requires ongoing educational and awareness programs for the general public, professionals, agencies, and stakeholders. Therefore, experience and exposure drive the progress and implementation of sustainability within a project system. Without these two driving components, civil engineering systems would remain static, and sustainability would be absent, unmanageable or simply unrecognized.

[12] Anderson, J. L. (2008). Sustainability in civil engineering. Thesis (M.S.C.E.)--University of Washington, 2008.

GREENROADS BENEFITS

There are particular sustainability-related benefits associated with Project Requirements and Voluntary Credits. These roughly correlate with the ideas of "natural laws" and "human values" that were outlined in the preceding sections. Greenroads identifies these benefits for each Project Requirements and Voluntary Credit making it easier to at least list, if not exactly quantify, the benefits associated with Greenroads certification. These benefits are:

Primarily Eco-centric Benefits	**Primarily Anthropocentric Benefits**
✓ Reduces Raw Materials Use	✓ Improves Access
✓ Reduces Fossil Fuel Use	✓ Improves Mobility
✓ Creates Energy	✓ Increases Service Life
✓ Reduces Water Use	✓ Improves Human Health & Safety
✓ Reduces Air Emissions	✓ Improves Local Economies
✓ Reduces Greenhouse Gases	✓ Reduces First Costs
✓ Reduces Water Pollution	✓ Reduces Lifecycle Costs
✓ Reduces Solid Waste	✓ Improves Accountability
✓ Restores Habitat	✓ Increases Awareness
✓ Creates Habitat	✓ Increases Aesthetics
✓ Reduces Manmade Footprint	✓ Creates New Information

We have listed these, along with each of the sustainability components addressed, on the front page of each PR and VC, so that it is easy to identify what is being addressed by acting on that PR or VC. This feature of the *Manual* may be particularly helpful for agencies or project teams that have predefined sustainability goals, values or internal benchmarks to meet.

Note that in the previous version of the *Greenroads Manual* we had made 16 benefits explicit: now there are 22. Based on feedback from users and also our students at the University of Washington, we broke apart these 16 benefits somewhat and changed the wording used to better reflect what we mean by "sustainability benefit" in terms that are more commonly understood to transportation professionals. We also have tried to identify them as being primarily eco-centric or anthropocentric but we recognize this may be debatable in some, if not all, instances. (See Other Notes on the following pages for more commentary.)

TRACING GREENROADS PRACTICES TO SUSTAINABILITY AND BENEFITS

Each Greenroads Project Requirement and Voluntary Credit can be traced back to at least one relevant sustainability component and one relevant benefit; most can be traced to several. We call this "mapping", and believe it is important because it provides the basis by which a Greenroads Project Requirement or Voluntary Credit can be considered to contribute to "sustainability" and provide benefits as Greenroads defines them. This mapping involves subjective judgment as to which components and which benefits map to which items. While elimination of this subjectivity would be ideal, more complex systems for mapping would likely just conceal rather than eliminate this subjectivity.

Mapping of an item back to sustainability and benefits is done, where practical, using empirical evidence with proper citations. The goal is to create a metric where each Project Requirement and Voluntary Credit is, to the extent possible, shown through existing research to have an impact on sustainability.

This mapping can assist in selecting Voluntary Credits to pursue based on user values or desired benefits. Importantly, the nature of sustainability requires users to make trade-offs between different aspects of sustainability. For instance, one might have to select between using recycled material that must be trucked over a long distance or using locally provided virgin material. Both concepts (recycled material, local material) relate to sustainability (e.g., ecology and economy) however only one can be chosen.

Decisions regarding these types of trade-offs are likely to be at least partly, if not wholly, based on the values held by a project, which is a conglomeration of values held by its stakeholders, owners, designers and constructors. Since these values are not likely to be identical between projects, over time or between stakeholders, one predetermined set of values included in a performance metric is probably not wise. Rather, Greenroads allows users to choose from a long list of Voluntary Credits based on their values. Mapping to sustainability components is done because users may find it more straightforward to choose between resources rather than Greenroads Voluntary Credits. For instance, it may be difficult to choose between warm mix asphalt and porous pavement unless a technical expert is consulted to fully explain each item. However, it may be easier to choose between the benefits they offer.

OTHER NOTES

1. Additionally, it is useful to note that several benefits may be directly quantifiable while others are more likely to be indirect benefits. Where possible, this is discussed in the supporting research for each credit in the *Manual.* We recognize that this still presents an incomplete picture of the benefits of sustainability, but our intent is to provide assistance in understanding a relatively new and sometimes complex idea.
2. Also, it would be remiss of us not to note that any ecological benefit is also a human benefit since our environment is fundamentally what supports us as living beings and impacts our quality of life. Similarly, sometimes there is beneficial interaction between these benefits where humans can impact the quality of non-human life in a positive way. For example, pursuing Credit EW-7 Ecological Connectivity can improve mobility and access for both humans and wildlife simultaneously, while achieving a number of the other benefits also listed above.
3. Finally, we recognize that reduction of greenhouse gases is a key goal of many agencies. This level of specificity, since they are a type of air pollution, correlates directly with the benefit of “reduced air emissions” and “reduced fossil fuel use.” We felt it was useful to provide this added specificity in light of current state and federal policy goals.

HOW GREENROADS IS WEIGHTED

The overall goal of weighting is to make each Voluntary Credit's point value commensurate with its impact on sustainability. This cannot be achieved by a strictly objective or empirical approach because:

- Some sustainability components are difficult to directly compare because there is no generally accepted metric of comparison (e.g., comparing scenic views to stormwater treatment).
- Traditionally accepted quantitative methods, e.g., lifecycle assessment (LCA), lifecycle cost analysis (LCCA), benefit-cost analysis, do not adequately address all sustainability components.
- Greenroads is designed to function as a supplement to current U.S. regulations. Therefore, some areas that might otherwise have been heavily weighted receive less emphasis in Greenroads because current U.S. regulation already requires many mandatory actions leaving little room for supplemental voluntary actions.
- There are some actions for which the direct impact on sustainability may be difficult or impossible to measure, however their execution may provide valuable information on which to base future decisions.

Weighting follows the general framework described here. As a beginning point, we established a minimum value of one point and a maximum value of five points. This range allows weights to reflect a range of sustainability impact but limits the impact of potential missteps. Individual construction activities during initial construction have the lowest impact (see discussion later) on sustainability so we start by assigning these Voluntary Credits one point each. From here Voluntary Credit point values are modified based on the logic presented next. Importantly, weights are based on the relationship of their associated prevailing broad concepts while the actual level of achievement necessary to qualify for a Voluntary Credit is based on an assessment of what is practically achievable given current technology and practice. The goal is to make the level of achievement beyond current practice but enticingly attainable using current technology. Using this logic, it follows that as the industry's sustainability savvy grows and technology advances Voluntary Credit requirements must change. The following sections discuss weighting details for the system. The figure below shows the weights of the categories (without Custom Credits).

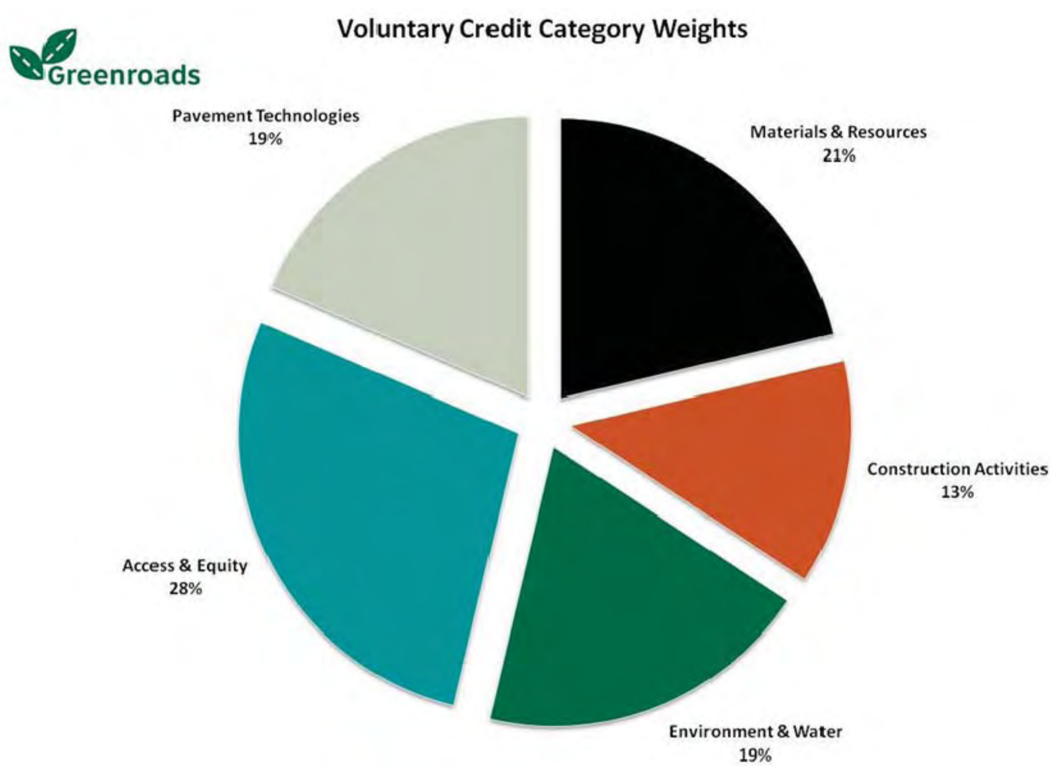

Figure I.5: Graph showing the distribution of Voluntary Credit points (by percentage of the total) in each of the 5 categories.

ECOLOGY WEIGHTING

While it is difficult to place a value on ecosystem services, some researchers have tried. One effort[13] valued them at US$16-54 trillion/yr with a mean of US$33 trillion/yr for 17 ecosystem services (in 1994 US dollars). This compares to a world gross national product (GNP) of US$18 trillion (1994 US dollars) making ecosystem services about 1.8 times the global GNP if the mean value is assumed. This effort acknowledges that the estimate is on the low side, incomplete and flawed but reason that some estimate is better than none. Based on this, we estimate the value of ecosystems as about three times the value of human economic systems (represented by the baseline value of one point) for the purposes of weighting Voluntary Credits. This uses the high end estimate (US$54 trillion) to at least partially account for their admitted underestimation. From this, we assign EW-2, EW-3, EW-5, EW-6, EW-7, EW-8 and PT-2 three points each because they are primarily concerned with ecosystem services.

EQUITY WEIGHTING

Equity, as it is reflected in Greenroads can primarily be addressed by portions of what is commonly called context sensitive design (CSD) or context sensitive solutions (CSS). To our knowledge, nobody has attempted to place a monetary value on CSD/CSS however, there is substantial evidence suggesting that it has come to be viewed as an important if not the essential component in U.S. roadway design over the last decade. While CSD/CSS also includes ecological elements, its strength lies in its approach to identifying and involving stakeholders and reflecting community values in a project (the equity component of sustainability). While CSD/CSS provides evidence of equity's importance it does not provide any insight regarding its level of importance in relation to other sustainability components. In fact, it argues that such value is context sensitive. We believe that the U.S. move towards CSD/CSS and its emphasis on a collaborative community-based approach to design (versus a strictly low-cost standards-based approach) shows that equity issues ought to be valued more than the minimum of one point. As a first-order approximation, we assign equity Voluntary Credits two points. Based on this we assign AE-1, AE-5, AE-6, AE-8, AE-9 two points each because they are primarily concerned with equity issues. We assign AE-3 the maximum of five points because it actually gives credit for a CSD/CSS approach, while the other AE Voluntary Credits address outcomes of a CSD/CSS approach.

LIFECYCLE ASSESSMENT (LCA) BASED WEIGHTING

For Voluntary Credits dealing with materials production, construction, transportation associated with the construction process and traffic use, weighting is based on lifecycle assessment (LCA) results to the greatest possible extent. Since Greenroads is meant to apply to any roadway project, LCA results specific to a particular project cannot be used alone because they are project-specific and not entirely transferrable. However, examining a range of specific LCAs may provide insight into some general trends that could be used to weight Voluntary Credits. We identified 12 roadway LCA peer-reviewed journal papers consisting of 43 assessments of either actual or hypothetical roadways.[14] Five papers addressed PCC pavements (10 assessments), while all 12 address HMA pavements (34 assessments). Some general trends observed were:

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[13] Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., van den Belt, M., (1997). The value of the world's ecosystem services and natural capital. *Nat.*, 387, 253-260.

[14] These papers are:

Stripple, H. *Life Cycle Inventory of Asphalt Pavements*. IVL Swedish Environmental research Institute Ltd report for the European Asphalt Pavement Association (EAPA) and Eurobitume, 2000.

Stripple, H. *Life Cycle Assessment of Road: A Pilot Study for Inventory Analysis, Second Revised Edition*. IVL Swedish Environmental Research Institute Ltd report for the Swedish National Road Administration, 2001.

Mroueh, U-M, Eskola, P., Laine-Ylijoki, J., Life-cycle impacts of the use of industrial by products in road and earth construction. *Waste Management* 21, 2001, pp. 271-277.

Treloar, G.J.; Love, P.E.D. and Crawford, R.H. Hybrid Life-Cycle Inventory for Road Construction and Use, *J. of Const. Engr. and Mgmt.* 130(1), 2004, pp. 43-49.

- Energy use and emissions for construction followed the same basic trends in most studies. Some general rules of thumb we found were:

  - ✓ Materials production has 20 times the impact of construction.
  - ✓ Transportation (of materials) has 5 times the impact of construction.
  - ✓ Maintenance has 1/3 the impact of initial construction.

- For the one study that quantified them, roadway operations (e.g., lighting, signals, etc.) over 40 years had about the same energy use as all construction activities (initial construction plus maintenance).
- For the two studies that related them, the energy expended in initial construction of a new roadway is roughly equivalent to the energy used by traffic on the facility over 1-2 years.

Based on these ideas, the following weighting is used:

- **Operations vs. construction:** MR-6 is assigned 5 points.
- **Traffic use vs. initial construction:** AE-2, AE-4, and AE-7 are assigned 5 points each.
- Transportation associated with construction: MR-5 is assigned 5 points.
- **Materials production:** MR-2 and MR-4 are assigned up to 5 points each. MR-3 is assigned 1 point and PT-3 is assigned 3 points.

INCENTIVE-BASED WEIGHTING

Some Voluntary Credits are assigned additional points to provide incentive to collect data, undertake organization-wide efforts and obtain high achievement levels. Generally, higher levels of achievement will correlate to incorporating a number of other voluntary activities that may be reflected in other credits too. The following Voluntary Credits use incentive-based weighting: EW-1, EW-2, EW-3, EW-5, AE-1, AE-2, AE-5, AE-6, AE-7, CA-1, CA-4, CA-5, CA-7, MR-1, MR-2, MR-4, MR-5 and PT-5.

DEVELOPED AREA WEIGHTING

The Urban Heat Island (UHI) effect is "…a measurable increase in ambient urban air temperatures resulting primarily from the replacement of vegetation with buildings, roads, and other heat-absorbing infrastructure."[15] UHI can impact sustainability by increasing energy consumption, and related emissions and affecting human health

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[13](cont.)

Zapata, P., Gambatese, J.A., Energy Consumption of Asphalt and Reinforced Concrete Pavement Materials and Construction. *J. of Infrastructure Systems* 11(1), 2005, pp. 9-20.

Rajendran, S., Gambatese, J.A. Solid Waste Generation in Asphalt and Reinforced Concrete Roadway Life Cycles. *J. of Infrastructure Systems* 13(2), 2005, pp. 88-96.

Athena Institute. *A Life-Cycle Perspective on Concrete and Asphalt Roadways: Embodied Primary Energy and Global Warming Potential*. Report to the Cement Association of Canada, 2006.

Tramore House Regional Design Office. *Integration of the Measurement of Energy Usage into Road Design*. Rept. to the Commission of the European D-G for Energy and Transport. Project Number 4.1031/Z/02-091/2002, 2006.

Weiland, C.D. *Life Cycle Assessment of Portland Cement Concrete Interstate Highway Rehabilitation and Replacement*. Master's Thesis, University of Washington, Seattle, WA, 2008.

Chui, C-T., Hsu, T-H., Yang, W-F. Life cycle assessment on using recycled materials for rehabilitating asphalt pavements. *Resources, Conservation and Recycling* 52, 2008, pp. 545- 556.

Huang, Y., Bird, R., Bell, M. A comparative study of the emissions by road maintenance works and the disrupted traffic using life cycle assessment and micro-simulation. *Transportation Research Part D* 14, 2009, pp. 197-204.

Huang, Y., Bird, R., Heidrich, O. Development of a life cycle assessment tool for construction and maintenance of asphalt pavements. *J. of Cleaner Production* 17, 2009, pp. 283-296.

[15] U.S. Environmental Protection Agency (EPA). *Heat Island Effect* website. [http://www.epa.gov/hiri] Accessed 9 June 2009.

and water quality. Based on research from the Lawrence Berkeley National Laboratory[16] a gross approximation is that road pavements constitute about one-quarter the total surface area contributing to the UHI. From this PT-4 is assigned 5 points. This weighting is also consistent with other concerns that are relevant in urban areas: AE-4 and MR-6.

DURABILITY WEIGHTING

Long life pavement generally results in lower lifecycle costs, less material and fewer traffic interruptions over the lifecycle of a pavement. While more work needs to be done in quantifying these reductions, a value for PT-1 can be attempted by drawing the link between less material and fewer traffic interruptions to less energy and lower emissions. PT-1 is assigned 5 points.

AESTHETIC WEIGHTING

One study[17] investigated different monetization approaches for the health impacts from road noise. From their work we assign noise one-third the impact of traffic-related emissions. Since tire-pavement noise is the predominant source or road noise above about 50 km/hr (for automobiles) a change in tire-pavement noise resulting from so-called "quieter pavement" use is about one-third as impactful as actions resulting in traffic-related emissions reduction. Noise reduction characteristics of quieter pavements tend to diminish over time. PT-5 is assigned 2 to 3 points. This correlates with EW-8, which is also assigned 3 points and addresses glare other unwanted light emissions.

[16] Rose, L.S., H. Akbari, and H. Taha. 2003. Characterizing the Fabric of the Urban Environment: A Case Study of Greater Houston, Texas. Paper LBNL-51448. Lawrence Berkeley National Laboratory, Berkeley, CA.
[17] Hofstetter, P., Müller-Wenk, R., 2005. Monetization of health damages from road noise with implications for monetizing health impacts in life cycle assessment. *J. of Clean. Production* 13, 1235-1245.

PROJECT REQUIREMENTS

ENVIRONMENTAL REVIEW PROCESS

GOAL

Evaluate impacts of roadway projects through an informed decision-making process.

REQUIREMENTS

Perform and document a comprehensive environmental review of the roadway project. This review should clearly and concisely document:

1. Project name and location.
2. Names and contact information of key players in the decision making process, including (but not limited to): the owner agency, agency representatives responsible for completing the environmental review process, other stakeholders, and relevant professionals involved.
3. Intent and purpose of the roadway project.
4. Descriptions of potential environmental, economic and social impacts of the intended roadway project.
5. Detailed descriptions of the extent of the significance of these impacts with respect to the decision-making process and feasible performance expectations.
6. Description of the public involvement opportunity in the environmental review process; document this opportunity and the results of input in the final decisions.
7. Any jurisdictional requirements for more detailed environmental review documents such as environmental impact statements (EIS) or environmental assessments (EA) to determine the significance of environmental impacts.
8. Description of the final environmental decisions made.

Details

An environmental review process is a method of decision-making used in project development. The basic intent of the process is to promote informed decision-making by explaining the project in a comprehensive, concise and understandable way. This explanation involves an evaluation of environmental, social and economic impacts in order to meet existing regulations and public stakeholder needs. These impacts, regulations, and needs shape basic decision criteria, vary significantly in complexity between projects, and dictate the effort required during the review process and project implementation. The National Environmental Policy Act (NEPA) provides formal guidelines for federally funded roadway projects, and many states have environmental review processes similar to NEPA.

DOCUMENTATION

- Copy of the final decision document that demonstrates an environmental review process has been completed for the project, with all appropriate agency or jurisdiction representative signatures. Any of the following documents will suffice:

  - Executive summary of the EA or EIS, the Record of Decision (ROD) or Finding of No Significant Impact (FONSI), or jurisdiction equivalent of these documents.
  - Completed copy of the Washington State Department of Ecology State Environmental Policy Act (SEPA) Checklist (or local equivalent). **Note:** Do this if the project is exempt from a formal environmental review or is classified as a "categorical exclusion" (CE).

PR-1

REQUIRED

RELATED CREDITS

- ✓ PR-2 Lifecycle Cost Analysis
- ✓ PR-3 Lifecycle Inventory
- ✓ AE-3 Context Sensitive Solutions
- ✓ MR-1 Lifecycle Assessment

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Expectations
- ✓ Exposure

BENEFITS

- ✓ Reduces Air Emissions
- ✓ Reduces Water Pollution
- ✓ Reduces Solid Waste
- ✓ Improves Human Health & Safety
- ✓ Improves Accountability
- ✓ Increases Awareness
- ✓ Increases Aesthetics

APPROACHES & STRATEGIES

- Check if your state has existing procedures that streamline the environmental review process specifically for roadway projects. The Council on Environmental Quality (CEQ) maintains an updated list of states that are compliant here: http://nepa.gov/nepa/regs/states/states.cfm
- Identify opportunities to involve the public early in the environmental review process. Usually this step is most effective during project planning.
- Recognize that the environmental review process can often be iterative, especially during planning and design stages when alternatives are still subject to change.
- Conduct a detailed, multi-disciplinary literature review at the start of a project. This review can help identify existing extraordinary circumstances, such as special wildlife and plant concerns and socio-economic issues.
- Use the checklist provided by the Washington state Department of Ecology State Environmental Policy Act (SEPA) as a guideline for an environmental review process in jurisdictions not subject to NEPA or similar local or state requirements. This checklist is easy and straightforward and may be completed to meet the intent of this Project Requirement. Note that many states also offer checklists that cover the same topics as the Washington SEPA checklist, and will also meet the intent of this Project Requirement. The Washington state checklist is readily available and downloadable for immediate use here: http://www.ecy.wa.gov/biblio/ecy05045.html.
- Make the environmental review documentation as concise and comprehensive as possible, while also limiting use of professional jargon. This will create an easy to read and understandable environmental review document for decision makers. There are a number of guidance documents available from the CEQ for NEPA documents, and individual states may also have helpful resources available. These are available from the CEQ here: http://ceq.hss.doe.gov/nepa/regs/guidance.html
- For projects typically considered categorically exempt**,** where jurisdictional precedent has been established for similar roadway projects in previous environmental review processes, complete the Washington state SEPA checklist for purposes of this requirement. This process will also demonstrate 1) that the review process has been completed and all impacts have been addressed, and 2) why your project has been determined a categorical exclusion.
- Follow Federal Highway Administration (FHWA) and Federal Transit Authority (FTA) guidelines for complex, detailed and larger projects that need to produce EIS reports. These guidelines are compiled in a straightforward guidance document located here: http://www.fhwa.dot.gov/hep/section6002/. This document includes steps required for the NEPA process and also exemplary project case studies that meet the requirements for the environmental review process.

Example: SEPA Checklists

Projects not subject to NEPA or an equivalent local or state policy for environmental review will need to submit a completed environmental review process checklist for purposes of this requirement. There are many available from various state agencies or Departments of Transportation (DOT), check with your owner/agency. Several examples of completed checklists are provided in Table PR-1.1.

Table PR-1.1: Sample Completed SEPA Checklists

Project Name	Owner	Type	Where to Find Checklist
SR 509/SR 518 Interchange Safety Improvement Project	Washington State DOT	Highway improvement	http://www.wsdot.wa.gov/NR/rdonlyres/624594AC-5B81-4D62-BA04-2D926347628C/0/SR518SafetySEPAChecklist.pdf
2009 AAC Program – Fauntleroy Way SW between SW Alaska St and SW Holly St	Seattle DOT (SDOT)	Resurfacing	http://www.seattle.gov/transportation/docs/SEPAFAUNTLEROY.pdf
Revised Aurora Avenue North Transit, Pedestrian and Safety Improvements	SDOT, WSDOT, FHWA	Multi-purpose urban arterial improvements	http://www.seattle.gov/Transportation/docs/aurora/RevAurora_SEPAchecklist_SigOnFile.pdf
Eagle Creek Road Improvement Project	Chelan County	Rural road improvements	http://www.co.chelan.wa.us/pw/data/sepa_checklist.pdf

Example: Federally Funded Projects and the National Environmental Policy Act (NEPA)

Federally funded roadway projects are required to use the NEPA (National Environmental Policy Act) environmental review process (CEQ, 2007). This includes all roadway projects managed by the Federal Highway Administration (FHWA).

NOTE: NEPA clearly states that the environmental review process does *not* require that agencies or project teams make final project decisions based on any of the environmental impacts that are studied or discovered. Rather, the intent of the NEPA process is to inform decision-makers of the potential effects of their actions (Caldwell, 1999; CEQ, 2007).

The FHWA, American Association of State Highway Transportation Officials (AASHTO) and the American Council of Engineering Companies (ACEC) have compiled a guidance document called *Improving the Quality of Environmental Documents* that highlights several case studies of exemplary, easy-to-read and comprehensive NEPA documents. A few of those projects are listed below:

- Alaskan Way Viaduct and Seawall Replacement Project (Washington State DOT)
- Mon/Fayette Transportation Project, PA Route 51 to I-376 (Pennsylvania Turnpike Commission)
- Route Post 13 (I-15) Interchange (Utah DOT)
- Southern Corridor (I-15) (Utah DOT)
- US 93 Somers to Whitefish (Montana DOT)
- I-69 Evansville to Indianapolis (Indiana DOT)
- Mid-Currituck Sound Bridge (North Carolina DOT)

Detailed information on each project (and other non-roadway transportation projects) is included in the completed report for the National Cooperative Highway Research Program (NCHRP) 25-25 Task 1 (2005). This NCHRP report also contains descriptions of why these reports are exemplary of a successful NEPA process.

According to regulations updated in 2001 from the FHWA, many transportation projects for both roadways and bridges, specifically rehabilitation activities, are considered to be categorically exempt (CEs) because they have been deemed to meet 40 CFR § 1508.4 based on past precedent. Accordingly, these certain project types:

- Do not have significant environmental, planned growth or land use impacts
- Do not need relocation of many people
- Do not have impact on natural, cultural, recreational, or historic resources
- Do not have air, noise, or water quality impacts
- Do not have significant impacts on travel patterns
- Do not, either individually or cumulatively, have any significant environmental impacts

See 40 CFR §1508.4 and 23 CFR §771.117. For purposes of this requirement, projects that qualify as NEPA CEs must complete a checklist equivalent to those shown in Table PR-1.1.

Example: States with Environmental Review Processes

Some states, regions and territories of the United States require an environmental review process that is similar to NEPA. These locations are listed in Table PR-1.2. Additionally, some local and regional departments of transportation (DOT), or projects funded by those agencies, may also require an environmental review process that is generally based on the NEPA. Completing such an owner/agency process meets this requirement, provided that it addresses all the steps noted. Note that some owners/agencies may have stricter criteria than NEPA. Also, guidance documents and examples at the federal level can often provide a helpful resource or template for state level documentation.

Table PR-1.2: U.S. Locations with Existing Environmental Review Processes[1]

California	Montana
Connecticut	Nevada/California – Tahoe
District of Columbia	New Jersey
Georgia	New York
Guam	North Carolina
Hawaii	Puerto Rico
Indiana	South Dakota
Maryland	Virginia
Massachusetts	Washington
Minnesota	Wisconsin

[1]http://nepa.gov/nepa/regs/states/states.cfm

POTENTIAL ISSUES

1. Projects that are typically classified as "categorical exclusions" under NEPA (or equivalent) may need to expend extra effort to achieve the intent of this requirement.
2. Inadequate or ineffective public, stakeholder, and agency involvement during project scoping, leading to a poorly defined or incomplete solution.
3. Lead agencies are responsible for the scope of the environmental review, but consultants or developers are often required to pay for and perform the work involved (CEQ, 2007).
4. Climate change is not often adequately addressed by the environmental review process, which has occasionally resulted in litigation (Clark, 1994; Lemons, 1998).
5. Inadequate mitigation of indirect and cumulative effects because of jurisdictional limitations or lack of scientific data (Clark, 1994; Lemons, 1998).

RESEARCH

An environmental review process has two main purposes: providing an avenue for more informed decision-making and allowing public involvement in agency projects that may have adverse impacts on the environment (CEQ, 2007). Generally speaking, it is the first step toward achieving a general mark of roadway sustainability; this step, when taken at the outset of design and construction, allows comprehensive consideration of elements that contribute to overall sustainability at the most basic level of project decision making.

Completion of an environmental review process ensures that the project has received early scrutiny and guidance from the public, stakeholders, and appropriate agencies and jurisdictions before it is designed and built. However, importantly, the process does not dictate the final decisions made. In other words, some impacts that are considered adverse may actually be implemented based on weighing a number of tradeoffs. This way, stakeholder values and local regulations provide the environmental, social, economic and other political parameters within which a project must fit.

Why is the environmental review process a requirement in Greenroads?

No matter how small the roadway project is, it still has an impact, even if it is considered at some regulatory level to be an "insignificant" one. Greenroads seeks to recognize those projects that have been subject to the robust public and regulatory agency review process imposed by the National Environmental Policy Act (NEPA) or a state-level equivalent procedure. To clarify, in particular, many roadway projects have been classified as Categorical Exclusions. Such regular exclusion of this process requirement detaches the impacts that are perceived as insignificant on a project basis and at a practical level actually has a potentially large aggregate environmental impact. Passing off insignificant impacts does not preclude the value of the process in a decision-making situation, especially for the broad range of impact that roadway projects have. Also, by considering using a metric like Greenroads in project-level planning, we feel that the environmental review process may be augmented by consideration of some of the ideas at the project conception.

Why is environmental review important for roadways?

Roadway construction and maintenance activities place an incredible demand on national environmental and financial resources. However, current roadway design and construction practice does not always systematically or holistically address environmental impacts or environmental quality. For many projects, often it is difficult to conceptualize the environmental impacts or influence that a roadway has on its surroundings. This could be due to three general problems: 1) decision-makers are unable to understand the complexity of ecosystems and how manmade roadways fit within this context; 2) the decision requires thoughtfulness that goes beyond conventional wisdom or traditional assumptions 3) decision-makers fail to understand the limits of control that humans have on ecosystem management (Caldwell, 1999). Also, not all projects are covered by NEPA or an equivalent state or local policy; sometimes existing policies require no more than a cursory evaluation of environmental, social and economic impacts. In these cases, many critical impacts are unintentionally overlooked or ignored and these impacts may have long-term consequences for the environment and local communities. Approaches that do not address direct, indirect and cumulative effects of roadway design and construction demonstrate, at best, weak stewardship efforts, and are inadequate toward achieving sustainability due to their lack of comprehensiveness.

For example, evaluation of project air emissions, total energy use, or surrounding ecosystems is rarely extended outside of regulatory compliance, such as meeting requirements for a cumulative effects assessment in National Environmental Policy Act (NEPA) documents. The Bureau of Transportation Statistics (2007) reports that approximately $54 billion was spent on pavement materials alone in 2006. Production, transport and placement of common pavement materials, such as hot-mix asphalt (HMA) and portland cement concrete (PCC), represent the majority of life cycle greenhouse gas emissions and energy usage associated with roadways (Zapata and Gambatese, 2005). Additionally, the U.S. Environmental Protection Agency (EPA) has attributed several direct, cumulative and long-term environmental impacts, such as ecosystem degradation, fragmentation and habitat loss, due to the linear and decentralized nature of the four million mile network of roadways in the U.S. (1994) Performing an environmental review on a roadway project provides a means of investigating these special environmental impacts in a more detailed manner in order to make better environmental decisions for roadway development.

What are the steps in the environmental review process?

Generally, there are three generic steps in the environmental review process. For projects with no environmental review process within their jurisdiction, these are guidelines provide a general idea of the process.

1. Complete the initial permitting process for the governing jurisdiction. Usually this involves some review of historical documentation for the area where the project will be located.
2. Determine if an environmental review is needed. Usually, a project falls into a certain classification which has specific environmental review requirements.
3. If needed, perform an environmental review and submit for approval by the governing agency.

These three steps may be iterative depending on the complexity of the project. The eight steps of this Project Requirement match this general framework, in slightly more detail, and without the agency permits.

How is the environmental review process used for decision-making?

Roadway design and construction is a complex process that requires experienced professionals and clearly defined expectations and values. The environmental review process is an important part of decision-making in roadway projects because ultimately, it helps tell the whole project story in an effective manner. Determining stakeholder expectations and needs, spatial and temporal bounds (Clark, 1994), feasible options and their environmental impacts, and which choices are most sensible based on all known costs and benefits are critical steps in approaching the project in a meaningful and comprehensive way. Further, without defining these same values, efforts toward project sustainability would be ineffective.

What is the public involvement role?

Public involvement plays a key role in a comprehensive environmental review process because the public is one of the largest stakeholders in most roadway and transportation-related projects. It plays a complementary role to the technical knowledge and experience of the interdisciplinary professionals involved in the design and construction of the roadway. Open consensus-based public participation strategies provide a critical avenue for exchange of important information about needs, opinions, expectations and local values between the public and project decision-makers. Essentially, this part of the environmental review process engages the people who will be most likely to be impacted by the decisions made.

The FHWA provides several publications and guidance materials on creating and implementing successful public involvement campaigns for roadway projects. http://www.fhwa.dot.gov/environment/pi_pubs.htm

What is considered in an environmental review process?

The Washington state Department of Ecology (DOE) SEPA checklist provides a comprehensive example of what is typically included in an environmental review process. Basic topics covered include those shown in Table PR-1.3.

Table PR-1.3: Topics Addressed by an Environmental Review Process

Earthen materials	Site topography, soil conditions, grading quantities, erosion potential, impervious surfaces
Air	Expected on-site and relevant off-site air emissions
Water	Water bodies in vicinity, in-water grading quantities, surface and groundwater conditions, floodplain status, expected point and non-point discharges, stormwater management
Plants	Native vegetation, vegetation management, landscaping plan, endangered species
Animals	Native wildlife, migratory habits, endangered species
Energy	Energy types needed and used, renewable energy sources, conservation efforts (if any)
Human health and safety	Exposure to toxic chemicals, risk of fire and explosion, spill, or hazardous waste, emergency services needed, hazard controls in place, safety issues and needs being addressed.
Noise	Traffic, equipment, operation (short-term, long-term), times of expected noise,
Land and shoreline use	Current use, existing structures (any planned demolition), agricultural status, zoning and master plan, current and displaced populations, environmental sensitivity,
Housing	Addition or loss of housing units
Aesthetics	Structure height, views in area
Light and glare	Time of day for expected glare, safety considerations, off-site glare,
Recreational, historic, cultural resources	Types of opportunities in vicinity, existing registrations (if any), any displacement of recreational, historical, or cultural opportunities as a result of project
Transportation	Access from other public streets and highways, transit facilities, parking, type of construction expected, nearness to air and rail modes, peak traffic volumes, trip generation
Public services and utilities	Types of public services and utilities needed or impacted, new services or utilities proposed

Generally, documentation of the environmental review process for roadway projects requires that sources of all potential environmental, economic and social impacts, expected nature and extent of these impacts, and the final decisions made in light of these impacts are stated concisely and clearly.

What is NEPA?

The National Environmental Policy Act (NEPA) is a broad declaration of environmental values intended to encourage changes in attitudes and social behaviors at a national level (Caldwell, 1999). NEPA was instituted as federal law in the United States in 1969 and published in the Federal Register in January 1970. (CFR 42 § 4321) The full text of the act is available online at http://ceq.hss.doe.gov/nepa/nepanet.htm. Compliance with NEPA is managed by the Council of Environmental Quality (CEQ, 2007). As a law, NEPA mandates that an interdisciplinary and transparent approach is taken during alternative selection in the decision-making process. Projects are required to state all known direct, indirect, and cumulative environmental, social and economic impacts that might result from implementing the project (CEQ, 2007).

NEPA applies to all federally funded projects, which commonly includes projects such as roadways managed by the Federal Highway Administration (FHWA), environmental remediation efforts through the EPA, government buildings and other infrastructure projects receiving federal funding. Because many roadway projects are at least partly funded by federal money, many agencies and consultants are likely to be experienced with the level of detail expected during the NEPA process. Additionally, many states may have regulations that map directly back to NEPA or have more stringent environmental review expectations due to local or statewide policy or other special environmental conditions.

In general, there are five classifications of projects that are subject to environmental review under NEPA. These are shown with a brief description of the documentation needed and produced to meet the requirements of NEPA process in Table PR-1.4. Significantly more detail regarding each type of report in the text of the Act itself and from CEQ at http://ceq.hss.doe.gov/nepa/nepanet.htm.

Table PR-1.4: Types of NEPA Environmental Reviews

NEPA Classification	Documentation Needs	How to Meet Needs
Significant Effects Identified	Environmental Impact Statement (EIS) Record of Decision (ROD)	Follow NEPA Process guidelines for generating an EIS. EPA reviews EIS.
Effects Uncertain	Environmental Assessment (EA) Finding of No Significant Impact (FONSI) or follow EIS procedure	Follow NEPA Process guidelines for generating an EA. Results of EA may dictate a more detailed EIS is required for the roadway project.
Listed Categorical Exclusion (CE)	Letter from the governing jurisdiction stating the existing CE for project. FHWA lists CEs in 23 CFR §771.117	Provide copy of existing statement of Categorical Exclusion (CE)
No CE listed by Agency	Environmental Assessment (EA) Finding of No Significant Impact (FONSI) or EIS and ROD	Follow NEPA Process guidelines for generating an EA. Results of EA may dictate a more detailed EIS is required for the roadway project.
Extraordinary circumstance for a listed CE	Environmental Assessment (EA) Finding of No Significant Impact (FONSI) or EIS and ROD	Follow NEPA Process guidelines for generating an EA. Results of EA may dictate a more detailed EIS is required for the roadway project.

Criticisms of NEPA

Some of the common criticisms of NEPA are outlined by *NCHRP Report 25-25(01)* (TransTech et al., 2005). Most complaints arise from loss of meaningfulness in the environmental review process due to two coupled issues, the vagueness of the language used in the Act and the bureaucratic approval process required of the NEPA documentation.

The language in the Act is very broad compared to other U.S. regulations, and often the requirements for NEPA are considered unclear by comparison. Interviewees in the NCHRP 25-25 initial survey cited the need for clearer language, less jargon, consistent styles and formats, and the need to be succinct (TransTech et al., 2005). However, the meaning of the process is not likely lost in the process itself, but rather in the unnecessarily verbose documents that are generated. Many sections often contain duplicate information. This problem has spurred the guidance documents available from FHWA, AASHTO, and ACEC (noted in the preceding Examples section) which stress brevity and clarity in final NEPA documents.

Historically, documentation of the NEPA process has also been considered unwieldy and arduous because project teams often try to present as much information in as broad of language as possible, in order to address the lack of specificity in the Act and avoid possible litigation for errors and omissions (Clark, 1994; Lemons, 1998). Interviewees frequently mentioned that demonstrating legal sufficiency is the main reason documents by DOTs are so long (TransTech et al., 2005). Consequently, these lengthy documents require lengthy reviews. The review process is complicated further if a project does not begin the NEPA environmental review in early stages of decision-making or if documentation is not properly tracked.

A third complaint that has actually resulted in recent (and complicated) litigation is the NEPA requirement for cumulative environmental effect assessment, specifically related to global climate change. Smith (2008) notes that the NEPA has traditionally not included any climate change analyses in the environmental impact assessment process. Recently though, climate change has appeared as a comment from the lead agency on reviews of environmental impact statements and environmental assessments. However, Lemons (1998, p. 89) states "Because of the significant amount of scientific uncertainty in prediction the environmental impacts of human activities [such as climate change], opponents of agency decisions have often been successful in challenging agency decisions if they can demonstrate that the agency did not rigorously consider certain impacts or if they can demonstrate that an agency did not follow prescribed steps in dealing with scientific uncertainty. Alternatively, if an agency has followed these prescribed steps, then opponents of an agency's decision will have a difficult time fulfilling the burden of proof requirements to overturn that decision." For example, Smith (2008, p. 76) identifies the landmark case, *Center for Biological Diversity v. National Highway Traffic Safety Administration,* as the "most significant NEPA climate change court decision to date" related to NEPA and transportation. In this decision, the National Highway Traffic Safety Administration failed to identify the cumulative effect of incremental emissions on climate change in the EA process. However, in this and similar cases, even the best scientific knowledge for ecosystem-related consequences can be too variable and uncertain to be considered significant evidence in a court of law. Statistical significance in science and engineering, unfortunately, does not translate to beyond a reasonable doubt in law.

Clark (1994, p. 322) echoes this difficulty and states that the "lack of consensus concerning the application of cumulative impact analysis methodology is primarily associated with issues of temporal and spatial bounds and the difficulty of reaching agreement upon the geographical boundaries of the study area and how far into the future and how far into the past one must look to adequately assess the cumulative impacts." In essence, the real issue is that most project teams are unable to define regional and global problems in a context relevant to project-level decisions. Most of the cumulative effect assessments for transportation projects miss the point (if completed at all), and more data (easy to collect) is often provided without completely synthesizing the information in a meaningful way (because analysis is more difficult) (TransTech et al., 2005). Guidelines for the level of detail required and process suggestions for cumulative effects studies of transportation projects are provided in *NCHRP 25-25(01)*.

American Recovery and Reinvestment Act of 2009 and NEPA

The NEPA process is required for any transportation infrastructure improvement project applying for or granted funds under the American Recovery and Reinvestment Act of 2009 (ARRA). According to the CEQ (2009c), NEPA reviews are representative of the sustainability and environmental stewardship goals embedded in ARRA. As of September 2009, infrastructure projects through the United States DOT amounted to 9% of the total funded projects in ARRA. NEPA was not applicable for only two of these projects funded for USDOT in 2009 (CEQ, 2009c).

Resources for Project Environmental Reviews

- Blank copies of the Washington state Department of Ecology SEPA checklist are available and downloadable for use here: http://www.ecy.wa.gov/biblio/ecy05045.html.
- Information for highway proposals and SAFETEA-LU requirements is available from the FHWA at http://www.fhwa.dot.gov/safetealu.
- A "Citizen's Guide to Transportation Decision-Making" and "The Metropolitan Transportation Planning Process: Key Issues. A Briefing Notebook for Transportation Decisionmakers, Officials, and Staff" are available from the FHWA at http://www.fhwa.gov/planning/citizen/index.htm.
- The FHWA provides an Environmental Review Toolkit that is a useful resource for many projects: http://www.fhwa.dot.gov/planning/metro/index.htm
- Detailed questions and answers for environmental review processes are spelled out in the SAFETEA-LU Final Guidance, available here: http://www.fhwa.dot.gov/hep/section6002/

- The FHWA also has guidance for creating effective public Involvement programs. A useful resource is *Public Involvement Techniques for Transportation Decision-making,* available on the web at: http://www.fhwa.dot.gov/REPORTS/PITTD/cover.htm
- The Transportation Research Board (TRB) has a committee focused on public involvement with several useful resources: http://www.trbpi.com/
- The AASHTO Center for Environmental Excellence has many guidelines and resources for addressing NEPA compliance, including a guidebook for SAFETEA-LU Environmental Review Processes. http://environment.transportation.org/center/products_programs/practitioners_handbooks.aspx

GLOSSARY

ACEC	American Council of Engineering Companies
AASHTO	American Association of State Highway and Transportation Officials
ARRA	American Recovery and Reinvestment Act of 2009
Categorical Exclusion (CE)	A decision, project, or activity that has no significant single or cumulative outcome that undermines the quality of the environment and requires no environmental assessment or environmental impact statement. (40 CFR §1508.4 and 23 CFR §771.117)
Categorically exempt	See Categorical Exclusion (CE)
CEQ	Council on Environmental Quality
EA	Environmental Assessment (40 CFR §1508.9)
EIS	Environmental Impact Statement (40 CFR §1508.11)
Environmental review process	A method of informed decision-making used in project development
Extraordinary circumstance	Any special situation that may indicate a need for a more detailed environmental assessment (EA), including (but not limited to): impacts to habitat for endangered species, archaeologically-sensitive areas, wetlands, low income communities, etc.
FHWA	Federal Highway Administration
FONSI	Finding of No Significant Impact (40 CFR §1508.13)
Lead agency	The agency held responsible for NEPA compliance (40 CFR §1508.16)
NCHRP	National Cooperative Highway Research Program
NEPA	National Environmental Policy Act of 1969
NHTSA	National Highway Transportation Safety Agency
ROD	Record of Decision
SEPA	State Environmental Policy Act. Note that some states have different acronyms for their environmental policies.

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LIFECYCLE COST ANALYSIS

PR-2

REQUIRED

GOAL

Determine the lifecycle cost for the roadway project to aid in decision-making.

REQUIREMENTS

Perform a life cycle cost analysis (LCCA) of the roadway project. LCCA must contain at least agency costs (listed below) and workzone user costs.

LCCA can be performed with manual calculations or by using recommended software (noted below for pavements and bridges). Initial values for calculations should be consistent with existing owner agency policies and **software should report probabilistic rather than deterministic results**. Where no owner agency policy exists for LCCA, do one or more of the following to determine input values for software:

- Justify the use of any default inputs
- Use historical data as representative values where available
- Use engineering estimates
- Use values recommended for select software where noted below

For projects with pavements:

Perform a LCCA of the project's pavement structure (comparison of multiple design alternatives is encouraged but not required) in accordance with the method described in the FHWA's Interim Technical bulletin, *Life-Cycle Cost Analysis in Pavement Design* (1998, currently being revised). This may be completed manually or by using the FHWA's RealCost software available for free at:
http://www.fhwa.dot.gov/infrastructure/asstmgmt/lccasoft.cfm

Use parameters for the LCCA that are consistent with existing owner agency policies. If no owner agency policy exists, use recommended values shown in Table PR-2.1 for the FHWA's *RealCost* software.

For projects with bridges:

Perform a LCCA of the project's bridges (comparison of multiple design alternatives is encouraged but not required) according to the guidance in the National Cooperative Highway Research Program (NCHRP) Report 483 (Hawk, 2003) and the software (called *BLCCA*) developed for this study. The report provides standard input values for a wide range of potential bridge projects and referenced sources for other input data. Other lifecycle cost analysis software may also be used at the discretion of the project manager, including *RealCost,* with some minor adjustments to the spreadsheet. A BLCCA may also be completed by hand. Table PR-2.1 may provide some useful inputs for user costs and traffic data.

- Use agency and user cost parameters that are consistent with agency policy, if one exists (though according to the body of research such policies for bridges are rare.)
- Use the same number of years for service life that is used for design of structural members subject to long term loading effects.

RELATED CREDITS

- ✓ PR-3 Lifecycle Inventory
- ✓ EW-4 Stormwater Cost Analysis
- ✓ MR-1 Lifecycle Assessment

SUSTAINABILITY COMPONENTS

- ✓ Economy
- ✓ Extent
- ✓ Expectations

BENEFITS

- ✓ Reduces Lifecycle Cost
- ✓ Improves Accountability

For projects with additional features:
Perform a LCCA of the project's major features (comparison of multiple design alternatives is encouraged but not required) in accordance with generally accepted engineering economics practices. Major features may include tunnels, retaining walls and other items.

Details

Typical LCCAs and BLCCAs include agency and user costs, defined below. Occasionally, third-party costs (such as monetized environmental damages or hazards) are included, but are not required for this Project Requirement. A cost-benefit analysis (CBA) that includes the minimum components below is acceptable. Assumptions used for agency and user costs should be consistent in each analysis for projects with multiple major features.

Agency Costs. Costs from the planning, construction and operation of the roadway and structures.

- **Preliminary Engineering.** Planning and design costs.
- **Contract Administration.** Bidding and contract oversight.
- **Initial construction.** Costs incurred during the initial construction.
- **Construction Supervision.** Construction management, inspections, and
- **Maintenance.** Pothole patching, crack sealing, restriping, etc.
- **Rehabilitation.** Costs to maintain and rehabilitate or retrofit an asset throughout its service life.
- **Administrative Costs.** Cost of pavement management and other administrative costs.
- **Salvage value.** Expected value of materials and equipment at end of service life.

User Costs. Those who use the facility incur costs during normal operation and during construction periods (e.g., time, safety, fuel and other vehicle operating costs).

- **Normal Operation.** Often ignored in LCCA, as they may be the same between alternatives.
- **Work Zone.** Costs incurred by the user from work zone delays.

The Federal government mandated LCCA in the National Highway System Designation Act of 1995 but then changed it to a voluntary standard in TEA-21. Section 1305(c) states that LCCA is not required but tasks the "…Secretary shall develop recommendations for the States to conduct life-cycle cost analyses." Most recently, the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) set a funding threshold that mandates the use of LCCA or other value engineering tools for bridge projects US$20 million or more. Another mandate threshold is set at US$25 million for any federal aid project (Federal Highway Administration, n.d).

Many roadway projects have both pavements and structures included in the scope of work. For such projects, the life cycle cost analysis prepared for this credit must reflect each substantial project feature for its entire service life. It may also be desirable to perform a LCCA on the entire roadway project (e.g., include all earthwork, traffic hardware, structures, etc.) but currently no straightforward means of doing this exists.

Many state departments of transportations (DOTs) already incorporate LCCA into a formal pavement type selection process or project alternative selection process, and thus already have a formal LCCA process in place for pavements. However, a formalized alternative selection process using BLCCA does not appear to be in widespread use for bridge or other structural projects (Özbay et al. 2004; Thompson, 2004).

DOCUMENTATION

- A copy of the LCCA and/or BLCCA calculations (if done by hand) or the report produced by the analysis software, including a summary of inputs and outputs.
- A link to or copy of agency policy on LCCA and/or BLCCA if one exists.
- A short 1-paragraph narrative describing which alternative was selected and the principal reasons for selection.

Table PR-2.1: Recommended LCCA Input Values for RealCost if No Standard Agency Policy Exists

Analysis Options	**Probability Distribution**	**Value**
Analysis period	NA	≥ 40 years
Discount Rate†	Triangular	min = 1.7%, most likely = 2.7%, max = 3.7%
Include agency cost residual value	NA	Yes
Include user costs in analysis	NA	Yes
User cost comparison method	NA	Calculated
Traffic direction	NA	Both or Inbound or Outbound
Include user cost residual value	NA	Yes
Traffic Data		
AADT	NA	Best estimate
Single unit trucks as % of AADT	NA	Best estimate
Combo unit trucks as % of AADT	NA	Best estimate
Annual growth rate of traffic	Normal	Best estimate
Speed limit under normal conditions	NA	Predominate speed limit in project
Lanes open in each direction under normal operation	NA	Best estimate
Free flow capacity	NA	Calculated by software
Queue dissipation capacity	Normal	average = 1818 vphpl, st. dev. = 144 vphpl
Maximum AADT both directions	NA	Best estimate
Maximum queue length	NA	Best estimate
Rural/Urban	NA	Best estimate
Value of User Time††		
Value of time for passenger cars	Triangular	min = $10, most likely = $11.50, max = $13
Value of time for single unit trucks	Triangular	min = $17, most likely = $18.50, max = $20
Value of time for combination trucks	Triangular	min = $21, most likely = $22.50, max = $24
Hourly Traffic Distribution		
Use default values if no region or project specific information available.		
Added Vehicle Time and Cost		
Use default values if no region or project specific information available.		
Alternatives		
Alternative description	NA	Fill in
Activity description	NA	Fill in
Agency construction cost	Normal	average = best estimate of cost st. dev. = 10% of the average
Activity service life	Triangular	Best estimate
Maintenance frequency	Triangular	Best estimate
Work zone length	NA	Best estimate
Work zone capacity	NA	Best estimate, if no data consider using Figure 3.4 in Walls and Smith (1998)
Work zone duration	NA	Best estimate
Work zone speed limit	NA	Posted value
Number of lanes open in each direction during work zone	NA	Best estimate
Work zone hours	NA	Planned hours

†Discount rate should be determined from most recent OMB Circular A-94. Appendix C contains real interest rates for treasury notes and bonds of various lengths. Treasury note maturity that most closely matches the project analysis period should be used. Use minimum and maximum values of ±1%.

††Dollar values in this table are taken directly from Walls and Smith (1998) and are given in August 1996 dollars. These values MUST be inflated to dollar values in the year that construction is scheduled to start using the U.S. Bureau of Labor Statistics (BLS) Consumer Price Index (CPI) U.S. city average for all urban consumers (not seasonally adjusted). The value for this index in 1996 was 156.9. The BLS CPI Inflation Calculator (http://www.bls.gov/data/inflation_calculator.htm) can be used to do this conversion quickly.

APPROACHES & STRATEGIES

- Complete the LCCA early enough in the project so that its results can be considered in selecting between project alternatives. This generally means it should happen during the planning stage and not the design or construction stage.
- Note that *RealCost* and *BLCCA* software are not required for this credit; however any other method used must conform to the FHWA's Interim Technical bulletin for pavements, *Life-Cycle Cost Analysis in Pavement Design* (Walls & Smith, 1998) and NCHRP 483 for bridges.
- Include LCCA considerations in the technical score of bidders for pavement projects in order for it to be considered in selecting a design alternative for Design-Build contract delivery methods. This is because the actual pavement design is often used as part of a design-build team's technical score in determining contract award, a LCCA of alternative designs cannot be performed by the agency until after the bid competition is complete. While this can be done, LCCA results should be properly weighted so that they influence contract award in a manner consistent with owner wishes. Unfortunately, Gransberg and Molenaar (2004) showed that design-build award algorithms often do not weight LCCA concerns heavily enough for them to be a significant factor in contract award.
- Incorporate results of other Related Credits, such as Project Development: Economy and Cost Benefit Analysis, into the LCCA for consistency across the whole project.

Example: Case Studies of LCCA

Rangaraju et al. (2008) report on LCCA efforts of the South Carolina DOT and list several case studies in Appendix E (page 117) that deal with the influence of discount rate and analysis period on LCCA outcomes.

The entire report, *Life Cycle Cost Analysis for Pavement* (Rangaraju et al. 2008) can be downloaded at: http://www.clemson.edu/t3s/scdot/pdf/projects/SPR656Final.pdf.

Example: Washington State Department of Transportation (WSDOT) LCCA Protocol

WSDOT follows a standard LCCA protocol when selecting pavement type for new facilities. This protocol is based on the FHWA's *Life-Cycle Cost Analysis in Pavement Design* (Walls and Smith, 1998) and uses RealCost software for calculations. It includes specified inputs for WSDOT analysis and how to consider results. Of note, cost difference between competing alternatives that are less than 15 percent are considered equal based on the uncertainty of input values.

The WSDOT *Pavement Type Selection Protocol* (2005) is available for download here: http://www.wsdot.wa.gov/biz/mats/Pavement/Technotes/PTSP_Jan2005.pdf.

Example: Caltrans LCCA Procedures Manual

Caltrans has developed a manual (Caltrans 2007) that describes LCCA procedures for use in Caltrans. The manual is based on RealCost software and provides standard input values for a wide range of potential projects. Caltrans has adopted an aggressive policy towards using LCCA mandating that it be used "…for all projects with include pavement work on the State Highway System regardless of funding source…" (Land 2007)

The manual can be downloaded at: http://www.dot.ca.gov/hq/esc/Translab/ope/LCCA.html.

POTENTIAL ISSUES

1. While LCCA is a fairly standard economic analysis tool, the potential exists to input incorrect or irrelevant numbers and misuse its results. Users should be familiar with the FHWA's *Life-Cycle Cost Analysis in Pavement Design* Interim Technical Bulletin (Walls and Smith 1998, currently being revised) before conducting an LCCA with *RealCost* or *BLCCA*.
2. A LCCA assumes that the benefits associated with project alternatives are equal. Thus, it only analyzes costs. Projects with different benefits between alternatives may desire a more comprehensive cost-benefit analysis.

3. The meaningfulness of LCCA outputs relies heavily on good estimates of future pavement life, rehabilitation costs and the interval between future rehabilitation efforts. These all rely on good engineering judgment and past history rather than economic theory or principals.
4. LCCA is based on estimated of total cost and can be easily manipulated by changing assumptions and input values. For this reason the results should not be weighted too heavily in the choice of design alternatives.
5. This credit does not contain a requirement to use or implement the lowest life-cycle cost project alternative. Therefore, it should be viewed as a credit that creates information that is useful in decision-making rather than a decision-making tool. It does not guarantee a lowest life-cycle cost decision.
6. This credit does not require the LCCA to be done during the planning stage where it would be most likely to influence project decisions. Therefore, it could be done late in design, or even during construction, meaning it would be undertaken for no other reason than to meet this credit, which misses the point.
7. Some rehabilitation efforts and even other efforts that take a systematic approach to choosing the proper project features (e.g., a pavement management system), there may not be a choice between two or more alternatives. This may be because such a system already incorporates a form of LCCA, or it may be because no other alternative is reasonably feasible.
8. Other prototype software programs for bridge life cycle cost analyses have been developed but do not appear to be in widespread use, such as the National Institute of Standards and Technology's *BridgeLCC* software which was last updated in 2003 (available at http://www.bfrl.nist.gov/bridgelcc/welcome.html). For purposes of this credit, any software can be used so long as the inputs and results are justifiable, reasonable, and validated by the professionals working on the project.

RESEARCH

Lifecycle cost analysis (LCCA) is a process for evaluating the total cost of a project, facility or product over its useful lifetime. For roadway projects, this means accounting for initial construction costs, maintenance and rehabilitation costs, roadway user costs and third-party costs. LCCA can contribute to the sustainability of a roadway project by allowing project personnel to account for total life cycle costs when making key project decisions.

An important distinction must be made between LCCA and life cycle assessment (LCA) as these terms use confusingly similar acronyms. Both have similar utility in the decision-making process, but the underlying purpose, scope and mathematical model for each are different. For this reason, LCA is discussed in detail in other credits in the *Greenroads Manual* (see PR-3 Lifecycle Inventory and MR-1 Lifecycle Assessment) while LCCA is discussed here.

Lifecycle Cost Analysis Method

LCCA is simply a mathematical accounting tool that can be used to compare the value of money at different times. Underlying the LCCA process are basic principles of business finance, which uses compound interest formulas (and tables) and reasonable assumptions about the future to translate different economic values to an equal reference point in time. LCCA may be quite familiar to many transportation professionals in the form of cost-benefit analysis (CBA) or commonly just "engineering economics." The how-to of business finance and engineering economics can be found in a plethora of textbooks and will not be discussed in depth here.

LCCA is a useful process in roadway design because the results quantify the total long-term value of project alternatives. This process allows for straightforward comparisons, usually in terms of a total lifetime cost or a total lifetime benefits. The key role of the decision-maker in LCCA is determining appropriate assumptions and scope for the comparison, as well as interpreting and acting on the quantified results.

For a basic example, consider a roadway project with two design alternatives; one is a thin pavement section and the other has thicker section. The initial construction cost of the first alternative is lower than the second, but the first alternative requires additional, more frequent expenditures for maintenance throughout its lifetime. The project manager completes an LCCA on each alternative. The results show that while first alternative is less expensive for initial construction, the second alternative actually has a much lower long-term cost. The second alternative has a higher upfront cost for initial construction, but saves the project owner more money over time.

Because this comparison is not limited to upfront costs alone, a project manager can better understand how their design and construction choices contribute to the overall economic impact of the project.

Lifecycle Costing, Roadways and Sustainability

There is substantial writing to suggest that LCCA contributes to sustainability. Most efforts are centered on buildings; however, the FHWA does contribute some useful information. Considering buildings, the Federal Facilities Council recognized the relationship between life-cycle costing and sustainable development by stating:

> *"Guidance related to life-cycle costing and value engineering was recognized as being supportive of sustainable development, in particular when used in the conceptual planning and design phases of acquisition, where decisions are made that substantially affect the ultimate performance of a building over its life cycle (Federal Facilities Council, 2001)."*

In essence, they were concerned that features that enhanced sustainability would be excluded to save on initial costs without considering life-cycle costs that could show such features to be warranted. The FHWA believes LCCA should be used because "…transportation investment decisions should consider all of the costs incurred during the period over which alternatives are compared (FHWA, 2002)." This means considering the total cost to the owner, users and externalities rather than just the first, or construction, cost.

- **Initial construction.** Costs incurred during the initial design and construction.
- **Preservation.** Costs to maintain and rehabilitate an asset.
- **Users.** Those who use the facility incur costs during normal operation and during construction periods (e.g., time, safety, fuel and other vehicle operating costs).
- **Externalities**. Costs that indirectly impact the users or the environment due to, for example, air emissions or a natural hazard.

Prevalence of LCCA and BLCCA

According to the comprehensive state-of-the-practice review of the applications of lifecycle costing in practice by Özbay et al. (2004), LCCA has been in use to some extent for almost 40 years for pavement selection. The authors completed a three year study that surveyed the division at 39 state departments of transportation (DOTs) which used LCCA the most. The majority of respondents in the survey indicated that LCCA is applied by:

- Research and design division (68%)
- Materials and pavements division (37.5%)
- Bridge offices (12.5%)

Additionally, the authors found that all agencies surveyed use LCCA on some form of pavement projects. In fact, 60% of the responding agencies have adopted formal guidelines for pavement LCCA. However, only 25% of those surveyed by Ozbay et al. (2004) indicated that BLCCA might be used on bridge projects at their state agencies while 100% indicated that it might be used on pavement projects.

State of the Practice - Pavements

A more recent study for the South Carolina Department of Transportation (Rangaraju et al., 2008) found that most states (i.e. state departments of transportation) conduct LCCA but to varying degrees. Their survey, completed in 2005, had responses from 33 states and 2 Canadian Provinces and found:

- 94% (33 of 35) of the agencies use LCCA as part of their decision-making process. This appears to be an increase in percentage over an earlier limited 2001 survey that found 8 of 16 responding states used LCCA.
- 69% (24 of 35) of respondents include or are planning to include user costs in LCCA. Typically this is done by quantifying user delay costs during construction only.
- Few (only 2 out of 32) used a fully probabilistic approach to calculating life cycle costs while others did conduct sensitivity analyses to determine how changes in assumed parameters affected analysis outcome.

State of the Practice - Bridges

Ehlen (1997) provides a strong, practical argument for the utility of systematic application of BLCCA and Thompson (2004) also provides a good summary of the state of BLCCA in bridge practice. He notes that streamlined tools will expand application opportunities for BLCCA, especially in terms of network level bridge management systems, but much more refinement may be necessary for uncertainties and assumptions to be unified from project to project. Much of the lifecycle literature for bridges appears to be relevant to optimization of the project and network level bridge management systems. These references are discussed in more detail in PR-9 Pavement Management System.

However, to date, the most comprehensive work on BLCCA was completed as part of the National Cooperative Highway Research Program *Report 483: Bridge Life-cycle Cost Analysis* (Hawk, 2003). This report contains details on specific methodologies that may be relevant to bridge designers, as well as limitations, assumptions, examples, and a software tool called *BLCCA*.

Some of the most recent work that is relevant to sustainability includes early BLCCA work by Ehlen (1999), who attempts to account for third-party costs (which he defines as costs of environmental damages) due to the lifecycle of bridge projects. However, values of zero were used for these costs in his model. Lately, BLCCA literature has focused more on reliability studies for catastrophic and long-term environmental stressors including work by Lee, Cho, and Cha (2006), Hosser et al. (2008) and Padgett, Dennemann, and Ghosh (2010). The latter authors applied LCCA principles using a risk-based analysis of several bridge retrofit options subject to seismic hazards. The study may be particularly relevant to practitioners trying to model their bridge to determine an appropriate retrofit solution and maintenance schedule.

Impact of LCCA

Given that most states use LCCA in some form already this credit may have the largest effect in three areas:

1. **Local agencies or other owners who do not typically conduct LCCAs.** *RealCost* and *BLCCA* are fairly straightforward free software tools that should be able to provide answers with reasonable effort.
2. **State or federal projects considered too small for LCCA.** Some projects (e.g., overlays or other preservation efforts) are generally deemed too small for LCCA and have historically omitted this process in decision-making.
3. **Non-pavement projects.** This credit may encourage the wider adoption of lifecycle costing on non-pavement projects such as bridges and other major structures, intelligent transportation systems, or other types of assets where LCCA applications are not common practice.

GLOSSARY

Agency cost	A cost incurred by the agency of a roadway such as maintenance, repair, rehabilitation, improvement, and replacement (Thompson, 2004)
BLCCA	Bridge Life Cycle Cost Analysis
Externality	An indirect cost incurred by any party due to the project, such as damage to the environment, which is hard to quantify using traditional accounting.
LCCA	Life Cycle Cost Analysis
Salvage value	The estimated monetary value of an asset at the end of its useful life.
Third-party cost	See *Externality.*
User cost	A cost incurred by the users of a roadway such as collision risk, detours, and time delay (Thompson, 2004)

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LIFECYCLE INVENTORY

PR-3

REQUIRED

GOAL

Incorporate energy and emissions information into the decision-making process for pavement design alternatives.

REQUIREMENTS

Complete a lifecycle inventory for the final pavement design alternative for the project using the software tool, PaLATE v2.2 as modified for Greenroads, or approved equal. Report only results for total energy use and global warming potential (GWP) (in carbon dioxide equivalent emissions, CO_2e) for the final pavement design alternative. The following input values are required for PaLATE v2.2:

- **Total weight and types of virgin materials.** This includes aggregates, binders, base materials, and structures. These amounts can be design estimates or constructed totals.
- **Total weight and types of recycled materials.** PaLATE v2.2 models emissions and energy for several types of materials.
- **Expected transportation distances for all materials.** This means distances from source to production as well as from production to site. Transportation of waste to disposal is also included.
- **Expected construction vehicle types.** These include, but are not limited to, pavers, mixers, hauling vehicles, excavators, rollers, and finishing equipment.
- **Estimated design life.** Use the same input data as used in the PR-2 Lifecycle Cost Analysis.
- **Scheduled years and expected type of maintenance.** Use the same input data as used in the PR-2 Lifecycle Cost Analysis. This information should also match the project specifications provided to meet the requirements for PR-9 Pavement Maintenance Plan and PR-10 Site Maintenance Plan.

Details

There are several built-in limitations to the PaLATE tool, which are discussed in detail in the modified tool documentation. We recommend use of this tool because we are aware of these limitations, we have checked (or modified) the data sources, we know that the software reports the two requested pieces of information reliably for both asphalt and concrete pavements (even with a variety of recycled materials), we find it relatively easy to use, and we have modified the tool to meet Greenroads informational needs. The tool is available on the Greenroads website (http://www.greenroads.us) for download.

There are a few other software tools that are available for developing lifecycle inventories, both free and proprietary. These tools are also acceptable if they are able to produce energy use and GWP outputs and use a transparent interface that clearly references data sources used to compute these values.

DOCUMENTATION

- A copy of the input/output page for PaLATE v2.2 for Greenroads. If other software is used, provide a list of data sources in addition to the input list and output values for total energy use and GWP.

RELATED CREDITS

- ✓ PR-2 Lifecycle Cost Analysis
- ✓ PR-9 Pavement Management System
- ✓ PR-10 Site Maintenance Plan
- ✓ MR-1 Lifecycle Assessment

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Equity
- ✓ Extent
- ✓ Expectations
- ✓ Exposure

BENEFITS

- ✓ Improves Accountability
- ✓ Increases Awareness
- ✓ Creates New Information

APPROACHES & STRATEGIES

- Use PaLATE v2.2 for Greenroads as modified by the University of Washington. The tool is available in Microsoft Excel 2003 and 2007 format on the Greenroads website at: http://www.greenroads.us. All limitations and modifications made by Greenroads have been detailed in the supporting worksheets within the tool itself.
- Provide a list of data sources if not using PaLATE v2.2 as modified for Greenroads.
- Download a copy of the original version of PaLATE and modify it for use on your project and future projects. The original PaLATE tool, created in 2003 by the Consortium of Green Design at the University of California, Berkeley, is available in Microsoft 2003 format from the Recycled Materials Resource Center at the University of New Hampshire here: http://www.recycledmaterials.org/Resources/CD/PaLATE/PaLATE.xls. We know the limitations of this tool and know how it works, and may be able to assist you in modifying the tool to correct some of the known errors that could impact the outcome of your project LCI (such as double-counting and material densities).
- Use process-based data from the free National Renewable Energy Laboratory (NREL) LCI database, emissions factor and fuel use data from the Environmental Protection Agency (EPA) and the Department of Energy (DOE), and follow the LCI process methodology outlined by the International Standards Organization (ISO) 14040 and 14044 to complete a process-based LCI for the final pavement section.
- Use economic input-output data in the customizable, free tool for Economic Input/Output Life Cycle Assessment (EIO-LCA) from the Green Design Institute at Carnegie Mellon University. However, this tool does not allow for inclusion of project-specific process data. The EIO-LCA tool, including guidance on how to use the tool, is available at http://www.eiolca.net. EIO-LCA is the basis of the PaLATE tool, so the guidance document may be helpful in developing an initial understanding of how the model works.
- Use new software tool CHANGER (Calculator for Harmonised Assessment and Normalisation of Greenhouse-gas Emissions for Roads), which has been specifically designed for roadways by the International Road Federation (IRF). This software is not free, but is available for download from the IRF at: http://www.irfnet.org/.
- Do not use lifecycle assessment tools that are available for buildings to construct the project LCI model for the roadway project. There are several of these tools available, however they do not include enough process data about roadway materials or associated construction equipment to present results that are meaningful to roadways and are often of questionable validity and relevance.
- Consider hiring a consultant with experience in lifecycle assessment (LCA) and involve them in project development. This approach may be useful in simultaneously meeting the credit requirements for Credit MR-1 Lifecycle Assessment. The benefits of this approach include a full, project-specific review of environmental emissions impacts that extends the scope past reporting CO2e and energy, all of which may be used to make a more informed decision about project design alternatives. LCA experts or firms may also have access to proprietary data and software which may produce a more accurate, comprehensive, and project-based models due to higher overall data quality and fewer data gaps. Additionally, there is less likelihood of double-counting.

Example: Sample PaLATE v2.2 Results

This example represents a fictitious 12-inch, 12-foot wide lane of asphalt pavement section with a 12-inch deep and 14 foot wide gravel subbase, comprised (by volume) of 80% gravel and 20% sand with an assumed design life of 15 years. This example uses typical production process and construction equipment and the default densities for all materials. It is also assumed that asphalt is 5% by weight of the final HMA mixture. Note that this is an unrealistic example of an LCI because it does not include transportation, maintenance or demolition for simplicity. It is only representative of the construction phase of the roadway.

Table PR-3.1 shows the input values used for PaLATE v2.2 on the "Construction" worksheet page. Output values, from the "Results" worksheet page, are shown in Table PR-3.2.

Table PR-3.1: PaLATE v2.2 for Greenroads input from "Construction" worksheet page.

	Material	Density	Subbase & Embankment	
	Unit	tons/CY	CY	tons
Subbase & Embankment	RAP from recycling plant/stockpile to site	1.85	0	0
	RCM from recycling plant/stockpile to site	1.88	0	0
	Rock	2.00	0	0
	Gravel	1.35	2190	2957
	Sand	1.25	548	685
	Soil	1.63	0	0

	Material	Density	HMA	
	Unit	tons/CY	CY	tons
HMA Pavements	Virgin Aggregate	1.85	2103	3891
	Asphalt Bitumen	0.84	244	205
	Tack Coat	0.84	0	0
	RAP Transportation	1.85	0	0
	Recycled Tires/ Crumb Rubber	0.97	0	0
	Glass Cullet	1.93	0	0
	Total: Asphalt mix to site	2.05		4096

Table PR-3.2: PaLATE v2.2 output table from "Results" worksheet page. Zero values mean not computed.

		Energy [GJ]	CO_2e [kg] = GWP
Initial Construction	Materials Production	2,767.6	944,391
	Materials Transportation	0.0	0
	Equipment	51.9	3,577
Maintenance	Materials Production	0.0	0
	Materials Transportation	0.0	0
	Equipment	0.0	0
Total	Materials Production	2,767.6	944,391
	Materials Transportation	0.0	0
	Equipment	51.9	3,577
	Total	**2,819.4**	**947,968**

Notes on the PaLATE v2.2 Data Sources

PaLATE v2.2 for Greenroads uses data from 2002 EIO-LCA producer data set and updated energy data for transportation modes from the 2009 Transportation Energy Data Book, available from the U.S. Department of Energy. However, this example is highly oversimplified and only intended to demonstrate the amount of information needed to document this Project Requirement. The transportation input data and maintenance data has been left out of this example model, and the input cells and rows for many of the material options and transportation modes have been hidden for simplicity and to limit image size. The output results show 0 for these phases and materials, and does not represent any emission from vehicle emissions in transportation, except as built into the sector data used.

PaLATE v2.2 uses the EIO-LCA data (http://www.eiolca.net) to make an asphalt pavement model. The model is built assuming the following materials are required to make asphalt: bitumen, virgin aggregate, gravel, and sand. The first is represented by the EIO-LCA sector called “asphalt paving mixture and block manufacture,” while the last three are from the “sand, gravel and clay refractory mining” sector. The differences between the last three are the densities. Basic emissions data for these three particular types of material is assumed to be the same even though the amount of processing (and thus energy and emissions) required to make these materials is realistically slightly different. Also, HMA plant production process data has been modified from the original PaLATE to be process based on data from the EPA AP-42.

The EIO-LCA database appears to use the Intergovernmental Panel on Climate Change (IPCC) 2nd Assessment Report (SAR) in 1996 to compute the index for Global Warming Potential based on CO_2e, though this is not explicitly stated. Note that the IPCC published revised values for greenhouse gas emissions in 2007 (see Solomon et al.). It is unclear if and when these new values will be incorporated into the EIO-LCA database; however, this detail is irrelevant to the intent of this Project Requirement and is likely to be only slightly higher or lower than the value computed.

Additionally, there are several limitations built in to a model that uses a pre-existing framework. Of particular importance is the potential for missing data where CO_2e or energy use is not recorded or otherwise measured, especially when taken as representative of an entire economic sector, because these missing data are hidden in the aggregated totals and are difficult to identify on a process level. The EIO-LCA assumptions and limitations regarding the economic sector energy and emissions model are cited in detail at:

- EIO-LCA Assumptions and Uncertainty: http://www.eiolca.net/Method/assumptions-and-uncertainty.html
- EIO-LCA Model Limitations: http://www.eiolca.net/Method/Limitations.html

References used for the original PaLATE data sources, as well as the data and modifications that have been made to the tool by the University of Washington, are documented in the tool itself.

POTENTIAL ISSUES

1. A simplified LCI, such as the one required here, is not intended to dictate final project decisions made. Instead, it is intended to inform the decision-making process through use of basic environmental accounting.
2. This Project Requirement requires reporting only two values for only one design alternative. The reason for this is that these two values are not generally considered in traditional roadway project planning or decision-making. However, in general, more than one alternative may be considered (and compared), and several types of emissions may also be pertinent to the decision-making process. We feel that requiring only the final design option is as a small step toward this comparison process, but could lead to more thoughtful accounting for multiple decision options in the future.
3. PaLATE investigations are limited to the pavement section and structures only. This includes base and subbase materials, and also recycled material options, but does not include other elements of the roadway environment.
4. Operational emissions due to vehicular traffic are also not considered in either version of PaLATE. These are, however, addressed elsewhere in Greenroads, because a different software tool is recommended for this modeling. See Credit AE-4 Traffic Emissions Reduction.
5. We believe that the EIO-LCA sector model used in the modified PaLATE v2.2 for Greenroads reports GWP based on outdated values assigned by the Intergovernmental Panel on Climate Change (IPCC) in 1996, instead of the more current 2007 values. Documentation regarding this issue is unclear. This means values output from PaLATE v2.2 can only be compared to other values output from PaLATE v2.2. Direct comparisons to other software tools, without a thorough investigation or review of their underlying assumptions or uncertainties, are therefore not valid.
6. Sector emissions and energy reported for the EIO-LCA data used in the modified version of PaLATE include feedstock emissions and energy from the extraction process of petroleum products and cement products (represented as a percentage of the total contribution to the cost for the streamlined processes modeled).
7. Technically, a full lifecycle assessment (LCA) is a much more involved and detailed process than a simple software-based lifecycle inventory (LCI) model can include. LCA involves additional considerations outside the pavement section alone and is highly dependent on quality, availability and relevance of data. Additionally, an impact assessment step is included in LCA which is not necessary for LCI. Impact assessment involves assigning

valuations and weights to certain outputs from the LCI. For this reason, credit is awarded for a full LCA in Credit MR-1 Lifecycle Assessment.

8. Economic lifecycle assessment models based on capital and lifetime maintenance costs do not typically include considerations of energy or emissions. However, lifecycle cost models are equally important and are covered under Project Requirement PR-2 Lifecycle Cost Analysis.
9. Similarly, social impacts can be measured using certain common metrics and indices that are intended to represent quality of life, health, or other equity-related, human-centric issues (such as birth and death rates or productivity rates). These are not well-researched and few systematic approaches have been refined well enough for incorporation into the lifecycle decision-making process requirements for Greenroads projects. The utility of applying these global metrics and indices on a project level are also not well understood or documented. However, the environmental review process (see PR-1 Environmental Review Process) addresses social impacts on a project-level.
10. The example leaves out transportation and maintenance on purpose. It should be understood that its simplicity is meant to demonstrate a process task; it is clearly not meant to be scaled by simple multiplication by the total mileage of the project. Each project will, and should be, different and none will match this example. This is also why both the input and output values are required for review.

RESEARCH

Lifecycle assessment (LCA) can be a useful decision-making tool for benchmarking roadway environmental performance (Schenck, 2000; Keoleian & Spitzley, 2006; Cooper & Fava, 2006) and as a method of environmental accounting for roadway systems. This particular requirement is the last part of a series of three related Project Requirements, which also include PR-1 Environmental Review Process and PR-2 Lifecycle Cost Analysis. This requirement focuses on developing a project-specific environmental accounting inventory (a lifecycle inventory: LCI) to aid in the decision-making process and also establishes baseline environmental performance (specifically energy use and carbon dioxide emissions) for the roadway pavement section. Project costs and social implications are addressed in prior requirements PR-1 and PR-2. A diagram of the main processes in a generic pavement lifecycle is provided in Figure PR-3.1 (next page).

A more detailed discussion of some of the finer details and types of LCA methodology is provided in the Research section of Credit MR-1 Lifecycle Assessment. This section introduces LCA and LCI and provides a review of existing literature for roads.

What is Lifecycle Assessment?

Lifecycle assessment (LCA) is a standardized, comprehensive tool that can be used for analyzing and quantifying the environmental impacts and sustainability of a product, system, and/or process. The International Standards Organization (ISO: 2006a) states that LCA is a process that "addresses the environmental aspects and potential environmental impacts (e.g. use of resources and the environmental consequences of releases) throughout a product's life cycle from raw material acquisition, through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave)." Effectively, the "product" for this Greenroads requirement is the entire roadway project system.

LCA is a tool that can provide perspective on many elements of a system, effectively linking the production of a material to its use (Keoleian & Spitzley, 2006). In engineering applications, LCA offers a holistic, systems-based approach to project development and project management. It is often employed as a method of developing process alternatives. A lifecycle perspective necessitates a unique, and often unconventional, management strategy to optimize performance of materials, supply-chains, and to minimize or eliminate polluting activities.

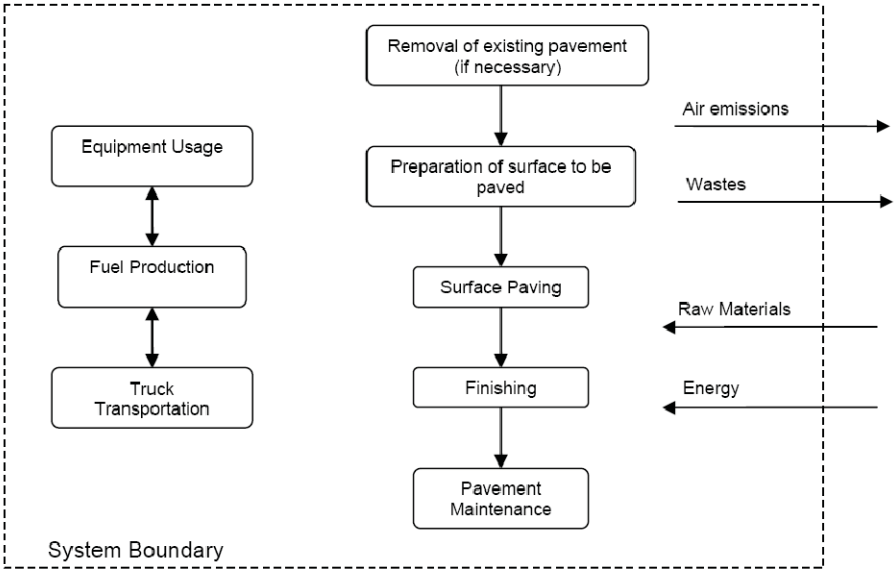

Figure PR-3.1: Basic lifecycle activities and system diagram for typical pavements. (Weiland, 2008)

Life cycle assessments have four stages (or phases) which are often iterative. These are shown graphically in Figure PR-3.2 and described below.

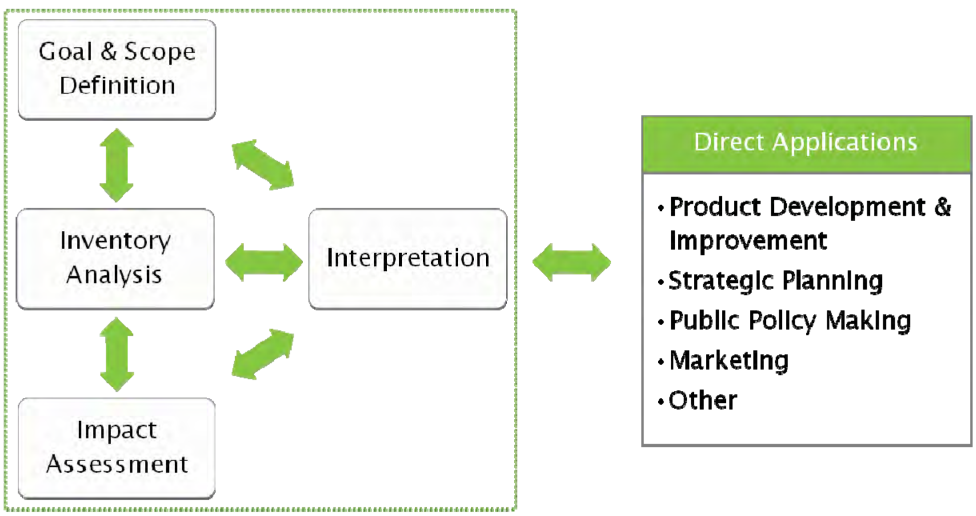

Figure PR-3.2: Stages of Lifecycle Assessment (Adapted from ISO, 2006a; ISO, 2006b)

- **Goal and Scope.** Specifying the goal of the project LCA documents the intended application, referenced literature for the project, intended audience (here the Greenroads review team), and proprietary status of final results. It also defines what thing or process will be studied and how much will be produced by the model. The most important part of this step comes with defining the system boundaries and identifying the processes and emissions to be included in the final outcome. Additionally, this section identifies some key limitations and assumptions of the model (specifically, what was scoped out, what processes were simplified and how they were estimated). Since the LCA process is iterative, it is crucial for the project team to develop a well-defined goal and scope in order to have a meaningful end product.
- **Lifecycle Inventory Analysis (LCI).** The 2006 ISO14044 Standard Section 4.3 provides the basic background and procedures required for life-cycle inventory analyses based on the functional units and reference flows defined in the Goal and Scope. A functional unit is defined as the "quantified performance of a product system for use as a reference unit." A reference flow is the "measure of the outputs from processes in a given product system

required to fulfil [sic] the function expressed by the functional unit." The alternatives under comparison for the inventory analyses are then described with reference to their specific unit processes and functional units. Each alternative will likely be comprised of slightly different processes. The purpose of the inventory analysis is to produce both qualitative and quantitative information and refined definitions of the unit processes within the system boundaries. The inventory analysis procedure consists of data collection, data processing and calculations, and allocation of environmental flows and releases, such as emissions, energy use, water, fuels, and other materials or byproducts that were specified in the Goal & Scope for the project.

- **Lifecycle Impact Assessment (LCIA).** The 2006 ISO14044 Standard Section 4.4 provides the basic background and procedures required for lifecycle impact assessments (LCIA) based on the functional units and reference flows defined in the Goal and Scope. Impact assessment uses the results of the inventory analysis to identify impacts associated with the emissions and material flows. Impacts must be classified and characterized according to the ISO14044 Standard (2006b). Usually this involves assigning equivalency factors to the inventory data (e.g. a conversion factor) to produce an aggregate indicator value that can be compared to another impact index, known metric or industry average. LCIA is typically used for comparing two or more products with the same functional unit.
- **Interpretation.** The last phase of the LCA is interpretation and presentation of the results. "The first step in decision analysis is to identify all important objectives and attributes. While this step may seem obvious, it is necessary to ensure that the valuation focuses on the right problem." (EPA, 2000) The FRED documentation provides additional guidance and suggestions for decision-making based on LCI and LCIA results, such as:

    - Adopting an existing decision-making weighting scheme.
    - Using the Analytical Hierarchy Process (AHP).
    - Using the Modified Delphi Technique.
    - Using a Multi-Attribute Utility Theory.

However, for this Project Requirement, neither the LCIA nor the interpretation steps are required. This Project Requirement focuses on one component of the LCA, the lifecycle inventory (LCI) analysis. The purpose of the inventory analysis is to collect various data on inputs and outputs of the system relevant to the goals of the study and within the defined boundaries of the study (ISO, 2006a) Thus by default, the LCI will also require a well-refined and clear goal statement and scope of assessment. Approaches to refining the goal and scope are not discussed here. Please see the research section of Credit MR-1 Lifecycle Assessment. Both LCI and LCA can be used in a more informed decision-making process (ISO, 2006a; Schenck, 2000).

LCI and LCA studies are similar, but cannot be compared unless the context of assessment is the same. ISO (2006a) states, "LCI studies are not to be confused with the LCI phase of an LCA study." Similarly, LCA and LCI are not to be confused with conventional lifecycle cost analysis (LCCA). LCCAs are frequently mistaken for the process-based and streamlined methods of life cycle assessment. LCCA is actually an approach used in what is typically termed "engineering economics" (a misnomer, for there is very little of either engineering or economics involved) which allows determination of past, present and future values of a variety of initial capital and long-term inputs and outputs based on cost alone, compounded over time. Additionally, LCCAs rarely systematically account for end-of-life costs, such as disposal fees or recycling costs, because these are difficult to estimate. While all methods are based on a similar timelines (the whole lifecycle), they each have fundamentally different outputs and resulting implications for the design process, and therefore different utility in decision-making. PR-2 discusses LCCA in detail.

LCA and Sustainability Benefits

Keoleian & Spitzley (2006) suggest that "Life cycle based sustainability models and metrics play a key role in guiding the transformation of technology, consumption patterns, and corporate and governmental policies for achieving a more sustainable society." An LCA approach can be used in many applications. Some of the most often cited are noted below:

- Lifecycle models promote an awareness of production effects and connect them to use or consumption of a system or process.

- Setting lifecycle boundaries at a system level allows for comprehensive environmental, social and economic accounting metrics to be used in a meaningful way to measure and monitor performance.
- Lifecycle metrics inform decision-makers and can be used by stakeholders to manage and assess the system or product (Keoleian & Spitzey, 2006).
- LCA can help identify "opportunities to improve environmental performance of products at various points in their lifecycle." (ISO, 2006a)
- LCA can help inform the industry decision-makers, government agencies and policy-makers for strategic planning, performance benchmarking, or product development and redesign. (ISO, 2006a)
- LCA can help evaluate the relevance of various indicators for environmental performance (ISO, 2006a).
- LCA provides a marketing opportunity such as eco-labeling and declarations of environmental performance (ISO, 2006a).

A survey completed by Cooper and Fava in 2006 shows that LCA is widely used for a number of applications. Table PR-3.3 summarizes the results, by percentage of respondents.

Table PR-3.3: Prevalence LCA Use by Practioners (Adapted from Cooper & Fava, 2006)

Use of LCA	Response
Business strategy and planning	63%
Product and system research and development	62%
Inputs for design (products or processes)	52%
Education	46%
Policy development	43%
Marketing schemes (labeling, environmental declarations)	37%
Sales	26%
Procurement	20%
Other (including bidding or tender packages)	8%

Types of LCAs

In general, there are three or four types of LCA models depending on the source of information. One type is the Economic Input-Output model (EIO) for Life Cycle Assessment (EIO-LCA). For example, this Project Requirement is based on an EIO-LCA model (http://www.eiolca.net). Second is a process-based LCA, which follows a standard methodology set forth by the International Standards Organization (ISO) 14040 and 14044 for Lifecycle Assessment. This method, also called ISO-LCA (Cooper & Fava, 2006), often produces more detailed results than the EIO-LCA model (Hendrickson, Lave & Matthews, 2006). Process-based LCAs involve project-specific process data and generally use a computational tool or matrix analysis to form a model and complete the assessment of data, such the method outlined by Heijungs and Suh (2002). There also is a third method of life cycle assessment, which is recently becoming more prevalent called Hybrid LCA, where an EIO model is supplemented by or integrated with process-based data to produce a more comprehensive representation of the environmental effects of the system processes. These are discussed in further detail in Credit MR-1 Lifecycle Assessment.

Modifying any of these three LCA methodologies may result in what is called a "streamlined LCA;" while not a specific class or type of LCA, a streamlined LCA strategically omits or simplifies the LCA method to make it less computationally intensive, such as through the creation of a software tool (Weitz, Todd, Curran & Malkin, 1996) that deliberately leaves out collection of some types of data or a particular impact assessment. The PaLATE v2.0 for Greenroads is an example of a streamlined EIO-LCA tool. There are a number of different streamlined tools available for roads which vary in LCA methodology (i.e. streamlined ISO-LCA tools). In addition to the PaLATE tools originally developed by Horvath et al. (2003):

- Huang et al. (2008, 2009) has developed a Microsoft Excel tool for streamlining pavement LCAs and system modeling (based in the United Kingdom)

- Birgisdóttir (2005), Christensen and Birgisdóttir (2006), Birgisdóttir et al. (2007) describe the development of the Danish ROAD-RES software tool for that incorporates municipal solid waste incinerator residues in pavement LCAs.
- Apul et al. (n.d.; Apul, 2007) at the University of Toledo developed a web-based tool for LCA called BenReMod-LCA (Beneficial Reuse Modules). An extension of this tool, as a multi-criteria decision-making tool, BenReMod-MCDA, is currently under development by the same authors. Both tools are available at: http://benremod.eng.utoledo.edu/BenReMod/
- CHANGER (the Calculator for Harmonised Assessment and Normalisation of Greenhouse-gas Emissions for Roads), a paid software tool, recently became available for modeling greenhouse gas emissions from pavements for from the International Road Federation (IRF, 2010). CHANGER includes data sources for 188 countries and global and regional income groups (IRF, 2010).

Each of these streamlined tools has drawbacks due to various built-in assumptions and limitations. Most commonly these tools suffer from double-counting errors, poor or very poor data quality, lack of transparency, data omissions and general user-unfriendliness. This means they may not produce reliable or meaningful results that accurately or precisely reflect roadway lifecycle impacts.

It is unlikely a process-based LCI will produce results that match of a streamlined LCI model or an EIO-LCA model. This is due to issues with data quality and the scope of the EIO models and their general lack of process-specificity to particular processes within a system. Thus, it is also unlikely that the inventory data produced for PR-3 will match the results of the Process-Based LCA or Hybrid LCA required for the Credit MR-1.

Existing Roadway LCAs

The weight of any Voluntary Credit in Greenroads v1.5 that involves materials, construction, transportation from construction and traffic use, was determined by a thorough review of existing lifecycle assessment literature for roads. We used the literature review process in attempt to identify patterns for typical LCA results for LCAs that used a transparent, systematic approach to evaluate the pavement section and reported the total energy use or total CO_2 (or CO_2e). Each document reviewed (there are, to date 13 papers with 45 different real or hypothetical road types). (Athena Institute, 2006; Carpenter et al., 2007; Chui et al., 2008; Horvath, 2003; Huang et al., 2009a; Huang et al., 2009b; Mroueh et al., 2001; Rajendran & Gambatese, 2007; Schenck, 2000; Stripple, 2000; Stripple, 2001; Weiland, 2008; Zapata & Gambatese, 2005) For more information on how the weighting decisions were made, please refer to the introduction of this manual or to Muench & Anderson (submitted for publication). We used a systematic, lifecycle-based approach to determine their overall credit weight on a five point scale, with some concessions, which are explained in Muench & Anderson.

Types of Investigations

Five papers addressed PCC pavements (10 assessments), while all 13 address HMA pavements (36 assessments). Note that Schenck (2000) addressed resurfacing maintenance only, and her results are not included in the following figures or tables. Figure PR-3.3 (next page) shows the described pavement structure for each studied assessment (12 papers, 43 total). Each author used different data sources and defined their system boundaries differently. However, a basic statistical analysis shows that there are some noticeable general trends on a per lane-kilometer basis of the 43 LCA studies. These trends include similarities in the scope of the study (pavement section only), results on energy use and CO_2 production, and a contribution analysis of the energy and CO_2 attributable according to each lifecycle phase of the roadway. We used median values to limit influence of extreme outliers in the data.

The scope and boundaries of most papers (10 assessments) examine only the pavement structure and exclude other elements of the roadway. Stripple (2001), however, completed the only full life cycle inventory that included other roadway activities and material needs, like land-clearing, electric utilities, and signs. This paper is discussed in further detail in Credit MR-1. The phases typically considered in the scope of the assessments are initial construction and pavement-related maintenance activities over a general range of assumed design lives between 40 to 50 years. Two papers also included vehicle emissions from traffic during the operation and use of the completed roadway (Stripple, 2001; Kennedy, 2006).

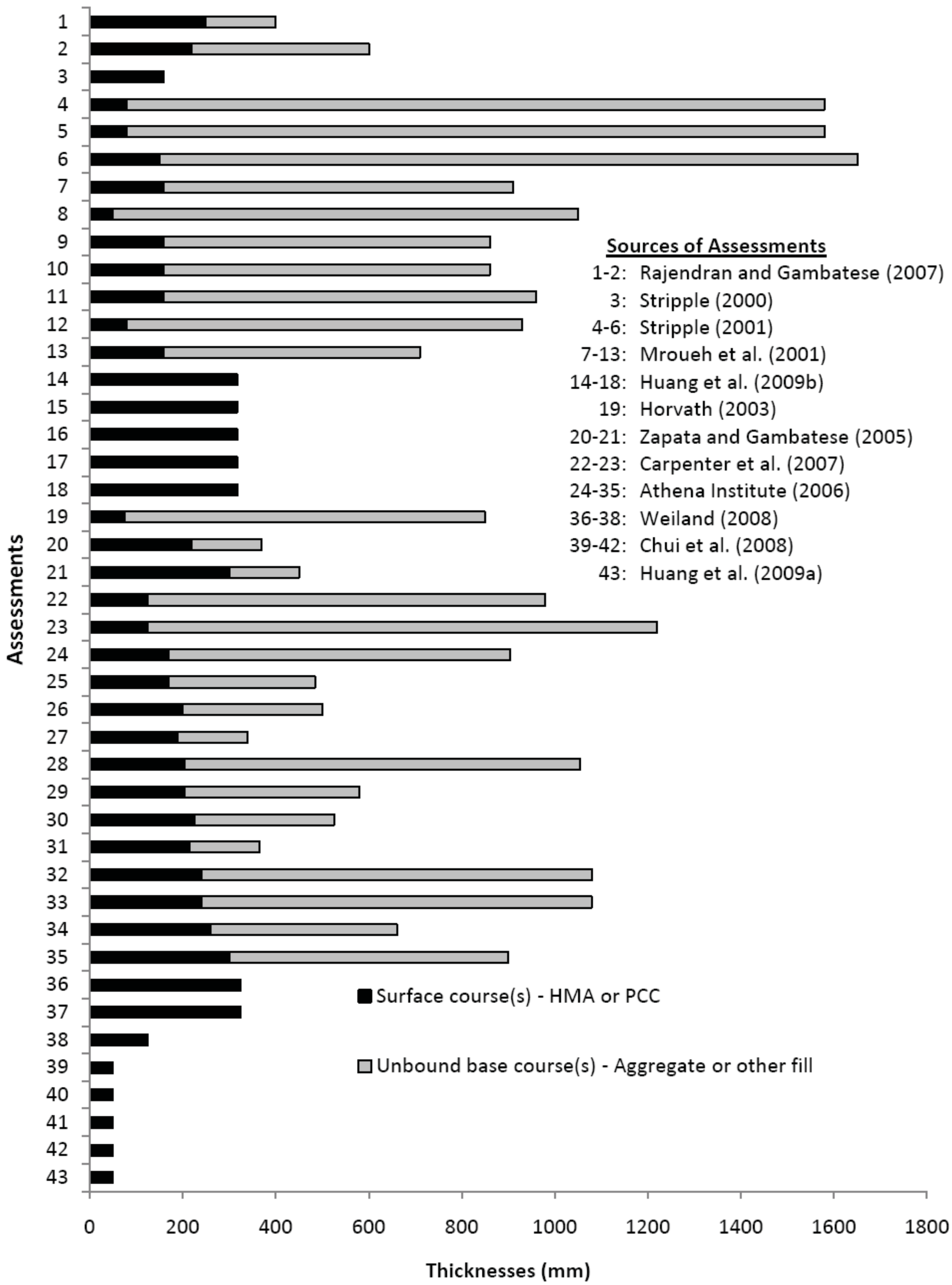

Figure PR-3.3: LCA assessments and their studied pavement structures. (Muench & Anderson, Submitted)

Energy Use

Total energy use was reported by 35 assessments, and the distribution in ranges of terajoules (TJ) is shown in Figure PR-3.4. The median result is approximately 3.17 TJ per lane-km. The study by Horvath (2003) represented the extreme outlier, reporting an energy use of 17.25 TJ per lane-km (10.72 TJ per lane-mile). This is the only study that uses the EIO-LCA model and the original version of the PaLATE software, which is recommended in modified form for completing this Greenroads Project Requirement. A review of the original PaLATE software indicated that there are several errors in key cost and emissions values, which in our opinion renders this number (but not the method) suspect. A reasonable approximation of the total energy expenditure attributable to one typical lane-km of pavement is 2-4 TJ, which varies slightly depending upon the pavement structure and material. In 2005, the average annual American residential household energy use was 0.1 TJ (94.9 million BTU: Energy Information Administration, 2009). This means one lane-km of roadway uses the same energy as 20-40 households do in one year. To put this in more familiar U.S. measures of roads: the median energy use of one mile of road represents the average energy use of 51 homes in one year, with the range of energy consumption representing that used by between 32-64 homes a year.

DID YOU KNOW?

The median energy use by one lane, one mile long, of road pavement represents the same energy use that about 51 average U.S. households use in one whole year.

How many households does it take you to drive to work?

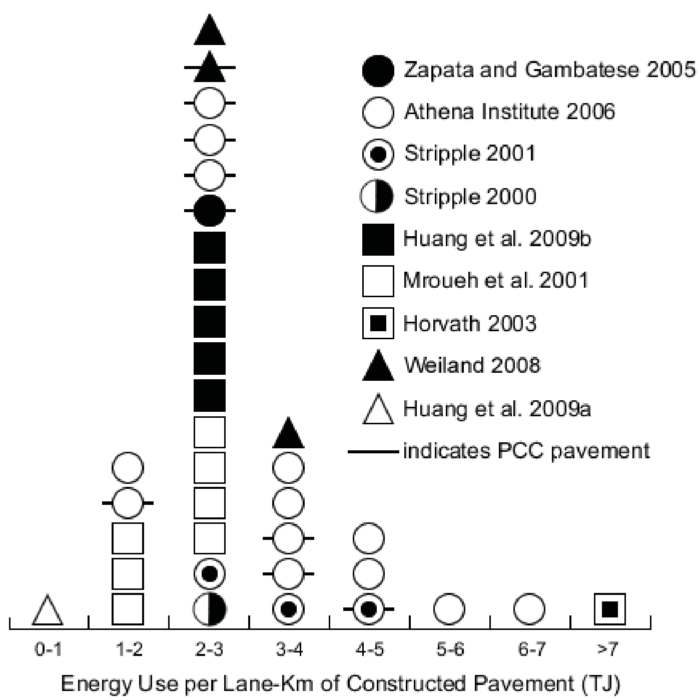

Figure PR-3.4. Distribution of energy use in pavements for 34 assessments in 9 pavement LCA papers. Each symbol represents one assessment. (Muench, Anderson, Submitted)

Carbon Dioxide (CO_2) Emissions

Six papers reported total CO_2 emissions from a total of 19 assessments and one paper reported global warming potential (expressed in CO_2e) rather than CO_2 only emissions on another 12 assessments (31 total). It is unclear if the first six papers were reporting CO_2e or only CO_2; however, this would not significantly influence the statistical results either way. The results show a median value of 243 metric tons (MT) per lane-km, though the distribution had higher variability than the results for energy use. The histogram is shown in Figure PR-3.5. The highest values were cited in the papers by Stripple (2000 and 2001) which included aspects of road construction outside the primary road structural materials and construction activities. Therefore, a reasonable approximate range of the total CO_2 emissions that is attributable to one typical lane-km of pavement is 100-500 MT, which varies slightly depending upon the pavement structure and material, and also the scope of the LCA. One metric tonne of CO_2, at standard temperature and pressure, has a volume of about 729 cubic meters (Figure PR-3.6).

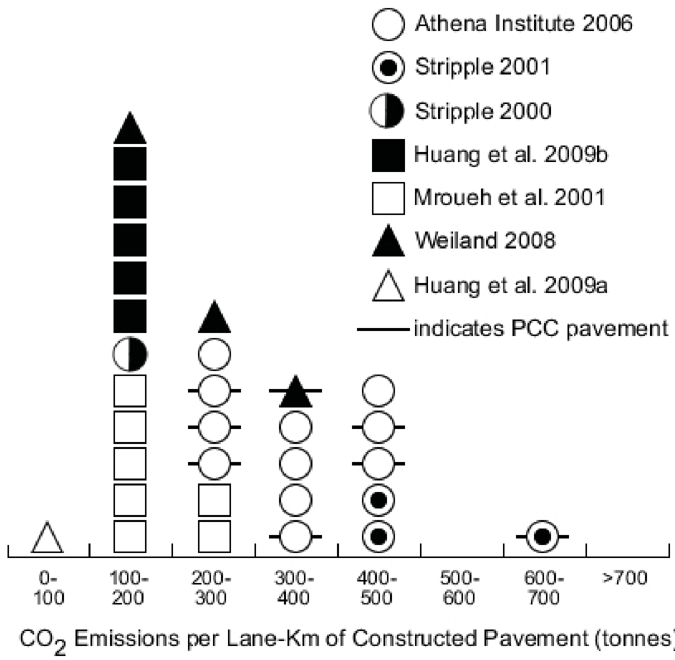

Figure PR-3.5. Distribution of CO_2 emissions in pavement for 32 assessments in 7 pavement LCA papers. Each symbol represents one assessment. (Muench, Anderson, Submitted)

Figure PR-3.6: One metric ton (MT) of CO_2 as modeled by a Massachusetts high school physics class. The cube is 27 feet per side. (http://www.energyrace.com/images/uploads/commentary/co2cube4.jpg)

Contribution Analysis of Lifecycle Stages

Several papers, as shown in Table PR-3.4 and Table PR-3.5, analyzed energy use and CO_2 emissions according to four major lifecycle stages or activities: materials production, pavement construction (initial and maintenance), and transportation associated with construction. The relative contributions of each stage or activity are reasonably consistent across the small number of studies. In general, materials production accounts for about 75% of energy use and 60-70% of CO_2 emissions; construction accounts for less than 5% of both energy use and CO_2 emissions; and transport of materials for production and during construction accounts for about 20% of energy use and about 10% of CO_2 emissions. Maintenance activities seem to account for about 25% of energy use and about 10-20% of CO_2 emissions when compared to initial construction.

Table PR-3.4: Relative Energy Contributions of Road Construction Lifecycle Stages (Adapted from Muench & Anderson, Submitted)

Lifecycle Stage	No. Papers	No. LCAs	Average (%)	Median (%)	St. Dev (%)	Range (%)
Materials Production	5	14	74	73	13	60-98
Construction	5	14	3	2	2	2-10
Transportation	4	12	21	21	11	7-38
Initial Construction	4	8	74	73	21	45-97
Maintenance	4	8	26	27	21	3-55

Table PR-3.5: Relative CO_2 Emission Contributions of Road Construction Lifecycle Stages (ibid.)

Lifecycle Stage	No. Papers	No. LCAs	Average (%)	Median (%)	St. Dev (%)	Range (%)
Materials Production	1	3	69	61	15	60-87
Construction	1	3	4	4	2	1-6
Transportation	1	3	8	9	3	4-10
Initial Construction	3	16	78	86	20	45-100
Maintenance	3	16	22	14	20	0-55

Based on these results, there are some general rules of thumb which are shown in Table PR-3.6.

Table PR-3.6: General rules of thumb for pavement energy and emissions (ibid.)

Comparison	Energy Use	CO_2 Emissions
Materials Production to Construction Processes	25 to 1	16 to 1
Transportation to Construction	8 to 1	3 to 1
Maintenance Activities to Initial Construction	1 to 3	1 to 4

A Note on Disposal, Use, and Operations Lifecycle Stages

Not included in the figures or tables above are three very critical lifecycle stages or activities: use (vehicular traffic), operations (such as lighting and signals), and the waste disposal process from demolished pavements. Rajendran and Gambatese (2007) attempted to quantify waste production processes throughout the roadway lifecycle, especially in construction. However, this is the only study that has done so. As noted in PR-6 Construction Waste Management Plan and by Rajendran and Gambetese (2007), there is very little information available about the generation or disposal of roadway waste products. Also, several authors investigated either a by-weight or by-volume approach to replacing pavement materials in-kind with different recycled materials (such as coal fly ash instead of cement) in order to reduce the lifecycle energy use or CO_2 emissions. These assessments, in general, are complicated to model because recycled materials generally came from another system that is outside the scope or the boundaries of the assessment. Introducing recycled materials into a new roadway project system or even reusing waste materials generated from the project itself represents a feedback loop, because the materials are reintroduced somewhere into a previous lifecycle stage along the system supply chain. It is therefore often difficult to disaggregate the environmental accountability and assign it to a responsible party when using recycled material. There are a variety of methods used, and again, each has its own assumptions, limitations, uncertainties, advantages and disadvantages.

Further, only one study (Stripple, 2001) investigated operations. In general, electrical equipment such as that used for signals and lighting contributed the most to energy use and CO2 emissions of all the operational components studied, (1) for rural environments, operations contributed almost negligibly for both energy and CO2, and (2) the energy mix used was based on Swedish power sources, which are mostly hydropower and nuclear energy.

Traffic use is rarely considered in pavement-based lifecycle assessments. However, two studies (Stripple, 2001 and Kennedy, 2006) model the impacts due to traffic use. If traffic is considered in the scope of the LCA, then vehicular emissions dominate the total energy consumption and carbon dioxide emissions. However, this is widely variable and depends a number of factors including (but not limited to) vehicle mix, modal access, fuel efficiency and type of fuel. Generally, the energy expended in construction is about the same as that expended by roadway users in the first two years of service. Typical pavement maintenance activities (overlays) generally use lower volumes of materials and this would represent a shorter timeline than one to two years.

Caveats of LCIs

Clearly, existing roadway LCIs and LCAs vary in method. Sometimes this variety lends to reporting contradictory or mixed results, which can be confusing, especially in a decision-making context. The effectiveness of LCI or LCA studies are highly dependent on the goal and scope definition, data sources and quality, model limitations and uncertainties. Additionally, many publicly available databases or completed LCIs often use or contain average information that cannot be easily applied in project-specific contexts. The converse is also true; project-specific LCIs should not necessarily become baseline models for other projects without thorough review of the variables that were considered. Thus results of the inventory are best used as a tool or a benchmarking method, but not as a baseline value. Another point that must be made expressly clear: completing a lifecycle inventory or a lifecycle assessment of your project does not, by virtue of the process or method alone, make a project more or less sustainable than another project.

Additional Resources

- The Carnegie Mellon Green Design Institute database is publicly available and free to use non-commercially. It also provides a very thorough explanation of the finer points of the EIO-LCA methodology as well as discussion and examples of the methodology. EIO-LCA is available at http://www.eiolca.net.
- The Society of Environmental Toxicology and Chemistry (SETAC) provides a thorough and concise description of the ISO-LCA methodology as well as links to other professional LCA resources and organizations. More information is available at http://www.setac.org/.

GLOSSARY

BenReMod	Beneficial Reuse Module
CHANGER	Calculator for Harmonised Assessment and Normalisation of Greenhouse-gas Emissions for Roads
CO2	Carbon dioxide
CO2e	Carbon dioxide equivalent emission
EIO	Economic Input-Output
EIO-LCA	Economic Input-Output for Life Cycle Assessment
EOL	End-of-life
Feedback loop	A process within a system where outputs of a process are reintroduced as inputs into a previous lifecycle stage somewhere along the same system supply chain
Functional unit	The quantified performance of a product system for use as a reference unit (ISO, 2006a)
ISO	International Standards Organization
ISO-LCA	Process-based LCA
LCA	Lifecycle assessment
LCCA	Lifecycle cost analysis

LCI	Lifecycle inventory analysis
LCIA	Lifecycle impact assessment
Lifecycle	consecutive and interlinked stages of a product [or project] system, from raw material acquisition or generation from natural resources to final disposal or [end-of life: EOL] (ISO, 2006a)
Lifecycle assessment	Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its lifecycle (ISO, 2006a)
Maintenance	Routine construction activities which are preservative in nature, such as patching and repair. Typically maintenance involves additional production of material as well as additional transport and construction activities. See also operations.
MCDA	Multi-Criteria Decision Analysis
Operations	Equipment, components or activities that are needed on a routine basis to ensure proper safety during use of a road, e.g. luminaires, signals, de-icing, striping, sanding, drawbridge mechanical equipment, toll booths, etc. (Muench & Anderson, submitted) See also maintenance.
PaLATE	Pavement Lifecycle Assessment Tool for Environmental and Economic Effects
Reference flow	The measure of the outputs from processes in a given product system required to fulfil [sic] the function expressed by the functional unit (ISO, 2006a)
SETAC	Society of Enviornmental Toxicology and Chemistry
System boundary	Set of criteria defining which unit processes are part of a system (ISO, 2006a)
Unit process	Smallest unit considered in the lifecycle inventory analysis for which input and output data are quantified (ISO, 2006a)

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QUALITY CONTROL PLAN

PR-4

REQUIRED

GOAL

Have a process in place to monitor and improve construction quality.

REQUIREMENTS

The prime contractor shall establish, implement, and maintain a formal construction Quality Control Plan (QCP). The QCP must address the following quality control elements:

1. Key quality control personnel, their responsibilities and their qualifications (résumés, certifications, etc.).
2. Procedures used to control quality during construction including (as a minimum):

   a. Items to be monitored (including pavement mix designs)
   b. Testing to be done (including testing standards and frequency)
   c. When corrective action is required (action limits)
   d. Procedures to implement corrective action
   e. Procedures to modify QCP if ineffective or when modifications are necessary

Details

Some state and local owner agencies already have requirements for such plans written in to their standard specifications. Such existing requirements should be able to meet the requirements above, however some only address construction quality for hot mix asphalt (HMA) or Portland cement concrete (PCC) paving and not construction of the overall project. Testing frequency and test procedures should not be based on minimum owner requirements for acceptance.

Some state highway agencies use contractor testing in their acceptance process. In these cases the independent assurance tests must be performed on samples that are taken independently of quality control samples. Quality control plans are required in these cases, as defined in CFR 637, Title 23.

The Quality Control Plan should cover all project construction; not just the pavement. Subcontractors need to be included in this plan, which typically means identifying a responsible party and obtaining a quality control procedure from the subcontractor.

A large document that repeats language from the contract specifications should not be generated for this Project Requirement. Rather, the document should clearly identify the major aspects of the prime contractor's plan to control project construction quality and who is responsible for implementing those aspects. A reasonable Quality Control Plan for a typical roadway project (i.e., less than $10 million contract price) can be written in about 6 to 12 pages (FLHD, 1998). A Quality Control Plan should be approved by the owner before construction begins.

DOCUMENTATION

- Copy of the contractor Quality Control Plan.

RELATED CREDITS

- ✓ CA-1 Quality Management System
- ✓ CA-8 Contractor Warranty
- ✓ PT-1 Long-Life Pavement
- ✓ PT-6 Pavement Performance Tracking

SUSTAINABILITY COMPONENTS

- ✓ Economy
- ✓ Extent
- ✓ Expectations

BENEFITS

- ✓ Increases Service Life
- ✓ Improves Human Health & Safety
- ✓ Reduces Lifecycle Costs
- ✓ Improves Accountability

APPROACHES & STRATEGIES

- Write a Quality Control Plan. Often this can be accomplished by having a prime contractor with an established quality control manual and then writing a plan that refers to that manual for procedures and identifies key personnel, materials and processes associated with the particular project in question.

Example: Agencies with Quality Control Plans

Many owners already require QCPs in their standard specifications. Following are examples of both comprehensive QCPs that cover all of construction and some that just refer to paving operations.

QCPs Covering All of Construction

These plans **do** meet the requirements for PR-4.

- **Federal Lands Highway Division.** This document discusses a QCP that covers all construction aspects and provides a fictitious example: http://www.wfl.fhwa.dot.gov/resources/construction/field-notes/documents/d-02-15.pdf.
- **Florida Department of Transportation (FDOT).** FDOT's *Construction Project Administration Manual (2007)* describes FDOT requirements and how to use a contractor's quality control manual to supplement a QCP in Section 3.3. Section 6-8 of the FDOT 2007 *Standard Specifications for Road and Bridge Construction* requires a contractor quality control program: http://www.dot.state.fl.us/construction/manuals/cpam/CPAMManual.shtm
- **Saskatchewan Highways and Transportation:** The *Standard Test Procedure Manual (1994)* Standard Test 400 (last updated in 1994) describes what a quality control plan does and its minimum elements: http://www.highways.gov.sk.ca/standard-test

QCPs Covering Paving Operations Only

These plans **do not** meet the requirements for PR-4.

- **Alabama DOT (ALDOT)** ALDOT-375-91: http://www.dot.state.al.us/NR/rdonlyres/A1E8B299-F518-41BF-B0A9-2326C1177C91/0/ALDOT375ApprovedFHWAOctober202008_.pdf
- **Illinois DOT** HMA QCP template: http://www.dot.state.il.us/aero/PDF/HMA%20QC%20plan%20template.pdf
- **North Carolina DOT** Section 609 of the Standard Specifications: http://www.ncdot.org/doh/preconstruct/ps/specifications/english/s609.html
- **Unified Facilities** Guide Specifications, Section 3.10: http://www.wbdg.org/ccb/DOD/UFGS/UFGS%2032%2012%2016.pdf

Many other organizations also have guides and specifications for contractor Quality Control Plans.

POTENTIAL ISSUES

1. It is not possible to determine from the content of the QCP whether quality construction will result. Therefore, this credit does not guarantee quality construction in any way.
2. A contractor Quality Control Plan that only addresses paving operations is not sufficient to meet the intent of this credit. For some owners, standard specification language may only require a Quality Control Plan for the paving operation. While paving needs to be covered in the Quality Control Plan, all other major components of construction (e.g., structures, earthwork, drainage, traffic control items, etc.) must also be covered.
3. The Quality Control Plan should not be a repeat of the technical specifications. Rather, the plan should address who is responsible for quality control for a particular item or process, when key inspections are made, when corrective actions are to be taken and how they are to be taken.
4. A formal process for monitoring and improving construction quality should not conflict with minimum quality standards that are maintained by the roadway owner.

RESEARCH

Construction quality can significantly influence final project quality and performance. Poor construction can lead to early and excessive maintenance and/or early replacement. This costs more money and uses more resources leading to a less sustainable project. Unfortunately, there is a general lack of empirical evidence to document these items as they are often taken to be intuitively obvious. This section, therefore, presents a discussion of several pavement items since for these items there is substantial evidence that construction quality impacts performance and cost.

Subgrade and Base Compaction

Subgrade or base material that is not adequately compacted may settle over time, which in turn causes the overlying pavement to settle and crack. This can lead to roughness and early pavement failure. Often adequate subgrade density is described in terms of relative density (e.g., 90 or 95 percent of maximum density).

Hot Mix Asphalt (HMA) Density

Compaction is the greatest determining factor in dense-graded hot mix asphalt performance (Scherocman & Martenson, 1984; Scherocman, 1984; Geller, 1984; Brown, 1984; Bell et. al., 1984; Hughes, 1984; Hughes, 1989). Inadequate compaction results in a pavement with decreased stiffness, reduced fatigue life, accelerated aging/decreased durability, rutting, raveling, and moisture damage (Hughes, 1984; Hughes, 1989).

HMA Aggregate Segregation

Based on several articles (Kennedy et al., 1987; Brown & Brownfield, 1988; Williams et al., 1996a and 1996b; Khedaywi & White, 1996; American Association of State Highway and Transportation Officials: AASHTO, 1997) the commonly accepted qualitative definition of **aggregate segregation** is "the non-uniform distribution of coarse and fine aggregate components within the asphalt mixture." The chief detrimental effects of segregation on HMA performance are: reduced fatigue life, rutting, raveling, and moisture damage. These effects can cause a severe reduction in pavement life. More information on segregation causes and cures can be found in Segregation Causes and Cures for Hot Mix Asphalt (QIP-110) by AASHTO and the National Asphalt Pavement Association (NAPA).

HMA Temperature Differentials

HMA temperature differentials are large mat temperature differences resulting from placement of a significantly cooler portion of HMA mass into the mat. This cooler mass comes from the surface layer (or crust) typically developed during HMA transport from the mixing plant to the job site. These cooler areas will reach cessation temperature more quickly than the surrounding mat. Roller patterns developed based on general mat temperatures may not be adequate to compact these cooler areas before they cool to cessation temperature resulting in isolated spots of inadequate compaction. Thus, temperature differentials can cause isolated areas of inadequate compaction resulting in decreased strength, reduced fatigue life, accelerated aging/decreased durability, rutting, raveling, and moisture damage (Hughes, 1984; Hughes, 1989).

Portland Cement Concrete (PCC) Consolidation

Consolidation is the process of making the freshly placed PCC into a more uniform and compact mass by eliminating undesirable air voids and causing it to move around potential obstructions (such as reinforcing steel). This is usually accomplished using vibrators. Inadequate consolidation can lead to undesirable air voids that can weaken PCC or be unsightly.

Pavement Roughness

Pavement roughness is an expression of irregularities in the pavement surface that adversely affect the ride quality of a vehicle (and thus the user). Roughness affects not only ride quality but also vehicle delay costs, fuel consumption and maintenance costs. The World Bank found road roughness to be a primary factor in the analyses and trade-offs involving road quality vs. user cost (UMTRI, 1998). Other studies (e.g., Papagiannakis & Delwar, 2001; Barnes & Langworthy, 2003) have attempted to quantify the cost of vehicle operation in relation to pavement roughness.

GLOSSARY

AASHTO	American Association of State Highway and Transportation Officials
Aggregate segregation	the non-uniform distribution of coarse and fine aggregate components within the asphalt mixture (Kennedy et. al., 1987; Brown and Brownfield, 1988; Williams et. al., 1996a and 1996b; Khedaywi and White, 1996; American Association of State Highway and Transportation Officials: AASHTO, 1997)
Consolidation	the process of making the freshly placed portland cement concrete into a more uniform and compact mass by eliminating undesirable air voids
HMA	Hot mix asphalt
NAPA	National Asphalt Paving Association
Pavement roughness	an expression of irregularities in the pavement surface that adversely affect the ride quality of a vehicle (and thus the user)
PCC	Portland cement concrete

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NOISE MITIGATION PLAN

GOAL

Reduce or eliminate annoyance or disturbance to surrounding neighborhoods and environments from road construction noise.

REQUIREMENTS

Establish, implement, and maintain a formal Noise Mitigation Plan (NMP) during construction for the prime contractor. The NMP must address, at minimum, the following elements:

1. Responsible party for noise mitigation activities, contact information, their responsibilities and their qualifications. Include information for NMP preparer, if applicable or completed by an outside party.
2. Project location and distance to closest receptor of noise. Include a description of the surrounding zoning and parcel information (i.e., commercial, residential, hospitals, schools, parks, sensitive habitat).
3. A list of proposed construction activities (e.g. demolition, excavation, paving, bridge foundations, finishing).
4. Dates and working hours of proposed construction activities.
5. A list of noise-generating devices used during each construction activity listed in #3.
6. A list of noise-mitigating devices used during each construction activity listed in #3, including personal safety equipment requirements for all site employees.
7. Noise permit numbers, agency or local authority policies associated with construction work, as applicable.
8. Description of noise monitoring standards, methods, and acceptable levels.
9. Description of correction procedures for non-compliant noise levels.
10. Signature of responsible party.

Details

The NMP should cover all of construction, including subcontractor work activities. Some state and local owner agencies already have requirements for such plans written in their standard specifications. However, a written specification requiring the prime contractor to have a Noise Mitigation Plan is insufficient, especially because many local authorities and owner agencies offer certain exemptions to their policies, such as daylight work schedules or projects with minimal areas of land-disturbing activities.

A large document need not be generated for this requirement. For projects that are deemed locally exempt (as noted above), show that the prime contractor has completed a review of noise as part of project planning. The New York Department of Environmental Protection (NYDEP 2008) offers a 4-page checklist-style NMP that addresses all of the elements above, except for items 9 and 10, which can be easily addressed in 1 page: http://nyc.gov/html/dep/pdf/noise_mitigation.pdf.

DOCUMENTATION

- Copy of the Noise Mitigation Plan.
- A copy of any applicable noise permits, or agency or local authority noise policies (a live hyperlink to any large policy documents is sufficient).

PR-5

REQUIRED

RELATED CREDITS

- ✓ PR-1 Environmental Review Process
- ✓ PT-5 Quiet Pavement

SUSTAINABILITY COMPONENTS

- ✓ Equity
- ✓ Expectations
- ✓ Experience
- ✓ Exposure

BENEFITS

- ✓ Improves Human Health & Safety
- ✓ Improves Accountability
- ✓ Increases Awareness
- ✓ Increases Aesthetics

APPROACHES & STRATEGIES

- Read the Federal Highway Administration (FHWA) *Highway Construction Noise Handbook* (Knauer et al., 2006) to understand the aspects of construction noise that could be relevant to your project. The *Highway Construction Noise Handbook* is available as a web document at: http://www.fhwa.dot.gov/environment/noise/handbook/index.htm. The Handbook is a relatively short read—Chapters 5-8 may be especially helpful for prime contractors or project leads not familiar with NMPs.
- Complete the NMP during the environmental review process, when the environmental documentation is being generated. Most environmental review regulations at federal and state levels, including the National Environmental Policy Act (NEPA), include an investigation of noise-related project impacts to surrounding communities, and these impacts often can be addressed in short narrative form (Knauer et al., 2006).
- Use the checklist-style NMP available from the NYDEP as a template to create and assemble custom owner agency NMPs for use on future projects. The NYDEP checklist is available here: http://nyc.gov/html/dep/pdf/noise_mitigation.pdf
- Estimate noise levels from your construction project by using the Roadway Construction Noise Model (RCNM) software available from the FHWA (Reheman et al., 2006). A user's guide for the software program is also available as part of the *Highway Construction Noise Handbook* as an Appendix. Most projects will not need comprehensive or detailed noise modeling and simplified manual noise analysis will be adequate (Knauer et al., 2006). However, local noise ordinances may be more stringent than what is called for in the environmental review requirements and may need more detailed analysis. (Knauer et al., 2006) The RCNM software tool is available for free download here: http://www.fhwa.dot.gov/environment/noise/cnstr_ns.htm.
- Communicate to stakeholders that noise mitigation is actively being investigated on your project and that a plan is being developed. This may help quell the potential "political noise" that often stems from too much "construction noise" (Thalheimer, 2000), especially for high impact, high dollar, or sensitive public projects.
- Hire an acoustical engineering firm or other qualified professional to complete the NMP.
- Deliver noise awareness training regarding the noise mitigation strategies and noise safety efforts employed on the project to all construction project employees, including subcontractor employees. This training will help ensure that the NMP is implemented effectively.
- Review individual state and local jurisdiction noise ordinances and any permits or agency coordination efforts during the project development process. Sometimes these ordinances contain restrictions associated with construction noise levels, even though there are currently no federal regulations for noise levels.
- Identify noise abatement opportunities during project design. Such things as locating storage areas, stationary equipment, haul roads and detours away from sensitive receivers, planning for concurrent construction, maintaining existing noise barriers for use during construction and scheduling the construction of new noise barriers early on in the project, can reduce noise impacts.
- Achieve mitigation of noise at the source by specifying use of less noisy equipment, requiring muffler systems on equipment, employing shields and modifying vehicles and equipment to reduce noise levels.
- Achieve path mitigation by building noise barriers, using tiered or layered vegetative barriers (Anderson, Mulligan &Goodman, 1984), or using existing barriers where appropriate.
- Achieve receiver mitigation by sealing intakes of sensitive receivers, acoustic window treatments (Thalheimer, 2000) or, where feasible, by temporarily relocating residents.

Example: Noise Mitigation Plan Sample Forms – City of New York, NY

The New York City Department of the Environmental Protection (NYDEP, 2008) enacted new noise rules in 2007 for construction activities requiring that unique noise mitigation plans are adopted, posted, applied, and monitored on construction projects when specific devices are used or certain activities are performed within city limits. Their municipal code rules list typical equipment, activities, and other devices that produce noise, and also establish minimum noise levels allowed for construction activities. The intent of the noise requirements is "to inform the user of the required plan elements that a responsible party must include when the listed devices are being used on site, and the mitigation strategies and best management practices that are being employed" (NYDEP, 2008). Alternative noise mitigation plans (ANMPs) may also be filed if the project cannot comply with the sound level criteria without undue hardship and can reduce or exempt certain activities from non-compliance penalties.

- The NYDEP Sample Noise Mitigation Plan is available here: http://nyc.gov/html/dep/pdf/noise_mitigation.pdf
- The NYDEP Sample Alternative Noise Mitigation Plan is available here: http://nyc.gov/html/dep/pdf/noise_alternative_mitigation.pdf

Additional information about NYDEP's noise code and noise mitigation planning rules for construction projects are available at: http://nyc.gov/html/dep/html/noise/index.shtml

Example: Case Study — Central Artery/Tunnel ("The Big Dig") in Boston, MA

This case study summarizes the article by Thalheimer (2000), which describes the noise control program for the Central Artery/Tunnel (CA/T) project in Boston, Massachusetts. The CA/T may be more commonly recognized by the public as the "Big Dig," and it was an engineering mega-project with "the most comprehensive and stringent construction noise control specification of any public works project in the country." The sheer size and duration of its construction impacts on the Boston's residents and businesses made noise mitigation a crucial aspect of the project. Note that most projects will not need to provide nearly the level of detail as that required for noise mitigation on the Central Artery/Tunnel (CA/T), however the approaches and strategies used for this project helped develop many of the guidance documents that are available on construction noise, such as the FHWA *Highway Construction Noise Handbook* (Knauer et al., 2006).

The project was championed by the former Massachusetts Turnpike Authority (MTA), which is currently managed by the Massachusetts Department of Transportation (MassDOT) Highway Division. Construction began in 1991 and was considered complete in 2006, with a multibillion dollar price tag. More information about the Big Dig project can be found at the following site: http://www.massdot.state.ma.us/Highway/bigdig/bigdigmain.aspx.

The project's noise control program had two main goals: 1) meet the commitments for mitigating environmental noise as stated in the environmental impact report and 2) control construction noise without posing hardship to local communities, project budget or construction schedule to the maximum extent feasible. Meeting these goals posed a significant challenge because construction activity occurred at all times of day in many areas of Boston, and sometimes in very close proximity (with 10 feet) of residences and sensitive locations. Additionally, the project was critical politically: function of Boston's core infrastructure depended on the outcome and the level of stakeholder involvement was extraordinarily high.

The Noise Mitigation Program for the CA/T involved establishing lot-line and equipment emission noise criteria limits, defining operational and/or equipment restrictions and also required the submission of noise control and monitoring plans, baseline and compliance noise data, equipment noise certification tests, and designs for proposed noise mitigation measures. "Mitigation measures were implemented only when justified based on careful consideration of all relevant technical, cost and policy issues."

The NMP prioritized mitigation measures as follows: source control, path control, and finally receptor control. Source control was most effective and easiest to monitor, but where this was not possible, path control measures were implemented to block sound directed at receptors. Path control options were considered cost-effective only if they could prevent noise at multiple receptors. Receptor control was also used in some cases, such as window treatments on buildings, and the success of this program was due largely to an effective public involvement process as well as partnerships developed during project design and planning.

Noise control lessons learned from the CA/T project that may be applicable to projects developing their own noise mitigation plans include:

- **Upholding noise policy commitments and goals.** To be effective, it is crucial that noise policies are communicated from the top layers of the project team and applied project-wide.
- **Engaging the public for active feedback.** Informing the public is critical to the overall success of the project noise mitigation plan, and a 24-hour hotline for communication was used successfully on the CA/T project.
- **Establishing an ambient level and monitoring construction noise.** Equitable noise policies cannot be created without first establishing a baseline noise level. Noise controls are not as effective if not monitored on a continuous basis.
- **Engaging professionals.** Noise technicians can often preempt noise problems and can quickly respond to complaints given proper authority.
- **Addressing the biggest complaints.** The biggest public complaint was vehicle backup alarms during night work, which was addressed by mandating installation of in-vehicle controls that were manually adjustable or ambient sensitive and prohibiting alarm use in especially sensitive areas at night with additional supervision from safety personnel.
- **Implementing comprehensive and concise specifications.** Contract specification language for contractors that is clear and unambiguous is essential for management of contractors and for implementation of a noise control plan.
- **Using multiple controls.** Noise mitigation measures must be flexible and include many alternatives and combinations of methods to meet noise policy goals.
- **Targeting receptor controls.** Prevention of noise at the receptor, such as acoustical treatments for windows, can be cost-effective solutions.
- **Using sound barriers as visual barriers.** Public perceptions of construction noise and level of nuisance or annoyance depend on sound levels of the activity as well as visibility of the activity. Thalheimer (2000) states that noise barriers were effective in reducing the level of annoyance perceived on the CA/T project. However, Aylor and Marks (1976) and Anderson, Mulligan and Goodman (1984) demonstrate that this perception is extremely variable with locale, typical ambient noise levels, type of barrier, how much of the activity is obscured by the barrier, familiarity of sound, and public expectations.

POTENTIAL ISSUES

1. It is not feasible to eliminate all construction noise, but it is often feasible to control most or all of it.
2. Multiple work sites may require a variety or combination of different controls. Some special areas of work sites may require closer analysis or modeling, which may be cost and time intensive.
3. Noise mitigation plans and project policies apply to all contractors and subcontractors on a construction site. Training may be necessary for some parties who are otherwise unfamiliar with noise mitigation or policies.
4. The subjectivity involved with perceptions of sound and noise presents an issue for managing public opinion and expectations.
5. Most jurisdictions provide an exemption from noise associated with daytime construction activities. For Greenroads all projects must create an NMP, even if exempt from noise policies and local ordinances.

RESEARCH

Noise issues on most roadway projects are initially addressed during the project environmental review (see PR-1 Environmental Review Process). This Project Requirement (PR) focuses on planning for and management of noise generated by the roadway project throughout its construction and operation phases.

What is Noise?

Noise is defined as unwanted sound (Environmental Protection Agency, 1973). Sound is part of the science of acoustics, which is a complex field dealing with sound generation, propagation and reception. This credit does not go into detail on sound physics. However, some terminology is useful for a basic understanding of noise.

A source is the point where a sound is generated. Sources can be mobile or stationary. For example, traffic noise sources are mobile, while construction noise is generally a mixture of stationary and mobile sources. The receptor (also, receiver) is the endpoint where sound is observed. The route along which sound passes from the source to the receptor is known as the path. The length of the path is important, as is the rate of change in length of the path. Generally, perception of sound changes along a path according to the “inverse square law”: as the distance between source and receiver increases, the sound decreases in proportion to the inverse square of the path length. (New York Division of Environmental Permits, 2001) The path length of sound from mobile sources changes with time (this is perceived by the human ear as what is commonly known as the Doppler Effect).

The following sound terms are briefly described (Sandberg & Ejsmont, 2002):

- **Sound pressure**. Sound travels through the surrounding medium (often air) as pressure waves. Measuring sound involves measuring the pressure of these waves. Thus a common measure of sound is in units of pressure. The perceived loudness of sound varies with pressure. Higher pressures are generally associated with sounds we perceive of as louder.
- **Sound pressure level and the decibel (dB)**. Sound pressure varies over such a wide range that it is commonly measured in a logarithmic unit called the decibel (dB) so reported numbers are easier to work with. Using the dB scale, a difference in 10 dB roughly corresponds to a doubling or halving of our hearing perception of that sound. Also, 1 dB is about the smallest difference in sound pressure that humans can perceive. Finally, if two incoherent sounds of equal sound pressure level (e.g., 70 dB) are added together, the resulting overall sound is 3 dB greater. Thus, 70 dB + 70 dB = 73 dB.
- **Frequency weighting**. Sound can occur over a wide range of frequencies. The human ear does not perceive all of these frequencies equally. Generally, for sound at a given pressure level, low and very high frequencies are interpreted as quieter than mid-range frequencies. Therefore, for sound measurements to be most meaningful to human hearing, the frequencies of sound need to be filtered such that the sound pressure levels of low and very high frequencies count less than the sound pressure levels of mid-range frequencies. A good approximation to human hearing is the “A filter,” thus sound is often reported as an “A weighted sound pressure level,” dB(A) or dBA.

It is important to emphasize the complexity in analyzing sound and the difference of sound perception in humans to the physical measurements of sound pressure. The response to any sound is a subjective experience and can depend on age, health, familiarity, time of day and more in addition to the characteristic of the sound itself. This complexity makes it somewhat difficult to express and compare sound levels using simplified numbers or averages such as the A-weighted decibel scale (dBA) that is typically used to describe transportation noise.

Undesirable Consequences of Noise

Noise can have an effect on human health and also on the general desirability of a location based on its exposure to noise. Noise impacts human health and well-being by increasing stress, causing hearing loss (in the case of loud noise), disrupting sleep, causing fatigue, hinders work efficiency, interrupting activities, and interfering with speech communication (Passchier-Vermeer & Passchier, 2000; EPA, 1978). Noise can also produce unwanted vibrations that may cause human discomfort (sonic fatigue) or disturb activities (EPA, 1973). In addition to the physiological and emotional responses of noise, transportation noise in particular can also impact real estate values hence impacting a community’s social, economical and development status.

Noise impacts from human activities do not only affect human populations. Kaseloo and Tyson (2004) synthesized the ecological information on noise impacts to wildlife populations living near roadways and determined there is sufficient evidence that noise effects populations, breeding habits, and biodiversity. However, there is very little conclusive data relative to road noise and populations of fish, amphibians, reptiles, and invertebrates. Burrowing species may be impacted due to road noise and noise vibrations, but this area also requires further study. Bird populations appear to be the most negatively impacted, with impacts proportional to the levels of traffic noise and volume. In many locations there is clear evidence of decreased bird breeding activity and population declines near rights-of-way (however, this may be related to displacement of prey or vegetation change). Large and small mammals may also be repelled by roadway noise.

Wildlife can experience similar adverse health effects and stresses because the structure and function of most animal ears is similar to the human ear (EPA, 1978). Not only do sound level ranges heard by animals differ from what is heard by humans (EPA, 1978), but their sensitivity to and corresponding health impacts from sound also vary. Physiological effects of noise on wildlife include stresses to endocrine, digestive, cardiovascular, and immune systems as well as reproductive function (Kaseloo & Tyson, 2004). Roadway noise can also impact vocalization and communication between wildlife species, especially where roadway noise may cause background noise across distances (Kaseloo & Tyson, 2004).

Construction Noise

Construction noise is temporary but may adversely affect nearby property owners, residents and wildlife. The FHWA provides guidance in its *Highway Construction Noise Handbook* (Knauer et al., 2006). Many of the recommendations for this guidance document were generated by the Central Artery/Tunnel project in Boston (featured in the Examples section above), and were documented by Thalheimer (2000) prior to being published by the FHWA.

Road construction noise is typically generated by three source types: mobile equipment, stationary equipment and blasting activity. Noise levels for individual equipment typically used on road construction projects are presented in Table PR-5.1.

Table PR-5.1: Maximum Sound Level of Construction Equipment Activity Measured at 50 feet. (Adapted from Thalheimer, 2000; Knauer et al., 2006)

Equipment	dBA	Equipment	dBA	Equipment	dBA
Auger Drill Rig	85	Flat Bed Truck	84	Rivet buster/Chipping gun	85
Backhoe	80	Front End Loader	80	Rock Drill	85
Bar Bender	80	Generator	82	Roller	85
Blasting	94	Gradall	85	Sand Blasting (Single Nozzle)	85
Boring Jack Power Unit	80	Grader	85	Scraper	85
Chain Saw	85	Grapple (on backhoe)	85	Shears (on backhoe)	85
Clam Shovel (dropping)	93	Horizontal Boring Hydraulic Jack	80	Slurry Plant	78
Compactor (ground)	80	Hydra Break Ram	90	Slurry Trenching Machine	82
Compressor (air)	80	Impact Pile Driver	95	Soil Mix Drill Rig	80
Concrete Batch Plant	83	Jackhammer	85	Tractor	84
Concrete Mixer Truck	85	Man Lift	85	Vacuum Excavator	85
Concrete Saw	90	Mounted Impact Hammer (hoe ram)	90	Vacuum Street Sweeper	80
Crane	85	Pavement Scarifier	85	Ventilation Fan	85
Dozer	85	Paver	85	Vibrating Hopper	85
Drill Rig Truck	84	Pickup Truck	55	Vibratory Concrete Mixer	80
Drum Mixer	80	Pneumatic Tools	85	Vibratory Pile Driver	95
Dump Truck	84	Pumps	77	Warning Horn	85
Excavator	85	Refrigerator Unit	82	Welder/Torch	73

The relative A-weighted noise levels of common sounds measured in the environment and industry for various qualitative sound levels are provided in Figure PR-5.1.

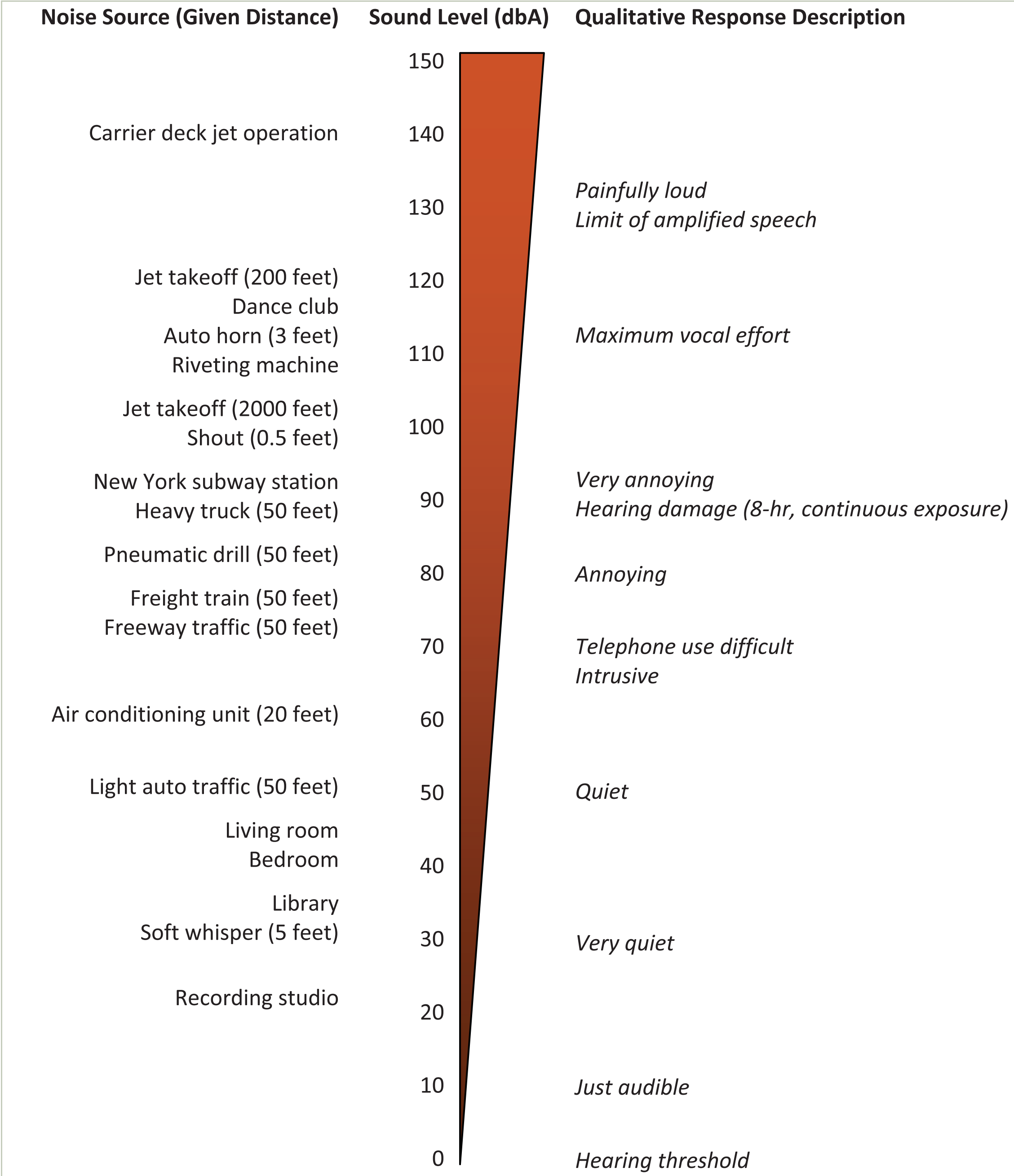

Figure PR-5.1: Typical Sound Levels Measured in the Environment and Industry (Adapted from Barksdale, 1991*).*

Traffic Noise

A discussion on traffic noise sources is provided in Credit PT-5 Quiet Pavement.

Regulation of Noise

In 1981, the Environmental Protection Agency (EPA) Office of Noise Abatement and Control (ONAC) was abolished and noise management authority was granted to individual states and municipalities. However, the 1972 Noise Act and the 1978 Quiet Communities Act are still valid but unfunded (EPA, 2009). Prior to the disintegration of ONAC, EPA did establish baseline guidance dBA levels for both indoor and outdoor receivers and exposure time criteria for preventing or limiting hearing loss (EPA, 2009). These laws were primarily put in place to protect noise-sensitive receivers. A noise-sensitive receiver is a location where people or endangered wildlife reside or where the presence of unwanted sound could adversely affect the designated use of the land or habitat (Knauer et al., 2006). Typically, noise-sensitive receivers include residences, hospitals, places of worship, libraries, schools, and may include nature and wildlife preserves and parks. For example, “Levels of 45 decibels are associated with indoor residential areas, hospitals and schools, whereas 55 decibels is identified for certain outdoor areas where human activity takes place. The level of 70 decibels is identified for all areas in order to prevent hearing loss.” (EPA, 2009). Roadway projects near these locations may be restricted by more stringent noise policies during both construction and operation (Knauer et al., 2006).

There are currently no federally regulated levels of construction noise; however the FHWA has set some standards for traffic noise levels. “The regulations [23 CFR § 772] contain noise abatement criteria which represent the upper limit of acceptable highway traffic noise for different types of land uses and human activities. The regulations do not require that the abatement criteria be met in every instance. Rather, they require that every reasonable and feasible effort be made to provide noise mitigation when the criteria are approached or exceeded.” (2006). In general, federally funded highway projects are required to follow a three step process during project development for noise abatement involving identification and mitigation of noise impacts, as well as land use planning coordination with local officials. Long-term noise control and mitigation measures for traffic noise are currently assessed via the environmental review process and associated documentation for the National Environmental Policy Act (NEPA) of 1969 under 23 CFR § 772. However, in September 2009, the FHWA published a Notice of Proposed Rulemaking (NPRM) to amend the current federal noise policy contained in 23 CFR § 772 which could mean highway agencies will need to review their existing noise policies, revise them, and obtain approval by the FHWA. (USDOT & FHWA, 2009)

Occupational exposures to noise for construction workers are closely regulated by the Occupational Health and Safety Administration (OSHA). For more information on OSHA noise and hearing safety standards, visit: http://www.osha.gov/SLTC/noisehearingconservation/

Considerations for Mitigating Noise

Many design and project planning methods can reduce engine or blast related noise from construction projects. Also, certain techniques and roadway surfacing materials can be used to reduce tire-pavement noise. The *FHWA Highway Construction Noise Handbook* (Knauer et al., 2006) describes the following elements for effective control of highway construction and operational noise which are applicable to all roadway projects.

- **Alternative design options.** Avoid generation of noise altogether. Examples are designated construction traffic routes, specially locating storage areas, or possibly even selection of an entirely different roadway alignment. Another design option would be considering alternative construction approaches, such as vibratory pile driving instead of impact pile driving. Alternative designs are usually very effective approaches, but they are not always cost-effective or practical.
- **Mitigation at the source.** Reduce, minimize or eliminate initial noise generation. An example would be installing mufflers or baffles on construction equipment or on a motor vehicle using the roadway. Contract specifications and special provisions are an excellent means of source mitigation, such as requiring contractors to use quieter equipment or setting strict noise limits for specific types of equipment. Additionally, construction employee training is considered a source mitigation technique. Quiet pavements, where tire-pavement noise is reduced at the source, may be a viable strategy for mitigating operational traffic noise (see Credit PT-5 Quiet Pavement). Source reduction is the most effective and often also most cost-effective type of mitigation strategy, because it is easiest to observe and inspect (Thalheimer, 2000).
- **Mitigation along the path.** Reduce or minimize noise propagation. Noise barriers and shields can be natural such as grade changes or permanent such as sound walls. Path mitigation is the least effective mitigation strategy, and has a number of disadvantages, especially if manmade. Path mitigation methods, such as sound barrier structures, are only effective at certain distances and geometries in relation to the roadway. Commonly, these are permanent manmade structures that tend to reduce visual quality, are high cost, energy-intensive, materials-intensive, and may potentially fragment or obstruct natural habitats depending on their placement in the right-of-way.

- **Mitigation at the receiver.** Reduce, minimize or avoid noise reception. Some examples are noise "masking" where unpleasant sound is covered up or interfered by a more pleasant sound, building envelope improvements, and temporary relocation of residents. Depending on the scale and location of the project, as well as the level of public and stakeholder involvement and project acceptability, receiver mitigation methods vary in cost. However, these methods are more effective at reducing noise received by the human ear than path mitigation, especially in targeted sensitive receptors (Thalheimer, 2000).

Most noise mitigation plans created for roadway projects will include a combination of many of these strategies.

GLOSSARY

ANMP	Alternative Noise Mitigation Plan
CA/T	Central Artery/Tunnel project. Also known as the Big Dig.
CFR	Code of Federal Regulations
dB	Decibel
dBA	A-weighted decibels
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
HMA	Hot mix asphalt
Masking	using acoustical techniques to cover up or interfere with unpleasant sound
MassDOT	Massachusetts Department of Transportation
MTA	Massachusetts Turnpike Authority
NMP	Noise Mitigation Plan
Noise	Unwanted sound, undesirable sound
Noise-sensitive receiver	A location where people or endangered wildlife reside or where the presence of unwanted sound could adversely affect the designated use of the land or habitat (Knauer et al., 2006)
NYDEP	New York City Department of Environmental Protection
Path	The route along which sound passes from the source to the receptor
PCC	Portland cement concrete
Receptor (receiver)	An endpoint where sound is observed
Source	A point where a sound is generated
USDOT	United States Department of Transportation

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WASTE MANAGEMENT PLAN

GOAL

Create an accounting and management plan for road construction waste materials.

REQUIREMENTS

Establish, implement, and maintain a formal Construction and Demolition Waste Management Plan (CWMP) during roadway construction. The CWMP should be included in the project contract documents and identify, at minimum, these items:

- Type of construction waste
- Expected (or actual) tonnage
- Costs and fees for landfills, recovery facilities, and hauling
- Contact information of responsible party for hauling
- Destination of waste (e.g. recycling facility, landfill, contractor's backyard)
- Contact information of responsible party for disposal site
- Management strategy for waste generated from mobile office activities and personal worker (household) waste

Details

The CWMP is typically completed by the prime contractor, submitted to the owner agency for approval, and implemented by all parties on the construction site. "Construction and demolition waste" (C&D waste) constitutes any material that must be hauled off-site for disposal or reprocessing, or, if disposed (stockpiled) within the project Right-of-Way (ROW) is not intended for use as structural material (e.g. pavements, embankments, shoulders, base materials, and fill). Materials that leave the ROW for reprocessing (recycling) activities are considered C&D waste because they are not used in their pre-construction form at the site. See more details under Credits MR-2 Pavement Reuse and MR-4 Recycled Materials.

Types of C&D for roadway construction projects may include (but is not limited to):

- Paving process waste (e.g. asphalt, concrete)
- Milling waste, concrete slough and grindings, cobble
- Metals (e.g. waste steel rebar, metal guardrails, pipes, luminaires, signs, aluminum, and various household metals)
- Plastic (e.g. waste plastic pipes)
- Excavated soil cuttings and boulders
- Sediment removed from temporary construction settling ponds
- Land clearing debris or excess topsoil
- Hazardous materials, including liquids
- Wood and paper products (e.g. packaging materials, cardboard and pallets)
- Glass

DOCUMENTATION

- Copy of the project CWMP

PR-6

REQUIRED

RELATED CREDITS

- ✓ PR-7 Pollution Prevention Plan
- ✓ PR-10 Site Maintenance Plan
- ✓ MR-2 Pavement Reuse
- ✓ MR-3 Earthwork Balance
- ✓ MR-4 Recycled Materials
- ✓ CA-3 Site Recycling Plan

SUSTAINABILITY COMPONENTS

- ✓ Expectations
- ✓ Exposure

BENEFITS

- ✓ Reduces Solid Waste
- ✓ Reduces Manmade Footprint
- ✓ Reduces First Costs
- ✓ Reduces Lifecycle Costs
- ✓ Improves Accountability
- ✓ Creates New Information

APPROACHES & STRATEGIES

- Integrate the CWMP with a Site Recycling Plan to earn credit CA-3 Site Recycling Plan.
- Modify, as appropriate for roads, versions of waste management plan specifications developed for building contractors by the Construction Materials Recycling Association (CMRA). The California Integrated Waste Management Board (CIWMB) provides Construction Specifications Institute (CSI) MasterFormat templates for Sections 01151 (New Construction) and 02060 (Demolition) for buildings construction debris. These tools were developed by the CMRA with funding from the Environmental Protection Agency and are available for free download and project-specific use at: http://www.ciwmb.ca.gov/conDemo/specs/CMRA.htm.
- Keep accurate records and retain all waste handling invoices and receipts. The site listed above also includes spreadsheet templates that contractors may use for tracking waste during construction.
- Specify a project diversion rate goal that may help establish appropriate waste handling procedures.
- The Construction Materials Recycling Association (CMRA) provides links to a variety of localities that offer construction and demolition waste recycling services. The list can be accessed at http://www.cdrecycling.org/.
- Include the Waste Management Plan in agency contract documents, bid packages, and/or specifications.
- Set waste reduction goals and explicitly state them in the Waste Management Plan
- Locate receptacles in easily accessible or highly frequented locations on the jobsite. Receptacles should not be placed in areas where they may cause harm to workers or the local environment. See Pollution Prevention Plan for more information.
- Hire a contractor with an Environmental Management System (EMS) in place. See Credit EW-1 Environmental Management System. These employers already have internal office procedures established to reduce office-related pollution and may be familiar with local agency waste management efforts.
- Develop and deliver training to workers to educate them on waste recovery efforts being implemented onsite and compliance with the general CWMP. This step will be critical to all projects. See Credit CA-2 Environmental Awareness Training for more approaches and strategies for education programs.
- Hire an experienced waste transport company to manage site waste and monitor waste streams for unacceptable materials.
- Identify local facilities that accept recyclables or salvaged materials. This is important in designating type of waste to separate, and in making arrangements for drop-off or delivery of materials.
- The 2007 Contractor's Guide by the King County Solid Waste Division and Seattle Public Utilities provides many helpful waste management and reduction strategies for the entire project. A sample waste management plan adapted from this guide is provided in the examples below.

Example: Sample CWMP Template with Materials Recovery

The following example content has been adapted from the 2007 Seattle/King County Contractor's Guide, which is available here: http://your.kingcounty.gov/solidwaste/greenbuilding/documents/ConGuide.pdf. Project teams should consider customizing the CWMP information based on project goals and owner expectations.

Greenroads™

WASTE MANAGEMENT PLAN

General Contractor:
Project Name:
Site Waste Coordinator:
Phone:
Debris Collection Agency:

Waste Management Goals:

Steps to inform contractors/subcontractors of Waste Management Plan policies.

1.
2.
3.
4.
5.

C&D Materials Expected to be Generated

The following charts identify materials expected to be generated by this project and the planned method for handling these materials for disposal and/or recycling.

DECONSTRUCTION & DEMOLITION PHASE

Material	***Quantity (units)***	***Haul Method & End Location***	***Handling Procedure***

CONSTRUCTION PHASE

Material	***Quantity (units)***	***Haul Method & End Location***	***Handling Procedure***

Figure PR-6.1 Sample CWMP Template. (Adapted from King County Solid Waste Division & Seattle Public Utilties, 2007)

Example: Case Study - City of Vancouver, British Columbia Recycling Initiative

In 2005, the City of Vancouver, British Columbia created a new engineering branch in their governmental agency strictly for management of infrastructure waste, such as waste generated from roadway, water and sewer development (see Figures PR-6.2 and PR-6.3). The estimated amount of this infrastructure waste exceeded 400,000 tonnes (MT: about 441,000 tons) annually. This waste had been previously been disposed in Vancouver Landfill, taking up massive and precious volume in this limited local resource.

The infrastructure waste included approximately 300,000 MT of excavated soil, 35,000 MT of hot mix asphalt pavement grindings, and 90,000 MT of concrete excavations. The latter amount is estimated to provide enough subbase material for 46 kilometers (almost 29 miles) of road.

After this initiative, some remarkable results were achieved through waste management activities that were implemented during the construction of roadways and infrastructure:

- 100% of annual hot mix asphalt milling waste is now recycled.
- 100% of annual concrete curb, sidewalk and roadway slab material is now recycled.
- Stockpiles of soil, asphalt, and concrete are now available for more projects after reprocessing and extraction of new aggregate is often avoided.

Figure PR-6.2: Typical pile of roadway construction waste. (Bremner & City of Vancouver, 2006)

Figure PR-6.3: Boulders excavated during roadway utility work. (Bremner & City of Vancouver, 2006)

- Transportation of waste materials was reduced by over 22,500 dump truck trips, resulting in substantial fuel cost savings, emissions reduction, and pavement wear.
- Total cost savings for all measures has an estimated value of over CN$500,000 annually (approximately $413,000 in 2005 U.S. dollars).

The information in this case study comes from the report produced by Bremner and the City of Vancouver (2006). The City of Vancouver recycling initiative was considered for nomination by the Transportation Association of Canada for their 2005 Environmental Achievement Award. More information about the project, including reprocessing and storage activities that are also part of this initiative, can be found at: http://www.tac-atc.ca/english/resourcecentre/readingroom/conference/conf2006/docs/s007/bremner.pdf

POTENTIAL ISSUES

1. Specifying and creating documents for waste management practices may be unfamiliar to roadway designers and decision-makers who do not normally manage waste. There may be a steep learning curve, as there is little data available to offer examples on how to monitor and measure road-related waste streams. This requirement may mean that additional people from outside agency engineering departments (such as environment, ecology or waste divisions) need to be included on the project team to implement a CWMP effectively.
2. Potential exists for tracked data to be measured inconsistently, either because of how the measurement is done or where in the waste stream it is measured. In order to address this, this requirement clearly notes that any material that leaves the boundaries of the roadway project site, even if intended for reuse later, is considered "waste." Therefore, probably a good place to measure the waste generated is actually at the source, and before it leaves the site. This way, quantities are more likely to be captured and representative of the project.
3. If disturbed or cut/fill material is stockpiled on-site and not intended for use on the roadway project, measurement may be more difficult if not monitored by truckloads (e.g. material is excavated in a large stockpile and left in place). Volume measurements, such as expected cut volumes, may be more appropriate

units of measure than mass. Some ingenuity may be required to determine an appropriate solution to account for on-site solid waste.

4. Careless behavior or lack of stewardship may be an issue that can result in recyclables being disposed in waste-only receptacles, or vice versa, especially if objectives of a WMP are not meaningful or communicated well to workers. This behavior can contaminate the recyclables stream and make an entire receptacle unsuitable for reprocessing or salvage, or accidentally send recyclables to a landfill.
5. Proper handling of recyclable materials is a key safety issue for new and unfamiliar recycling activities. Communication and training is critical to minimize risk and preserve safety.
6. Safety and security considerations should be taken into account relative to storage on-site of recoverable materials of high value. Opportunities for theft may be increased, especially for some types of metals that are commonly used in infrastructure or electrical utilities like copper wire.
7. At this time, points are not available for achieving waste reduction based on percentage of total waste. This is due to lack of data regarding waste management for roadway construction activities.

RESEARCH

"Solid material waste generation is one of the many environmental burdens associated with the roadway life cycle." (Rajendran & Gambatese, 2007, p. 88). Waste management, especially as recycling, minimization or reuse, is one of the cornerstone principles of sustainable development and pollution prevention programs. Both municipal solid waste (MSW) and building industry construction and demolition (C&D) waste are well-characterized. These types of waste are monitored and measured by the Environmental Protection Agency (EPA) and many state agencies. Remarkably little is known about quantities and types of solid waste generated by the transportation industry during road and bridge construction and rehabilitation activities (EPA, 2009a; Rajendran & Gambetese, 2007; Rajendran & Gambetese, 2005; Aquino, 2003; Northeast Waste Management Officials' Association, 2009). A key component is also very unclear: where the waste actually ends up.

This may be partly due to the relative ease with which hot mix asphalt, concrete, soil and cobble waste is recovered and reprocessed. Facilities that manage C&D waste are relatively unregulated parts of the waste management industry, even though they may receive a very large volume of materials from road and bridge construction. Bloomquist et al. (1993; cited in Rajendran & Gambatese, 2007) state in their report to the U.S. Department of Transportation (USDOT) and the Federal Highway Administration (FHWA) that approximately 75% of highway pavement materials are recovered. Note that this data is nearly 20 years old (or more) and no significant progress on characterizing road construction waste has been made, except at very few local agencies (see Examples noted above) where the focus is on cost-reduction and the savings associated with incorporating recycled materials into design standards.

What is Construction and Demolition (C&D) Waste?

The definition of what is considered construction and demolition (C&D) waste varies by state and local jurisdiction. The EPA definition is just as broad: materials that consist of "debris generated during the construction, renovation, and demolition of buildings, roads, and bridges" (EPA, 2009e). Construction debris is considered to be a specific type of solid waste, which is clearly defined under the 1984 Hazardous and Solid Waste Amendments (HSWA) to the United States 1972 Resource Conservation and Recovery Act (RCRA) Title 40 CFR § 261.2 (EPA, 2009d; ICF, 1995b). It is also considered industrial waste to differentiate its origin in the commercial and institutional sectors from MSW, which is mostly residential in origin (EPA, 2009b). Most of the waste is perceived as inert, however, some can be considered hazardous, such as structural elements with lead-based paint.

C&D waste is generated from "construction, renovation, repair, and demolition of structures such as residential and commercial buildings, roads, and bridges" and in general is comprised of a variety of materials (ICF, 1995b). The most common material in building C&D landfilled waste streams is waste wood, hot mix asphalt (from parking lots), drywall and masonry (ICF, 1995b); clearly the waste stream from roads and bridges has a different composition. For example, in Vancouver, British Columbia, earthen materials composed over half of the infrastructure demolition of the waste stream, followed by concrete and hot mix asphalt pavement materials in lesser quantities (Bremner, 2006). Franklin Associates (1998) justifies omitting roadway construction and demolition debris from their report to the EPA on C&D waste because it was not easily characterized and no point-source data was available for their study. Generally, data for percent composition of roadway waste stream materials is not available from any reliable source and it is clearly rarely tracked in a meaningful way. The waste stream for every roadway project will be unique in both volume and composition and end point, due to many factors such as: project size, location, material type, construction or demolition means, schedule, contractor site waste management practices (ICF, 1995b).

How Much C&D Waste Is There?

In March 2009, the EPA released 2003 data on construction and demolition waste from the building industry, which generated an estimated 170 million tons (EPA, 2009a), up from 136 million tons stated in 1996 (Franklin Associates, 1998; EPA, 2008b) The EPA notes that "Significant additional quantities of C&D materials are generated from the construction of roads and bridges, from land clearing at construction sites, and at military installations" (EPA, 2008b). The most recent waste stream characterization study funded by the EPA and conducted by the Northeast Waste Management Officials' Association (NEWMOA, 2009) characterized the 2006 C&D waste stream for several New England states. Interestingly, this study specifically excluded aggregated data relevant to the hot mix asphalt, brick and concrete (ABC) waste generated from road, bridge and land clearing projects because "the quantity of ABC material generated by road and bridge projects often dwarfs the quantity generated from other sources and can significantly bias the data on overall management of C&D wastes." (p. 2). This is, in part, due to the variations between C&D facilities relative to waste handling practices and types and quantities of materials that they receive, and the tendency to classify road ABC waste as "aggregate" in the waste stream reports. In addition, the report justifies its exclusion of transportation waste because roadway project material is often recycled into new aggregate for road base or pavement sections and processing often occurs on-site or at specialized facility (NEWMOA, 2009).

Gambetese and Rajendran (2005) note that little research is available on lifecycle impacts of roadway waste material, especially at end-of-life of the pavement sections, and have attempted to model this road waste. These same authors (2007) provide a good summary of road C&D waste estimates from various agencies and authors, and include what is known about waste quantities and percentages throughout the world for roadways. However, importantly, they note that "no exact estimates of C&D waste from the transportation industry are available" and that existing literature indicates road and bridge waste contributes significantly to the waste stream, more so than the building industry. William Turley, Executive Director of the Construction Materials Recycling Association (CMRA) estimated in 2003 that the annual C&D waste generated in the United States was roughly 320 million tons (Aquino, 2003). Following the publishing of the EPA 2009 report on 2003 building industry waste, Turley noted (Johnson, 2009) that the total waste stream is more realistically estimated at 325 to 350 million tons (for 2003) after infrastructure waste is accounted in the total. This would mean transportation-related construction, demolition, and rehabilitation activities generate and dispose of C&D waste at approximately the same rate as the building industry.

Based on available lifecycle process data and their collected end-of-life waste statistics for road waste, Rajendran and Gambetese (2007) conducted a quantitative lifecycle inventory (LCI) model of typical hot mix asphalt and concrete pavement sections from extraction of materials to end-of-life to estimate the waste contributions from each pavement type. Their model showed that over 50% of the lifecycle waste was generated from end-of-life waste disposal practices for both pavement models. However, their models did not include any recycling or reprocessing activities because these processes are not well-characterized. Waste generation rates at end-of-life, and during construction (scraps and refuse) are shown in Table PR-6.1.

Table PR-6.1: Roadway Material Waste Rates at End-of-Life and Construction (Adapted from Rajendran & Gambetese, 2007)

Pavement Material Type	Waste Rate at End-of-Life (% of Material)	Waste Rate during Placement of New Road (% of Material)
Concrete Pavement	25	2.5
Concrete Pavement – Cement	-	2.45
Concrete Pavement – Aggregates	-	3.0
Steel Rebar	55	1.79
Asphalt Pavement	18	0.102
Asphalt Pavement – Asphalt	-	0.86
Crushed Stone Base	17.1	0.88
Crushed Gravel Base	18.5	0.88
Granular Subbase	23	0.80
Subgrade	12.8	-

The EPA (2009c) notes that Industrial processes contributed to a total of 7.6 billion tons of non-hazardous solid waste generated in the U.S. in 2006. These processes include pavement material production such as asphalt and cement manufacturing. These wastes are outside the scope of Greenroads (at this time) because they occur earlier in the supply chain than materials produced (mixed) after ground-breaking for the roadway project. However, agencies and contractors are encouraged to work with industries that demonstrate responsible waste management practices.

Where Does It Go?

Most roadway, bridge and land clearing debris is managed by the same C&D landfills and reprocessing facilities as the building industry and represent a very large portion of the total C&D waste received by these facilities (Franklin Associates, 1998). Approximately 1,500 C&D landfills were operational in the United States in 2004 (EPA, 2009a). However, while building C&D waste composition and volume is monitored, the EPA admits that commercially generated C&D waste, such as from transportation and industry, is not because it is typically collected and disposed by the private sector. This makes managing these processes more difficult for municipalities, who have been slow to target this waste stream (EPA, 2009b). Also, the EPA reports that "Unknown amounts of C&D materials are also believed to go to combustion facilities or unpermitted landfills." (2008c).

Many states also accept exported wastes from other states, which complicates tracking recovery activities (NEWMOA, 2009). States also differ in waste management practices: in some cases the majority of C&D waste is sent directly to landfill while other states will pre-process the waste before it gets landfilled. "There is no common standard as to how C&D wastes are processed at facilities in different states or even within a single state." (NEWMOA, 2009). The type of receiving facility varies and can be C&D only landfills, C&D recovery facilities (which still dispose unrecoverable materials into landfills eventually), municipal solid waste (MSW) landfills, or combined C&D and MSW facilities (EPA, 2008a; EPA, 2008c). The type of landfill where C&D waste might be received for your project depends on local opportunity, and no federal regulation specifically dictates where it must go. Facilities in the U.S. that accept C&D waste, sorted by EPA Regions, are provided by the Construction Industry Compliance Assistance Center (CICA): http://www.cicacenter.org/.

Costs of Roadway Waste

Generally, road waste materials, like aggregate, asphalt and concrete, are heavy and, therefore, costly to transport. Reprocessed inert waste products are often cost-competitive with virgin aggregate because many waste recovery facilities will crush and resell these wastes to avoid transport to landfill (NEWMOA, 2009), but this may not be the case where there is open landfill space, low tipping fees, or other low-cost or virtually-free disposal options available (William Turley qtd. in Aquino, 2003). Essentially, this likely makes waste management commonplace in the transportation industry, because it is a cost-effective best practice.

In 1995, the EPA issued a report (ICF, 1995a) on environmental damages associated with C&D landfills, specifically to collect available data on groundwater or surface water pollution and ecosystem or habitat impacts, and to determine if these impacts can be attributed to specific types of C&D waste, landfill operations and environmental location. The study found that minimal data was available, many sites lacked basic environmental controls (like liners), and focused on only 11 C&D landfill sites. On-site groundwater contamination was present at several of these sites that exceeded acceptable levels of inorganic contaminants for state secondary groundwater quality standards (i.e. taste). Additionally, several sites were found to have inorganic surface water contamination that exceeded either state levels or EPA Ambient Water Quality Criteria for freshwater aquatic life. Some of these impacts were attributed to characteristics of the landfill location such as shallow groundwater or permeable soils (ICF, 1995a). Notably, there are many other impacts associated with long-term environmental degradation, using open space or habitat for landfills, and social and economic impacts that are not easily quantifiable. Current data on existing C&D landfill capacity in the United States is not available from any reliable source. Also, due to the high variability of size, location, capacities, and facility types lumped in industry census statistics for waste management does not adequately characterize the costs of landfilling large volumes of roadway waste.

How is C&D Waste Regulated?

While MSW regulations are a core part of the RCRA and governed at a federal level by the EPA, most of the regulations regarding C&D waste are generally non-specific and managed by states and local jurisdictions. However, the 1995 draft report created for the EPA Office of Solid Waste, indicates that all 50 states have some regulations for the C&D landfill facilities not located on private property, though many are not as strict as those for MSW facilities, which are covered under RCRA Title 40 CFR § 257 and 258. Additionally, "Executive Order 13423 requires all federal construction, renovation, and demolition projects to achieve a 50% recycling rate where markets or on-site recycling opportunities exist." (EPA, 2009a). The most detailed review for the EPA regarding the variability of landfill regulatory requirements is given in the 1995 draft report from ICF Incorporated.

In Departments of Transportation across the U.S., the story is similar: regulations are varied and often vague or non-existent. In fact, most Departments of Transportation (DOTs) do not have any management control over the waste and typically, road-related waste is handled by a different state agency (environmental or ecology, for example). The lack of consistency in characterizing and regulating this massive waste stream fundamentally demonstrates a large opportunity for both source reduction and waste minimization management protocols for roadway C&D waste.

Waste Management Planning

Waste management planning may be an unfamiliar consideration for roadway design agencies, engineers or contractors because traditionally this is not one of their professional responsibilities. However, Kibert (2005) notes that proper planning and quality assurance plans are imperative to the successful construction and continued performance of building industry projects, and the same may be said for roadway projects. Poorly defined parameters for C&D waste, including what it is and what it is not, are necessary for an effective waste management plan. Another key part of waste management is measurement. Consistency in any measurement program should include clear identification of where the waste is to be measured (i.e. leaving the construction site) and by what unit of measure (volume or mass) (ICF, 1995b). Responsible treatment of waste materials, if the wasteful practices themselves cannot be eliminated, is a necessity for reducing the long-term need for landfill space filled with inert, reusable materials.

Kibert (2005) also notes that with thoughtful planning and engineering, final contract documents can often anticipate sources of construction waste and generally generate less of it (as well as having fewer errors and change orders throughout the process). Specifications will also require a clear definition of what C&D waste means for the project. He states that source reduction (reduced need for materials) is most effective in minimizing waste, especially for new projects. Such success was demonstrated by the Examples from TxDOT and the City of Vancouver (Bremner, 2006), which were achieved largely through contract language (including specific instructions for recyclability, salvagability and special handling) and assignment of waste management responsibilities to various parties. Since the pavement engineer is responsible for the main material components project, i.e. the largest portion of the mass, there is an indirect responsibility to handle the selection process for these materials by keeping the end of the design life in mind.

Additional Resources

- The report from the EPA called *RCRA in Focus: Construction, Demolition and Renovation* is a freely available report that provides suggested strategies for inclusion in a waste management plan without violating regulatory requirements and discusses special materials-handling issues in C&D waste. It is available here: http://www.epa.gov/waste/inforesources/pubs/infocus/rif-c&d.pdf
- Two organizations that compile information for waste management activities relevant to roadway design and construction are the Construction Materials Recycling Association (http://www.cdrecycling.org) and the Green Highways Partnership (http://www.greenhighwayspartnership.org/).

GLOSSARY

C&D	Construction and demolition
CFR	Code of Federal Regulations
CMRA	Construction Materials Recycling Association
Construction & demolition waste	Material that must be hauled off-site for disposal or reprocessing, or, if disposed within the project ROW, is not intended for engineered use on-site
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
HSWA	Hazardous and Solid Waste Amendments of 1984 to RCRA
MSW	Municipal solid waste
MT	Metric ton (tonne)
NEWMOA	Northeast Waste Management Officials' Association
RCRA	Resource Conservation and Recovery Act (1972)
ROW	Right-of-Way
TxDOT	Texas Department of Transportation
USDOT	United States Department of Transportation

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POLLUTION PREVENTION PLAN

GOAL

Reduce pollution and associated effects from construction activities.

REQUIREMENTS

Create and implement a comprehensive Stormwater Pollution Prevention Plan (SWPPP) or Temporary Erosion and Sedimentation Control (TESC) plan that conforms to the requirements of the current Environmental Protection Agency (EPA) Construction General Permit OR the local or state Construction General Permit in areas that manage their own permitting plan, whichever is more stringent. The SWPPP/TESC must address water quality control and dust control activities used during construction of the roadway project.

Details

Note: A SWPPP for construction activities is also sometimes called a Temporary Erosion and Sedimentation Control (TESC) Plan or Pollution Prevention Plan (PPP) depending on local jurisdictions.

This requirement applies to ALL Greenroads projects, regardless of size.

DOCUMENTATION

- Copy of the Stormwater Pollution Prevention Plan (SWPPP) or Temporary Erosion and Sedimentation Control Plan (TESC) signed by the certified Erosion and Sediment Control inspector or authorized specialist for the project upon completion of construction.

PR-7

REQUIRED

RELATED CREDITS

- ✓ PR-4 Quality Control Plan
- ✓ PR-6 Waste Management Plan
- ✓ PR-8 Low Impact Development
- ✓ EW-1 Environmental Management System
- ✓ EW-2 Runoff Flow Control
- ✓ EW-3 Runoff Quality
- ✓ CA-1 Quality Management System
- ✓ CA-2 Environmental Training

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Expectations

BENEFITS

- ✓ Reduces Air Emissions
- ✓ Reduces Water Pollution
- ✓ Reduces Solid Waste

APPROACHES & STRATEGIES

- Evaluate federal, state and local requirements for most stringent pollution prevention standards
- Identify any high risk pollution-related elements of the project early in design.
- Use design and construction staff properly trained in pollution prevention.
- Consider site topography carefully during planning for construction staging areas and storage areas for aggregates, wastes and other materials.
- Create the pollution prevention plan during project development. (USGBC, 2009)
- Use more than one strategy to prevent pollution on your project such as (Sustainable Sites Initiative, 2009; USGBC, 2009):

    - Temporary and permanent seeding
    - Mulching
    - Earth dikes
    - Sediment traps
    - Sediment basins
    - Filter socks
    - Compost berms and blankets
    - Secondary containment
    - Spill control equipment
    - Hazardous waste manifests, and
    - Overfill alarms.
    - Silt fencing

- Seal pavement only when weather is not rainy. (Sustainable Sites Initiative, 2009).
- Do not conduct mass grading operations before large storms are forecast (Sustainable Sites Initiative, 2009).
- Coordinate staging activities with a contractor during design where possible.
- Use care when sequencing construction activities, especially for installation of low-impact development (LID) infiltration systems (Sustainable Sites Initiative, 2009).
- Have an environmental monitor on site to make sure that the requirements of the SWPPP are being followed.

Example: EPA SWPPP Templates and Guidance

The EPA provides a significant amount of guidance to aid in developing stormwater pollution prevention plan for construction activities. A number of tools are available, such as:

- SWPPP Template for states authorized to implement NPDES: http://www.epa.gov/npdes/pubs/sw_swppp_template_authstates.doc
- SWPPP Template for jurisdictions not authorized to implement NPDES (Alaska, Massachusetts, Idaho, New Mexico, New Hampshire, the District of Columbia, U.S. Territories, and Indian land): http://www.epa.gov/npdes/pubs/sw_swppp_template_unauthstates.doc
- Helpful guidance on developing SWPPPs for your construction site, *Developing Your Stormwater Pollution Prevention Plan: a Guide for Construction Sites:* http://www.epa.gov/npdes/pubs/sw_swppp_guide.pdf.

More tools, sample plans, inspection templates and other helpful information are available at http://cfpub.epa.gov/npdes/Stormwater/swppp.cfm. (EPA, 2008)

POTENTIAL ISSUES

1. The EPA only requires Construction General Permits for land disturbing activities greater than one acre in size. However, every Greenroads project must have a plan for controlling construction stormwater runoff, regardless of size, because size does not dictate good practice or insignificance of pollution generated by these construction activities. The precedence for this requirement has been established by other sustainability rating

systems, such as the 2009 Sustainable Sites Initiative (see “Prerequisite 7.1 Control and retain construction pollutants”) and the LEED™ 2009 Green Building Rating System (see “Prerequisite 1 Construction Activity Pollution Prevention” in the “Sustainable Sites” credit category).
2. For small projects that do not normally need to complete a SWPPP, a SWPPP will need to be generated. This could require additional man hours for the project, especially if the SWPPP development process is unfamiliar.
3. Some jurisdictions may have stormwater requirements in place that are similar but not identical to the NPDES requirements. In such cases, additional supporting documentation may be requested to demonstrate that the project SWPPP in place is equal to or more stringent the requirements for the EPA Construction General Permit. However, this requirement does not intend to generate extra paperwork, so where possible, links to current agency policies may be provided in support of this Project Requirement.

RESEARCH

Providing an erosion and sediment control plan during the construction of infrastructure holds both contractors and owners accountable to protect the surrounding environment from negative effects of excess sediment and pollution in stormwater.

Providing erosion and sedimentation control during construction of roadway infrastructure prevents:

- Degradation of aquatic habitats of fish and insects (EPA, 1999) as well as other wildlife communities.
- Increased sediment loading in nearby streams and outfalls (EPA, 1999).

The increase in sediment found in runoff on construction sites can be attributed to land that has been cleared of vegetation leaving exposed soil. Increased sediment loading in rivers and streams is the most common problem for water quality (EPA, 2009b). If rain events occur, this can cause erosion, and if erosion is not contained using the stormwater best management practices outlined in the NPDES, sediment can then be mixed with stormwater. At construction sites, these have often been found to contain metals and organic material, which can cause damage to wetland habitats (EPA, 1999). Furthermore, excessive sedimentation degrades habitats and cause significant decreases to the fish and insect populations of a watershed.

The United States EPA recommends keeping current water habitats to the same quality as they were before construction takes place. The intent of this is to ensure the water quality preconstruction is the same as the water quality post construction, meaning it is important to ensure the same volumes of water are being discharged naturally before and after development (EPA, 1999). In the EPA’s report to congress in 1999 the agency shows a clear message that the intent of these permits is to prevent any and all negative impacts to streams:

> *”In many cases, consideration of the increased flow rate, velocity and energy of storm water discharges following development unavoidably must be taken into consideration in order to reduce the discharge of pollutants, to meet water quality standards and to prevent degradation of receiving streams.”* (EPA, 1999)

The NPDES construction general permit is the governing permit set forth by the United States EPA for the discharge of construction stormwater. This permit regulates the effluent limits for both sediment and pollution and is available at http://www.epa.gov/npdes/pubs/cgp2008_finalpermit.pdf. However, local or state regulations may include more stringent requirements. Most states are authorized by the EPA to manage their own stormwater pollution control activities (all but five and the District of Columbia: Massachusetts, New Hampshire, New Mexico, Alaska and Idaho). The EPA also governs these activities in territories and Indian Country (EPA, 2009a).

The United States EPA outlines the provisions necessary to comply with Phase I and Phase II of the National Pollutant Discharge Elimination System (NPDES) program. The major difference between the two phases is in the size of the footprint. The Phase II permit applies to all sites in which between one and five acres of land disturbing activity occur (Illinois EPA). While Phase I encompasses all construction sites disturbing five acres or more (Illinois

EPA). Information on the EPA's NPDES program is available at http://cfpub2.epa.gov/npdes/index.cfm (EPA, 2009b).

GLOSSARY

Effluent	Outflowing water
EPA	Environmental Protection Agency
Erosion	A physical process that removes solid materials from their source and transports them to another location
NPDES	National Pollution Discharge Elimination System
Sedimentation	The accumulation of soil particles in water bodies
Stormwater	Water from rainfall events
SWPPP	Stormwater Pollution Prevention Plan
TESC	Temporary Erosion and Sedimentation Control Plan

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LOW IMPACT DEVELOPMENT

PR-8

REQUIRED

GOAL

Use low-impact development (LID) stormwater management solutions where appropriate to better mimic pre-development hydrological conditions.

REQUIREMENTS

Determine the feasibility of LID best management practices (BMPs) for stormwater management in the right-of-way (ROW). Complete a basic LID hydrologic evaluation according to the steps outlined in Chapter 3, "LID Hydrologic Analysis," of the 1999 *Low-Impact Development Design Strategies: An Integrated Approach* ("LID Manual") by the Prince George's County, Maryland, Department of Environmental Resources, Programs and Planning Division (PGC). If an alternative approach is used to investigate LID, show that it meets the general steps provided in the referenced guideline. The PGC guideline is available here: http://www.lowimpactdevelopment.org/pubs/LID_Hydrology_National_Manual.pdf.

Details

Low impact development (LID) is a term that describes a broad collection of engineered controls, stormwater management facilities, and other land development BMPs that attempt to mimic pre-development hydrologic conditions by emphasizing infiltration, evapotranspiration, or stormwater reuse for long-term flow control and runoff treatment. Hydrologic analysis is a systematic way to evaluate existing stormwater controls and new stormwater management or improvement opportunities. The LID Manual states:

> *The purpose of the hydrologic evaluation is to determine the level of control required to achieve the stormwater management goals for LID sites. The required level of control may be achieved through application of the various hydrologic tools during the site planning process, the use of IMPs, and supplemental controls. The hydrologic evaluation is performed using hydrologic modeling and analysis techniques. The output of the hydrologic analysis provides the basis for comparison with the four evaluation measures (i.e., runoff volume, peak runoff, frequency, and water quality control).* (PGC, 1999)

Note: This Project Requirement does not mandate the use of LID techniques on the roadway project. Instead, it is intended to inform the decision-making process. Therefore, any pre-existing procedure that meets the stated objectives will suffice.

Projects that are not changing the total existing surface area of the roadway facility (i.e. most rehabilitation or resurfacing projects) must also complete this requirement. This is discussed in further detail in later sections of this Project Requirement. Also, for projects with only minor stormwater improvements, the hydrologic analysis or LID evaluation may be scaled accordingly (i.e. simplified).

DOCUMENTATION

- Copy of the completed LID hydrologic evaluation. Scopes of standard drainage or geotechnical reports may already meet these evaluation requirements or need only minor changes to include LID. A separate document is NOT required in this case.

RELATED CREDITS

- ✓ PR-7 Pollution Prevention Plan
- ✓ EW-2 Runoff Flow Control
- ✓ EW-3 Runoff Quality
- ✓ EW-4 Stormwater Cost Analysis
- ✓ EW-5 Site Vegetation
- ✓ EW-6 Habitat Restoration

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Expectations
- ✓ Experience
- ✓ Exposure

BENEFITS

- ✓ Reduces Water Pollution
- ✓ Reduces Solid Waste
- ✓ Reduces Manmade Footprint
- ✓ Increases Awareness

APPROACHES & STRATEGIES

Meeting this Project Requirement

- Evaluate the opportunities on site for using LID techniques. Chances are that there are many opportunities available for every project. This in general means that four steps are completed as part of the evaluation:

  a. Topographical assessment (i.e. forests, floodplains, etc.)
  b. Soils assessment
  c. Hydrology assessment
  d. Existing vegetation and water features (i.e. wetlands, riparian areas, etc.)

- Follow the stated guideline, or follow any other guideline that uses a systematic site assessment to evaluate geological and hydrological conditions and meets the goal of this Project Requirement. For example, the Prince George's County recommendations have been specified in more technical detail for the Puget Sound region of Washington in the Puget Sound Partnership's *Low Impact Development Technical Guidance Manual for Puget Sound* (Hinman, 2005). This Project Requirement relies on the former because LID was pioneered in practice by Prince George's County and their LID Manual is the default guide for many organizations (EPA, 2000).
- Evaluate the site for potential stormwater improvements even if the project involves basic surface maintenance activities or is otherwise considered to be categorically excluded from stormwater considerations. It may be that a particular project cannot feasibly implement any stormwater improvements, either by cost, existing regulations, etc. The intent here is that (1) stormwater improvements are considered systematically as an opportunity for all roadway projects and (2) that any decisions made not to implement stormwater management are documented. All projects have some impact, even if they are determined to be insignificant or categorically excluded from environmental review, or local policies are considered "not applicable" to certain project types. It may be cost-effective for owner agencies to improve existing infrastructure in conjunction with the roadway project, even if stormwater management is not in the initial scope.
- Use design and construction staff properly trained in stormwater LID design.
- Identify opportunities for stormwater related BMPs elements early in project development.

Some Potential LID Opportunities

- Minimize impact to existing undisturbed soil and vegetation through avoidance, reduced project footprints elements (e.g. lane widths, shoulder widths, slopes).
- Use permeable hard surfaces (e.g. porous asphalt, porous pavers, porous concrete) instead of conventional impervious surfaces.
- Use amended or engineered soils instead of conventional compacted soils.
- Incorporate dispersed, evapotranspiration (ET) and infiltration-based practices (e.g. dispersion, bioretention) instead of enclosed drainage systems.
- The Federal Highway Administration (FHWA), Environmental Protection Agency (EPA), the American Association of State Highway and Transportation Officials (AASHTO) Center for Environmental Excellence, and the National Cooperative Highway Research Program (NCHRP) as well as many state agencies outline a variety of provisions incorporating LID measures into roadways. A variety of resources are listed at the end of this credit for reference.

Example: Case Study — High Point Subdivision, Seattle, WA

The High Point subdivision in the West Seattle neighborhood of Seattle, Washington is one of the first comprehensive installations of a Natural Drainage Systems scheme for stormwater management in a large scale urban environment. (In Seattle, streetside LID is referred to as "Natural Drainage Systems" to distinguish these facilities from in-lot installations.) High Point was a joint effort of Seattle Public Utilities and the Seattle Housing Authority (SPU, 2009) and was a large-scale low-income development community that redeveloped land from a former military base.

High Point incorporates a suite of LID techniques including bioswales, infiltration basins and permeable pavements (sidewalks and heavily traveled residential streets). See Figure PR-8.1. These LID techniques helped the City of Seattle achieve some of its stormwater management goals. Some highlights of the project include:

- 10 percent of the watershed for Longfellow Creek (a priority watershed for Coho salmon) is accommodated by controls in High Point.
- Predevelopment conditions were mimicked through bioswales and landscaped ponds that became amenities to the community.
- While standard detention basins were still required for emergency and fire purposes for the subdivision, the size of the detention facility was scaled down to 25% of what would have been needed by conventionally designed controls.
- High Point stormwater functions similar to the predeveloped conditions of a forest meadow.

Figure PR-8.1: Three LID techniques are featured in this photo taken at High Point Subdivision in Seattle, WA. The grassy area (far left) is actually turf placed over a large infiltration basin. A bioswale (center) is featured, and still in early growth. Also, the sidewalk (left) and the street (right) are paved with permeable concrete. (Photo by J. Anderson)

More information about High Point LID techniques are available at:
http://www.seattle.gov/util/About_SPU/Drainage_&_Sewer_System/GreenStormwaterInfrastructure/NaturalDrainageProjects/HighPointNaturalDrainageSystem/index.htm

Example: Case Study — SEA Street, Seattle, Washington

Another example from Seattle, "SEA Street," was actually one of the first pilot projects for low-impact development infrastructure in Seattle. (Here, SEA stands for Street Edge Alternatives) (SPU, 2009). The SEA street program focused on improving natural drainage of existing residential street areas through three main LID techniques:

- Narrower streets (which also provide a traffic calming effect). See Figure PR-8.2. (Note that narrow streets are typically considered to be an approach in "conservation design") (EPA, 2000).

- Added vegetation (for increased infiltration and public amenities).
- Vegetated filter strips. Compare the conventional asphalt lined channel (Figure PR-8.3) with the new vegetated filters strips installed along the sidewalks (Figure PR-8.4).

Figure PR-8.2: This street was designed to be narrower in order to produce a traffic calming effect for this residential area. (Photo by J. Anderson)

Figure PR-8.3: A conventional asphalt lined channel near SEA Street. (Photo by J. Anderson)

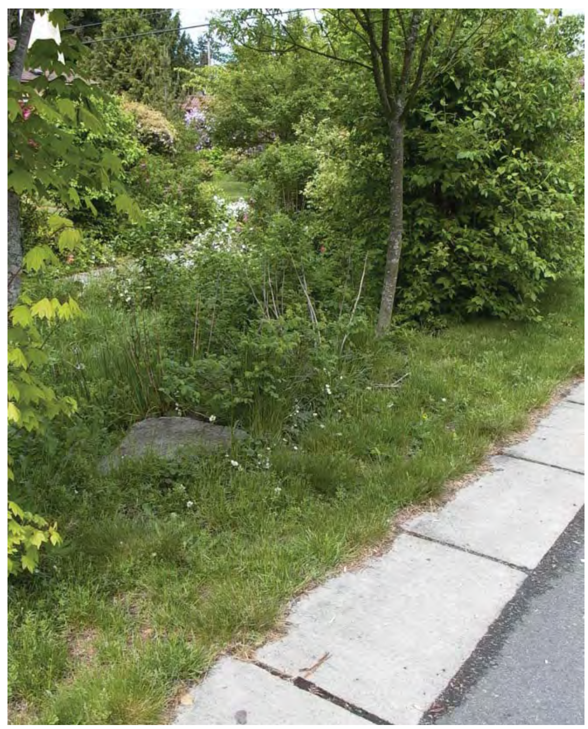

Figure PR-8.4: A bioswale on SEA Street between the sidewalk and street. (Photo by J. Anderson)

More information about SEA Street is available from Seattle Public Utilities at:
http://www.seattle.gov/util/About_SPU/Drainage_&_Sewer_System/GreenStormwaterInfrastructure/NaturalDrainageProjects/StreetEdgeAlternatives/index.htm

Example: City of Kirkland, Washington Surface Water Low Impact Development

The City of Kirkland requires the use of surface water low impact development (LID) techniques as feasible on new development. The City has adopted the King County Surface Water Design Manual (KCSWDM), which requires that development projects perform a surface water LID feasibility study and install stormwater LID to the maximum extent feasible and to install at least one element for surface water runoff in all situations (City of Kirkland, 2010). The KCSWDM can be found here:
http://www.kingcounty.gov/environment/waterandland/stormwater/documents/surface-water-design-manual.aspx.

POTENTIAL ISSUES

1. Most sites will be able to incorporate some LID techniques; however, soil conditions in every project will be different. In general, there will be a tradeoff between function and cost for implementing LID.
2. Some sites have existing soil or water pollution issues where infiltration through soils and into groundwater tables or other aquifers may not be allowed or is not advisable.
3. Some regulations or urban planning policies may be in place in some areas that dictate a number of urban improvements, such as widening sidewalks or adding width to lanes. These add impervious surface, and do not allow much room for LID in the right-of-way. Often these regulatory implications will be difficult to overcome (EPA, 2000). In general, a review of existing policy should be part of the LID evaluation.
4. The LID Manual referenced in this credit refers to the "Hydrologic Analysis" by Prince George's County, Maryland. As it turns out, this particular process is outlined in two different documents by PGC. Either is acceptable for this Project Requirement because they are equivalent. The *Low Impact Development Hydrologic Analysis* is an abridged version of the one specified here and it is available from the AASHTO via the EPA at: http://www.epa.gov/owow/nps/lid/lid_hydr.pdf.
5. This Project Requirement applies to all projects, even those that typically do not consider stormwater as one of their main project objectives. There is documented evidence that shows consideration of stormwater in project planning for urban roads can often result in strategic benefits for urban environments where stormwater management is increasingly a problem (City of Seattle, 2009). Additionally, where roadways are located in watersheds with total maximum daily load (TMDL) requirements, LID techniques are becoming one way that a roadway stormwater management system can help reduce the non-point source water pollution impact on the receiving waters from stormwater generated on the impervious surface (EPA, 2008). In essence, this Project Requirement is not requiring that LID is implemented; instead, it is requiring that it is considered. Some projects will specifically avoid stormwater issues just to save cost, but this practice does not ultimately agree with the goals and intents of Greenroads.

RESEARCH

Low-impact development (LID) is a well-documented approach to stormwater management. The best way to describe LID is as a collection of decentralized, small-scale, engineered stormwater controls that collect and treat stormwater at the source as it is generated (EPA, 2000; Huber et al., 2006; Hinman, 2005; City of Seattle, 2009). A number of hydrological objectives are achieved by this approach, because it relies heavily on the natural ecosystem processes infiltration (IF) and evapotranspiration (ET). Surface flows are reduced and also attenuated, some level of water quality treatment is often provided, and groundwater tables can be recharged, which help maintain stream flows: all of these things help an "unnatural" (i.e. manmade) system such as a building or a roadway more effectively mimic the natural ecosystem's preexisting hydrology (relative to its undeveloped condition). LID strategies thus combine to become an effective and efficient stormwater management scheme that results in an overall smaller ecosystem footprint.

Generally, this is contrary to the philosophy behind most conventional structural stormwater systems, which collect and convey stormwater to meet only an efficiency objective, i.e. remove it from the site and treat it elsewhere (an end-of-pipe approach) often using a lot of material along the way to construct the needed infrastructure to perform these tasks (EPA, 2000).

Sometimes, LID is also called "green infrastructure" or GI (EPA, 2009), or also "Natural Drainage Systems" (SPU, 2009) and also usually includes some elements of another development approach known as "Conservation Design" or CD (EPA, 2000).

How Do LID Techniques Work?

Put simply, LID works by minimizing the amount of impervious area on a site, sometimes called the "effective impervious area" (EIA) though this nomenclature varies (EPA, 2000). An impervious surface is "a hard surface area that either prevents or retards the entry of water into the soil mantle or causes water to run off the surface in greater quantities or at an increased rate" (Tilley & Slonecker, 2006). Developed areas have high levels of impervious surfaces compared to their otherwise undeveloped conditions (i.e. "predevelopment"). According to a recent study for Federal Highway Administration by the United States Geological Service (Tilley & Slonecker, 2006), roads and sidewalks accounted for an average of about 31.5 percent of the total impervious surface in six studied urban and suburban watersheds.

Because increased impervious surfaces lead to higher volumes of surface runoff (at higher velocities and faster times to peak flows), streams and watersheds can be damaged with erosion-producing flows. Erosive flows are characterized by higher sediment loads that degrade aquatic habitats. Conventional stormwater control techniques tend to decouple the rainfall event from one of its main hydrological functions: groundwater recharge (EPA, 2000). Figure PR-8.5 shows this phenomenon graphically.

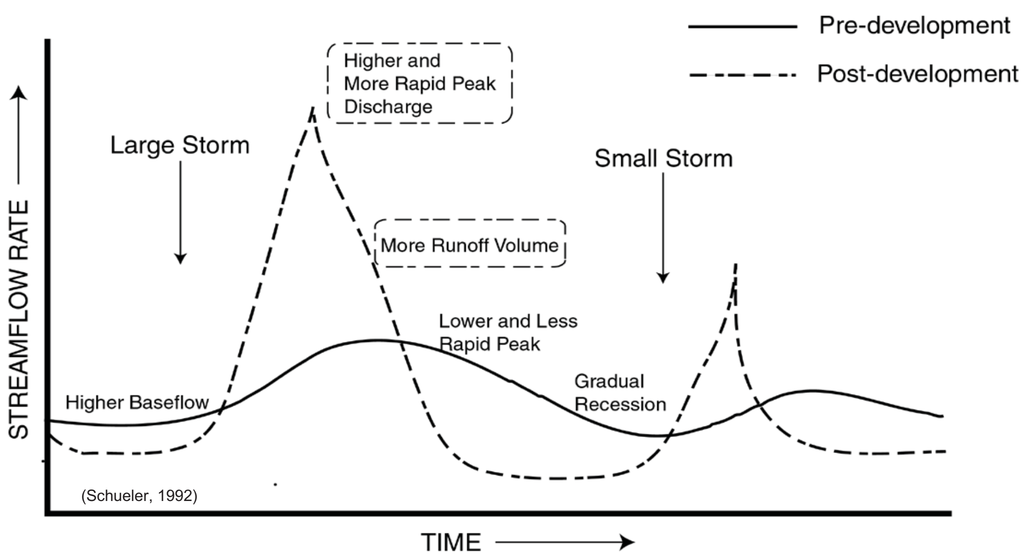

Figure PR-8.5: Comparison of predevelopment hydrology and developed hydrology. (From Schuler, 1987)

Stormwater management, then, in any environment (rural and urban), plays an enormous role in sustainability or maintaining existing hydrology. LID techniques can help restore the predevelopment hydrological balance in areas that have been ultra-urbanized (City of Seattle, 2009; EPA, 2009) and can also help maintain a close match for existing hydrological function in areas that have not been developed.

In general, LID techniques have the following common features (Hinman, 2005):

- Infiltration and evapotranspiration are the primary modes of runoff controls

- Impermeable surfaces are avoided or significantly decreased
- Natural soils are used, often with organic compositions (organics) instead of engineered or off-site fill
- Native vegetation is used (for some select techniques)
- Usually they are used in combination.
- Usually not all of them are appropriate for every site.

Depending on flow control objectives, there are a variety of LID design techniques to increase retention, increase time of concentration and reduce total volume (primarily through IF and ET). Consequently, before LID is used on any site, that site must be assessed for such things as soil properties, existing hydrological In order to determine if LID is appropriate (PGC, 1999).

What are the benefits of LID?

There is a laundry list of benefits associated with LID, including human health and aesthetic benefits that go hand in hand with a number of environmental benefits.

- Flow control for volume and time of concentration (reduced erosive flows, and reduced load on municipal stormwater facilities too) (EPA, 2009)
- Groundwater recharge through infiltration (*ibid.)*
- Improved water quality (*ibid.)*
- Reduced sewer overflow (*ibid.)*
- Increased carbon sequestration through increased vegetation (*ibid.)*
- Urban Heat Island mitigation and reduced energy demands in cities and developed areas (*ibid.)*
- Improved air quality primarily through increased use of vegetation, also includes a cooling effect (*ibid.)*
- Creation of habitat and recreational space (*ibid.)*
- Improved human health through connection to place and the natural environment (*ibid.)*
- Increased property values due to added aesthetics and performance (*ibid.)*
- Reduced cost and size for supplemental conventional stormwater infrastructure (EPA, 2000)
- Easily incorporated into a number of urbanized features, such as parking spaces and streetsides (EPA, 2000)

LID Limitations

While LID is a best management practice, it is the means to an end for every stormwater management issue. Like any practice or technology, there are certain limitations to LID techniques that must be understood prior to implementing them on a roadway project.

1. Some especially-sensitive watersheds may have objectives (i.e. quality and flow control) that cannot be achieved via LID alone. Some larger structural measures may be necessary for some projects (EPA, 2000).
2. The overall performance of LID elements on a project is very site-specific (EPA, 2000). This means that a comprehensive site evaluation is an extremely important step in an effective stormwater management scheme.
3. Long-term maintenance of LID elements can be an issue, usually because of contractor unfamiliarity. Also frequency of maintenance activities usually is higher than for conventional controls, which can cause long-term funding issues (EPA, 2000).
4. Lack of maintenance can often be very detrimental to LID performance and function (Hinman, 2005).
5. Construction of LID elements requires special care for some facilities. For example, overcompaction of infiltration basin soils or amended soils can lead to poor performance for flow control (Hinman, 2005).
6. Some sites may be ideal candidates for LID BMPs, but regulatory standards disallow them and require that impervious surfaces are installed instead. These could be subdivision codes, zoning rules, parking and street widths and sidewalk requirements, and other development standards that can essentially trump good stormwater design opportunities (EPA, 2000; Hinman, 2005).
7. LID techniques are not the best for handling large storm events. Usually, they behave much the same as natural hydrological features in these situations. Sometimes, LID measures will need to be supplemented by conventional conveyance as a contingency (Hinman, 2005).

8. Huber et al. (2006) note that the road right-of-way can restrict the ability of the engineer to incorporate LID practices due, simply, to lack of space.

Why is a LID evaluation a requirement for Greenroads?

The environmental impacts of stormwater generated from roadway facilities are not to be ignored. The decentralized nature of LID techniques fits well with the environment of many roads, even in urban environments. However, many roadway facilities do not take advantage of the hydrological benefits of IF and ET in standard design practice. It is the intent of this Project Requirement to provide an opportunity to evaluate these design approaches, which represent a higher level of practice for managing stormwater.

What Happens If Infiltration Is Not Appropriate For My Project?

For this Project Requirement (PGC, 1999), the main steps required in this study are:

a. Identify the project watershed and microwatershed areas
b. Define design storms or long-term performance requirements
c. Define modeling techniques to be employed
d. Compile information for predevelopment conditions
e. Evaluate predevelopment conditions and develop baseline measures
f. Evaluate site planning benefits and compare with baseline
g. Evaluate BMPs
h. Evaluate supplemental needs

If infiltration and ET are not appropriate for the project, or cannot be used in an effective comprehensive manner, then clearly conventional structural stormwater controls will likely require consideration for stormwater management. This requirement does not dictate that LID must be used. However, other credits in Greenroads may become more difficult to earn, such as EW-2 Runoff Flow Control, EW-3 Runoff Quality and EW-4 Stormwater Cost Analysis.

How Much Does LID Cost?

In general, costs can vary for LID stormwater controls. See the discussion included in Credit EW-4 Stormwater Cost Analysis. Many projects have been shown to be cheaper conventional conveyance and treatment systems. However, there is little reliable cost information regarding performance of such LID systems in a highway environment. While the idea of using LID is well-documented for highway environments (see Huber et al., 2006), the long-term performance of LID on highways, if practiced, is not. However, many local agencies in urban areas have found that road maintenance and rehabilitation projects offer a unique opportunity to improve stormwater infrastructure in these cities (e.g. Seattle, Washington; Prince George's County Maryland).

Some Examples of LID Techniques

There are a number of LID Techniques that are becoming more commonplace. Many of them, however, are more appropriate for buildings or on parcels instead of in roadways (i.e. green roofs and rainwater cisterns). There are still several technologies that can easily be implemented in most right-of-ways for roads. Also, the selection of BMP ultimately must align with project objectives, i.e. flow control, water quality treatment, aesthetics, thermal effects, or air quality (Hinman, 2005). A short list is provided below with a brief description (this list is not exhaustive).

- **Bioretention swales or ponds.** These facilities can also be known as "rain gardens" (small-scale) or "constructed wetlands" (very large scale); sometimes "bioinfiltration" or "bioswale" is also used. Generally, the purpose of bioretention facilities is to incorporate a number of runoff controls into one engineered facility by providing a mix of vegetation, amended soils, and different drainage configurations to achieve flow control and quality performance (City of Seattle, 2009).
- **Vegetated or grassed wet and dry swales.** Wet and dry swales are basically linearized bioretention facilities, commonly "bioswales" as noted above or "filter strips" (EPA, 1995b). The "wet" or "dry" notation indicates the type of plant life that is incorporated (City of Seattle, 2009). They are not quite the same as a roadside ditch, as

they are usually composed of amended soils and a select variety of plants to achieve a specific level of infiltration. They can also be designed to have weirs for added retention on some steeper grades and slopes. See EW-2 for a photo.

- **Permeable pavements.** There are a number of different kinds of permeable pavements. These are discussed in detail in Credit PT-2 Permeable Pavement.
- **Infiltration basins.** These can be found in a number of forms, including trenches, fields, or depressions. In general the rule of thumb is that the larger the area, the more infiltration can take place. Infiltration-based LID BMPs often suffer from constructability issues such as overcompaction (City of Seattle, 2009).
- **Trees.** Trees function as a stormwater control by increasing infiltration demand. They also provide transpiration and participate actively in the hydrologic cycle. They may also be an aesthetic amenity, especially in urban environments. Generally, preservation of treed areas is a good practice (City of Seattle, 2009).
- **Dispersion.** Some examples are splash blocks or gravel trenches. Generally, these are a means of distributing the energy in runoff flow into a vegetated infiltration area (City of Seattle, 2009). Depending on their design and level of attenuation, check dams and terracing efforts also fit here (EPA, 1995b).

Brief Review of Existing Regulatory Requirements

While there are no specific mandates for using LID in roads, highways and bridges, there are a number of federal regulations and policies in place to address the non-point source pollution generated by these entities (mostly water quality related). These are, in brief, the Coastal Zone Management Act of 1972, the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU, currently expired and not replaced legislatively as of this writing), and several sections of the Clean Water Act. Additionally, both the Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) have policies in place for managing stormwater runoff and provide guidance documents (EPA, 1995b; Strecker, Mayo, Quigley & Howell, 2001; AASHTO, 2009). The AASHTO guidance document provides a brief review of states with existing BMP manuals for stormwater runoff and recommends the LID hydrological evaluation from Prince George's County that is specified in this Project Requirement (AASHTO, 2009).

Additional Resources

There is a wide body of literature on LID for stormwater management. A few select documents are highlighted here. More specific techniques for stormwater management are addressed in Credits EW-2 Runoff Flow Control and EW-3 Runoff Quality.

- FHWA (Shoemaker, Lahlou, Doll & Cazenas, 2002) provides guidance on ultra-urban BMP selection and monitoring available at: http://www.fhwa.dot.gov/environment/ultraurb/3fs10.htm
- AASHTO Center for Environmental Excellence's *Environmental Issue Construction and Maintenance Practices Compendium,* Chapter 3, Section 7 provides some design guidance on LID available at: http://environment.transportation.org/environmental_issues/construct_maint_prac/compendium/manual/3_7.aspx
- Huber et al. (2006) compiled a comprehensive review of highway runoff control programs as part of the *National Cooperative Highway Research Program (NCHRP) Report 565: Evaluation of Best Practices for Highway Runoff Control.* This report is available in PDF format, with supplemental appendices, at: http://onlinepubs.trb.org/Onlinepubs/nchrp/nchrp_rpt_565.pdf
- The City of Seattle recently published a BAS (Best Available Science) Review as part of the updates to their stormwater code. This is available in Word Format at http://www.seattle.gov/dpd/static/BAS%20Review_FINAL_30JUN09_LatestReleased_DPDP017711.doc
- The Low Impact Development Technical Guidance Manual (Hinman, 2005) for Puget Sound is available and offers a somewhat more structured approach to hydrologic analysis than the Prince George's County LID Manual, and includes many different site considerations, primarily useful in urban areas and for lot development: www.psp.wa.gov/downloads/LID/LID_manual2005.pdf

GLOSSARY

BMP	Best management practice
CD	Conservation design
EIA	Effective impervious area
Evapotranspiration	the combined effects of evaporation and transpiration in reducing the volume of water in a vegetated area during a specific period of time (Huber et al. 2006)
GI	Green infrastructure
Impervious surface	a hard surface area that either prevents or retards the entry of water into the soil mantle or causes water to run off the surface in greater quantities or at an increased rate (Tilley and Slonecker, 2006)
Infiltration	the downward movement of water into the soil after surficial entry and percolation through pore spaces (Huber et al. 2006)
Low impact development	a broad collection of engineered controls, stormwater management facilities, and other land development BMPs that attempt to mimic pre-development hydrologic conditions by emphasizing infiltration, evapotranspiration, or stormwater reuse for long-term flow control and runoff treatment
NDS	Natural drainage systems
SEA	Street Edge Alternatives

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PAVEMENT MANAGEMENT SYSTEM

PR-9

REQUIRED

GOAL

Make roadway capital assets last longer and perform better by preserving and maintaining them.

REQUIREMENTS

Have asset management systems in effect that include the pavement and critical structural features on a project, such as bridges. Asset management system(s) must serve the roadway project and include, at minimum, these activities:

1. Measure conditions of pavement structure and bridge structures at least once every two years.
2. Possess documented decision criteria for timing preservation actions.
3. Record when preservation efforts occur.
4. Store information from #1-3 in a retrievable format.
5. Display information from #1-3 to the roadway user.

Generally, this means the owner-agency of the roadway should have pavement management systems (PMS) and bridge management systems (BMS) in place for the extent of their roadway network. Projects with both pavements and major structures must demonstrate that both types of asset management systems are in place and operational for all such features.

Details

An **"**asset management system" is a formal systematic process of maintaining, upgrading and operating a particular structure or network of structures. Asset management systems typically involve the use of one or more decision support tools (often computer-based) to organize the five activities detailed above. For purposes of this credit, we refer primarily to pavement management systems (PMS) and bridge management systems (BMS). "Preservation" refers to a set of maintenance and rehabilitation practices used to improve roadway condition and extend roadway life and also applies to both pavements and bridges.

Theoretically, any "asset" on a roadway project can be managed using the principles outlined here. While there are also separate asset management systems and tools for site infrastructure, traffic controls, standalone retaining walls and vegetation, for purposes of this Project Requirement such management systems are not required. Projects that have such systems in place should determine if the systems meet the five criteria above and apply for a Greenroads Custom Credit.

DOCUMENTATION

- A signed letter from an owner's representative stating the following:

1. A PMS and BMS (where appropriate) is either in-place or will be put in place for the project pavement and/or bridges.
2. The agency will manage the project pavement(s) and/or bridge(s).
3. The proposed means of accomplishing the five activities (e.g. the names of the consultant or software system in use).

RELATED CREDITS

- ✓ PR-2 Lifecycle Cost Analysis
- ✓ PR-10 Site Maintenance Plan
- ✓ MR-2 Pavement Reuse
- ✓ PT-1 Long Life Pavement
- ✓ PT-6 Pavement Performance Tracking

SUSTAINABILITY COMPONENTS

- ✓ Extent
- ✓ Expectations
- ✓ Experience

BENEFITS

- ✓ Increases Service Life
- ✓ Improves Human Health & Safety
- ✓ Reduces Lifecycle Costs
- ✓ Improves Accountability
- ✓ Increases Aesthetics

APPROACHES & STRATEGIES

- Ensure that the project roadway is part of a new or existing management system. It is likely that there is already a system in use by the roadway owner, which means that provisions for the project pavement to be included need to be made.
- For pavements, adopt a pavement management system that incorporates the project pavement. This is generally not practical unless the pavement management system incorporates other pavements also managed by the owner.

Example: Pavement Management Systems

All 50 states have some form of pavement management program in place (Finn, 1998). Many local pavement owner agencies also have pavement management systems that vary in complexity. While there is no requirement that they be computer-based, most current systems are. A few examples follow.

- **Dynatest Pavement Management System.** An example of a commercially available product (there are many), this system is integrated with the condition assessment equipment that Dynatest also manufactures.
- **StreetSaver.** A new online program developed by the Bay Area Metropolitan Transportation Commission (MTC) for use by local governments. It is used by a number of owner agencies, many of which are in California and Oregon. The interface is web-based and has been integrated with ArcGIS by Farallon Geographics, Inc. An example is Chula Vista, CA: http://www.chulavistaca.gov/city_Services/Development_Services/engineering/pavementmgmtsystem.asp
- **MicroPAVER.** A desktop pavement management system from the U.S. Army Corps of Engineers. It is available for free and is widely used by the U.S. military and other agency owners. Information at: http://owww.cecer.army.mil/paver/Paver.htm.

Example: Case Study – Washington State Pavement Management System (WSPMS)

The Washington State Department of Transportation (WSDOT) pavement management system (WSPMS) is an example of an internally built system and is one of the oldest systems in the U.S. WSDOT began collecting data in 1963 (Muench et al., 2004) and developed a management system in 1982 (FHWA, 2008). More details are given in the case study example below. A description of the system can be found at:

http://www.wsdot.wa.gov/Research/Reports/300/315.2.htm.

A recent Federal Highway Administration (FHWA) case study (2008) highlighted the Washington State Pavement Management System (WSPMS) and its contribution to overall condition and life cycle costs of pavements managed by the Washington State Department of Transportation (WSDOT). While the case study does not separate the level of funding from the use of WSPMS, it makes a case that WSPMS has contributed to a marked shift towards pavements in good condition since 1971 (Figure PR-9.1).

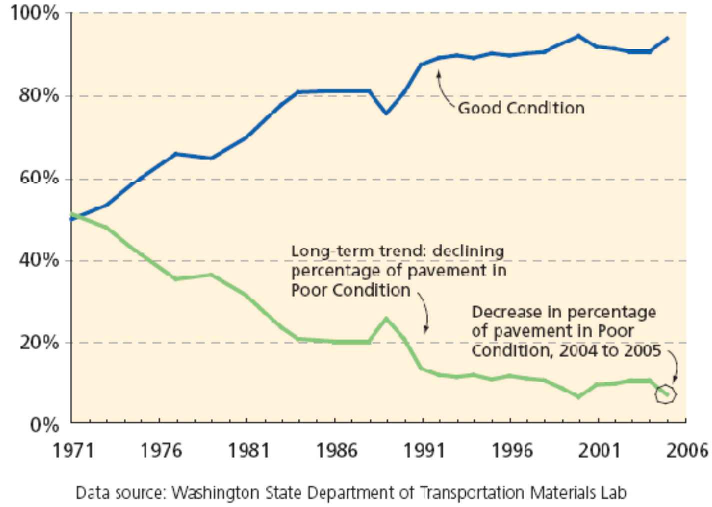

Figure PR-9.1: Trends in poor and good pavement condition of Washington State highways, 1971–2005, following adoption of a pavement condition survey in 1969 and a pavement management system in 1982 (FHWA, 2008).

WSDOT uses WSPMS to not only track pavement condition but also to choose when and by what means the pavement should be preserved and/or rehabilitated. WSPMS has simple built-in models that predict future pavement condition based on current and past condition. This way, WSDOT is able to predict with reasonable accuracy when preservation/rehabilitation need to occur. In 1993 WSDOT received legislative mandate that their project selection criteria should be based on lowest life-cycle cost, which further reinforced their pavement management approach. Overall, Figure PT-9.2 shows the condition of WSDOT pavements from 1969-2005 and gives clear evidence that pavement condition has improved markedly over this 36 year stretch.

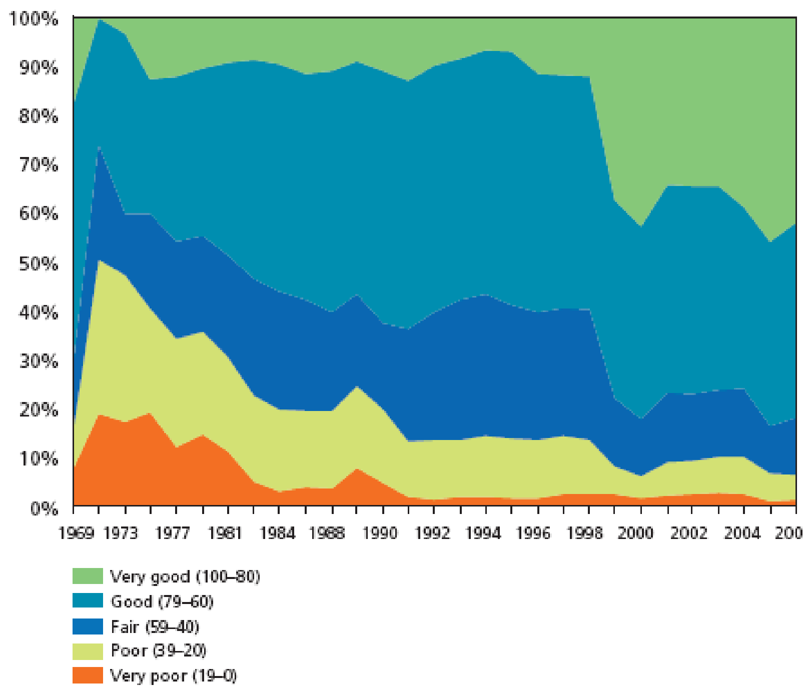

Figure PR-9.2: Trends in Washington State pavement structural condition, 1969–2006 (FHWA, 2008). Data source: Washington State Department of Transportation Materials Laboratory.

Example: Michigan DOT Bridge Management System

Michigan DOT (MDOT) has developed a Bridge Management System (BMS), one of six components of their Transportation Management System. The BMS is the decision-support tool responsible for managing the inspection, analysis and maintenance of the numerous components that make up a bridge. MDOT utilizes software American Association of State Highway and Transportation Officials (AASHTO) has developed called "Pontis" to aid their BMS. A description of the system can be found at: http://michigan.gov/documents/bridge_16549_7.pdf

Example: Virtis and Opis – Bridge Management System Tools

AASHTO's BRIDGEWare, a software design system, developed comprehensive bridge rating and design tools called Virtis and Opis. "The Opis bridge design package and the Virtis bridge load–rating package share a detailed database of structure descriptions that is integrated with the database of the Pontis bridge management data" (Thompson, 2004). More information is available at: http://aashto.bakerprojects.com/virtis/VirtisOpisBrochure0303.pdf

POTENTIAL ISSUES

This Project Requirement asks for asset management systems but does not verify execution of that management system. Therefore, the possibility exists that a management system could be presented and then not executed.

RESEARCH

Pavement Management Systems

The American Association of State Highway and Transportation Officials (AASHTO) defines pavement management as "…the effective and efficient directing of the various activities involved in providing and sustaining pavements in a condition acceptable to the traveling public at the least life cycle cost" (AASHTO, 1985). Pavement management consists of 3 major components (Pavement Management, 2007):

1. **Pavement life-cycle.** This includes how pavements are built, how their condition changes over time, and how this process can be affected by different forms of maintenance, rehabilitation and reconstruction.
2. **Costs associated with the pavement life-cycle.** This includes the costs of initial construction, maintenance and rehabilitation, assessing end-of-life pavement salvage value, and determining user costs incurred throughout the life-cycle.
3. **Pavement management systems.** This includes all the different systems used to determine the most appropriate time to rehabilitate pavement, what the most cost-effective method is, and how many dollars it will take to maintain a roadway system at a desirable condition level (WSDOT, 1994).

The fundamental idea is that pavement management will lead to lower overall life cycle costs for a pavement or network of pavements and thus be a more sustainable approach. This idea has been theoretically shown many times (e.g., Scrivner et al., 1968; Hudson et al., 1979; MAPC, 1986; Kay et al., 1993; Pierce et al., 2001) but has not been shown by direct comparison of a managed system and one that is not. A corollary, that some believe is true but has yet to be shown by empirical evidence, is that pavement management will also lead to lower use of natural resources, less energy input and fewer emissions associated with a pavement network.

A basic asset management system should include the following 5 components (Peterson, 1987):

1. **Roadway condition surveys.** A survey of the roadway structure to assess current condition and strength
2. **Database containing all related roadway structure information.** Information about other aspects of each roadway section including things like location, pavement thickness, ownership, date last constructed, etc.
3. **Analysis scheme.** Algorithms used to interpret roadway condition and other data in a meaningful way and produce information such as cost and deterioration models that assist in programming roadway preservation/rehabilitation/maintenance efforts. Recent software can combine the database, analysis scheme

and decision criteria in one package. Recent research has focused on advancing or refining life-cycle costing analysis, optimization algorithms and performance prediction.

4. **Decision criteria**. Rules developed to guide asset management decisions. As asset management systems have evolved, decision criteria have become more complex and now account for items such as user delay, vehicle operating costs and, in limited cases, environmental effects. For bridges, this would include optimization and analysis models.
5. **Implementation procedures.** Methods used to apply management decisions to roadway sections. Implementation is a political, budgetary or procedural issue.

Pavement Management Leads to Lower Life Cycle Costs

Choosing the optimal timing of preservation efforts can lead to lower life cycle costs. In turn, lower life cycle costs can be one of the outputs of a more sustainable roadway. Thus, there is an indirect relationship between a pavement management system, which can help in determining the best timing of preservation efforts, and sustainability.

In general, pavement deteriorates as pictured in Figure PR-9.3. Deterioration is slow at first and then increases at an increasing rate. Preservation efforts provide a step increase in pavement condition and essentially reset the deterioration process. Preservation efforts applied too soon do not achieve much improvement in condition for their cost while those applied too late (Figure PR-9.4) achieve an improvement in condition at substantial cost (Stevens, 1985; FHWA, 2008).

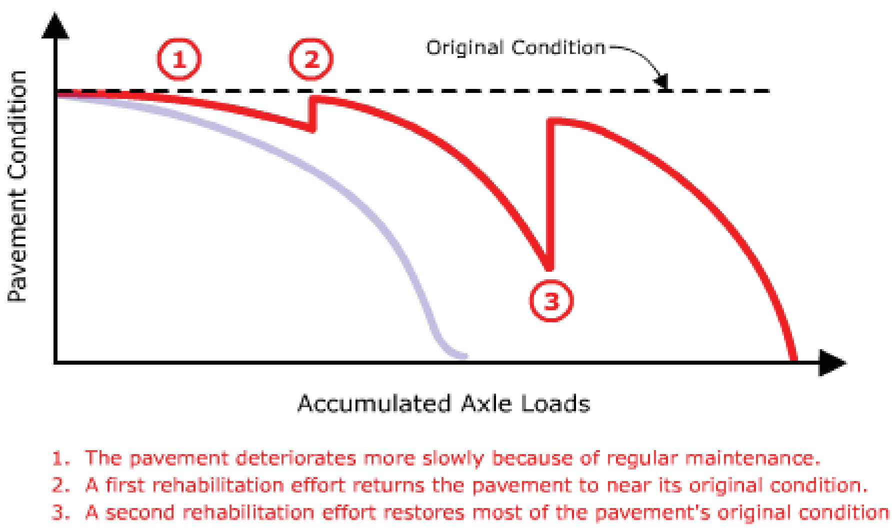

Figure PR-9.3: Pavement condition illustration.

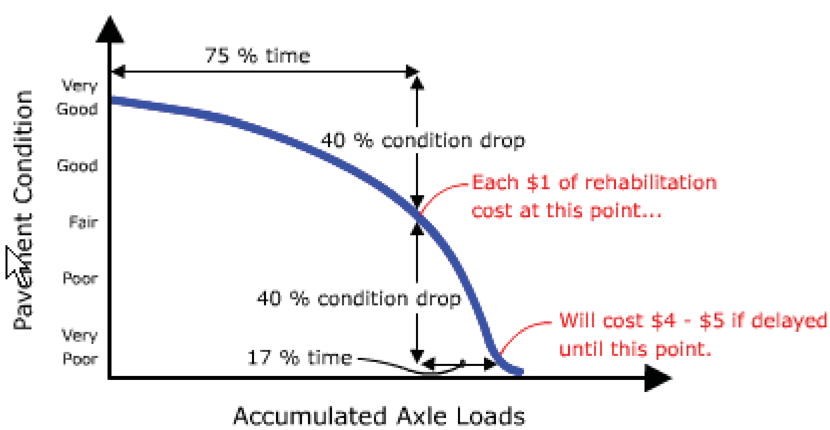

Figure PR-9.4: Rehabilitation time vs. cost (based on an illustration in Stevens, 1985).

Bridge Management Systems

The Federal Highway Administration recognizes the importance of maintenance and preservation of bridge sturctures too. For roadways, bridges are considered critical points or "nodes" along an otherwise continuous network of pavements. However, similar to pavement management systems, agencies usually develop a BMS that is tailored to their organizational, financial, managerial, political, and technical modes of operation.

Currently, all state DOTs have a bridge management system (Özbay et al., 2004). Each BMS may vary due to (Markow & Hyman, 2009):

1. Different philosophies of bridge management;
2. Different approaches to planning, programming, and budgeting;
3. the characteristics of each agency's transportation system and its infrastructures; and
4. The policy, financial, technical, and institutional environment in which each agency operates.

A study by the Transportation Research Board (TRB) in 1994, found that only 6 of 33 states responding to a survey said they were satisfied with the cost data they had available to provide to their bridge management systems (Thompson, 2004). This may suggest that agencies consider the accuracy and availability of cost and management data and other information required to develop a comprehensive asset management system to be inadequate.

In 1994, a 20-page questionnaire was distributed to 52 departments of transportation (DOT) in the 50 states, the District of Columbia, and Puerto Rico (Thompson & Markow, 1996). A total of 33 state DOTs provided usable responses.

- 76% (25 of 33) of the agencies use Pontis as part of their bridge management system;
- 12% (4 of 33) are developing their own system; and
- 10% (3 of 33) are undecided.

The percentage of those using Pontis is decreasing as new technologies emerge and become more accurate and reliable. More recent studies show that an increasing number of agencies are resorting to developing their own system in conjunction with current design software.

In 2009, Markow and Hyman prepared a detailed synthesis report on BMS for the National Cooperative Highway Research Program (NCHRP), *Report 397*. Currently, this is the most up to date and comprehensive information on the state of the practice of bridge management systems and the need, utility, level of implementation and cost implications at various state agencies. It also includes a survey of DOTs for prevalence of use of BMS, but there were similar results to the 1994 study mentioned above and fewer respondents to the survey.

Bridge Management Software

During the early 1990s, FHWA and Cambridge Systematics and Optima, Inc. developed a bridge management system called Pontis. Cambridge Systematics and Optima, Inc. (2010) describe Pontis as a decision-support software tool that includes a structural inventory for use in preservation and maintenance activities. Pontis provides a way for bridge managers to document inspections by structural element and develop cost-effective plans for maintenance activities in an existing bridge network. Newer software suites like AASHTO's BridgeWARE line of products incorporate additional tools like Virtis and Opis which can assist in load-rating and design that utilize the Pontis database (Transportation Research Board, Committee on Bridge Management Systems, 2003; Thompson, 2004).

Bridge Management Systems and Lifecycle Cost Analysis

Bridge management systems and lifecycle cost analysis (see PR-2 Lifecycle Cost Analysis) are complementary tools for long term decision-making in bridge maintenance, preservation and operation. Much of the current literature overlaps at optimization models for integrating lifecycle costing into network level BMS as well as at the project level (Morcous, 2007; Frangopol & Liu, 2007; Estes & Frangopol, 2001; Frangopol, 2004; Hegazy, Elbeltagi, & El-Behairy, 2004; Okasha & Frangopol, 2009) as well as for preservation and maintenance decisions

(List, 2007; Strauss et al. 2007; Naus & Johnston, 2001). More recent research has been in the area of reliability and risk analysis for lifetime weathering and other hazards, (Lee, Cho, & Cha, 2006; Hosser et al. 2008; Padgett, Dennemann, & Ghosh, 2010). For a comprehensive review of bridge life cycle cost analysis (BLCCA) and its potential applications at project and network-level BMS, the reader is referred to NCHRP Report 483 (Hawk, 2003), which provides the most comprehensive information on integrative lifecycle thinking for bridges.

Other Types of Asset Management Systems

Ancillary structures. Currently, the Federal Highway Administration is investigating development of decision-support tools for data management and preservation efforts for ancillary structures such as luminares, sign trusses, and other non-bridge and non-pavement features. The current program effort is led by the Office of Bridge Technology, which provides a free helpful guidance manual for these features called *Guidelines for the Installation, Inspection, Maintenance and Repair of Structural Supports for Highway Signs, Luminaires, and Traffic Signals* (FHWA, 2005).

Tunnels and retaining wall structures. Tunnel and wall structures are a very small percentage of structural roadway features. Much of the research on tunnel maintenance and preservation is managed under the purview of the Federal Highway Administration's Office of Bridge Technology and integrates with highway and rail transit in their web-based guidance document from the 2005 *Highway & Rail Transit Tunnel Maintenance & Rehabilitation Manual* (FHWA, 2007).

Vegetation. Additionally, there is a wealth of information available on vegetation management practices such as street trees, native vegetation, pesticide and herbicide use, and maintenance of other landscaping features, especially with regard to management of above and below ground utilities. However, a consensus does not appear to exist on computerized tools for systematic implementation of such vegetation management strategies and practices. AASHTO's Center on Environmental Excellence provides some guidance on management of these types of living assets on roadsides at this link under "Integrated Roadside Vegetation Management:" http://environment.transportation.org/environmental_issues/invasive_species (AASHTO, 2011).

GLOSSARY

Asset management system	a formal systematic process of maintaining, upgrading and operating a particular asset or network of assets, such as pavements and bridges
Preservation	a set of maintenance and rehabilitation practices used to improve condition and extend life of a structure(s)

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SITE MAINTENANCE PLAN

PR-10

REQUIRED

GOAL

Maintain environmental quality and aesthetics of the roadway project during use.

REQUIREMENTS

Have and implement a comprehensive ongoing site maintenance plan that addresses (at a minimum) responsible parties/organizations, standards, schedule, methods to be used and funding source(s) for the following items (listed by major topics):

- Roadway maintenance
  - Pavement patching, repair and crack sealing
  - Shoulder/sidewalk maintenance and repair
- Stormwater system cleaning and repair
- Roadside vegetation
  - Landscaping
  - Control of noxious weeds and nuisance plants
- Snow and ice control
- Traffic control infrastructure
  - Pavement marking maintenance and repair
  - Sign maintenance and repair
  - Safety device maintenance and repair
  - Traffic signal maintenance and repair
  - Roadway lighting maintenance and repair
  - Intelligent transportation system maintenance and repair
- Cleaning
  - Pavement sweeping and cleaning
  - Litter control
  - Trash collection

If any items are not applicable they should be listed as such and accompanied with a short reason for the "not applicable" listing. The site maintenance plan should cover the expected lifetime of the roadway facility.

Details

It is likely that some or all of the required activities are addressed by different documents or by different organizations. A separate stand-alone site maintenance plan is not required; references to relevant existing documents are sufficient.

DOCUMENTATION

- A copy of the stand-alone site maintenance plan or copies of existing documentation or plans that address the items noted above.

OR

- A list of each item that addresses responsible parties/organizations, schedule, methods and funding source(s).

RELATED CREDITS

- ✓ PR-9 Pavement Management System
- ✓ EW-2 Runoff Quality
- ✓ EW-3 Runoff Flow Control
- ✓ EW-4 Stormwater Cost Analysis
- ✓ EW-5 Site Vegetation

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Extent
- ✓ Expectations
- ✓ Experience

BENEFITS

- ✓ Improves Human Health & Safety
- ✓ Reduces Lifecycle Cost
- ✓ Improves Accountability
- ✓ Increases Aesthetics

APPROACHES & STRATEGIES

- Use standard agency maintenance guidelines and specifications.
- Seek a long-term maintenance contract or partnership. Long-term maintenance agreements can be an effective maintenance solution and improve cost efficiency over the lifetime of the facility.
- Initiate discussions and document the public involvement process of outlining design elements in relation to maintenance requirements during project planning. Discuss how maintenance partnerships are formed and explore the benefits of successful maintenance guidelines. (This may include initiation of a public involvement/volunteer program.)
- Establish a public involvement program and marketing strategy. For example, community-supported and volunteer programs like Adopt-a-Highway can be an effective approach to litter and graffiti control and increase community ownership of the infrastructure.

Example: Documentation

This is an example of documentation that meets the intent of this requirement. The example is for a fictional 2-lane road being expanded in to a multimodal facility (e.g., bicycles, pedestrians, new two-way left turn lane) in the greater Seattle, WA area for the Washington State Department of Transportation (WSDOT). This site maintenance requirement is met by existing programs within WSDOT. Therefore, documentation need only cite these programs and their relevant manuals and procedures. Note that Figures PR-10.1 and PR-10.2 show more than the required information of "funding source(s)" because they break down all funding sources for the entire Washington State Transportation budget (not just the funding source for site maintenance) and the entire distribution of state collected transportation revenues and funds (not required).

Documentation

For this particular project, WSDOT is the owner agency and is responsible for site maintenance (as defined by this requirement). This is true in many jurisdictions but not all. In some jurisdictions, the owner agency contracts out to private companies for portions of site maintenance. The overarching document that describes WSDOT site maintenance responsible parties, schedule and methods is the *WSDOT Maintenance Manual (M 51-01)* (http://www.wsdot.wa.gov/Publications/Manuals/M51-01.htm). The WSDOT *Maintenance Performance Measures* website (http://www.wsdot.wa.gov/Maintenance/Accountability/default.htm) describes the standards and targets for current and past years. Additional guidance on roadside vegetation is given in the *Northwest Region, Area 5: Integrated Roadside Vegetation Management Plan* (http://www.wsdot.wa.gov/Maintenance/Roadside/mgmt_plans.htm). Additional guidance on snow and ice control is given in the Statewide Snow and Ice Plan: 2009-2010 (http://www.wsdot.wa.gov/winter/SnowIcePlan.htm). In WSDOT's 2009-2011 transportation budget, "Highway Maintenance" is funded at $355.4 million (about 6.1% of the total WSDOT budget). Figures PR-10.1 and PR-10.2 describe the collection and distribution of funds.

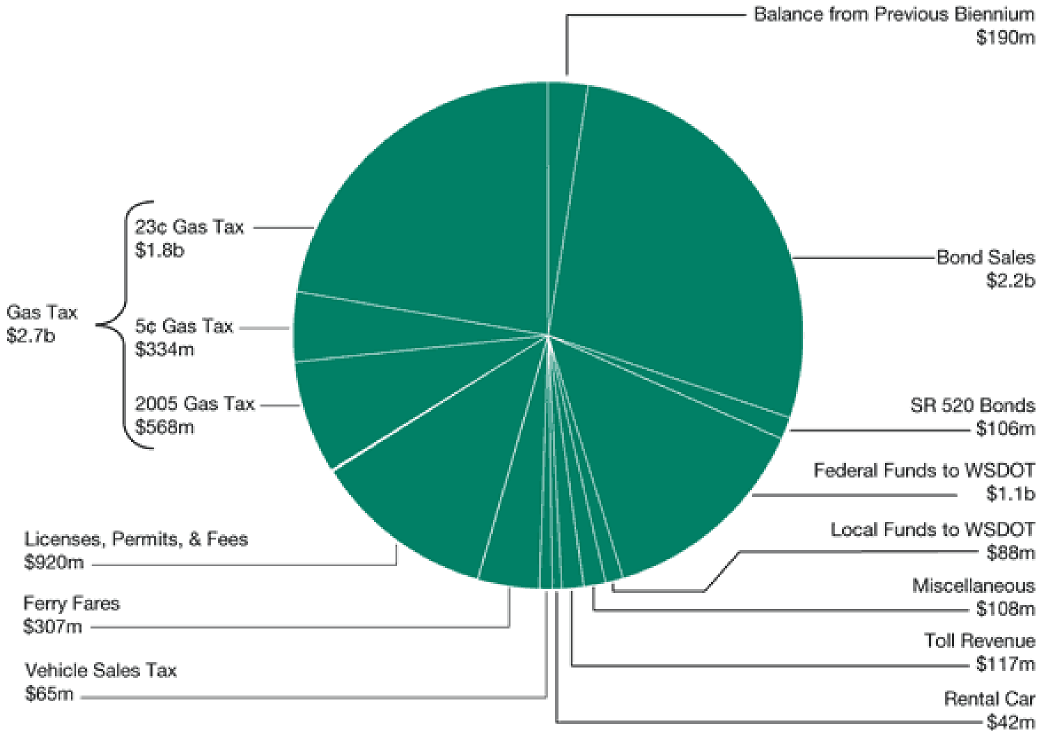

Figure PR-10.1: Transportation Revenues and Funds Collected by the State (WSDOT, 2009).

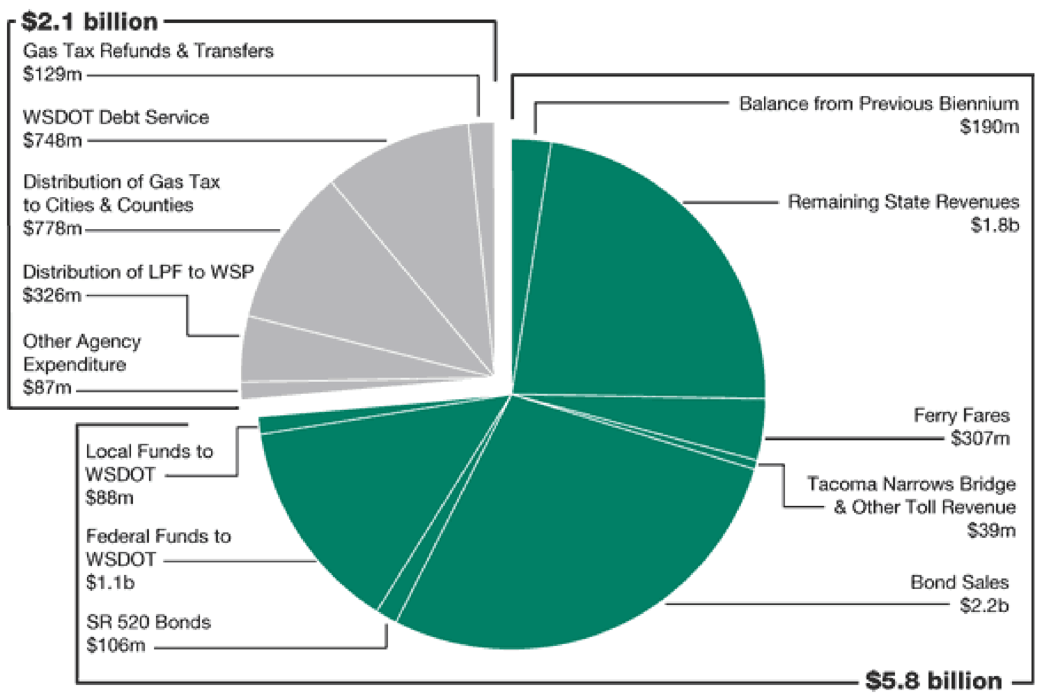

Figure PR-10.2: Distribution of State Collected Transportation Revenues and Funds (WSDOT, 2009).

More about the WSDOT Maintenance Accountability Program (MAP)

The Washington State Department of Transportation (WSDOT) has developed a Maintenance Accountability Program (MAP) designed to track, measure, and communicate the results of maintenance activities on state roadways (http://www.wsdot.wa.gov/Maintenance/Accountability). The program was developed in 1996 out of necessity as a response to impending budget cuts by the Washington State legislature for road maintenance.

The MAP exists to comprehensively measure the performance of road maintenance within the state by providing tools that link strategic planning, the budget and delivery of service, and analyzing the results quantitatively. To do this the MAP is divided into 33 distinct categories that aim to comprehensively cover the scope of road maintenance. Analysis is derived from data collected by randomly sampling roadways twice a year via comprehensive sampling procedures, and from records of accomplished work. The data is then compared with the established standards to arrive at a level of service (LOS) designation for each category. These LOS designations are then compared with WSDOT goals and targets to responsibly track progress and maintain accountability in all facets of maintenance operations.

The success of the MAP has been to the benefit of WSDOT and their maintenance division as the maintenance budget is now performance based. Thorough analysis of program successes and failures allows WSDOT to analyze budget proposals and accurately project the consequences of budget decisions on road maintenance performance, from which they can lobby the legislature to secure adequate funding. Thus, by being careful, logical, and doing their research, WSDOT is able to secure the money necessary to keep their roadway investments in good working condition, obviously to the benefit of all residents of the state. Furthermore, if the final budget falls short of funding everything that WSDOT desires, they can effectively scale back their goals and targets to produce ones that maximize the productivity of the road infrastructure and accurately evaluate the performance of maintenance based on the funding provided.

The MAP is considered to be a successful program. It has been heavily borrowed for use in other states, and its measurement techniques were so successful that part of the program was used as the pilot for performance based budgeting in Washington State.

POTENTIAL ISSUES

1. Some responsibilities, standards, schedules, methods and funding sources may not be known or are not documented. Such documentation may need to be created above the individual project level.
2. Funding for site maintenance may not be secured long-term. While this is certainly recommended, listing the current funding source is adequate for this requirement.
3. This requirement only specifies that a site maintenance plan exist. It does not ensure that site maintenance is actually done.
4. This requirement only specifies broad categories of site maintenance. It does not specify effectiveness, costs or utility of individual efforts.

RESEARCH

Maintenance can increase the useful life of most infrastructure components, promotes public safety, and benefits both public and ecosystem health. The following is a series of brief discussions on the value and nature of infrastructure maintenance broken down by general category.

Street Cleaning & Litter Removal

Street cleaning and litter removal retain the value of the roadway by sustaining the environmental and aesthetic benefits over its lifespan. During its operating cycle the roadway will, due to use and nature, necessarily accumulate various debris that, left alone, will negatively impact the roadway's relationship with its environment. Both dirt and dangerous pollutants (e.g. phosphorus, nitrogen, lead) will collect on the roadway over time and pose a legitimate threat to vegetation and water quality in the area (Hyman, 1999). Street sweeping has traditionally been viewed as effective against dirt and dust control only, but advancements in sweeper technology have shown it to be very effective in removing small pollutants as well (James, 1997). Removal of dirt and dust from the roadway also improves safety by maximizing the surface area of tires the meet the road surface and enhances the aesthetics of the site for its users (Hyman, 1999). Similarly, litter on the site can be an eyesore and a gateway to pollution of earth and water. Volunteer litter removal programs, such as Adopt-a-highway, have been shown to be the most effective method of combating litter accumulation (Hyman, 1999).

Vegetation Maintenance

Native vegetation growth near the roadway is necessary for the roadway to maintain a good relationship with its environment, but unchecked vegetation growth can negatively affect the performance and safety of the roadway. Maintaining vegetation limits improve safety and traffic flow by maximizing sight distance for drivers, providing more accessible shoulders for emergencies, and preventing damage to and interference with roadside structures and signs (WSDOT, 2009; MassTran, 2003). Furthermore, keeping vegetation growth clear of the edge of the roadway helps prevent the pooling of water, prolonging the life of the pavement (WSDOT, 2009). The key is to maintain vegetation, since root systems can provide necessary support and stabilization of embankments supporting the road (MassTran, 2003). For an example discussion of the methods of vegetation maintenance including important sustainability aspects, see the Integrated Roadside Vegetation Management Program of MassHighway (2003).

Pavement Repair

Despite our best efforts, use of the roadway over its lifetime will cause it to begin to break down, resulting in small pavement failures that can negatively impact the performance of a roadway. Maintenance on the roadway has two main effects: it immediately improves the condition of the pavement and slows the rate of future deterioration (Deighton, 1997). These effects maintain life of the road for a longer period of time, maximizing the capital investment.

Aside from economic concerns, unmaintained paved surfaces can also become very dangerous safety risks to drivers, passengers, and pedestrians by damaging vehicles and requiring additional driver attention. While best management practices for pavement maintenance are widespread, comprehensive supporting research is not. However, the process of retaining the value and function of the roadway over time represents a significant portion of that roadway's sustainability benefit, so well designed maintenance procedures must be considered (Wei, 2004). For a comprehensive discussion of pavement maintenance benefits, definitions, costs, methods, and references see Pavement Interactive at http://www.pavementinteractive.org.

Storm Drain Maintenance and Cleaning

Drainage structures, essential for an environmentally sensitive and functioning roadway, require periodic maintenance to maintain efficiency. Without maintenance, significant declines in performance and flow rates have been well documented (Hyman, 1999). Best management practices are also well documented, and include routine maintenance (especially right before a rainy season) and data collection to track when and where storm drains tend to fail in an effort to clean and/or fix them before failure occurs. Hyman (1999) has a good baseline sampling of some effective best management practices.

Cost Analysis

While the benefits of site maintenance on a roadway have been relatively well-documented, cost analyses of these procedures are much less so. Since road maintenance costs vary considerably by roadway type, road use patterns, regional weather factors, and chosen best management practices by local agencies, there is no easy definition for the maintenance cost of any specific roadway. However, there are some commonly cited costs of site maintenance that can provide an understanding of the resources required to maintain the asset.

The Washington State Department of Transportation (WSDOT) has $355.4 million allocated in the 2009-2011 budget for highway maintenance of roughly 7,000 centerline miles of roadway. Furthermore, their Maintenance Accountability Program divides that money into 33 distinct activities within site maintenance to measure resource distribution more accurately. Sub-budgets include $137 million for roadway maintenance, including pavement patching & repair, shoulder repair, and cleaning & sweeping; $27 million for drainage maintenance and slope repair; and $35 million for roadside and vegetation management, including litter pickup and control of intrusive and interfering vegetation (WSDOT, 2008).

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EDUCATIONAL OUTREACH

PR-11

REQUIRED

GOAL

Increase public, agency and stakeholder awareness of roadway sustainability activities.

REQUIREMENTS

Incorporate a comprehensive public educational outreach program into the operational phase of the roadway facility project.

A minimum of three out of the following eight educational elements, to be installed within the roadway project limits or within the purview of the lead agency, must be completed to meet the intent of this project requirement:

1. Install and maintain a permanent project-oriented signage program along the roadway right-of-way. During construction registered projects may use temporary signs to display factual information about the Greenroads™ certification level being pursued, as noted in the Greenroads trademark policy (available on the website).
2. Install and maintain at least one offroad, permanent point-of-interest kiosk that displays the Greenroads certification level pursued, project information, and the certification level actually achieved.
3. Provide a publicly available and maintained informational project website with capacity for submitting feedback and comments.
4. Develop an agency and/or stakeholder guide, specification, or policy that incorporates or otherwise clearly references and reflects the ideals and intents of Greenroads.
5. Institute an internal agency continuing professional education and training program related to Greenroads.
6. Perform at least two presentations about the project for primary and secondary schools.
7. Perform one professional technical presentation.
8. Document the project experience using Greenroads (i.e. conduct a detailed case study for the roadway project).

Details

Note that the official Greenroads logo may only be used on project signs, public installations or project documents by permission of Greenroads.

DOCUMENTATION

The following correspond to the numbered sequence in the preceding section.

1. Provide photos of temporary and permanent signs installed in the right-of-way.
2. Provide a text or printed copy of the information offered at the kiosk (i.e. brochure or static installation) AND a photo of the kiosk structure and location as installed.
3. Provide the website address. (Note: hyperlinks must be live.)
4. Provide a copy of the agency guide, manual or specification.
5. Provide a copy of the learning objectives and schedule for the training program.
6. Provide a copy of each presentation and the time and date of the presentation.
7. Provide a copy of the abstract along with the technical paper and/or presentation.
8. Provide a copy of the completed case study.

RELATED CREDITS

- ✓ PR-1 Environmental Review Process
- ✓ CA-2 Environmental Training
- ✓ AE-8 Scenic Views
- ✓ AE-9 Cultural Outreach

SUSTAINABILITY COMPONENTS

- ✓ Equity
- ✓ Expectations
- ✓ Exposure

BENEFITS

- ✓ Increases Awareness

APPROACHES & STRATEGIES

- Use the environmental review process (see PR-1) as a starting point for establishing public awareness needs.
- Involve business development personnel, marketing professionals, and public relations officers early in the project planning process.
- Expand construction team health and safety training meetings to incorporate Greenroads goals for the project (see CA-2).
- Identify people within the project team, agency or company who may be interested in leading external and internal educational efforts relative to incorporating Greenroads and sustainability in the organization.
- Consider collaboration with professional website developers.
- Contact the Greenroads Team if interested in participating in a case study. Resources, such as report templates and scorecards, are available by request.
- Follow the guidelines for active outreach (and related public interaction topics) outlined in the "Public Involvement Techniques for Transportation Decision-making" (FHWA-PD-96-031). This document contains a number of potential activities that could be used alone or in combination to meet the intent of this Project Requirement, as well as several additional useful references and resources.

Example: Kickinghorse Canyon Project — British Columbia Ministry of Transportation

The Kickinghorse Canyon Project on the Trans-Canada Highway (Highway 1) by the British Columbia Ministry of Transportation offers an excellent example of a comprehensive public educational outreach program.

This project has a detailed website (http://www.th.gov.bc.ca/kickinghorse/index.htm), a printable fact sheet (available http://www.th.gov.bc.ca/kickinghorse/updates/KHCP_Fact_Sheet.pdf), and has completed a case study (available by written request). Additionally, the completed project includes improvements to a rest area which will incorporate project and historical information for the site.

POTENTIAL ISSUES

1. Graffiti on installed signs or public information kiosks.
2. Potentially inflammatory or offensive comments or spam on project websites.

RESEARCH

At the heart of the Greenroads program is encouragement of broad sustainability education for people who use, design, and build transportation infrastructure. Public outreach programs are encouraged at most transportation agencies and often required on many projects as part of the initial planning process (such as during environmental review). However, most of these open-communication-oriented initiatives are relevant only during the decision-making process and are not deliberately educational over the long-term life of the project. Greenroads seeks to support roadway projects that offer built-in educational resources for the benefit of public interest and professional learning and development.

Need & Opportunity

The Brundtland Report notes "…the changes in attitudes, in social values, and in aspirations….will depend on vast campaigns of education, debate and public participation" (WCED, 1987, p. 16). Sustainability has certainly become a popular literature topic, but the volume of research on education is too vast to summarize here. Many authors on sustainability as well as other environmental organizations suggest or explicitly stress the importance of sustainability education (Edwards, 2005; Benyus, 2002; WCED, 1987; USGBC, 2009; Wilson, 2002; Daly, 2005; Robèrt, 1997, 2002; Kibert, 2005), but few offer actionable solutions or implementation. In most cases, current educational efforts occur internally within companies or agencies, or are directed toward children and young adults in elementary schools through college. Specific academic research on either the success or failure of implementing roadway-based public outreach programs for sustainability education is difficult to find (or, more likely, it simply does not exist yet).

Roadways present a unique opportunity to interact with their main stakeholder, the public, throughout the life of the project. Over 100 hours per person per year are spent commuting to work in the United States (Buckner & Gonzales, 2005). This exceeds the amount of personal vacation time for most traditional salaried positions, is twice as long as spring breaks for most schools, and is two to five times the amount of time that most states require for Continuing Education Units (CEU) for licensed professionals like engineers, doctors, and lawyers. Clearly, time spent on a roadway provides ample opportunity for Exposure to different sustainability topics, as well as time for reflection, repetition and reinforcement on a nearly daily basis for most commuters. However, when the project ownership changes into the public hands, often any learning opportunities pertaining to the project (such as how a new pavement technology was implemented, how energy use was reduced in the lighting, or what types of stormwater treatments were used) are lost.

In addition to institutional learning, professional and technical organizations also play a vital role in furthering knowledge of sustainability throughout their membership. Organizations like the Transportation Research Board (TRB), whose mission statement is oriented toward promoting information exchange and interdisciplinary research (TRB, 2009), and other government bodies promote continuing education of the transportation professional community. Conference presentations, technical papers, and presentations to local schools are all considered to be worthwhile efforts made to forward sustainability education through outreach.

Finally, rating systems like Greenroads offer unique opportunities for agencies and organizations to track and measure internal processes. Using a sustainability rating system is a simple way to measure progress and improvements over the long-term and stimulate innovation within an agency. Case studies can provide valuable snapshots of overall performance on the project and be used to develop agency-specific benchmarks for sustainability for future projects.

Precedence in Buildings

The LEED® Green Building Rating System awards one point in all of its rating system programs for instituting a project-oriented Educational Outreach program that meets the intent of the credit category called Innovation in Design, which rewards superior performance and creative implementation of ideas or technologies (USGBC, 2008). This credit awarded for the built environment establishes precedence for the need, validity and acceptance of such educational programs and public awareness programs. Transportation and infrastructure have a similar need for such precedence.

Further, though using a building as a model for cost of roadways is not ideal, the availability of an educational opportunity such as a roadside point-of-interest or signs lining the street may be perceived as a large value-added benefit for the public at a very minimal added cost to the design budget. A cost analysis of such educational programs, signage and/or displays incorporated in LEED-rated buildings (using a generic building model) showed only minor added costs for implementation to the project bottom line (Steven Winter Associates, 2004). Additionally, this study showed that most of these costs are “soft costs” that are typically administrative in nature.

The primary mode of establishing and communicating public values in transportation and infrastructure is consensus-based political mandate or other regulatory rulings. Also, a federal mandate was recently instituted for high performance and green buildings as Executive Order (EO) 13423: Strengthening Federal Environmental, Energy, and Transportation Management (2007). EO Section 3(c) makes federal agency leads accountable for establishment of internal agency programs for environmental training, including management, compliance and audit, and leadership recognition. This could be considered a premonition for mandated sustainability training and education in roadway system projects and for internal programs in transportation agencies and organizations.

Ongoing sustainability education programs can teach people to understand the consequences of their actions, such as the impact of personal resource use, and to relate their values and behaviors to current political and environmental conditions (Palmer, 1998). Roads are highly accessible to the public; thus, roads can offer a creative means of exposure to sustainability concepts which can help users make more informed decisions regarding sustainability in their daily lives, communities and cultures. Greenroads adds education as another step toward establishing a connection between people and the places that they live, travel, work and recreate.

GLOSSARY

EO	United States Executive Order
Kiosk	A small structure that can be used to access information, such as a newsstand or computer terminal
LEED	Leadership in Energy & Environmental Design, a rating system for green buildings by the United States Green Building Council
TRB	Transportation Research Board
USGBC	United States Green Building Council

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ENVIRONMENT & WATER

ENVIRONMENTAL MANAGEMENT SYSTEM

EW-1

2 POINTS

GOAL

Improve environmental stewardship by using a contractor that has a formal environmental management process.

CREDIT REQUIREMENTS

The prime contractor, design-builder or construction management firm shall have a documented environmental management system (EMS) for the entire company or at least the portion(s) of the company participating in the project. The EMS must be in place for the duration of project construction. As a minimum, the EMS and its documentation shall meet the requirements of International Standards Organization (ISO) 14001:2004.

Details

The prime contractor, design-builder or construction management firm is considered to have a documented EMS if it has:

- ISO 14001:2004 certification.
- An EMS that meets ISO 14001:2004 requirements but is not formally certified.

DOCUMENTATION

Submit one (1) of the following items:

1. Documentation of the ISO 14001:2004 certification for the prime contractor, design-builder or construction management firm.
2. A copy of the prime contractor, design-builder or construction management firm's EMS documentation to include:
   - Environmental policy
   - Environmental objectives and targets
   - Identified regulatory requirements and compliance with requirements
   - Defined roles and responsibilities
   - Employee training plan
   - Listing of documented processes
   - Preventive actions
   - Corrective actions
   - Emergency procedures

RELATED CREDITS

- ✓ PR-1 Environmental Review Process
- ✓ PR-10 Site Maintenance Plan
- ✓ CA-1 Quality Management System
- ✓ CA-2 Environmental Training

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Extent
- ✓ Expectations
- ✓ Experience
- ✓ Exposure

BENEFITS

- ✓ Reduces Water Use
- ✓ Reduces Fossil Fuel Use
- ✓ Reduces Raw Materials
- ✓ Reduces Air Emissions
- ✓ Reduces Greenhouse Gases
- ✓ Reduces Water Pollution
- ✓ Reduces Solid Waste
- ✓ Improves Human Health & Safety
- ✓ Improves Accountability
- ✓ Increases Awareness

APPROACHES & STRATEGIES

- Have a prime contractor with ISO 14001:2004.
- Have a prime contractor with a documented EMS that meets the requirements of ISO 14001:2004.

Example: Environmental Management System (EMS) Manuals

While it is not possible to present an entire EMS, there are many examples of key EMS documents available on the Web including the following EMS manuals:

- U.S. Environmental Protection Agency, Philadelphia Office: http://www.epa.gov/region03/ems/philly_manual.htm
- Robins Air Force Base: http://205.153.241.230/ems/basics/emsrobins.pdf
- The City of San Diego (contains PowerPoint presentations on key ISO 14001 facets): http://www.sandiego.gov/environmental-services/ems/emp_manual.shtml
- Mass Highway: http://www.mhd.state.ma.us/downloads/projdev/emsmanual.pdf
- North Carolina Department of Environment and Natural Resources (they have a generic guide EMS manual for use by those wishing to create one): http://www.p2pays.org/ref/08/07378/0737829.pdf
- The American Association of State Highway and Transportation Officials (AASHTO) maintains an EMS implementation guide website at: http://environment.transportation.org/documents/ems_implementation_guide.asp.

POTENTIAL ISSUES

1. Smaller firms may not be able to afford the ISO certification process.
2. Documentation of an EMS is not the same has having an effective EMS; however collection of documentation (in lieu of an actual audit) is an efficient way of gathering evidence of an effective EMS.

RESEARCH

According to ISO (2009) an EMS is a management tool that "…provides a framework for a holistic, strategic approach to the organization's environmental policy, plans and actions." One of the more comprehensive descriptions of such a system comes from ISO in their 14000 family of standards.

ISO 14000

The ISO 14000 family of documents addresses various aspects of environmental management. ISO 14001 and ISO 14004 specifically address EMS requirements and guidelines respectively. Essentially, it is a formal description of an EMS and all that is involved in its creation, implementation and use. The ISO is a standard publishing body similar to ASTM International or the American Association of State Highway and Transportation Officials (AASHTO).

Certification: ISO 14001

The requirements for certification are contained in ISO 14001. Therefore, organizations are certified in accordance with ISO 14001; the number is appended with the year of the standard that applied when the organization was certified. The most current version is ISO 14001:2004.

ISO does not certify organizations itself. Most countries have formed formal groups or "certification bodies," which audit organizations applying for ISO 14001 certification. Through mutual agreements these bodies ensure that certification audit standards are relatively the same worldwide. Certification, once granted, must be renewed at standard intervals, often three years.

ISO does not require certification and many organizations just choose to follow ISO 14000 requirements but forego certification. However, it is common practice in many parts of the world (e.g., Western Europe, China, India, etc.) to require ISO certification as a prerequisite for doing business. Therefore, countries that require this usually see the highest certification rates.

Arguments for Certification
Arguments for certification typically cite the general idea that proper and active management of a company's impact on the environment can result in better regulatory compliance, better business opportunities, less impact on the environment and improved safety. Typically these items are measured by counting regulatory violations, market share, sales growth, reduced injuries and other metrics.

Arguments against Certification
Opponents of certification argue that the actual act of certification and existence of documentation do not, in and of themselves, guarantee improved environmental impacts. Further, they point out that ISO 14001 certification can be an expensive and burdensome process that does not necessarily produce results.

Certification Cost
According to Christini et al. (2004), it cost one major U.S. construction firm about $1 million to achieve certification. Most research (e.g., Zeng et al. 2003; Ofori et al.; 2000) tends to investigate reasons for ISO 14000 adoption and not the actual cost.

Worldwide ISO 14001 Certification
Data from 2006 show worldwide ISO 14001 certifications at 129,199 in 140 different countries and growing (Figure EW-1.1). In December 2006 the U.S. had 5,585 certifications, which ranked seventh worldwide (Figure EW-1.2). ISO 14001 certification is far more common in Europe and Eastern Asia with 44% and 41% of worldwide certifications respectively. North America (consisting of only the U.S., Canada and Mexico) comprised almost 6% of the worldwide total.

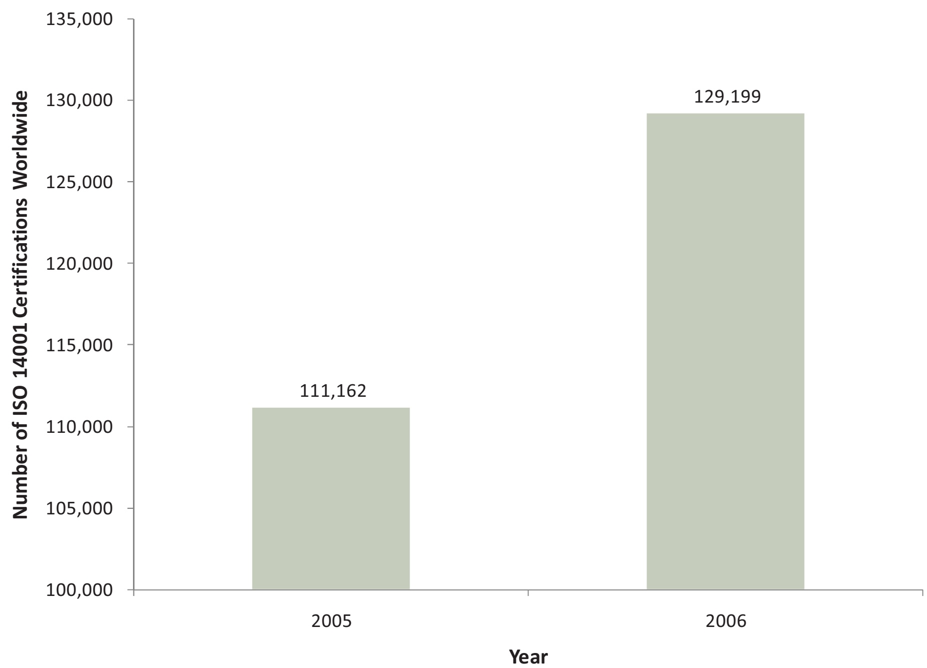

Figure EW-1.1: ISO 14001 certification worldwide growth 2005-2006 (data from ISO 2006).

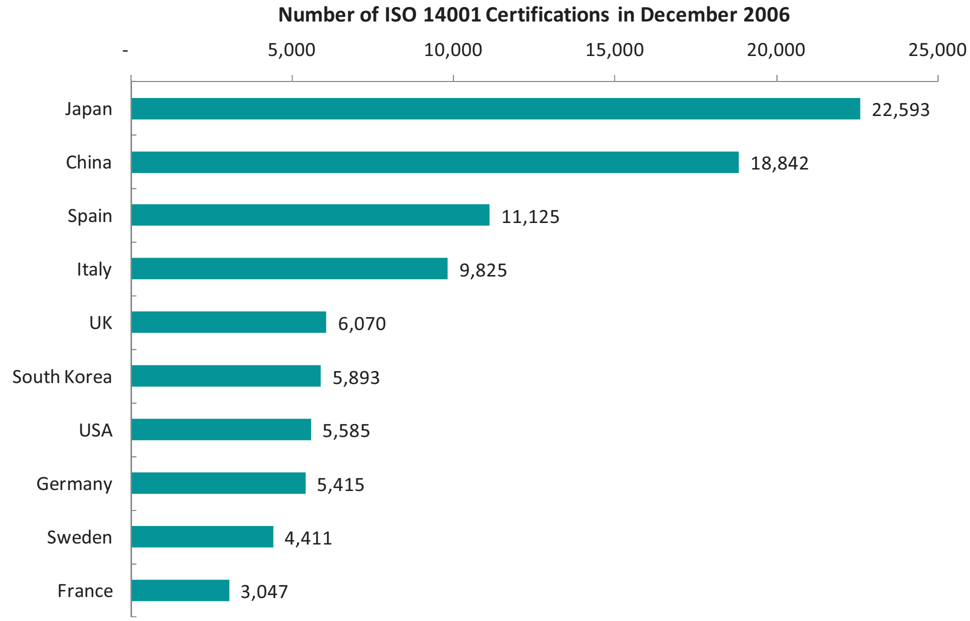

Figure EW-1.2: Top 10 countries in terms of number of ISO 14001 certifications in 2006 (data from ISO 2006).

ISO 14001 Certification in the U.S. Construction Industry

ISO 14000 enjoys growing worldwide popularity, however relatively few U.S. construction firms are certified (Christini et al. 2004). Reasons for the low popularity in the U.S. are somewhat non-specific but perhaps can be attributed to a lack of any government requirement, no insistence by clients, implementation costs, and a subcontracting system that makes it difficult to use an EMS on a particular job (Tse 2001).

Evidence to support the positive outcomes of ISO 14001 certification generally comes from surveys or case studies of contractors that are largely already ISO certified (e.g., Christini et al. 2004; Valdez and Chini 2002; Ofori et al. 2000) or segregate the certified firms and then ask them what the benefits were they were seeking in certification (Zeng et al. 2003). It is not surprising that results indicate a general benefit to ISO 14001 certification. Even so, there is evidence to suggest that ISO 14000 can reduce landfilled waste and produce financial savings (Christini et al. 2004).

GLOSSARY

ISO	International Standards Organization
EMS	environmental management system

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RUNOFF FLOW CONTROL

EW-2

1-3 POINTS

GOAL

Mimic predevelopment hydrological conditions in the right of way (ROW) and minimize offsite stormwater controls.

CREDIT REQUIREMENTS

1. Develop a stormwater management plan for the site using stormwater best management practices (BMPs) for flow control. Explicitly state the goals of this plan and how performance will be measured.
2. Use low-impact development (LID) BMPs to the maximum extent feasible as determined in Project Requirement PR-8 by a licensed professional.
3. Compute the 90th percentile average annual rainfall event values for the following predevelopment and post-construction conditions:
   - V_{preROW} = inside ROW predevelopment volume of runoff
   - $V_{pre\text{-}out}$ = outside ROW predevelopment volume of run-on
   - $V_{total\text{-}pre} = V_{preROW} + V_{pre\text{-}out}$ = total predevelopment volume
   - Q_{pre} = predevelopment flow rate measured at water body receiving effluent from the site, based on $V_{total\text{-}pre}$
   - $V_{postROW}$ = inside ROW post-construction volume of runoff
   - $V_{post\text{-}out}$ = outside ROW post-construction volume of run-on
   - $V_{total\text{-}post} = V_{postROW} + V_{post\text{-}out}$ = total post-construction volume
   - Q_{post} = post-construction flow rate measured at the same location as Q_{pre}, based on $V_{total\text{-}post}$
4. Provide BMPs for stormwater flow control. List the types, manufacturers, total volumes and flow rates controlled by BMPs within the ROW or outside of the ROW.
5. Demonstrate that the planned BMPs meet the following flow control criteria:
   - BMPs **conform to all applicable minimum flow control standards** for all effluent leaving the ROW set by the governing jurisdiction for volume, flow control and time of concentration. State the minimum requirements, including critical erosive flow criteria, and provide referenced document or policy.
   - R_V = Ratio of Volume Achieved = $V_{total\text{-}post}/V_{total\text{-}pre} \leq 1.20$
   - R_F = Ratio of Flow Rate Achieved = $Q_{post}/Q_{pre} \leq 1.20$
   - Points are awarded per Table EW-2.1 based on type of alignment, location of BMPs and level of control achieved. Use R_V and R_F, whichever is higher, to determine if points have been earned.

Table EW-2.1: Points for Flow Control Achievement

Type of Alignment	Location of BMPs	$V_{total\text{-}post}$ Includes Run-on?	Higher of R_V or R_F: 1.20 – 1.10	1.10 – 1.00	≤1.00
New	Within ROW	No	0	0	2
		Yes	0	0	3
	Out of ROW	No	0	0	1
		Yes	0	0	2
Existing	Within ROW	No	0	1	2
		Yes	1	2	3
	Out of ROW	No	0	0	1
		Yes	0	1	2

RELATED CREDITS

- ✓ PR-8 Low Impact Development
- ✓ PR-10 Site Maintenance Plan
- ✓ EW-3 Runoff Quality
- ✓ EW-4 Stormwater Cost Analysis

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Extent

BENEFITS

- ✓ Reduces Water Pollution
- ✓ Reduces Solid Waste
- ✓ Reduces Manmade Footprint

Details

Stormwater flows are measured by flow rate, time of concentration, and volume. “Predevelopment conditions” are the estimated values of these three variables that existed in the ROW at a prior time relative to regional historic, natural or undeveloped conditions as defined by the governing local watershed authority. If no local authority or no existing definition, use the definition for green-, gray- and brownfields provided in the 2009 Sustainable Sites Initiative (SSI) Credit 3.5 “Manage stormwater on site.” While continuous stormwater simulation models are most appropriate for this credit, the modified curve numbers provided in SSI Credit 3.5 may be used to simplify calculations. “Post-construction” means the expected performance of the designed BMPs in the stormwater management plan.

DOCUMENTATION

A copy of the executive summary of the project drainage design report that includes, at minimum, the following:

- Short narrative that addresses each of the credit requirements.

As needed, supporting calculations for runoff areas, runoff volume (output from any rainfall modeling software used is adequate), and treatment levels may be requested.

APPROACHES & STRATEGIES

- The Sustainable Sites Initiative (2009) modified curve number (CN) approach is acceptable and may be used to achieve this credit. New alignments and rehabilitation (or widening) of rural roads will fall under “greenfield" CNs while almost all other projects will use “grayfield” CNs. (See additional notes in the “Potential Issues” section.) The guidelines for Sustainable Sites are available here: http://www.sustainablesites.org/report/
- Preserve native vegetation.
- Protect soils with good infiltration capacity.
- Minimize compaction of soils to preserve natural infiltration capacity.
- Distribute stormwater controls throughout the project area instead of using a few relatively large centralized facilities.
- Assess the feasibility of infiltration and evapotranspiration to reduce the need for detention ponds outside the right of way.
- Reduce land area impacts by avoiding the use of traditional detention ponds.

Example: Northshore Drive, Bellingham, WA - Case Study

The Northshore Drive project is located in the Silver Beach area of the City of Bellingham, Washington on the north shore of Lake Whatcom. The project includes all of Northshore Drive from the Dakin Street intersection to the Britton Road intersection. The design was loosely based on a recent project by the City of Olympia called RW Johnson Boulevard that used porous bike lanes and sidewalks along a traditional roadway. Northshore Drive received an asphalt overlay after surface grinding the existing roadway and making minor alignment modifications. Lane widths were reduced to 11 feet to accommodate new bike lanes and sidewalks. A new stormwater drainage system was also installed.

1. Calculate Pervious and Impervious Area

Alabama Ave to Silver Beach Store
Total segment length = 2450 ft
Total width of cross section = 37.5 ft

Existing:	29 ft impervious hot mix asphalt (HMA)	Area 1= 29 ft x 2,450 ft = 71,050 sf
	8.5 ft of pervious grass/gravel	Area 2 = 8.5 ft x 2,450 ft = 20,825 sf

Proposed:	22.5 ft impervious HMA, intersections, aprons, curb	Area 3 = 22.5 ft x 2,450 ft = 55,125 sf
	15 ft pervious HMA	Area 4 = 15 ft x 2,450 ft = 36,750 sf

Total new and replaced impervious surface for segment = Area 3 = 55,125 sf
Decrease in impervious surface for segment = Area 1 – Area 3 = 15,925 sf

Silver Beach Store to Britton Road

Total segment length = 1,550 ft
Total width of cross section = 29 ft (excludes existing gutter pan)

Existing:	27 ft impervious HMA	Area 5 = 29 ft x 1,550 ft = 41,850 sf
	2 ft of pervious grass/gravel	Area 6 = 2 ft x 1,550 ft = 3,100 sf
Proposed:	29 ft impervious HMA	Area 7 = 29 ft x 1,550 ft = 44,950 sf

Total new and replaced impervious surface for segment = Area 7 = 44,950 sf
Increase in impervious surface for segment = Area 7 – Area 5 = Area 6 = 3,100 sf

Project Totals

Total Existing Impervious Surface = Area 1 + Area 5 = 112,900 sf
Total New and Replaced Impervious Surface = Area 3 + Area 7 = 100,075 sf
✓ Net Change in Impervious Surface = 112,900 sf – 100,075 sf =12,825 sf (Decrease)

Total Existing Pervious Surface = 23,925 sf
Total New Pervious Surface = 36,750 sf
✓ Net Change in Pervious Surface = 36,750 sf – 23,925 sf = 12,825 sf (Increase)

2. Minimum Requirements from 2008 WSDOT Highway Runoff Manual (HRM)

Figures 3.1, 3.2, and 3.3 of the HRM are used to determine the minimum requirements applicable for a project.* Section 3-2.2 of the HRM lists possible exceptions for this project.** No special exceptions apply but the project discharges directly into an exempt water body (Lake Whatcom) which does not have flow control requirements. However, WSDOT requires that regardless of an exemption, on-site BMPs need to be used to infiltrate as much runoff as reasonably possible.

3. Determine Flow Control Values

Time of concentration, flowrates and runoff volumes were not required to be computed for exempt projects for flow control, nor were they computed for quality treatment purposes because a net decrease in impervious surface occurred.

4. Apply Stormwater Best Management Practices

This project used permeable pavements with underdrains for bikelanes and sidewalks. Infiltration rates are shown in Table EW-2.2 from the project geotechnical report.

Table EW-2.2: Estimated long-term design infiltration rates (Northshore Geotechnical report)

Sample Depth	USDA Textural Classification	Infiltration Rate (in/hr)***
T.P.1@ 2.0’ - 3.0’	Loam	0.13
T.P.4@ 1.5’ - 2.5’	Sandy Loam	0.25

5. Determine Flow Control Achieved

Since total impervious surface on the project was reduced from existing surface areas and BMPs, greater than

100% of predevelopment flow control rates and volumes were achieved. The project earns **3 points**.

Notes:

*These figures make up a decision tree used to guide the engineer in the applicable minimum requirements when designing a stormwater management facility based on known surface areas, relative perviousness, and pollution generating capacity.

** Generally, if the amount of impervious surfaces is greater than a specified minimum value, certain requirements must be applied to that impervious surface. These values are called "minimum requirements."

*** Includes the recommended correction factors presented in the SWMM.

Figure 1: Northshore Drive in Bellingham, Washington. Cyclists using permeable pavement bikelanes adjacent to permeable sidewalk. Photo by C.Weiland

Example: Bioswale with Flow Control Weirs

Figure EW-2.2 shows a set of streetside flow control weirs in a bioswale BMP. This swale provides flow control benefits of increased infiltration, increased retention, and flow attenuation.

Figure EW-2.2: A bioswale with flow control weirs. (Photo by J. Anderson)

Example: Continuous Modeling Scenarios

The effect of low impact development (LID) stormwater controls toward restoring the original hydrology can be illustrated analyzing the erosive potential of flows under various scenarios. Stream erosion is caused by excessive shear stress applied by the flow on the stream banks and bed. For this example, a suite of LID methods were modeled as part of an alternatives study for roadway realignment and associated stormwater management options for the Interstate 70 expansion project.

Figure EW-2.3 on the following page shows the average distribution of shear stress in a stream near Columbia, Missouri. Ideally, the distribution after development should remain close to the pre-development curve. The graphic shows several key things:

- Detention basins designed to control extreme events (e.g., those with return periods of 2 to 100 years) do little to restore the shear stress distribution when compared with the post-developed scenario.
- Basins designed to control water quality and protect channels (i.e., designed for the 1-year storm) do lower the shear stress but notably change the distribution over time.
- In this specific case, LID controls, although still not exactly replicating the pre-development condition, afford the closest match.

Figure EW-2.3 was created with CH2M HILL's LIFE™ continuous modeling software for LID runoff controls.

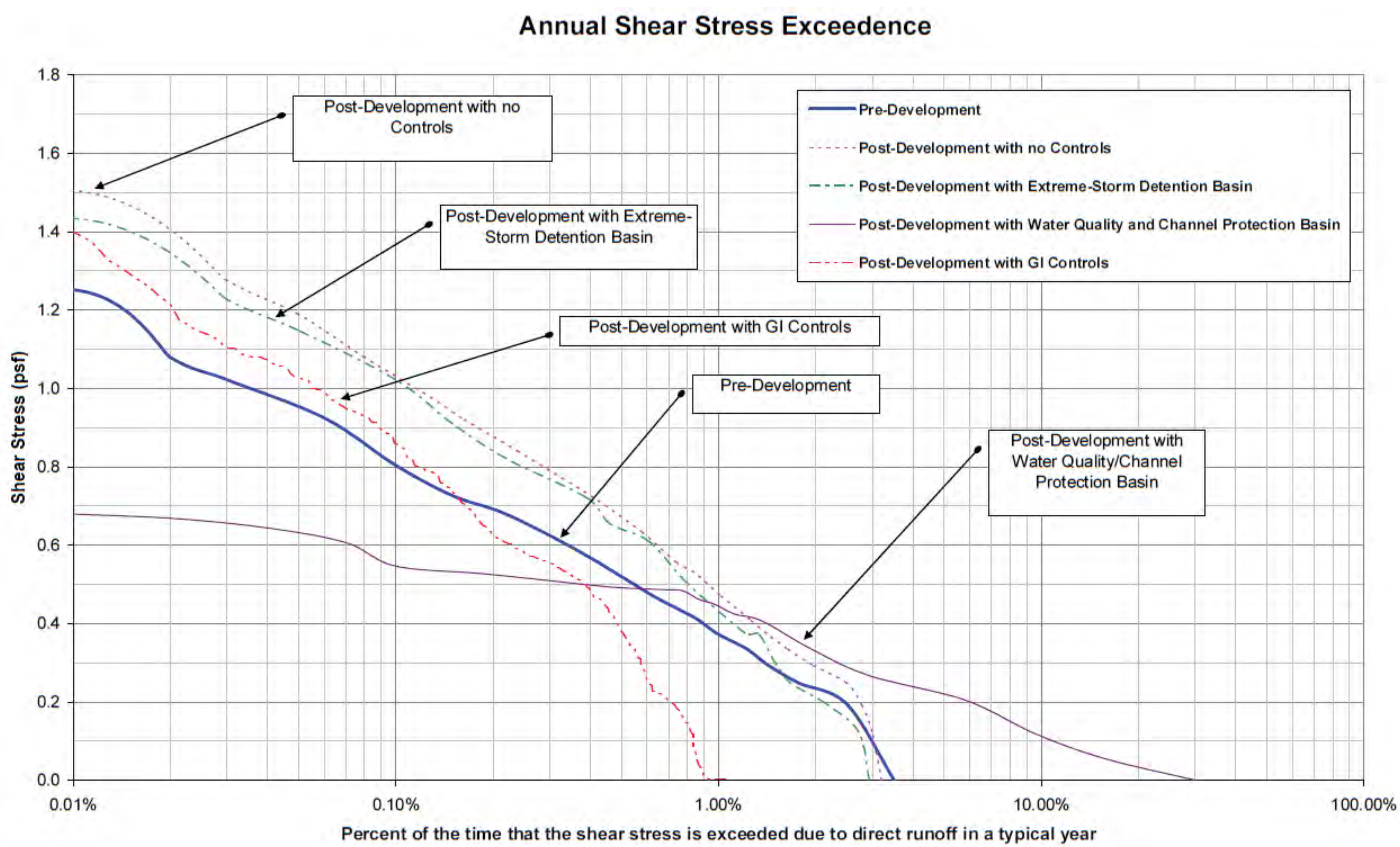

Figure EW-2.2: Average annual distribution of shear stress in a test stream near Columbia, Missouri. LID strategies (here "GI Controls") were implemented to better mimic predevelopment hydrology at the site. (Image courtesy CH2M HILL)

POTENTIAL ISSUES

1. There are numerous methods to calculate runoff volume. Many are applicable to storms of large magnitude and underestimate the runoff generated by small storms, which occur more frequently and represent most of the annual runoff volume. Average annual runoff volumes have been specified for use in all of the stormwater related credits in Greenroads to provide consistency between credits.
2. The LID evaluation process that is required to meet Project Requirement PR-8 does not require an average annual runoff model. In fact, it recommends the use of design storms to model peak flow. This practice is now outdated and the preferred approach to runoff quantity management is through flow control methods. (City of Seattle, 2009)
3. Continuous modeling can be time intensive and costly and this can vary greatly between projects and by size of project. The 2009 Sustainable Sites Initiative (SSI) provides an alternative model that can be used to meet the intent of this credit. It is based on the old TR-55 software model from the National Resource Conservation Service (NRCS) in combination with a continuous modeling program based on the Stormwater Management Model (SWMM) software by the EPA. The 2009 SSI credit provides charts and target curve numbers for achieving certain points in that rating system. (In general, probably a good rule of thumb is that points for the SSI credit are worth 5, 7, and 10 points which probably correspond to 1, 2, and 3 points in Greenroads, respectively. However, Greenroads also requires supporting calculations to show that flow control performance guidelines have been met according to this credit and to date no projects have attempted this credit or the SSI approach.)
4. Any models that are used inherently have some limitations and assumptions. Some are better than others depending on project location. This credit defaults to the integrity of the designer to choose the appropriate modeling software.

RESEARCH

Altering the imperviousness of the land to make way for roads can have major impacts on the physical and chemical integrity of a watershed (Southerland, 1994; Forman and Alexander, 1998; Environmental Protection Agency: EPA, 2007). This Greenroads credit primarily addresses changes to physical integrity of watersheds based on physical quantities of runoff generated by a roadway; however, many of the topics are inherently tied to water quality issues because all best management practices that address flow control also address water quality (Quigley et al., 2009). Credit EW-3 Runoff Quality addresses chemical runoff characteristics (water quality) while an often ignored component of watershed health, biological integrity, is addressed by Credit EW-6 Habitat Restoration.

Physical Impacts from Stormwater Runoff

The general relationship between volume of water and velocity of flows on streambeds seems intuitive —more water and faster flows means more erosion and thus higher sediment loads — however, the relationship between volume, pollutant (sediment) transport, and aquatic biological integrity is actually quite complex. Much of this complexity stems from the scale of the problem. To illustrate this issue, in 2007, there were actually more miles of roadway in the United States (almost 4.1 million) than there were documented river *and* coastal *and* lake shoreline miles (about 3.6 million) (Federal Highway Administration: FHWA, 2008; EPA, 2010). The EPA notes (2007):

> *"The effect that a road network has on stream networks largely depends on the extent to which the networks are interconnected. Road networks can be hydrologically connected to stream networks where road surface runoff is delivered directly to stream channels (at stream crossings or via ditches or gullies that direct flow off the road into a stream) and where road cuts transform subsurface flow into surface flow (in road ditches or on road surfaces that deliver sediment and water to streams much more quickly than without a road present). The combined effects of these drainage network connections are increased sedimentation and peak flows that are higher and arrive more quickly after storms. This can lead to increased instream erosion and stream channel changes, especially in small watersheds."*

Figure EW-2.3 below shows how interconnected both of these systems actually are in the United States. Note that the scale of this image only allows a level of detail that shows major Interstates and major watershed streams; local or arterial roads and smaller watersheds are not shown: these smaller watersheds are most sensitive to nearby roadway project impacts.

Figure EW-2.3: United States streams (blue) and the Interstate highway system (light red). (Enviromapper, n.d.)

Figure EW-2.3 suggests that a significant amount of hydromodification is attributable to roadways. Hydromodification is a term used by the EPA to mean “alteration of the hydrologic characteristics of coastal and non-coastal waters, which in turn could cause degradation of water resources.” (EPA, 2007) Hydromodification encompasses river engineering activities for improving river channels (i.e. dredging) and also building dams. It also includes forestry practices, recreation and industrial use, construction sites and other point source activities, and a plethora of urban runoff issues including stream restoration practices (EPA, 2010). Roads are innately tied to each of these activities.

The primary concerns with hydromodification are:

- Pollutant generation and transport
- Habitat degradation and loss of habitat
- Species loss
- Streambank slope stability
- Erosion of channels or changes in flow path of streams
- Flooding

A majority of the literature regarding stormwater management and roads and bridges addresses the issues of water pollution (water quality) and controlling pollutant transport. Importantly, sediment is considered to be one of the primary pollutants for water bodies that threaten aquatic habitats and species (EPA, 2008). Together, these issues can broadly be termed “watershed health." (Pollutants and impacts associated with pollution are discussed further in Credit EW-3. It is important to note that an effective flow control measure also has the co-benefit of reducing pollutant loads due to the hierarchical nature of physical processes. Additionally, note that some best management practices applied for flow control offer more effective mitigation of pollutants than others.) Watershed health is directly related to nearby effective impervious surface. (EPA, 2008; Tilley and Slonecker, 2007; City of Seattle, 2009; EPA, 2010) It follows that watershed health is directly related to management of stormwater runoff quantities generated by those impervious surfaces.

Bank stability, erosion and flooding, however, are primarily flow control concerns associated with physical impacts of runoff, not quality. These are often considered "drainage issues" and have historically been the primary application of stormwater management governed by EPA permits up until 1987, when runoff quality came to be addressed as well. (Pitt and Maestre, 2005) These physical attributes of runoff can impact sensitive watershed habitats and aquatic life in both urban and rural environments (Southerland, 1994; City of Seattle, 2009). For example, "When a stream changes its physical configuration and substrate due to increased flows, habitats are altered….The biological communities in wetlands are also severely impacted and altered by the hydrological changes. Relatively small changes in the natural water elevation fluctuations can cause dramatic shifts in vegetative and animal species composition" (City of Seattle, 2009). Furthermore, in 2007, approximately 73% of the roads in the United States were designated as "rural" by the FHWA (2008); 43% of rural roads are unpaved. The EPA (2007) states:

> *"Roads built in rural areas, such as forest and recreational roads, alter the natural landscape and can destroy riparian habitat. If not properly installed and maintained, these types of roads erode and supply increased sediment and pollutants to adjacent streams. Additionally, roads may increase imperviousness, which leads to flashier runoff events. Stream crossings associated with rural roads can block fish passage, trap debris during storms, and lead to increased streambank erosion in nearby areas."*

In urban environments, the problem is sometimes worse. More water and faster flows in this case mean that an aging infrastructure system in an already degraded watershed can easily become overloaded with increasing development in surrounding areas. Much of the stormwater infrastructure in cities is built in tandem with roads in the public right-of-way. This means that (1) many stormwater infrastructure projects also become roadway projects, and more importantly for Greenroads, (2) flow control clearly presents both a challenge and a stormwater management opportunity to roadway projects.

Hydromodification and Roads: The Smoking Gun

The EPA's definition of hydromodification is quite broad—while it is impossible to isolate hydromodification impacts with roadways alone for a number of reasons, it is also difficult to argue that they do not cause hydromodification. Which is correct seems to be a matter of philosophical debate (FHWA, 1990; EPA, 2008). Water courses are dynamic by nature and respond to stressors, changing paths and eroding "naturally." (Wilcock, Pitlick and Cui, 2009) The behavior of rivers and streams is ultimately governed by principles of geomorphology and hydraulics, not by humans. It appears that the core issue is one of values and how one defines something as "natural." For example, it is true that more water and faster flows are generated from higher levels of impervious surfaces (Maestre and Pitt, 2005), which can prevent or impede "natural" groundwater recharge and have a number of thus "unnatural" effects on streamflows in localized areas of watersheds (EPA, 2007; EPA, 2008). It is also true however, that even stream restoration activities are accounted for in the list of hydromodification impacts associated with degradation of watersheds (EPA, 2008). So, stream preservation via manmade controls intended to repair a stream to what is considered "natural" may actually have unintended consequences of further degradation. There is little evidence to show that the stream would not have acted that way on its own, but the converse is also true.

The stressors of concern, then, are really human activities themselves. In particular, the stress is caused by urbanization or development (two more very broad terms). The interaction between human activities and the hydrologic cycle is also complex. It is important to note that many important relationships are not well enough understood to be able to quantify the total accountability for roads and bridges for hydromodification beyond indirect association. Many uncertainties and variability arise, for example, due to lack of understanding of:

- The amount of streambank erodability (Morrissey, Rizzo, Ross, and Young, 2009) that occurs due to upstream changes
- The level of change between surface and base flows associated with different hydraulic controls (i.e. storm Sewers, catch basins and ponds) (Tilley and Slonecker, 2007)

- Amounts of sediment and sediment transport capacity of different types of river and stream flows (Wilcock, Pitlick and Cui, 2009)
- Inconsistencies and variability in monitoring and assessment of watersheds (Strecker, Mayo, Quigley, and Howell, 2001)
- The biological integrity of receiving watersheds (City of Seattle, 2009)

Urbanization, Hydromodification and Roads

Development, including roads, changes the hydrologic profile of a site or area usually by increasing the total impervious surface area. This correlation was confirmed in a recent study by Maestre and Pitt (2005) and a graph is shown in Figure EW-2.4 that illustrates the clear relationship between volumetric runoff coefficients and percent imperviousness of a surface.

The United States is 5% developed with ranges of impervious between 20-80% in some areas. (EPA, 2008) Though previously estimated at much higher percentages, roads and sidewalks make up about 33% of the total impervious surface in average urban and suburban areas (Tilley and Slonecker, 2007). In rural environments, up to 100% of the total impervious surface area can be attributed to roads and highways depending on the scale of the watershed being studied.

Therefore, hydromodification (bank stability, erosion, flooding, and related water quality issues) can be directly attributed to increases in runoff discharges from impervious surfaces due to urbanization. Gregory and Chin (2002) composed a brief list that provides a good summary of how quantities of stormwater discharge are related to urbanization and a variety of hydromodification hazards. Awareness of these effects can assist in development of appropriate stormwater management plans. These are shown in Figure EW-2.5.

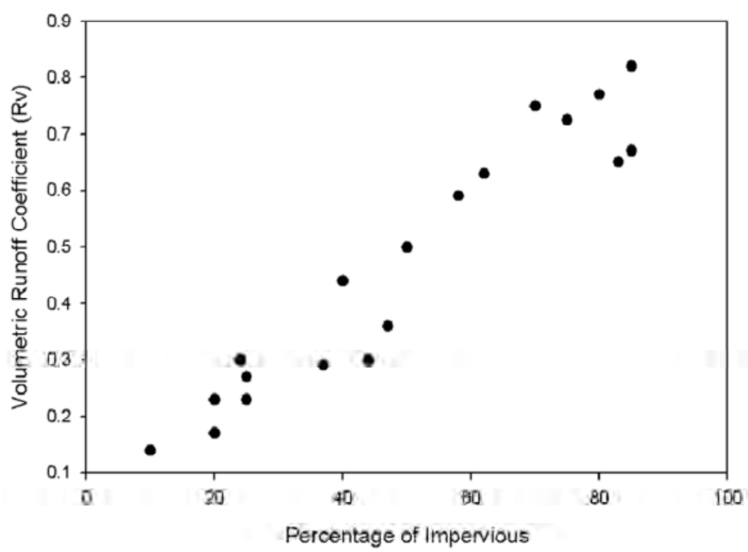

Figure EW-2.4: Discharge quantities are directly proportional to impervious surfaces. (Maestre & Pitt, 2005)

Urbanization: channel effects and responses	Urban channel hazards
URBANIZATION EFFECTS: Discharge increase: Peak flows increase, peak flows more frequent, overbank flows more frequent Sediment yield increase during building construction Sediment yield decrease with subsequent increase in impervious areas Water quality change due to pollution CHANNEL RESPONSE: Channel enlargement: widening, deepening, bank erosion, gullying Headcut/knickpoint recession upstream Channel pattern adjustment single thread to multithread Siltation may result from high sediment loads Decrease in channel capacity, narrowing, shallowing Riparian vegetation increase, decrease MANAGEMENT RESPONSE: Clearing channels snagging Vegetation clearance: remove exotic species, total clearance Resectioned channels to accommodate greater discharges Bank protection to control erosion Channelization Detention basins and ponds Culverts for streams Infilling and grading sections and crossings	*Channel system* Compartmented by road and rail network *Flood frequency* Increase *Drainage* Temporary floods *Bank erosion* *Scour:* Along channels Downstream from crossings Below culverts Behind revetment At bridge piers *Aggradation:* Along channel Above crossings Buried structures Contracted bridge openings Urban debris accumulation *Blockage:* Due to culvert size or slope or bridge opening *Aquatic communities change:* Reduced species Diversity Productivity reduced *Vegetation:* Fire hazard increase Invasion of exotic species *Quarrying of channel sediments:* Gravel Sand *Dredging*

Figure EW-2.5: Urban channel hazards related to urbanizations. (Gregory & Chin, 2002)

Design Alternatives for Roadway Flow Control

Hydrologic conditions at each roadway site are highly variable, even within the same site. Granato, Zenone, and Cazenas (2003) note "Stormwater flows respond differently to different types of storms and may respond differently to the same type of storm in different seasons of the year." Just like the interconnectedness of roadways and watersheds, stormwater flow control design can be complex and easily lends itself to oversimplification. This is perhaps exemplified with the fluctuations for flow control standards in the past thirty years (City of Seattle, 2009). A variety of approaches have been used, including peak-flow designs that limited flow rates to control erosive flows, setting certain percentages of those rates to those supposed to be more representative of predevelopment peaks, and finally flow duration standards. This shift in practice represented a shift from event-based methods at a microscale level to continuous simulation modeling at a watershed scale.

Typically, allowable regulatory levels for certain flows and certain types of roadway projects are set and "flow control" really means a predetermined suite or range of allowable flow volumes, rates and times to concentration that are considered to pose an acceptable risk of erosion receiving waters. (City of Seattle, 2009) These threshold levels are primarily determined "based on the amount of new and replaced impervious surfaces,…which can also be dependent on the type of project, size of project, and the drainage basin in which the project is located." (City of Seattle, 2009) There is a mounting body of evidence however to suggest that single-event design approaches are insufficient to maintain streambank and channel integrity and structure. (City of Seattle, 2009; Bledsoe, 2002; Huber et al. 2006). Bledsoe (2002) notes:

> *To fully address the potential for channel response, it is necessary to expand standard design approaches to address the temporal distribution of erosive forces relative to both bed materials and bank conditions. Single-event techniques for maintaining the cumulative bedload transport volume, unless modified to account for differential transport by size fractions across a broader range of flow events, may alter predevelopment fluvial processes and affect channel morphology and the quality of instream habitat. Given the sensitivity of fine-grained streams to inflowing bed material load, reproducing the predevelopment hydrograph will not necessarily ensure stability if there is a sufficient long-term reduction in sediment delivery. Thus, stormwater management strategies should be carefully weighed in terms of their long-term geomorphic implications in addition to flood control and pollutant removal functions.*

Event-based methods often result in overly-conservative drainage designs (Huber et al. 2006) and in general do not meet stream channel protection objectives (Booth, 1991; Booth and Jackson, 2007). Huber et al. (2006) notes that though most of the hyetographs (graphs of rainfall distributions over time) from event-based designs can be applied to monitored rainfall data, they are generally not; and they are also sensitive to initial conditions and assumptions as well as storage capacity and infiltration capabilities of the site. These imperfect traits and limitations then get adopted into water quality designs, which are consequently also overly conservative, or worse, ineffective. Despite the disadvantages to each of these approaches and the research to justify that synthetic storm event-based methods are inefficient to model actual rainfall events (City of Seattle, 2009; Huber et al; 2006), “these methods are embedded in several versions of commercial software and are routinely accepted by the hydrologic engineering profession in spite of the issues just mentioned.” (Huber et al. 2006). FHWA and the American Association of State Highway and Transportation Officials (AASHTO) and most state departments of transportation still recommend use of the traditional design storms for hydrologic and hydraulic design of roadways, presumably due to the single-event, catastrophic nature of flood events. (FHWA, 2009; AASHTO, 2005) Some regulatory agencies now require 2, 10 and 100 years instead of one or other (FHWA, 2009; WSDOT, 2008).

Currently, low impact development (LID) methods have become the preferred standard of practice for the built environment and for site development (City of Seattle, 2009). The most appropriate way to emulate the performance of LID methods is through continuous modeling (City of Seattle, 2009; Huber et al., 2006). Continuous hydrological modeling has its own disadvantages, primarily in time intensiveness (and thus cost) and unavailability of data (Huber et al., 2006; City of Seattle, 2009). In general, these LID methods are being pushed mostly in urban areas to help manage the increasing imperviousness and the associated water quality issues in cities as populations in these communities grow to relieve stress on existing infrastructure and attempt to achieve “natural” conditions as a baseline for performance. However, due to the high concern of flooding impacts on roadways, it may be most appropriate to use a combined approach, which may require a combination of both LID and conventional methods in order to meet flood control demands and also maintain water quality standards. (Washington Department of Transportation: WSDOT, 2008)

Low impact Development for Flow Control

A brief introduction to LID techniques was provided in Project Requirement PR-8. The relevant concepts for LID methods in flow control (all offer quality benefits unless otherwise noted) are briefly described below. (City of Seattle, 2009) Most LID techniques incorporate more than one.

- **Infiltration.** Runoff is percolated into receiving soils. The infiltration capacity is closely related to the hydraulic conductivity and capacity of the soils. Evaporation is often also present as well as transpiration as these facilities are often vegetated.
- **Evaporation.** Runoff is vaporized and absorbed into the air.
- **Transpiration.** Runoff is absorbed by plants and then released as vapor.
- **Dispersion.** Runoff area is increased to delay the flow.
- **Interception.** Rainfall is trapped by the leaves of plants.
- **Storage and release (retention and detention).** Runoff is collected temporarily and released via a controlled outflow. (True retention facilities rely on infiltration and evaporation and no outflow.)

- **Storage and reuse.** Runoff is collected and stored for stored for other uses (commonly "harvesting rainwater"). Often storage facilities are vaults beneath roadways and their flow control utility is based on their total volume and opening sizes.

The Prince George's County LID Manual (1999) presents a more detailed description of the LID methods: the reader is referred to the Manual for more detailed information. A summary of the flow control attributes of some common LID techniques is shown in Figure EW-2.6. (For most roadway facilities, storage will be underground.)

	Low-Impact Development Technique															
Low-Impact Hydrologic Design and Analysis Components	Flatten slope	Increase flow path	Increase sheet flow	Increase roughness	Minimize disturbance	Flatten slopes on swales	Infiltration swales	Vegetative filter strips	Constricted Pipes	Disconnected impervious areas	Reduce curb and gutter	Rain barrels	Rooftop storage	Bioretention	Revegetation	Vegetation preservation
Lower Postdevelopment CN					✓		✓	✓		✓	✓			✓	✓	✓
Increase Tc	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
Retention							✓	✓				✓	✓	✓	✓	✓
Detention						✓			✓			✓	✓			

Figure EW-2.6 The suite of flow control attributes for LID methods. (Prince George's County, 1999)

Flow Control by Avoidance

The EPA (2007) suggests that the geometric design of a road can do much to aid in flow control, however the primary objective of their "non-eroding roadway" design concept is to stabilize and orient the roadbed to minimize production of sediment due to erosion of slopes, base materials and surface courses and avoid uncontrolled drainage of pollutants into sensitive areas. Further design considerations include not sloping the roadway toward wetland areas (unless the wetlands are part of the treatment scheme) or planning alignments to fall as far as possible away from existing water courses. Nevertheless, the shape and surface course material design is clearly tied to the amount of runoff generated by the roadway. The design approach is especially critical for unpaved roads where erosion and sedimentation of the road itself is an important issue. (EPA, 2007)

Flow Control by Soil Amendment

"Soil amendment" is a process that describes adding organic content such as compost or mulch to native and fill soils. The organic content aids in flow control by providing additional storage through absorption, higher infiltration and evapotranspiration from increased surface area of finer soil particles, improved groundwater recharge and also improved affinity for vegetation. It also offers several pollutant-reducing benefits and can offer urban benefits such as reduced irrigation and fertilizer needs. (City of Seattle, 2009) Time of concentration is increased and peak flows are attenuated and reduced through this method. Many of the compost-amended soil approaches are outlined in site development guidance documents for buildings; however, Swiss engineers Piguet, Parriaux and Bensimon (2008) offer a road-specific design approach called "infiltration slopes" that allows implementation of soil amendment that maintain the overall impermeability of the roadway for fast runoff removal without promoting water intrusion in roadway subbase materials. Their models of infiltration slopes are shown in Figure EW-2.7 with various slope and material configurations using different soils and geotechnical reinforcments. The authors found increased infiltration capacity, improved groundwater recharge, increased evapotranspiration and improved flow control.

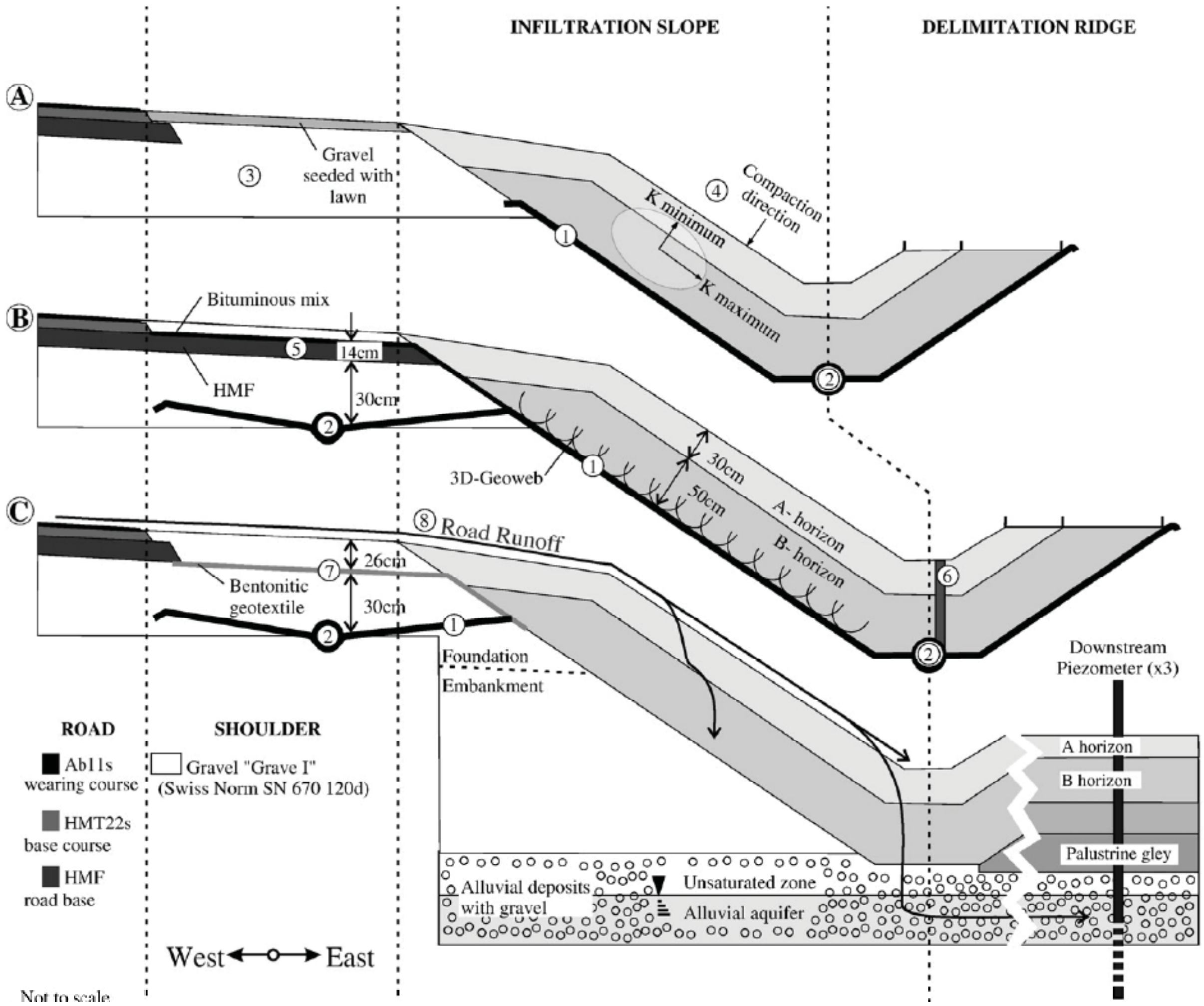

Figure EW-2.7: Infiltration slope cross-sections. (Piguet, Parriaux & Bensimon 2008)

Controversy of Detention Facilities

Detention facilities used as flow control devices are a matter of some controversy. To receive this credit, land may not be procured outside of the right-of-way to serve as conventional detention or storage facilities. This criterion attempts to mitigate the overall land-area impact of conventional detention facilities by restricting construction of such facilities within ROW limits without restricting the use of this common BMP. However, the thorough literature review from the City of Seattle (2009) indicates that detention ponds may not be effective flow control measures for mitigating hydromodification impacts, other flow control methods offer much higher pollutant removal than detention ponds, and the ponds have limited hydrological benefits especially when more than one is present in the same watershed.

There are some documented benefits of detention and retention facilities of reducing large debris delivered to streams and bed scour. Also, they are easily understood by hydraulic designers and offer much control over runoff releases. (FHWA, 2009) Completely disallowing detention ponds in Greenroads would effectively eliminate the most commonly used method of stormwater controls available to most highway, street and roadway projects (FHWA, 2009). However, LID techniques have been shown to be able to reduce the needed size of detention ponds or eliminate them and conventional conveyance altogether in some cases (Hinman, 2005; City of Seattle, 2009).

The preferred alternative to conventional detention ponds in Greenroads are multi-functional BMPs such as bioretention or stormwater storage and reuse.

When LID Is Not Appropriate

In general, LID flow control BMPs may not be appropriate and should be avoided in areas (WSDOT, 2008)

- With high or seasonally high water tables
- Below the 100-year flood plain
- With distressed groundwater
- In intertidal areas
- In sensitive watersheds or forests (these have a higher net benefit than LID.)

However, a site-specific design built on watershed parameters and topography will be most effective for controlling runoff flows and some of flow control techniques may be viable even in these conditions.

Additional Resources

- For further discussion on the merits of detention facilities, see the *Environmentally Critical Areas: Best Available Science* report by the City of Seattle (2009), available at: http://www.seattle.gov/dpd/static/BAS%20Review_FINAL_30JUN09_LatestReleased_DPDP017711.doc
- Current performance data on flow control for LID BMPs is available at the International BMP Database: http://www.bmpdatabase.org. They also track cost data as it is volunteered along with submissions.

For more information and additional resources on specific LID techniques, see the discussion in Project Requirement PR-8 Low Impact Development.

GLOSSARY

AASHTO	American Association of State Highway and Transportation Officials
Biodiversity	Total number of species present
Biological integrity	The ability to support and maintain a balanced, integrated adaptive assemblage of organisms having species composition, diversity, and functional organization comparable to that of natural habitat of the region (Karr and Dudley, 1981).
BMP	Best management practice
BMPDB	International BMP Database (http://www.bmpdatabase.org)
Channel	A streambed
Detention	The process of holding and delaying runoff with a controlled release
EIA	Effective impervious area
EPA	Environmental Protection Agency
Erosion	Surface wearing due to physical processes such as water, wind and heat
Evaporation	The process of water becoming water vapor
Evapotranspiration	the combined effects of evaporation and transpiration in reducing the volume of water in a vegetated area during a specific period of time (Huber et al. 2006)
FHWA	Federal Highway Administration
Flow control	Management of runoff volume physical characteristics including peak flows and time of concentration
Hydromodification	alteration of the hydrologic characteristics of coastal and non-coastal waters, which in turn could cause degradation of water resources (EPA, 2007)

Impervious surface	a hard surface area that either prevents or retards the entry of water into the soil mantle or causes water to run off the surface in greater quantities or at an increased rate (Tilley and Slonecker, 2006)
Infiltration	the downward movement of water into the soil after surficial entry and percolation through pore spaces (Huber et al. 2006)
Interception	The process of leaves of plants preventing rainfall from hitting a surface
Low impact development	a broad collection of engineered controls, stormwater management facilities, and other land development BMPs that attempt to mimic pre-development hydrologic conditions by emphasizing infiltration, evapotranspiration, or stormwater reuse for long-term flow control and runoff treatment
Reach	The length of a river or stream between river bends
Retention	The process of holding runoff, ideally no release occurs and all runoff is infiltrated or evaporated
TIA	Total impervious area
Transpiration	The process of water uptake in plants
Urbanization	The process of and activities associated with human development

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RUNOFF QUALITY

EW-3

1-3 POINTS

GOAL

Improve water quality of stormwater runoff leaving the roadway Right-of-Way (ROW)

CREDIT REQUIREMENTS

1. Develop a stormwater management plan for the site using stormwater best management practices (BMPs) for water quality treatment. Explicitly state the goals of this plan and how performance will be measured.
2. Use low-impact development (LID) BMPs to the maximum extent feasible as determined in Project Requirement PR-8 by a licensed professional.
3. Compute the 90^{th} percentile average annual rainfall event post-construction runoff volumes (V_{total}) for two areas as follows:
   - V_{runoff}: the total pollution generating surface (PGS) area of the project ROW
   - $V_{run\text{-}on}$: The total PGS area outside the ROW that may generate untreated stormwater which runs into the ROW BMPs, if any.
   - $V_{total} = V_{runoff} + V_{run\text{-}on}$
   - $V_{treated} = V_{runoff\text{-}treated} + V_{run\text{-}on\text{-}treated}$
   - % of Total Post-Construction Runoff Volume Treated = $V_{treated}/V_{total}$ x 100%
   - Compute a weighted average of volumes treated for the total volume managed in the project where more than one BMP is used.
4. Provide treatment for a desired percentage of the total computed runoff volume for either of the areas noted in Table EW-3.1. List the types, manufacturers, treatment levels, and total volumes treated in BMPs.
5. Demonstrate that the planned BMPs meet the following quality criteria:
   - BMPs reduce sediment loads to **total suspended solids (TSS) concentrations of 25 mg/L or** less, as an indicator of overall treatment level. See Table EW-3.2.
   - BMPs **conform to all applicable minimum water quality standards** for all effluent leaving the ROW set by the governing jurisdiction for contaminants, such as heavy metals, hydrocarbons, pathogens, water temperature and turbidity. State the minimum requirements, including critical erosive flow criteria, and provide referenced document or policy.

Table EW-3.1: Greenroads points for % volumes of treated runoff

Type of Runoff Volume	Volume Treated	Treatment Level	Points
Pollution generating surfaces (PGS) from within the project ROW only (runoff)	80%	Basic	-
		Basic & Enhanced	-
		Basic, Enhanced & Oil	1
	90%	Basic	-
		Basic & Enhanced	1
		Basic, Enhanced & Oil	2
Pollution generating surfaces (PGS) from within the project ROW and from outside areas (run-on and runoff)	80%	Basic	-
		Basic & Enhanced	1
		Basic, Enhanced & Oil	2
	90%	Basic	1
		Basic & Enhanced	2
		Basic, Enhanced & Oil	3

RELATED CREDITS

- ✓ PR-8 Low Impact Development
- ✓ PR-10 Site Maintenance Plan
- ✓ EW-2 Runoff Flow Control
- ✓ EW-4 Stormwater Cost Analysis
- ✓ EW-5 Site Vegetation

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Extent

BENEFITS

- ✓ Reduces Water Pollution
- ✓ Reduces Solid Waste
- ✓ Reduces Manmade Footprint

Details

This credit is an adaptation of the 2009 Sustainable Sites Initiative Credit 3.6: "Protect and enhance water quality" and the LEED™ Green Building Rating System Sustainable Sites Credit SS-6.2 "Stormwater Design: Quality Control." It also draws heavily on concepts from the Washington State Department of Transportation *Highway Runoff Manual.* Continuous modeling approaches are recommended (see Credit EW-2).

If more than one BMP is used in the project, calculate a weighted average of the % total volume treated by each BMP and its quality achieved. Note that BMPs should be sized appropriately if considering any runoff volumes generated from outside the project ROW. "Basic," "Enhanced" and "Oil" treatment criteria are defined by local governing agencies or by the Washington State Department of Transportation (WSDOT) Highway Runoff Manual, in absence of a local definition.

DOCUMENTATION

A copy of the executive summary of the project drainage design report that includes, at minimum, the following:

- Short narrative that addresses each of the credit requirements.

As needed, supporting calculations for runoff areas, runoff volume (output from any rainfall modeling software used is adequate), and treatment levels may be requested.

Table EW-3.2: Median of average influent and effluent concentrations. (Reproduced from table in Geosyntec & Wright Water, 2008)

Constituents	Sample Location	Detention Pond (n=25)[1]	Wet Pond (n=46)[1]	Wetland Basin (n=19)[1]	Biofilter (n=57)[1]	Media Filter (n=38)[1]	Hydrodynamic Device (n=32)[1]	Porous Pavement (n=6)[1]
Suspended Solids (mg/L)	Influent	72.65 (41.70-103.59)	34.13 (19.16-49.10)	37.76 (18.10-53.39)	52.15 (41.41-62.88)	43.27 (27.25-59.58)	39.61 (21.95-76.27)	--
	Effluent	31.04 (16.07-46.01)	13.37 (7.29-19.45)	17.77 (9.26-26.29)	23.92 (15.07-32.78)	15.86 (9.74-21.98)	37.67 (21.28-54.02)	16.96 (5.90-48.72)
Total Calcium (µg/L)	Influent	0.71 (0.45-1.28)	0.49 (0.20-0.79)	0.36 (0.11-0.60)	0.54 (0.40-0.67)	0.25 (0.12-0.49)	0.74 (0.37-1.11)	--
	Effluent	0.47 (0.25-0.87)	0.27 (0.12-0.61)	0.24 (0.11-0.55)	0.30 (0.26-0.35)	0.19 (0.1-0.37)	0.57 (0.25-1.33)	--
Dissolved Calcium (µg/L)	Influent	0.24 (0.15-0.33)	0.19 (0.10-0.28)	--	0.25 (0.21-0.28)	0.16 (0.11-0.21)	0.33 (0.11-0.55)	--
	Effluent	0.25 (0.17-0.36)	0.11 (0.08-0.15)	--	0.21 (0.19-0.23)	0.13 (0.10-0.18)	0.31 (0.13-0.71)	--
Total Copper (µg/L)	Influent	20.14 (8.41-31.79)	8.91 (5.29-12.52)	5.65 (2.67-38.61)	31.93 (25.25-38.61)	14.57 (10.87-18.27)	15.42 (9.20-21.63)	--
	Effluent	12.10 (5.41-18.80)	6.36 (4.70-8.01)	4.23 (0.62-7.83)	10.66 (7.68-13.68)	10.25 (8.21-12.29)	14.17 (8.33-20.01)	2.78 (0.88-8.78)
Dissolved Copper (µg/L)	Influent	6.66 (0.73-12.59)	7.33 (5.40-9.26)	--	14.15 (10.14-18.16)	7.75 (4.55-10.96)	13.59 (9.82-17.36)	--
	Effluent	7.37 (3.28-11.45)	4.37 (3.73-5.73)	--	8.40 (5.65-11.45)	9.00 (7.28-10.72)	13.92 (4.40-23.44)	--
Total Chromium (µg/L)	Influent	7.36 (5.49-9.88)	6.00 (3.58-10.08)	--	5.63 (4.49-7.05)	2.18 (1.66-2.86)	4.07 (2.39-6.91)	--

Constituents	Sample Location	Detention Pond (n=25)[1]	Wet Pond (n=46)[1]	Wetland Basin (n=19)[1]	Biofilter (n=57)[1]	Media Filter (n=38)[1]	Hydrodynamic Device (n=32)[1]	Porous Pavement (n=6)[1]
	Effluent	3.18 (2.10-4.84)	1.44 (0.79-2.66)	--	4.64 (3.08-6.98)	1.48 (0.82-2.70)	3.52 (2.14-5.80)	--
Total Lead (µg/L)	Influent	25.01 (12.06-37.95)	14.36 (8.32-20.40)	4.62 (1.43-11.89)	19.53 (10.11-28.95)	11.32 (6.09-16.55)	18.12 (5.70-30.53)	--
	Effluent	15.77 (4.67-26.87)	5.32 (1.63-9.01)	3.26 (2.31-4.22)	6.70 (2.81-10.59)	3.76 (1.08-6.44)	10.56 (4.27-16.85)	7.88 (1.64-37.96)
Dissolved Lead (µg/L)	Influent	1.25 (0.33-2.17)	3.40 (1.12-5.68)	0.50 (0.33-0.67)	2.25 (0.77-3.74)	1.44 (1.05-1.82)	1.89 (0.83-2.95)	--
	Effluent	2.06 (0.93-3.19)	2.48 (0.98-5.36)	0.87 (0.85-0.89)	1.96 (1.26-2.67)	1.18 (0.77-1.60)	3.34 (2.22-4.47)	--
Total Zinc (µg/L)	Influent	111.56 (51.50-171.63)	60.75 (45.23-76.27)	47.07 (24.47-90.51)	176.71 (128.28-225.15)	92.34 (52.29-132.40)	119.08 (73.50-164.67)	--
	Effluent	60.20 (20.70-99.70)	29.35 (21.13-37.66)	30.71 (12.80-66.69)	39.83 (28.01-51.56)	37.63 (16.80-58.46)	80.17 (52.72-107.61)	16.60 (5.91-16.61)
Dissolved Zinc (µg/L)	Influent	26.11 (5.20-75.10)	47.46 (37.65-57.27)	--	58.31 (32.46-79.16)	69.27 (37.97-100.58)	35.93 (4.96-66.90)	--
	Effluent	25.84 (10.75-40.93)	32.86 (17.70-48.01)	--	25.40 (18.71-32.09)	51.25 (29.04-73.46)	42.46 (10.38-74.55)	--
Total Phoshporus (mg/L)	Influent	0.19 (0.17-0.22)	0.21 (0.13-0.29)	0.27 (0.11-0.43)	0.25 (0.22-0.28)	0.20 (0.15-0.26)	0.24 (0.01-0.46)	--
	Effluent	0.19 (0.12-0.27)	0.12 (0.09-0.16)	0.14 (0.04-0.24)	0.34 (0.26-0.41)	0.14 (0.11-0.16)	0.26 (0.12-0.48)	0.09 (0.05-0.15)
Dissolved Phosphorus (mg/L)	Influent	0.09 (0.06-0.13)	0.09 (0.06-0.13)	0.10 (0.04-0.22)	0.09 (0.07-0.11)	0.09 (0.03-0.11)	0.06 (0.01-0.11)	--
	Effluent	0.12 (0.07-0.18)	0.08 (0.04-0.11)	0.17 (0.03-0.31)	0.44 (0.21-0.67)	0.09 (0.07-0.11)	0.09 (0.04-0.13)	--
Total Nitrogen (mg/L)	Influent	1.25 (0.83-1.66)	1.64 (1.39-1.94)	2.12 (1.58-2.66)	0.94 (0.94-1.69)	1.31 (1.19-1.42)	1.25 (0.33-2.16)	--
	Effluent	2.72 (1.81-3.63)	1.43 (1.17-1.68)	1.15 (0.82-1.62)	0.78 (0.53-1.03)	0.76 (0.62-0.89)	2.01 (1.37-2.65)	--
Nitrate-Nitrogen (mg/L)	Influent	0.70 (0.35-1.05)	0.36 (0.21-0.51)	0.22 (0.01-0.47)	0.59 (0.44-0.73)	0.41 (0.30-0.51)	0.40 (0.06-0.73)	--
	Effluent	0.58 (0.25-0.91)	0.23 (0.13-0.37)	0.13 (0.07-0.26)	0.60 (0.41-0.79)	0.82 (0.60-1.05)	0.51 (0.08-1.34)	--
TKN (mg/L)	Influent	1.45 (0.97-1.94)	1.26 (1.03-1.49)	1.15 (0.81-1.48)	1.80 (1.62-1.99)	1.52 (1.07-1.96)	1.09 (0.52-1.57)	--
	Effluent	1.89 (1.58-2.19)	1.09 (0.87-1.31)	1.05 (0.82-1.34)	1.51 (1.24-1.78)	1.55 (1.22-1.83)	1.48 (0.87-2.47)	1.23 (0.44-3.44)

APPROACHES & STRATEGIES

- Reduce or disconnect impervious cover, such as between lanes with a vegetated median or sidewalks with a buffer strip. (Sustainable Sites Initiative: SSI, 2009)
- Provide depression storage in the landscape (SSI, 2009)
- Convey stormwater in swales to promote infiltration (SSI, 2009)
- Use biofiltration to provide vegetated and soil filtering (SSI, 2009)
- Evapotranspire (e.g., use engineered soils and vegetation in biofiltration areas/landscaping to maximize evapotranspiration potential) (SSI, 2009)
- Infiltrate stormwater (infiltration basins and trenches, permeable pavement, etc.) (SSI, 2009)
- Develop and implement a spill response plan (SSI, 2009)
- Minimize the use of salt for deicing and consider organic deicers or sand instead (SSI, 2009)
- Use a “treatment train” of many BMPs in series. (SSI, 2009)
- Use a stormwater treatment system or BMPs that have been demonstrated to achieve the 25 milligrams/liter TSS discharge. Some of these are (SSI, 2009):

    - Water quality wet ponds
    - Constructed stormwater wetlands
    - Bioretention
    - Biofiltration (e.g., raingardens)
    - Vegetated buffer strips
    - Sand filters
    - Bioswales (usually most effective as the first in line of a treatment train)
    - Other BMPs like vaults and pretreatment or mechanical separators may not be able to earn this credit alone but could be used in a treatment train effectively.

- Perform regular inspections and monitoring activities to ensure long-term performance. This includes visual inspection of controls. (EPA, 1995)
- Clean out accumulated sediment regularly. (EPA, 1995)
- Replace old fabrics, filters and other materials as they deteriorate to maintain BMP effectiveness. (EPA, 1995)
- Remove temporary BMPs used in construction and replace them with permanent controls. (EPA, 1995)
- Seed with grass and compost amended mulch or soil to develop vegetation and provide stabilized slopes. (EPA, 1995)
- Use wildflower cover to provide erosion control and aesthetic benefits. (EPA, 1995)
- Use established grass sod blankets on prepared soils. (EPA, 1995)
- Design the roadway facility for treatment using grassed swales, check dams, filter strips, terracing, infiltration trenches and/or basins. (EPA, 1995)
- Consider constructed wetlands for increased quality and new provision of habitat. (EPA, 1995)
- Set performance goals for basic treatment (i.e. 80% removal of TSS), enhanced treatment (i.e. metals removal) and oil or phosphorous control. (Washington State Department of Transportation: WSDOT, 2008)
- Consider infiltration slopes (Piguet, Parriaux & Bensimon 2008) and “Ecology ditches” (City of Seattle, 2009) (these are similar approaches using compost amended soils for promoting infiltration and pollutant removal).
- Consider geometric design for erosion control and flow moderation (EPA, 2007)

Example: City of Kirkland 120th Street Extension

The City of Kirkland proposes to extend NE 120th Street one city block between 124th Avenue NE to Slater Avenue NE. Improvements include the approximate 0.16-mile extension of NE 120th Street, complete with 5-foot sidewalks, 5-foot bicycle lanes in each direction, 4.5-foot planter strips, and continuous two-way left turn lanes at each intersection.

The extended roadway will have a maximum 44-foot curb to curb section. A new traffic signal will also be constructed at the intersection of NE 120th Street and 124th Avenue NE. Partial acquisitions of up to four commercially zoned properties will be required to complete the project. Associated improvements include utilities and stormwater structure installation. The proposed measures will enhance traffic circulation and safety in Kirkland's Totem Lake area. The design team used a continuous hydrologic modeling tool to calculate their flowrates and runoff volumes.

Table EW-3.3: Summary of Water Quality Calculations

Total Inflow to Project BMPs	**5548.96 ac-ft**
Total Area Treated	**1.188 ac**
Proposed PGIS Area for Project	**0.99 ac**
Amount of Additional Treatment Area	**+0.198 ac**
Total Volume Treated As Percent of Project PGS	**120%**
Weighted Average Annual Treatment Volume Achieved by BMPs	**93.1%**
Basic Treatment (80% TSS removal, <25 mg/L)	**Yes**
Enhanced Treatment (dissolved metals)	**Yes**
Enhanced Treatment (oil)	**Not Pursued**
Enhanced Treatment (other)	**Not Pursued**
Total Points	**2**

Summary of Credit Calculations

1. Post-construction runoff volume: 5548.96 acre-feet. LID techniques were used to treat a minimum of 90% of the average annual post-construction runoff volume.

   a. The project treated run-on and runoff in the ROW BMPs.
   b. Calculation: 1.118 acres treated > 0.99 acres acres of pollution generating surfaces in the ROW only (120% treated).
   c. No detention facilities were used outside of the ROW.

2. Calculation: 93.1% average volume filtered (see Detailed Calculations below).
3. Treatment definitions and project water quality goals:

   a. Basic Treatment: 80% TSS removal (WSDOT, 2008)
   b. Enhanced treatment: BMPs provide a higher rate of removal than basic treatment facilities for dissolved copper and dissolved zinc (WSDOT, 2008)

4. Concentration testing information for the tree box filters used was provided by the Washington Department of Ecology (2010). No expected effluent values exceed the stated 25 mg/L TSS limit (Sustainable Sites, 2009) or special Washington State standards for removal of heavy metals or oils (enhanced treatment).
5. Product approval by the Washington State Department of Ecology is available here: http://www.ecy.wa.gov/programs/wq/stormwater/newtech/use_designations/filterrauld111306.pdf
6. Based on Table 1, 2 points are earned by this project for treatment of 93.1% of the total run-on and runoff according to stated standards for enhanced treatment.

Detailed Calculations

1. Threshold Analysis

- The threshold analysis calculations are required to determine the applicable minimum requirements for the project and threshold discharge area.
- Within the project limit, there is one threshold discharge area (TDA). Two downstream paths that exit the project limit join together at a distance that is a little more than a quarter mile downstream from the

project site, at a wetland. This flow discharges into a culvert to Totem Lake. These two systems are hydraulically connected because the water level at the quarter-mile point is that the level of Totem Lake.

2. Assumptions

- All roadway areas are considered pollutant-generating impervious surface (PGIS), sidewalks as non-pollution-generating impervious surface (NPGIS), and planter strip and other landscape as non-pollution-generating pervious surface (NPGPS).
- Rubblized pavement left in place and paved over is not considered replaced pavement.

3. Definitions (from Table 3-1 of the 2008 WSDOT *Highway Runoff Manual)*

Basic Treatment

- Applies to all project threshold discharge areas (TDAs) where runoff treatment threshold is met (project adds 5000 sf or more of PGIS)

Performance Goal: 80% removal of total suspended solids (TSS)

Enhanced Treatment (dissolved metals)

- Applies to all project threshold discharge areas (TDAs) where runoff treatment threshold is met (project adds 5000 sf or more of PGIS)
- Does not discharge to Basic Treatment receiving water body
- Applies to roadways within Urban Growth Areas (UGAs) with Average Daily Trip (ADT) ≥ 7,500 (For this project area, ADT is 8700)

Performance Goal: Provide a higher rate of removal of dissolved metals than Basic Treatment facilities for influent concentrations ranging from 0.003 to 0.02 mg/L for dissolved copper and 0.02-0.3 mg/L for dissolved zinc.

4. Pervious and Impervious Area Calculations

- Tabulated calculations are shown in Tables EW-3.4 and EW-3.5.

Table EW-3.4: Impervious area summary

Category	Area (sf)	Area (Acres)
Existing Impervious	35,240	0.81
New Impervious	22,140	0.51
Replaced Impervious	9,735	0.22
Removed Impervious	1,647	0.04
Proposed Impervious	55,733	1.28
Effective Impervious	31,875	0.73

Table EW-3.5: PGIS summary

Category	Area (sf)	Area (Acres)
Existing PGIS	34,201	0.79
New PGIS	16,404	0.38
Replaced PGIS	4,321	0.10
Removed PGIS	7,646	0.18
Proposed PGIS	42,959	0.99
Effective PGIS	16,404	0.38

5. Minimum Requirements from 2008 WSDOT Highway Runoff Manual (HRM)

Figures 3.1, 3.2, and 3.3 of the HRM are used to determine the minimum requirements applicable for a project.* Section 3-2.2 of the HRM lists possible exceptions for this project.** No special exceptions apply, so minimum requirements 1-9 of the HRM states that new pollution-generating impervious surface must provide water quality treatment meeting the stated performance goals for basic and enhanced treatment.

6. Calculate the Predeveloped and Developed Runoff Areas***

A continuous modeling software tool was used to calculate the total area in the right of way (ROW) and the tributary areas providing run-on into project stormwater treatment facilities. See Table EW-3.6.

Table EW-3.6: Total predeveloped and developed runoff area

Subbasin Number	Total Area (Acres)	
	Predeveloped	Developed
Subbasin 1	0.770	23.850
Subbasin 2	0.770	0.770

7. Calculate Predevelopment Flowrate

Predevelopment flowrate was computed using a 2-year recurrence interval for onsite (0.016 cfs) and offsite flows (2.640 cfs).

8. Calculate Post-Construction Runoff Volume

The total inflow volume to project stormwater treatment facilities from Subbasin 1 was computed to be 5549 acre-feet. There was no change in runoff area from Subbasin 2.

9. Identify Types of Stormwater Best Management Practices (BMPs) To Be Used

Five subsurface biorention systems (tree box filters)**** were selected by the project team for treating stormwater runoff and run-on. See Figure EW-3.1.

10. Select Locations BMPs and Compute Treatment Levels for Stormwater Volumes

The weighted average annual treatment for water quality on the project was 93.1% for runoff and run-on. See Table EW-3.7 for computations.

Table EW-3.7: Runoff area treated by the tree box filters

Area Extents	Area (ac)	Infiltration* (%)
Station 160+50 to 102+73 (north half)	0.244	91.4
Station 160+50 to 102+73 (south half)	0.284	91.1
Station 108 +50 to 160+50 (south)	0.183	94.9
Station 102+73 to Station 100+00 (south)	0.236	95.4
Station 102+73 to Station 100+00 (north)	0.241	93.5
Weighted Average		**93.1**

Notes:

*These figures make up a decision tree used to guide the engineer in the applicable minimum requirements when designing a stormwater management facility based on known surface areas, relative perviousness, and pollution generating capacity.

** Generally, if the amount of impervious surfaces is greater than a specified minimum value, certain requirements must be applied to that impervious surface. These values are called "minimum requirements."

*** This calculation and the following calculations were completed using the Western Washington Hydrology Model (WWHM), a continuous modeling software tool.

****These treatment systems have underdrains in place that bypass excess runoff into a detention vault during higher intensity events.

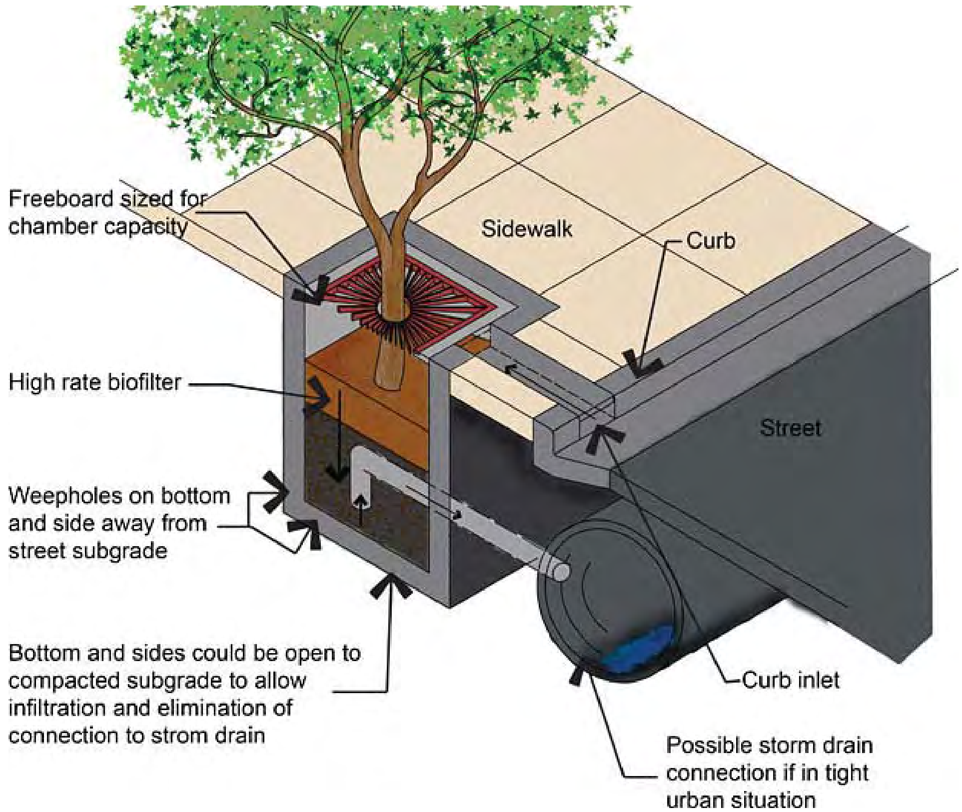

Figure EW-3.1: Tree box filter schematic (http://www.ladstudios.com/LADsites/Sustainability/Strategies/images/treebox-Model.jpg)

Example: Streetside Bioswale

Installed as part of the Street Edge Alternatives (SEA Street) Project by the City of Seattle, the bioswale pictured below in Figure EW-3.2 is an example of a structural stormwater control for water quality treatment. The bioswales on SEA Street successfully mitigate 98% of the rainy season stormwater and 100% of the dry season water. This detention based approach achieves quality treatment primarily through control of flow volumes and infiltration. Additionally, there are six detention facilities which allow for a treatment train for any stormwater that enters the conventional infrastructure. Quality treatment is provided by plant uptake and compost amended soils that help treat street runoff and remove heavy metals. A virtual tour of SEA Street is available at http://www2.cityofseattle.net/util/tours/seastreet/slide1.htm. More information about Seattle's Natural Drainage System program (including other projects) is also available at: http://www.seattle.gov/util/About_SPU/Drainage_&_Sewer_System/GreenStormwaterInfrastructure/NaturalDrainageProjects/index.htm

Figure EW-3.2: A well-established vegetated swale ("bioswale") that uses compost amended soil and no flow control devices or structures. Residential street to right. Seattle, WA. (Photo by J. Anderson)

POTENTIAL ISSUES

1. Actual water quality may be difficult to model and may be different than designed. This credit does not require monitoring to be in place to verify pollutant removals are achieved at this time.
2. Long-term performance data for many low-impact development methods used for quality control are not available for roadway projects or lack consistency. For example, case studies of grassed swales in the late 1990s performed by the Federal Highway Administration showed quality and quantity benefits but data were not collected consistently. (EPA, 2000)
3. Detention ponds are not allowed except within the right-of-way. A discussion of the reasoning for this is provided in Credit EW-2.
4. Infiltration practices are not recommended where groundwater contamination is a concern.
5. Heavy precipitation and high peak flow events can wash pollutants out of some treatment systems.
6. Maintenance and monitoring are imperative for the success of a water quality treatment program.
7. Continuous modeling can be time intensive and expensive. However, there are a variety of software programs available to model pollutant loadings.

RESEARCH

This Greenroads credit primarily addresses changes to chemical concentrations of water of watersheds based on chemicals collected on roadways and passed into receiving water bodies by stormwater runoff. All best management practices that address flow control also address water quality (Quigley et al., 2009); however, Credit EW-2 Runoff Flow Control addresses physical runoff management practices. Biological integrity of receiving waters is addressed by Credit EW-6 Habitat Restoration.

Existing Literature for Roadway Stormwater Quality

The relationship between stormwater runoff quality and roadways as a pollutant generator is well-documented (Maestre and Pitt, 2005; Strecker, Mayo, Quigley, and Howell, 2001; Clarke et al., 2007; Huber et. al., 2006; Environmental Protection Agency: EPA, 2007; Shoemaker, Lahlou, Doll and Cazenas, 2002; EPA, 2000). Clarke et al. (2007) provides an annotated bibliography of all stormwater literature between 1996 and 2006 for all types of urban runoff practices, including a brief (five pages) review of literature for "highways and other roads." The

National Cooperative Highway Research Program (NCHRP) Report 565 (Huber et al. 2006) provides another excellent reference specifically relevant for roadways using low impact development approaches for stormwater quality management (and flow control) in a highway environment. The reader is referred to these documents for more detailed information. A brief introduction of roadway water quality issues is presented below, including an overview of stormwater treatment objectives, terminology, impacts and types of pollutants and some recommended LID controls for runoff treatment.

What is Non-Point Source Pollution?

The EPA identifies roadways, in their operational phases, as non-point source pollution generators, which means that the source of the pollutants is diffuse (EPA, 2010a). Non-point source runoff comes from rain or snowmelt that washes over surfaces, collecting and transporting particles, which vary in human and environmental toxicity, into receiving bodies of water. Pollutants are collected on impervious surfaces through a variety of processes such as tire wear, erosion of pavement surfaces and embankments, atmospheric deposition and routine maintenance of roadways. The regulatory framework that governs non-point source pollution in the U.S. includes (Shoemaker, Lahlou, Doll, and Cazenas, 2002):

- National Environmental Policy Act (NEPA)
- Clean Water Act: National Pollutant Discharge Elimination System (NPDES)
- Clean Water Act: Nonpoint Source Pollution Control Program
- Coastal Zone Act Reauthorization Amendments (CZARA)
- Other state and local regulatory requirements.

Water Quality Treatment Objectives

The primary concerns with non-point source runoff are generation and transport of pollutants, habitat degradation, habitat loss, loss of biodiversity, and preservation of beneficial use (such as drinking water supplies) (EPA, 2010a; Southerland, 1994) Federal guidance is intended to meet the following objectives (EPA, 2005)

- *Protect sensitive ecosystems, including wetlands and estuaries, by minimizing road- and bridge-related impacts and water crossings, and by establishing protective measures including setbacks during construction*
- *Reduce the runoff of pollutants through the use and proper maintenance of structural controls*
- *Reduce the generation of pollutants from maintenance operations by minimizing the use of pesticides, herbicides, fertilizers, and deicing salts and chemicals*
- *Reduce the generation and runoff of pollutants during highway and bridge repair operations by decreasing the use of hazardous materials and incorporating practices to prevent spillage into sensitive areas.*

Many states have water quality objectives that align with federal regulatory compliance with the Clean Water Act and intend to protect state water resources. Some examples from the Washington State Department (WSDOT) Highway Runoff Manual (2008) are:

- *Prevent pollution of state waters and protect water quality, including compliance with state water quality standards.*
- *Satisfy state requirements for all known available and reasonable methods of prevention, control, and treatment of wastes prior to discharge to waters of the state.*
- *Satisfy the federal technology-based treatment requirements under 40 CFR Part 125.3.*

Water Quality Treatment Terminology

Non-point source pollution can be managed through a variety of "structural" and "non-structural" controls. These are typically referred to as "best management practices" (BMPs) or "integrated management practices" (IMPs), and sometimes simply as "stormwater controls" or "stormwater control measures" (SCM) (Quigley et al. 2009). For the purposes of Greenroads, the term BMP is used, as are the definitions of structural and non-structural controls provided by the International Stormwater Best Management Practices Database (*ibid.*) A stormwater quality BMP is a "device, practice or method for removing, reducing, retarding or preventing targeted stormwater runoff constituents, pollutants and contaminants from reaching receiving waters" (*ibid.*) There are five types of structural controls that are defined based on their inflow and outflow characteristics. They are (*ibid.*):

- ***Type I.*** *BMPs with well-defined inlets and outlets (e.g., detention basins, vegetated swales, catch basin inserts). These are the "easy" BMPs to monitor where inflow and outflow can typically be paired to assess performance. In the case of systems such as wet ponds with substantial residence times or storage volumes, data may be straightforward to collect, but challenging to evaluate for individual storms. In such cases, a seasonal mass balance approach is often more appropriate than a storm-based, paired influent-effluent approach because it is likely that the effluent sample for small storms is displaced water originating from prior events.*
- ***Type II.*** *BMPs with well-defined inlets, but not outlets (e.g., infiltration basins, infiltration trenches, bioretention cells). Monitoring strategies for these BMPs are more complex and may involve sampling of underdrains, vadose (unsaturated) zone monitoring, groundwater monitoring, measuring infiltration rates and surface overflow. At a minimum, the influent and surface overflow must be quantified, since the difference between the two should represent the volume infiltrated. If an underdrain is used to direct partially treated water back to the surface drainage, then it should also be monitored. Evaluation of data from these types of studies should focus on mass balance approaches.*
- ***Type III.*** *BMPs with well-defined outlets, but not inlets (e.g., grass swales where inflow is overland flow along the length of the swale, buffer strips, green roofs).*
- ***Type IV.*** *BMPs without any well-defined inlets or outlets and/or institutional BMPs (e.g., buffer strips, basin-wide catch basin retrofits, education programs, source control programs, disconnected impervious area practices).*
- ***Type V.*** *Low-Impact Development (LID)/Distributed Controls/Overall Site Designs where some defined monitoring locations are available that may include monitoring of individual practices within a development, in combination with an overall site monitoring mechanism.*

Effective communication is necessary to meet stormwater management quality objectives, so it is useful to compare other definitions of some terms that are available in some related guidance documents and within Greenroads. The term BMP is used more broadly in Greenroads in reference to many of the activities involved in meeting the Project Requirements and Voluntary Credits, and does not necessarily always refer to a water quality objective. BMPs can be temporary (such as erosion control during construction) or permanent, such as those BMPs addressed in this credit. This credit addresses structural controls for quality treatment. Non-structural controls for operations and maintenance and temporary BMPs for construction are covered in the Project Requirements and Construction Activities categories.

Table EW-3.8 compares the definitions used in some current stormwater management guidance and other sustainability rating systems that are sometimes applied to roadways and infrastructure. It is particularly important to note the discrepancies between the 2009 LEED™ Rating System (LEED), two separate documents from the same agency (the FHWA), and the guidance referenced by Greenroads in the BMPDB (also used in Huber et al. 2006). Notably, LEED appears to use the term "non-structural" to mean "biological" or "vegetated," which matches the most recent guidance from the FHWA. However, the FHWA appears to use the term "structural" control to describe BMPs that provide what is normally called "enhanced treatment" filters or "oil control" facilities which are usually small or moderately sized mechanical filters or separators that parse surface oils and grease from settled sediments (City of Seattle, 2009). Furthermore, the FHWA confusingly uses the term "ultra-urban" to refer to what is equivalent in most site development guidance documents to mean LID techniques. (See Project Requirement PR-8 Low Impact Development). This is probably an attempt to distinguish standard highway drainage practices such as, for example, "grassed swales" (which generally means long, vegetated, generally non-engineered outside of flow control sizing, non-maintenance-intensive roadside ditches) from "bioswales" (which generally means small, decentralized, engineered and deliberately vegetated for water quality treatment and flow control, not necessarily maintenance-intensive roadside ditches). Greenroads uses the term LID for consistency across credits and requirements.

Table EW-3.8: Varying Definitions of Stormwater Treatment Controls in Select Guidance Documents

Source	Structural Control	Non-Structural Control
2009 LEED™ Rating System (USGBC, 2009)	"Structural measures, such as rainwater cisterns, manhole treatment devices and ponds can be used to remove pollutants from runoff from impervious areas and sometimes reuse the water for irrigation or building flush fixtures….Structural measures are preferred on urban or constrained sites and make it possible to effectively clean the runoff with minimal space allocation and land use. For existing sites with greater than 50% imperviousness, structural techniques may include restoration and repair of deteriorated storm sewers, or separation of combined sewers."	"Non-structural strategies, such as vegetated swales, disconnection of impervious areas, and pervious pavement, can be used to infiltrate and limit runoff. In these cases you are 'capturing and treating' runoff by allowing it to naturally filter into the soil and vegetation. Pollutants are broken down by microorganisms in the soil and the plants….Non-structural methods are often preferred because they may be less costly to construct and maintain and they help recharge groundwater supplies."
2009 Sustainable Sites Initiative	Not explicitly defined	Not explicitly defined
2009 National Highway Institute/Federal Highway Administration Urban Drainage Manual	"…these engineered devices are typically structural and are made on a production line in a factory."	Vegetative practices such as grassed swales, filter strips and wetlands "are non-structural BMPs and are significantly less costly than structural controls"
2002 Federal Highway Administration Stormwater Best Management Practices in an Ultra-Urban Setting (Shoemaker, Lahlou, Doll and Cazenas)	Infiltration technologies, including bioretention, ponds and pond/wetland combinations, enhanced treatment systems, filtering systems, vegetated swales and filter strips, water quality inlets, porous pavements	Streetsweeping, source controls
2009 Stormwater BMP Monitoring Manual (Quigley et al. 2009), ***Greenroads***	**"Structural BMPs include a variety of practices that rely on a wide range of hydrologic, physical, biological, and chemical processes to improve water quality and manage runoff.**	**"Non-structural BMPs such as education and source control ordinances typically depend on a combination of behavioral change and enforcement."**

Impacts of Pollutants in Roadway Runoff

Few stormwater quality management approaches consider the aggregate and systemic impacts to the full reach of a water course, let alone the watershed (Wilcock, Pitlick and Cui, 2009). As discussed in Credit EW-2 Runoff Flow Control, impervious surfaces are directly related to runoff volumes. These volumes of runoff carry pollutants into receiving water bodies, such as rivers and streams, bays, wetlands and ocean environments. Tilley and Slonecker (2006) determined that imperviousness as low as one percent can cause an aquatic ecosystem area to be labeled as "stressed" and up to 25% imperviousness can cause "irreversible environmental degradation." They also show that roads and sidewalks comprise up to 33% of the impervious area in average suburban and urban environments, while in rural environments, nearly all of the impervious area is due to roadways (Maestre and Pitt , 2005). The pollutants generated from roadways in areas of existing watershed impairment are monitored and managed by water quality programs through the EPA or authorized state or local agencies.

Total Maximum Daily Loads and Roads

The EPA gathers statistics on water quality for a variety of water bodies as part of the ongoing water quality program called Assessment Total Maximum Daily Load (TMDL) Tracking and Implementation System (ATTAINS), which is regulated through sections 305(b) and 303(d) of the Clean Water Act (EPA, 2009b). Reporting is required from states with non-attainment water bodies (those exceeding their TMDLs) every two years until attainment is reached for each assessed pollutant (EPA, 2009a). Roadways are part of TMDL computations as they are considered to be non-point contributors of pollution (they are counted as part of the total load allocation for effluent) – the contribution is based on total contributing area or length in a watershed. Table EW-3.9 was constructed from the current TMDL statistics listed in the ATTAINS database. For example, of the 26% of the assessed mileage of U.S. rivers and streams receiving roadway runoff, over 50% are considered impaired and threatened. Impaired water bodies are those that have not met the quality criteria for one or more of its assessed beneficial uses, whereas threatened water bodies meet all assessed beneficial uses but demonstrate an apparent decline in water quality (EPA, 2008).

According to ATTAINS, some states have reported roadways as a direct probable cause of impairment (not including threatened waters) for receiving streams and rivers. Roads and road construction activities are probably directly responsible for about 3.4% of the assessed impaired waters. However, the impact of roadways is much greater than this figure indicates. As discussed in the previous credit (EW-2 Runoff Flow Control), runoff generated on impervious surfaces such as roadways and bridges can cause degradation of habitat, loss of wetland habitat, clearing of vegetation and many other activities associated with hydromodification. Many of these impacts result from or are otherwise indirectly related to roadway construction and use. While not all rivers and stream miles in the U.S. were assessed, these indirect habitat and ecosystem changes associated with roadway potentially represent an additional 20% of the total impairments in assessed rivers and streams. The diffuse impacts due to roadway development could be up to 56% for bays and estuaries. These TMDL statistics likely include several different non-point sources; however, many data were also not reported (denoted as "NA" in Table EW-3.9). For example, ATTAINS includes additional information on coastal and near coastal waters and shorelines, but there is extremely limited data for roadways and the indirect activities noted; these were omitted from the table.

When Pollution is Worst

Maestre and Pitt (2005) showed that streets in urban areas generate approximately 20-50% of the initial runoff up to half an inch, which is often called the "first flush" event. Prince George's County (PGC: 1999) explains the concept of the "first flush," which is "the first half inch of runoff from an impervious surface [that is] expected to carry with most of the pollutant load associated with stormwater. In terms of a typical storm hydrograph, the "first flush" represents a small portion of a storm's total discharge, but a larger percentage of the total loading for a particular contaminant." This hypothesis was investigated by statistical analysis of the National Stormwater Quality Database by Maestre and Pitt (2005), who showed that while peak pollutant concentrations occur often with peak flows, on small areas of pavement with small or localized drainage facilities it is likely that there will be a first flush where concentrations peak early due to the washing away of most pollutants with initial rainfall. However, at larger scales and higher rainfall, and with more complex drainage systems, the pollutant load is less likely to be detected in terms of statistically significant concentration differences. This suggests that LID methods, which are small, decentralized and efficient at treating the first half inch of runoff, may be appropriate for roads and may also help agencies meet requirements for TMDL attainment levels (Huber et al., 2006, PGC, 1999).

Table EW-3.9: National Probable Source Groups Contributing to Water Body Impairments Due to Roads and Bridges Based on water body assessment data from the National Summary of State Information. (EPA, 2010b)

Water Body	Rivers & Streams	Lakes, Reservoirs & Ponds	Bays & Estuaries	Wetlands
(unit)	(mi)	(ac)	(mi^2)	(ac)
Total U.S. Waters	3,533,205	41,666,049	87,791	107,700,000
Total Assessed Waters	*933,384*	*17,576,176*	*18,444*	*2,051,861*
Percent of U.S. Waters Assessed	26.4%	42.2%	21.0%	1.9%
Percent of Impaired Assessed Waters	49.6%	66.0%	63.7%	36.4%
Good Waters	464,428	5,928,815	6,687	1,304,892
Threatened Waters	6,355	47,330	17	805
Impaired Waters	**462,601**	**11,600,032**	**11,740**	**746,163**
Total Assessed Impaired Waters Directly or Indirectly Attributable to Roads/Bridges/Highways	**23.3%**	**5.8%**	**55.8%**	**14.6%**
DIRECT CAUSES OF IMPAIRMENT				
Urban-related runoff probable source group				
Highway/road/bridge runoff (non-construction)	7,712	18,705	2	NA
Construction probable source group				
Highway/road/bridge infrastructure	6,591	100,796	NA	NA
Forestry probable source group				
Forest & logging roads (construction and use)	1,273	NA	NA	NA
Directly Assessed Probable Impairment from Roads/Bridges/Highways	**3.4%**	**1.0%**	**0%**	**0%**
INDIRECT CAUSES OF IMPAIRMENT				
Habitat alterations (not directly related to hydromodification) probable source group				
Loss of riparian habitat	11,028	4,506	2,091	NA
Removal of vegetation	389	NA	NA	NA
Hydromodification probable source group				
Channel erosion/incision from upstream hydromodifications	723	NA	NA	NA
Channelization (including lined channels)	19,380	31,925	NA	220
Clean sediments	1,132	NA	1,916	NA
Erosion & siltation	12,520	2,300	2	NA
Flow alterations from water diversions	3,038	27,510	NA	1,000
Flow regulation/modification	199	NA	NA	NA
Hydromodification	17,660	302,373	607	98,412
Post-development erosion & sedimentation	1,369	16,185	NA	NA
Sediment resuspension	563	101,420	1,918	965
Streambank modifications/destabilization	10,227	63,721	NA	8,491
Transfer of water from an outside watershed	252	73	NA	NA
Upstream impoundment	8,122	7,647	13	NA
Water diversions	5,537	NA	NA	75
Indirectly Assessed Probable Impairment from Roads/Bridges/Highways	**19.9%**	**4.8%**	**55.8%**	**14.6%**

Notes: NA means Not Assessed, Not Available or Not Applicable.
Not all waters in U.S. have been assessed. Coastal waters, near shorelines, and oceans had no data for roadways or listed indirect causes.
Forest-clearing, wetland alterations, and mining and resource extraction activities are not included in this table.
Some entries have been aggregated where multiple entries used same title in database under same probable source group headings.
Indirect causes of impairment represent aggregated data for all potential source groups.
Statistics based on aggregated data collected from all reporting states.

Common Pollutants and Sources

The most common types of pollutants found in roadway runoff are sediment (total suspended solids: TSS and total dissolved solids: TDS), heavy metals, hydrocarbons (oils and grease), and pathogens. Concentrations of these pollutants vary widely depending on traffic loads, environmental setting and land use. For example, Huber et al. (2006) showed that TSS is generally greater for higher average daily traffic (ADT) loads. TSS concentrations averaged about 172 mg/L and had a widespread range from as low as 2 mg/L (Interstate 205 in Vancouver, Washington: 17 x 10^3 ADT) to as high as 8735 mg/L (Interstate 10 in Baton Rouge, Louisiana: 78 x 10^3 ADT).

Some common roadway pollutants are shown in Table EW-3.10 and their potential concentrations in Table EW-3.11 below.

Table EW-3.10: Common constituents and sources of road runoff (Shoemaker, Lahlou, Doll, and Cazenas, 2002)

Constituent	Source
Particulates	Pavement wear, vehicles, atmospheric deposition, maintenance activities
Nitrogen, Phosphorus	Atmospheric deposition and fertilizer application
Lead	Leaded gasoline from auto exhausts and tire wear
Zinc	Tire wear, motor oil, and grease
Iron	Auto body rust, steel highway structures such as bridges and guardrails, and moving engine parts
Copper	Metal plating, bearing and brushing wear, moving engine parts, brake lining wear, fungicides and insecticides
Cadmium	Tire wear and insecticide application
Chromium	Metal plating, moving engine parts, and brake lining wear
Nickel	Diesel fuel and gasoline, lubricating oil, metal plating, bushing wear, brake lining wear, and asphalt paving
Manganese	Moving engine parts
Cyanide	Anti-caking compounds used to keep deicing salts granular
Sodium, Calcium, Chloride	Deicing salts
Sulphates	Roadway beds, fuel, and deicing salts
Petroleum	Spill, leaks, antifreeze and hydraulic fluids, and asphalt surface leachate

Table EW-3.11: Common constituents and sources of road runoff (Shoemaker, Lahlou, Doll, and Cazenas, 2002; EPA, 2005; adapted in these sources from Barrett et al. 1995)

Parameter	Concentration (mg/L, unless noted)
Total Suspended Solids (TSS)	45-798
Volatile Suspended Solids (VSS)	4.3-79
Total Organic Carbon (TOC)	24-77
Chemical Oxygen Demand (COD)	14.7-272
Biochemical Oxygen Demand (BOD)	12.7-37
Nitrate+Nitrite (NO3+NO2)	0.15-1.636
Total Kjeldahl Nitrogen (TKN)	0.335-55.0
Total Phosphorus as P	0.113-0.998
Copper (Cu)	0.022-7.033
Lead (Pb)	0.073-1.78
Zinc (Zn)	0.056-0.929
Fecal coliform	50-590 (organisms/100 ml)

Other Quality Concerns: Temperature and Turbidity

Temperature and turbidity are two other common measures of water quality. Temperature, which is technically a physical characteristic of water, is usually included in quality measurements as an indicator of biological impacts, especially in sensitive aquatic habitats such as riparian areas (Hinman, 2005). Turbidity, or relative clarity of the water, is another physical measure that is used as an indicator of suspended sediment loads (EPA, 2006). Different jurisdictions and monitoring criteria will dictate whether these water quality parameters are measured for a water body.

Low Impact Development for Runoff Quality Control

A brief introduction to LID techniques was provided in Project Requirement PR-8. The relevant mechanisms at work that provide quality treatment with LID methods briefly described below (Shoemaker, Lahlou, Doll and Cazenas, 2002; City of Seattle, 2009). Most LID techniques incorporate more than one of these methods. Additionally, all flow control methods provide some degree of mitigating treatment or prevention for pollutant transport into receiving waters (Huber et al. 2006; Shoemaker, Lahlou, Doll and Cazenas, 2002).

- **Detention/Sedimentation.** Runoff is collected temporarily and released via a controlled outflow. The slow release allows for particles to settle out based on density.
- **Flotation.** Pollutants are pulled out of runoff by physical processes that separate them based on density (e.g. oil/water separators).
- **Biological removal mechanisms**. This includes vegetative and bacterial processes such as nutrient uptake or metabolization of organic or inorganic compounds.
- **Filtration/Sorption.** Pollutants are trapped and strained through different materials, such as fine sand.
- **Chemical treatment**. Chemicals are added to runoff to remove pollutants.
- **Proprietary treatment methods**. Mechanical or otherwise fabricated pollutant removal equipment.

Huber et al. (2006) presents a more detailed description of the LID processes. Table EW-3.2 presents the pollutant removal performance for several different types of LID BMPs that have been statistically analyzed and shown in terms of influent and effluent concentrations (Geosyntec Consultants and Wright Water Engineers, 2008). In general, a mix of all of these methods will be most effective on a site. "Treatment trains" or LID BMPs arranged in series can also be used to treat particularly polluted effluent in many cases (Quigley et al. 2009; SSI, 2009). Concentration, rather than percent removal, is the preferred reporting method for runoff quality performance for a number of reasons. A concise discussion of this reasoning is given at the BMPDB by Wright Water Engineers and Geosyntec Consultants (2007): http://www.bmpdatabase.org/Docs/FAQPercentRemoval.pdf.

Additionally, two of the methods described in Credit EW-2 Runoff Flow Control, compost amended soils (such as infiltration slopes) and design by avoidance (such as non-eroding roadways or planning alignments away from sensitive watersheds) also present significant water quality benefits.

Additional Resources

- For a good, brief summary of recent water quality literature for roadways through 2006, see Clarke et. al (2007). The discussion of roads and highways begins on page 39 and is available for free at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.87.9494&rep=rep1&type=pdf
- EPA's 2005 *National Management Measures to Control Nonpoint Source Pollution from Urban Areas* covers highways and bridges in Management Measure 7 (Chapter 7) and is available for download here: http://www.epa.gov/nps/urbanmm/
- Huber et. al (2006) compiled a comprehensive review of highway runoff control programs as part of the *National Cooperative Highway Research Program (NCHRP) Report 565: Evaluation of Best Practices for Highway Runoff Control.* This report is available in PDF format, with supplemental appendices, at: http://onlinepubs.trb.org/Onlinepubs/nchrp/nchrp_rpt_565.pdf
- A variety of guidance from the FHWA on water quality and stormwater management publications are available at: http://www.fhwa.dot.gov/environment/h2o_abs.htm
- FHWA (Shoemaker, Lahlou, Doll and Cazenas, 2002) provides guidance on ultra-urban BMP selection and monitoring available at: http://www.fhwa.dot.gov/environment/ultraurb/3fs10.htm
- AASHTO Center for Environmental Excellence provides an overview of water quality issues and wetlands available at: http://environment.transportation.org/environmental_issues/water_wetlands/

- Current performance data on quality control for LID BMPs is available at the International BMP Database: http://www.bmpdatabase.org. They also track cost data as it is volunteered along with submissions.

GLOSSARY

AASHTO	American Association of State Highway and Transportation Officials
ADT	Average daily traffic
Biodiversity	Total number of species present
Biological integrity	The ability to support and maintain a balanced, integrated adaptive assemblage of organisms having species composition, diversity, and functional organization comparable to that of natural habitat of the region (Karr and Dudley, 1981).
BMP	Best management practice
BMPDB	International BMP Database (http://www.bmpdatabase.org)
Detention	The process of holding and delaying runoff with a controlled release
EPA	Environmental Protection Agency
Erosion	Surface wearing due to physical processes such as water, wind and heat
FHWA	Federal Highway Administration
Flow control	Management of runoff volume physical characteristics including peak flows and time of concentration
Hydromodification	alteration of the hydrologic characteristics of coastal and non-coastal waters, which in turn could cause degradation of water resources (EPA, 2007)
IMP	Integrated management practice
Impaired water body	Bodies of water that have not met the water quality criteria for one or more of its assessed beneficial uses based on TMDL (EPA, 2008)
Impervious surface	a hard surface area that either prevents or retards the entry of water into the soil mantle or causes water to run off the surface in greater quantities or at an increased rate (Tilley and Slonecker, 2006)
Infiltration	the downward movement of water into the soil after surficial entry and percolation through pore spaces (Huber et al. 2006)
LA	Load allocation (used to compute TMDL), non-point sources
LEED	Leadership in Energy and Environmental Design™
Low impact development	a broad collection of engineered controls, stormwater management facilities, and other land development BMPs that attempt to mimic pre-development hydrologic conditions by emphasizing infiltration, evapotranspiration, or stormwater reuse for long-term flow control and runoff treatment
Non-point source	A diffuse generator of pollution or contaminants
Non-structural control	BMPs that depend on behavioral change and enforcement (Quigley et al., 2009)
Reach	The length of a river or stream between river bends
Retention	The process of holding runoff, ideally no release occurs and all runoff is infiltrated or evaporated
SSI	Sustainable Sites Initiative
Structural control	BMPs that use a wide range of hydrologic, physical, biological, and chemical processes to improve water quality and manage runoff.
TDS	Total dissolved solids
Threatened water body	Bodies of water that have met all relevant water quality criteria for its assessed beneficial uses based on TMDL but demonstrate an apparent decline in water quality (EPA, 2008)
TMDL	Total maximum daily load

TSS	Total suspended solids
Turbidity	Relative clarity of water
WLA	Waste load allocation (used to compute TMDL), point sources

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STORMWATER COST ANALYSIS

EW-4

1 POINT

GOAL

Determine lifecycle costs and savings associated with low impact development techniques and best management practices for stormwater utilities.

CREDIT REQUIREMENTS

Conduct a **lifecycle cost analysis** (LCCA) for stormwater utilities according to the National Cooperative Highway Research Program (NCHRP) Report 565: Evaluation of Best Management Practices for Highway Runoff Control Guidelines Manual.

NCHRP Report 565 can be accessed at the following link:
http://144.171.11.107/Main/Blurbs/Evaluation_of_Best_Management_Practices_for_Highwa_158397.aspx

The Guidelines Manual is available to download as a CD image file (*.iso). This file can be burned to a CD and then viewed as a PDF.

Details

Note: This credit is applicable only for projects where PR-8 has identified that low impact development technologies are appropriate for implementation for stormwater management.

DOCUMENTATION

Provide a copy of the LCCA spreadsheet showing the final results of the cost analysis and highlighting the final alternative chosen. The results must show, at minimum, that the following criteria have been addressed:

- Expected service life
- Construction costs
- Maintenance costs
- Interest rate
- Salvage value
- Estimated annual cost of the stormwater management system

RELATED CREDITS

- ✓ PR-2 Lifecycle Cost Analysis
- ✓ PR-7 Pollution Prevention Plan
- ✓ PR-8 Low Impact Development
- ✓ PR-10 Site Maintenance Plan
- ✓ EW-2 Runoff Flow Control
- ✓ EW-3 Runoff Quality

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Economy
- ✓ Extent
- ✓ Expectations
- ✓ Exposure

BENEFITS

- ✓ Improves Accountability
- ✓ Reduces Lifecycle Costs
- ✓ Creates New Information

APPROACHES & STRATEGIES

- Use a financial approach (strictly monetary costs and benefits) for the LCCA.
- Evaluate design alternatives based on the goals of the stormwater management plan.
- Set up a spreadsheet to compute costs based on budget inputs.
- Use estimated costs for LID BMPs available from the BMP Database (BMPDB) available at: http://www.bmpdatabase.org.
- Consider avoided costs of stormwater treatment at off-site locations, or avoided permitting costs.
- Include several different methods and alternatives in the evaluation of the stormwater system when performing the LCCA. Investigate both structural and non-structural controls, including conventional controls such as detention or infiltration (Huber et. al., 2006).

Example: LCCA Calculation

The following example uses the NCHRP Report outline to perform an LCCA for a potential stormwater system. The system being analyzed consists of 150 linear feet of 12-inch portland cement concrete pipe connected to two 48" manholes.

Table EW-4.1 shows the initial construction costs associated with the potential stormwater system.

Table EW-4.1: Initial construction costs.

Cost of 150 LF of 12" Concrete Pipe	$1,200.00
Cost of 2 48" Manholes	$4,800.00
Right of Way Cost	$100.00
Total Initial Construction Cost	**$6,100.00**

Table EW-4.2 shows some of the other costs associated with the stormwater system, including salvage value, interest rate, and design life.

Table EW-4.2: Incidental Costs

Annual Maintenance Cost	$300.00
Salvage Value	$750.00
Interest Rate	4.00%
Design Life (Years)	30

To begin the lifecycle cost analysis, all of the future and annual costs associated with the system must be converted into a present worth value.

First, the annual maintenance cost is converted into a present worth using Equation EW-4.1:

Equation EW-4.1:

$$P = A(\frac{(1+i)^n - 1}{i(1+i)^n} = 300(\frac{(1+.04)^{30} - 1}{.04(1+.04)^{30}} = \$5187.61$$

Secondly, the salvage value is converted into a present worth using Equation EW-4.2:

Equation EW-4.2:

$$P = \frac{F}{(1+i)^n} = \frac{750}{(1+.04)^{30}} = \$231.24$$

The total initial cost is then found by adding the total construction costs to the two calculated present worth values. This makes the total cost associated with this stormwater system $11,518.85.

Next, by annualizing this value using Equation EW-4.3, it can be shown that the annual cost for the new stormwater system will be $666.14 per year for a 30 year lifetime.

Equation EW-4.3:

$$A = P\frac{i(1+i)^n}{(1+i)^n - 1} = 11{,}518.85\frac{.04(1+.04)^{30}}{(1+.04)^{30} - 1} = \$666.14$$

POTENTIAL ISSUES

1. Complexity of the cost analysis will be proportional to the extent and labor involved in installing the stormwater utilities system.
2. LCCA does not necessarily reflect the actual cost or functionality of the finished stormwater system.

RESEARCH

Many agencies' project evaluation process considers only the initial capital costs of projects without considering long-term operations and maintenance. Focusing only on capital costs makes it less likely that projects will adopt stormwater controls that may have higher initial costs, but are less expensive to operate and maintain in the long term. There are also non-monetary risks and costs associated with stormwater systems that are relevant to decision-making such as permanent land use changes associated with detention ponds, a common feature of conventional stormwater infrastructure.

Overall capital and maintenance costs are not the only costs that should be involved in the lifecycle cost assessment. The cost of actually treating the stormwater should be included as well. Preliminary estimates in NCHRP Report 565 show that the cost of treating stormwater can vary from $0.10 to $3.00 per gallon based on the treatment methodology (Huber et.al, 2006).

Drastic changes to stormwater systems can affect both water quality and flow rates. Evaluating both in a lifecycle cost analysis as well as a water quality analysis can be an effective method of design evaluation. The design team should ensure that the overall goals of the stormwater system are not generated specifically on cost, but functionality as well (Huber et. al., 2006). Other possible factors to consider in design evaluation include existing infrastructure, property ownership, health and safety, and volume reduction (Huber et. al, 2006).

Case studies of 17 low-impact development installations for stormwater flow control and quality management were completed by the Environmental Protection Agency in 2007. Results of the study showed that applying LID techniques usually reduced project costs and had the added benefit of improved environmental performance (for both flow control and quality of discharge). In some cases, LID was more expensive than conventional best management practices, due in part to contractor unfamiliarity. In most cases, significant capital costs were reduced by avoiding grading, stormwater infrastructure, additional paving and vegetation. Savings ranged from 15-80 percent with the few exceptions mentioned (EPA, 2007).

GLOSSARY

LCCA	Lifecycle cost analysis

REFERENCES

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SITE VEGETATION

GOAL

Promote sustainable site vegetation that does not require irrigation.

CREDIT REQUIREMENTS

Site vegetation shall be subject to the following requirements in order to receive the points listed:

- **1 point:** Use non-invasive plant species only
- **1 point:** Do not use water (no irrigation) after the plant establishment period
- **1 point:** Use native plant species only

Details

"Site vegetation" is defined as all vegetation associated with a particular roadway project and shall include all vegetation within the roadway's right-of-way. This can include roadside vegetation, decorative planting (e.g., planter boxes or potted plants in urban areas) and vegetation contained in stormwater facilities (e.g., bioswales and rain gardens).

The following items must be performed to ensure that a plant species is considered "non-invasive":

1. Consult existing local (e.g. city, county, state, park service) vegetation policy and procedure that is applicable to the roadway project and is specifically formulated to prevent the use of invasive plant species and noxious weeds.
2. Use local and/or regional lists to identify invasive plant species.
3. Comply with local and/or national noxious weed laws.

"No water use" means that the site vegetation will not require any irrigation after the plant establishment period. The "plant establishment period" shall be stated in the project specifications. Typical plant establishment periods are 1-3 years. This requirement means that vegetation requiring irrigation such as seasonal planter boxes cannot receive the associated point even if it is fully comprised of non-invasive or native species.

"Native plant species" are plants native to the EPA Level III ecoregion that contains the roadway project site or known to naturally occur within 200 miles of the roadway construction site (The Sustainable Sites Initiative, 2009a).

DOCUMENTATION

- A vegetation or landscape plan showing type and location of all plant species. This can often be found in the standard project plans.
- The specification sections relating to site vegetation including planting bed requirements. These are typically found in the technical specifications.
- A copy of or reference to (e.g., web address) the policy or procedure used to select plant species.

EW-5

1-3 POINTS

RELATED CREDITS

- ✓ PR-10 Site Maintenance Plan
- ✓ EW-3 Runoff Quality
- ✓ EW-6 Habitat Restoration

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Economy
- ✓ Equity
- ✓ Extent

BENEFITS

- ✓ Reduces Water Use
- ✓ Reduces Water Pollution
- ✓ Reduces Greenhouse Gases
- ✓ Reduces Solid Waste
- ✓ Increases Aesthetics

APPROACHES & STRATEGIES

Use a Pre-Defined List of Approved Plants

In many cases the local road owner (e.g., City, County, State or other authority) already has a pre-defined list of acceptable plant species for site vegetation. Usually, these lists have been carefully developed to exclude invasive plants and noxious weeds; however they should still be checked against local/regional lists and laws. Often times, these pre-defined lists also identify native plants and drought tolerant plants (e.g., no water use). Following such lists can often achieve the non-invasive species point and zero water use point. Selecting native plants species (which may also be identified on these lists) can then earn the third point.

Pre-defined lists are advantageous because they are straightforward and easy to follow; plants are either on the list or not. However, when used alone they may not provide adequate guidance on establishing long-term ecosystem goals, management of site vegetation after planting, appropriate location and density of vegetation and other more advanced concepts.

Follow a Pre-Defined Process

It may be possible to identify a site vegetation process that has been approved or adopted by the local authority. These processes typically identify the site vegetation strategy and describe the actions and major steps needed to establish site vegetation. These plans can be complex, such as Western Federal Lands Highway Division's *Roadside Revegetation: An Integrated Approach to Establishing Native Plants* (Steinfeld et al. 2007) or more general in nature like Xeriscape Colorado (Colorado Waterwise 2009).

Sustainable Sites Initiative

One robust pre-defined process is associated with the Sustainable Sites Initiative (www.sustainablesites.org). This is "an interdisciplinary effort…to create voluntary national guidelines and performance benchmarks for sustainable land design, construction and maintenance practices." (The Sustainable Site Initiative 2009c). A roadway project participating in the Sustainable Sites Initiative program and recognized as a "sustainable site" would likely quality for at least 1 point in this Voluntary Credit and, depending upon which Sustainable Sites credit benchmarks are achieved, could achieve all 3 points. Overall, the Sustainable Sites Initiative is a more robust set of benchmarks for site vegetation than Greenroads because its scope is limited to site development and does not include roadways, mobility, access or other metrics associated with transportation.

Have an Expert Develop a Site-Specific Vegetation Strategy

In the absence of existing guidance, it may be necessary to have an expert develop an entirely new site-specific vegetation plan. While this is an acceptable option, the expertise and time to develop the plan can be expensive in relation to the amount of site vegetation; especially on small projects where vegetation is limited. In addition to careful selection of appropriate plants, plan development requires consideration of planting bed specifications, topsoil needs, and planting techniques. Finally, long term maintenance plans and goals must be established for the plant community.

Example: City of Portland, OR

The City of Portland's Bureau of Planning and Sustainability has maintained a *Portland Plant List* since 1991. This list includes:

- **Native plants**. Plants historically found in the City of Portland. They are grouped by type (tree, arborescent shrubs, shrubs and ground covers) and include the scientific name, common name, and wetland indicator status and habitat type.
- **Nuisance plants**. Plants that can be removed manually without requiring an environmental review or greenway review. Plants are considered a nuisance because they have a tendency to dominate plant communities or are harmful to humans. Nuisance plants may be native, exotic or naturalized.
- **Prohibited plants**. Plants prohibited from use in all reviewed landscaping situations. These plants pose a serious threat to native plant and animal health/vitality.

Example: City of Seattle, WA

The City of Seattle provides guidance for project site vegetation using:

- Department of Transportation suggested plant list for street use.
- Links to plant selection databases.
- Tree protection ordinance, specifications and standard plans.
- Heritage tree program.
- Recommended street tree list.
- Landscape standard plans.

The suggested plant list for street use is called the “Seattle Green Factor Plant List” (http://www.seattle.gov/dpd/static/Green%20Factor%20Plant%20List_LatestReleased_DPDP015968.pdf).

Example: Western Federal Lands Highway Division

In 2007, Western Federal Lands Highway Division (WFLHD) published a native revegetation manual (Steinfeld et al. 2007) that they now use as their standard process for revegetating disturbed land on roadway projects. This manual does not provide a specific plant list but rather describes a comprehensive process for roadside revegetation and creation of a sustainable plant community. This process includes (1) necessary integration, (2) initiation, (3) planning, (4) implementation and (5) monitoring, and is illustrated on the web at: www.nativerevegetation.org.

Example: Sustainable Sites Initiative Case Studies

The Sustainable Sites Initiative website contains a number of case studies demonstrating sustainable landscape practices at: http://www.sustainablesites.org/cases

POTENTIAL ISSUES

1. Site planting without proper integration with other roadway activities (e.g., maintenance, roadside safety).
2. Inadequate plant establishment.
3. Not considering the suitability of a plant species specific for site conditions including cold/heat tolerance, salt tolerance and soil pH, sun/shade requirements, pest susceptibility, and maintenance requirements (The Sustainable Sites Initiative 2009). The roadway environment might be significantly different from the surrounding area, and may not necessarily support its indigenous plant species.
4. Site vegetation must be considered in the context of soils, compaction, slopes, and hydrology in order to be successful on road projects.
5. Disturbed soil conditions must be modified to create conditions that will sustain native plant growth. Planting beds should be prepared based on disturbed conditions and specified in project docuements.
6. This Greenroads credit does not currently track projects beyond construction to ensure continued maintenance and no water use.

RESEARCH

Site vegetation can impact four primary roadway sustainability components: ecology, economic, equity and extent. In the broad sense, arguments for sustainable site vegetation center on their contribution to the local ecosystem, which leads to broad arguments for how ecosystems and ecosystem services affect these areas of sustainability. In a more narrow sense, arguments for sustainable site vegetation center on how they may influence project specific ecological issues, costs, safety, culture, and durability. While these issues are often thought of as self-evident, it can be difficult to find quantifiable empirical evidence to use as proof. The following sections address site vegetation impacts by category.

Ecological

Site vegetation is part of the local ecosystem. The Millennium Ecosystem Assessment (2005) defines an ecosystem as "…a dynamic complex of plant, animal, and microorganism communities and the nonliving environment interacting as a functional unit." These can be systems relatively untouched by humans (e.g., natural forests) or those that have been significantly modified (e.g., urban areas and agricultural lands) (MEA 2005). In looking at ecosystems over the last 50 years the Millennium Ecosystem Assessment (2005) arrived at four major findings:

- Over the past 50 years humans have changed ecosystems more rapidly and extensively than in any comparable period of human history.
- Ecosystem changes have contributed to substantial net gains in human well-being and economic development, but these gains are at the expense of substantially diminishing the benefits that future generations obtain from ecosystems.
- The degradation of ecosystem services could grow significantly worse during the first half of the twenty-first century.
- Reversing ecosystem degradation can be done but involves significant changes in policies, institutions and practices that are not currently underway.

Thus, to the extent that site vegetation helps manage ecosystems more sustainably, it can contribute positively, though perhaps only slightly, to the reversal of some of the degradation seen over the last 50 years. Benefits attributed to more sustainable site vegetation include the regional and local impacts outlined below (MEA 2005):

Regional:
- Better air quality
- Climate regulation
- Water regulation
- Erosion regulation
- Water quality
- Pest regulation
- Pollination
- Natural hazard regulation

Local:
- Lower water use
- Reduced erosion
- Prevention of exotic plant species from out-compete native species
- Better survivability of site vegetation because it is better-adapted to the local environment (though plants indigenous to the local ecosystem are not necessarily suitable for the altered roadway environment).

Economic

As part of the local ecosystem, site vegetation can, in a broad sense, provide economic benefits such as clean air, clean water, food, renewable resources and waste decomposition (The Sustainable Sites Initiative, 2009b). It is difficult to value ecosystem services properly because (1) our attempts to value them are generally based on human values and not what might be considered objective value sets, and (2) they are not fully valued or quantified in commercial markets or policy decisions (Costanza et al. 1997). Nonetheless, attempts have been made to value ecosystem services that can provide insight. Costanza et al. (1997) provide a comprehensive overview on the value of the world's ecosystem services based on a synthesis of previous work. In short, they found a range of potential values of US$16 -54 trillion/yr with a mean of US$33 trillion/yr for 17 ecosystem services (in 1994 US dollars). This compares to a world gross national product (GNP) of US$18 trillion (1994 US dollars) making ecosystem services about 1.8 times the global GNP if the mean value is assumed. This estimate is based on marginal cost by "…determining the differences that relatively small changes in these services make to human welfare." (Costanza et al. 1997). They acknowledge that their estimates are on the low side, incomplete and flawed but reason that some estimate is better than none (Costanza et al. 1997).

In a narrow sense, site vegetation contributes to individual project cost over its life cycle if costs such as site maintenance, water demand, erosion control and problematic vegetation control are considered (Steinfeld et al. 2007a). One example of this comes from the City of Santa Monica in their garden\garden demonstration project. In this project the City and Water District compared two landscape strategies: sustainable vs. traditional (Santa Monica Office of Sustainability and Environment 2009). Table EW-5.1 summarizes some findings from the comparison.

Table EW-5.1: Landscape Comparison in Santa Monica, CA for the entire year of 2007

Category	Sustainable Landscape	Traditional Landscape
Initial Construction Cost	$16,700	$12,400
Water Use	14,300 gallons	76,700 gallons
Annual Water Cost	$14	$74
Yard Waste	250 lbs	670 lbs
Maintenance	15 hours	80 hours
Annual Maintenance Cost	$800	$3,000

It should be noted that direct comparisons between sustainable and traditional vegetation with actual values for cost, water use, waste, etc. such as that done by the City of Santa Monica are difficult to find.

Equity

As part of the local ecosystem, site vegetation can provide human equity benefits such as improved human health (e.g., better water quality) and cultural services like spiritual and religious values, recreation and aesthetics (MEA 2005). On a local scale, site vegetation can contribute to improved roadway safety by improving visibility and can create natural beauty that is appreciated and valued by motorists.

Extent

Site vegetation can also have an impact on the durability of a particular project, which affects project life or at least the level of necessary maintenance to achieve a specific project life. For instance, native revegetation of a highway roadside can be better than traditional non-native turf coverage because it can have a higher probability of surviving, last longer, require less maintenance and better prevent soil erosion based on a deeper and more hearty root structure (see comparison between Figures EW-5.1 and EW-5.2).

Figure EW-5.1: A failing revegetation effort on a steep slope that did not use a native revegetation approach (from Steinfeld et al. 2007a).

Figure EW-5.2: A native roadside revegetation in Glacier National Park (from Steinfeld et al. 2007a, photo by Tara Luna).

GLOSSARY

Native plant	Plant that is native to the EPA Level III ecoregion that contains the roadway project site or known to naturally occur within 200 miles of the roadway construction site (Sustainable Sites Initiative, 2009a).
Plant establishment period	Duration of time that allows newly installed vegetation to reach a state of maturity that requires minimal ongoing maintenance for survival. Activities during the plant establishment period can include: removal of litter and trash, weeding, water application (even for non-irrigated vegetation), replacement of dead plants and pest control (including the use of approved pesticides).
Xeriscape	A set of gardening principles designed to save water while creating a lush and colorful landscape.

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HABITAT RESTORATION

GOAL

Offset the destruction and deterioration of natural habitat caused by road construction. Restore and protect natural habitat beyond regulatory requirements.

CREDIT REQUIREMENTS

Complete Option A or B.

Option A – For projects required to mitigate habitat impacts through restorative practices (3 points)
Implement a restoration/preservation plan that restores and/or preserves more area by 5% beyond what is required such that one of the following metrics below is met:

1. Total area of restored and/or preserved habitat equals or exceeds 105% of total required mitigation area
2. Total restoration and/or restoration cost equals or exceeds 105% of total cost required for restoration/preservation due to the roadway project

Option B - For projects not required to mitigate habitat impacts through restorative practices (3 points)
Conduct a biological assessment of the pre-development condition of the project site and surrounding ecosystem or watershed and implement a restoration plan that includes all seven items below:

1. Restores an area equal to the total disturbed surface area of the roadway project.
2. States quantifiable goals regarding at least one of the performance metrics outlined below.
3. Describes ecological design or engineering elements that are expected, with reasonable professional certainty, to meet the goals stated above.
4. Lists responsible parties for restoration activities and subsequent monitoring efforts.
5. Lists sources of funding for restoration activities and subsequent monitoring efforts.
6. Completes restoration activities prior to the roadway facility opens to traffic, ideally during project planning.
7. Is signed and approved by the responsible parties or the project ecologist.

Details

Disturbed surface area includes all cut and fill soils for pavement areas, shoulders, embankments, bridge abutments and construction staging areas. In other words, any earthwork area that is required for the road itself is included, but the area designated for habitat creation or restoration is not.

The total required surface area can be made up of multiple types of restoration and preservation efforts, so long as the project team can show that the total restored and preserved areas meet the above requirements.

Preserved habitat areas may not be previously designated open space. Preservation designations must be directly associated with the project and be in place by 40

EW-6

3 POINTS

RELATED CREDITS

- ✓ EW-2 Runoff Flow Control
- ✓ EW-3 Runoff Quality
- ✓ EW-5 Site Vegetation
- ✓ EW-7 Ecological Connectivity
- ✓ EW-8 Light Pollution

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Equity
- ✓ Extent
- ✓ Experience

BENEFITS

- ✓ Restores Habitat
- ✓ Creates Habitat
- ✓ Reduces Manmade Footprint
- ✓ Increases Aesthetics

years after the end of construction, the expected design lifetime of the project, or local regulations, whichever is longest. Preservation areas must also be:

- Formally designated permanent as open space according to the definitions of the governing agency or zoning authority.
- Clearly and publicly attributed to the work done for the roadway project.
- Compliant with all applicable zoning requirements of the jurisdiction.
- Appropriately vegetated for the location and context.

The following performance metrics are considered suitable for achieving credit where a restoration plan is developed:

- For roadways with watersheds receiving stormwater runoff from the roadway, determine the predevelopment Index of Biological Integrity (IBI) as part of the biological assessment. **Predevelopment IBI** (for purposes of this credit only) means the reference condition for this metric that is established exclusively for restoration work for the roadway project, measured within a reasonable amount of time prior to groundbreaking of construction. Set a target IBI that meets or exceeds predevelopment conditions.
- For roadway projects including stream restoration, set a target limit on unstable slopes. This target should not exceed predevelopment conditions. In addition, establish a minimum riparian buffer width for the stream.
- For forest restoration, maintain areas of interior habitat equal to predevelopment conditions. Interior habitat requirements (distance to forest edge) should be defined in the biological assessment.
- Restoration of Brownfield sites must result in removal of Brownfield status. This should result in land that is suitable for development. Note that this includes Brownfield land used for the roadway corridor.
- If a specific species is the target of a restoration plan, set population goals for the target species. Plant and animal species are both acceptable, but must be native to the project region.
- Other restoration goals as recommended by the project ecologist, biologist, or other restoration expert. Justification of this goal should be included in the restoration plan.

While these metrics represent important performance indicators, the overall goal of the restoration project should be promotion of biodiversity and creation of dynamic, functioning habitat.

DOCUMENTATION

- Copy of the executive summary from the biological assessment.
- Copy of the restoration/preservation plan, highlighting the boundaries of the restored areas and the roadway project. If offsite, provide separate plans showing both areas.
- Copy of the schedule of restoration activities or preservation efforts demonstrating that the completion of all restoration activities and preservation efforts coincides with or occurs prior to opening to traffic.

APPROACHES & STRATEGIES

- Follow the guidelines for habitat restoration outlined in the Federal Highway Administration Eco-logical: An Ecosystem Approach to Developing Infrastructure Projects (Brown, 2006). Eco-logical can also be used for guidance in development of regional ecological frameworks. This document is available at: http://www.environment.fhwa.dot.gov/ecological/eco_index.asp
- Involve an ecologist or other biological professional early in the planning phase of the project to determine feasibility of restoration work.
- Coordinate with land use management agencies early in the planning phase of the project to determine scope and significance of potential restoration activities.
- Coordinate with water management agencies early in the planning phase of the project to determine IBI for the biological assessment, especially in the cases where stormwater runoff from roadways is not treated.

- Use geographic information systems (GIS) mapping software to determine calculations for disturbed and restored surface areas.
- Anticipate that restoration activities take a significant amount of thoughtful planning, and are best started prior to the construction of the roadway project.
- Start a community stream monitoring effort. Most bioindicator species can be identified by amateurs and those willing to learn well enough to establish at least a family taxonomic level. (University of Washington, 2001)
- Collaborate with adjacent governing agencies to create mutually beneficial (and potentially mutually funded) restoration projects in conjunction with the roadway.
- Coordinate with water resources professionals early in the planning phase of the project to develop and implement a watershed management plan in tandem with a habitat conservation plan (Brown, 2006). Roadway projects can be integrated into both types of plans, including establishing minimum goals for treatment of stormwater impacts on water quality for receiving water bodies and preservation of aquatic habitat.
- Avoid introduction of invasive species through landscaping activities. See also Credit EW-5 Site Vegetation.

Example: Off-Site Mitigation - Springbrook Creek Wetland & Habitat Mitigation Bank

The Springbrook Creek Wetland & Habitat Mitigation Bank was a combination of wetland enhancement and restoration covering 130 acres in Renton, Washington. These efforts were aimed at mitigating the increased runoff caused by construction of additional lanes on Interstate 405 and future regional transportation projects, as well as creating wildlife habitat. The project site is located in an area surrounded by heavy development and two major freeways. An emphasis was placed on the planting of a large variety and number of native plants, enhancing the attractiveness of the site to local fauna. In addition, a boardwalk was constructed through the site to raise public awareness of the importance of wetland habitat. Construction was completed in June, 2009. Figures EW-6.2 and EW-6.3 show the restored wetland and boardwalk, as well as local wildlife.

More information on this project is available at: http://www.wsdot.wa.gov/Projects/i405/Springbrook/

Figure EW-6.2: Geese family in the Springbrook Creek wetland (Photo by WSDOT)

Figure EW-6.3: Great blue heron perched on boardwalk (Photo by WSDOT)

Example: Management Tools for Habitat Restoration

There are several guidance documents available for roadway projects on watershed assessment and habitat restoration from many public agencies.

- State Wildlife Action Plans. Comprehensive wildlife conservation strategies are mandated by the federal government and managed by the states. These strategies offer broad reaching wildlife goals tailored to each state. Helpful resources, including sample plans, are available through the Association of Fish & Wildlife Agencies: http://www.wildlifeactionplans.org
- EPA's Handbook for Developing Watershed Plans to Protect and Restore Our Waters. EPA provides a wealth of informational resources on watershed planning: http://water.epa.gov/polwaste/nps/handbook_index.cfm
- The National Action Plan to Implement the Hydrogeomorphic Approach to Assessing Wetland Functions. This action plan provides ways to measure watershed functions: http://water.epa.gov/lawsregs/guidance/wetlands/hgm.cfm

Example: Indiana Department of Transportation and Indiana Bat Habitat

The need for highway improvements near the Indianapolis International Airport brought together several agencies, including the Indiana Department of Transportation and the local Federal Highway Administration, to develop a plan to protect and conserve local habitat for the Indiana bat, an endangered species. The plan, called the HCP (Habitat Conservation Plan) has the following features that would help meet this credit:

- 3,600 acres protected (approximately 10% existing bat habitat)
- 346 acres of newly planted habitat
- A public outreach program
- A 15-year monitoring program

The HCP was completed in conjunction with approximately $1.5 billion in highway improvements in an area forecasted for high urban growth. More information about the HCP can be found in *Eco-Logical* (Brown, 2006).

POTENTIAL ISSUES

1. Ecologists and environmental engineers are not always aware of all biological or habitat needs of all species that may be targeted for a habitat, nor can all of the resources to meet these needs be acquired in all cases. Thus, there is a large amount of uncertainty underlying many ecological assumptions made.

2. Restored or engineered wetland and habitat areas may function well, but placement within a largely developed area can severely limit interaction of species within the site.
3. Adjacent habitat can influence whether a target species can use a site because many species use multiple habitats as part of their lifecycle. In particular, most large species also do not live in one habitat during their entire life.
4. Habitat age can influence the degree to which species use an area. Created sites are always ecologically young.
5. Completing restoration activities in tandem with roadway construction may not be optimal. Mitigating activities such as restorations often function best when completed prior to the start of construction so that the newly mitigated habitat can stabilize and be fully functional. Specificity of design does not necessarily dictate successful use by particular species of wildlife. Detailed targeting efforts do not always work, even if species-specific design features of a habitat are incorporated.
6. During the lifetime of a habitat, all targeted species may use the site, but not necessarily all at the same time. Monitoring expectations should therefore be set accordingly.
7. Some habitats cannot be fully restored to predevelopment conditions.
8. Loss of biodiversity or species diversity is difficult, if not impossible, to replace.
9. Many newly restored habitats, especially sensitive or critical ones, may not function as efficiently or effectively as planned and intended. Only some of the functions may be successfully replaced or improved artificially.
10. Planners and designers should be taken to avoid locating or creating potentially sensitive habitat near edges and boundaries of roadway projects. Where possible, the roadway clear zone should be maintained to preserve safety and visibility.
11. Monitoring and data collection efforts should be tied to performance metrics determined during the planning stage of restoration projects to make them meaningful.

RESEARCH

Natural ecosystems provide a variety of important services to both human and non-human life, and rely on a wide array of complex interactions to function. Inevitably, the change of land use by human development can disrupt these delicate processes, or eliminate important areas of ecosystem altogether. Habitat restoration is the process of retaining the natural functionality of a given impacted ecosystem, through local improvement or the creation of analogous ecosystem elsewhere. In practice, many restoration projects are aimed at restoring watershed management activities, known as "wetland restoration". However, restoration can apply to damaged non-aqueous ecosystems as well, which are not always regulated to similar standards. While restoration efforts are often oriented towards a particular ecosystem function, it is recognized that ecosystems function most effectively under natural conditions (EPA, 1994). Restoration is a delicate process requiring significant knowledge of the specific ecosystem at hand, and monitoring efforts are usually required to ensure the continuing success of a restored habitat. Legal mandates (primarily the Clean Water Act) and or political directives generally dictate the type and method of most watershed restoration processes, as well as monitoring requirements.

Roads and Habitat Loss

Roads and highways can negatively impact natural habitat in a number of ways. These impacts have traditionally been divided into destruction, fragmentation, and degradation of habitat (EPA, 1994; Ament et al, 2008). Destruction refers to the actual replacement of habitat by roadway placement. This includes the roadway itself as well as any substantially altered corridor. Fragmentation is the breaking up of remaining habitat and elimination of critical migration pathways. In addition, fragmentation of habitat area increases the proportion of "edge" habitat exposed to the outside environment, which can have significantly different characteristics from interior habitat (Fuentes-Montemayor et Al, 2009). Degradation involves disturbances to surrounding habitat due to factors such as noise, pollutant contamination, and other secondary impacts. Road construction, for example, can introduce invasive species, alter soil properties, increase erosion, etc. (Forman and Alexander, 1998).

A particularly important degradation effect of roads is the creation of polluted runoff. As a result of the range of these various impacts, road construction disturbs habitat in an area much greater than the actual roadway corridor. Because roads cover approximately one percent of the United States, their ecological effects have widespread impacts (Forman and Alexander, 1998).

The Importance of Habitat Loss

Natural ecosystems provide a variety of important services to both human and non-human life, and rely on the presence of suitable habitat to function. Loss of habitat disrupts the important benefits of these ecosystems. Natural processes have important functions: maintaining air and water quality, regulating climate, production of goods, and other important processes (Wilson, 2002). The global value of these services has been estimated to be between 16 and 54 trillion dollars annually (Constanza et al, 1997).

In a roadway setting, preservation of surrounding habitat can aid in stormwater control, a function made increasingly important by the extra runoff created by the roadway itself (NCHRP, 2006). In addition, habitat destruction leads to the reduction of biodiversity (Wilson, 2002). Societal acceptance of the value of biodiversity in the U.S. has been exemplified explicitly in legislation such as the Endangered Species Act (1973), which states that "species of fish, wildlife, and plants are of esthetic, ecological, educational, historical, recreational, and scientific value to the Nation and its people". In addition, biodiversity is often considered an economic good based on its importance in science, industry, and medicine. Therefore, preservation of biodiversity is vital to both to ecosystem health and human health (Wilson, 2002).

Precedent for Restoration

Most of the required habitat restoration in the United States is mandated by Section 404 of the Clean Water Act, which regulates activity in U.S. waters including wetlands. To obtain a permit under this act, the developer must show that measures have been taken to avoid and reduce wetland impacts, and that any necessary impacts have been compensated for (EPA, 2009a). Habitat restoration can be considered a form of compensation through the creation of new wetland environments. Construction of wetlands has also traditionally been used as a "best-management practice" for acquisition of a permit under the National Pollutant Discharge Elimination System (NPDES), which is generally required by the Clean Water Act when construction will cause pollutant discharge to surface waters (NCHRP, 2006).

In addition, habitat restoration can be employed to meet the requirements of the Endangered Species Act. Actions which would cause incidental harm to a conserved species (including habitat loss) require submittal of a Habitat Conservation Plan (HCP). These HCP's must show that "the applicant will, to the maximum extent practicable, minimize and mitigate the impacts of the taking". Similar to the provisions of the clean water act, restoration of previously disturbed habitat can satisfy requirements for mitigation efforts. (U.S. FWS, 2009)

Brownfield Restoration

The term **brownfield** refers to an area in which development or use has been complicated by a threat of contamination. This is commonly a result of previous industrial use but is caused by other activities as well. Remediation of these areas, which usually involves soil and groundwater cleanup, can convert the land back to usable condition. This increases the value of the property and can help preserve undeveloped land. Private developers are often reluctant to remediate brownfields due to financial risks and liability issues, however many different government agencies incentivize these activities (Opp, 2009). The Environmental Protection Agency (EPA) has created a Brownfields Program that provides funding to brownfield revitalization projects, which has in turn contributed to higher levels of owner investment, creation of jobs, and increases in nearby property values (EPA, 2009). In addition, each state has their own brownfield program, providing varying levels of funding and liability protection for cleanup efforts (Opp, 2009).

A number of treatment methods exist for the removal of hazardous pollutants from soil and groundwater. These can be broken down into techniques that remove contaminants through biological, chemical, or physical processes (Hamby, 1996). Bioremediation refers to the use of microorganisms that can break down or transform dangerous chemical compounds through their own metabolic pathways. When appropriate, this can be a low-cost alternative to other remediation options (Hamby, 1996, EPA, 1991). Phytoremediation, another example of a biological approach, uses plants to clean soil and groundwater through sorption and water uptake. Chemical methods rely on the introduction of compounds that can destroy, transform, bind to, or otherwise render contaminants harmless. Finally, physical techniques include treatments such as stripping, pumping, and washing of the soil or water in question (Hamby, 1996). Both of these categories are to numerous and varied to be discussed in detail here.

Index of Biological Integrity

The **Index of Biological Integrity** (IBI) is a multi-metric assessment tool that characterizes the biological functionality of a water body based on a number of sensitive biological measures. Specifically, IBI (and other derivatives of this metric) measures the impacts of human activities on biological communities. Integrity of living systems within a water body is required to perform necessary ecosystem services (Karr and Chu, 1997). Thus, "biological integrity" is the "ability to support and maintain a balanced, integrated adaptive assemblage of organisms having species composition, diversity, and functional organization comparable to that of natural habitat of the region" (Karr and Dudley, 1981). As a result, the IBI provides important information about the condition of a water body relative to surrounding levels of human influence. A key point is that determination of the IBI requires trained biologists familiar with the specific aquatic ecosystem.

Additionally, since it is a relative measure, use of the IBI requires determining a reference condition for the area. The EPA (2006) describes the reference condition for biological integrity, RC(BI), as "the natural biological condition of a water body, undisturbed by human activity. As a conceptual aid, it is useful to think of an absolute 'natural' or pristine condition that could exist in the absence of all historical and current human disturbances. This definition recognizes the need for a reference condition term reserved for 'naturalness' or 'biological integrity' even though we might only approximate it in most parts of the world." It also requires some level of data collection, some of which may already be established via continuous monitoring. Data for computing IBI scores is based on the "lowest practical taxonomic level" which means to the furthest taxonomic extent allowed by current science (University of Washington, 2001) for local "bioindicator species" (EPA, 2009b) for purposes of this credit. Examples of common bioindicator species are macroinvertebrates, which are aquatic insects ("benthos," hence, the Benthic-IBI).

GLOSSARY

Benthos	Greek for macroinvertebrates
B-IBI	Benthic Index of Biological Integrity
Biodiversity	Total number of species present
Bioindicator	See "indicator species"
Biological Integrity	The ability to support and maintain a balanced, integrated adaptive assemblage of organisms having species composition, diversity, and functional organization comparable to that of natural habitat of the region (Karr and Dudley, 1981).
Brownfield	An area made unsuitable for development by previous use, commonly industrial.
Ecosystem Services	Natural processes that provide benefits for humankind
Fragmentation	Division of a single population or disruption of migration routes between smaller populations
IBI	Index of Biological Integrity
Indicator species	A species which responds predictably to stressors from human disturbance (EPA, 2009b)
RC(BI)	Reference condition for biological integrity
Reference condition	The natural biological condition of a water body, undisturbed by human activity. As a conceptual aid, it is useful to think of an absolute 'natural' or pristine condition that could exist in the absence of all historical and current human disturbances (EPA, 2006)
Total disturbed area	Any area disturbed for construction activities including construction staging areas and cleared or stripped plant life, but not including any areas designated for restoration or habitat creation purposes

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ECOLOGICAL CONNECTIVITY

GOAL

Provide or improve wildlife access and mobility across roadway facility boundaries and reduce vehicle-wildlife collisions and related accidents.

CREDIT REQUIREMENTS

Complete a site-specific wildlife assessment for the roadway project. Report the resulting impacts that the roadway has on surrounding major ecosystems, identifying all non-human life that is impacted by the roadway facility according to the best scientific knowledge available for the ecosystem. Both point scenarios below require approval of the project ecologist.

AND

Complete one of the two of the following options:

OPTION A - Existing Alignments ONLY (1 point)
Replace in-kind, retrofit, or upgrade any and all existing culverts and wildlife fencing structures deemed structurally deficient, damaged, obsolete, insufficiently sized, or otherwise inadequate.

OR

OPTION B - New and Existing Alignments (3 points)
Install new dedicated wildlife crossing structures and protective fencing (if needed) as recommended by the wildlife assessment. In addition, existing alignments must also replace in-kind, retrofit, or upgrade all existing culverts and fencing structures deemed structurally deficient, damaged, obsolete, insufficiently sized, or otherwise inadequate.

Details

Dedicated wildlife crossings are structural features of the roadway that are not used by motorized vehicles. Where deemed appropriate by an ecologist, crossings may be shared by non-motorized modes of transport. No points will be awarded in the following conditions:

1. For projects that maintain or rehabilitate existing ecological connections to out-of-date or current standards (i.e. routine maintenance of drainage culverts does not qualify).
2. Pre-existing ecological connectivity features: all new features or upgrades must be due to and completed as part of the roadway project.
3. Projects that add wildlife connectivity features where such features are clearly outside of the project context.
4. Projects located in a network that is systematically inadequate. However, points could be awarded for such projects where it is demonstrated that a program is in place at the owner-agency for systematic improvements on that network, and that this project fits this program.

EW-7

1-3 POINTS

RELATED CREDITS

- ✓ PR-1 Environmental Review Process
- ✓ PR-10 Site Maintenance Plan
- ✓ EW-6 Habitat Restoration
- ✓ AE-1 Safety Audit

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Experience

BENEFITS

- ✓ Restores Habitat
- ✓ Reduces Manmade Footprint
- ✓ Improves Access
- ✓ Improves Mobility
- ✓ Improves Human Health & Safety

DOCUMENTATION

1. Copy of the executive summary of the ecological study performed for the project. At minimum, this summary should contain:

   a. Site location map and site plan. Highlight locations, types and sizes of ecological connections in the facility.
   b. A list of non-human species identified. Include common name, Latin name, size, photos of the species, and highlight the largest species.
   c. The size of the connection required in order to accommodate the largest species identified above
   d. A list of planned new dedicated connections, new culverts and fencing to be installed, and any upgraded culverts and fencing installations.
   e. Signature of the project ecologist.

2. Photos of all culverts and fencing (new and upgraded, if any) and dedicated crossings after construction. Use a familiar object in the photo for scaling purposes (hammer, measuring tape, shovel, etc.) or provide scale on the image.

APPROACHES & STRATEGIES

- For existing projects, use roadkill data to identify key species in the project area. In addition, if underpasses or other similar structures exist for other purposes than ecological connectivity, monitor animal or aquatic organism movement through these passages.
- For new and existing projects, determine the makeup of animal populations in the area and migration patterns. Animal population data can be obtained from existing ecological records or by more traditional methods such as the analysis of tracks or other identifying animal features. Migration patterns can be predicted using GIS landscape data, GPS tracking collars, analysis of animal tracks, and most commonly through use of cameras along the proposed or existing roadway.

Example: Case Study - Banff National Park of Canada

Banff National Park in Canada Highway Fencing and Wildlife Crossings is an example of one of the first and most successful projects to accommodate terrestrial habitat connectivity. In response to high and rising traffic volumes, sections of the Trans-Canada Highway (TCH) have been upgraded from a two-lane to a four-lane divided highway in Banff National Park.

To reduce the negative impacts of a larger highway on wildlife populations in Banff National Park:

- Fencing has been installed on both sides of the twinned highway sections to prevent large animals from getting onto the highway. Vehicle-wildlife collisions have been significantly reduced.
- Wildlife underpasses and overpasses have been installed to connect vital habitats and help sustain biodiversity.
- In 1996, the highway mitigation research project began studying the impacts of roads on wildlife in terms of road mortality, wildlife movements and habitat connectivity in the Bow Valley. Research results are being applied in highway upgrade projects in the mountain parks and beyond, including other countries.

Examples of connectivity structures are shown in figures EW-7.1 and EW-7.2 below.


Figure EW-7.1: Wolverine overpass Figure EW-7.2: Deer using a bridge crossing
(http://www.pc.gc.ca/pn-np/ab/banff/docs/routes/sec3/page42_e.asp#redearth3)

For more information, visit: http://www.pc.gc.ca/pn-np/ab/banff/index_e.asp.

Example: Case Study – Interstate 90 Snoqualmie Pass East Mitigation Project

Interstate 90, which stretches across the northern United States, is currently undergoing a number of improvements along a five mile stretch between Hyak and Keechelus Dam including the addition of two lanes and a number of connectivity features. This stretch of highway is a vital corridor connecting eastern and western Washington State. To meet the ecological needs of the area, Washington State Department of Transportation has identified a number of Connectivity Emphasis Areas (CEAs) that link vital patches of aquatic or terrestrial habitat.

To facilitate connectivity across the roadway, these CEA's will feature:

- Bridges ranging from 120 to 900 feet in length as well as a number of culverts to preserve aquatic migratory ability and hydrologic function.
- Three over-road wildlife crossings combined with fences to direct animals to these locations.

For more information, visit: http://www.wsdot.wa.gov/Projects/I90/SnoqualmiePassEast/Default.htm.

POTENTIAL ISSUES

1. Identifying ecological connectivity requirements needs well-designed long-term studies. In many cases these may need to be conducted over multiple years.
2. Lack of ecological or species data.
3. Development conflicts with ecologically sensitive areas.
4. Design of connectivity structures that will be accepted and used by target organisms can be difficult.
5. For new projects, prior migration patterns and other animal and aquatic organism behaviors may be altered by the presence of the roadway. This should be carefully considered as a long term impact, especially during environmental review.
6. In general, cases where this credit may not be appropriate are rare, even in urban environments, but are heavily dependent on available ecosystem data. This data may not be available in urbanized ecosystems that are not closely monitored.
7. In rare cases, projects that have conducted an ecological study may determine that ecological connections will undermine the safety of human users.

RESEARCH

What is ecological connectivity?

Ecological connectivity is the relative ease with which dispersive and dynamic ecological processes (such as species migration, water movement, soil transmission, pollination, etc.) occur across various ecosystem boundaries (Interstate 90 Snoqualmie Pass Development Team 2006). In Greenroads, specifically, ecological connectivity refers to the movement of non-human organisms (wildlife and plant species) across various manmade ecosystem boundaries, such as roadways. An **ecological connection** is a deliberate attempt to provide a pathway for transmission of non-human life across, under, above, or through a roadway project footprint without impacting the safety of human users.

Consideration of and compensation for adverse effects on ecological connectivity are not specific requirements of the National Environmental Policy Act (NEPA) or state environmental laws. Instead, consideration of ecological connectivity is driven by stakeholders, regulatory and natural resource agencies such as the U. S. Army Corps of Engineers (USACE), Environmental Protection Agency (through Section 404 of the Clean Water Act), the U. S. Fish and Wildlife Service, federal land management agencies, or the state natural resources management agency.

Why is ecological connectivity important?

Migration ability is necessary to the survival of many species, and roads that disrupt vital habitat corridors have the potential to seriously debilitate an ecosystem. Animal crossing of traditional roads has huge costs in the form of human and animal life in addition to monetary losses. However, with careful planning, wildlife crossing can be effectively facilitated in a safe and non-disruptive manner. It is important to note that there is no single solution to every connectivity problem, and there is not necessarily a solution for every species that might be encountered on a project. When well researched and tailored to a specific project, connectivity features have the potential to create safer roads, improve habitat, and save money. Establishing or maintaining ecological connectivity for existing and new projects, respectively, will reduce the long-term ecological impacts of roads, help to sustain populations, and possibly reduce the need for legal protection for species.

Access & Mobility for Wildlife

Among the animal kingdom, there are few species that live in single, static ranges throughout their lifetimes. Suitable habitat for a specific species might only be found in small parcels throughout a region, which often forces a species to inhabit small isolated chunks of land. This population structure is defined as a **metapopulation**, or a group of small populations which make up the total population. Because of low **genetic variability** within these smaller populations, the threat of individual group extinction and the need for a constant food source, connectivity between different habitat patches is vital for the survival of many species (Freeman et al. 2005). Ilka Hansi, who extensively studied Glanville butterfly populations in one of the defining studies of population dynamics, concluded that the ability of smaller populations to be replaced by individuals from other groups is necessary to avoid extinction (Hanski, 1995).

Roadways and highways are long linear structures which can often separate animals from important destinations, resulting in a loss of ecosystem functionality for those that do not attempt to cross and a more direct hazard in the form of automobile collision for those that do. In the Appalachians, areas in which black bears commonly attempt to cross roads have significant mortality rates, while higher traffic roads deter bear crossing and force small, isolated populations threatened by low genetic variability (Donaldson 2007). In addition to terrestrial animals, population, genetic diversity, and long-term survival of many fish species can be significantly reduced by loss of migration ability, which can be hindered or prevented by typical culverts found at stream and river crossings. (Mirati 1999, Fitch 1995)

Human Safety

The crossing of roadways by animals has a very direct human cost as well. In 2002, an estimated 1.5 million collisions between automobiles and deer occurred in the United States, killing about 150 people and causing over $1.1 billion in vehicle damage. (Hedlund et. Al 2003) In this case, there is little threat to the survival of the species. In fact, the rapid growth rate of deer population indicates that this trend will worsen over time.

In most cases, the installation of wildlife passage structures has led to increased animal crossing and reduced collisions, and federal funding has been made available for such projects under the Transportation Equity Act of 1998. (Hartmann 2003) For mammal crossing the most effective crossing systems have been underpasses coupled with fencing to funnel animals to the appropriate point (Hedlund et. al 2003; Dodd et. al 2007). Important factors influencing the use of such underpasses include the height of the underpass, surrounding vegetation, and type of ground surface visible (Donaldson 2007; Dodd et. Al 2007). Underpass use is reported for deer alone in seven different states, and both underpasses and overpasses have been used to allow passage of elk, bear, panther, mountain goats, and salamanders (Hartmann 2003; Romin and Bissonette 1996). A series of underpasses and fencing on the newly reconstructed Arizona SR 260 is estimated to save $1 million dollars per year by preventing collisions (primarily with elk), which have been reduced 56% from 1992-1997 levels despite increased traffic volume. (Dodd et. Al 2007, Brown and Laird 1999) In Virginia, underpasses were effectively used by deer, raccoons, groundhogs, and a wide range of other mammals, birds, amphibians and reptiles, but were unable to allow the passage of black bears, one of the targets of the project. (Donaldson 2007) When properly researched and constructed, underpasses can provide critical passageways for animals, but there is no guarantee that a given population will be willing to use such structures without prior evidence.

Aquatic Connectivity

Culvert design for stream and river crossings can have an important impact on the ability of fish to successfully cross a roadway. High water velocities caused by steep slopes and narrowed flow are often impassable to certain fish species (Belford and Gould 1989). Because of this and other factors, the slope of a culvert plays a key role in the effectiveness of a crossing. Ideally, culverts will be placed at grade with the stream. Culverts at lower grade risk causing dangerous hydraulic jumps or outlet drops, while steep grades typically mean higher velocity flows (Fitch 1995). While bridges are the most effective way to eliminate impediment of fish travel, this is often a prohibitively expensive option. Well-designed culverts with controlled flow velocity placed at grade can successfully accommodate fish passage and are generally a more feasible alternative (Fitch 1995).

Additional Resources & Tools

- The most comprehensive review of relatively recent work for ecological connections and societal benefits is presented in a book called *Road Ecology: Science and Solutions* by R. T. T. Forman et al. (2003).
- The Federal Highway Administration's website called "Wildlife Protection and Habitat Connectivity" includes several hundred examples of projects implemented around the United States and Europe: http://www.fhwa.dot.gov/environment/hconnect/index.htm
- Current research, policy issues, and best practices are posted by North Carolina State University's Institute for Transportation Research and Education, Center for Transportation and the Environment "Wildlife Fisheries and Transportation Web Gateway" http://www.cte.ncsu.edu/cte/gateway/home.asp

GLOSSARY

Ecological connection	A deliberate attempt to provide a pathway for transmission of non-human life across, under, above, or through a roadway project footprint without impacting the safety of human users
Ecological connectivity	the movement of non-human organisms (wildlife and plant species) across various manmade ecosystem boundaries, such as roadways
Genetic diversity	The number of different kinds of genes that exist within a population or group. Populations with low genetic diversity are less likely to be able to adapt to changing environmental pressures and are therefore at higher risk of extinction.
Metapopulation	A population consisting of a number of smaller dispersed populations. Individual organisms typically move between smaller groups to maintain a healthy ecosystem.

Migration	Either a one time or repeating movement of a population from one range of habitat to another.

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LIGHT POLLUTION

EW-8

3 POINTS

GOAL

Safely illuminate roadways while minimizing unnecessary and potentially harmful illumination of surrounding sky and habitat.

CREDIT REQUIREMENTS

Provide lighting fixtures that are Dark-Sky compliant or equivalent. A list of Dark-Sky approved fixtures can be found at http://www.DarkSky.org.

Details

This credit addresses two key components of roadway design, nighttime safety and light trespass into adjacent ecosystems and the night sky.

The International Dark-Sky Association (IDA) fixture certification program is based on upward light emission. Approved fixtures must emit no light above 90 degrees (often called "full cut-off"). For fixtures to become certified, photometric imagery from a certified testing lab must be submitted to the IDA for examination.

"Equivalent" standards will meet the criteria for IDA but may not carry the Dark-Sky seal. Equivalence can be shown by providing documentation demonstrating that IDA standards are met or exceeded by selected fixtures. Such documentation should be reviewed and approved by the project lighting professional or electrical engineer and a letter shall be provided stating equivalence.

Projects that deliberately reduce existing lighting or completely eliminate lighting are eligible for this credit provided that:

a. Lighting is within the project scope or otherwise is normally required by standard specifications (e.g., a preservation hot mix asphalt pavement overlay is not likely to have roadway lighting within its scope and is therefore not eligible for this credit). "Within scope" can be demonstrated by credit PR-1 Environmental Review Process or by AE-3 Context Sensitive Solutions.
b. The project provides evidence to show that lighting is not required to meet minimum roadway safety requirements or that reducing existing lighting is safe. This generally means an intentional decision has been made to reduce or eliminate lighting within the alignment based on a full safety investigation. (See also AE-1 Safety Audit).
c. Any lighting used conforms to IDA fixture standards or equivalent.

DOCUMENTATION

- Executive summary of the lighting safety study demonstrating appropriateness of lighting configured for roadway, signed by the lead electrical professional.
- Lighting or electrical plan. Highlight ALL locations of fixture, bulb and cover technology used.
- A list of the fixtures, bulbs and covers installed, including name of technologies, wattage, area of shade, code compliance (if any).
- Copy of the Dark-Sky certification for any product specified and installed.

RELATED CREDITS

- ✓ AE-1 Safety Audit
- ✓ AE-3 Context Sensitive Solutions
- ✓ MR-6 Energy Efficiency

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Experience

BENEFITS

- ✓ Reduces Fossil Fuel Use
- ✓ Reduces Greenhouse Gases
- ✓ Restores Habitat
- ✓ Improves Human Health & Safety
- ✓ Increases Aesthetics

APPROACHES & STRATEGIES

- U.S. Department of Energy's Energy Star program has been expanded to include roadway lighting. The standards for upward illumination for Energy Star certified fixtures are such that fixtures receiving this certification are likely to be dark sky compliant. Selection of fixtures that meet both specifications can reduce both energy use and light pollution (see MR-6 Energy Efficiency).
- Effective lighting design creates an impression of elegance, comfort, and clarity on the roadway at night. This can be accomplished using the latest lighting design software to model the appearance of the project, as well as designing project attributes such as signage for maximum visibility.

Example: Dark-Sky Certified Fixture Label

Figure EW-8.1 below is an example of a label that can be found on fixtures that are DarkSky compliant.

Figure EW-8.1:IDA Label for Dark-Sky Approved Devices
http://www.Dark-Sky.org/mc/page.do?sitePageId=56421&orgId=idsa

POTENTIAL ISSUES

1. Lighting modifications implemented to promote ecosystem health also must maintain sufficient light levels necessary for human safety.
2. Non-overhead roadway lights are not currently Dark-Sky certifiable through IDA.

RESEARCH

Roadway lighting is an important requirement for a safe nighttime driving environment. Though about 25% of driving occurs at night, the fatality rate of nighttime driving is more than double that of the day (FHWA, 1985, Sivak et al., 2007). The increased ability to identify potential hazards provided by overhead lighting fixtures significantly decreases nighttime accident risk. Therefore, installation of roadway lighting systems can save human life and money. However, excessive lighting can have negative impacts, and the safety benefits of additional lighting diminish at higher intensity levels (Fisher, 1977). In addition to useful light that illuminates the roadway, light can be emitted upward directly from light fixtures, or reflect from the roadway surface, both of which contribute to sky glow. In addition to these forms of light pollution, light from overhead fixtures can "trespass" and illuminate surfaces and areas other than the roadway including private property or natural habitat. This excess light can have consequences for human comfort, ecosystem function, and the ability to conduct astronomical observations. However, in many cases, careful lighting design can provide safe driving conditions while minimizing wasted light and adverse lighting effects.

Environmental Impacts

Light pollution can negatively impact a wide range of plant and animal species. Outdoor sky glow effects can be significant enough that nighttime conditions mimic those naturally observed at twilight (Navara and Nelson, 2007). Estimates indicate that 20% of land in the continental United States is located within 127 meters of a roadway (Ritters and Wickham, 2003). Because of this, the ecological consequences of light pollution from roadway lighting have huge potential impacts. In the plant kingdom, artificial light can disrupt the natural mechanisms used to regulate flowering and other seasonal actions (Select Commission on Science and Technology, 1997). Impacts on the animal kingdom however are far more diverse and cause a wide array of ecosystem alteration. In some cases, light pollution can be devastating. For instance, sea turtle hatchlings navigate their way to the ocean based on the relative darkness of land mass, and artificial lights can render this ability completely ineffective (Salmon, 2003). Nocturnal animals are also particularly vulnerable. Street lighting limits the flying routes of endangered bat species and can cause habitat fragmentation (Stone et al., 2009). When nocturnal habitats are fragmented, populations become increasingly at risk of loss of genetic diversity and local extinction. Increased lighting conditions can alter reproductive behavior in animals such as frogs, which are more wary in the absence of darkness, or glow worms, which communicate visually to attract a mate (Longcore and Rich, 2004; Navara and Nelson, 2007). While these examples are far from a comprehensive list, they illustrate the kinds of important ecosystem disruptions precipitated from a seemingly minor environmental change.

Though light has obvious benefits to human society, excess light can have negative human impacts. Surveys have indicated public displeasure in some cases with freeway lighting that inadvertently lights their yards and houses during the night (Khan, 2003). In addition, light pollution has seriously reduced the aesthetic value of the night sky. Most urban residents are now unable to view the once omnipresent Milky Way galaxy. In addition, many astronomical observatories have become significantly less useful as even a small change in sky brightness can have a huge impact on the ability to view extremely distant objects. In addition, more and more research is being conducted on a possible link between light pollution and certain types of cancer.

Light Pollution Prevention

Light pollution can be mitigated in a number of ways. LED lighting systems are generally more efficient at directing light to desired areas, therefore reducing the amount of light escaping to nearby environments for safe levels of lighting. While only about half the light from traditional roadway luminaries reaches the roadway, as much as 85% of LED lighting can do so (Wu et al., 2009). Direct, physical shielding of lamps is another effective method of curbing stray light. However, because light is reflected from illuminated surfaces, light pollution cannot be eliminated by direction and shielding alone (Soardo et al., 2008). Therefore, it is important to identify the minimum light intensity needed to provide safe roadway visibility. This needs to be considered carefully, as numerous attempts to conserve electricity use through light dimming have been shown to have increased nighttime accidents (FHWA, 1985). Sophisticated tests are available for measurements of luminance or illuminance to determine whether roadways are significantly lit to provide a safe environment. Light fixtures that provide more uniform lighting can provide safe conditions on all points on a roadway with less total light output, and therefore less reflected light pollution.

Scientific analysis of the consequences of light pollution is a relatively new phenomenon. However, research to date has already uncovered a host of important detriments to human health and ecosystem function in addition to the degradation of the intrinsic aesthetic value of the cosmos. Electrical lighting has been in existence for a time period that is insignificant from an evolutionary perspective, meaning that humans and other animals have had no opportunity to adapt to this drastic environmental shift (Pauley, 2004). While roadway lighting is far from the only culprit, streets are a major contributor to elevated light levels and are a significant opportunity for reduction of light pollution. Roadway illumination is responsible for approximately 70% of luminous flux in urban areas, and presents the only major source of artificial light in certain rural settings (Soardo et al., 2008). Light pollution and trespass are not only wasteful, but also damage the ability of our built environment to sustain human and ecosystem health.

International Dark-Sky Association (IDA)

Formed in 1988, the International Dark-Sky Association (IDA) is the authoritative voice on light pollution. IDA educates lighting designers, manufacturers, technical committees, and the public about light pollution abatement. The IDA’s goal of protecting and restoring natural night environment and heritage of dark skies is through promotion of quality outdoor lighting. They have developed the Fixture Seal of Approval (FSA) program for dark sky friendly fixtures.

The Fixture Seal of Approval provides objective, third-party certification for luminaires that minimize glare, reduce light trespass, and don’t pollute the night sky. For a modest fee, IDA will evaluate the photometric data of any luminaire submitted by its manufacturer. When the fixture is approved, the manufacturer receives a certificate and the Fixture Seal of Approval. Manufacturers may use the FSA seal to promote and advertise their IDA-Approved™ dark sky friendly products.

GLOSSARY

Light pollution	The unwanted contribution of manmade lighting to nighttime brightness and sky glow.
Light trespass	Direct shining of electrical light onto surfaces besides those meant to be lit.

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ACCESS & EQUITY

SAFETY AUDIT

AE-1

1-2 POINTS

GOAL

Improve roadway safety through review by an independent audit team.

CREDIT REQUIREMENTS

Conduct a road safety audit (RSA) on the project roadway in accordance with the procedures set forth in FHWA's *Road Safety Audit Guidelines*. The *Guidelines* define three general phases of a project during which a RSA may be conducted.

1 point is awarded for each RSA conducted up to a maximum of **2 points**.

1. **Preconstruction phase RSA.** Performed before construction begins. Recommended changes are generally less costly and result in less delay.
2. **Construction phase RSA.** Performed during preparations construction. They allow the roadway to be viewed as built and offer a last chance to assess safety before it is opened to the public.
3. **Post-construction phase RSA.** Performed on existing roads to identify road safety issues for different road users.

Note: For a given roadway project, it is likely that preconstruction and construction phase RSAs are appropriate. A post-construction phase RSA in addition to these two RSAs would typically be redundant and is therefore not advisable. See the "Examples" section for situations where a post-construction phase RSA may be appropriate.

Details

The FHWA *RSA Guidelines* are available at:

- http://safety.fhwa.dot.gov/rsa/guidelines.

Many owner agencies already have safety audit programs that meet RSA guidelines, but the programs may be called other names. Such a program must meet the intent of an RSA as defined in the FHWA's Road Safety Audit Guidelines. Specifically, the RSA must involve a review by an independent team and focus solely on safety.

DOCUMENTATION

- Submit a copy of the "RSA report" and "formal response" as defined in the FHWA's *Road Safety Audit Guidelines* (2006) for each RSA.

OR

- For agencies with existing safety audit programs, provide a letter, signed by the agency representative for the project, stating that the existing agency program meets or exceeds the requirements defined in the FHWA's *Road Safety Audit Guidelines* (2006). Submit a copy of agency program documents that meet the criteria defined in FHWA's guidelines as noted above.

RELATED CREDITS

- ✓ PR-1 Environmental Review Process
- ✓ AE-3 Context Sensitive Solutions

SUSTAINABILITY COMPONENTS

- ✓ Equity
- ✓ Expectations

BENEFITS

- ✓ Improves Human Health & Safety

APPROACHES & STRATEGIES

- Follow advice given by the FHWA Publication No. FHWA-SA-06-06, available at: http://safety.fhwa.dot.gov/rsa/guidelines/documents/FHWA_SA_06_06.pdf.
- Refer to the recommendations in the FHWA's *Road Safety Audit Guidelines* (Chapter 2) for introducing RSAs into an organization as an internal program. These recommendations note that effective and successful RSAs require a management commitment, an agreed-upon policy, informed project managers, an ongoing training program, and skilled auditors (FHWA, 2006).

Example: Hypothetical Case Study

A 2-inch overlay is scheduled for 20 lane-miles of a 2-lane rural road. A pre-construction RSA is conducted and makes recommendations on moving warning signs to better locations and installing a rumble strip along the centerline. The overlay project adopts these recommendations and includes them in the project. The project would receive 1 point for the pre-construction RSA. A construction phase RSA could be conducted to achieve another point however the project team did not see benefit in this and elected not to conduct one.

Example: When to Consider a Post-Construction RSA

A post-construction RSA could be useful in the following situations:

1. An owner agency undertakes a roadway project on a section of road that previously had a RSA conducted on it as an existing facility. This RSA would provide input into the planning and design phase of the project and make the pre-construction RSA redundant.
2. An owner agency is inventorying all *Greenroads* points it can obtain for a given network rather than using *Greenroads* to certify an individual project it might be able to improve its network score by including the RSAs it has conducted on existing facilities.
3. An owner agency desires a list of modifications that could result in future safety issue changes.

Examples: FHWA Case Studies

For further examples, the FHWA's *Road Safety Audit Guidelines* contains six RSA case studies.

POTENTIAL ISSUES

1. RSA use when it is not part of a formal agency policy may seem arbitrary and RSA execution may be cumbersome.
2. The RSA process as described in the FHWA's Road Safety Audit Guidelines (2006) allows a design team to essentially disagree with all audit recommendations. Therefore, it is possible, if not likely, that no recommendations are implemented and the roadway's overall safety does not benefit from the RSA.

RESEARCH

Roadway crashes and their resultant injuries and costs have an immense impact on society. Each year highway crashes in the U.S. injure 3 million, kill 43,000 and cost over $230 billion (Wilson and Lipinski, 2004). Generally, society views these deaths, injuries and costs as avoidable and has placed a high premium on reducing their number and severity. Three examples of this viewpoint follow:

- "…the toll of deaths and injuries on our roadways is among the most compelling public health issues of our time." (AASHTO, 2007)
- "…road traffic injuries (pose) a global public health crisis requiring urgent national and international action." (United Nations, 2008)
- "Safety is our top priority…" (acting FHWA administrator Jim Ray in Roads Can be Safer…, 2008)

Most of this section provides a summary of road safety audits from two main documents:

- *NCHRP Synthesis 336: Road Safety Audits* (2004), which summarizes RSA processes and their current usage in the U.S. and worldwide.
- *Road Safety Audit Guidelines* (2006) from the Federal Highway Administration, which provides guidance for agencies to draw upon when developing RSA policies and procedures.

Roadway Safety Audits

One method that has shown promise in improving roadway safety is what is commonly referred to as a Road Safety Audit (RSA). "An RSA is a formal safety performance examination of an existing or future road or intersection by an independent audit team. It qualitatively estimates and reports on potential road safety issues and identifies opportunities for improvements in safety for all road users" (FHWA, 2006). RSAs are generally thought of as an additional tool to improve safety rather than a replacement for other established practices such as safety impact studies, modeling, safety impact studies and safety compliance reviews (FHWA, 2006).

Applicable Project Types

RSAs can be beneficial to all types of projects. The FHWA (2006) specifically mentions the following types of projects and benefits:

- **Capital improvement projects.** RSAs can provide significant safety benefits in the design process.
- **Rehabilitation projects.** The scope and funding of such projects makes incorporating RSA recommendations often achievable with only minor changes in overall design.
- **Surface improvement projects.** Have the greatest potential to benefit from RSAs. Often low-cost, high-impact solutions can be identified and implemented.
- **Bridge reconstruction projects.** All projects, but especially broadly scoped ones, can be successful in incorporating major safety improvements recommended by an RSA.
- **Safety projects.** These may only use reactive techniques in identifying hazards and could benefit from the proactive nature of RSAs.
- **Developer-led projects.** Generally, they are candidates by no specific evidence is offered.

When to Conduct an RSA

RSAs are generally conducted at one or more points in the project timeline:

- **Preconstruction phase RSA.** Performed before construction begins. Recommended changes are generally less costly and result in less delay.
- **Construction phase RSA.** Performed during preparations construction. They allow the roadway to be viewed as built and offer a last chance to assess safety before it is opened to the public.
- **Post-construction phase RSA.** Performed on existing roads to identify road safety issues for different road users. Performing a RSA at this stage may be the most beneficial for future projects as changes after construction can be costly.

RSAs can impact project schedule but the impact depends on their recommendations and how they are addressed.

Safety Benefits

Both U.S. and international evidence suggests that RSAs are low-cost and can provide substantial, measurable benefits. Benefits generally come from reducing reconstruction costs associated with safety deficiencies, reducing life-cycle costs, reducing societal costs associated with collisions and reducing liability claims. Some specific examples are (Wilson and Lipinski, 2004; FHWA, 2006):

- A UK study analyzed crash data from 19 audited and 19 non-audited sites. It found a casualty savings of 1.25 per year (fatal crash rates dropped from 2.08 to 0.83 per year) for the audited sites and only 0.26 per year (fatal crash rates dropped from 2.6 to 2.34 per year) for the non-audited sites.
- A UK study analyzed 22 audited trunk road sites and placed the average savings per site at £11,373 per site.

- Austroads described 9 audited design-state sites that reported 250 findings with benefit/cost ratios between 3:1 and 242:1.
- The New York Department of Transportation reports a 20-40% reduction in crashes at more than 300 high-crash locations that had received safety improvements recommended by RSAs.
- Early South Carolina Department of Transportation results (at the 1-year point) showed decreased crashes and economic savings. One site implementing 4 of 8 recommendations showed a 12.5% decrease in crashes with a savings of $40,000, a second site had a 15.8% increase in crashes when only 2 of 13 recommendations were implemented, a third site that implemented all 9 recommendations saw a 60% reduction in fatalities resulting in a $3.66 million savings, and a fourth site that implemented 25 of 37 recommendations had a 23.4% reduction in crashes and a savings of $147,000.

Costs & Legal Considerations

Generally RSAs cost between $1,000 and $8,000 (Wilson and Lipinski, 2004), which usually represents a small fraction of engineering design costs. Therefore, analyses that calculate rate of return generally give values of over 100%. This is especially true when even one life saved is attributed to the RSA. In practice, however, it is difficult to attribute saving a life to any one audit, recommendation or action.

The FHWA (2006) mentions that some agencies have been reluctant to conduct RSAs due to a fear that reports will be used against them in tort liability lawsuits. In states where training on RSAs was conducted local legal staffs gave a common message: RSAs are a positive approach and do not increase the agency's liability and, in fact, help in the defense of tort liability (Wilson and Lipinski, 2004).

GLOSSARY

FHWA	Federal Highway Administration
RSA	Road safety audit

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INTELLIGENT TRANSPORTATION SYSTEMS

AE-2

2-5 POINTS

GOAL

Meet economic and social needs and improve mobility without adding capacity, or improve the efficiency of transportation systems.

CREDIT REQUIREMENTS

Include intelligent transportation system (ITS) applications listed in the Federal Highway Administration's (FHWA) Research and Innovative Technology Administration (RITA) Office of Intelligent Transportation Systems *Applications Overview* portion of their ITS website (see at: http://www.itsoverview.its.dot.gov). Table AE-2.1 (opposite page) lists the standard ITS applications and RITA ITS website categories allowable for this credit.

2 points
Install at least 1 application in 2 separate categories.

3 points
Install at least 1 application in 3 separate categories.

4 points
Install at least 1 application in 4 separate categories.

5 points
Install at least 1 application in 5 separate categories.

Details

Additionally, in order for an ITS application to count for this credit it needs to exist within the project limits in a meaningful manner. The FHWA's RITA ITS website separates ITS applications into broad categories. The intention of this credit is to have at least two of these RITA ITS website categories represented with the project limits to earn points. So, if the project is an improvement of an existing facility and that existing facility already includes one or more ITS applications, those existing applications can be counted toward the total points. Additionally, note that in no case can more than 5 points be earned. There must be at least 1 application in 2 separate categories in order for any points to be earned.

DOCUMENTATION

- A list of the ITS applications and their corresponding categories
- Evidence that these ITS applications are physically installed on the project or are applicable to the project area. This evidence can be any one of the following:
    - The page(s) in the project plans and specifications that refer to the application
    - Documentation that shows a particular application is operational in the project area (e.g., the geographic coverage area for the 511 traveler information service, a screenshot of an online dynamic map that identifies the project area and clearly shows the project area is included in the map)
- Photo(s) of each application installed if it is a physical entity.

RELATED CREDITS

- ✓ AE-3 Context Sensitive Solutions
- ✓ AE-5 Pedestrian Access
- ✓ AE-6 Bicycle Access
- ✓ AE-7 Transit & HOV Access
- ✓ MR-6 Energy Efficiency

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Equity
- ✓ Economy
- ✓ Extent
- ✓ Expectations
- ✓ Experience
- ✓ Exposure

BENEFITS

- ✓ Reduces Fossil Fuel Use
- ✓ Reduces Air Emissions
- ✓ Reduces Greenhouse Gases
- ✓ Improves Mobility
- ✓ Improves Human Health & Safety
- ✓ Reduces Lifecycle Costs
- ✓ Increases Awareness

Table AE-2.1: Allowable ITS Applications for AE-2

Category	Application
Surveillance	Traffic Infrastructure
Traffic Control	Adaptive Signal Control Advanced Signal Systems Variable Speed Limits Bicycle & Pedestrian Special Events
Lane Management	HOV Facilities Reversible Flow Lanes Pricing Lane Control Variable Speed Limits Emergency Evacuation
Information Dissemination	Dynamic Message Signs (DMS) Highway Advisory Radio (HAR)
Enforcement	Speed Enforcement Traffic Signal Enforcement Ramp Meter Enforcement HOV Facilities Enforcement
Ramp Control	Ramp Metering Priority Access
Warning Systems	Ramp Rollover Curve Speed Warning Downhill Speed Warning Overheight/Overwidth Warning Highway-Rail Crossing Warning Systems Intersection Collision Warning Pedestrian Safety Bicycle Warning Animal Warning
Road Weather Management	Pavement Conditions Atmospheric Conditions Water Level
Transit Management	Dynamic Routing/Scheduling In-Terminal/Wayside Information Dissemination
Traveler Information	Internet/Wireless 511 Telephone
Electronic Payment/Pricing	Toll Collection Transit Fare Payment
Traffic Incident Management	Call Boxes Service Patrols Emergency Vehicle Signal Preemption
Notes: The application nomenclature and definitions come directly from the FHWA's RITA ITS *Applications Overview* web page (http://www.itsoverview.its.dot.gov).	

APPROACHES & STRATEGIES

- The FHWA's RITA ITS website (http://www.its.dot.gov) maintains a current database of ITS benefits, costs, lessons learned and deployment statistics. It is an excellent resource for approaches and strategies.
- ITS America, a not-for-profit organization, also maintains a website (http://www.itsa.org) with substantial documentation on ITS efforts.

Example: How to Calculate Points

3 points

A freeway on-ramp is being upgraded to include a ramp metering system. In addition there are already video surveillance cameras in use that are accessible by the general public through a common traffic website. The area is also covered by a 511 traffic information system and highway advisory radio (HAR). This project would earn 3 points because 3 application categories are represented. Note that a project cannot earn 1 point for this Voluntary Credit. At least 2 categories must be represented to earn the minimum of 2 points.

- **Surveillance**. The traffic cameras are an application in this category.
- **Traveler information**: the 511 service and website are both applications in this category. Although this category is represented by two separate systems, it is still only counted once.
- **Information dissemination**: the HAR is an application in this category.

5 points

An arterial is being upgraded to be more context sensitive. Existing arterial facilities that remain in place include a variable message sign and video traffic signal enforcement. The project is adding timed signal lights and sensors to include it in the area-wide network shown online at the agency's website. Traffic surveillance cameras are also being added. This project would earn 5 points because 5 application categories are represented. Note that a project cannot earn 1 point for this Voluntary Credit. At least 2 categories must be represented to earn the minimum of 2 points.

- **Surveillance**. The added traffic cameras are an application in this category.
- **Traffic control**. The added signal timing is an application in this category.
- **Information dissemination**. The existing dynamic message sign is an application in this category.
- **Enforcement**. The existing traffic signal video enforcement is an application in this category.
- **Traveler information**: the inclusion of this arterial in the agency's online traffic flow map is an application in this category.

Example: ITS Categories

Some examples of ITS use from the RITA's *Intelligent Transportation Systems Benefits, Costs, and Lessons Learned: 2008 Update* are (these are direct quotes from the executive summary, italics added to distinguish from other text):

Arterial Management

> *Optimizing signal timing is considered a low-cost approach to reducing congestion. Based on data from six separate studies, the costs range from $2,500 to $3,100 per signal per update (Sunkari 2004; TEI Engineering 2005; Harris 2005; NTOC 2005; Luor 2006; Heminger 2006). Based on a series of surveys of arterial management agencies in 78 of the largest U.S. metropolitan areas, half of traffic signals in these metropolitan areas were under centralized control through closed-loop or computer control in 2006.*

Freeway Management

> *There are numerous ITS strategies to improve freeway operations. Metropolitan areas that deploy ITS infrastructure including dynamic message signs (DMS) to manage freeway and arterial traffic,*

and integrate traveler information with incident management systems can increase peak period freeway speeds by 8 to 13 percent (Smith and Perez 1992; Birst and Ayman 2000), improve travel time, and according to simulation studies, reduce crash rates and improve trip time reliability with delay reductions ranging from 1 to 22 percent (Smith and Perez 1992; FHWA 1999a; FHWA 1999b; Brist and Ayman 2000; FHWA 2000; FHWA 2001; Jeannotte 2001). In Minneapolis-St. Paul, the benefit-to-cost ratio for a ramp metering system was estimated at 15:1 (Cambridge Systematics 2001).

Crash Prevention and Safety

Downhill speed warning systems have decreased truck crashes by up to 13 percent at problem sites in Oregon and Colorado (Drakopoulos 2006). As part of an evaluation of automated truck rollover warning systems, the Pennsylvania DOT researched systems in other states. The cost of these systems varied significantly, ranging from $50,000 to $500,000, as did their configurations: invasive and non-invasive detection, weight-based versus simplified speed class algorithms, and system calibrations for warnings (Pento 2005). The three most widely adopted systems are curve and ramp speed, rail crossing warning systems and pedestrian safety systems. Next in popularity, and adopted by about half as many states, are downhill warning systems, intersection collision avoidance systems, and animal warning systems.

Road Weather Management

Evaluation data show that 80 to 94 percent of motorists who use traveler information Web sites think road weather information enhances their safety and prepares them for adverse road weather.(FHWA 2004; FHWA 2006). Studies have found that anti-icing programs can lower snow and ice control costs by 10 to 50 percent and reduce crash rates by 7 to 83 percent (Breen 2001; McCormick Rankin Corporation and Ecoplans Ltd. 2004; O'Keefe and Shi 2005).

Electronic Payment and Pricing

On freeways, variable pricing strategies are effective at influencing traveler behavior. Although initial public support for such tolls may be low, research indicates that road users value time savings and are willing to pay a price to avoid congestion and delay (North Central Texas Council of Governments 2005; Douma et al. 2006). In California, for example, public support for variable tolling on State Route 91 was initially low; but after 18 months of operations, nearly 75 percent of the commuting public expressed approval of virtually all aspects of the express lanes program (North Central Texas Council of Governments 2005).

Traveler Information

Studies show that drivers who use route-specific travel time information instead of area-wide traffic advisories can improve on-time performance by 5 to 13 percent (Vasudevan et al. 2005). Recent evaluation data show that customer satisfaction with regional 511 deployments range from 68 to 92 percent (511 Deployment Coalition 2005). The 511 Deployment Coalition conducted an in-depth cost analysis based on the experience from nine 511 deployers. On average, the statewide systems cost approximately $2.5 million to design, implement, and operate during the first year. Metropolitan systems cost an average of $1.8 million to design, implement, and operate during the first year (511 Deployment Coalition 2006). The two most popular media for distributing traveler information in the 78 largest U.S. metropolitan areas are Web sites and e-mail, followed by automatic telephone and pagers. Thirty (30) of the 78 metropolitan areas use dedicated TV to distribute traveler information and 18 use kiosks, a medium which has seen no growth in recent years.

POTENTIAL ISSUES

The ITS applications used should provide quantified benefits that justify their cost.

RESEARCH

The FHWA's RITA ITS website (http://www.its.dot.gov) maintains a current database of ITS benefits, costs, lessons learned and deployment statistics. ITS America, a not-for-profit organization, also maintains a website (http://www.itsa.org) with substantial documentation on ITS efforts.

Perceived and Measured Benefits of ITS

The goal area definitions listed below (which can be found at the bottom of this website: http://www.itsbenefits.its.dot.gov/its/benecost.nsf/ByInfo/WhatIsBClassifications#goal) give an overview of the perceived and measured benefits of ITS. The most relevant sustainability components are listed at the end of each goal area description.

Safety

Several specific applications aim to reduce both the number and severity of crashes. This benefit is directly related to the equity component of sustainability. Measures of effectiveness include crash rate, fatality rate, and injury rate. *Equity*

Mobility

Many applications aim to reduce travel delay and travel time. This benefit is related to the equity (improved mobility), economy (lower user cost associated with facility use due to faster travel time) and ecology (more efficient use can but may not always lead to less fuel consumption and fewer emissions). Measures of effectiveness include delay time and variability of travel time. *Ecology, economy*

Productivity

Some applications aim to reduce operating costs and allow productivity improvements. This includes applications that may save time in completing business or regulatory processes, systems that have lower life cycle costs compared to traditional transportation systems, and information collection/aggregation applications that can lead to economic savings or performance improvement. Measures of effectiveness are usually some form of cost savings achieved by using ITS. *Economy, extent, expectations*.

Efficiency

Many applications are designed to improve the efficiency of existing facilities so that mobility, access and other needs can be met with the existing or less physical infrastructure than would otherwise be possible. Traditional methods of measuring capacity (e.g., those in the *Highway Capacity Manual 2000*) often do not account for ITS applications that can improve capacity beyond that for a traditional roadway without ITS. A typical measure of effectiveness is "effective capacity", or the maximum potential rate at which persons or vehicles may traverse a link, node, or network under a representative composite of roadway conditions including weather, incidents, and variation in traffic demand patterns. *Economy, equity, extent, expectations*.

Energy and Environment

Some applications have the secondary effect of improving air quality and lessening energy impacts of transportation because of improved efficiency or other improvement measures. Measures of effectiveness include modeled or simulated reductions in emissions and energy use. *Ecology, economy*.

Customer Satisfaction

Many applications provide improved customer satisfaction by more closely meeting traveler expectations. Typical measures of effectiveness are traveler surveys, product awareness, expectation/realization of benefits and assessment of value. *Equity*.

GLOSSARY

Effective capacity	The maximum potential rate at which persons or vehicles may traverse a link, node, or network under a representative composite of roadway conditions including weather, incidents, and variation in traffic demand patterns.
Intelligent Transportation System	An application of integrated information, telecommunications and computer-based technologies to infrastructure and vehicles in order to improve safety and mobility on surface transportation networks.

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CONTEXT SENSITIVE SOLUTIONS

AE-3

5 POINTS

GOAL

Deliver projects that synthesize transportation requirements and community values through effective decision-making and thoughtful design.

CREDIT REQUIREMENTS

Design the project according to the principles of Context Sensitive Solutions (CSS).

Fill out the submission form from the CSS National Dialog website for project design and construction. The form can be found here: http://www.cssnationaldialog.org/documents/design.pdf.

OR

Create a short white paper (narrative) document describing the following:

1. The purpose and need for the project.
2. The planning horizon and proposed timeline or schedule for project completion.
3. A list or organizational chart of the management structure for the project: this includes, project planners, design professionals, consultants, agency leads, and other stakeholders involved.
4. The elements of the decision making process used.
5. The local and regional context and issues surrounding the project, other federal context and issues, and applicable jurisdictional regulations and policies.
6. The public involvement process for CSD and results of this process.
7. The transportation modes considered and results of this consideration.
8. The visual and aesthetic components of the project.
9. The plan for long-term on-going monitoring during operations (if any).
10. The final alternatives and design elements chosen for implementation (a summary is sufficient).

Details

Note: This credit must be earned in order to earn credits AE-4 Traffic Emissions Reduction, AE-5 Pedestrian Access, AE-6 Bicycle Access, and AE-7 Transit Access.

Context Sensitive Solutions (also Context Sensitive Design; CSD) is defined as a collaborative, interdisciplinary approach that involves all stakeholders to provide a transportation facility that fits its setting. It is an approach that leads to preserving and enhancing scenic, aesthetic, historic, community, and environmental resources, while improving or maintaining safety, mobility, and infrastructure conditions. (FHWA, 2009)

DOCUMENTATION

- Copy of the implementation of CSS in transportation project design and construction form **OR** copy of the Context Sensitive Planning white paper addressing all 10 items above.

RELATED CREDITS

- ✓ PR-1 Environmental Review Process
- ✓ AE-4 Traffic Emissions Reduction
- ✓ AE-5 Pedestrian Access
- ✓ AE-6 Bicycle Access
- ✓ AE-7 Transit & HOV Access
- ✓ AE-8 Scenic Views
- ✓ AE-9 Cultural Outreach

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Equity
- ✓ Economy
- ✓ Extent
- ✓ Expectations
- ✓ Experience
- ✓ Exposure

BENEFITS

- ✓ Reduces Manmade Footprint
- ✓ Improves Access
- ✓ Improves Mobility
- ✓ Improves Human Health & Safety
- ✓ Improves Accountability
- ✓ Increases Awareness
- ✓ Increases Aesthetics

APPROACHES & STRATEGIES

The CSS/CSD Framework

- Consult existing guidance documents and resources to understand the framework and review a variety of examples. See the "Additional Resources" listed at the end of this credit.
- Follow the CSS framework (Stamatiadis et al., 2009; Neuman et al., 2002). There are six key steps in the CSS project development process:

  1. Develop a decision-making process and management structure.
  2. Define the problem.
  3. Develop the project and the evaluation framework for the project.
  4. Determine alternatives.
  5. Screen the alternatives.
  6. Evaluate and select an alternative.

Interdisciplinary Decision-Making

- Collaborate with local experts in both transportation and non-transportation planning and design professions.
- Use a transparent decision process with clear channels for community participation. This will ensure design of a project that meets the needs of the transportation system as well as the community as a whole.
- Incorporate the following five elements in the decision process throughout the project for the most effective approach (from Neuman et al., 2002):

  1. The decision points in the process or project milestones.
  2. Who will make each decision.
  3. Who will make recommendations for each decision.
  4. Who will be consulted on each decision.
  5. How recommendations and comments will be transmitted to decision makers.

- Document each of these elements clearly in the project paper trail. This will help ensure that project decision-makers are held accountable for their responsibilities and actions.

Planning and Design Considerations

- Consider the appropriateness of including bike, pedestrian or transit facilities in the design of the roadway during project planning. This might be as simple as constructing bike lanes and sidewalks as called for in local design standards.
- Review local plans for roadway design standards and functions.
- Consult with local planners from appropriate agencies (parks dept., public works, planning, transportation and transit) to determine if your assessment is complete.
- Use visualization tools, such as photograph rendering or computer models. These can often can help in design alternative selection process.
- Consider the project no-build condition. Some local standards may require elements that may not be appropriate for environmental or engineering reasons and may be able to be granted an exception which can be pursued during planning. An example would be designing narrower streets than required by standard specifications in a residential neighborhood, which can improve safety by slowing neighborhood traffic.

CSD for Multimodal Access

- Consider all modes at the initial stages of planning. While each individual roadway does not have to accommodate people using all modes, a system should be accessible to people on bikes, foot, and transit, as well as in cars and trucks, where the purpose and need statement for the project define these elements as appropriate.

- Consult local plans for existing and future planned bike, pedestrian and transit elements to see if the project includes or crosses named elements. Many jurisdictions have adopted plans related to bike, pedestrian and transit systems.
- Incorporate new modal elements such as bike lanes, sidewalks or trails, and transit facilities should be included in designs where applicable. Generally, design standards or plans will dictate placement of these elements, or they may be requested by the public during project scoping.
- Considering roadway improvements which may impact the existing or master-planned bike, pedestrian and transit networks. Improvements to these modal elements should be made as appropriate to mitigate user impacts.

Public Involvement Considerations

- Consult with stakeholders to understand community issues, to envision solutions, and, ultimately, to understand how a project fits into a community. Through this process, planners and designers are more likely to design a project that minimizes impacts to the community and supports the community's vision.
- Conduct an appropriately-scaled stakeholder consultation process in project planning for the whole project and specific issues as needed. This process might be as simple as holding a project open house to identify community concerns, issues or opportunities, or it might be a long process with multiple opportunities for stakeholder engagement including public workshops, committee meetings, and other engagement opportunities.
- Include in the public involvement plan the following steps: issue identification, development of evaluation criteria, development of potential solutions, evaluation of solutions, and selection of a solution that best meets the evaluation criteria.
- Follow the guidance available on stakeholder consultation, such as the FHWA's *Public Involvement Techniques for Transportation Decision Making* and *How to Engage Low-Literacy and Limited-English-Proficiency Populations in Transportation Decisionmaking.*
- Development a plan for stakeholder involvement so that the sessions run smoothly and achieve objectives. This plan requires an understanding of the community that can be informed by conversations with local leaders or jurisdictional staff, research on the web, or previous work in the community. The plan should identify milestones for stakeholder involvement, a clear decision process that illustrates how input will be used, and tools or methods for involving stakeholders.
- Document and track public input and how that input is reflected in project planning and design.
- Set up a comment and resolution log that lists community comments and team actions.
- Use narratives or minutes that describe input gathered at each project milestone and how that input will be reflected in the process.
- Remember that the stakeholder consultation process does not require acquiescence to every stakeholder request. Some requests will be too expensive, will be out of step with the project purpose, or will not reflect the values of the community as a whole.
- Developing an evaluation framework that reflects community goals and project goals creates a filter for determining which requests are integrated into the project and which are set aside.

Example: Aurora Avenue North Multimodal Corridor Project — Shoreline, WA

The City of Shoreline implemented a new roadway design for three miles of State Route 99 (also known as Aurora Avenue North) to alleviate traffic congestion, improve business access, and provide pedestrian access. Context-Sensitive Solutions (CSS) were used to design an environmentally conscious roadway that protected salmon and provided multimodal mobility improvements to the Northwest, including pedestrians, bicyclists, motorists, and freight truckers. See Figures AE-3.1 through AE-3.3.

Some highlights of the CSS process followed by the project include:

- Photosimulations helped stakeholders visualize the impact of proposed solutions

- Multimodal connectivity was successfully provided for cyclists and pedestrians via the Interurban Trail, which sails across the roadway, giving safe and dedicated access for these travelers. Continuous 11-foot wide sidewalks with disability access were also installed, reducing pedestrian fatalities and injuries.
- Transit service was enhanced via Bus-Rapid Transit (BRT: Figure AE-3.2), including dedicated bus lanes, in-line stops, access improvements at bus zones and shelters, and signal priority. These enhancements resulted in major efficiency (80% speed increase) and scheduling improvements (600% reliability increase).

Figure AE-3.1: Bicycle and Pedestrian Bridge. Photo by CH2M Hill.

Figure AE-3.2: Aerial view of Aurora Avenue and BRT. Photo by CH2M Hill.

Figure AE-3.3: Interurban Trail Bicycle and Pedestrian Bridge over SR-99. Photo by CH2M Hill.

- Stakeholders worked along with planners and designers to reach a consensus that best fit goals and values, (though a good portion of the remaining SR-99 corridor is still a matter of public debate.)
- Traffic efficiency improvements, such as intersection capacity, corridor-wide traffic management, new signals and access locations, resulted in flow improvements over 36% over the no-build condition.
- Access management and illumination of the corridor increased safety by reducing severity of crashes and reducing total crashes by 25%.
- Aesthetic improvements were incorporated, including landscaping, trees, screening and burying utilities, public art and architectural features. This resulted in increased property values and redevelopment and a more livable community.
- Stormwater management incorporated biofiltration areas and in Right-of-Way treatment facilities, ultimately reducing impervious surface by 15% and improving stormwater quality by 100% over no-build.

More information about the SR-99 Improvements is available here from the Washington State Department of Transportation: http://www.wsdot.wa.gov/projects/SR99/Shoreline_NCTHOV/

Example: Case Study — Whittier Access Project — Whittier, Alaska

The Alaska Department of Transportation and Public Facilities began the Whittier Access Project to increase access and mobility to the region for both train and highway travel. For the first time in 50 years, Whittier would have a highway, providing access to emergency services, recreation, tourism, travel and commerce in the environmentally-sensitive setting of Prince William Sound and the Chugach National Forest.

Two fundamental objectives guided the project: meet transportation access needs for residents, freight and visitors and minimize environmental impact from construction. Planning for the 4-mile access road, two tunnels (one 500-feet and another 2.5-mile combined-access for rail and highway), two bridges , and portal buildings began in 1993. The completed project opened to the public in 2000. Note that pedestrian and bicycle access is not provided for safety reasons. Additionally, there is no public transit in Whittier. See Figure AE-3.4.

Figure AE-3.4: Whittier Access project. Photo by CH2M Hill.

Some project highlights include:

- The roadway alignments used existing topographical features to minimize visual impact by screening the road with the new 500-foot-long tunnel.
- The alignments also minimized impacts to sensitive plants, salmon spawning grounds, wildlife and provided drainage structures adequate for fish passage.
- Blasting techniques were used as an aesthetic tool to leave an irregular surface that was similar to the look of natural rock formations. This minimized visual impacts from the nearby Portage Lake.
- The bridges were designed to be low-profile and minimum footprint with single-column piers to allow boating access and minimize obstruction of a nearby glacial viewpoint.
- Bridge girders were sandblasted and textured to match surroundings.

More information about the Whittier Access project can be found from the Alaska Department of Transportation and Public Facilities here: http://www.dot.state.ak.us/creg/whittiertunnel/index.shtml

POTENTIAL ISSUES

1. For smaller projects that typically do not require involvement of many people, or direct management by stakeholders, this credit requires that an additional document is generated.
2. CSS does not guarantee effectiveness of the final design alternative. This is especially true relative to cost and scheduling concerns.
3. CSS does not address construction management issues except broadly.
4. This particular credit does not have any means of tracking or monitoring the success (or failure) of a project after it is constructed, i.e. to determine if the CSS planning process resulted in a positive or negative outcome.

RESEARCH

"If highway designers are not aware of opportunities to use their creative abilities, the standard or conservative use of the *Green Book* criteria and related State standards, along with a lack of full consideration of community values, can cause a road to be out of context with its surroundings. It may also preclude designers from avoiding impacts on important natural and human resources" (Federal Highway Administration, 1997). **Context sensitive design (CSD)**, sometimes called **Context Sensitive Solutions (CSS)**, is a well-documented approach to project delivery that relies on an understanding of and response to the project's context – its physical and social place – in all aspects of design. There are several definitions of CSS, but all of them are consistent with industry best practice (ICF International, 2009). According to the FHWA, the definition of CSS is:

> ***A** collaborative, interdisciplinary approach that involves all stakeholders to provide a transportation facility that fits its setting. It is an approach that leads to preserving and enhancing scenic, aesthetic, historic, community, and environmental resources, while improving or maintaining safety, mobility, and infrastructure conditions. (FHWA, 2009)*

CSS synthesizes conventional engineering, professional expertise and thoughtful planning with human values through a systems-approach for project delivery. Integrating CSS into project decision-making requires a multidisciplinary approach to planning and design and an open dialogue with stakeholders. CSS also refers to an overall product or outcome: a roadway project that is generally more suitable and valuable to its community (ICF International, 2009).

Several federal, state and local laws mandate (or otherwise strongly recommend) the use of context-sensitive design. The most recent federal regulation that was relevant to CSS was the Safe, Accountable, Flexible, Transportation Efficiency Act: A Legacy for Users (SAFETEA-LU), which recently expired and has not been replaced by a subsequent regulation as of this writing. Section 6008 Historically, CSS concepts have been embedded in federal law since the institution of the National Environmental Policy Act (NEPA) at the start of 1970. (American Association of State Highway Transportation Officials: AASHTO, 2010; Context Sensitive Solutions.org, 2010)

While environmental review processes like the NEPA share some traits with CSS planning and design approaches, they are not one and the same. Instead, CSS and the environmental review process are complementary decision-making processes. Both processes (and their resulting implementation) are comprehensive in nature, but their focus is generally different. For example, harmonizing environmental needs for the project in the CSS process could easily be addressed in the environmental review process, if required by the agency or jurisdiction. Many project teams use CSS as an opportunity to complete the environmental review process even if the project is not subject to NEPA or local requirements. This choice is generally seen as a way to minimize backtracking for documentation that would need to occur if, for instance, the project happened to qualify midway through the design process for federal funding. (Neuman et al., 2002).

Characteristics of CSS

Interestingly (and unlike other credits in Greenroads), there is no clear corollary to CSS in the building industry or in the LEED Green Building Rating system. CSS is an approach exclusive to transportation in planning and development. The best analogy is that CSS is to transportation as architecture and urban design are to the built environment. However, there is one key difference between standard design approaches for roadway projects and CSS. Conventional design process follows a linear approach: these methods usually involve books of standards and reading from tables to develop the alternatives in order to fit a roadway to a place. However, this process often results in a conservative, uncreative design, or worse, an unsustainable one that ignores or omits important environmental concerns. Conversely, the CSS approach provides an iterative and interdisciplinary approach to planning and design that recognizes and implements key synergies that will ultimately result in a more functional, more appropriate, and more applicable roadway project. This integrated approach is shown in Figure AE-3.5.

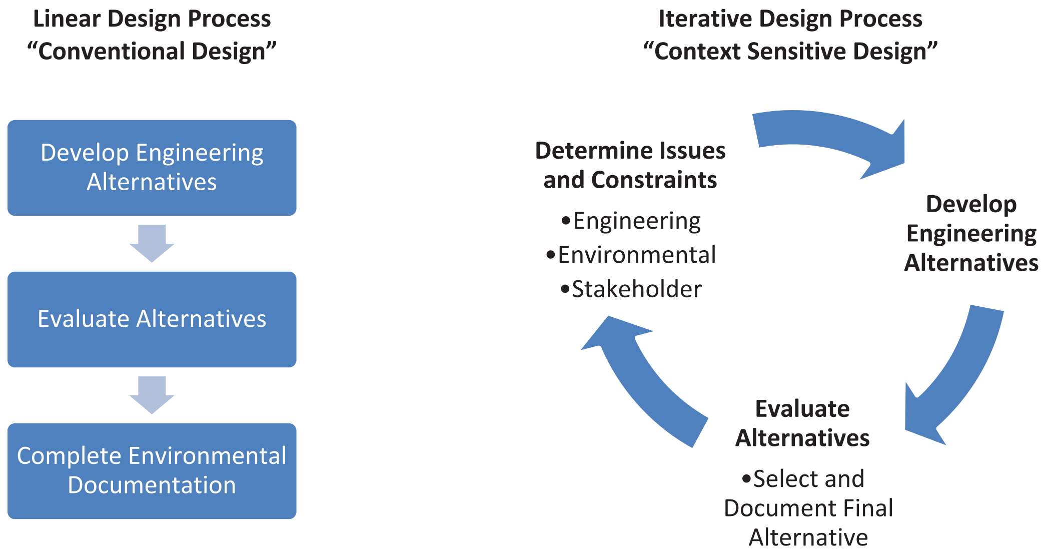

Figure AE-3.5: Comparison of a conventional design process to a Context-Sensitive design process. (Adapted from Neuman et al., 2002)

CSS Principles

According to Stamatiadis et al. (2009) there are fifteen core principles of CSS that are applicable and relevant to transportation professionals in practice. The diagram shown in Figure AE-3.6 provides a good illustration of the principles, and their relative importance. Importantly, Principles 1-3 form the foundation to a successful CSS program. The second level of the foundation, Principles 4-7, represents the four common agency goals which help to define the project needs and purpose (Stamatiadis et al., 2009; Neuman et al., 2002). The third level (the pillars: principles 8-13) represents the solution "enablers." These are the policy commitments and agency goals, and the perspectives that allow for an effective solution to be approached and achieved. The fourth (principle 14) and fifth (principle 15) level stand for successful project delivery and effective long-range planning. Every CSS project exemplifies all of these principles, though there is much variability in both initial design and final outcome from project to project (Stamatiadias et al., 2009).

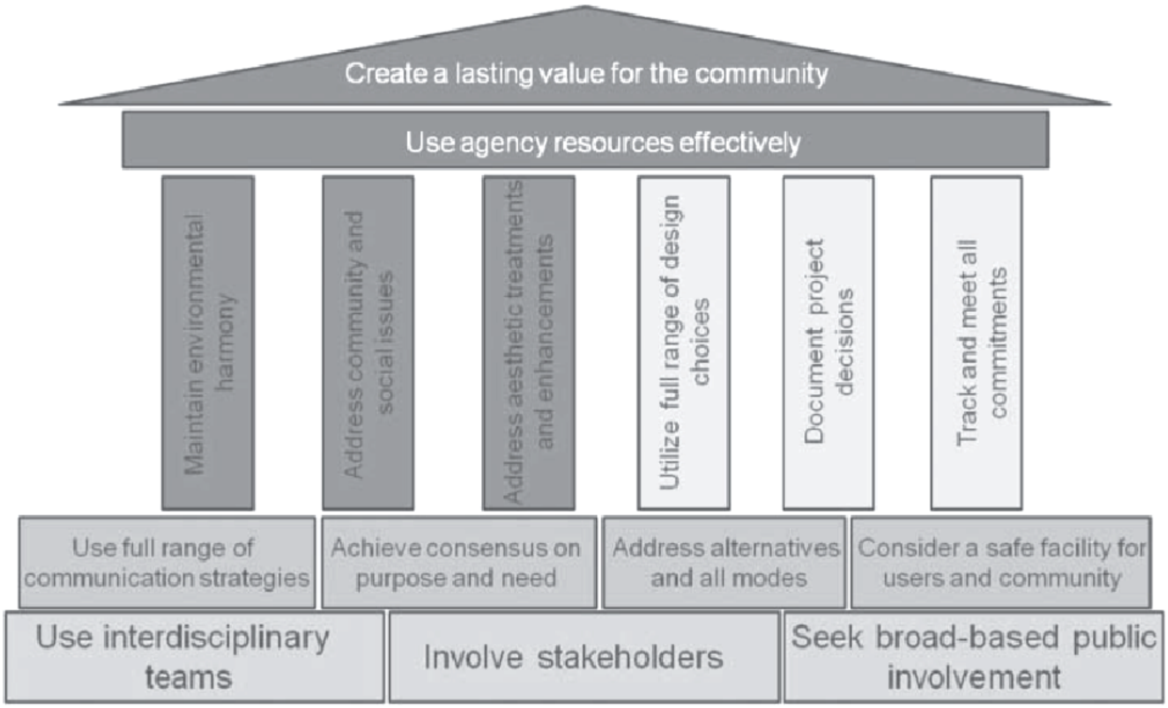

Figure AE-3.6: Graphical depiction of 15 principles of Context-Sensitive Solutions. (Stamatiadis et al., 2009)

Benefits of CSS

There are several benefits of CSS. Stamatiadis et al. (2009) recently attempted to identify the quantifiable benefits of CSS. His group established 22 quantifiable benefits of applying CSS principles. These are shown in Table AE-3.1.

Table AE-3.1: 22 Benefits of CSS (adapted from NCHRP Report No. 690 by Stamatiadis et al., 2009)

Improved by CSS	**Optimized by CSS**
Performance predictability and project delivery	Maintenance and operations
Scoping and budgeting process	Design appropriate for context
Long-term decisions and investments	**Increased by CSS**
Environmental stewardship	Risk management protection
Mobility for users	Stakeholder/public feedback
Walkability and bikeability	Stakeholder/public participation, ownership and trust
Safety (vehicles, pedestrians and bikes)	Partnering opportunities
Access to multi-modal options (including transit)	**Minimized by CSS**
Community satisfaction	Overall impact to human and natural environment
Quality of life for community	Construction-related disruption
Speed management	Overall costs for project delivery
	Overall time for project delivery

In addition to the quantifiable benefits, some qualitative highlights of CSS planning and design principles are:

- **CSS is universal.** A key strength of CSS/CSD is its universality and applicability to all stakeholders in the project, including owner agencies, the public and design professionals. The NCHRP 480 (Neuman et al., 2002) document summarizes strategies and approaches based on six areas of people who have a stake in the overall outcome of the project. The document is organized into sections based on professional area and the reader is referred to this document instead of summarizing each of those approaches herein.

- **CSS is applicable and effective at a project level.** CSS projects require effective and successful project delivery based on structured decision-making, thoughtful consideration of community input and values, environmental awareness, protection of safety, and an understanding of how the project fits within organizational needs and constraints (Neuman et al., 2002)
- **CSS promotes environmental stewardship.** Environmental resources are identified and goals are set to manage these resources at the beginning of the project. This approach helps to prevent unnecessary or minimize environmental impacts (ICF International, 2009).
- **CSS allows a clear definition of scope.** Implementing a project management structure that aligns with CSS principles can clearly define the project needs and scope. This helps prioritize problems that may arise during construction or even preempt them through thoughtful planning. (Stamitidias et al., 2009) It also allows for a unified vision statement; FHWA, 2007)
- **CSS offers a more-informed decision-making process.** Effective decision-making requires information from all collaborating parties. CSS accomplishes this collaboration by instituting a mantra of informed consent, through active stakeholder engagement and open communication. (Stamitidias et al., 2009; ICF International, 2009)
- **CSS engages stakeholders.** Stakeholder involvement is a core principle of CSS. Collection and integration of stakeholder values translates those values directly into the final project outcomes. (FHWA, 2009; AASHTO, pavement conference; Neuman et al., 2002; Stamiditidiadlas; ICF International, 2009) CSS opens lines of communication with all stakeholders early and keeps them open throughout project development and delivery (FWHA, 2007)
- **CSS is interdisciplinary**. Decisions made are consensus-based, and draw from project managers, environmental managers, roadway designers and engineers, owner agencies, and the public (Neuman et al., 2002).
- **CSS is cost-effective**. In a study by the Washington State Department of Transportation (WSDOT) and the University of Washington, WSDOT found that context-sensitive planning for community design elements in main street areas of urban centers help to preempt scope and scheduling changes, which resulted in potential overall savings for the agency. (Nicholls and Reeves, 2009)
- **CSS can be integrated into policy**. CSS is a well-established best practice that has been successfully integrated within many agencies to help achieve internal goals and objectives, such as at WSDOT and the Utah Department of Transportation (UDOT) (FHWA, 2007; ICF International, 2009).
- **CSS is ubiquitous.** The CSS/CSD process for projects (and for guidance documents) is well-suited to an online, collaborative and interactive environment. Many tools are available for project teams to create and manage the CSS elements of the project, including public involvement. The depth of the internet infrastructure that supports CSS ideas and implementation. The online database of CSS, http://www.contextsensitivesolutions.org is just one example of the resources available. Additionally, the FHWA and AASHTO Center for Environmental Excellence have created an open forum for all practitioners and professionals:

CSS and Sustainability

CSS is well-established and accepted as a best practice for roadway designers. However, it may be said that while using AASHTO's *Green Book* is considered a best practice for designing many roads, it certainly does not guarantee that the road itself will be "green" or more sustainable. Sustainability is a system characteristic that describes that system's capacity to support natural laws and human values. What actually makes the roadway more sustainable though is a team of proactive and thoughtful professionals making a deliberate attempt to be considerate of community needs, values and environmental surroundings while planning and designing the project. The multi-disciplinary, consensus-based, whole-system approach is the key difference between conventional practice and CSS, and it is also the reason why CSD usually results in a more sustainable project. In fact, CSS addresses all seven sustainability components under its wide umbrella of characteristics. Table AE-3.2 shows how the 15 principles of Context Sensitive Solutions address the seven components of sustainability and how they align with the Greenroads taxonomy of sustainability benefits.

Table AE-3.2: CSS and Sustainability (Adapted from Stamatidias et al., 2009)

No.	CSS Principle	Sustainability Components	Potential Benefits
1	Use of interdisciplinary teams.	✓ Experience	✓ Improves Business Practice
2	Involve stakeholders.	✓ Expectations ✓ Exposure	✓ Increases Awareness
3	Seek broad-based public involvement.	✓ Exposure	✓ Increases Awareness ✓ Improves Business Practice ✓ Creates New Information
4	Use a full range of communication strategies	✓ Exposure ✓ Experience	✓ Improves Business Practice ✓ Increases Awareness
5	Achieve consensus on purpose and need	✓ Expectations	✓ Improves Business Practice ✓ Increases Lifecycle Savings
6	Address alternatives and all modes	✓ Extent ✓ Experience	✓ Improves Business Practice ✓ Increases Lifecycle Savings
7	Consider a safe facility for users and community	✓ Equity	✓ Improves Human Health & Safety
8	Maintain environmental harmony	✓ Ecology ✓ Experience	✓ Optimizes Habitat & Land Use
9	Address community and social issues	✓ Equity ✓ Exposure	✓ Improves Access & Mobility ✓ Improves Human Health & Safety ✓ Improves Business Practice ✓ Aesthetics
10	Address aesthetic treatments and enhancements	✓ Exposure	✓ Aesthetics
11	Utilize a full range of design choices	✓ Experience ✓ Extent	✓ Optimizes Habitat & Land Use ✓ Improves Access & Mobility ✓ Increases Lifecycle Savings ✓ Increases Lifecycle Service
12	Document project decisions	✓ Expectations	✓ Improves Business Practice
13	Track and meet all commitments	✓ Expectations	✓ Improves Business Practice
14	Use agency resources effectively	✓ Economy	✓ Increases Lifecycle Savings ✓ Improves Business Practice
15	Create long-lasting community value	✓ Extent ✓ Expectations ✓ Equity	✓ Optimizes Habitat & Land Use ✓ Improves Human Health & Safety ✓ Improves Access & Mobility ✓ Increases Lifecycle Service ✓ Aesthetics

Following the CSS framework does not ultimately *guarantee* roadway sustainability as an end product, nor does it imply that sustainability must be necessarily considered during project development. However, CSS and sustainability are complementary approaches to the same endpoint. The CSS framework is well-suited to accommodating sustainability considerations, such as those outlined by Greenroads, early in project development.

Limitations of This Credit

Generally, CSS is a planning and design step that is comprehensive because it involves consideration of the entire project lifecycle and uses systems-thinking to create solutions. This lifecycle perspective necessitates an evaluation or assessment process that occurs during the operation and maintenance phase of the project (i.e. long-term performance monitoring). However, the credit requirements do not require detailed discussion of planning considerations for the roadway maintenance. This is because such plans and documentation for lifetime maintenance and operations are covered elsewhere in Greenroads (in fact, they are required under the Project Requirements PR-9 Pavement Maintenance and PR-10 Site Maintenance). Currently there is no credit given for monitoring or evaluation because there is no feasible mechanism available for a rating system to enforce or validate such activities.

Additional Resources

There are many, many resources available for CSS, from guidebooks to websites to formal research reports. Many of the ideas overlap and are shared between resources. The reader is referred to these sources for more detailed information on CSS. A brief description and a link (where applicable) are provided below:

- The hub for all things context-sensitive can be found at ContextSensitiveSolutions.org: http://www.contextsensitivesolutions.org
- The AASHTO Center for Environmental Excellence Context-Sensitive Solutions page includes a brief history and applicable federal, state and local laws, policies and guidance documents. Additionally, a number of user forums are available for public use. This page is available at: http://environment.transportation.org/environmental_issues/context_sens_sol/
- The *Flexibility in Highway Design* provides one of the earlier foundation documents for CSS and includes practical guidance for creating highways that are safe, effective and efficient using CSS principles.
- Two reports from NCHRP are heavily referenced in this discussion. They are *NCHRP 480: A guide to best practices for achieving context sensitive solutions* and *NCHRP 642: Quantifying the benefits of Context Sensitive Solutions*. The first offers a very qualitative review, and the second, a quantitative one.
- Public involvement is a core issue and there are two definitive FHWA resources available for facilitating effective stakeholder communication and public involvement processes. They are *Public Involvement Techniques for Transportation Decision Making* and *How to Engage Low-Literacy and Limited-English-Proficiency Populations in Transportation Decisionmaking.*

GLOSSARY

Context-sensitive design	See context-sensitive solutions
Context-sensitive solutions	A collaborative, interdisciplinary approach that involves all stakeholders to provide a transportation facility that fits its setting. It is an approach that leads to preserving and enhancing scenic, aesthetic, historic, community, and environmental resources, while improving or maintaining safety, mobility, and infrastructure conditions (also Context Sensitive Design)
CSD	Context sensitive design
CSS	Context sensitive solutions
Multimodal	Concerning more than one transportation mode
FHWA	Federal Highway Administration
NCHRP	National Cooperative Highway Research Program
AASHTO	American Association of State Highway and Transportation Officials

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TRAFFIC EMISSIONS REDUCTION

AE-4

5 POINTS

GOAL

Reduce operational mobile-source emissions to improve air quality and human health.

CREDIT REQUIREMENTS

Show that **congestion pricing** was used on this project. This usually is part of a larger congestion pricing program. Use the EPA MOVES2010 software to compute the total greenhouse gas emissions and criteria pollutant emissions reduced by the tolling or pricing program compared to the non-priced alternative for the length of the project.

Details

Emissions modeling will require establishing a **baseline case.** This should consist of the length of the project without congestion pricing and should use the same assumptions that are made in the **congestion pricing** case. **Congestion pricing** schemes reduce the number of vehicles on a roadway by charging money for use during peak periods, therefore reducing fuel use and total emissions. Congestion **pricing** need not apply to all lanes of a roadway.

DOCUMENTATION

Copy of the project design report showing the project's planned congestion pricing and a copy of the executive summary for the MOVES2010 traffic model study completed for the project for both the **baseline case** and **congestion pricing** case. The summary should include the same details of the model as noted above.

RELATED CREDITS

- ✓ PR-1 Environmental Review Process
- ✓ AE-2 Intelligent Transportation Systems
- ✓ AE-3 Context Sensitive Solutions
- ✓ AE-5 Pedestrian Access
- ✓ AE-6 Bicycle Access
- ✓ AE-7 Transit & HOV Access

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Equity
- ✓ Economy
- ✓ Extent
- ✓ Expectations

BENEFITS

- ✓ Reduces Fossil Fuel Use
- ✓ Reduces Air Emissions
- ✓ Reduces Greenhouse Gases
- ✓ Improves Mobility
- ✓ Increases Service Life
- ✓ Improves Human Health & Safety
- ✓ Reduces Lifecycle Cost

APPROACHES & STRATEGIES

- Become an early adopter agency of the MOVES2010 software.
- Consider implementing intelligent transportation systems (ITS) for dynamic pricing and conversion of existing high occupancy vehicle (HOV) lanes to high-occupancy toll (HOT) lanes.
- Note that some tolled facilities were not installed to manage congestion. In order for toll facilities to meet the intent of this credit, roadway projects within a tolled system, especially if the user cost is static, reduces congestion using the MOVES2010 software and providing supporting information as noted.

Example: Congestion Pricing in Puget Sound – Traffic Choices Study

In 2002, the Puget Sound Regional Council (PSRC) received a grant to become a pilot project with the Value Pricing Pilot (VPP) program with the Federal Highway Administration. The object of the study was to monitor behavioral changes (number of trips, mode, route, and time of vehicle trips) to variable or congestion-based tolling. The Traffic Choices Study (PSRC, 2008) used global positioning system (GPS) tolling meters to track driving patterns for 275 volunteer households, before and after experimental tolls were charged for use of major freeways and arterials in Seattle. While no cost was incurred by the volunteers, several important changes in travel demand were observed that have significant implications on reducing emissions. These results included:

- All trips (tours per week) decreased 7%
- Vehicle miles traveled (miles per week) decreased 12%
- Drive time (minutes of driving per week) decreased 8%
- Tour segments (segments of tours per week) decreased 6%
- Miles driven on tolled roads (tolled miles per week) decreased 13%.

More information about the Traffic Choices Study is available at: http://www.psrc.org/transportation/traffic.

POTENTIAL ISSUES

1. Note that the transportation sector designation of many energy use or GHG emissions statistics do not include processes for design or construction of roadways. This is likely due to the small time scale of construction activities when compared to the much longer service life of the road itself. Depending on the lifecycle model used and what the system boundaries of that model are, either the use phase (i.e. vehicular emissions) or the production of materials (i.e. the manufacturing or construction process) have been shown to have the highest overall impact on GHG and energy use. These values are highly variable dependent on location, capacity, type of roadway, multi-modal access, maintenance, and amount of congestion, to name just a few.
2. The EPA MOVES2010 model is currently the best available quantitative approach to modeling use-phase vehicle emissions. (EPA, 2009f) As with any software program, this model has built-in assumptions that may be counter-indicative of appropriateness for a particular roadway project. The limitations of EPA MOVES2010 should be understood prior to pursuing this credit.

RESEARCH

Though Greenroads is intended to be most easily implemented during the design and construction phases of the roadway lifecycle, the impact of the use and operations phase and the planning implications of the roadway in this phase are unavoidable. Ignoring these implications would be remiss, since clearly implementing such emissions reduction programs results in a roadway that is more sustainable overall. This credit rewards planning steps that have been implemented in order to reduce the overall lifecycle emissions impact due to vehicular traffic from roads in order to promote human and environmental health. Additionally, research in these areas also shows that there are external benefits, such as increased service life (and therefore, reduced long term maintenance costs) and human health improvements, that are associated with systematic tolling programs.

Air Emissions Impacts of the Transportation Sector

The most recent statistical data available from the EPA (2009a) and the Department of Energy (DOE: Davis, Diegel & Boundy, 2009) show that the transportation sector is one of the biggest contributors for many of the air emissions considered greenhouse gases and criteria pollutants. This is primarily due to the combustion of fossil fuels, most commonly gasoline and diesel. The amounts of these gases that are released during combustion depend primarily on the carbon content of the fuel. (Davis, Diegel & Boundy, 2009)

What are Greenhouse Gases?

Greenhouse gases (GHGs) are a group of 22 long-lived chemical compounds (Solomon et al., 2007) that are found in air emissions from human activities and natural processes. Increasing concentrations of these gases in the Earth's atmosphere have been identified to be major factors in global warming and climate change (sometimes these are combined to one term "global change"). High levels of these gases in the atmosphere disturb the energy balance of Earth's climate systems and act like a blanket around the Earth, trapping heat from solar radiation within the Earth's atmosphere which might otherwise escape via normal climate processes. The potency or concentration of these gases is measured in units of change in radiative forcing, which is a reflection of their overall warming (or cooling) influence. Currently, most GHG emissions are not as strictly regulated or otherwise monitored by the EPA.

The four GHGs that have been identified are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and halocarbons (a group of gases with fluorine, chlorine or bromine). Each gas has a different influence on global warming due to their properties and lifetimes. Typically, the gases are compared to a baseline unit of CO_2 using an index (multiplier) called Global Warming Potential (GWP) that reflects that compounds relative radiative forcing compared to CO_2. GWP is usually expressed in units of carbon dioxide equivalent (CO_2e, sometimes CO_2-eq) emissions, but does not necessarily reflect the same climate responses. (Bernstein et al., 2007) For example, 1 unit emission of methane has a GWP in 100 years equivalent to 25 units of carbon dioxide according to the Intergovernmental Panel on Climate Change Fourth Assessment Report, so it is expressed as 25 CO_2e. (Solomon et al., 2007; Bernstein et al., 2007)

The 2009 U.S. Greenhouse Gas Inventory Report (EPA, 2009a) states:

> *From 1990 to 2007, transportation emissions rose by 29 percent due, in large part, to increased demand for travel and the stagnation of fuel efficiency across the U.S. vehicle fleet. The number of vehicle miles traveled by light-duty motor vehicles (passenger cars and light-duty trucks) increased 40 percent from 1990 to 2007, as a result of a confluence of factors including population growth, economic growth, urban sprawl, and low fuel prices over much of this period. A similar set of social and economic trends has led to a significant increase in air travel and freight transportation by both air and road modes during the time series.*

According to this report, the transportation sector was responsible for 33% of CO_2 emissions, 26% methane (CH_4) emissions, and 67% of nitrous oxide (N_2O) emissions from fossil fuel combustion. These statistics have been adjusted for end-use sector (so contributions due to electricity generation have been included) and do not include air and freight modes. Generally, the end-use adjustment increases overall percentage contributions and direct emissions are less. The transportation sector is also accountable for 0.9% of the halocarbon emissions, mostly in the form of the refrigerant HFC-134a. (EPA, 2009a). End-use adjusted statistics were not specified for halocarbons in the transportation sector.

What are Criteria Pollutants?

The criteria pollutants are six common pollutants in air that are known have detrimental human health impacts as well as potential to damage property. The pollutants are particulate matter (PM_{10} and $PM_{2.5}$), ground-level ozone (O_3), nitrogen oxides (NO_x), carbon monoxide (CO), sulfur dioxide (SO_2), and lead (Pb). Of these pollutants, particle pollution and ground-level ozone are the greatest threats to human health and environmental damage. (EPA, 2009d) The six pollutants are called "criteria" pollutants because concentrations in the air are regulated by the EPA, who compares tested levels to allowable levels set in the 1990 Clean Air Act (CAA) amendments (40 CFR § 50) National Ambient Air Quality Standard (NAAQS). (EPA, 2009b; EPA, 2009c)

It is important to note fuel combustion also accounts for most of the indirect greenhouse gases (EPA, 2009a) which include CO, NO_X, non-methane volatile organic compounds (NMVOCs), and SO_2. Indirect greenhouse gases "do not have a direct global warming effect, but indirectly affect terrestrial radiation absorption by influencing the formation and destruction of tropospheric and stratospheric ozone, or, in the case of SO_2, by affecting the absorptive characteristics of the atmosphere. Additionally, some of these gases may react with other chemical compounds in the atmosphere to form compounds that are greenhouse gases." (EPA, 2009a)

Table AE-4.1 summarizes the percentage contributions of selected pollutants from the transportation sector. Most of the emissions come from use of highway vehicles and heavy trucks. Also, notably, transportation accounts for the majority of carbon monoxide and nitrogen oxide emissions in the United States (Davis, Diegel & Boundy, 2009).

Table AE-4.1: Transportation's Share of U.S. Emissions of Various Pollutants, 2007
(Adapted from Table 12.1 in Davis, Diegel & Boundy, 2009)

Pollutants	Chemical Symbol	Percentage of Total U.S. Emissions (%) in 2007
Carbon monoxide	CO	68.4
Nitrogen oxides	NO_X	57.1
Volatile organic compounds (VOC)	Various	33.9
Sulfur dioxide	SO_2	8.9
Ammonia	NH_3	5.7
Particulate matter	PM_{10}	2.7
	$PM_{2.5}$	7.2
Lead	Pb	Not included
Ozone	O_3	Not Included

Note that the term transportation sector means human use of vehicles on roadways, and commonly the air pollutant contributions due to construction are omitted from statistical reports. The DOE data in Table AE-4.1 were also not specifically adjusted for end-use electricity or energy for the transportation sector and includes contributions from air and freight modes. Due to the increased availability of unleaded gasoline and related regulations since the mid-1980s, the prevalence of the criteria pollutant lead has decreased significantly (EPA, 2009d) and it is not included in the statistics shown. Similarly, ground-level ozone is not included because it is not emitted directly; instead, it is formed due to a chemical reaction of nitrogen oxides and VOCs in sunlight (2009d).

How are Air Emissions from Transportation Modeled?

The EPA is required by the CAA to continually track and update air quality data from mobile source emissions, as well as its software models used to measure vehicle emissions. Prior to the December 2009 release of MOVES2010 software from the Office of Transportation and Air Quality (OTAQ), either MOBILE6.2 or previous versions of the MOVES program were required to be used to develop emissions models during creation of state implementation plans for air quality performance. Now, the EPA states that MOVES2010 is the best available tool for emissions modeling for transport. (EPA, 2009f) Recent data (collected within the last 10 years using the best available technologies and improved monitoring and controls) was used to develop the emissions algorithms in MOVES2010. Currently, there is a two year grace period before the EPA will require adoption of the MOVES2010 software in all regulated agencies. (EPA, 2009f) The added features of MOVES2010, when compared to MOBILE6.2, allow improved calculation of greenhouse gas emissions (as well as criteria pollutants) because it is based upon user inputs for transportation planning, vehicle-miles traveled (VMT) and speeds and not solely upon fuel consumption. (ICF Consulting, 2006)

Human Health, Air Quality & Public Policy

Human health impacts due to poor air quality, especially due to criteria pollutants from mobile sources like traffic, are well-documented. A systematic review by Woodcock et al. (2007) found that the health impacts of transport pollution are evidenced by increased total deaths, increased respiratory and cardiovascular death and diseases, increased allergies and also potentially link to cases of lung cancer. Additional deaths result from health dangers such as traffic accidents, and are commonly argued to be due to behavioral choices and lifestyles. An excerpt from the foreword of the 2005 World Health Organization (WHO) report, *Health Effects of Transport-Related Air Pollution,* frames the situation well:

> *Transport plays a fundamental role in the lives of societies and individuals: how people interact, work, play, organize production, develop cities, and get access to services, amenities and goods is inextricably linked with the development of mobility and the choices people make about it. In societies that rely heavily and increasingly on private motorized transport, vehicles are expected to become safer, more luxurious and powerful, and to be driven more frequently. These expectations, however, often do not take account of the ensuing consequences: increased fuel consumption, greater emissions of air pollutants and greater exposure of people to hazardous pollution that causes serious health problems. The increased intensity of and reliance on transport also increase the risk of road-traffic injuries, exposure to noise and sedentary lifestyles. These risks are a disproportional threat to the most vulnerable groups in the population, such as children and the elderly, and they raise important questions about social inequalities.* (Krzyżanowski, Kuna-Dibbert, & Schneider, 2005)

While the health effects of criteria pollutants are both well-documented and regulated, the health effects of greenhouse gas emissions are less well-understood. In 2009, Haines et al. published a summary for policy makers at the end of a comprehensive series of studies on the public health impact of greenhouse gases. All scenarios modeled by that group (see Woodcock et al. 2009) demonstrated significant increases in total human health based on three indicators (physical activity, outdoor air pollution and road traffic injury) when sustainable transport policies were implemented, as well as active transport and multi-modal solutions. Also, all scenarios demonstrated decreases in overall CO_2e emissions. (Woodcock et al. 2009) However, Chan (2009) notes that many policy makers have not made the connection between climate change and public health. She also notes that the carbon-reduction policy can provide benefits to public health which could be substantial, and includes reductions in chronic health problems such as heart disease, cancer, obesity, diabetes and respiratory ailments. Some regions have recently begun to change course and carbon-reduction policy is becoming more prevalent (Chan, 2009).

Haines et al. (2009) provide some key messages to policy makers, some of which are highlighted below:

- Substantial health benefits can be recognized by policies and measures made toward reducing greenhouse gas emissions at both regional and global levels.
- Specific transportation policies that can reduce GHG emissions and improve public health are increased walking and cycling modal access and reduced private vehicle use in urban areas.
- Some measures may have negative health effects too, but these tradeoffs must be weighed accordingly during decision-making (for example, reducing the danger of car accidents by encouraging cycling may increase danger of bicycle accidents).
- Costs of these measures vary but may be offset by the savings in healthcare costs, and in some cases the savings may outweigh costs in the long-term.
- Woodcock et al. (2009) also state that the avoided costs of healthcare are potentially enormous, though difficult to model.

The Role of Congestion Pricing

The concept of congestion pricing is not new (Congressional Budget Office: CBO, 2009). Pollution due to congestion is higher because stop-and-go traffic tends to increase fuel demand and therefore can produce more emissions. Increasing roadway physical capacity to meet traffic demand has been found to encourage additional demand and therefore increase vehicle trips, fossil fuel use, and air pollutant emissions. While substantial improvements in vehicle fuel efficiency have been achieved in the past decades, there are simply more drivers on the road at peak hours in many locations than can fit comfortably. Congestion pricing offers a means of approaching these challenges through more effective use of roadway capacity and influencing traveler behaviors through economic tools.

Congestion pricing works by applying a variable cost to the users of the roadway facility during peak travel times, thereby lowering travel demand, reducing the number of vehicles on a roadway, and reducing emissions due to fewer idling vehicles (CBO, 2009; Daniel & Bekka, 2000). Daniel & Bekka (2000) note that "Travelers do not consider costs of delay or pollution they impose on others, but only their own travel costs. Assessing congestion fees equal to the additional travel costs that travelers impose on others internalizes these costs and promotes efficient use of limited roadway capacity." Because congestion pricing improves efficiency (by not overloading the structural capacity of the pavement), the lifetime of the roadway is increased, which corresponds to less lifetime maintenance need and therefore reduced lifecycle costs. Also, congestion pricing has also been found to produce enormous net social benefits valued between $19-45 billion (2005 dollars) (CBO, 2009), and once implemented, has a surprisingly low public disapproval rating in most cases (Verbruggen, 2008).

A Brief Note on Equity

The role of equity in the debate over air quality in transportation policy is complex, as with any ethical debate regarding politics, economics and communities of people. Woodcock et al. (2007) notes that current levels of automobile use in high-income communities are not sustainable because they do not provide equal access or mobility. A recent study by Dietz & Atkinson (2005) highlights several of the core equity issues, including disparity between pollution distribution because of physical processes (i.e. some areas have lower air quality than others), economic policy (where the economic or tax burden of transport policies is often unevenly distributed, and sometimes hardest hit are low-income groups), and accountability for the generation of transportation emissions. However, the CBO (2009) reports that studies of the equity challenges due to congestion pricing have found support among all income groups where it has been implemented. Notably, Dietz & Atkinson (2005) point out "the fact that some enjoy cleaner air than others is significant." From this it follows that because cleaner air benefits everyone and the environment, the human equity discussion (while both important and inevitable) is secondary to the overall environmental quality goal. Also, other important equity issues can arise between communities and roadways due to certain placement or location near high density traffic areas (Appatova, Ryan, LeMasters & Grinshpun, 2008), or proximity and density of certain communities to low-rise structures which can trap pollutants in a "street canyon" effect (Salizzoni, Soulhac & Mejean, 2009). Equity issues regarding access and mobility needs are further addressed in subsequent Greenroads credits for multi-modal transport alternatives and solutions. However, Greenroads does not address land use, planning and zoning or other community location issues; it is not known if this is either possible or appropriate for such a metric, and in general these issues fall outside the scope of Greenroads.

Project Level Implications

The Clean Air Act (CAA) and well as former federal mandates, such as the Intermodal Surface Transportation Efficiency Act (ISTEA), the Transportation Equity Act for the 21st Century (TEA-21), and the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) give state agencies the authority to regulate and control air pollution through a variety of means (Daniel & Bekka, 2000) [*Note that as of this writing, the SAFETEA-LU regulation has expired and no replacement has been passed by Congress. It is assumed the state authority will be preserved.]* In general, implementing broad agency policies that provide mitigation strategies for curbing air emissions are likely to be very challenging (Fisher & Costanza, 2005) and also unfamiliar. Congestion pricing schemes may also be unfamiliar (or worse, unwanted) by public stakeholders (Verbruggen, 2008, CBO, 2009). But, D'Avignon et al. (2009) show that while global air emissions impacts do not translate well enough to be measured easily or meaningfully at local and regional scales, the impacts of local emissions policies can still be effective at reducing local sector contributions. Similarly, congestion pricing has been well-established as an effective measure for reducing vehicle emissions and increasing efficiency of roadway capacity. (FHWA, 2009; Hecker, 2003; CBO, 2009; Verbruggen, 2008)

D'Avignon et al. (2009) state that this is true especially when emissions inventories are used to establish initial policy benchmarks, reduction targets, and local action plans for mitigation. (For more information on emissions inventories, see Project Requirement PR-3 Life Cycle Inventory). While an emissions action plan or policy does not guarantee success or effectiveness, especially if targets are continually unmet or pushed further into the future, it does allow for increased local adaptability for long range climate change planning and project-specificity for emissions, as well as uniformity of local and regional policy and practice (Fisher & Costanza, 2005). The introduction of pricing schemes in the short-term might assist in future acceptance of such policies.

Pricing schemes differ in utility at a project level compared to regional policies because they can be applied on a project-by-project basis. Basically, this allows a corridor to be built and pricing to be implemented in a piecewise manner, which is more manageable and realistic on a project scale. However, piecewise management also comes with tradeoffs because it still requires adequate and thoughtful planning as well as public involvement prior to being implemented successfully and effectively.

Additional Resources

The American Association of State Highway and Transportation Officials (AASHTO) as part of National Cooperative Highway Research Program (NCHRP) of the Transportation Research Board (TRB) Task 25-25 completed a comprehensive study in 2006 of available assessment techniques for modeling greenhouse gas emissions in transportation projects (ICF Consulting, 2006). This report reviews the best available techniques and policy recommendations for transportation planners, and also highlights various tools for calculation, strategic planning, and energy/economic forecasting. The document discusses the advantages and limitations of the EPA MOVES software for emissions modeling. More information is available in *NCHRP 25-25(17), Assessment of Greenhouse Gas Analysis Techniques for Transportation Projects.*

The EPA provides up-to-date and detailed statistical information about GHG, indirect GHG, and criteria pollutant emissions due to fossil fuel combustion and the transportation sector. Additionally, the EPA provides and manages distribution of the free MOVES2010 software and provides policy guidance for implementing in SIPs. More information on these topics is available here:

- *2010 U.S. Greenhouse Gas Inventory Report:* http://www.epa.gov/climatechange/emissions/usinventoryreport.html
- *Green Book: Non-Attainment Areas on Criteria Pollutants* (includes NAAQS and data links): http://www.epa.gov/oar/oaqps/greenbk/index.html
- The Motor Vehicle Emissions Simulator (MOVES2010) and all relevant guidance and technical documentation: http://www.epa.gov/otaq/models/moves/index.htm

While the United States did not ratify the Kyoto Protocol, many individual states have become involved at a policy level in climate change and emissions targeting (Fisher & Costanza, 2005; Mayors' Climate Protection Center, 2009). The Mayors Climate Protection Center lists 1,016 individual cities whose mayors have agreed to reduce local emissions from 1990 values by 7% in 2012. There are also many regional initiatives, such as the Regional Greenhouse Gas Initiative (RGGI) and the Western Climate Initiative which have started CO_2 budget trading programs. More information about local and regional GHG initiatives can be found here:

- Mayors Climate Protection Center: http://usmayors.org/climateprotection/list.asp
- Western Climate Initiative: http://www.westernclimateinitiative.org/
- Regional Greenhouse Gas Initiative: http://www.rggi.org/home

The Congressional Budget Office (CBO) recently (2009) published a comprehensive review of congestion pricing in the United States, *Using Congestion Pricing to Reduce Traffic Congestion.* This document is available for free at http://www.cbo.gov/ftpdocs/97xx/doc9750/03-11-CongestionPricing.pdf

GLOSSARY

AASHTO	American Association of State Highway and Transportation Officials
Baseline case	The benchmark used to compare alternative emissions scenarios
CAA	Clean Air Act
CBO	Congressional Budget Office
Congestion pricing	An economic transportation planning tool increases the efficiency of the roadway by charging for use during peak periods
Criteria pollutant	One of six common pollutants in air that are known have detrimental human health impacts as well as potential to damage property
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
GHG	Greenhouse gas
Greenhouse gas	A long-lived chemical compound found in the atmosphere as a result of human and natural activities
ISTEA	Intermodal Surface Transportation Efficiency Act
NAAQS	National Ambient Air Quality Standard
NCHRP	National Cooperative Highway Research Program
Non-attainment area	Areas of the U.S. where air pollution levels persistently exceed the national ambient air quality standards
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
SIP	State implementation plan
State implementation plan	A plan for a state that shows how it is to comply with the Clean Air Act
TEA-21	Transportation Equity Act for the 21st Century
TRB	Transportation Research Board
WHO	World Health Organization

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PEDESTRIAN ACCESS

GOAL

Promote walkable communities by providing sidewalk facilities within the roadway right of way.

CREDIT REQUIREMENTS

Achieve Credit AE-3 Context Sensitive Solutions (CSS) and describe the need, purpose and appropriateness for planned, new, or upgraded pedestrian facilities in the submitted documentation for Credit AE-3. The CSS document should clearly note whether pedestrian facilities or improvements are required or have otherwise been requested by the public. Table AE-5.1 shows the points available for this credit.

Table AE-5.1: Available Points for Credit AE-5

Points	Requirements
1	Implement new (or improve existing) operations or technologies for pedestrian facilities. This includes added signage or minor access improvements for pedestrians, such as signalized intersections or crosswalks, shelters, and wheelchair ramps.
2	Implement physical or constructed changes to the roadway structure, dimensions or form that provide pedestrian access within the ROW, such as a sidewalk, raised crosswalk, bulb-out or pedestrian bridge structure.

Details

Pedestrian is defined as a person whose main mode of transportation is walking, including disabled individuals that need assistance devices for personal travel and mobility.

Sidewalk is defined as a paved surface provided specifically for pedestrian travel that is separate from the roadway and located within the roadway Right-of-Way.

Shared-use pathway is defined as a multi-use pathway for all non motorized users including pedestrians and bicyclists. This may be located within a roadway Right-of-Way yet must be separated from the roadway and have wider widths than sidewalks.

Current facilities do not qualify for this credit without additional effort, such as upgrades, improvements or construction of new facilities. The attempt to provide pedestrian access must be deliberate and as a direct result of the project.

DOCUMENTATION

- Copy of the section that focuses on pedestrian facilities in the Credit AE-3: Context Sensitive Solutions documentation. This section should address:
  a. Purpose and need for pedestrian access on the roadway project, including how it fits with existing land uses and/or existing General and Transportation Plans
  b. Regulatory or jurisdictional standards addressed, if any
  c. Results of public input on proposed pedestrian facilities, if any
  d. Total cost associated with new or improved pedestrian facilities
  e. Copy of the contract specifications and plans for proposed pedestrian facilities.

AE-5

1-2 POINTS

RELATED CREDITS

- ✓ AE-3 Context Sensitive Solutions
- ✓ AE-4 Traffic Emissions Reduction
- ✓ AE-6 Bicycle Access
- ✓ AE-7 Transit & HOV Access

SUSTAINABILITY COMPONENTS

- ✓ Equity
- ✓ Economy

BENEFITS

- ✓ Reduces Fossil Fuel Use
- ✓ Reduces Air Emissions
- ✓ Reduces Greenhouse Gases
- ✓ Improves Access
- ✓ Improves Mobility
- ✓ Improves Health & Safety
- ✓ Improves Local Economies

APPROACHES & STRATEGIES

- Include elements such as sidewalks or adjacent shared-use paths in designs when required by design standards, or community transportation plans, or by community request.
- Consider how a new or redesigned roadway will impact the existing or planned pedestrian networks and integrate design elements with other modal facilities (e.g. bicycle and transit) to mitigate overall impacts. This may mean providing connections or adaptability for future pathways, sidewalks, and crossings within the pedestrian network. Review local walking plans and maps of the existing pedestrian networks to understand how the roadway will interact with the existing and planned pedestrian and bicycle system. This may include shared-use paths or park plans.
- Include local pedestrian planners and advocates in advisory committees, project development or management teams, or decision-making committees as appropriate.
- Consult with planners and ADA advocates to understand how the project can support development of the pedestrian network to promote walkable communities.
- Design the roadway to accommodate existing new and planned pedestrian facilities.
- Upgrade or improve existing access points and sidewalks to meet the requirements of the Americans with Disabilities Act (ADA). Guidance on ADA transition plans is provided by the FHWA here: http://www.fhwa.dot.gov/civilrights/programs/ada_sect504qa.htm#q10
- Rely on the assessment of local planners and advocates where no existing pedestrian plan exists about how to integrate existing and future multimodal facilities into the project design. AASHTO provides helpful guidance in its *AASHTO Guide for the Planning, Design, and Operation of Pedestrian Facilities*.

Mulry Square – New York City

In 2001 Mulry Square in New York City was improved to improve and enhance pedestrian mobility through the area. As shown in the figures below, the crosswalks were more clearly marked as well as sidewalks being renovated to provide a more safe interaction between pedestrian and vehicle traffic (CSS, 2005).

Figure AE-5.1 and AE-5.2 show the clear difference before and after the intersection improvements were made. The pedestrian facilities are clearly improved in order to promote safer travel to pedestrians and make traffic more aware of pedestrians in the vicinity.

Figure AE-5.1: Mulry Square Before Construction (Context Sensitive Solutions, 2005)

Figure AE-5.2 - Mulry Square After Construction (Context Sensitive Solutions, 2005)

POTENTIAL ISSUES

1. A number of aesthetic treatments to the roadway or thoroughfare may be considered "pedestrian" benefits, but those treatments are covered elsewhere in Greenroads and are not included in this credit. See AE-8 Scenic Views and AE-9 Cultural Outreach.
2. Major intersections could see an increase in pedestrian vehicle accidents.
3. Many rural areas do not have surrounding pedestrian infrastructure or master plans to support the addition of new pedestrian facilities. Short term and long term goals, objectives and general pedestrian strategy should be considered when accommodating pedestrians within these areas.

RESEARCH

The inclusion or improvement of a pedestrian facility can drastically improve not only the quality and comfort of how people travel, but can change the mode of transportation used. Several sustainability components can be addressed by the improvement of pedestrian facilities, including: ecology, equity, and economy.

Reduced Emissions

Improved access and dedicated pedestrian facilities can convince people to change their mode of travel to walking instead of driving their vehicles. With fewer cars driving, there will be an obvious decrease in the greenhouse gas emissions associated with fossil-fuel driven vehicles.

Improved Health & Safety and Improved Mobility & Access

A person's transportation mode choice can be based around several different decisions. Several studies link the comfort and safety of the travel to the overall mode choice of a traveler (i.e. walking on a shoulder of a highway versus a sidewalk). Therefore an improvement of the safety of the current pedestrian facilities means that people will be more likely to travel on foot.

Designing facilities that are safe for pedestrians are of the utmost importance when considering pedestrian mobility. The main goal is to ensure the pedestrians have a means of travel that is separate from vehicle traffic to avoid any possible collisions. Typical design standards allow for timed crossing signals at cross walks, sidewalks that are elevated from the roadway, and other various methods. Raised sidewalks provide not only a slight barrier of separation, but also provide a slight comfort to the user that they are separated from traffic (Ewing & Dumbaugh, 2009). Other means of safe design include, increasing the distance between the stop line and cross walk at an intersection and putting up some sort of notification to drivers (signs, lights, etc.) that pedestrians are likely to be present in the area (Ewing & Dumbaugh, 2009).

Benefits of Active Transport

Increased pedestrian travel can also provide health benefits. A recent study compared the current state of travel and modeled a more sustainable type of travel using more walking and bicycles and reducing the amount of cars on the road. The study found the tendency for several chronic diseases could be reduced by having a higher population of travelers whom use walking or bicycles as their main mode of transportation (Woodcock et. al., 2009).

Considerations for Disabled Users

The goal of providing pedestrian facilities is to provide a means for everyone to travel, including people with special needs. Some improvements to sidewalks are mandated by the Americans with Disabilities Act (ADA) of 1990 and specific guidelines are available at: http://www.access-board.gov/adaag/html/adaag.htm. For transportation facilities this could include: sidewalks sloped for easy access or noise making devices installed at intersection crosswalks.

Boost Local Economies & Improve Mobility

The advent of new facilities on its own can also encourage travel throughout the area. This is simply based on increasing the overall pedestrian network throughout the area. With gaps in a pedestrian network, it can increase the distance a pedestrian is forced to travel, and can discourage them from using walking as a primary mode of transportation (Randall & Baetz, 2001).

GLOSSARY

ADA	Americans with Disabilities Act
Pedestrian	A person whom is traveling without the use of a mechanical device and main mode of transportation is walking.
Sidewalk	A surface provided specifically for pedestrian travel that is separate from the roadway

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BICYCLE ACCESS

AE-6

1-2 POINTS

GOAL

Promote bicycling in communities by providing dedicated cycling facilities within the project right of way.

CREDIT REQUIREMENTS

Achieve Credit AE-3 Context Sensitive Solutions (CSS) and describe the need, purpose and appropriateness for planned, new, or upgraded bicycle facilities in the submitted document for Credit AE-3. The CSS document should clearly note whether bicycle facilities or improvements are required or have otherwise been requested by the public. In order to achieve this credit, a bicycle-only facility must be present within the ROW at the start of construction or result from construction of this project. Table AE-6.1 shows the points available for this credit.

Table AE-6.1: Available Points for Credit AE-6

Points	Requirements
1	Implement new (or improve existing) operations or technologies for bicycle facilities. This includes (but is not limited to) added signage or minor access improvements for bicycles, such as installing bicycle detectors in driving lanes or granting signal priority, adding bicycle-friendly stormwater drains, code-required dimension upgrades, resurfacing existing bicycle lanes, or adding new streetside bicycle storage facilities (lockers, racks, etc.).
2	Implement physical or constructed changes to the roadway structure, dimensions, or form that provide bicycle-only facilities with dedicated access within the ROW, such as a bicycle lane, or other bikeway. Lanes shared with motorized vehicles do not meet this requirement.

Details

For purposes of this credit, the term **bicycle** refers to a pedal-driven, human-powered vehicle with at least one seat for an operator. **Shared-use pathway** is defined as a multi-use pathway for all non motorized users including pedestrians and bicyclists. This may be located within a roadway Right-of-Way yet must be separated from the roadway and have wider widths than sidewalks.

Current facilities do not alone qualify for this credit without additional effort, such as upgrades, improvements or construction of new facilities. The attempt to provide pedestrian access must be deliberate and as a direct result of the project.

DOCUMENTATION

- Copy of the section that focuses on bicycle facilities in the Credit AE-3: Context Sensitive Solutions documentation. This section should address:

  a. Purpose and need for bicycle access on the roadway project determined through a project analysis or a Bicycle Master planning process.
  b. Regulatory or jurisdictional standards addressed, if any
  c. Results of public input on proposed bicycle facilities, if any
  d. Total cost associated with new or improved bicycle facilities
  e. Contract specifications and plans for proposed bicycle facilities

RELATED CREDITS

- ✓ AE-3 Context Sensitive Solutions
- ✓ AE-4 Traffic Emissions Reduction
- ✓ AE-5 Pedestrian Access
- ✓ AE-7 Transit & HOV Access

SUSTAINABILITY COMPONENTS

- ✓ Equity
- ✓ Economy

BENEFITS

- ✓ Reduces Fossil Fuel Use
- ✓ Reduces Air Emissions
- ✓ Reduces Greenhouse Gases
- ✓ Improves Access
- ✓ Improves Mobility
- ✓ Improves Human Health & Safety
- ✓ Improves Local Economies

APPROACHES & STRATEGIES

- Include elements such as bicycle lanes, separated bicycle paths or adjacent shared-use paths in designs when required by design standards, or community transportation plans, or by community request.
- Review local bicycle plans and maps of the existing bicycle networks to understand how the roadway will interact with the existing and planned, roadway transportation, and bicycle and pedestrian systems.. This may include shared-use pathways or park plans.
- Include local bicycle planners and advocates in advisory committees, project development or management teams, or decision-making committees as appropriate. Consult with planners to understand how the project can support the development of the bicycle network and to promote cycling in communities.
- Design roadway improvements and new roadways to accommodate existing, new and planned bicycle facilities.
- Rely on the assessment of local planners and advocates where no existing bicycle plan exists about how to integrate existing and future multimodal facilities into the project design.
- Consider how a new or redesigned roadway will impact the existing or planned bicycle networks and integrate design elements with other modal facilities (e.g. bicycle and transit) to mitigate overall impacts. This may mean providing connections or adaptability for future bicycle lanes, shared-use pathways, crossings or other facilities within the bicycle network.

Example: Dedicated Access on a Roadway

Below, Figure AE-6.1 shows how a dedicated access for bicycles should be marked according to the Manual for Uniform Traffic Control Devices (FHWA, 2009).

R3-17 R4-4 W16-1P

1 point **1 point** **1 point**

Figure AE-6.1: Examples of appropriate signage for dedicated bicycle access. (FHWA, 2009)

Figure AE-6.2 is an example of lane markings that promote dedicated bicycle access (FHWA, 2009). As shown in the figure, bicyclists are provided their own separate lane on a roadway for travel.

Figure AE-6.3 shows how access should be marked for bicycles that are utilizing the same space as motor vehicles; however while the sign above earns one point (if none previously existed) because this helps increases awareness of bicycle users on a route with motor vehicles (and theoretically increases safety), the lane itself by definition does not provided *dedicated* access for bicyclists.

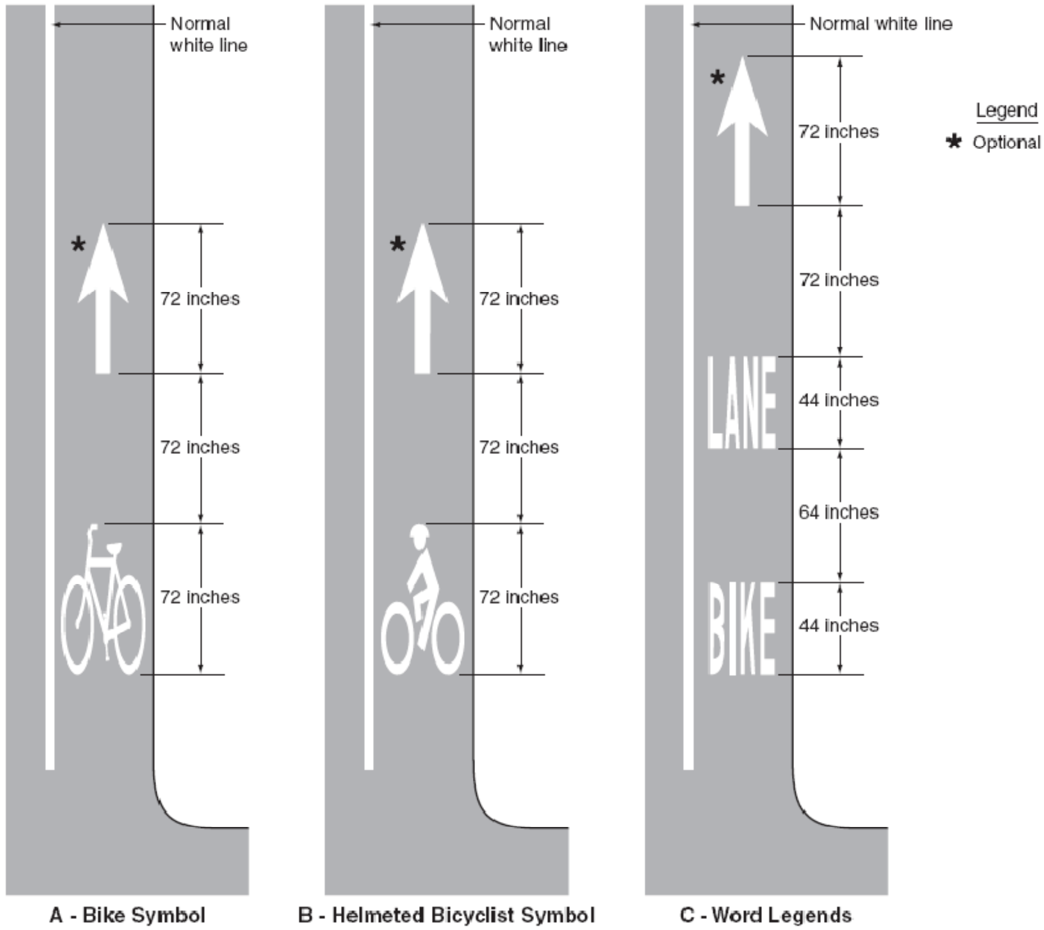

Figure AE-6.2: Examples of dedicated lanes for bicycle access. ***2 points if new or improved to meet or exceed these minimum dimensions.*** **(FHWA, 2009)**

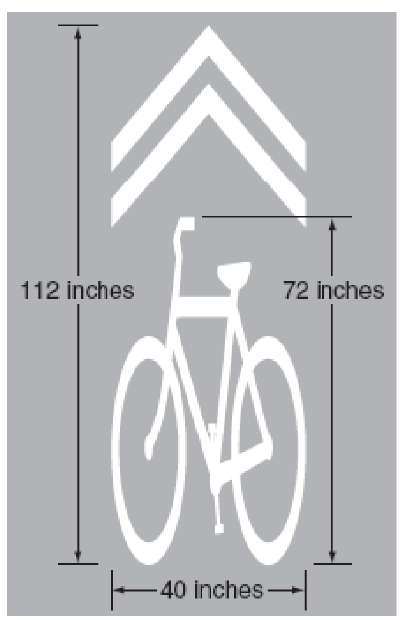

Figure AE-6.3: Access for bicycles in a motorized vehicle lane. ***No points.*** **(FHWA, 2009)**

Example: Case Study - Bridgeport Way University Place, Washington

Bridgeport Way was improved in 2005 to accommodate a more context sensitive roadway in University Place, Washington. In doing so, the city of University Place was able to significantly reduce accidents on the roadway, while providing an increased emphasis on pedestrian, bicycle and transit use in through the area. As shown in the figures below, there was a drastic change in the channelization of the roadway to provide adequate facilities to broaden the modes available for use through the corridor. The new design of the roadway proved to reduce traffic speeds which can encourage more bicycle use through the area (Context Sensitive Solutions, 2005). Simply by adding the facilities to the roadway, the city of University Place has encouraged the use of bicycle travel as well as pedestrian travel.

Figure AE-6.4: Bridgeport Way Before Construction. (Context Sensitive Solutions, 2005)

Figure AE-6.5 - Bridgeport Way After Construction (Context Sensitive Solutions, 2005)

POTENTIAL ISSUES

Encouraging cycling in areas where there was previously no cycling may result in increased bicycle crashes and collisions. Careful planning for bicycles and meeting engineering and safety standards can help to mitigate these instances.

RESEARCH

Increasing the bicycle facilities along a given corridor can have a beneficial result on the overall sustainability of a given roadway. The benefits of including bicycle facilities can include making a more equitable roadway, decreasing the amount of current traffic on the roadway, and also provide health benefits to users of the facilities. Bicycles and pedestrians are often grouped together because they are easily distinguished from motorized modes that use a right-of-way. Also, both walking and bicycling are considered "active transport" (Woodcock et al., 2009) modes. Therefore, much of supporting research for this credit and Credit AE-5 Pedestrian Access overlap, and will not be repeated here for brevity. Improved mobility and access, environmental and economic benefits, and health improvements of these active modes are addressed in Credit AE-5.

Bicycle Safety

The safety considerations for bicyclists are typically involved in driving on the same surface as motor vehicles. Several safety measures are available to increases the safety of both motor vehicles and bicyclists. The American Association of State Highway and Transportation Officials recommends that bike lanes have dimensions of at least four feet in width and are located between the lane of travel and sidewalk or parking lane. This reduces the chance of accidents between bicycles and vehicles (AASHTO, 1999).

However, Ewing and Dumbaugh (2009) show that the best method to increase safety for bicycles and pedestrians is by increasing awareness through notification or signage along a right-of-way. They also show that increases in overall numbers of bicyclists (and pedestrians) offer "safety in numbers" because of heightened awareness. Furthermore, dedicated access for bicycles provides comfortable travel without lane sharing as well as improved safety. Reynolds et al. (2009) has shown dedicated access can reduce bicycle-vehicle accidents by up to 50 percent compared to shared-use lanes.

GLOSSARY

AASHTO	American Association of State Highway and Transportation Officials
Active transport	Walking or biking (human-powered transport)
Bicycle	A pedal-driven, human-powered vehicle with at least one seat for an operator
FHWA	Federal Highway Administration

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TRANSIT & HOV ACCESS

GOAL

Promote use of public transit and carpools in communities by providing new transit and HOV facilities or by upgrading existing facilities in the roadway right-of-way.

CREDIT REQUIREMENTS

Achieve Credit AE-3 Context Sensitive Solutions (CSS) and describe the need, purpose and appropriateness for planned, new, or upgraded transit and HOV facilities in the submitted document for Credit AE-3. The CSS document must demonstrate that at least one mass transit route and/or HOV facility exists, or is planned to exist within 5 years of the start of construction, that is accessible from the project ROW within 0.25 mile. Table AE-7.1 shows the point criteria for this credit.

Table AE-7.1: Available Points for Credit AE-7

Points	Requirements
Any 1	a. Enhance at least 50% of transit station or stop amenities (lighting, trash bins, benches, pay phones, heating and/or cooling, etc.) b. Improve at least 50% of the transit and HOV facility signage (related to transit & HOV) and vehicular access (beyond basic ADA requirements) c. Provide transit shelters at more than 50% of the corridor stations/stops d. Provide access to new park & ride lots in strategic locations.
2	Implement two or more of the improvements from the list above.
3	Implement physical or constructed changes to the roadway structure, dimensions or form that provide HOV access or minor dedicated transit access within the ROW, such as a **carpool lane** for HOV vehicle or **queue jump lanes** for transit vehicles**.**
4	Implement physical or constructed changes to the roadway structure, dimensions or form that provide dedicated transit access within the ROW, such as an **on-street bus lane or an expressway bus lane.**
5	Implement physical or constructed changes to the roadway structure, dimensions or form that provide exclusive mass transit access within the ROW, such as **at-grade or grade-separated transitways**.

Details

The point criteria for this credit are roughly based on the Federal Transity Authority (FTA) criteria from *Characteristics of Bus Rapid Transit for Decision-Making (CBRT)* and *TCRP 90, Bus Rapid Transit* by Diaz and Hinebaugh (2009).

DOCUMENTATION

- Copy of the section that focuses on transit & HOV facilities in the Credit AE-3: Context Sensitive Solutions white paper. This section should address:
  a. Purpose and need for transit & HOV access on the roadway project, including how it fits with existing land uses and/or existing General and Transportation Plans
  b. Regulatory or jurisdictional standards addressed, if any
  c. Results of public input on proposed transit & HOV, if any
  d. Total cost associated with new or improved transit & HOV facilities
  e. Contract specifications and budget items addressing transit & HOV

AE-7

1-5 POINTS

RELATED CREDITS

- ✓ AE-2 Intelligent Transportation Systems
- ✓ AE-3 Context Sensitive Solutions
- ✓ AE-4 Traffic Emissions Reduction
- ✓ AE-5 Pedestrian Access
- ✓ AE-6 Bicycle Access

SUSTAINABILITY COMPONENTS

- ✓ Equity
- ✓ Economy
- ✓ Experience

BENEFITS

- ✓ Reduces Fossil Fuel Use
- ✓ Reduces Air Emissions
- ✓ Reduces Greenhouse Gases
- ✓ Improves Access
- ✓ Improves Mobility

APPROACHES & STRATEGIES

- Review local plans and existing transit service plans to understand how the roadway will interact with the existing and planned transit system. Because of the strong connections between the pedestrian and bike system and transit, this may overlap with bike and pedestrian planning. See related credits for further details.
- Include the local transit provider(s) in advisory committees, project development or management teams, or decision-making committees as appropriate.
- Consult with local transit provider(s) to understand how the roadway project can support their operations and future expansion.
- Consider how a new or redesigned roadway will impact the existing or planned pedestrian networks and integrate design elements with other modal facilities (e.g. bicycle and transit) to mitigate overall impacts. For example, this might mean including a pedestrian crossing on a major arterial that could be a barrier to residents reaching a transit facility.
- Survey existing routes and ask stakeholders for suggestions on how to improve access to existing transit facilities during the public involvement process.
- Locate enhancements to transit station/stop amenities at more than 50% of the stations/stops along the corridor based on cost. Amenities could include installing safety lighting, trash receptacles, benches, pay phones, heating and/or cooling and other similar enhancements. This should be reflected somewhere in the project bid list or budget.
- Install signage and improve access that is exclusively for transit and HOV vehicles only to earn this credit. This distinction is not to discourage a comprehensive signage program; however, signage for pedestrian and bicycles are addressed in Credit AE-5 Pedestrian Access and Credit AE-6 Bicycle Access. A comprehensive approach to signage and access improvements at a transit and HOV facility can ultimately include all modes and be eligible for points in multiple credits.
- Identify trouble spots for transit and combine transit signal priority with queue jump lanes to create an efficient transit facility at minimal cost. This can also earn points with Credit AE-2 Intelligent Transportation Systems.
- Consider adding a carpool lane, which encourages multiple passengers in each vehicle and can improve transit travel times and reliability.
- Improve access beyond basic requirements, such as ADA.
- Improve signage beyond basic requirements where signage already exists. Types of signage improvements could include providing passenger information amenities (maps, schedules, real-time signage) at facilities and signs along the roadway to designate transit stations.
- Place additional park and ride lots in strategic transit and/or carpool access locations.
- Provide extra width on sidewalks to accommodate transit shelters.
- Design the roadway to accommodate an exclusive transit lane.
- Accommodate any planned fixed guideways by constructing grade-separated crossings.

Example: Point Calculations

2 points
A roadway with several major transit routes is being resurfaced and above ground electrical wires are being buried as a component of the project. Along with the roadway improvements, all (100%) of the major transit stops along the route are being enhanced with real-time bus arrival information, lighting, surveillance cameras, area map displays and trash cans. This project would earn 2 points because it includes significant improvements (over 50%) to both (a) amenities and (b) signage.

4 points
A bus rapid transit project includes a roadway widening and restriping to add an outside dedicated transit lane with signal priority at intersections. The project also includes station enhancements at all the stations along the corridor with new shelters, grade-separated pedestrian access, real-time passenger information, bicycle storage lockers and several station amenities. This project would receive 4 points under Transit & HOV Access. The transit signal priority improvements would be eligible for the ITS credit and pedestrian and bicycle improvements would be eligible for the Pedestrian Access and Bicycle Access credits. See Figure AE-7.1.

Figure AE-7.1: An on-street bus lane in Vancouver, Canada. *4 points.* (Photo by K. Watkins)

5 points

See examples of a grade separated transitway in Figure AE-7.2 and an at-grade transitway in Figure AE-7.3.

Figure AE-7.2: A grade separated transitway in Ottawa, Canada worth. *5 points.* (Photo by K. Watkins)

Figure AE-7.3: An at-grade transitway in Eugene, Oregon. *5 points*. (Photo by K. Watkins)

POTENTIAL ISSUES

1. Many transit and HOV facilities (such as park and ride lots and transit centers) will involve improvements that cross multiple modes. In order to award credit here, especially where no drastic physical changes to the roadway structure or form are implemented, improvements and changes should be exclusive to HOV and transit users and distinguishable, via a budget item for example, from other amenities that are for pedestrian and bicyclists. An example would be improvements to bus stops where the sidewalk grades are raised to accommodate bus ramps for disable passengers. Although the integration of transit with bicycles and pedestrians is key to obtaining higher ridership, amenities which are included in the Pedestrian Access credit AE-5 and Bicycle Access credit AE-6 cannot be applied again here.
2. This credit presupposes the integrity of the designer: appropriate signage and safety must be preserved with the higher points available in this credit. This means that a transit or HOV facility such as a dedicated busway or carpool lane is assumed to be signed appropriately and will not be designed to increase safety risk. Additional points are not awarded for signage and access improvements for the higher value credits for this reason.
3. Intelligent Transportation Systems (ITS), transit & HOV often go hand in hand but are explicitly not covered in this credit because they are included in Credit AE-2 Intelligent Transportation Systems. However, many ITS applications, such as traveler information, transit management, and lane management pair nicely with the improvements in this credit.

4. Aesthetic improvements to transit and HOV facilities or other public art, while considered amenities, are not included in this credit. See Credit AE-9 Cultural Outreach. It is possible to include all of these things and earn points across multiple credits.
5. Light rail or busway projects can qualify for this credit if they meet the criteria and are completed within the roadway right-of-way. In general, many of the credits available in Greenroads are broadly applicable and may also be applied to these types of projects, but they may lack the specificity needed to be effective as a metric for such facilities.
6. This credit focuses in two areas, runningways and stations. This is the supporting infrastructure for transit and HOV access, facilities and system services. Corridor enhancements such as service improvements (increased service, new or specialized service, route restructuring), branding, marketing and partnership programs, information systems, fare innovations, and new or enhanced vehicles are encouraged but are outside the scope of the Greenroads Rating System.

RESEARCH

The societal benefits of public transportation are numerous. Transit provides mobility to those who cannot or chose not to drive, including access to jobs, education and medical services. Transit reduces congestion, gasoline consumption and the nation's carbon footprint (America's Public Transportation Association: APTA, 2008). In 2007, public transportation saved 646 million hours of travel delay and 398 million gallons of fuel in the U.S., resulting in a savings of $13.7 billion in congestion costs (Schrank and Lomax, 2009). Use of public transportation reduced U.S. carbon dioxide (CO_2) emissions by 6.9 million metric tons in 2005 (Davis and Hale, 2007). The increased use of transit on a per capita basis is critical to the nation's economy and meeting environmental goals.

Improvements to public transportation infrastructure are critical to any plan to improve the sustainability of transportation. In the Urban Land Institute's recently produced "Moving Cooler" report (Cambridge Systematics, 2009), transit capital investments had the ability to produce cumulative greenhouse gas reductions of 0.4 to 1.1 percent of baseline emissions. The report identifies public transportation improvements as one of nine key categories that can be bundled to reduce emissions. Further, the World Bank (Gwilliam, Kojima, and Johnson, 2004) identifies modal shifts to non-SOV modes as a key to reducing transport sector emissions. They point out however, that mixing cars, other vehicles and nonmotorized transport with public transport vehicles "reduces the average speed of traffic and makes it difficult to establish an effective bus system."

Infrastructure improvements should include means to separate transit vehicles from general purpose traffic to make the mode competitive (Vuchic, 2005; 2007). Without exclusive right-of-way, transit vehicles are held captive by the congestion caused by low occupancy vehicles and cannot improve the efficiency of the transportation system. For this reason, this credit includes higher point values as the exclusivity of transit right-of-way improves.

Additional Resources

Two of the most useful references to understanding the elements for this credit are:

- The Federal Transit Administration's *Characteristics of Bus Rapid Transit for Decision-Making (CBRT)* guidance document by Diaz and Hinebaugh (2009), which is available at: http://www.fta.dot.gov/documents/CBRT_2009_Update.pdf
- Transportation Research Board's *Transit Cooperative Research Program (TCRP) 90, Bus Rapid Transit: Volume 2: Implementation Guidelines*, by Levinson et al. (2003). This document is available at: http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_90v2.pdf

Many additional references are included for consideration of other applicable planning and design guidelines. Although credits are obtained for including elements, proper design is critical to the functionality of the facilities and the References section at the end of this credit should be considered a starting point.

GLOSSARY

At-grade transitway	Roads for the exclusive use of transit vehicles with access allowed only at designed points, however intersections and other crossings are at-grade and subject to signalization
BRT	Bus rapid transit – a flexible, high performance rapid transit mode that combines a variety of physical, operating and system elements into a permanently integrated system with a quality image and unique identity
CBRT	Characteristics of Bus Rapid Transit for Decision-Making, an FTA document describing the major elements of BRT and impact on system performance
Carpool lane	A roadway lane designated for vehicles with more than one occupant
Dedicated lane	A lane designated for only transit or only HOV use
Expressway bus lane	Bus lane on an expressway dedicated to bus use only
FTA	Federal Transit Administration
Grade-separated transitway	Roads for the exclusive use of transit vehicles with access allowed only at designed points, include overpasses or other grade-separate at crossings to minimize conflicts with other vehicles
HOV	High Occupancy Vehicle – a vehicle with two or more occupants
HOV facility	A physical entity, structure or space that provides HOV access or services to or in the ROW, such as a park and ride, carpool lane or transit center
ITS	Intelligent transportation systems - the integration of information and electronics technology into transportation infrastructure to relieve congestion, improve safety and enhance productivity
Mass transit	See transit
On-street bus lane	A lane on an arterial or collector street reserved for bus use only
Public transit	See transit
Queue jump lane	A lane used at a bottleneck location (typically intersections) to allow transit vehicles to come to the front of waiting traffic and bypass the queues by receiving an early green signal
Single-Occupant Vehicle	Vehicles with one occupant of driving age (the driver)
Station	Transit passenger pick-up and drop-off locations that serve as the entry and exit point from the public transportation system
Runningway	The track or roadway on which transit operates
TCRP	Transit Cooperative Research Program - a Transportation Research Board research initiative for public transportation
Transit	A mode of transportation that includes vehicles open to public use such as buses, light rail, subways, ferries and trains
Transit signal priority	Alters signal timing to give priority to transit vehicles by extending green time, giving early green time or providing an exclusive transit phase

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SCENIC VIEWS

AE-8

1-2 POINTS

GOAL

Feature National Scenic Byways Program (NSBP) values in a roadway.

CREDIT REQUIREMENTS

EITHER requirement may be met for credit.

1 Point: Any portion of the project is part of the National Scenic Byways Program (NSBP) (http://www.byways.org) meaning it has been designated as one of America's Byways® (National Scenic Byway or All-American Road), a State Scenic Byway, or an Indian Tribe Scenic Byway because of its scenic, natural, and/or recreational qualities.

OR

2 Points: Provide at least one access from the project to a designated area for vehicles to exit the traffic stream, stop and experience scenic, natural or recreational features along the roadway. These areas may be scenic viewpoints or overlooks, welcome centers, tourist activities or information centers or recreation areas. They must be identified with signage conforming to 23 CFR 655 (the Manual on Uniform Traffic Control Devices, current revision) Part 2 – Signs.

Details

The NSBP is a broad program that captures many roadway qualities. These can best be categorized as scenic, historical, cultural, natural, recreational and archeological. This credit covers scenic, natural and recreational qualities. Credit AE-9 Cultural Outreach covers historical, cultural and archeological features.

DOCUMENTATION

If a scenic route designation is used to satisfy this credit, provide documentation of national, State, or Indian tribe designation. Also provide a picture of the route that best captures its scenery or other important features.

OR

If a roadside access point is used to satisfy this credit, indicate in the submitted plans and specifications where the viewpoint or overlook is drawn and specified. Also provide a picture of the access point and a picture of the related attraction.

RELATED CREDITS

- ✓ PR-11 Educational Outreach
- ✓ AE-3 Context Sensitive Solutions
- ✓ AE-9 Cultural Outreach

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Equity
- ✓ Exposure

BENEFITS

- ✓ Increases Awareness
- ✓ Increases Aesthetics

APPROACHES & STRATEGIES

- Work through formal channels to have a roadway or portion of roadway designated as a National Scenic Byway, an All-American Road, a State scenic byway, or and Indian Tribe scenic byway.. This can be done through the National Scenic Byways Program or through a State or Indian Tribe program that formally recognizes scenic roadways.
- Provide locations, such as viewpoints or pullouts, where drivers can stop to enjoy a scenic, historic, cultural, natural, recreational, or archaeological feature of the roadway area.
- For America's Byways® and State designated byways, apply for a grant with the NBSP to enhance one of the above qualities.

Example: National Scenic Byways Program

The National Scenic Byways Program (NSBP), part of the Federal Highway Administration, has a mission to "…provide resources to the byway community in creating a unique travel experience and enhanced local quality of life through efforts to preserve, protect, interpret, and promote the intrinsic qualities of designated byways." (NSBP, 2009). The program formally recognizes certain roads for their archaeological, cultural, historic, natural, recreational and scenic qualities. To become an official "Byway" (the overarching term the NSBP uses to describe these roads) a roadway must be nominated (the nomination can originate from any person or organization) through a detailed process. The NSBP defines six intrinsic roadway qualities that a roadway can possess. National Scenic Byways possess "characteristics or regional significance" in at least one of these intrinsic qualities, while All-American Roads possess "characteristics of national significance" in at least two of these intrinsic qualities (NSBP, 2009). The six intrinsic qualities are (paraphrased from NSBP, 2009):

- **Archaeological.** Physical evidence of historic or prehistoric human life or activity that is visible and capable of being inventoried and interpreted.
- **Cultural.** Evidence and expressions of the customs or traditions of a distinct group of people.
- **Historic.** Legacies of the past that are distinctly associated with physical elements of the landscape, whether natural or manmade, that are of such historic significance that they educate the viewer and stir an appreciation for the past.
- **Natural.** Those features in the visual environment that are in a relatively undisturbed state. These features predate the arrival of human populations and may include geological formations, fossils, landform, water bodies, vegetation, and wildlife.
- **Recreational.** Outdoor recreational activities directly association with and dependent upon the natural and cultural elements of the corridor's landscape. They provide opportunities for active and passive recreational experiences.
- **Scenic.** Heightened visual experience derived from the view of natural and manmade elements of the visual environment of the scenic byway corridor.

Figure AE-8.1 shows a map of registered National Scenic Byways and All-American Roads in the U.S. as classified by the NSBP. The NSBP website gives maps and locations for Byways (Figure AE-8.2) that can be used to determine if a particular project encompasses part of one.

Figure AE-8.1: United States Scenic Byways. (NSBP, 2009).

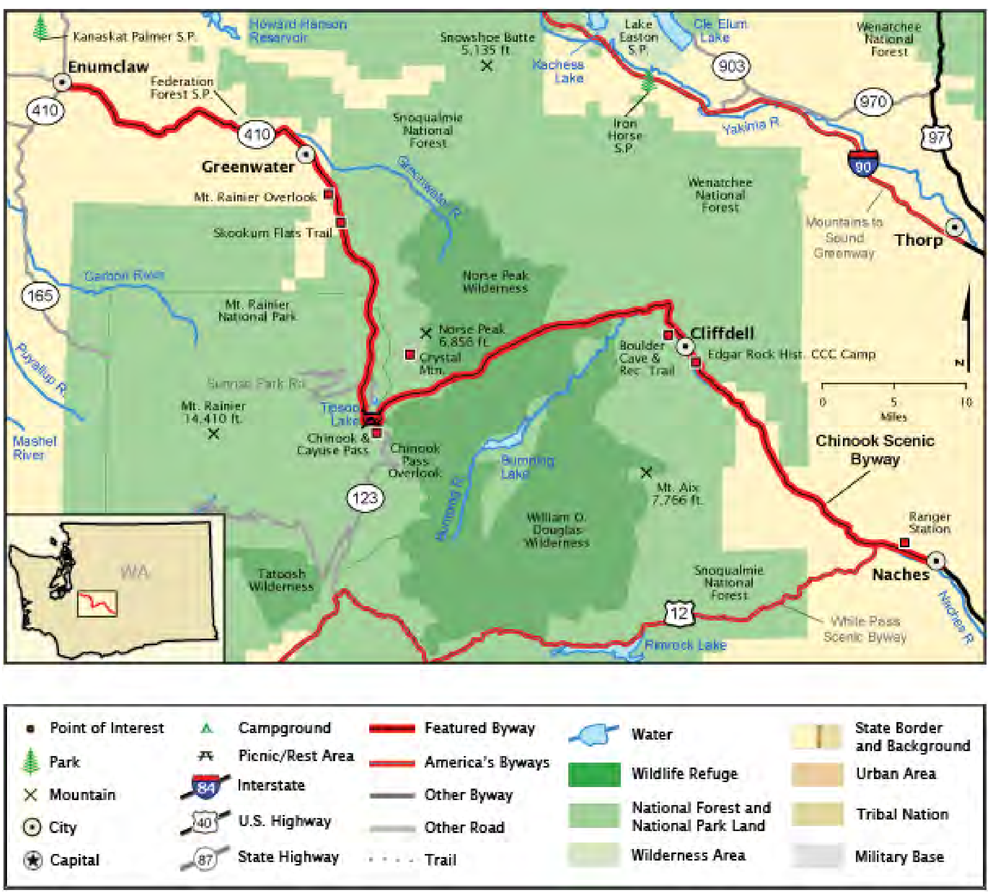

Figure AE-8.2: An example of the maps available at the NSBP website (NSBP, 2009). This map is for the Chinook Scenic Byway near Mt. Rainier in Washington State.

Example: Oregon Scenic Byways

Oregon has its own Scenic Byways Program that includes federal, state, city and county defined scenic roads and highways. Some are in the NSBP and some are not. This program lists its scenic byways at: http://www.oregon.gov/ODOT/HWY/SCENICBYWAYS/index.shtml. As an example, the Silver Falls Scenic Byway is a 55-mile route near Salem, OR that goes through Silver Falls State Park. Although it is not part of the NSBP, it still qualifies for this Voluntary Credit based on its designation by the state of Oregon.

Example: Scenic Viewpoint

Roadways can offer opportunities to safely view scenery by providing designated pullouts or viewing areas that allow motorists to stop and exit their vehicles to take in scenery. These viewing areas can be large constructed parking lots with visitor amenities (Figure AE-8.3) or can be simple widened shoulder pullouts (Figure AE-8.4). In either case the viewpoint or overlook should be properly signed and identified.

Figure AE-8.3: Scenic viewpoint showing Mt. St. Helens accessible from Forest Highway 25 in the Gifford Pinchot National Forest.

Figure AE-8.4: Scenic pull out (slightly left and lower from center) on SR 410 in Mt. Rainier National Park.

POTENTIAL ISSUES

1. Although a roadway may provide pleasing scenery, it cannot be considered for this Voluntary Credit unless it is (1) formally designated as a scenic roadway, or (2) provides an area for drivers to pull off the travelled way and stop to enjoy the scenery.
2. Historical roadways or those with access to specific cultural or geological features are specifically included in Credit AE-9: Cultural Outreach. In some cases, a roadway might qualify for both AE-8 and AE-9.
3. Providing signage or direction to a scenic viewpoint or overlook that is not directly part of the roadway project does NOT satisfy this Voluntary Credit.

RESEARCH

"Scenery is defined as the general appearance of a place and the features of its views or landscapes" (Gallioano and Loeffler, 2000). In the context of this Voluntary Credit it more specifically refers to predominantly natural features rather than man-made. Along a roadway, scenery is then the natural features and beautiful views that can be seen from or nearby the roadway. In the context of sustainability, humans place value on what they can see and its quality so the availability of scenic views along roadways can contribute to the equity component of sustainability (i.e., scenic views are something we value as humans). There are also measurable physical and psychological benefits to attractive scenery (Gallioano and Loeffler, 2000 cite Driver et al., 1992; Ulrich, 1984) and human preference for natural landscapes is identifiable and measurable (Gallioano and Loeffler, 2000 cite Magill, 1992; Lee, 1976; Litton, 1984; Daniel & Boster, 1976). Therefore, providing access to scenic views has value and can contribute to the sustainability of a roadway. The exact nature of the value can be complex but such value is based primarily on human perception and economic worth. The next two sections briefly survey these ideas.

Assessing Visual Landscape Quality

In a broad sense, visual landscape quality (a term that implies "scenic views" and a rating of their degree of excellence) is typically quantified using expert design approaches or public perception approaches (Daniel, 2001). Expert design approaches rely on translating landscape features to formal design parameters that can then be related to how humans perceive them based on models or theory. Public perception approaches rely on how landscape features function as stimuli to evoke human response. Either method is fundamentally related to how humans perceive landscape features. These perceptions are, on average, quite consistent in that people tend to prefer natural-appearing landscapes (Lee, 1976; McGuire, 1979; Newby, 1971; Noe, 1988) and generally like the same things (Zube, 1976). Therefore, in a broad sense it is possible to predict human preferences for visual quality and plan for them in a roadway. An opposite approach that is gaining momentum seeks to directly assess the ecological function of the landscape and deem human perception and preferences irrelevant (Daniel, 2001). This approach may even find that not building *any* road may be the best approach to preserving visual landscape quality.

Economic Value of Scenery

Scenery can also be judged based on its economic value. Most research in this area investigates what humans have paid for the privilege of enjoying a view or what they would be willing to pay. For example, in looking at Hong Kong apartments Jim and Chen (2009) found that people are willing to pay a premium for attractive views; e.g., a broad harbor view of Hong Kong Harbor could increase the apartment value by 2.97% or about $15,173. In something perhaps more related to roadway scenery, Batistan et al. (2002) looked at the value of agricultural land in Wyoming (near Yellowstone and Grand Teton National Parks) and found that "…remote agricultural lands, which include wildlife habitat, angling opportunities and scenic vistas, command higher prices per acre than those which primarily possess agricultural production capacity." Another, perhaps simpler, way to demonstrate the economic value of scenic views is to look at the pricing of hotel rooms. Lange and Shaeffer (2001) looked at room pricing in Zurich, Switzerland and found there to be significant value in views (a somewhat obvious conclusion but nonetheless supported by proper statistical analysis). Such economic analysis is not entirely new either. An 1879 article in the New York Times (Jarves, 1879) provides an early view into what scenery is worth. In this article Jarves looks at tourist visits to Switzerland and claims 1.4 million visitors have spent over $45 million, which, he argues, can be viewed as the interest at 5% on $900 million, "…which may be considered the actual market value of the landscape alone…" In 2009 dollars that conservatively comes to well over $20 billion.

The National Scenic Byway Program (NSBP)

The NSBP chooses less scientifically rigorous methods for selecting roadways for designation as National Scenic Byways or All-American Roads. The definition of their six intrinsic qualities that these roads have (archaeological, cultural, historic, natural, recreational, scenic) indicates that the NSBP definition is broader than the Gallioano and Loeffler (2000) definition of "general appearance and the qualities of its view and landscapes." However a review of these six intrinsic qualities shows that each one must essentially be represented by a physical presence that can be viewed or experienced. The specific requirements for scenic byway designation are outlined by the FHWA in their interim policy on Scenic Byways (National Scenic Byways Program, 1995). Specifically, roadways nominated should:

- Safely and conveniently accommodate two-wheel drive automobiles with standard clearances.
- Accommodate, wherever feasible, bicycle and pedestrian travel.
- Safely accommodate conventional tour buses.
- Have a scenic byways corridor management plan. For All-American Roads, there must be a demonstration of the extent to which enforcement mechanisms are being implemented by communities along the highway in accordance with the corridor management plan.
- User facilities (e.g. overlooks, food services, etc.) should be available for travelers.
- Have continuity. Roadways should have too many gaps but rather should be as continuous as possible and should minimize intrusions on the visitor's experience.

Also, and importantly, *any road nominated for the National Scenic Byway or All-American Road designation is considered to be designated a State scenic byway*. Many of the scenic byways running through the United States are not just viewed as part of the how people travel, but can be recognized as cultural landmarks (Youngs, White and Wodrich, 2008).

GLOSSARY

All-American Road	A road designated by the National Scenic Byways Program and possessing characteristics of national significance within at least two of the following intrinsic qualities: archaeological, cultural, historic, natural, recreational and scenic.
National Scenic Byway	A road designated by the National Scenic Byways Program and possessing characteristics of regional significance within at least one of the following intrinsic qualities: archaeological, cultural, historic, natural, recreational and scenic.
Scenery	The general appearance of a place and the features of its views or landscapes.
Scenic View	A pleasing sight or vista that involves a landscape predominated by natural (as opposed to man-made) features.

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CULTURAL OUTREACH

AE-9

1-2 POINTS

GOAL

Promote cultural awareness, community connectivity and art.

CREDIT REQUIREMENTS

1 point

Any part of the project or any item within 10 miles of the project boundary is either:

- Listed in the United States National Register of Historic Places
- Subject of a Determination of Eligibility (DOE) made by a State Historic Preservation Officer.
- Part of the National Scenic Byways Program (NSBP) (http://www.byways.org) meaning it has been designated as one of America's Byways® (National Scenic Byway or All-American Road), a State Scenic Byway, or an Indian Tribe Scenic Byway because of its cultural, historical, or archeological features.

AND

Install informational infrastructure (e.g., viewpoint, kiosk, sign, or other small-scale installation for visitors detailing historical, cultural, or archeological significance) to explain the site or direct roadway users to the site. An existing installation meets this informational infrastructure portion of the requirement.

2 points

Dedicate a minimum of 1% of the total project budget (not to exceed $200,000) to art or community culture installations along the roadway right-of-way (ROW).

Details

Many National Park System (NPS) units are automatically listed in the National Register of Historic Place. As of December 2009 those include: international historic sites, national battlefields, national battlefield parks, national battlefield sites, national historic sites, national historical parks, national memorial, national military parks and national monuments.

The NSBP is a broad program that captures many roadway qualities. These can best be categorized as scenic, historical, cultural, natural, recreational and archeological. This credit covers historical, cultural, and archeological qualities. Credit AE-8 Scenic Views covers scenic, natural, and recreational qualities.

For the purposes of Greenroads, "art" is broadly defined as the behavior of making things special.

DOCUMENTATION

1 point

- A copy of the registration of the item or location in the United States National Register of Historic Places or documentation of NSBP designation. A screenshot of the item listed in the National Register of Historic Places on the official website (www.nps.gov/nr) is acceptable. Or, if a DOE is used, a copy of the official DOE.

RELATED CREDITS

- ✓ PR-11 Educational Outreach
- ✓ AE-3 Context Sensitive Solutions
- ✓ AE-8 Scenic Views

SUSTAINABILITY COMPONENTS

- ✓ Equity
- ✓ Exposure

BENEFITS

- ✓ Increases Awareness
- ✓ Increases Aesthetics

- A map showing that the item or location is in the project area or within 10 miles of the project boundary.
- A photograph of the item or location and the informational infrastructure.

2 points

- Copy of the project budget showing a minimum of 1% of the total budget or $200,000 (whichever is less) has been dedicated toward art.
- At least one photograph of the installed artwork.

APPROACHES & STRATEGIES

- Integrate context-sensitive aesthetic treatments, as determined by participating stakeholders, into the design of transportation facilities. Examples may include treatments to sound walls, structures, street furniture, screening, fences, signage, piers or lighting.
- Set aside 0.5% of the total project budget toward art or cultural installations. Allow for community contributions and suggestions during the public involvement process during project scoping.
- Encourage public engagement through mural painting or other participatory activities.
- Investigate places on the National Register of Historical Places to see if any may help the project qualify for this Voluntary Credit.
- Investigate registering an item or place on the National Register of Historical Places.

Example: National Register of Historic Places

The National Register of Historic Places (www.nps.gov/nr) is the official list of U.S. historic places worthy of preservation. It is authorized by the National Historical Preservation Act of 1966 and is maintained by the National Park Service. The National Register of Historic Places program maintains a nomination process (states, tribes and other federal agencies may nominate properties for inclusion in the list); offers guidance and helps qualified properties receive preservation benefits. Roads can be and are included in the register. For example, record number 336109 concerns the Columbia River Highway District, which addressed an historical roadway that travels along the Oregon side of the Columbia River.

Example: Historic Roads Website

This resource (www.historicroads.org) provides ideas for what constitutes an historic road and resources to assist with documentation and designation/recognition.

Example: Wisconsin's Rustic Roads Program

Established in 1973, the Wisconsin Rustic Roads program (http://www.dot.wisconsin.gov/travel/scenic/rusticroads.htm) helps citizens and local government to preserve scenic, lightly traveled country roads. There are now 108 such roads, designated with an "R" in front of the route number (e.g., R62 or R108). According to the Wisconsin Department of Transportation a road must have the following characteristics to qualify for the Rustic Road program:

- Outstanding natural features along its borders such as rugged terrain, native vegetation, native wildlife, or include open areas with agricultural vistas which singly or in combination uniquely set this road apart from other roads.
- Lightly traveled local access road, one which serves the adjacent property owners and those wishing to travel by auto, bicycle, or hiking for purposes of recreational enjoyment of its rustic features.
- Not scheduled nor anticipated for major improvements which would change its rustic characteristics.
- Have, preferably, a minimum length of 2 miles and, where feasible, should provide a completed closure or loop, or connect to major highways at both ends of the route.

Example: Percentage for Art Programs

Incorporating a percentage of the project budget for art or cultural endeavors is common in many major municipalities. Examples are:

- The City of Seattle has a Public Art Ordinance (passed in 1973) that dedicates 1% of construction costs to art. Importantly, the City defines "construction project" as "…any capital project paid for wholly or in part by the City to construct or remodel any building, structure, park, utility, street, sidewalk, or parking facility, or any portion thereof, within the limits of The City of Seattle." (City of Seattle, 2009a).
- Sound Transit (in the Puget Sound region of Washington State) administers the Start Public Art Program, which allocates 1% of project construction costs to art (Sound Transit, 2009).
- Washington State's Art in Public Places Program adds 0.5% for the acquisition of artwork to new construction budgets for state-owned buildings (Washington State Arts Commission, 2009).
- New York's City Art Program uses one percent of a total public project budgets to fund artistic installations at public buildings (Heartney & New York Department of Cultural Affairs, 2005).
- Oregon's Percent for Art legislation (passed in 1975) guides the acquisition of Oregon's State Art Collection. It sets aside "…1% of the direct construction funds of new or remodeled state buildings with construction budgets of $100,000 or greater for the acquisition of art work which may be an integral part of the building, attached thereto, or capable of display in other State Buildings" (Oregon Arts Commission, 2009).
- Hawaii's Art in Public Places Program (established in 1967) was created to "…enhance the environmental quality of state public buildings and spaces throughout the state for the enjoyment and enrichment of the public; cultivate the public's awareness, understanding and appreciation of visual arts in all media, styles and techniques; contribute toward the development and recognition of a professional artistic community; and acquire, interpret, preserve and display works of art expressive of the character of the Hawaiian Islands, the multicultural heritage of its people, and the various creative interests of its artists." (Hawaii State Foundation on Culture and the Arts, 2009).

Figures AE-9.1 through AE-9.3 are examples of streetscape art in the greater Seattle area.

Figure AE-9.1: Richard Beyer's *People Waiting for the Interurban* (1979) at the corner of Fremont Avenue North and North 34th Street. Paid for by community donations, the Seattle Arts Commission (Now the Office of Arts & Cultural Affairs) and the Washington State Arts Commission (City of Seattle, 1979).

Figure AE-9.2: Jack Mackie's *Dancers' Series: Steps* (1982) found in 8 locations along Broadway Avenue in the Capitol Hill area of Seattle. Paid for by the Engineering Department (now part of Seattle Public Utilities) 1% for Art and private businesses in the Broadway Local Improvement District (City of Seattle, 2009b).

Figure AE-9.2: Tom Askman and Lea Anne Lake's *Ballard Gateway* (2003) on the 15th Avenue N.W. approach to the Ballard Bridge. Paid for by the Seattle Department of Transportation 1% for Art, Seattle City Light 1% for Art and Millennium Lighting Funds, Department of Neighborhoods Matching Funds (City of Seattle, 2009b).

POTENTIAL ISSUES

1. It may not always be appropriate or possible to include cultural outreach or art on a project.
2. Art can be controversial.
3. Sometimes it is difficult to specify exactly what art is. Beyond the general definition used in this Voluntary Credit, something more precise is generally needed to include in contract documents in order to define what qualifies as "art."

RESEARCH

Construction of transportation infrastructure represents a large public investment in many communities. Roadway projects not only connect places and economies, they also connect people to place. Roadway designers and contractors are in position to offer more to society than simply meeting basic needs, project deadlines, and bottom lines. Designing aesthetic treatments that reflect community identity or integrating public art into transportation projects is an opportunity to enhance communities, particularly those without resources to pursue independent public art or landscape programs. Most civil engineering works, by definition, meet needs and serve to better the greater good of the public. In roadway projects, opportunities for promoting this sense of community can be accomplished through incorporating historical and cultural information facilities, connection to national landmarks and community-centered artwork. This research section attempts to define what art is and why it might be viewed as important.

Ethnologic View of Art

The following discussion of Art is largely taken from the work of Ellen Dissanayake, an Affiliate Professor in the School of Music at the University of Washington. She generally takes an ethological view of art; that is she approaches art as something living creatures (humans) do in their everyday life that somehow has an adaptive or selective value in human evolution.

What is Art?

Dissanayake (1980) broadly defines art as "…the ability to recognize or confer 'specialness,' a level or order different from the everyday." In short, art is the act of making special. This encompasses a broad range of items including song, dance, ritual, play and even organized sports. Importantly, the idea of art does not include a quality judgment or involve an understanding of how art manages to achieve specialness.

Why is Art Important?

Human ethologists believe that certain human behaviors have persisted over time because they contribute positively to the evolution and success of the species (Dissanayake, 1980). In terms of art, this means that as a behavior art exists because it is somehow important to the success of the human species. Art would not exist universally if it did not have selective value. Art is not, as the modern view goes "for its own sake" (i.e., no practical value). Art is also not just for artists; it is a common behavior to all humans.

> "It is the degree to which art embodies and communicates experience that makes it unique and irreplaceable (gives it value). Although there are likely many who appear to do just fine without art (as we know it today) it is only recently (last 100 or so years) that art has become detached from the rest of life and regarded for its own sake. For most of history, the activity of giving meaning and embellishing life was not an impractical leisure-time activity but rather the way the human mind worked – a way of comprehending the world." (Dissanayake, 1980).

Art contributes essential social benefits such as documentation, expression, storytelling, entertainment, display of wealth and power and representation of custom and tradition. In other words, art gives shape to and embellishes life; what makes art unique and irreplaceable is the degree to which art embodies and communicates experience (Dissanayake, 1980). Only in the last 100 years or so has art become detached from ritual and play and been viewed as an independent activity. For most of human existence, the primary task of artists was to give shape to and embellish life; to help find meaning in life. Artists recorded events, decorated homes and embellished ceremonial observances (Dissanayake, 1980).

In summary, there four key points to take away from the ethological viewpoint:

1. **Art is the ability to "make special."** Art recognizes or confers 'specialness,' a level or order different from everyday. Equally important is the behavior of appreciating that some things are special. These ideas are fundamental and universal.
2. **Art has selective value, i.e., in some way it enhances the survival of the species.** Art would not exist universally if it did not have selective value. It's not, as the modern view goes "for its own sake" (i.e., no practical value).
3. **The behavior of art is a common behavior to all human beings, not just artists.** It's important to note that "art" does not mean "good art."
4. **Art is valuable because it gives meaning and embellishes life.** As humans, we simply cannot bear senselessness or lack of meaning.

How Art is Publically Funded

Magie (1997) reviewed major sources of public funding for the arts. Among the art funding sources she discussed, the following could apply to roadway construction art funding:

General fund appropriations. The most common public funding mechanism. Art is often included as a line item in a state, city, county, etc. budget. Usually, general fund allocations require strong advocacy and political support. In general, support at the state and federal level has been declining, however support and the city, county and local level has been increasing.

Taxes and fees. Many public organizations have set up taxes or fees whose revenue support or partially supports the arts. Special tax districts, sales taxes, property taxes, hotel-motel (transient occupancy) taxes, entertainment taxes (e.g., theaters, concerts, sports), franchise fees (e.g., from cable companies), real estate taxes and even a portion of lottery/gambling proceeds have been used to generate arts funds.

Endowments. This approach collects money by similar pubic mechanism as the "taxes and fees" section, however the money is held onto and only the interest payments are used to support the arts.

Bonds. Funding for infrastructure can be large and many public organizations have issued bonds for the express purposes of supporting art and culture infrastructure. For instance, the Rock and Roll Hall of Fame and Museum was built largely with bond funding.

Percent for art programs. These programs specify that a percentage (often 1%) of capital construction costs for a new or renovated building be set aside for artwork. These programs began in the 1960s but now there are more than 135 state and locally funded programs in the U.S.

Transportation mitigation or enhancement funds. While public art in roadway construction is still developing, public organizations often support art through mitigation or enhancement funds that are dedicated to add value to property and areas that have been negatively impacted by roadway construction.

Corporate support. Corporate sponsors have often been instrumental in art programs and infrastructure to support such programs. However, corporate sponsorship has not been heavily used in roadway-related art.

Examples of Art in Roadway Projects

The following figures show some examples of how art has been incorporated into roadway projects.

Figure AE-9.3: Art incorporated into the fascia for an I-5 freeway wall associated with an expansion project on I-5 near its intersection with SR 16 in Tacoma, WA.

Figure AE-9.4: Seattle-to-Bremerton ferry tunnel in Bremerton, WA. Photo from the Washington State Department of Transportation.

Figure AE-9.5: James Angus, *Ellipsoidal Freeway Sculpture* (2008)
Eastlink freeway: Nunawading to Frankston, Melbourne. Photo from the Roslyn Oxley9 Gallery (http://www.roslynoxley9.com.au/artists/5/James_Angus/1116/41258).

GLOSSARY

Art	The act of making special.
United States National Register of Historic Places	Official list of U.S. historic places worthy of preservation. Authorized by the National Historical Preservation Act of 1966 and maintained by the National Park Service.

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CONSTRUCTION ACTIVITIES

QUALITY MANAGEMENT SYSTEM

CA-1

2 POINTS

GOAL

Improve construction quality by using a contractor that has a formal quality management process.

CREDIT REQUIREMENTS

The prime contractor, design-builder or construction management firm shall have a documented quality management system (QMS) for the entire company or at least the portion(s) of the company participating in the project. The QMS must be in place for the duration of project construction. As a minimum, the QMS and its documentation shall meet the requirements of International Standards Organization (ISO) 9001:2008 or ISO 9001:2000.

Details

The prime contractor, design-builder or construction management firm is considered to have a documented QMS if it is:

- Is ISO 9001:2008 or ISO 9001:2000 certified
- Has a QMS that meets ISO 9001:2008 or ISO 9001:2000 requirements but is not formally certified
- The recipient of the Malcolm Baldrige National Quality Award (any year)

DOCUMENTATION

Submit one (1) of the following items:

1. Documentation of the ISO 9001:2008 or ISO 9001:2000 certification for the prime contractor, design-builder or construction management firm
2. A copy of the prime contractor, design-builder or construction management firm's QMS documentation to include:

   - Quality policy and objective
   - Quality manual
   - Listing of documented procedures
   - Listing of records retained in accordance with their QMS

3. Documentation of the Malcolm Baldrige National Quality Award awarded to the prime contractor, design-builder or construction management firm

RELATED CREDITS

- ✓ PR-1 Environmental Review Process
- ✓ PR-4 Quality Control Plan
- ✓ PR-11 Educational Outreach
- ✓ EW-1 Environmental Management System
- ✓ CA-2 Environmental Training

SUSTAINABILITY COMPONENTS

- ✓ Extent
- ✓ Expectations
- ✓ Experience
- ✓ Exposure

BENEFITS

- ✓ Improves Human Health & Safety
- ✓ Improves Accountability
- ✓ Increases Awareness

APPROACHES & STRATEGIES

- Have a prime contractor with ISO 9001:2008 or ISO 9001:2000 certification.
- Have a prime contractor with a documented QMS that meets the requirements of ISO 9001:2008 or ISO 9001:2000.
- Select a prime contractor that has won the Malcolm Baldrige National Quality Award. As of 2009, no prime contractor, design-builder or construction management firm has won this award.

Example Quality Manuals

While it is not possible to present an entire QMS, there are many examples of key QMS documents available on the Web including the following quality manuals:

- R&D Systems: http://www.rndsystems.com/DAM_public/5722.pdf
- Continental Steel & Tube Co.: http://www.continentalsteel.com/pdf/continental-steel-quality-manual.pdf
- Cirrus logic: http://cirrus.com/en/pubs/misc/Quality_Manual.pdf
- PAR Nuclear supplier quality manual: http://www.parnuclear.com/PaRNuclear/docs/SQM.pdf
- Westinghouse Nuclear: http://www.westinghousenuclear.com/Our_Company/Quality_Management_System/docs/E6_qms.pdf

There are also companies that will sell quality manual templates to assist in getting started.

POTENTIAL ISSUES

1. Smaller firms may not be able to afford the ISO certification process.
2. Documentation of a QMS is not the same has having an effective QMS, however collection of documentation (in lieu of an actual audit) is an efficient way of gathering evidence of an effective QMS.

RESEARCH

According to ISO (2009), a QMS is refers to what the organization does to manage its processes, or activities, so that its products or services satisfy the customer's quality requirements and comply with regulations. One of the more comprehensive descriptions of such a system comes from ISO in their 9000 family of standards.

ISO 9000

According to ISO (2009), "The ISO 9000 family of standards represents an international consensus on good quality management practices. It consists of standards and guidelines relating to quality management systems and related supporting standards." Essentially, it is a formal description of a QMS and all that is involved in its creation, implementation and use. Just as ASTM International or the American Association of State Highway and Transportation Officials (AASHTO) set standards, so does ISO.

Certification: ISO 9001

While the entire QMS standard is contained in the ISO 9000 family of standards, the actual requirements for certification are contained in ISO 9001. Therefore, organizations are certified in accordance with ISO 9001; the number is appended with the year of the standard that applied when the organization was certified. The most current version is ISO 9001:2008, however many organizations still have ISO 9001:2000 certifications (the prior version).

ISO does not certify organizations itself. Most countries have formed formal groups or "certification bodies," which audit organizations applying for ISO 9001 certification. Through mutual agreements these bodies ensure that certification audit standards are relatively the same worldwide. Certification, once granted, must be renewed at standard intervals; often three years.

ISO does not require certification and many organizations just choose to follow ISO 9000 requirements but forego certification. However, it is common practice in many parts of the world (e.g., western Europe, China, India, etc.) to require ISO certification as a prerequisite for doing business. Therefore, countries that require this usually see the highest certification rates.

Arguments for Certification

Arguments for certification typically cite the general idea that proper management of quality improves business, which can be measured by larger market share, sales growth, higher margins, competitive advantage and other metrics.

Arguments against Certification

Arguments against certification claim that the actual act of certification and existence of documentation do not, in and of themselves, guarantee improved business. Further, they point out that ISO 9001 certification can be an expensive process that does not guarantee results.

Certification Cost

According to the survey completed by Yates and Aniftos (1997), the cost of the ISO certification process ranged from $0 to $500,000, but certification costs generally range from $300,000 to $400,000. This reported data range is unclear due to how the survey question was posed. It is possible that some companies reported additional costs including internal training budgets, neglected the cost of the certification itself, or that some did not have any additional costs. Certification through ISO requires approximately 12 to 18 months, on average.

Worldwide ISO 9001 Certification

Data from 2006 show worldwide ISO 9001 certifications at 625,742 in 170 different countries and growing (Figure CA-1.1). In December 2006 the U.S. had 44,883 certifications, which ranked sixth worldwide (Figure CA-1.2). ISO 9001 certification is far more popular in Europe and the Far East (Eastern Asia) with 46% and 34% of worldwide certifications respectively. North America (consisting of only the U.S., Canada and Mexico) comprised almost 7% of the worldwide total. According to Yates and Aniftos (1996, 1997), very little participation by organizations within the United States has been noted. The majority of the ISO standard stakeholders are in the European community and the bulk of influence on the globalization of such standards comes from a group called the European Committee for Standardization (CEN).

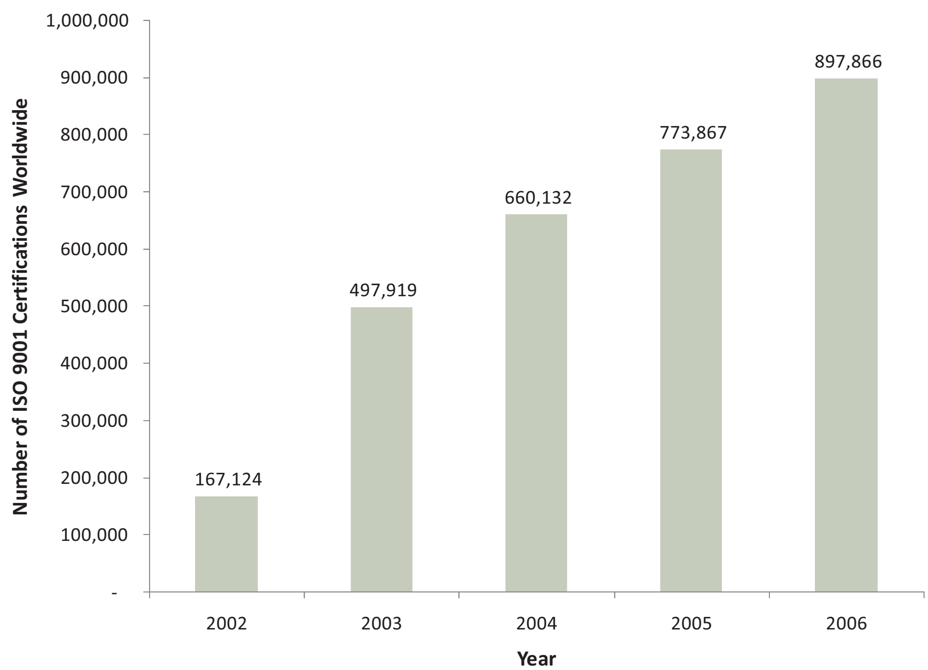

Figure CA-1.1: ISO 9001 certification worldwide growth 2002-2006 (data from ISO, 2006).

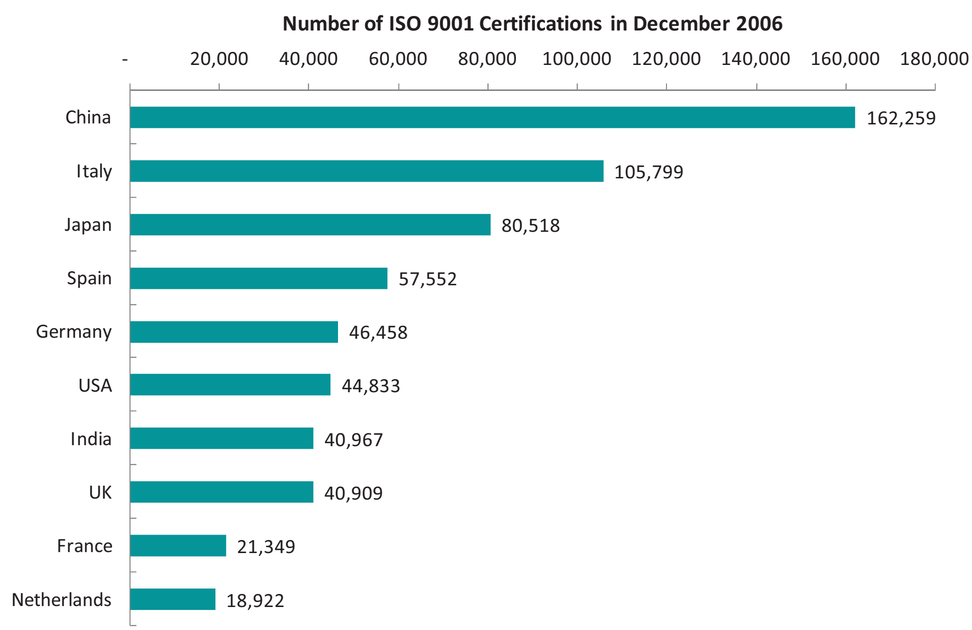

Figure CA-1.2: Top 10 countries in terms of number of ISO 9001 certifications in 2006 (data from ISO, 2006).

ISO 9001 Certification in the U.S. Construction Industry

ISO 9000 enjoys substantial worldwide popularity, however relatively few U.S. construction firms are certified. The 2006 ISO *Survey of Certifications* reported 80,432 construction companies certified worldwide. Of the 39 industrial sectors listed construction ranked first with 12.9% of the total certified companies. However, relatively few construction firms in the U.S. have adopted ISO 9000 standards and become certified (Chini & Valdez, 2003). Reasons given for this lack of adoption tend to focus on the idea that ISO 9000 is not promoted or required by U.S. clients or government like it is elsewhere (Ahmed et al., 2005) so there is no perceived advantage of formal certification. Chini and Valdez (2003) show evidence of this when they found 36% of U.S. certified construction-related firms were located in Michigan and another 14% in Ohio. Not coincidentally, these states are where U.S. automakers, companies that require ISO 9001 certification from those they contract with, are largely located (at least in 2000).

Evidence to support the positive outcomes of ISO 9001 certification generally comes from surveys of or interviews with contractors that are already ISO certified (e.g., Ahmed et al., 2005; Chini & Valdez, 2003; Moatazed-Keivani et al., 1999) so it is not surprising that results indicate a general benefit to ISO 9001 certification. Even so, there is ample evidence to suggest that ISO 9000 is at least *applicable* to construction and can be adopted (Nee, 1996; Chung, 1999) and arguments have been made that it can help standardize corporate procedures (Chung, 1999), reduce waste, improve quality and provide independent verification that such things are being done (Love & Li, 2000). A comparison of the U.S. and Hong Kong construction industries (Ahmed et al., 2005) found that promotion of ISO 9001 certification amongst clients and government is minimal in the U.S. while it is prominent in Hong Kong.

GLOSSARY

ISO	International Standards Organization
QMS	Quality process management system
Quality	Degree to which a set of inherent characteristics fulfills requirements. This is a broad definition. Note that in this context is does not refer to a degree of excellence.

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ENVIRONMENTAL TRAINING

CA-2

1 POINT

GOAL

Provide construction personnel with the knowledge to identify environmental issues and best practice methods to minimize environmental impacts.

CREDIT REQUIREMENTS

Provide an environmental training plan that is customized to the project, including:

1. List of the types of project personnel to be trained. This may be a list by job-type or by employer need not contain actual employee names.
2. Description of the types, goals and objectives of training to be given.
3. A process to track training efforts, including dates, means (e.g., online, classroom, field training), topics, the identification of those participating in training, and attendance numbers
4. A process to measure of training effectiveness such as self-assessment, pre-test and post- test, and productivity measurement.

Details

The environmental awareness training plan shall address the following training elements, or state why any are inappropriate:

a. Permit conditions, performance standards, environmental commitments, and environmental regulations related to the project
b. Overall importance of environmental issues (i.e., ecological impact of actions)
c. Identifying work activities that present the greatest risk for compliance (i.e., specific environmental sensitivities of the project)
d. Required environmental qualifications and certifications
e. Environmental records management
f. Environmental compliance monitoring and reporting procedures
g. Unanticipated historic resource or archaeological discoveries
h. Environmental notification triggers and emergency response procedures
i. Oil spill prevention and response procedures
j. Construction stormwater management (including monitoring sites and monitoring and reporting procedures)
k. Erosion and sediment control procedures (including dust mitigation)
l. In-water work
m. Reduction of air pollution
n. Management of known or suspected contamination
o. Waste management and recycling
p. Hazardous materials management
q. Management of noise impacts
r. Littering and good housekeeping
s. Plan for training subcontractors and field personnel not immediately involved at project start or planning. These personnel must also receive training.

DOCUMENTATION

- A copy of the environmental training plan and any updates to that plan that occur throughout the construction.
- A signed letter from an owner's representative stating that the contractor(s) followed the environmental training plan as submitted and updated.

RELATED CREDITS

- ✓ PR-11 Educational Outreach
- ✓ EW-1 Environmental Management System
- ✓ CA-1 Quality Management System

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Equity
- ✓ Expectations
- ✓ Experience
- ✓ Exposure

BENEFITS

- ✓ Reduces Air Emissions
- ✓ Reduces Water Pollution
- ✓ Reduces Solid Waste
- ✓ Improves Human Health & Safety
- ✓ Improves Accountability
- ✓ Increases Awareness

APPROACHES & STRATEGIES

- Provide environmental training as part of standard orientation training to a construction project. Done in combination with construction health and safety training can ensure that all personnel are reached before entering the work site, and can reduce training cost by avoiding multiple training sessions.
- Deliver activity-specific toolbox or tailgate talk topics onsite, targeting the pertinent construction personnel prior to each new activity. Toolbox environmental talks might rely on commercially available presentations, supplemented by customized project and work location-specific topics.
- Deliver environmental training on regular or as-needed bases via teleconferences, periodic e-mail environmental alerts, environmental awareness meetings, design review meetings, weekly project meetings, pre-construction meetings for each work phase/activity, and field discussions during site monitoring and inspection.
- Focus environmental training components on target audiences with appropriate frequencies as follows:

  - Environmental Stewardship training: Discuss stewardship principles at the construction kick-off meeting.
  - Baseline environmental awareness training: Provide environmental orientation for all field personnel, personally delivered prior to entry into work phases via a consistent audiovisual presentation; address permit conditions, performance standards, environmental commitments, environmental regulations, and overall importance of environmental issues.
  - Environmental design training: Deliver this training to designers at design review/validation meetings during the construction phase (i.e., design-build projects).
  - Project management team training: Conduct training during steering meetings. Discuss upcoming construction schedule and corresponding environmental compliance challenges. Address environmental commitments and applicable content of environmental guidance manuals. Orient discussion to the specific and appropriate work stages, time of year, or work activity.
  - Construction training: Meet onsite to give construction workers tool box/tailgate training in specific activities prior to initiating construction. Highlight pre-construction and awareness of compliance needs and how to support the zero violations goal. Provide pre-activity environmental compliance pocket checklists for improved environmental performance.
  - Environmental staff training: Provide the environmental team with bi-weekly or as-needed specific instruction in monitoring tasks, performance documentation and compliance, and environmental compliance support procedures.
  - Skill- and need-specific training: Ensure competency among selected environmental staff and crews in water quality monitoring procedures, erosion and sediment control inspections, in-water work, etc.

Examples

Washington State Department of Transportation (WSDOT)

WSDOT's Environmental Management System delivers environmental training to provide tools and information to assist staff in ensuring that projects stay in compliance with environmental laws, regulations, and policies (WSDOT, 2008a). A key component of their Construction Environmental Management Program is training the appropriate personnel on the applicable procedures to ensure compliance with environmental requirements during construction. Training sessions target various audiences, including environmental practitioners, construction staff, and maintenance and operations staff. For example:

- Drainage design lead engineers who are responsible for stormwater design (including downstream analysis, bridge scour analysis, and floodplain fill and hydraulic impact mitigation evaluations) must complete WSDOT's training course in the Highway Runoff Manual.
- WSDOT trains contractors to ensure water quality is monitored in accordance with the Highway Runoff Manual protocols, project-specific permit conditions, performance standards, and environmental commitments.
- Erosion and sediment control design must be prepared by an individual who has successfully completed WSDOT's Construction Site Erosion and Sediment Control course.

Some types of environmental training are required by regulation. For example, spill prevention, containment, and response training for all spill responders is required in Washington in accordance with Washington Administrative Code (WAC) 296-824. Hazardous materials surveys, including asbestos containing materials/lead based paint (ACM/LBP) must be completed by an Asbestos Hazard Emergency Response Act (AHERA)-certified inspector.

Measuring Performance of Environmental Training

Research suggests that environmental training as a component of environmental management systems (e.g., ISO 14001 standards) improves: (1) employee awareness, (2) operational efficiency, (3) managerial awareness, and (4) operational effectiveness (Rondinelli & Vastag, 2000; Sroufe, 2003).

DOTs prepare quarterly and annual reports on program-wide environmental performance. For example, Washington DOT's *Gray Notebook* indicates environmental performance through Environmental Compliance Assurance metrics (WSDOT, 2008b). Washington DOT believes that its Environmental Compliance Assurance Procedures and the environmental compliance for construction inspectors training course have raised the general awareness of non-compliance events, with events being cited and quickly resolved with increasing numbers.

POTENTIAL ISSUES

1. Construction personnel may turn over during the project.
2. Some subcontractors, operators and drivers may be onsite only once or infrequently.

RESEARCH

This research section covers the idea of environmental training in two distinct sections. First, the value of training in general is addressed (e.g., why should any organization spend money on training?) and then examples of and reasons for construction-related environmental training are discussed.

The Value of Training in General

Knowledge is a vital organizational asset. This is the essential unstated assumption associated with almost all training discussions. While American corporations spend in excess of $50 billion annually on training (Galvin, 2002) and numerous authors espouse the virtue and necessity of training, few make an effort to actually show its value. This section highlights the fundamental premise for continued and even increased support for training: it is an investment in a valuable commodity that produces high returns.

Knowledge is Valuable

Today, in the information age, organizations are routinely valued not on their physical but rather their intellectual capital. Edvinsson and Malone (1997) define intellectual capital as "the possession of the knowledge, applied experience, organizational technology, customer relationships and professional skills that provide [an organization] with a competitive edge in the market." Bassi and Van Buren (1999) point out that "intellectual capital is the only source of competitive advantage within a growing number of industries." For instance, the market value of Microsoft far exceeds the value of its physical assets. To be sure, much of this value is based on speculation, but much is also based on Microsoft's intellectual capital – what it knows.

Training is one of the chief methods of maintaining and improving intellectual capital. Because of this, an organization's training can affect its value. Bassi and Van Buren (1999) found training as a percentage of payroll to be significantly correlated with the market-to-book value of publicly traded companies. Where the average U.S. employer spent about 0.9% of payroll on education and training (Bassi et al., 1996), training magazine's 2002 top 100 training companies averaged 4% with Pfizer ranking first at 14%.

Training is an Investment

General accounting standards classify training as an expense. However, training is really an investment: an organization typically invests upfront to train its employees (in the form of enrollment fees, travel expenses and opportunity cost of the employees' time) and, in return, expects future returns (in the form of increased knowledge, skills and productivity). As with any other investment, if the returns outweigh the investment, training is a worthwhile endeavor.

Training is also an investment from the employee's perspective. Training increases skills and knowledge, which can lead to better pay or promotion. So who benefits most from the training investment: the employee with increased wages and/or promotion or the employer with increased productivity? Loewenstein and Spletzer (1998) researched this question and concluded, "...the effect of an hour of training on productivity growth is about five times as large as the effect on wage growth." Therefore, employers "reap almost all the returns to company training" (Bartel, 2000). This may be oversimplifying because employees generally view training as either a gift from the employer or at least a sign of commitment on the part of the employee, which is important to job satisfaction (Barrett & O'Connell, 2001).

In sum, both the employee and employer benefit from the training investment. The question now shifts to one of measurement: do the returns on training outweigh the investment?

Training Return on Investment (ROI)

When calculated using sound methodology, training has been shown to provide significant return on investment: on the order of 5 to 200 percent. The problem is that methods used to quantify training ROI can often be suspect or even outright self-promotion. Furthermore, it is often very difficult to quantify the effects of training. For instance, one of training's effects can be increased job satisfaction, which is difficult if not impossible to quantify. Intuitively we know this is important in retaining good employees; however it will not show up on a ROI calculation.

In 2000, Bartel provided one of the best objective looks at the value of training to the employer. She looked at 10 large data set surveys and 16 individual case studies in an attempt to determine the employer's return on investment for employee training. She found the following:

- Methods using large data sets to compare many different organizations estimated training ROI from 7 to 50 percent.
- Individual case studies estimated training ROI from 100 to 5900 percent. Bartel believes the high ROIs in this category are based on faulty methodology. Her in-depth analysis of two well-constructed internal case studies revealed a 100 to 200 percent ROI.

Therefore, even the most conservative estimate puts training's ROI at 7 percent – an acceptable rate of return by most standards. Additionally, although it is not appropriate to generalize based on the results of two case studies, it can be said that based on Bartel's in-depth analysis of two well-constructed internal case studies, training's ROI can be much higher: approaching 100 to 200 percent.

Summary

Training is a valuable commodity that, if viewed as an investment rather than an expense, can produce high returns. While it is true that training costs money and uses valuable employee time and resources, studies tend to show training provides a positive return on investment – sometimes in the neighborhood of several hundred percent. Therefore, although training might seem like a luxury expense in tight financial times, it is, in fact, one of the most sure and sound investments available.

Environmental Training

Environmental training is, for the most part, a response to public demand for better environmental performance in infrastructure construction. This is generally seen in two ways: (1) public owner agencies have begun to require not only that projects meet environmental regulations but also that they incorporate employee environmental training in order to improve understanding and compliance, and (2) private firms (e.g., construction firms) using training programs as a way to gain competitive advantage based on owner requirements and also as a component in their approach to addressing owner and shareholder (in the case of public companies) demands for environmental accounting.

Owner-Agency Training and Required Training for Contract Work

Many state departments of transportation (DOTs) provide environmental training to their employees and some are beginning to require training of certain key personnel from contractors working on public projects. In a 2002 survey of state DOTs (Venner Consulting & Parsons Brinderhoff, 2004), 24 were performing general nature resources and/or regulatory training for engineers and/or construction personnel; while about 60% offered general training in the National Environmental Policy Act (NEPA), public involvement, environmental processes and best management practices (BMPs) for maintenance and water quality.

It is also becoming more common for owner-agencies to require contractor training in stormwater pollution prevention methods, commonly referred to as temporary erosion and sediment control (TESC) on construction sites. Typically a supervisor NPDES to have a trained erosion and sediment control person on-site to manage a project's temporary erosion and sediment control efforts. For example, for construction in high quality or impaired waters, Tennessee requires the contractor's erosion prevention and sediment control inspector and environmental supervisor to have completed a specified formal course (or equivalent) (TDOT, 2005).

Construction Firm Training

Construction firms have begun to recognize a need to formally manage their impact on the environment and have included training programs (both company-wide and project-specific) to help. Reasons for having an environmental training program include:

a. **Compliance help**. The number and complexity of existing U.S. environmental regulations and their associated costly fines if violated (see U.S. EPA, 2005) necessitates an organized approach to understanding and complying with these regulations. In a Hong Kong study (Tam et al., 2006) "management and training" was identified as the most important evaluation factor for assessing environmental issues in construction projects.
b. **Showing commitment to the public**. Publically held companies, especially those listed in European exchanges, are under pressure to show their sustainability efforts to their stockholders. These often include "environmental management systems" (EMS) – see EW-1. A fundamental component of an EMS is an employee training plan (Christini et al., 2004). Thus, those companies with EMSs or those progressing towards them have a need for environmental training.
c. **Competitive advantage**. Some public contracts, especially design-build ones, have a scoring system that awards environmental considerations beyond regulatory compliance. Also, some clients may soon require contractors to have an EMS (including the training component) in place (Christini et al., 2004).

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SITE RECYCLING PLAN

GOAL

Minimize the amount of construction-related waste destined for landfill and promote environmental stewardship through good housekeeping practices at the work site.

CREDIT REQUIREMENTS

Establish, implement, and maintain a formal Site Recycling Plan as part of the Construction and Demolition Waste Management Plan (CWMP) during construction.

The Site Recycling Plan must clearly describe the plan for implementing, communicating, monitoring and maintaining appropriate recycling and diversion practices on site. The following topics must be specifically addressed.

1. Expected types, quantities, processing or disposal facilities, locations of receptacles and proper handling for recyclable (or reusable) roadway materials generated from roadway construction processes such as (but not limited to):

    - Paving process waste (e.g. hot mix asphalt, concrete)
    - Milling waste, concrete slough and grindings, cobble
    - Excess steel rebar and other metal products or scraps
    - Excess plastic pipes and packaging
    - Excavated soil cuttings and boulders
    - Land clearing debris and topsoil
    - Wood and paper products (e.g. packaging materials, cardboard and pallets)

2. Expected types, quantities, processing or disposal facilities, locations of receptacles and proper handling for recyclable (or reusable) materials generated from mobile office (e.g. job trailer, site office) activities and personal worker (household) waste such as (but not limited to):

    - Paper, copier paper, paper products
    - Plastic
    - Aluminum and various household metals
    - Glass
    - Household trash or compostables

3. Communication expectations for jobsite housekeeping practices for the general contractor (also intended for any subcontractors) regarding:

    - Litter control
    - Expected types of site- and worker-generated recyclables.
    - Collection practices for site- and worker-generated recyclables.
    - Locations of recycling receptacles.
    - Training requirements for all site employees and means of corrective action.

DOCUMENTATION

- Copy of the Site Recycling Plan.

CA-3

1 POINT

RELATED CREDITS

- ✓ PR-6 Waste Management Plan
- ✓ PR-10 Site Maintenance Plan
- ✓ EW-1 Environmental Management System
- ✓ MR-4 Recycled Materials
- ✓ CA-2 Environmental Training

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Expectations
- ✓ Exposure

BENEFITS

- ✓ Reduces Air Emissions
- ✓ Reduces Solid Waste
- ✓ Reduces Manmade Footprint
- ✓ Reduces Lifecycle Costs
- ✓ Improves Accountability
- ✓ Increases Awareness

APPROACHES & STRATEGIES

- Include the Site Recycling Plan in agency contract documents, bid packages, and/or specifications.
- Set waste reduction goals and explicitly state them in the Site Recycling Plan.
- Locate receptacles in easily accessible or highly frequented locations on the jobsite. Receptacles should not be placed in areas where they may cause harm to workers or the local environment. See PR-7 Pollution Prevention Plan for more information.
- Clearly label receptacles and recycling locations. Large color photos of what is recyclable and what is not are often very helpful, especially, for multi-lingual work environments.
- Provide waste receptacles that are smaller than the recycling receptacles, slightly more difficult to open, or slightly more difficult to access. This provides a visual or behavioral cue indicating that the trash is supposed to be limited and there are ample recycling alternatives.
- Include instructions or warnings on the waste bin such as: “Are You Sure This Is Not Recyclable?”
- Many recycling facilities can accept co-mingled recyclables, which means that less sorting and fewer receptacles are required. However, quantities of these co-mingled materials are often harder to track and require detailed receipts from the waste transport agency to assess the composition of co-mingled streams.
- Designate a particular person or a few people to be the site monitor for helping workers recycle properly.
- Review local environmental maintenance plans used for litter control and roadway cleanup activities. These plans may be helpful references when developing the Site Recycling Plan, or at minimum, reduce potential for conflict between existing policy and practice. See also PR-10 Site Maintenance Plan.
- Hire a contractor with an Environmental Management System (EMS) in place. (See Credit EW-1 Environmental Management System). These employers already have internal office procedures established to reduce office-related pollution and may be familiar with local agency recovery efforts and recycling or salvage facilities.
- Develop and deliver training to workers to educate them on waste recovery efforts being implemented onsite and compliance with the general CWMP and the Site Recycling Plan. This step will be critical to all projects. See Credit CA-2 Environmental Training for more approaches and strategies for education programs.
- Create an incentive or recognition plan for workers to engage actively in recycling efforts of personal trash that rewards positive and successful behavior.
- Hire an experienced waste transport company to manage site waste and monitor waste streams for unacceptable materials.
- Identify local facilities that accept recyclables or salvaged materials. This is important in designating type of waste to separate, and in making arrangements for drop-off or delivery of materials.
- Identify existing recycling collection facilities that may be decentralized (i.e. recycle bins along a city street). Many urbanized areas will have access or provisions for local recycling programs and may have resources available for use.
- The 2007 Contractor’s Guide by the King County Solid Waste Division and Seattle Public Utilities provides many helpful waste management and reduction strategies for the entire project. A sample waste management plan adapted from this guide is provided in the examples below.

Example: Sample Specification Language for Site Recycling Plan

- The King County Solid Waste Division (King County, 2009) provides some helpful tools for writing clear and manageable recycling and diversion expectations into contract documents at http://www.greentools.us. A sample of “Section 01505 (or 1524) – Construction Waste Management” is provided at the link below in Construction Specifications Institute (CSI) MasterFormat (King County, 2008): http://your.kingcounty.gov/solidwaste/greenbuilding/documents/Sect01505_const_waste-mgmt.pdf
- Communicating the plan expectations with subcontractors is equally important. Following is a sample clause for subcontractor agreements:

"The subcontractor will make a good-faith effort to reduce the amount of waste generated on the jobsite and recycle material as per the contractor's waste management plan. The subcontractor will follow the designated handling procedures for each type of waste generated on site and provide documentation to verify material reuse, recycling and disposal as indicated in the waste management plan." (King County, 2008)

Example: Sample Construction Waste Management Plan with Materials Recovery

The following example content has been adapted from the 2007 Seattle/King County Contractor's Guide, which is available here: http://your.kingcounty.gov/solidwaste/greenbuilding/documents/ConGuide.pdf. Projects teams should consider customizing the Site Recycling Plan information based on project goals and agency or client expectations.

Greenroads

SITE RECYCLING PLAN

General Contractor:
Project Name:
Site Recycling Coordinator:
Phone:
Debris Collection Agency:

Site Recycling/Diversion Goals:

Steps to inform contractors/subcontractors of Site Recycling Plan policies.

1.
2.
3.
4.
5.

C&D Materials Expected to be Generated and Proposed Diversion Method

The following charts identify materials expected to be generated by this project and the planned method for diverting these materials from disposal as a waste.

DECONSTRUCTION & DEMOLITION PHASE

Material	*Quantity (units)*	*Diversion Method & Location*	*Handling Procedure*

CONSTRUCTION PHASE

Material	*Quantity (units)*	*Diversion Method & Location*	*Handling Procedure*

Figure CA-3.1: Sample site recycling plan format.

POTENTIAL ISSUES

1. A central location for collecting recyclables on a roadway project may not be feasible for jobsites that consistently change starting locations on a daily basis (i.e. several miles down the roadway away from the collection area). This may result in unnecessary vehicle or worker trips to and from a particular location just to deposit something in a correct recycling receptacle. The authors are unaware of any practices that have been used on roadway construction projects that could solve or avoid this problem.
2. There is a trade-off between transport costs (including environmental costs from emissions) and the overall utility or value of the recycled or salvaged materials. Some locations, especially many rural areas, may have difficulty finding recovery facilities that are located near enough to the project to be financially or environmentally cost-effective.
3. Technology is quickly developing for recycling of materials into reconstituted building materials (See credit MR-4). However, new technologies may not be available locally or in rural areas.
4. Careless behavior or lack of stewardship may be an issue that can result in recyclables being disposed of in waste-only receptacles, or vice versa, especially if objectives of a Site Recycling Plan are not meaningful or communicated well to workers. This behavior can contaminate the recyclables stream and make an entire receptacle unsuitable for reprocessing or salvage, or accidentally send recyclables to a landfill.
5. Proper handling of recyclable materials is a key safety issue for new and unfamiliar recycling activities. Communication and training is critical to minimize risk and preserve safety.
6. Safety and security considerations should be taken into account relative to on-site storage of recoverable materials of high value. Opportunities for theft may be increased, especially for some types of metals that are commonly used in infrastructure or electrical utilities like copper wire.
7. Storage areas must comply with relevant regulations and the pollution prevention plan (see Project Requirement PR-7).
8. At this time, points are not available for achieving waste reduction based on percentage of total waste. This is due to lack of data regarding waste management for roadway construction activities.

RESEARCH

This section describes known challenges about implementing a recycling and recovery plan at roadway construction sites and explores the potential environmental benefits of such plans. For detailed background information on what is known about construction and demolition (C&D) waste management for roadways, the reader is referred to Project Requirement PR-6 Waste Management Plan. Similarly, for detailed information on planning for bulk roadway materials recycling, recovery or reuse (the first requirement for the Site Recovery Plan), the reader is directed toward the Materials & Resources Credits MR-2 Pavement Reuse, MR-3 Earthwork Balance, and MR-4 Recycled Materials. These credits contain many approaches and strategies that may be synergistic when pursuing this credit.

This section addresses two key points which are not addressed in the requirements or credits noted above: what is known about the state of recycling housekeeping practices and municipal solid waste (MSW, also known as household or personal waste) generation on construction sites and the benefits and costs of applicable construction materials recovery activities. Helpful resources are also listed at the end for more information.

State of the Road Industry Recycling Practice

While several agencies and authors promote recycling material waste products used in roadway construction, information on the recyclable material wastes generated by roadway construction and demolition projects is hard to locate. The following list identifies areas of construction activities for which there is currently little or no relevant data:

- Waste management plans for transportation contractors
- Sorting, segregation and processing activities for roadway construction waste, and where these activities occur (i.e. on-site, off-site)
- Behaviors and stewardship practices of road construction employees

- Generation rates and quantities of personal trash
- Generation rates and quantities of office-related trash for construction site offices
- Costs associated with C&D and MSW management from construction worksites

Existing regulatory requirements focus mainly on stormwater, sediment and dust control and other standard pollution prevention activities, such as the National Pollution Discharge and Elimination System (see also Project requirement PR-7 Pollution Prevention Plan). Some agencies may also have Environmental Management Systems (EMS) in place (see Credit EW-1 Environmental Management System) which often institute personal and office waste management policies, but no information is available relative to whether these EMS plans are implemented and followed at the construction site.

The lack of information is likely partly because recycling activities represent a materials feedback loop at many levels of the roadway system, from design and construction to start and end of the supply chain. Waste management and recovery of resources fit near the end of the pollution prevention scheme, but these activities themselves can inject materials into various lifecycle phases of the overall project (EPA, 2009b). This makes environmental costs and benefits of recycling difficult to quantify, characterize and compare between different projects. Some environmental costs of materials and products due to extraction and initial production are effectively extended into a second service life through downcycling recovery activities (where some original value is lost), general recycling or upcycling (value is gained) practices. (McDonough & Braungart, 2002) It also means long-range and upstream planning and reduction strategies can often provide more evident reduction benefits later in the lifecycle (EPA, 2009b).

Rajendran and Gambetese (2007) estimated waste rates for C&D material types based on literature review and quantitative modeling. Their estimates, however, do not include MSW materials generated from personal or office activities or behaviors of site staff (their estimated rates are itemized in Table PR-6.1). Solid waste recovery for construction and demolition debris is addressed in PR-6 and MR-4.

Cost Effectiveness of Construction Recycling Programs

A few authors (Seydel et al., 2002; Kourmpanis et al., 2008; Schultmann & Sunke, 2007) have attempted to quantify costs and perceived benefits associated with construction waste management practices. Those that have done so successfully have only followed construction of buildings and building site infrastructure components. Because building sites are relatively compact compared to the linear nature of roads, and because of the vast difference in the expected types of material quantities (e.g. hot mix asphalt and concrete materials), the relevance of these studies may be minor. However, the recycling activities and methods used for buildings projects vary widely. Many different waste management or waste recovery processes may also be applicable to roadway and bridge demolition and construction. Additionally, no quantitative cost models were based on U.S. data.

Schultmann and Sunke (2007) use a lifecycle energy analysis model to show that recovery of waste construction materials reduces lifecycle costs, mostly due to reduced energy use during extraction of materials. These savings appear to translate well to roadway materials based on the energy analysis for roadway construction completed by Rajendran and Gambetese (2007), which does use relevant U.S data. Schultmann and Sunke (2007), as well as the Construction Industry Research and Information Association (CIRIA, 2004), also note that closed-loop design and planning for deconstruction activities, also known as complete selective demolition (Kourmpanis et al., 2008), instead of destruction activities presents a valuable route to potential cost savings for many material products. Kourmpanis et al. (2008) also suggest that a combination of conventional demolition and deconstruction activities (partial selective demolition) and complete selective demolition of buildings can lower material handling and transport costs and increased recovered value of materials. However, transport costs and machinery costs for on-site activities must be weighed because they are highly variable between projects, especially by location.

Seydel, Wilson and Skitmore’s (2002) study (which tracked only three materials in one building project in Australia) demonstrated that recycling and sorting practices require heightened environmental awareness, more supervision of handling operations and more overall sorting that is perceived to be in addition to normal environmental controls. Their highest effort recovery scenario, including sorting and disposal, reduced transport and disposal costs of the waste by 18% from traditional practices and 9.5% from minimally controlled waste. However, the bottom line cost was increased due to the more complicated waste plan and more time spent managing and monitoring contractor employee waste activities. The authors state that the overall potential for the waste recovery plan to be successfully cost-effective and environmentally beneficial was not realized due to contractor inexperience with such planning. Additionally, they suggest that added planning and environmental stewardship could increase cost-competitiveness among construction contractors.

Poon et al. (2001) state that source separation, which takes place at the construction site, is heavily dependent on an environmentally-educated work-force, including subcontractors, that has been trained in proper materials handling and sorting procedures. “For most of them, it is usually a long learning process to be familiar and feel comfortable with performing waste separation.” (p. 169). Proper training has cost implications which are discussed further in Credit CA-2 Environmental Training. Crude separation, however, lowers the overall value of the recoverable material, because it often reduces the sorting efficiency downstream and requires specialized employees to complete the separation at an off-site location (Poon et al., 2001). Off-site waste sorting is typically the preferred option of most building contractors because it does not require additional labor force, supervised work on site, no additional facilities, or added training costs (Poon et al., 2001). Put simply: out of “site,” out of mind. Because this management option avoids on-site stewardship practices entirely, this method is not recommended (Poon et al., 2001).

Notable Recycling Statistics for MSW

None of the studies noted above consider MSW streams originating from any type of construction project. What follows in this section are general statistics that may be useful in identifying and characterizing the MSW portion of the waste stream generated on roadway and bridge construction sites.

Generally, in the U.S. municipal solid waste generation has increased over the last five decades, but recycling and composting rates have also increased (EPA, 2009b; EPA, 2009c). The waste stream for MSW landfills has been well-studied and characterized by the EPA. Data below is from the EPA’s *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2008* and includes statistics for waste types that may be potential encountered at construction sites.

- Out of 250 million tons of MSW disposed, about 83 million tons were recycled or composted in 2008. Of the total waste generated, the EPA estimates that approximately 35% to 45% was from commercial and institutional locations but the majority was residential origin.
- The U.S. waste stream was 31% paper and paper products (before recycling). See Figure CA-3.2.
- Approximately 54% of all MSW is discarded, while 33% is recovered for recycling, and the remainder is burned at landfills for energy production. Figure CA-3.3 shows the trends and distributions of MSW since 1960 to 2008.
- By weight, paper and paper products are the largest source of waste, with the highest overall recovered weight (55.5% recovered), though other materials have higher rates of recovery and less recovered mass. Specifically, 71% percent of office-related paper materials were recovered.
- Figure CA-3.4 shows a table of EPA 2008 statistics that includes all materials characterized in the waste streams monitored. Many could be commonly found in site offices and personal belongings, including food products. In fact, vegetative wastes and debris, containers, and packaging account for 44% of the total MSW stream sent to landfill and 15% of wood packaging was recovered (which was mostly pallets).
- As noted in PR-6 Waste Management Plan, some municipal solid waste landfills also accept construction and demolition debris (EPA, 2008a; EPA, 2008d). Materials such as hot mix asphalt and concrete make up a small percentage of the total MSW waste stream and are categorized in Figures CA-3.2 and CA-3.4 as “Other.”

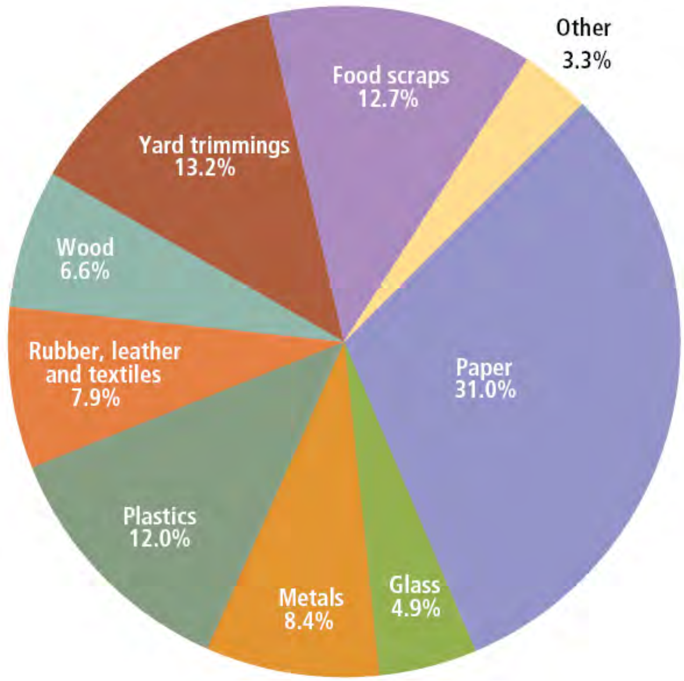

Figure CA-3.2: Composition of 2008 U.S. MSW waste stream, 250 million tons total (before recycling) (EPA, 2009c).

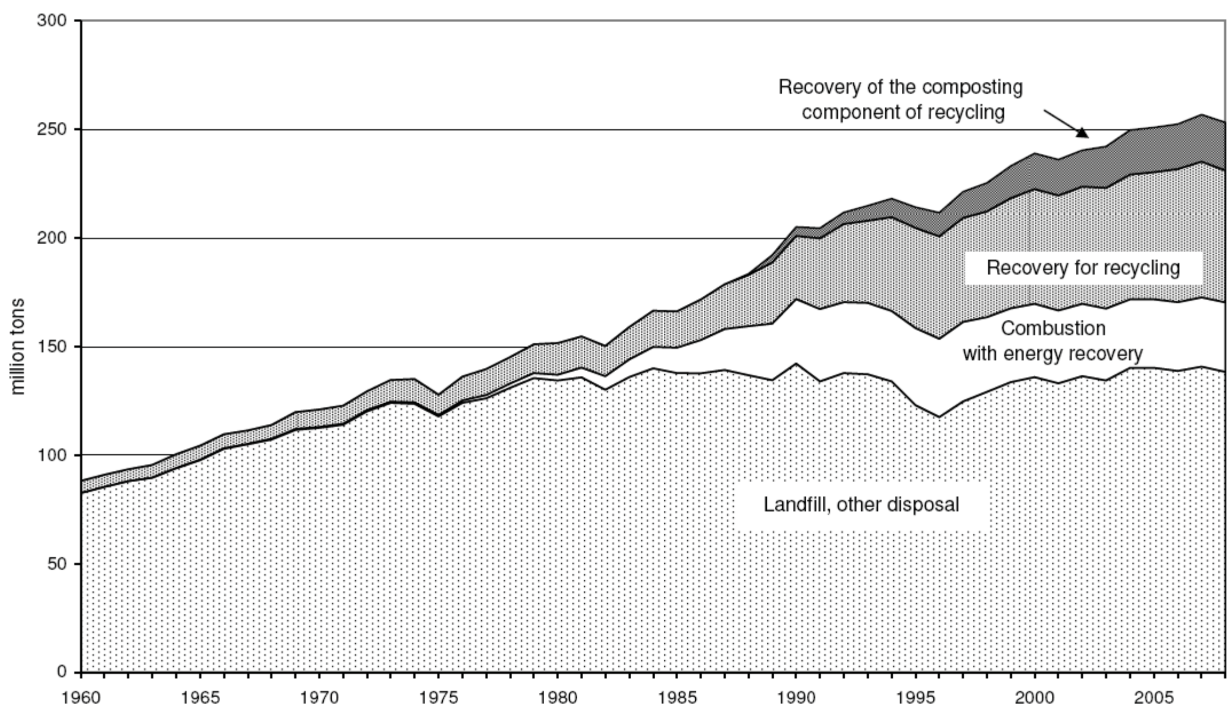

Figure CA-3.3: Disposal trends for MSW in the United States, 1960-2008 (EPA, 2009b).

Material	Weight Generated	Weight Recovered	Recovery as Percent of Generation
Paper and paperboard	77.42	42.94	55.5%
Glass	12.15	2.81	23.1%
Metals			
Steel	15.68	5.29	33.7%
Aluminum	3.41	0.72	21.1%
Other nonferrous metals†	1.76	1.21	68.8%
Total metals	**20.85**	**7.22**	**34.6%**
Plastics	30.05	2.12	7.1%
Rubber and leather	7.41	1.06	14.3%
Textiles	12.37	1.89	15.3%
Wood	16.39	1.58	9.6%
Other materials	4.50	1.15	25.6%
Total materials in products	**181.14**	**60.77**	**33.5%**
Other wastes			
Food, other‡	31.79	0.80	2.5%
Yard trimmings	32.90	21.30	64.7%
Miscellaneous inorganic wastes	3.78	Negligible	Negligible
Total other wastes	**68.47**	**22.10**	**32.3%**
Total municipal solid waste	**249.61**	**82.87**	**33.2%**

* Includes waste from residential, commercial, and institutional sources.
† Includes lead from lead-acid batteries.
‡ Includes recovery of other MSW organics for composting.
Details might not add to totals due to rounding.
Negligible = Less than 5,000 tons or 0.05 percent.

Figure CA-3.4: Generation and Recovery of Materials in MSW, 2008 (in millions of tons and percent of generation of each material) (EPA, 2009c).

Benefits of Recycling MSW

The EPA (2009c) states, "Recycling has environmental benefits at every stage in the life cycle of a consumer product—from the raw material with which it's made to its final method of disposal. Aside from reducing [greenhouse gas] emissions, which contribute to global warming, recycling also reduces air and water pollution associated with making new products from raw materials." In 2008, the 83 million tons of MSW that were recovered represent 182 million metric tons of carbon dioxide equivalent emissions saved annually. This is similar to removing the air emissions impact generated by 33 million passenger cars in one year (EPA, 2009c).

For MSW products, paper and wood products (organic materials) are the most common materials in the waste stream that end up in landfills. Diversion of these materials from landfills, as well as other organics such as topsoils and land clearing debris, offers reduced methane emissions due to fewer landfill emissions from decomposition of these organic materials. Methane is a greenhouse gas that contributes 21 times as much to global warming and climate change as carbon dioxide emissions. (Intergovernmental Panel on Climate Change, 2007) Also, paper waste is easily and commonly recycled, reducing the overall need for forested materials. Therefore, the EPA (2008) states that by not decreasing trees, more carbon dioxide is able to be stored in forest resources, (EPA, 2008) and priceless habitat is preserved.

The EPA promotes solid waste management through prevention (source reduction), recycling and composting (2008c) as three clear ways to reduce climate change impacts due to greenhouse gas emissions and energy consumption. “Less energy is needed to extract, transport, and process raw materials and to manufacture products when people reuse things or when products are made with less material.” (EPA, 2009a). As shown in Schultmann and Sunke (2001), materials that can reduce fossil energy need means fewer associated emissions from the energy sector with the recycled material than for a new material that has been extracted and manufactured from virgin materials (EPA, 2008b). Waste prevention practices (also known as pollution prevention or P2: EPA, 2008e), which are supported by the EPA as the most effective way to reduce environmental impacts, can reduce lifecycle emissions and energy use than construction and demolition and MSW recycling (2008b).

Future of this Credit

Other familiar sustainability rating systems, such as LEED (USGBC, 2009) for buildings and the Sustainable Sites Initiative (2009), award credit for reduction of solid waste and diversion practices for construction and demolition materials. Currently, no minimum recycling standard or data on average waste generated per project is available for common types of roadway construction projects. At this time, Greenroads cannot justify awarding points to one project over another based on waste management practices or goal setting without a known benchmark for this best practice.

Additional Resources

- CIRIA, the Construction Industry Research and Information Association, provides some helpful hints for design and construction best practice for managing waste and resources (2004): http://www.ciria.org.uk/cwr/good_practice_pointers.htm
- The California Integrated Waste Management Board (CIWMB) offers a number of resources and tools, including videos of recycling best practices, (2009) available at: http://www.ciwmb.ca.gov/Recycle/
- The EPA’s P2 (Pollution Prevention) Resource Exchange provides contact information for regional agencies that can help connect project leaders to the right resources and opportunities for creating new waste management programs: http://www.epa.gov/p2/pubs/p2rx.html
- WasteCap Resource Solutions offers tips and tricks used by the building industry. Of particular interest and applicability to roadway projects are pre-written specifications (free) and additional links and resources. Training videos and receptacle magnetic signs are also available for a small fee. WasteCap also offers an online documentation program for waste management planning called *WasteCapDirect* (price not specified). More information is available here: http://www.wastecapwi.org/resources/construction-demolition

GLOSSARY

C&D	Construction and demolition
CIRIA	Construction Industry Research and Information Association
CIWMB	California Integrated Waste Management Board
Closed-loop design	An approach that considers waste management in project planning in order to avoid or eliminate processes that generate waste
Complete selective demolition	See “deconstruction”
CSI	Construction Specifications Institute
CWMP	Construction Waste Management Plan
Deconstruction	The whole or partial disassembly of a product to facilitate component reuse and materials recycling
Demolition	Conventional means of disassembly, or taking apart, a product or facility that is typically destructive and generally un-planned

Diversion	Avoiding placement in a landfill through recovery processes such as recycling or reuse
Downcycling	Recovering a portion of a used product or material in a manner that reduces the original value of the product or material after being reintroduced into the manufacturing or construction process (McDonough & Braungart, 2002)
Partial selective demolition	Engineered areas where waste is placed into the land (EPA, 2008)
Receptacle	A bin or container
Recycling (recyclable)	Recovering a portion of a used product or material from the waste stream and processing such that those same materials can be reintroduced into the manufacturing or construction process (CIWMB, 2009)
Reuse (reusable)	Recovering a portion of a used product or material from the waste stream that requires minimal, if any, processing to be reintroduced into the manufacturing or construction process
ROW	Right-of-way
Upcycling	Recovering a portion of a used product or material in a manner that increases the original value of the product or material after being reintroduced into the manufacturing or construction process
Waste	Any material that must be hauled off-site for disposal or reprocessing, or, if disposed within the project ROW, is not intended for engineered use on-site

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FOSSIL FUEL REDUCTION

CA-4

1-2 POINTS

GOAL

Reduce the overall consumption of fossil fuels by nonroad construction equipment.

CREDIT REQUIREMENTS

Reduce the fossil fuel requirements of nonroad construction equipment by using biofuel or biofuel blends as a replacement for fossil fuel. Points are awarded as follows:

1 point
Reduce the fossil fuel requirements of the nonroad construction equipment fleet by 15% through the use of biofuel or biofuel blends as a replacement for fossil fuel.

2 points
Reduce the fossil fuel requirements of the nonroad construction equipment fleet by 25% through the use of biofuel or biofuel blends as a replacement for fossil fuel.

Details

For this credit, at least 15% (for 1 point) or 25% (for 2 points) of the fuel consumed by nonroad construction equipment on the project should be from a source other than fossil fuel. In most cases, the most straightforward way of achieving this is by using a biofuel (B100) or biofuel blend (e.g., B20, B50) as onsite fuel for the equipment fleet.

DOCUMENTATION

1. A signed letter from the prime contractor that describes the fossil fuel use reduction measures used and the percentage reduction achieved.
2. A spreadsheet summarizing all receipts for all fuel used in nonroad equipment for the project. The spreadsheet should indicate (and receipts should show) associated biofuel blend (e.g., B5, B20, B100) used.

RELATED CREDITS

- ✓ CA-5 Equipment Emission Reduction
- ✓ CA-6 Paving Emissions Reduction

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Economy

BENEFITS

- ✓ Reduces Fossil Fuel Use
- ✓ Reduces Air Emissions
- ✓ Reduces Greenhouse Gases

APPROACHES & STRATEGIES

- Support the environmental and health benefits of biodiesel by providing economic incentive to the general contractor. This can be done either by budgeting for added costs of biodiesel fuel sources to help offset potential costs or through other contract-related incentives.
- Purchase and use biodiesel as the on-site diesel fuel. Using B20 as the exclusive on-site diesel would be a means to ensure at least a 20% reduction in fossil fuel use is achieved.

Example

Some example scenarios are provided below based on a hypothetical nonroad construction equipment fleet that consumes 1,000 gallons of fuel during project construction.

No points

- B5 (a fuel that is 5% biofuel and 95% petroleum diesel) is used for all 1,000 gallons of fuel. This amounts to a 5% reduction in fossil fuel use.
- B100 (a fuel that is 100% biofuel) is used for 100 gallons of fuel and petroleum diesel is used for the remaining 900 gallons. This amounts to a 10% reduction in fossil fuel use.

1 point

- B20 (a fuel that is 20% biofuel and 80% petroleum diesel) is used for all 1,000 gallons of fuel. This amounts to a 20% reduction in fossil fuel use, which exceeds 15% but is less than 25%.

2 points

- B50 (a fuel that is 50% biofuel and 50% petroleum diesel) is used for 200 gallons of fuel and B20 is used for the remaining 800 gallons. This amounts to a 26% reduction in fossil fuel use.
- B50 (a fuel that is 50% biofuel and 50% petroleum diesel) is used for 500 gallons of fuel and B20 is used for the remaining 500 gallons of fuel. This amounts to a 35% reduction in fossil fuel use.

Example: Turner Construction Company Case Study

B99, a 99% proportion of biodiesel to conventional fuel, was used during the construction of the Microsoft Windows Live Columbia One Data Center in Quincy, Washington to fuel equipment operated by subcontractors hired by Turner Construction Company. Discussions with the Safety Manager assigned to the project reveal that the reason behind the switch to biodiesel for the on-site construction equipment was to provide a remedy for the noxious diesel fumes that were emitted by the nonroad construction equipment. Workers reported no issues with air quality during the first half of the project, however the second half of the project was when a considerable portion of the construction work was performed within the semi-enclosed shell and core structure. It was during this stage when the particulate matter and carbon monoxide levels emitted by the nonroad construction equipment became a concern to the operators and laborers working alongside. The situation was promptly brought to the attention of the Safety Manager.

Upon the Safety Manager’s recommendation, Turner Construction negotiated the use of biodiesel fuel for the equipment being leased from the subcontractor who was providing the equipment for the project. The project called for approximately 15-20 pieces of construction equipment which was leased from RSC Equipment Rentals based out of Ellensburg, Washington (National Biodiesel Board, 2008). Discussions with the Turner Construction’s Safety Manager and the Equipment Manager from RSC Equipment Rentals confirmed that no retrofitting was required for the equipment prior to making the switch to biodiesel fuel.

As a proactive means to provide preventative maintenance, and as a result of the anticipated cleansing of the fuel delivery system attributed to the solvent action of biodiesel, fuel filters for each piece of equipment were replaced after the first and third tankfuls of fuel. Observations from the equipment operators detected no noticeable loss in fuel efficiency during the operation of the equipment. Fuel use was not monitored on an individual equipment basis and, as a result, data is unavailable to calculate and confirm improvements or reductions to the fuel efficiency of the equipment. Furthermore, operators observed no significant loss of power for the equipment operating on biodiesel although the operator of a CAT 330 excavator noticed a small power loss near full operating load. The lack of a noticeable power loss for the majority of the equipment was likely due to the equipment not being utilized to its full power potential.

Air quality data was collected by Turner Construction Company and the Washington State Department of Labor & Industries shortly after making the switch to biodiesel. Unfortunately, the data collected by Turner Construction's Safety Manager was lost as a result of damage to the Safety Manager's portable computer. Based on the Safety Manager's recollection however, the following information pertains to the air quality management proceedings:

- The air quality was assessed during the operation of concrete pump trucks fueled with B99 biodiesel and measured while operating within the confines of the shell and core structure. The measurement was taken at the truck exhaust using an air monitor. Readings were as follows:
    - Turner Construction: 2 ppm CO at the exhaust
    - Department of Labor & Industries: 3-4 ppm CO at the exhaust

Air quality regulations permit carbon monoxide concentrations at the exhaust to approach 40-45 ppm. An interesting side comment made by Department of Labor & Industry technicians, and noted by the Safety Manager, was that the proper functioning of their air monitors were called into question because the carbon monoxide measurements were unexpectedly low.

POTENTIAL ISSUES

1. Currently, biodiesel in the most common form, B20 (a 20 percent blend of ethanol and conventional diesel) offers no significant economic advantage and the environmental and social advantages are often overlooked.
2. There may be a cost premium per gallon for biodiesel over that of conventional diesel fuel.
3. Biodiesel is currently not produced in sufficient quantities to meet widespread demand.
4. Engine manufacturers may not honor diesel engine warranties if such engines use biofuels. As of 2009, most engine manufacturers allow B5 and some allow up to B20 under their current warranties.
5. Lack of industry data for engine performance leads to skeptic equipment manufacturers.
6. Limited availability of ethanol feedstock because of the tradeoff within the agricultural industry for production of food versus production of fuel.
7. There are a limited number of nonroad construction equipment models that offer hybrid electric drive engines.

RESEARCH

A fuel that exhibits properties similar to that of conventional diesel but offers several associated benefits resulting from its use is biodiesel. Biodiesel can be used as a direct replacement for conventional diesel in its purest or blended forms and is produced from the esters of vegetable oils and animal fats (Van Gerpen et al., 2007). This fuel source can be used to power diesel engines and typically requires no equipment modifications and is able to utilize the current fueling infrastructure for distribution (USDOE, 1995).

Biodiesel is produced through the transesterfication process. This process requires feedstock materials which include rapeseed, soybean, vegetable oils and animal fats (USDOE, 1995). The animal fat or vegetable oil is combined with alcohol in the first stage of the process in a chemical reaction which combines the feedstock material with an alcohol to produce an ester and glycerol (Van Gerpen et al., 2007). Alcohols typically used in the process include methanol and ethanol though methanol is more commonly used as a result of its lower cost (You, 2007). This reaction is usually catalyzed to improve the reaction rate and the quantity that can be produced. The byproduct of this reaction is glycerol which is removed and separated from the alcohol/ester mixture. The alcohol is further separated from the ester. It is the remaining esters which make up the raw biodiesel (You, 2007).

Biofuels such as ethanol and biodiesel are derived from biomass and offer several advantages. They are considered renewable forms of fuel because their use involves a closed carbon cycle (Puppan, 2001). In addition to helping reduce our dependency on foreign oil, the use of biodiesel has shown several environmental and human health benefits associated with its use as a construction fuel. For example, the use of biodiesel mitigates the impacts of global warming and climate change since there is no net production of carbon dioxide during the lifecycle of biodiesel production and use (Van Gerpen et al., 2007). Furthermore, since biodiesel is an oxygenated fuel, it produces fewer hydrocarbons, less carbon monoxide and less particulate matter than that of conventional No. 2 diesel fuel from the combustion process in a diesel engine (Van Gerpen et al., 2007). As a result, the use of biodiesel promotes localized improvement to air quality and worker health from the decrease in the emission of compounds that are classified as human health hazards such as carbon monoxide, sulfur dioxide, lead and particulate matter (Puppan, 2001).

Other advantages include the lubricity properties of biodiesel that permit it to contribute to enhancing the efficiency of an engine as well as improving the life expectancy of the equipment (Van Gerpen et al., 2007). Moreover, biodiesel features a detergent action or solvent property which improves engine efficiency by removing sedimentation and deposits from an engine's fuel system (USDOE, 2001). These factors contribute to the possibility of eventual long-term cost savings as a result of decreased maintenance costs over that observed when conventional diesel is used to fuel equipment.

The cost to retrofit equipment to operate on biodiesel is typically negligible. Usually no retrofitting of engine components is required to permit equipment to utilize biodiesel for fuel. However, the fuel system for the engine should have no rubber parts such as rubber hoses, seals and gaskets which could deteriorate from any physical contact with biodiesel (USDOE, 1995). Rubber components typically exist in equipment manufactured prior to 1994 and engine damage as a result of fuel system failure resulting from the deterioration of engine components could result from the solvent action of biodiesel (USDOE, 2001).

An important economic advantage to the use of biodiesel is that it can be used in its pure form (as B100) or blended with petroleum-derived diesel. As such, the use of biodiesel requires little-to-no modifications to the current fueling infrastructure or vehicle engine and fuel delivery systems in preparation for its use (USDOE Clean Cities Fact Sheet).

The results of a limited-scope life cycle assessment (LCA) of the construction of one lane-mile of portland cement concrete roadway using a generic set of non-road construction equipment required to place the concrete (i.e. a paving machine and texture/curing machine) indicated that the production and utilization of biodiesel consumes more energy than that required to produce and utilize conventional or ultra-low sulfur diesel fuel. However, based on the data collected from the LCA, it is clear that biodiesel is the fuel source that is the least contributing to the potential for global warming. In other words, conventional diesel and ultra-low sulfur diesel contribute more to global warming than biodiesel. The difference in the level of contribution between conventional and ultra-low sulfur diesel was found to be almost negligible. On the other hand, biodiesel was determined to bring about a larger contribution to smog formation due to the increased formation of NO_X and further reaction of the NO_X with VOCs to form smog. Difference in the contribution to smog formation between conventional diesel and ultra-low sulfur diesel was found to be negligible.

GLOSSARY

Biofuel	Renewable fuels derived from biological materials that can be regenerated. This distinguishes them from fossil fuels which are considered nonrenewable. Examples of biofuels are ethanol, methanol, and biodiesel.
Hybrid-electric	A power system that combines a conventional internal combustion engine (e.g., diesel) and an electric motor and/or storage system to provide the primary power for the vehicle.

B5, B20, B50, B100	Short notation to describe a blend of biodiesel with traditional petroleum diesel. The number describes the percentage of biodiesel (e.g., B20 is 20% biodiesel and 80% petroleum diesel).

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EQUIPMENT EMISSION REDUCTION

CA-5

1-2 POINTS

GOAL

Reduce air emissions from nonroad construction equipment.

CREDIT REQUIREMENTS

Use emission reduction exhaust retrofits and add-on fuel efficiency technologies that achieve the EPA Tier 4 emission standard for nonroad construction equipment. Points are awarded as follows:

1 point

At least 50% of the nonroad construction equipment fleet operating hours for the project are accomplished on equipment with installed emission reduction exhaust retrofits and add-on fuel efficiency technologies that achieve the EPA Tier 4 emission standard.

2 points

At least 75% of the nonroad construction equipment fleet operating hours for the project are accomplished on equipment with installed emission reduction exhaust retrofits and add-on fuel efficiency technologies that achieve the EPA Tier 4 emission standard.

Details

For this credit to be implemented successfully, workers may require additional training on how to keep track of equipment operating hours accurately. See also CA-2 Environmental Training.

DOCUMENTATION

Provide a list of all nonroad construction equipment used on the project that contains the following information for each piece of equipment:

1. Make and model of each piece of equipment.
2. Operating hours associated with the project.
3. For equipment achieving Tier 4 emissions standards, documented evidence that the equipment either (a) meets EPA Tier 4 emissions standards, or (b) has installed emission reduction exhaust retrofits and add-on fuel efficiency technologies that achieve the EPA Tier 4 standard.

RELATED CREDITS

- ✓ CA-2 Environmental Training
- ✓ CA-4 Fossil Fuel Reduction
- ✓ CA-6 Paving Emissions Reduction

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Equity

BENEFITS

- ✓ Reduces Air Emissions
- ✓ Reduces Greenhouse Gases
- ✓ Improves Human Health & Safety

APPROACHES & STRATEGIES

- Retrofit exhaust equipment on nonroad vehicles.
- Replace engines where this option is more cost-effective than retrofit.
- Switch to use ultra-low sulfur diesel (ULSD) in conjunction with the add-on fuel efficiency technologies installed in the equipment fleet.

Example: Scenarios

Some example scenarios are provided below based on a hypothetical nonroad fleet operating for a total of 1,000 equipment hours.

No points

- 400 of 1,000 total operating hours (40%) are associated with equipment that achieve the EPA Tier 4 emissions standard.

1 point

- 500 of 1,000 total operating hours (50%) are associated with equipment that achieve the EPA Tier 4 emissions standard.

2 points

- 800 of 1,000 total operating hours (80%) are associated with equipment that achieve the EPA Tier 4 emissions standard.

Example: Case Studies Documented by the U.S. EPA

The EPA describes several diesel engine emission reduction effort case studies at: http://www.epa.gov/diesel/construction/casestudies.htm

Example: Washington State Department of Ecology Strategy

One example of an overall statewide approach that this Voluntary Credit is consistent with is the Washington State Department of Ecology's "Diesel Particulate Emission Reduction Strategy." The goals expected under this approach are (Ecology, 2006):

1. Install emission reduction exhaust retrofits on fifty percent of the public legacy diesel fleet in four years.

2. Install emission reduction exhaust retrofits and add-on fuel efficiency technologies on fifty percent of the private legacy diesel fleet in eight years.

3. Evaluate, develop and implement an idle reduction program that addresses and remedies unnecessary idling through on-board retrofits, on-the-ground infrastructure and anti-idling regulations.

4. Replace twenty-five percent of older (pre-1996 for non-road) legacy vehicles in the private fleet in eight years.

POTENTIAL ISSUES

1. Retrofits and replacements of engines can represent a significant added cost to the contractor.

RESEARCH

Construction air emissions are largely from three main sources: (1) dust and particles from the construction activities, also called fugitive dust, (2) emissions from construction equipment exhausts, or (3) emissions from construction materials (such as fumes and vapors from hot asphalt). This Voluntary Credit addresses construction equipment emissions in general and specifically, diesel exhaust emissions from nonroad diesel equipment.

Nonroad Engine Defined

40 CFR Part 1068 (the General Compliance Provisions for Nonroad Programs) defines precisely what a nonroad diesel engine is and is not. In summary (40 CFR 1068 has exact definitions and exclusions), a nonroad engine is defined to be any internal combustion engine that is:

1. In or on a piece of equipment that is self-propelled or serves a dual purpose by both propelling itself and performing another function.
2. In or on a piece of equipment that is intended to be propelled while performing its function.
3. That, by itself or in or on a piece of equipment, is portable or transportable.

In general, diesel powered self-propelled and portable construction equipment with an internal combustion engine are considered to be nonroad engines.

Health Effects

Diesel engines emit a complex mixture of gaseous pollutants and fine particles and are a major source of air pollution. Particular emissions are nitrogen oxides (NOx), particulate matter (PM), sulfur oxide gases (SOx), and other toxic air pollutants which contribute to serious adverse health and environmental effects (EPA, 1995; ICF, 2005). Emissions from diesel engines have been found to include over forty cancer causing substances, and the U.S. Environmental Protection Agency (EPA) has concluded that diesel exhaust is likely to be carcinogenic to humans by inhalation at occupational and environmental levels of exposure (EPA, 2002). In Washington State, the Washington State Department of Ecology has identified diesel exhaust as the air pollutant most harmful to public health in Washington State. They found that 70% of the cancer risk from airborne pollutants is from diesel exhaust, mainly due to the PM 2.5 emissions (Washington State Department of Ecology, 2006). Until the mid-1990s, emissions from these engines were largely uncontrolled. In order to combat the health effects of diesel emissions, the EPA started a program in 2007 to reduce diesel engine emissions in the U.S. (EPA, 2004). The plan is estimated to reduce emissions by more than 90% by 2030.

Contribution of Nonroad Diesel Engines to Emissions Inventory

According to EPA's National Emission Inventory (2008 year data) (NEI, 2009), nonroad diesel engines (using the category of "off highway") are responsible for 26% of NOx emissions nationally (4,255,000 tons per year), and for 5.8% of fine particulate emissions (PM 2.5) (283,000 tons per year) nationally. These percentages can be considerably higher in some urban areas. In Washington State, the Department of Ecology states that construction activities are responsible for 18% of the State's PM 2.5 emissions (2002 data) (Figure CA-5.1).

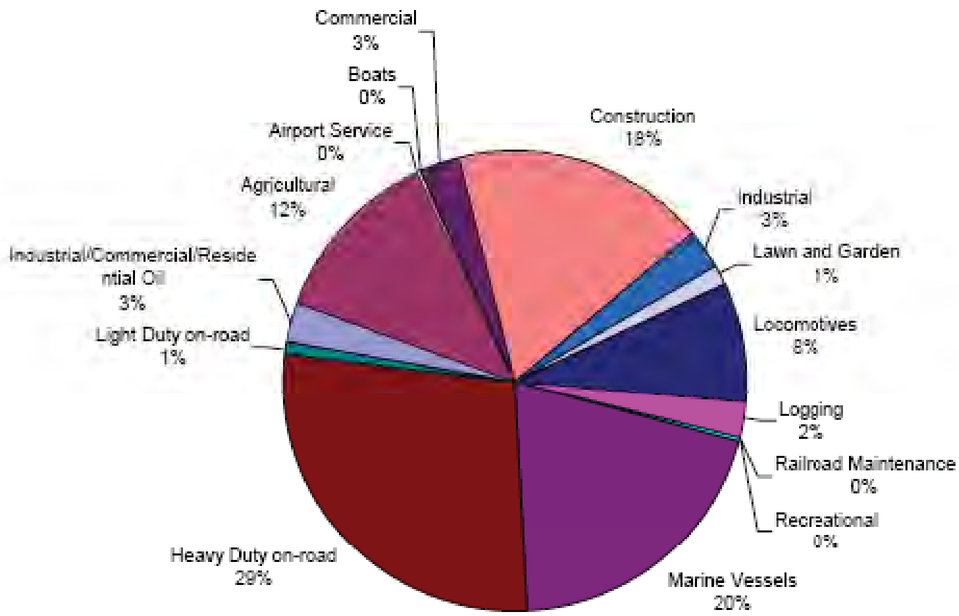

Figure CA-5.1:
(Washington State Department of Ecology, 2006).

1.

Improvement Efforts

Recognizing the large impact that diesel engine exhaust has on human health and the environment (e.g., CARB, n.d.), there are substantial efforts to reduce diesel exhaust emissions through burning cleaner diesel fuels (e.g., ultra low sulfur diesel or ULSD), installing exhaust retrofits to reduce emissions from existing engines and producing new diesel engines that emit less.

Pace of Change

Although efforts to reduce diesel emissions are underway, significant impacts may be years away. Nonroad diesel equipment can last 20 to 30 years and typical new emissions standards are not required to be met by existing equipment. Therefore, the impacts of such changes are likely to be felt as a majority of equipment fleets age and are replaced by equipment meeting newer, more stringent regulations. Furthermore, change and its pace will likely be controlled by the private sector as they own nearly 90 percent of diesel vehicles and diesel engines (Washington State Department of Ecology, 2006). Thus, efforts to incent the private sector to change ahead of natural equipment turnover rates may help make diesel emission reductions happen sooner.

Cost Considerations

A majority of construction companies are small firms. To retrofit or change their equipment requires large capital investments, which they may not be able to bear. For many private smaller construction companies, this cost is significant and interferes with the environmental benefits this would achieve. Also the cost of using alternative fuel or low-sulfur fuel is an issue.

The EPA estimates the incremental cost of producing 500 ppm fuel to be on average 2.5 cents per gallon, and 15 ppm around 5 cents per gallon. (This takes into account all the necessary changes in both refining and distribution practices, however this estimated costs vary widely for equipment of different sizes and for different applications) (EPA, 2003). For the vast majority of equipment, the cost of meeting emission standards will be roughly 1-2% compared with the typical retail price. As an example, EPA estimates that for a 175-hp bulldozer, it will cost an additional $2,600 to add the advanced emission control systems to the engine and to design the bulldozer to accommodate the modified engine. A new 175-hp bulldozer costs approximately $230,000 (EPA, 2003), so the increased costs are about 1 % of the total purchase price. Costs could be higher for some types of equipment. As a benefit, engines running on low-sulfur fuel will have reduced maintenance expenses (EPA, 2003). As incentive, there are several grant programs available at local and federal level for companies to retrofit or change part of their equipment fleet (Washington State Department of Ecology, 2006; EPA, 2009).

In the broader context, the benefits to society of reduced health costs resulting from fewer emissions are substantial. The EPA estimated the benefit-to-cost ratio (health benefits to compliance cost) of 30 (CARB, n.d.). In general, the California Air Resources Board (CARB) reports benefit-cost ratios in the literature from 2 to 8.

GLOSSARY

Tier 4 emission standard	EPA standards that require emissions to be reduced over current Tier 2 and 3 standards. Reductions of particulate matter (PM) for engines above 19kW and nitrous oxides (NOx) for engines larger than 56 kW are substantial. Hydrocarbon limits are also substantially reduced for engines larger than 56 kW. Such emission reductions can be achieved through the use of control technologies including advanced exhaust gas after treatment. Tier 4 standards are to be phased in over the period of 2008-2015.
Ultra low sulfur diesel (ULSD)	Standard term for diesel fuel having less than 15 ppm sulfur. As of 2009, most on-highway diesel fuel sold at retail locations is ULSD. The previous standard, low sulfur diesel (LSD), allowed 500 PPM sulfur.

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PAVING EMISSIONS REDUCTION

CA-6

1 POINT

GOAL

Improve human health by reducing worker exposure to asphalt fumes.

CREDIT REQUIREMENTS

Place at least 90% of the hot mix asphalt (HMA) on the project using a paver that is certified to have met National Institute for Occupational Safety and Health (NIOSH) emission guidelines as set forth in Engineering Control Guidelines for Hot Mix Asphalt Pavers, Part 1: New Highway-Class Pavers (Department of Health and Human Services (NIOSH) Publication No. 97-105, April 1997 printing).

Details

If more than one paver is used on a project, the percentage of HMA placed by each paver shall be determined using the total weight of HMA placed by each paver. Use Equation CA-6.1 to compute the total percentage placed by the NIOSH paver. Calculations should be done by weight of HMA placed. For the purposes of this calculation, all placed bituminous asphaltic mixtures (e.g., hot mix asphalt, warm mix asphalt, open-graded asphalt, stone matrix asphalt, etc.) shall be counted as "HMA."

Equation CA-6.1:

$$\frac{Total\ HMA\ Pavement\ Placed\ by\ NIOSH\ Pavers}{Total\ HMA\ Pavement\ on\ Project} \times 100\% \geq 90\%$$

DOCUMENTATION

- Copy of the manufacturing certification provided with the paver(s) when purchased. Page 5 of the NIOSH (1997) document provides an example of the certification wording.
- Signed statement by a paving contractor representative indicating that the certified paver(s) referenced in the first document was (were) used on the job and did place at least 90% of the HMA.

RELATED CREDITS

- ✓ CA-4 Fossil Fuel Reduction
- ✓ CA-5 Equipment Emission Reduction
- ✓ PT-3 Warm Mix Asphalt

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Equity

BENEFITS

- ✓ Reduces Air Emissions
- ✓ Reduces Greenhouse Gases
- ✓ Improves Human Health & Safety

APPROACHES & STRATEGIES

- Use a paver that meets NIOSH engineering control guidelines. A quick check can be done by locating the exhaust stack or required 3- by 5-inch information plate (Figure CA-6.1) on the paver being used. These information plates are required to be attached by the manufacturer.

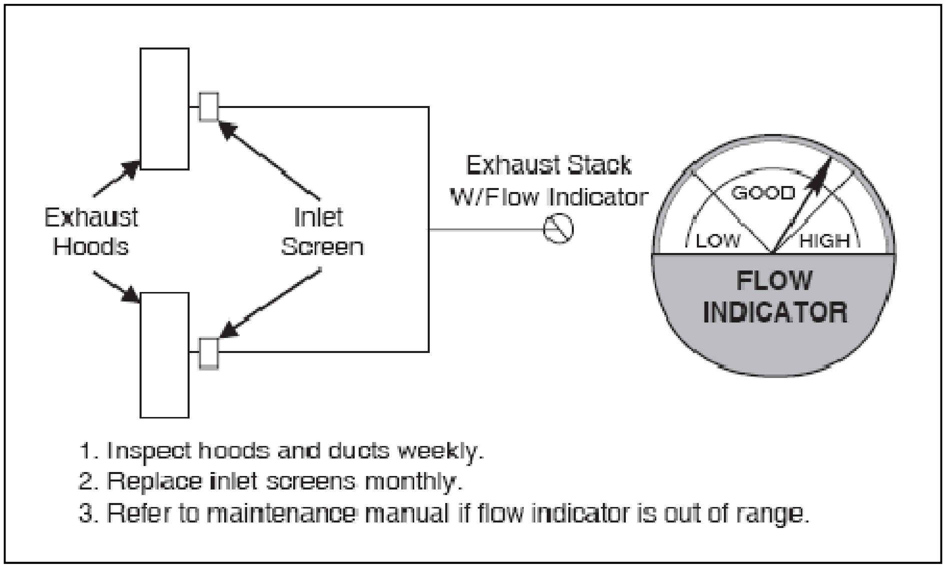

Figure CA-6.1: Example of a manufacturer information plate (from NIOSH, 1997).

Example: Photos

Figures CA-6.2 and CA-6.3 show examples of pavers with and without exhaust ventilation systems.

Figure CA-6.2: The large black exhaust stack to the right of the operator is part of a NIOSH compliant exhaust ventilation system.

Figure CA-6.3: This paver is NOT equipped with an exhaust ventilation system.

Example: Calculation

An urban paving project places a 1.5-inch overlay on a 2-lane city arterial street. The overlay includes overlaying small areas on each cross street. A paver having a ventilation exhaust system meeting NIOSH guidelines is used for paving the arterial while a small paver, not equipped with a ventilation exhaust system, is used to pave the cross street areas. On completion of the project, a review of truck tickets show that the NIOSH paver placed 4,250 tons of HMA while the non-NIOSH paver placed 200 tons of HMA.

$$Total\ HMA\ on\ the\ Project = 4{,}250\ tons + 200\ tons = 4{,}450\ tons$$

$$\%\ HMA\ Placed\ by\ NIOSH\ Paver = \frac{4{,}250\ tons}{4{,}450\ tons} \times 100\% \ = 95.5\% \geq 90\%$$

Therefore, this project qualifies for 1 point since 95.5% exceeds the 90% requirement.

POTENTIAL ISSUES

1. Having a NIOSH compliant paver but having a malfunctioning exhaust system or not using the exhaust system.
2. Having a NIOSH compliant paver with an exhaust system that no longer meets NIOSH requirements for indoor capture efficiency.

RESEARCH

While many pavers being used in construction have NIOSH engineering controls on them, not all do. Currently, most highway pavers (manufactured since 1997) have fume controls installed in/on them in accordance with NIOSH standards. However, smaller pavers are not required to have such controls.

These engineering controls are basically an exhaust ventilation system that collects fugitive emissions near the augers (Figure CA-6.4), and releases them through an exhaust stack that is high enough such that workers are not exposed to emissions from that stack (Figure CA-6.5). This reduces worker exposure to asphalt fumes. According to NIOSH (1997), each new self-propelled HMA paver weighing 16,000 pounds or more and manufactured after July 1, 1997 "…should develop and install exhaust ventilation systems with a minimum controlled indoor capture efficiency of 80%...” The NIOSH (1997) document, which was developed in concert with the National Asphalt Pavement Association (NAPA), describes the detailed requirements for the exhaust ventilation system including the performance testing criteria, labeling, certification, operation, maintenance and training.

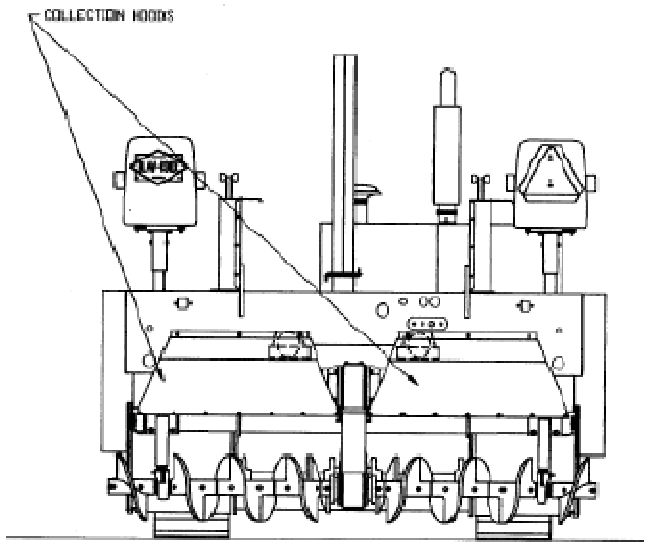

Figure CA-6.4: Drawing of the collection hoods used to collect fumes near the auger (from Construction Innovation Forum, 2006)

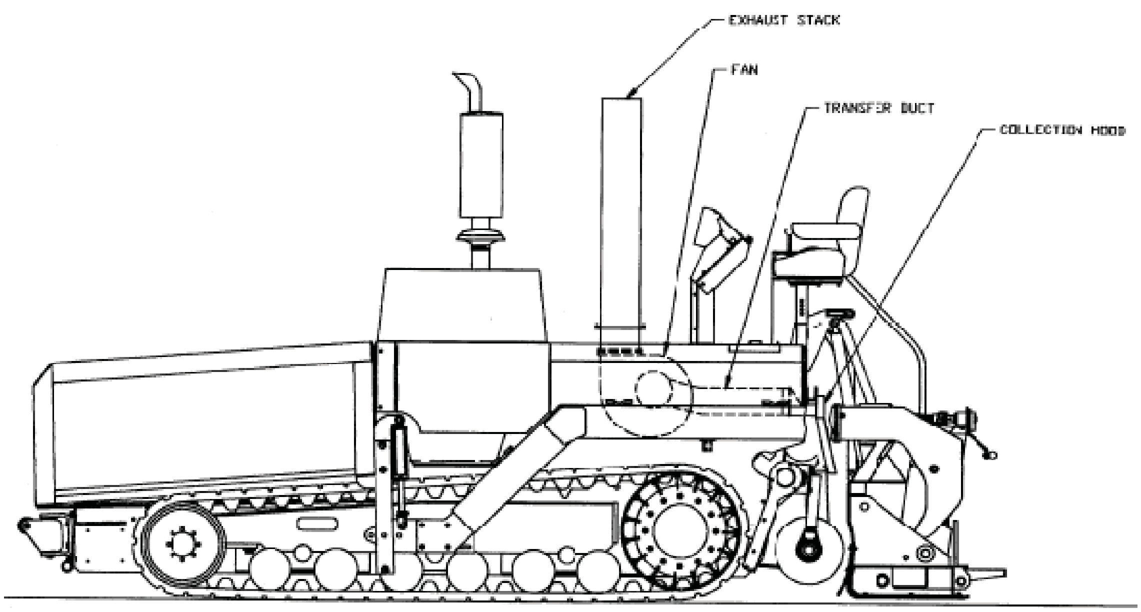

Figure CA-6.5: Drawing of the exhaust ventilation system with key parts labeled (from Construction Innovation Forum, 2006).

The NIOSH summary of health effects of occupational exposure to asphalt fumes generally indicates that there are acute (immediate or short-term) and chronic (long-term) impacts to human health. While not all studies agree on the effects or their significance there is generally strong enough evidence to show that such effects can be present. Given that, it is beneficial to reduce asphalt fume exposure to paving workers even if it is below established limits. Established exposure limits are generally to prevent acute effects; in some cases they do not fully address chronic effects and it is very difficult to do so.

More information is available in the full NIOSH document on the web at: http://www.cdc.gov/niosh/asphalt.html

GLOSSARY

HMA	Hot mix asphalt
NAPA	National Asphalt Pavement Association
NIOSH	National Institute of Occupational Health and Safety
WMA	Warm mix asphalt (see also Credit PT-3)

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WATER USE TRACKING

CA-7

2 POINTS

GOAL

Generate project-level information about construction water use.

CREDIT REQUIREMENTS

Create a spreadsheet that records total water use during construction. This spreadsheet should identify, at minimum:

1. Dates of use.
2. Amounts of use.
3. Locations and sources of water used.
4. Potability of water source(s).
5. Each construction activity requiring water use.
6. Total water quantity used in each construction activity.
7. Method of measurement to determine total quantity used.
8. Disposal practice for unused water.
9. Type of water use permit, if any.
10. Total cost of water used from each source, if any.

Details

Water use can be measured by meter, hose capacity, number of water tanks, pumping rate over time, or other appropriate source-dependent estimates.

The credit does not require specific performance criteria for water conservation. Eventually, water use data will be compiled to establish benchmarks for roadway construction water efficiency and to develop guidelines for appropriate water conservation practices and principles to reduce potable water usage and negative impacts to the environment.

DOCUMENTATION

- Copy of the spreadsheet used to record construction water use.

RELATED CREDITS

- ✓ PR-7 Pollution Prevention Plan
- ✓ PR-10 Site Maintenance

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Expectations
- ✓ Exposure

BENEFITS

- ✓ Improves Accountability
- ✓ Increases Awareness
- ✓ Creates New Information

APPROACHES & STRATEGIES

- Ask individual workers to record water use on their daily reports.
- Provide copies of the tracking spreadsheet at locations where water is used and measured for gathering consistent recordings.

Example: Sample Spreadsheet

Sample spreadsheet entries for different construction activities that commonly use water are shown in Table CA-7.1 for three different types of projects. Note that each activity has a separate column and associated data. Note that, realistically, the data for the project will require information for each activity on the project that uses water and will likely be larger than the small sample shown.

Table CA-7.1: Sample Water Use Spreadsheet Entries for Different Types of Projects

Project Type	*Urban*	*Rural (Delivered Water)*	*Rural (Well Water)*
Date(s)	6/1/09 - 6/12/09	January - May 2009	August 2009
Construction Activity	Dust suppression	Mixing concrete	Equipment cleaning
Water Volume Used	12,000	27,000	3,500
Volume Unit	Gal	gal	Gal
Measurement Method	City water meter	750 gallon tanks	Hose meter
Water Location/Source	Hydrant	Tank delivery	On-site well
Potable Water?	Yes	No	Yes
Disposal Practice of Unused Water	Stormdrain	Storage	Ground surface
Water Use Permit Type	Hydrant	None	None
Water Cost (per gal)	-	$8.13	$0.08
Water Cost (per ccf)	$4.00	-	-
Total Cost	$64.16	$219,510.00	$280.00
Notes	Hydrant permit fees not included.	Includes delivery charge	-

Some commonly useful conversions for water volume are shown in Table CA-7.2.

Table CA-7.2: Typical Units of Water Volume

U.S. Customary Units	Metric Units (S.I.)
1 cubic foot (cf) = 7.481 gallons (gal)	1 liter (L) = 0.001 cubic meters (m^3)
100 cubic feet (cf) = 1 centum cubic foot (ccf)	1 cubic meters (m^3)= 1000 liters (L)

Example: Monitored Water Sources for Road Construction in the U.S.

- Montana limits water leases for construction to 60,000 gallons/day or 120,000 gallons/day/project (Overcast, 2001). Requests for more water must be accompanied by an analysis of potential adverse effects and a description of planned mitigation actions at the proposed point of diversion.
- Oregon allows public agencies to register a water use for road and highway maintenance, construction; in lieu of a permit for a water right (Oregon Water Resources Department, 2007).
- The City of Bend, Oregon requires hydrant use permits for water measurement, protection of drinking water quality, water system operational protection, and fire hydrant integrity and maintenance. The permits apply to water obtained by normal meter installation, daily fill station use, monthly hydrant meter and backflow units, or custom water supply installation.
- The City of Southlake, Texas regulates water use only during drought conditions.

POTENTIAL ISSUES

1. Tracking water use on roadway construction projects may be unfamiliar to site workers. Training may be necessary to accurately track all relevant water data.
2. Water use for road construction may be regulated by local jurisdictions. Check with authorities to determine water use requirements.
3. Where roadway construction includes the use of non-potable water, there is an obligation to ensure that workplace health and safety is not negatively affected by the use of the water. This must include the management of any risks arising from the use, handling, storage, transport, and disposal of the water at the project site.

RESEARCH

Growing cities are putting stress on available water supplies, and demand for water is growing faster than the human population. A recent government survey showed that, under normal conditions, at least 36 states are anticipating local, regional, or statewide water shortages by 2013, and drought conditions will exacerbate shortage impacts (GAO, 2003). Communities in water-supply-challenged regions of the world have begun to address the ongoing issue of potable (or drinking quality) water use on road construction and maintenance projects (CFV, MAV and IPWEA, 2007). Critical to understanding the issue is to determine exactly how much water is used during roadway construction and maintenance.

Water Uses in Roadway Construction

Water has many uses for roadway construction. However, there is little information available on the amount of water used during road construction. Sand and gravel operations are major users, and cement production relies heavily on water. On-site construction uses of water include: concrete mixing, concrete curing, dust control, construction equipment washing, vegetation establishment, geotechnical borings, adding water to backfill material/soil compaction, pipe flushing and pressure testing, and site clean-up.

Water Sources for Roadway Construction

Typical water sources include natural waterbodies, potable water supply pipelines (e.g., hydrants), non-potable water from stormwater or industrial discharges, and reused water from wastewater treatment plants. Water withdrawals from these facilities may or may not be regulated by the governing jurisdiction. Frequently, water use from public supplies requires a temporary water right or permit allowing the local jurisdiction control over the amount and method of water withdrawn for approved construction uses. Many regions also regulate potential harm to fish from water withdrawal from natural waterbodies. For example, the National Marine Fisheries Service (NMFS) developed intake pumping and screening criteria for fish protection that must be installed, operated, and maintained when protected aquatic species are present (NMFS, 2008). Occasionally, these policies require water systems to measure and account for all water delivered. However, these systems are also likely to be provided by private water suppliers.

Estimates of actual water use by project activity are needed for making more informed water use decisions. To enable information sharing for improved water sourcing decisions, some regions are developing a centralized “Water Atlas” of all alternative water sources, including quality and quantity information, to reduce demand on potable supplies. Also, in development is an “Industrial Waste Water Exchange” to match producers of suitable industrial waste water with users of water for construction purposes, allowing industrial users to have their waste water disposed of and reused, resulting in potentially lower costs for both parties and less overall potable water use. (CCFV, MAV and IPWEA, 2007)

Water Potability and Quality Issues

Large volumes of potable water are commonly used in road construction, but drinking water is subject to competing demands by human populations. Also, many municipalities chlorinate their water supply, and the level of chlorine in chlorinated tap water (as high as 1.0 milligram of chlorine per liter of water) is toxic to fish and other aquatic organisms (Greater Vancouver Regional District, 1997) and may be unsuitable for roadway use without prior mitigation.

Alternative water supplies alleviate demand for potable drinking water through management of related health and environmental risks associated with construction work activities. Brackish and oil-contaminated water show promise for road construction in water-limited regions (Taha et al., 2005; Kansas Department of Health and Environment, 2000). Construction site managers are increasingly harvesting stormwater from their own sites and storing it for later use (Queensland Government, 2007a). Recycled water from municipal wastewater treatment plants is a potable-water substitute for operational and landscaping purposes (Queensland Government, 2007b).

Discharges of construction site water are governed by the Environmental Protection Agency National Pollution Discharge and Elimination System (NPDES) permits, or state or local equivalent policies.

GLOSSARY

Brackish	Water with more salinity than fresh water but less than seawater
Potability	Water that is suitable for human consumption

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CONTRACTOR WARRANTY

CA-8

3 POINTS

GOAL

Incorporate construction quality into the public low-bid process through the use of warranties.

CREDIT REQUIREMENTS

The project construction contract shall include, as a minimum, a 3-year warranty for constructed portions of the pavement structure to include surfacing (e.g., hot mix asphalt, portland cement concrete, etc.) as well as any underlying layers (e.g., granular base material). Other items may also be included in the warranty but are not required to be for this credit.

The terms of the warranty shall be defined by the owner and may include contractor input if desired. As a minimum, the contractual warranty specifications shall include:

- Definition of what product(s) are warranted
- Length of the warranty period
- Responsibilities of the owner
- Responsibilities of the contractor
- Responsibility for maintenance
- Conflict resolution process
- Contractor quality control plan
- Measurement methods
- Performance based requirements and associated threshold levels that require corrective action by the contractor
- Requirements for remedial corrective action
- Requirements for elective or preventative actions
- Basis of payment
- Final warranty acceptance

Details

The intention of this credit is to include a short-term 3-year pavement warranty in the contract specifications. This warranty duration is intended to be long enough to cover any pavement performance issues due to poor quality construction but short enough so as not to create warranty bonding issues associated with contractor assumption of risk for unduly long periods of time.

Ultimately, warranties must meet all applicable local and federal regulations. Federal regulations are described in 23 CFR 635, Subpart D, Section 413, *Guarantee and Warranty Clauses*.

DOCUMENTATION

- A copy of the warranty specifications included in the contract.

RELATED CREDITS

- ✓ PR-4 Quality Control Plan
- ✓ PR-9 Pavement Management System
- ✓ CA-1 Quality Management System
- ✓ PT-6 Pavement Performance Tracking

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Economy
- ✓ Extent
- ✓ Expectations
- ✓ Experience

BENEFITS

- ✓ Increases Service Life
- ✓ Reduces Lifecycle Costs
- ✓ Improves Accountability

APPROACHES & STRATEGIES

Develop a standard warranty policy (or a specific one for the project in question) that has been vetted with industry that includes:

- The types of work to be covered by the warranty (i.e. the surface course or entire pavement section)
- The warrantee guarantee and bonding requirements
- An outlet for conflict resolution for both contractor and owner
- Pavement distress thresholds and remedial action
- Agency Maintenance Responsibilities
- Method of performance based measurement for monitoring the pavement
- Final warranty acceptance
- A selection process of projects for which warranties will be included

The NCHRP Project 10-68 "Guidelines for the Use of Highway Pavement Warranties" final report should serve as an excellent source for viable approaches when released. As of October 2010, it is still in final editing.

Example: Wisconsin Department of Transportation Asphalt Pavement Warranty

NCHRP Report 451 (Anderson & Russell, 2001) describes a standard process model for warranty contracting (Figure CA-8.1) and then shows a case study of Wisconsin Department of Transportation (DOT) warranted asphalt pavements in its Appendix A as an example.

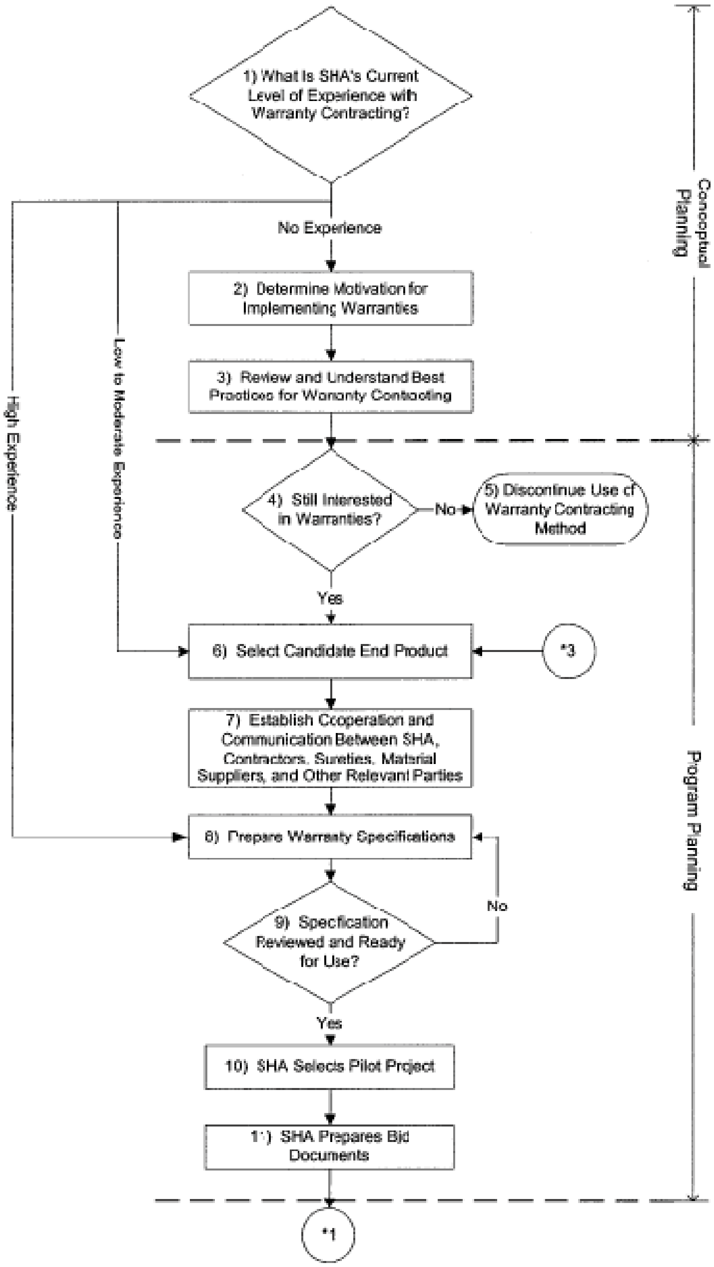

Figure CA-8.1: Flowchart process model for warranty contracting (from Anderson & Russell, 2001).

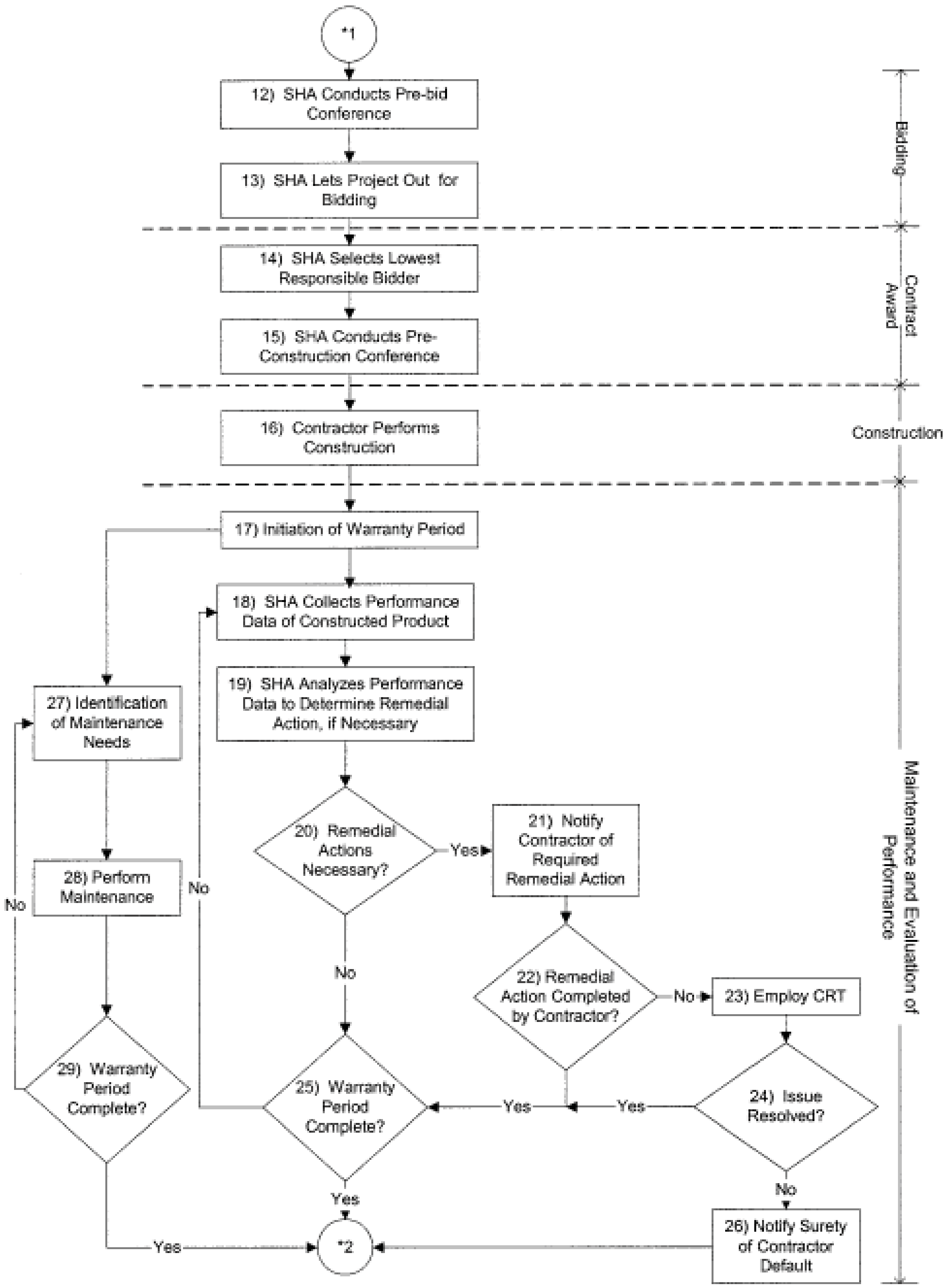

Figure CA-8.1 (continued): Flowchart process model for warranty contracting (from Anderson & Russell, 2001).

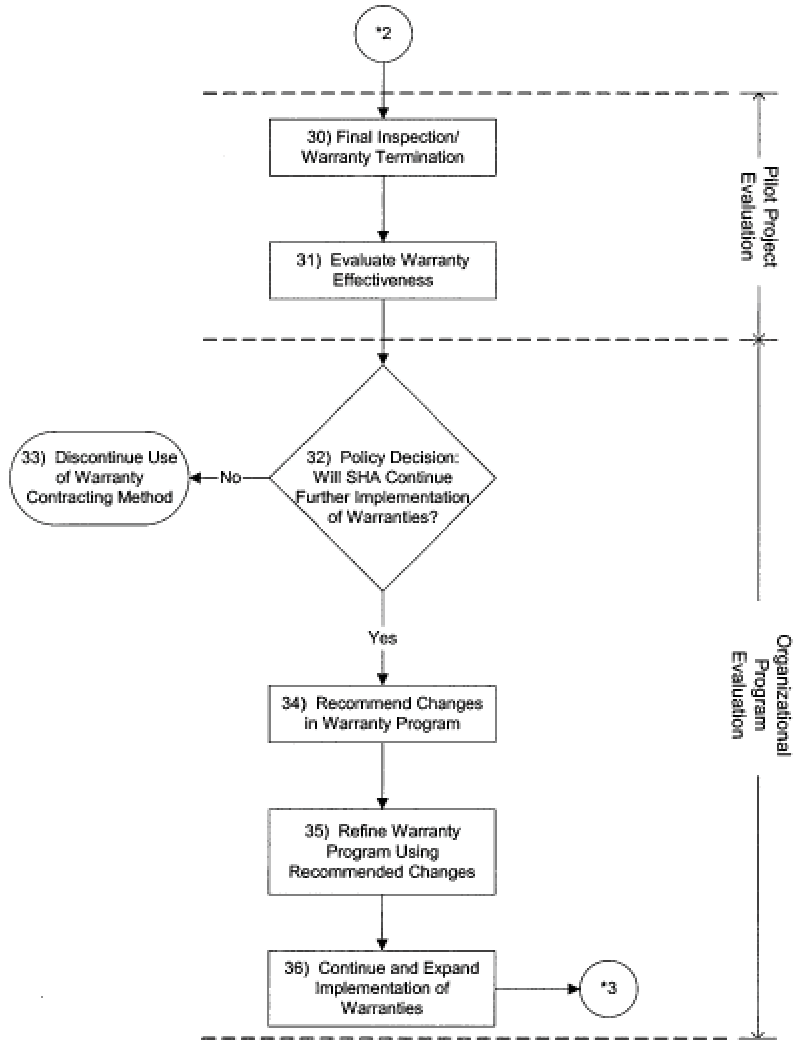

Figure CA-8.1 (continued): Flowchart process model for warranty contracting (from Anderson & Russell, 2001).

Specifics of the case study can be viewed at: http://144.171.11.40/news/blurb_detail.asp?id=5476.

POTENTIAL ISSUES

1. Using a warranty clause in roadway construction contracts is typically a programmatic decision (must be implemented as standard practice within an owner agency) and not a project-specific one.
2. Warranty provisions as a matter of standard practice can reduce contractor competition as sureties decide which contractors to bond and which ones not to. Experience to date has been that bonding for short-term warranties (like the 5-year warranty in this credit) have not been an issue when done correctly.
3. Long-term performance warranties can reduce contractor bonding capacity because of the increased risk they must carry on their books.
4. Warranties are not free. They are generally priced based on the risk or perceived risk they transfer to the contractor.
5. Performance measures on which a completed project is to be judged can be difficult to agree upon. It can also be difficult to firmly establish a link between contractor construction and performance parameter measurement.

6. Instituting a new warranty program can be difficult because of the learning period involved where both contractors and owners adjust to the warranty clause, its implementation and interpretation.
7. A warranty does not guarantee improved quality, however, most research to date cites better quality as an outcome of contractor warranty programs.

RESEARCH

A warranty is a fairly common tool in consumer transactions. Essentially, a warranty is an assurance by the seller that property or goods are as represented or promised. This assurance is often backed by a specifically stated remedy in the event the property or good fails to meet the warranty.

A Brief History

In roadways, warranties have been used in association with pavements for quite some time. The earliest pavement warranties arose in the late 1800s; one example being the 15 year warranty offered by the Warren Brothers Company on their patented Warrenite Bitulithic Pavement (FHWA, 2009). In the 1900s warranties fell out of favor. For instance, prior to 1991 a longstanding FHWA policy used to restricted warranties on federal-aid projects to electrical and mechanical equipment because it was felt that without this restriction federal funds could be used for routine maintenance, which was illegal (FHWA, 2007). In the 1990s pavement warranties began to make a comeback. Rule changes and an evolving view of warranties led to several agencies experimenting with and then using warranties on a regular basis. Although they are still more common elsewhere (e.g., Europe) warranties are common for some owner agencies in the U.S. For other agencies, they are either not used or expressly forbidden.

Reasons for Warranty Use

Warranty use can be viewed as driven largely by two forces: (1) the desire to improve pavement quality and durability, and (2) the desire to reduce owner oversight during construction (AGC, n.d.). The first concern (improved quality) can also be addressed by other non-warranty solutions such as a quality control specification or tighter specifications. Also, a warranty requirement does not directly ensure any greater quality; it only requires a contractor to provide a remedy if certain parameters (e.g., smoothness, cracking, rutting) are not met. As with all warranties, a pavement warranty is priced and bid accordingly. In an extreme situation, a contractor may choose to include the cost of an entire overlay or partial reconstruction into the bid price to mitigate the risk of corrective actions required by the warranty. The second reason (reduced oversight) may not be realized because owner personnel are usually needed to oversee warranted pavements (AGC, n.d.).

Types of Warranties

In general, there are three basic types of pavement warranties:

- **Materials and workmanship**. Almost all construction is covered by a short duration (usually 1 year) materials and workmanship warranty. This type of warranty assigns risk to the contractor for following agency specifications in regards to materials and workmanship. If a problem or defect is detected within the warranty period, the agency usually uses a forensic analysis to determine the cause. If it is determined that specification non-compliance caused the problem, it is repaired at the contractor's expense. Otherwise, the agency assumes repair costs. This type of warranty is almost universal, rarely collected on and is usually covered by sureties at no additional charge to the contractor.
- **Short-term performance**. A warranty based on the performance of the finished pavement product that lasts for 2-7 years. These warranties specify a number of performance parameters that the pavement must meet over time. If they are not met the contractor is required to repair/replace the poor-performing pavement. The general intent of these short-term performance warranties is to place the risk of poor construction on the contractor. In most situations, poor pavement construction will manifest itself in poor pavement condition within about 2-5 years.
- **Long-term performance**. A warranty based on the performance of the finished pavement product that lasts for up to 20 years and beyond. These warranties specify a number of performance parameters that the pavement must meet over time. If they are not met the contractor is required to repair/replace the poor-performing

pavement. These long-term performance warranties essentially make the contractor responsible for maintenance and rehabilitation of the pavement in question.

Benefits and Market Realities of Warranties

Most often, owners pursue warranties because of a perceived benefit. However, the use of contracted warranties also creates a number of market conditions that may or may not negate any perceived benefits. The following is a brief listing of warranty benefits and market realities.

Benefits

Allow evaluation based on performance. Warranty contracts often provide little direction in materials and methods and relay instead on defining performance over time as the key contract element. This allows owner agencies and contractors to concentrate their efforts on end results rather than methods. This aligns owner evaluation of construction with the public perception of the construction as well as allows contractors substantial latitude to innovate since methods are not defined in the contract.

Improved quality. In 2004, Bayraktar et al. (2004) showed 13 states were experienced with warranty contracting with varying degrees of success. Michigan, Ohio, Florida, and South Carolina had the highest amount of warranty contracts each having a 10 to 30 percent of construction contracts containing a pavement warranty. In the same study, 69 percent of the state departments of transportation that responded, noted an improvement in the overall quality of the final product (Bayraktar M. et al., 2004).

Reduced owner risk. Warranties tend to place more of the risk of poor construction on the contractor. Typically, even a poorly constructed pavement is likely to last 1 year (the typical duration of a materials and workmanship warranty) in fairly good condition. With a warranty, an owner can collect from a contractor for poor construction based on pavement condition measured over the life of the warranty.

Inclusion of construction quality in a competitive bid. In most traditional competitively bid design-bid-build pavement contracts, pavement quality is assumed to be a minimum standard to be met rather than the subject of contractor competition. Warranty requirements usually will require contractors to build their perceived cost of the warranty (their price for the risk incurred) into their competitive bid. Therefore, contractors that build high quality pavement and have good knowledge of their construction quality are theoretically able to reduce their bid amount because of a known lower risk. In essence, pavement quality becomes a competitively bid item.

Market Realities (AGC, n.d.)

Limiting competition. Asking contractors to assume risk for pavements after they are built generally means that sureties are required to provide warranty bonds. Sureties can be selective in their issuance of warrant bonds, which may limit competition.

Reduced bonding capacity. The value of the warranty bonds a contractor carries can reduce its bonding capacity, thus limiting the number and value of jobs it can bid. Long-term pavement warranties can especially tax bonding capacity and sureties because the long duration they must be carried. Also, there is considerable pressure on sureties; those who bond contractors. With a warranty essentially holding a contractor at risk for the warranty period, the surety will also be held liable for the warranty period. The requirement of a separate warranty bond has been the common practice for contractors participating in pavement warranty contracts. Sureties have a very different responsibility when evaluating contractors bidding on warranty contracts. Some sureties view the process as a difficult situation. For instance, they are essentially required to predict that the contractors that they insure will be in business for the entire warranty period. For sureties, the major sources of risk when evaluating contractors for warranty projects include warranty period, financial strength, project experience, and past performance (Bayraktar et al., 2006).

Increased cost. Warranties may increase construction costs because (1) higher quality construction may cost more because better materials or more meticulous methods are used, or (2) the cost of warranties are bid into contracts. Ultimately, a warranty transfers risk to the contractor and that risk is priced. The inclusion of a warranty provision can increase contract costs by 5-10% (Bayraktar M. et al., 2004). However, warranties have also led to lower pavement life cycle costs (Singh et al., 2007). Specifically in Indiana, some estimates have shown an increase of over thirty percent in the expected cost effectiveness of a warranty program (Singh et al., 2007).

Difficulty in setting objective performance measures. It is difficult to settle on an objective set of performance measures by which an owner can judge a pavement and determine if defects are due to contractor construction. Typical performance measures can be roughness, rut depth, surface friction and cracking. It is often difficult to establish that such items are directly related to construction quality and not some other factor such as heavier than anticipated loading or poor subgrade.

Difficulting in starting a warranty program. Outside states using warranties regularly, contractor experience is limited. The majority of owner agencies using warranties have seen a similar number of bidders on projects compared to projects without warranties. However, when West Virginia began its warranty program, it had many projects that contained a single bidder (Bayraktar M. et al., 2006). Contractors showed a tendency to either not bid due to being concerned about the risk, or to charge more on a given bid. Ultimately, there may be some time involved where contractors and owner agencies become familiar with the terms of warranties and how these terms are enforced. During this time, it is not uncommon for contractors to bid higher to compensate for increased risk.

State of the Practice

The Federal Highway Administration (FHWA) maintains a website on construction warranties in federal-aid contracts. They also include a subsection on pavement warranties (FHWA, 2009). Table CA-8.1 lists various states with warranty experience in roadway construction.

Table CA-8.1: Warranty Provisions Used by Various States (FHWA 2007)

HMA/Rubberized HMA	3-8 years	AL, CA, CO, FL, IN, ME, MI, MO, MS, OH, NM, UT, WI
HMA Crack Treatment	2 years	MI
PCC Pavement	5-10 years	KY, ME, MI, MS, UT, WI
Bridge Components	5-10 years	WA, ME, NM
Bridge Painting	2-10 years	IN, MA, MD, ME, MI, NH
Chip Sealing	1-2 years	CA, MI
ITS Components/Buildings	2-3 years	VA, NC
Landscaping/Irrigation	1 year	WY
Microsurfacing	2 years	CO, MI, NV, OH
Pavement Marking	2-6 years	FL, MT, OR, PA, UT, WV
Sign Sheeting	7-12 years	WV
Roofing	10 years	HI

For further discussion of warranty contracting, see *NCHRP Report 451 Guidelines for Warranty, Multi-Parameter, and Best Value Contractin*g (Anderson & Russell, 2001).

GLOSSARY

Warranty	A collateral assurance or guarantee by a seller that a property or goods are as represented or promised. This assurance is often backed by a specifically stated remedy in the even the property or good fails to meet the warranty.

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MATERIALS & RESOURCES

LIFECYCLE ASSESSMENT

GOAL

Create new lifecycle assessment information for roads.

CREDIT REQUIREMENTS

Conduct a detailed process-based lifecycle assessment (ISO-LCA) or hybrid economic input-output lifecycle assessment (Hybrid-EIO) according to the ISO14040 standard frameworks for the final roadway design alternative. Include all items on the project bid list in the initial scope of the study before any streamlining of the scope is done. Use primary data for all processes where possible. Where no primary data exists, use the best available data and justify the substitution. Choose at least three impact categories to report for the lifecycle impact assessment (LCIA) from the Environmental Protection Agency (EPA) Framework for Responsible Environmental Decision-Making (FRED: 2000). Use equivalency factors for the impact assessment based on the most current version of the indicator model referenced. FRED is available from the American Center for Life Cycle Assessment here: http://www.lcacenter.org/library/pdf/fred.pdf. Note that some equivalency factors in this document are outdated. See the following MR-1 Research section for more details.

Details

The LCA may be streamlined according to the streamlining process recommendations from the 1999 Society of Environmental Toxicology and Chemistry (SETAC) report "Streamlined Life-Cycle Assessment: A Final Report from the SETAC North America Streamlined LCA Workgroup" (Weitz et al., 1999).

Social impact assessment is not required for this credit, but may be completed if social metrics or indices are appropriate or relevant for the project.

DOCUMENTATION

Copy of the completed LCA. This document should include, at minimum, the following specific information.

- Name and contact information of person(s) who conducted the LCA. Be sure to list any LCA Certified Professionals (LCACP) involved in the project.
- A list of all data sources used, and the input data used. If data is proprietary, list the owner and contact information, and identify all processes included in the proprietary data sets.
- List any material inputs not listed in PR-3 but included in the LCA (these will be non-pavement items).
- Detailed results of the life cycle inventory (LCI).
- Life cycle impact assessment (LCIA) results showing a minimum of three impact categories (i.e. global warming potential, acidification, photochemical smog, human health, etc.) from FRED. List sources of equivalency factors used.
- The data quality score of the final alternative (see MR-1 Research section.)
- A list of the top three contributing processes to the impact categories (based on normalized results, such as annual energy use per American household, etc.)
- A list of all limitations of the study scope and data used.

MR-1

2 POINTS

RELATED CREDITS

- ✓ PR-2 Lifecycle Cost Analysis
- ✓ PR-3 Lifecycle Inventory
- ✓ PR-6 Waste Management Plan
- ✓ EW-4 Stormwater Cost Analysis
- ✓ CA-3 Site Recycling Plan
- ✓ CA-7 Water Use Tracking

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Economy
- ✓ Extent
- ✓ Expectations
- ✓ Exposure

BENEFITS

- ✓ Improves Accountability
- ✓ Increases Awareness
- ✓ Creates New Information

APPROACHES & STRATEGIES

- Create a spreadsheet to capture all of the processes for production of the roadway project and complete an LCA in accordance with the referenced ISO standards.
- Hire a professional third-party consultant if possible to review the project and produce a final LCA report. The benefits: sometimes they have access to some proprietary data and software that is more recent or higher quality than publicly available sources.
- Use an open source software program for LCA. These are becoming more common and are publically available for free via a number of LCA organizations.
- Consider using a hybrid EIO model that incorporates both economic sector data and process-based data.
- Collect primary emissions data wherever possible.
- Use data that is current, local or otherwise project specific to improve data quality for the project LCA model.

Example: Comprehensive Process-Based LCA Approach (Stripple, 2001)

While not a complete LCA because the impact assessment and interpretation steps were not completed, Stripple (2001) provides the best available example to date of what should be considered in a comprehensive roadway lifecycle inventory analysis and impact assessment based on an ISO-LCA model (from SETAC Europe). The lifecycle phases studied were construction, operation, maintenance and associated transportation activities. Extraction activities and traffic were included, but disposal of waste and production of capital equipment were not considered. In a truly comprehensive study, waste generation and recycling activities for most pavements will have a large role in the overall assessment of the roadway. Capital equipment production may also be included but it is not unusual for it to be excluded via the streamlining process.

Following is a list of unit processes (and equipment) that were considered for the inventory analysis within his defined Goal, Scope, and system boundaries (slightly adapted for clarity). (Stripple, 2001)

Table MR-1.1: Example unit processes in Stripple (2001)

• Aggregate production (blasting, crushing) • Aluminium [sic] production • Bitumen production • Cement production • Cement stabilization of base course in concrete road construction • Land clearing of right-of-way • Clearing snow • Cold-mix asphalt production • Concrete production (mixing) • Concrete texturing • Driving diesel maintenance vehicles • Electricity production • Erection and removal of snow posts • Extraction of quarry gravel and sand • Extraction of salt for winter road maintenance	• Felling (trees) • Foundation reinforcement using cement/lime columns • Foundation reinforcement using concrete piles • Freight transportation by sea • Hot-mix asphalt production • Laying of concrete wearing course in concrete road construction • Laying of road markings • Minor operational activities (minor repairs, other) • Mowing of right-of-way • Operating asphalt pavers • Operating asphalt rollers • Operating dump trucks • Operating excavators • Operating the tack coat truck • Operating wheel loaders • Polyethylene plastic production	• Quicklime production • Road marking, sign, lighting, traffic light, other railing and fence production • Salt gritting of road in winter road maintenance • Sand gritting of road in winter road maintenance • Saw cutting joints in concrete • Sealing concrete joints • Steel production • Surface milling of concrete and asphalt paving • Synthetic rubber (EPDM) production • Trench digging in road maintenance • Truck transportation • Washing of road signs • Washing of roadside posts • Wildlife fences • Zinc production

The functional units in the study were:

- The construction, maintenance and operation over a 40 year period of 1 lane-km of road, 13 meters in width, with 0.5m surface course and 1m base course paved with **hot-mix asphalt** and using vehicles for construction and maintenance with low emission diesel engines.
- The construction, maintenance and operation over a 40 year period of 1 lane-km of road, 13 meters in width, with 0.5m surface course and 1m base course paved with **cold-mix asphalt** and using vehicles for construction and maintenance with low emission diesel engines.
- The construction, maintenance and operation over a 40 year period of 1 lane-km of road, 13 meters in width, with 0.5m surface course and 1m base course paved with **concrete** and using vehicles for construction and maintenance with low emission diesel engines.

The results of the inventory analysis for energy use are shown in Figure MR-1.1 below.

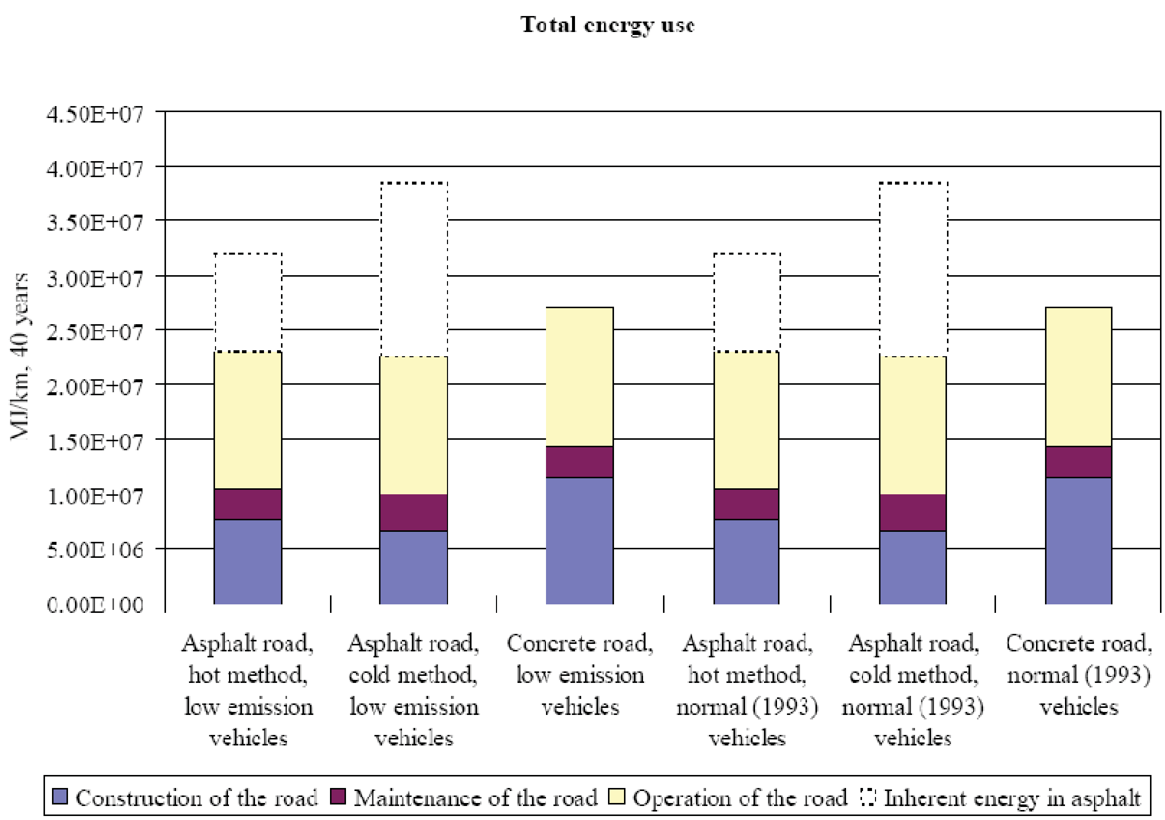

Figure MR-1.1: Results of life cycle inventory analysis for energy of three types of roadways. Dotted lines represent stored energy in asphalt. (Stripple, 2001)

The full report (2nd edition) is available from the IVL Swedish Environmental Research Institute, Ltd. here: http://www3.ivl.se/rapporter/pdf/B1210E.pdf

Example: Impact Assessment for HMA Overlay Using FRED (EPA, 2000; Schenck, 2000)

In their documentation for the FRED tool, the EPA provides a perfectly relevant example of an impact assessment for a roadway product, asphalt cement. The following is taken from Appendix C: Asphalt Coating Case Study and Schenck (2000). The article by Schenck (2000) provides further explanation of how LCA, especially the impact assessment step, can be used to make procurement decisions for road maintenance activities for the Department of Defense.

Goal & Scope of Study

The study modeled a 1.5 inch thick overlay applied with a frequency of 7-9 years over a 20 year time period and estimated the temperature of application at or above 165°F. For purposes of this Example, the inventory and impact assessment results for the water based asphalt emulsion alternative, GSB 88 (gilsonite), are omitted to minimize confusion with the LCIA process that is required for this credit. Note that in general, this was a very simplified life cycle assessment model due to the simplicity of the product itself (EPA, 2000). Explicit data criteria limits ensured that Input and output data was not collected if it represented less than one percent of the total mass, energy, or expected toxicity score contribution (human health and ecosystem health indicators). Table MR-1.2 below shows the processes and material data, sources and types of data collected for the model.

Table MR-1.2: Data Sources for LCA Study (Schenck, 2000; EPA, 2000)

Process or Material Data	Type	Source
Asphalt	Industry Average	Industry Association
Aggregate	Primary	Manufacturer
Diesel (HMA Production)	Primary: surrogate	Applier
Diesel (Construction Vehicle Fuels)	Industry Average	Published Data
Sand	Primary	Manufacturer
Gilsonite	Primary	Manufacturer
Hydrochloric acid (HCl)	Primary	Manufacturer
Water	Primary	Manufacturer
NP-40 (Detergent)	Primary	Manufacturer
Surfactant	Industry Average	Published Data
Light Cycle Oil	Primary	Manufacturer
Land Use (Road, m^2)	Calculated	This study
Land Use (Manufacturing, m^2)	Mixed	Manufacturer, Engr. Estimate

Inventory Analysis

Table MR-1.3 presents the results of the lifecycle inventory analysis for the HMA application only. A zero indicates that a particular raw material was used to make the "Thin Layer of HMA" product.

Table MR-1.3: Summary of HMA Inventory

System Description (Raw Materials)	Thin Layer of HMA (2 Applications) lb/lane-mi/20 yr
Asphalt	122,621
Aggegate	2,181,960
Diesel (Construction Vehicle Fuels)	3,063
Diesel (HMA Production)	884
Sand	0
Gilsonite	0
Hydrochloric acid (HCl)	32
Water	4,779
NP-40 (Detergent)	0
Surfactant	156
Light Cycle Oil	0
Land Use (Road, m^2)	5888
Land Use (Manufacturing, m^2)	<10

Impact Assessment

Table MR-1.4 presents the results of the lifecycle impact assessment for the HMA application only. Notably, the values in Table MR-1.3 above translate through to Table MR-1.4: a zero indicates that a particular value in the inventory analysis was also zero. This is because the MR-1.3 values are multiplied by equivalency factors as defined in the FRED. (Technically, it could also mean that: 1. the equivalency factor assigned to a particular impact was zero though generally an impact with zero equivalency would not be reported (i.e. not studied), or 2. the result could be considered negligible and reported as zero.)

Table MR-1.4: LCIA Results

Impact	**Thin Layer of HMA (2 Applications) lb/lane-mi/20 yr**
Indicator	*LCIA Results*
Global Warming Potential (kg CO_2e)	40,000
Ozone Depletion (kg CFC-11e)	0
Acidification (kg SO_2e)	300
Eutrophication (kg PO_4e)	0.02
Photochemical Smog (kg O_3e)	80
Human Toxicity	
Cancer	0.2
Non-Cancer	5
Ecotoxicity (dimensionless)	2000
Resource Depletion	
Fossil (tons oil equivalent)	90000
Mineral (equivalent tons)	0
Precious metals (equivalent tons)	0
Other Indicators	
Land Use (ha)	0.6
Water Use (m3)	2
Solid Waste (ton)	800

Figure MR-1.2 shows an example of a contribution analysis, where the relative contributions (on a scale of 100 percent) are shown as assigned to each lifecycle stage. A contribution analysis may also be done with the LCIA results to show which processes contribute most to certain impacts.

Indicator	Raw Materials	Manufacturing	Transport	Use	Disposal
GWP	9	76	14	1	0
ODP	0	0	0	0	0
Acidification	13	66	19	2	0
Eutrophication	0	98	2	0	0
Photochemical Smog	20	20	59	0	0
Human Health					
Cancer	12	85	3	0	0
Non-Cancer	9	88	2	0	0
Eco Health	25	47	22	8	0
Resource Depletion					
Fossil	82	16	2	0	0
Mineral	0	0	0	0	0
Precious	0	0	0	0	0
Other Indicators:					
Land Use	0	0	0	100	0
Water Use	0	100	0	0	0
Solid Waste	0	0	0	0	100

Figure MR-1.2: Example contribution analysis for LCIA of asphalt cement. (Schenck, 2000)

Some Notes on Results (Interpretation)

This Example only shows half the picture, but the full LCA was actually completed on both types of maintenance techniques and is explained in Schenck (2000) and the FRED documentation. However, evaluating these two alternatives by comparing the impacts of the two products must take into account the relative data quality available. A few brief examples of notes that might be useful to a reader of an LCA report for the interpretation step follow:

- In Table MR-1.2, secondary data (average data) for asphalt production was used and may not be representative of the actual product studied. Information from the manufacturer for the GSB 88 was from primary sources and may be more representative. If primary data were available for the asphalt, the results may be different than those produced by the model. This is true for many different parts of the data used.
- Close scrutiny of the data in the inventory analysis shows that many of the data values were not available or not reported for either product, as denoted by "NA" in the FRED case study.
- If the FRED case study is compared to the published results of the LCIA, it is clear that there is very high uncertainty in the results because the computed results report up to five significant digits. The amount, for example, of GWP that was computed was 44,368 kg CO2e. That computed level of precision is not reasonable, and the value reported only reflects one significant digit (40,000 kg CO2e).
- It is unclear why the inventory amount reported for "Resource Depletion - Minerals" is 0. This should probably have been documented somewhere.
- It is unclear what the assumed transportation distance was for either product (both in Schenck and the FRED documentation).

Further discussion and the full lifecycle inventory, impact assessment, and interpretation for this EPA case study are available in the FRED guidance document available at: http://www.lcacenter.org/library/pdf/fred.pdf. The reader is referred to that resource to make his/her own interpretations of the case studies provided.

POTENTIAL ISSUES

1. Missing or otherwise unavailable data (such as from proprietary sources). Wherever possible, data should be collected for the project. This includes (but is not limited to) emissions and energy use such as emissions data gathered from at the hot-mix asphalt (HMA) batch plant, amounts of water used in concrete mixes, fuel types, tipping fee receipts, cut/fill volumes, etc. In general, secondary data choices should be based on realistic project-based information.
2. Professional lifecycle assessment may incur an added cost to the project. Projects should budget for this additional cost where possible when planning to attempt this credit.
3. Data management in process-based LCAs can require much manpower, be time consuming, and also high cost.
4. There is no such thing as a simple product. All products and processes are more complicated than humans could ever conceive. LCAs still only present a simplified model of the actual lifecycle. The goal is that the LCA model is realistic and representative, not exact.
5. Stakeholders involved in LCA tend to set system boundaries and conditions to their credit. This can skew or discredit results in some cases. Transparency is a key issue in part, for this reason.
6. Professional lifecycle assessment infers that final results may be proprietary. Verify rights to share this information prior to submitting documentation for this credit. Where possible, use data sources or LCA software that does not incorporate proprietary data unless, adequately referenced and documented for the project. Using OpenSource LCA programs may be able to help avoid such issues.
7. Any uncertainties or assumptions made in the LCA must be clearly specified or documented (per the ISO standards). Additionally, any substitutions or generic data used must be explicitly stated.
8. Allocation procedures used for estimations or assumptions should be transparent and supporting documentation (including references) should be provided (where publishing and proprietary rights permit).
9. Comprehensive lifecycle assessments require detailed attention to data quality.

RESEARCH

This particular credit is available as a supplement to the three related Project Requirements: PR-1 Environmental Review Process, PR-2 Lifecycle Cost Analysis, and PR-3 Lifecycle Inventory. This credit represents both an added step (impact assessment) to the basic process involved in these three credits and an expanded roadway system scope for the inventory analysis step completed for PR-3. PR-2 and PR-3 provide decision-making information about cost and baseline environmental performance (specifically energy use and carbon dioxide emissions) for the roadway pavement section. Similarly, social impact classification and characterization is part of the environmental review process (see PR-1) for many roadway projects, but generally this process will not require or specify the use of any particular social metric (e.g. birth and death rates, obesity rates, productivity rates, etc.) for measurement of these impacts. This credit requires an expanded scope of these three Project Requirements that includes the entire roadway project system as well as an impact assessment step for the project.

Note that an introduction to LCA, its basic framework components, and variety of LCA methods is provided in the Research section of PR-3. This research discussion is supplemental.

Existing Literature

Most existing literature for roadway lifecycle assessments focus on the initial construction and maintenance of pavement sections alone. To our knowledge no studies have completed a full system-wide LCA for a roadway project. However, one study completed by Stripple et al. (2001), has completed a full life cycle inventory (LCI) that incorporates all aspects of a roadway, from production processes of several kinds of pavement all the way to the components of the roadway such as electric utilities and wildlife fencing. This study followed the recommendations for the LCA process by the Society of Environmental Toxicology and Chemistry (SETAC Europe), but is considered an incomplete LCA because the impact assessment and interpretation steps were not done. However, the paper serves as a great example of the first two steps in LCA, but note that the applicability and utility of the primarily European data set is questionable for applications in the United States (i.e. it is difficult to justify substitution of Stripple's inventory data into a non-European LCA study without close scrutiny of his data). However, because SETAC references the same methodology for LCA, namely the International Standards Organization (ISO) 14040 and 14044 standards, this paper is a great example of the framework and approach for this credit. See the first Example in the previous section for more details.

LCA Methodology Steps

A lifecycle is defined as "consecutive and interlinked stages of a product [or project] system, from raw material acquisition or generation from natural resources to final disposal or [end-of life: EOL]" (International Standards Organization: ISO, 2006a). Generally, there are four basic steps to any type of lifecycle assessment. A different interpretation of these steps than that shown in Figure PR-3.2 is shown in Figure MR-1.3 from SETAC. Definition of the goal and scope (the boundaries and extent of the study) will always take place for every LCA project, and the variation in methodology will result from the initial choices made in this initial. Inventory Analysis, the second step, will take place as one of three general types as noted in PR-3. These are briefly:

- Process-Based LCA (also ISO-LCA)
- Economic Input-Output LCA (EIO-LCA)
- Hybrid LCA (also Hybrid EIO-LCA)

Each of these approaches will produce different results for the inventory analysis and in general cannot be compared cross-platform because the processes considered and system boundaries will vary widely.

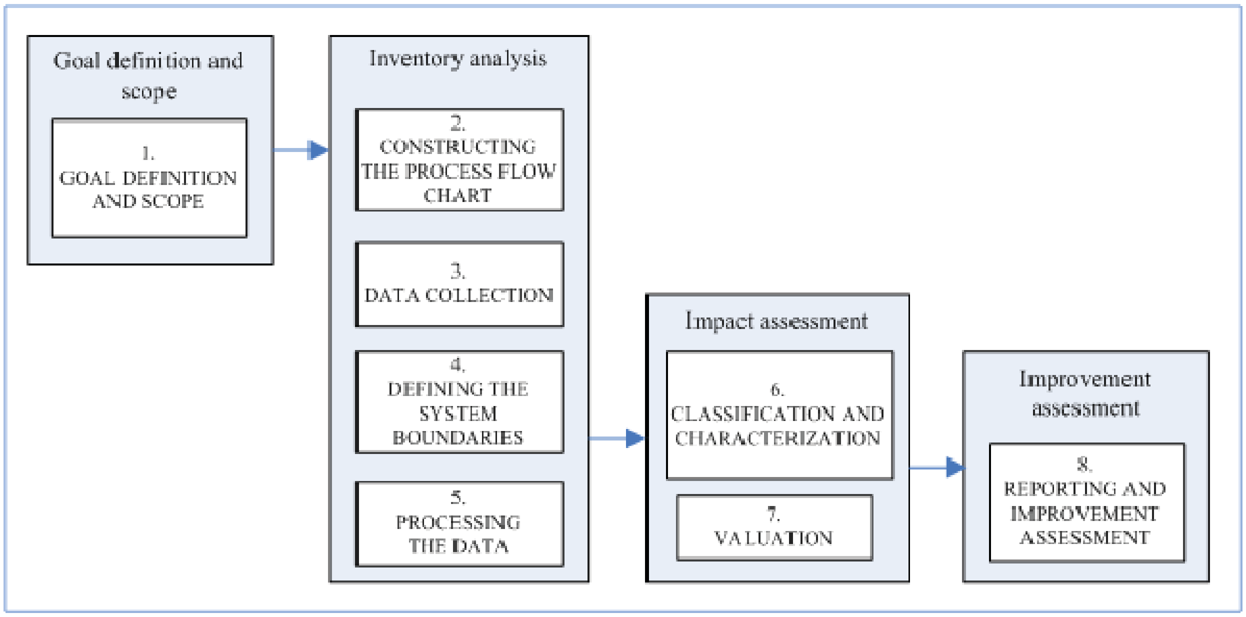

Figure MR-1.3: The framework for Life Cycle Assessment (Consoli, 1993)

The final two steps of the LCA are the impact assessment and interpretation of the results. The impact assessment step involves an assignment or application of subjective values, wherein particular indicators or metrics are chosen to weigh the results of the inventory analysis according to those subjective values. These values also need to be explicitly defined in the goal and scope in order to produce a meaningful result for interpretation. Due to the iterative nature of LCAs, however, it is more practical to state that the interpretation step really happens throughout the entire LCA process, and often results in refining the scope when data is collected and analyzed in the inventory analysis.

Choosing the LCA Model

A **process-based lifecycle assessment** is one that is conducted (usually) according to the standards set by the International Standards Organization (ISO) lifecycle assessment standards, ISO14040 and ISO14044 (2006a, 2006b). The ISO clearly outlines the steps and iterative process behind a technical LCA in both of those standards. The basic idea of a process-based LCA is that everything is made of a sum of different parts. Those parts are also results of different processes. Fundamentally, every part and process needs materials and energy (e.g. "makes") in order to fit together into a whole (e.g. "takes").

For a simple example, making one ton of the product called "hot mix asphalt" ("HMA") is actually the result of taking two materials, "asphalt binder" and "aggregate", through a process that makes HMA, "mixing." So the processes that that the HMA product actually takes are: asphalt binder production (material), aggregate production (material), and HMA mixing (a process).

These three processes could be further broken down into even more specific processes, called "unit processes." For example, "HMA mixing" is composed of "heating," "drum plant operating," and "fuel combustion for heating," etc. The model, and also the data collection requirement, expands as the processes get more specific. Similarly, each of these processes "take" more than just asphalt and aggregate to make HMA: they also require energy from electricity, capital equipment and workers, who also need food and housing, healthcare, a car to drive to work, and so on. If the process-based model were continued and scaled up to include such information, it would become incredibly complex and difficult. Clearly, the scope, system boundaries and purpose of the LCA are key issues.

This scoping issue is somewhat alleviated by **Economic Input-Output LCA** (EIOLCA) models. EIOLCA uses a basis of economic input-output (EIO) analysis to model how sector-based national industries interact and how products are intertwined. LCA was easily combined with EIO data because the computational structure was similar to the EIO approach. EIOLCA uses only publicly available information to determine economy-wide, system-level results instead of process-specific results (Hendrickson et al., 1998). This means that EIOLCA aggregates sector-level of data to quantify the environmental impact contributed directly or indirectly by each sector of the economy. It is typically based on monetary inputs instead of dimensions or mass and outputs a handful of common environmental impacts, depending on the index selected. **This method will not earn Greenroads credit.**

Hybrid LCA is a combination of process-based and EIO-based LCA (Bilec et al., 2006), effectively eliminating most of the disadvantages of either model aside from built-in uncertainties in data. EIO data are usually used for common products or processes, while others are described by the process-based method. Hybrid LCA can be further categorized into following types: tiered hybrid analysis, input-output based hybrid analysis, integrated hybrid analysis, and augmented process-based hybrid analysis (Suh, 2004; Bilec et al., 2006). These types differ in technical details such as how data is allocated or aggregated, where the specific boundaries are drawn between process and EIO analysis, and general data processing techniques.

Streamlined LCA is a proposed method of minimizing data collection efforts at the start of a LCA project by scoping out particular processes through educated assumptions (most of the time). This inevitably leads to a technically non-ISO conformant framework, because valuation is applied at the start, before data has been collected and analyzed. Curran et al. (1996) note that streamlining is really part of a continuum that falls somewhere between the level of detail for an ISO-LCA and an EIO-LCA, and also technically all LCAs are streamlined to some extent due to their iterative nature.

A comparison of the advantages and disadvantages of the common types of LCA are shown in Table MR-1.5. Ultimately it is up to the project team to determine which method will be most appropriate.

Table MR-1.5: Process-Based LCA and EIO-LCA (Expanded from Hendrickson, Lave & Matthews, 2006)

LCA Method	Advantages	Disadvantages
Process-Based LCA (ISO-LCA) *(ISO, 2006a; ISO 2006b)*	• Detailed, process-specific results • Allows for specific product comparisons • Identifies areas in supply chain for improvement (weakest links, or lack of data) • Provides a basis for process-specific information that may be used for other development processes and assessments • Can be done with publicly available data	• System boundaries are subjective (or project-specific) • May be high cost and time intensive • Hard to use when initially developing a process or product • Often use proprietary data • Cannot be replicated if confidential data is used • Uncertainty in data or missing data
EIO-LCA *(Hendrickson et al, 1998; Hendrickson, Matthews & Lave, 2006)* **NOTE:** **METHOD WILL NOT EARN THIS CREDIT. DO NOT USE.**	• Results are economy-wide, comprehensive assessments • Allows for systems-level comparisons • Provides information on every commodity in the economy • Provides a basis for information that may be used for other future development of products and processes and assessments • Can be done with publicly available data	• Product assessments contain aggregate data (such as food that feeds workers and the wood that makes their housing) • Process assessments are difficult • Must link monetary values with physical units • Economic imports are treated as products created within economic (region, state or country) boundaries • Lack of complete data for environmental effects • Difficult to apply to an open economy (with substantial non-comparable imports) • Uncertainty in data

LCA Method	Advantages	Disadvantages
Tiered Hybrid LCA *(Suh & Huppes, 2005)*	• Combines process and EIO data to produce more representative result • Facilitates inventory analysis • Reduces data collection time • Incorporates advantages from both ISO and EIO models	• Double-counting errors may be present in results • May omit important processes • Does not always model interaction between process and I-O data appropriately • Incorporates some disadvantages from both ISO and EIO models
Hybrid EIO *(Treloar, 1997; Joshi, 2000; Crawford, 2008)*	• Combines process and EIO data to produce more representative result • Disaggregates I-O key sectors and substitutes detailed economic information • Incorporates advantages from both ISO and EIO models • Use and disposal phases are addressed manually instead of by sector • Fills process data gaps where previously no information existed	• Requires iteration • Incorporates some disadvantages from both ISO and EIO models • Substitution of IO data for missing processes may reduce model reliability
Integrated Hybrid *(Suh, 2004; Bilec et al., 2006)*	• Combines process and EIO data to produce more representative result • Incorporates advantages from both ISO and EIO models • Connects process and EIO models in matrix • Eliminates need for tiered analysis • Addresses interactions between sector and process data • Consistent computational framework • No double counting	• Incorporates some disadvantages from both ISO and EIO models • Computationally complex • Difficult to learn • Data intensive • Time intensive
Augmented Process-Based Hybrid *(Guggemos, 2003; Guggemos & Horvath, 2005)*	• Starts with process data and system and scales up • Uses economy as ultimate system boundary • Uses mostly process data	• Incorporates some disadvantages from both ISO and EIO models
Streamlined LCA *(Curran et al., 1996; Weitz et al., 1999)*	• May save money • May save time • Requires reasonable data management efforts • Processes assigned significance early in scoping and align with goals of study • Provides focused assessment	• Excludes upstream and/or downstream processes • Limits raw material input considerations • Results may be more subjective due to weighting assigned early (by scoping out processes or data requirements) • May ignore important impacts unintentionally • May result in reporting incomplete results to public

Additional Notes on LCIA: FRED Framework

Equivalency factors for impact classification and characterization for this Greenroads credit are provided by the Environmental Protection Agency's (EPA) Framework for Responsible Environmental Decision-Making (FRED) (EPA, 2000). The factors are subdivided into eight categories and three general types of flows are investigated: (1) emissions to air, (2) emissions to water, and (3) resource depletion (includes raw materials, fuels, water and land). We recognize that there are a number of metrics, indicators and indices available for use; the FRED framework is flexible, broadly applicable, comprehensive, and documented respectably. Currently this is the most transparent and flexible tool that is publicly available for impact assessment.

FRED is based on a variety of different indicator tools or metrics that have been developed by different institutions, and reflect global averages or indicators. However, documentation for some of the indicators used in the tool has not been updated, likely due to lack of funding. The user may consult those individual sources in order to check for updates, determine applicability, or substitute regional and local indicator values where appropriate (EPA, 2000). “The designers of FRED consider impact model selection to be an iterative process. As the science and the data supporting the science [develop], newer, more environmentally relevant models will gradually replace the current models” (EPA, 2000). Some other limitations of the FRED tool are provided explicitly in the documentation. Notably, any data uncertainties in the established equivalency factors that are used within the tool itself are inherent issues. Also, FRED does not include any social or economic impacts.

Greenroads has provided some suggested resources to use in place of those listed in the FRED documentation. Either may be used in support of this credit (the process is what we are looking for here), but references for the selected indicator must be cited to earn this credit. Table MR-1.6 (next page) lists the FRED impact categories with some typical examples that would be found in an LCI and used in the impact assessment. Note that this is only a sample, and that the FRED documentation provides a number of chemical compounds to track.

Note that ideally FRED is designed to compare two or more products that have the same functional unit. The utility of completing an impact assessment for just one single project is that there is not necessarily any established industry average in terms of environmental performance that can be used for comparison of pavements. This credit aims to help develop this information in a systematic way by using the framework provided for impact assessment by the EPA’s FRED tool. Results of the impact assessment may therefore not be suitable for evaluative purposes (EPA, 2000), however, this does not mean that two different design alternatives should not be compared using LCA. For reporting purposes in this Greenroads credit, we just want to know about the final design alternative.

Other LCIA Tools

- Another EPA tool, the Tools for Reduction and Assessment of Chemical and Other Releases (TRACI), is no longer available from the EPA. As of this writing, we understand that this tool is currently being updated. (EPA, 2008).
- Commonly used proprietary software tools may have built-in impact assessment indicators, such as GaBi and SimaPro. These tools often report a single value for all impacts (an index) that does not necessarily disaggregate contributions to that index from each impact or process, and may not be appropriate for use in this credit because the weighting can lack transparency.
- Other tools for impact assessment are available through the National Institute of Science and Technology (NIST), such as the BEES (Building or Environmental and Economic Sustainability) tool. The caveat with BEES is that it is mostly used in the building industry, so valuation and weighting systems used by NIST impact assessment tools may not be adequate for weighting impacts of pavement or infrastructure projects without further adjustment and review. Also, this software tool generates only one index as a “score” instead of reporting disaggregated impacts.

Table MR-1.6: FRED Impact Categories and Indicator Models for the FRED LCA System (EPA, 2000)

Impact Category	Impact Indicator Model/Source	Indicator*	Example LCI Data Needed for Model	Greenroads Comment
Global Warming Potential	Intergovernmental Panel on Climate Change (IPCC)	CO_2e (kg)	Carbon dioxide (CO_2) Nitrous oxide (N_2O) Methane (CH_4) Halons	Recommend using updated equivalency factors from IPCC 2007 FAR (Solomon et. al.), especially for CH_4, N_2O. Others are less prevalent in roads/paving.
Stratospheric Ozone Depletion	World Meterological Organization (WMO)	CFC-11e	Methyl bromide Chlorofluorocarbons (CFCs) Hydrofluorocarbons (HCFCs)	Recommend using updated indicator for equivalency factors: Effective Equivalent Stratospheric Chlorine concentration (EECl, EESC). See EPA's 2006 *Air Quality Criteria for Ozone and Other Photochemical Oxidants*
Acidification	Chemical Equivalents	Acidification Potential (AP)	Ammonia Nitric oxide Nitrogen dioxide Sulfur dioxide	
Photochemical Smog	Empirical Kinetic Modeling Approach (EKMA)	Maximum Incremental Reactivity (MIR)	Acetone Carbon Monoxide Formaldehyde Alkanes Aromatics (VOCs) Napthalenes	Recommend using a box or Eulerian model and MIR values from Carter (2009) with binned reactivities based upon n-alkane, iso-alkane, cyclo-alkane, aromatics and napthalenes. See also Leuken and Mebust (2008).
Eutrophication	Redfield Ratio	PO_4e (kg)	Phosphates Nitric oxide Nitrates Ammonia	
Human Health	University of California, Berkeley (UCB) TEPs	Benzene TEP (cancer) Toulene TEP (non-cancer)	Toxic chemicals	Recommend using current data from the Environmental Defense Fund (EDF) Scorecard and UCB TEPs as shown in FRED documentation. See also McKone and Hertwich (2001) and Hertwich et al. (2006)
Ecological Toxicity	Research Triangle Institute (RTI) LCIA Expert (Version 1)	N/A	Toxic chemicals	Recommend RTI model and data from EPA's ECOTOX database to determine specific weighting as shown in FRED documentation (EPA, 2000; 2010)
Resource Depletion	Life Cycle Stressor Environmental Assessment (LCSEA) Model by Scientific Certification Systems	Mass, volume (water) or land area	Various	Recommend using computed "resource depletion" equivalency factors using updated SCS -002-2008 (Draft) as shown in FRED document (EPA, 2000; SCS, 2008)

Data Quality

The most important step in the interpretation phase of the LCA is the identification of the data quality and statement of uncertainties. Quality of data used in an LCA can be evaluated during the interpretation stage of the LCA using data quality scores. For this credit, each piece of data should be rated with numbers 1 to 5 and scored according to the criteria set forward by the University of Washington Design for Environment Lab (College of

Engineering, Department of Mechanical Engineering, under the direction of Dr. Joyce Cooper), based on ISO14040:2006 requirements. The scoring is shown in Table MR-1.7.

Table MR-1.7: Data quality scores (DQS) by the University of Washington Department Of Mechanical Engineering Design for Environment Lab (Cooper et al., n.d.)

Score ID	ISO14040 Data Quality Indicators	Supporting Information	Scoring Method
DQS1	Time-Related Coverage Data (i.e. data age)	Start date of valid time span End date of valid time span	Deviation from intended period (difference in years to year of study) 1. Less than 3 years 2. Less than 6 years 3. Less than 10 years 4. Less than 15 years 5. Age of data unknown or more than 15 years
DQS2	Geographical Coverage	Area and country names	Deviation from intended area 1. Data from study area 2. Average data from larger area which includes study area 3. Data from area under similar production conditions 4. Data from area with slightly similar production conditions 5. Data from unknown area or area with different production conditions
DQS3	Technology Coverage	Technology description Included processes Extrapolations	Deviation from intended technology 1. Data from enterprises, processes and materials under study 2. Data from processes and materials under study but different enterprises 3. Data from processes and materials under study but different technology 4. Data on related process and materials but same technology 5. Data on related process and materials but different technology
DQS4	Precision, completeness, and representativeness of the data	Sampling procedure Number of samples Absolute sample volume Relative sample volume Extrapolations Uncertainty adjustments	Representativeness for intended process 1. Very high (data represent all aspects of system under study) 2. High (data represent a majority subset of the system under study) 3. Moderate (data represent a minority subset of the system under study) 4. Low (data represent an example of the system under study) 5. Very low or unknown (the extent to which the data represents the study is unknown)

Score ID	ISO14040 Data Quality Indicators	Supporting Information	Scoring Method
DQS5	Consistency and reproducibility of the methods used throughout the LCA	Description of method for data collection and data treatment	1. Very high (data are based on direct measurements using a widely accepted test method or on sound engineering models representing the current technology and have been extensively peer reviewed. Also, the source provides a transparent account of the assumptions made.) 2. High (although the data are based on a generally sound test method or model and the source provides a transparent account of the assumptions made, the data are dated or lack enough detail for adequate validation or have not been extensively peer reviewed) 3. Moderate (data are based on an unproven or new methodology or are lacking a significant amount of background information) 4. Low (data are based on a generally unacceptable method, but the method may provide an order-of-magnitude flow) 5. Very low or unknown (data are based on an unknown method, but the method may provide an order-of-magnitude value of the flow)
DQS6	Sources and their representativeness	References used for data collection and data treatment	Type of reference 1. Data from reviewed source 2. Data from public written source (not reviewed) 3. Data from closed written source (not reviewed) 4. Other sources 5. Unknown source
DQS7	Uncertainty of the information	Mean value Standard deviation Uncertainty type Description of strengths and weaknesses (e.g. occurrence of data gaps)	Coefficient of variance 1. Below 10% 2. 10-25% 3. 25-50% 4. 50-100% 5. Over 100% or unknown

GLOSSARY

CO2	Carbon dioxide
CO2e	Carbon dioxide equivalent emission
-e	Equivalent
EIO	Economic Input-Output
EIO-LCA	Economic Input-Output for Life Cycle Assessment
EOL	End-of-life
Functional unit	The quantified performance of a product system for use as a reference unit (ISO, 2006a)
Hybrid LCA	A type of LCA that combines both process-based and economic input-output models
ISO	International Standards Organization

ISO-LCA	Process-based LCA
LCA	Lifecycle assessment
LCCA	Lifecycle cost analysis
LCI	Lifecycle inventory analysis
LCIA	Lifecycle impact assessment
Lifecycle	consecutive and interlinked stages of a product [or project] system, from raw material acquisition or generation from natural resources to final disposal or [end-of life: EOL] (ISO, 2006a)
Lifecycle assessment	Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its lifecycle (ISO, 2006a)
Process-based LCA	An LCA conducted according to ISO Standard 14040
Reference flow	The measure of the outputs from processes in a given product system required to fulfil [sic] the function expressed by the functional unit (ISO, 2006a)
SETAC	Society of Enviornmental Toxicology and Chemistry
Streamlined LCA	Identification of elements of an LCA that can be omitted or where surrogate or generic data can be used without significantly affecting the accuracy of the results (Weitz et al., 1999)
System boundary	Set of criteria defining which unit processes are part of a system (ISO, 2006a)
Unit process	Smallest unit considered in the lifecycle inventory analysis for which input and output data are quantified (ISO, 2006a)

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PAVEMENT REUSE

MR-2

1-5 POINTS

GOAL

Reuse existing pavement and structural materials.

CREDIT REQUIREMENTS

Reuse at a minimum, a percentage of existing pavement materials or structural elements by estimated volume or weight as shown in Table MR-2.1. The materials considered in volume calculations can include but are not limited to hot mix asphalt (HMA), portland cement concrete (PCC), unbound granular base material, stabilized base material, reinforced concrete, structural steel, and timber. In general, pavement materials will be easier to calculate by volume while structural materials should be calculated in terms of weight, unless material volumes are adjusted for density.

Table MR-2.1: Points for Estimated Volume or Weight of Reused Materials

Credit MR-2 Points	1	2	3	4	5
% Reuse of Existing Pavement Materials or Structural Elements	50	60	70	80	90

Details

"Reuse" is defined as a continued use or repurposing of existing materials within the project limits. Specifically, this means the material in question has not been transported beyond the project limits at any time during project construction and that it has been minimally processed or changed from its original condition.

This definition differentiates "reuse" from "recycle." Pavement reuse methods are intentionally used to extend the life of the existing pavement structure in place. Similarly, in most cases, reuse of structures, such as bridges or retaining walls, is typically known as a "retrofit," where specific methods are implemented to extend the life of the existing structure in place. Reused materials may be used in place, or they may be temporarily removed from their original location if:

1. The materials substantially remain in the same condition as they were removed.
2. The materials are replaced in the same location on the project or are moved to a new location on the project and repurposed without processing.

"Retrofit" is defined as the reinforcement of structures to become more resistant and resilient to the forces of natural hazards and other environmental factors such as aging and weathering. It involves the consideration of changes in the mass, stiffness, damping, load path and ductility of materials, as well as radical changes such as the introduction of energy absorbing dampers and base isolation systems.

"Recycle" is defined as recovering a portion of a used product or material from the waste stream for reprocessing and/or repurposing with minimal or no transport offsite or within the project limits. A "recycled material" is any material, from any project, that has been:

1. Processed at a location outside of the roadway project limits
2. Processed at a location inside of the project limits, but substantially displaced or otherwise moved or removed from its existing location specifically in order to process the material, such as temporary or mobile on-site recycling facilities.

RELATED CREDITS

- ✓ PR-2 Lifecycle Cost Analysis
- ✓ PR-9 Asset Management Plan
- ✓ MR-3 Earthwork Balance
- ✓ MR-4 Recycled Materials
- ✓ PT-1 Long-Life Pavement
- ✓ PT-6 Pavement Performance Tracking

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Economy

BENEFITS

- ✓ Reduces Raw Materials
- ✓ Reduces Fossil Fuel Use
- ✓ Reduces Air Emissions
- ✓ Reduces Greenhouse Gases
- ✓ Reduces Solid Waste
- ✓ Reduces Manmade Footprint
- ✓ Increases Service Life
- ✓ Reduces Lifecycle Costs

3. Material from any outside source that has been repurposed for use on the roadway project, even if salvaged and still its original condition.

"Existing pavement material" is defined as all material within the project limits in the existing pavement structure (including surfacing and base material). This includes travelled lanes and shoulders, and pavement structures for physically separated bicycle and pedestrian pathways.

"Existing structural material" is defined as all material within the project limits in existing non-pavement structures such as bridges (including overpasses), retaining walls, and stormwater infrastructure such as vaults, pipes and culverts. All existing structural materials include their foundations, for which volumes may be difficult to estimate. Where actual weights are not available, reasonable estimates may be used or volume may be estimated. To compute volume of hollow structural sections such as prefabricated members or corrugated steel, estimate the mass of the material and adjust for material density to determine volume. Note that for typical reinforced concrete sections, the steel does not need to be separated from the composite section for purposes of volume calculations and a composite density may be used.

In order to achieve credit, some activity must be done to either the pavement or a structure such that the materials or assembly is improved or upgraded in some way. Cleaning, regular maintenance and minor repairs done as part of routine operations and maintenance do not qualify for this credit.

This credit is NOT appropriate for construction of an entirely new roadway or bridge replacement, nor does it apply to materials in existing subgrade (natural in-situ material), fill material or sidewalks that are not explicitly part of the pavement structure or structural element. Additionally, this reuse credit does not include minor structural elements such as luminaires, signs, or signals because they do not make up a significant amount of the total volume of materials on the project and they do not bear regular loads of people or vehicles.

This credit IS appropriate for:

- Pavement rehabilitation actions that place new material over the existing pavement structure such as hot mix asphalt (HMA) overlays, PCC overlays (either bonded or unbounded) and pavement surface treatments (e.g., chip seals, slurry seals).
- In-place reprocessing operations (even though some are referred to as "recycling") such as hot in-place recycling, cold in-place recycling, full depth reclamation, portland cement concrete (PCC) crack-and-seat and rubblization.
- Repurposing of existing material for other purposes in the same project. The material must not leave the project boundary to be considered. If it does leave the project boundary it may still be considered in the Recycled Materials credit.
- Any of several bridge retrofit methods:
  - Stainless steel wire mesh (SSWM) composites
  - Full height steel jackets
  - Elastomeric bearings
  - Steel restrainer cables
  - Shear keys
  - Fiber reinforced polymers (FRP) wraps
  - Shape memory alloy (SMA) devices
  - Metallic and viscoelastic dampers
  - Pipe seat extenders
- Reuse and repairs of structural foundations
- Retaining wall retrofits such as leveling, seismic retrofits, and slope stabilization methods that leave a majority of the original wall in place.

DOCUMENTATION

A calculation that shows the computed percent of material reused including the following four items at minimum:

1. Total volume of existing pavement structure
2. Total volume of reused pavement structure
3. The computed percentage of the total reused volume, and
4. A short written description of how the structure was reused.

APPROACHES & STRATEGIES

- Where feasible, undertake pavement preservation efforts (e.g., overlays, diamond grinds, etc.) that preserve a majority of the existing pavement structure. Pavement structure should not be reused if its engineering properties are inadequate for the pavement's intended function. In this instance, this credit serves as a reward for an agency maintaining an active pavement preservation program that addresses deteriorated pavement early enough so as to avoid a total reconstruction as the only viable remedy.
- Use in-place recycling techniques such as hot in-place recycling, cold in-place recycling and full depth reclamation. These methods qualify as reuse because the material has not crossed project boundaries.
- Use a crack-and-seat or rubblization option for deteriorated PCC rather than removing and replacing the existing PCC. Such operations usually involve paving additional structure over the cracked-and-seated or rubblized PCC; therefore, additional considerations would be bridge clearance, drainage flows and matching grades for cross-streets, ramps and other access roads.
- Retrofit or refurbish existing structures. There are a variety of methods available for retrofits depending on existing issues.
- Perform a lifecycle cost analysis of retrofit options for bridges when considering design alternatives.
- Reuse the pavement on bridges where it exists.
- Plan to reuse foundations because it reduces environmental impacts, especially for in-water work.
- Reuse subassemblies and components of structures if the entire structural element cannot be reused.
- Evaluate the structural condition of existing elements such as bridges and retaining walls. This is typically determined by a structural engineer. Do not reuse elements that have been damaged by corrosion or natural hazards without review by a structural engineer.
- Where structural elements are determined to be inadequate for reuse, consider salvaging them or deconstructing them for use on another project or purpose.

Example: "Reuse" versus "Recycle"

Greenroads makes a distinction between the terms "reuse" and "recycle." The following discussion provides more details for distinguishing between the two.

Reused materials: These materials originate from within the project limits and are either maintained in place (such as existing pavement structure) or disturbed/removed but are not transported outside the project limits. Examples include:

- Overlaying an existing pavement structure with new pavement material. The existing structure is counted as reused material. This is specific to pavements since, for instance, a stop sign that remains undisturbed during a roadway project does not count as being reused.
- Removing crushed aggregate base course from one location and reusing it as crushed aggregate base course in another location within the project.
- Hot in-place recycling (HIR). The processing and treatment of an existing HMA pavement section (usually 1-2 inches of the surface only). Treatment involves heating the existing HMA surface, the addition of bituminous and/or chemical additives and, often, some additional new HMA. The existing pavement materials remain in place and essentially serve their original purpose.

- Cold in-place recycling (CIR). The processing and treatment with bituminous and/or chemical additives of an existing HMA pavement section without heating to produce a restored pavement layer. The existing pavement materials remain in place and essentially serve their original purpose. In many cases the resultant product is used as a stabilized base course that may or may not be subsequently overlaid with a new surface course.
- Full-depth reclamation (FDR). The processing and treatment with bituminous and/or chemical additives of an existing HMA pavement (may also include base material) without heating to produce a restored pavement layer. The existing pavement materials remain in place and essentially serve their original purpose. In many cases the resultant product is used as a stabilized base course that may or may not be subsequently overlaid with a new surface course.

Recycled materials: These materials may originate within or external to the project limits and are diverted from final disposal (i.e. landfill) and are reprocessed or repurposed for use in the project. The essential difference between “recycling” and “reuse” is that recycling involves reprocessing/repurposing and, usually, substantial transportation (usually to and from the reprocessing facility and sometimes to and from the project site). Also, a recycled material can often originate from outside the project limits before use on the project, whereas reused material does not. Examples include:

- HMA from the project in question or another project, commonly called reclaimed asphalt pavement (RAP), is transported to a storage location or HMA plant location and included as a constituent of a new HMA mixture for the project in question.
- An existing concrete structure from the project in question or another project is demolished and crushed into an appropriate gradation and used as a crushed aggregate base material or an aggregate component in new PCC on the project in question.
- An industrial byproduct (e.g., coal fly ash, silica fume, ground granulated blast furnace slag) is incorporated as a component in a new material (e.g., PCC).
- Diverted waste material (e.g., discarded rubber tires, crushed glass) is incorporated as a component in a new material (e.g., HMA, PCC).

Example: What Is and What Is Not “Existing Pavement Structure”

Figures MR-2.1 through MR-2.4 show examples of what should and should not be included in this calculation.

- Figure MR-2.1: This bicycle path should NOT be counted as existing pavement structure because it is a separate bicycle/pedestrian path that is not accessible to automobiles.
- Figure MR-2.2: This bicycle lane should be counted as existing pavement structure because although it is marked as a bicycle lane, it is accessible to automobiles. Specifically, it must be crossed by vehicles accessing curbside parking.
- Figure MR-2.3: This paved median should NOT be counted as existing pavement structure because it is separated from the travelled way by a curb structure and is not accessible to automobiles.
- Figure MR-2.4: This paved median area should be counted as existing pavement structure because it is accessible to automobiles even though the double yellow line implies that they should stay out.

Figure MR-2.1: A bicycle path in Auburn, AL.

Figure MR-2.2: A bicycle path as part of the roadway (image from Google Maps).

Figure MR-2.3: A paved non-accessible median (image from Bing Maps).

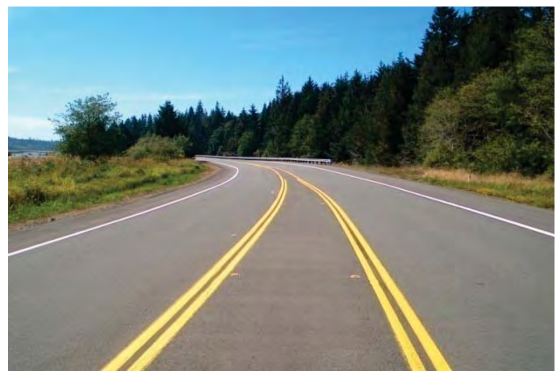

Figure MR-2.4: A paved accessible median on US 101 in Washington State.

Example: Calculation for Widening an Existing Roadway

Description: Four miles of an existing two-lane road with 12-foot wide lanes and no shoulders is to be widened to include a 10-foot wide two-way left turn lane and 8-foot shoulders. The existing pavement structure consists of 5 inches of HMA over 8 inches of crushed aggregate. The existing pavement is kept in place except that the top 1.5 inches of HMA is removed by a milling machine. New pavement of the same structure is built on either side of the existing pavement structure to accommodate the wider final alignment.

Calculation logic: All 8 inches of the base material and 3.5 inches of the HMA are reused. The 1.5 inches removed by the milling machine is not considered “reused.” If it is recycled then it may qualify for consideration under MR-4 Recycled Materials.

Calculation:
Total volume of existing pavement:

$$(24\ ft)(5\ inches\ +8\ inches)\left(\frac{1\ ft}{12\ inches}\right)(4\ miles)\left(\frac{5{,}280\ ft}{mile}\right)\left(\frac{1\ yd^3}{27\ ft^3}\right)=20{,}338\ yd^3$$

Reused volume of existing pavement:

$$(24\ ft)(3.5\ inches\ +8\ inches)\left(\frac{1\ ft}{12\ inches}\right)(4\ miles)\left(\frac{5{,}280\ ft}{mile}\right)\left(\frac{1\ yd^3}{27\ ft^3}\right)=17{,}991\ yd^3$$

Percentage of existing pavement reused:

$$\frac{17{,}991\ yd^3}{20{,}338\ yd^3} = 0.88 = 88\%\ reuse$$

This project would qualify for **4 points**.

Example: Calculation for Bridge Retrofit Project – State Route 99 Aurora Bridge

Description: The landmark Aurora Bridge in the City of Seattle was built in 1932 and has undergone several rehabilitation activities. Currently, it is scheduled for additional retrofit of 18 of its 48 unique columns, as well as its supporting trusses, girders and beams starting in late 2010. The columns are “cruciform” shaped, which makes it difficult to use traditional retrofit options such as steel column jackets. The Washington State Department of Transportation intends to spend $2.1 million to complete the upgrade the seismic capacity of the bridge.

Figure MR-2.5: Aurora Bridge, Seattle, WA (Photo Courtesy of WSDOT)

Calculation logic: The entire bridge structure is to remain in place for the planned 2010 retrofit, therefore 100% of it is reused.

Calculation: None needed. All existing structural materials are reused.

This project would qualify for **5 points**.

Example: Calculation for Bridge Retrofit Project – State Route 104 Hood Canal Bridge

Description: The Hood Canal Bridge is the longest floating bridge over saltwater in the world. At 1.5 miles, the bridge is comprised of two approaches, two transition spans and 36 pontoons. The west “half” of the bridge has 19 pontoons and the east has 17. The west approach span of the bridge and some of the existing pontoon structures were retrofitted. This portion of the bridge had been replaced in 1982 after sinking in 1979. The east “half” of the bridge was completely replaced with construction completing in early 2010.

Calculation logic: Use weight as an indicator for actual material volume of the pontoons. (Total volume of materials can be computed from WSDOT data, but density information is not available.) The east portion of the bridge (17 pontoons) weighs 107,111 tons with an approach slab weighing 3,800 tons. The west portion of the bridge weighs 127,817 tons with an approach slab weighing 1,000 tons. There are two transition spans (steel truss) that are 800 tons each.

Calculation: Compute the total weight of the bridge.

$$[107{,}111 + 127{,}817 + 3{,}800 + 1{,}000 + 2(800)] = 241{,}328 \text{ tons}$$

Compute the total weight of the retrofitted sections. (Note this calculation presumes 100% of the west half features were retrofitted for ease of calculation.)

$$[127{,}817 + 1{,}000 + 800] = 129{,}617 \text{ tons}$$

Compute the percentage of the total bridge weight of the retrofitted section.

129,617 tons/241,328 tons = **53.7%**

This project would qualify for 1 point. Additionally, the pontoons were sold to a company in Canada and they have been reborn as marina structures. The replaced bridge trusses were not able to be reused but were salvaged for scrap.

Figure MR-2.6: Hood Canal floating bridge retrofit and replacement project. (Photo Courtesy of WSDOT)

Example: Calculation for Preservation Overlay of an Existing HMA Pavement

Description: Six miles of an existing four-lane highway with 12-foot wide lanes and 8-foot shoulders is to be overlaid with 2 inches of additional HMA. All of the exiting pavement structure is to remain in place.

Calculation logic: All of the existing pavement structure is to remain in place therefore 100% of it is reused.

Calculation: None needed. All existing pavement is reused.

This project would qualify for **5 points**.

Example: Calculation for Rubblization of an Existing PCC Roadway

Description: Three miles of a four-lane highway with 12-foot wide lanes and 8-foot shoulders is to be rubblized and overlaid with 6 inches of HMA. The existing pavement structure across all lanes and shoulders consists of 9 inches of PCC over 12 inches of crushed aggregate.

Calculation logic: All of the existing pavement structure is to remain in place therefore 100% of it is reused.

Calculation: None needed. All existing pavement is reused.

This project would qualify for **5 points**.

Example: Calculation for Hot In-Place Recycling of an Existing HMA Roadway

Description: Two miles of a two-lane highway with 12-foot wide lanes and 4-foot shoulders is to be hot in-place recycled. Hot in-place recycling will be done on the top 2 inches of HMA pavement using a heater scarification approach (http://pavementinteractive.org/index.php?title=HIPR). This method uses a plant that heats the pavement surface (typically using propane radiant heaters), scarifies the pavement surface using a bank of non-rotating teeth, adds a rejuvenating agent to improve the asphalt binder viscosity, then mixes and levels the mix using a standard auger system. The pavement is then compacted using conventional compaction equipment.

Calculation logic: All of the existing pavement structure is reprocessed and reused on the project, therefore 100% is reused.

Calculation: None needed. All existing pavement is reused.

This project would qualify for **5 points**.

Example: Calculation for Reconstruction of One Lane of an Existing Roadway

Description: One mile of the outside southbound lane of an existing six-lane arterial with 12-foot wide lanes is to be removed and replaced with PCC to accommodate a bus rapid transit lane. The arterial has no shoulders and has a raised vegetated median that is not accessible to automobiles. The existing pavement structure consists of 7 inches of HMA over 9 inches of crushed aggregate. The outside southbound lane construction requires a pavement structure of 12 inches of PCC over 7 inches of crushed aggregate. Therefore, all the pavement structure in the outside lane must be removed and a further three inches of excavation must be done to accommodate the thicker pavement section. Once the excavation is done, 7 inches of the previously removed crushed aggregate is placed. Then, 12 inches of new PCC is placed. The project scope includes all southbound lanes because other median work and restriping is to be done. The project scope does not include the northbound lanes.

Calculation logic: The project scope only includes the southbound lanes; only material in these lanes shall be included in the calculation. Also, since 7 inches of the existing crushed aggregate was reused as base course for the new PCC lane, it can be included.

Calculation: Total volume of existing pavement in the southbound lanes:

$$(36\ ft)(7\ inches\ +9\ inches)\left(\frac{1\ ft}{12\ inches}\right)(1\ mile)\left(\frac{5{,}280\ ft}{mile}\right)\left(\frac{1\ yd^3}{27\ ft^3}\right)=9{,}387\ yd^3$$

Reused volume pavement in the two left-hand existing lanes (those not reconstructed):

$$(24\ ft)(7\ inches\ +9\ inches)\left(\frac{1\ ft}{12\ inches}\right)(1\ mile)\left(\frac{5{,}280\ ft}{mile}\right)\left(\frac{1\ yd^3}{27\ ft^3}\right)=6{,}258\ yd^3$$

Reused volume of crushed aggregate in the reconstructed right-hand lane:

$$(12\ ft)(7\ inches)\left(\frac{1\ ft}{12\ inches}\right)(1\ mile)\left(\frac{5{,}280\ ft}{mile}\right)\left(\frac{1\ yd^3}{27\ ft^3}\right)=1{,}368\ yd^3$$

Percentage of existing pavement reused:

$$\frac{6{,}258\ yd^3+1{,}368\ yd^3}{9{,}387\ yd^3}=0.81=81\%\ reuse$$

This project would qualify for **4 points**.

If the project did not reuse the existing aggregate in the right lane, the calculation would be as follows:

$$\frac{6{,}258\ yd^3}{9{,}387\ yd^3}=0.66=66\%\ reuse$$

The project would qualify for **2 points**.

POTENTIAL ISSUES

1. A project may misclassify a material as "reused" instead of "recycled." Usually this is a minor issue since both processes can receive Greenroads points. See MR-4 Recycled Materials for more information.
2. Pavement thickness in older road sections may be highly variable; therefore estimating existing volume may be difficult. In such cases, it is important to clearly state assumptions and the sources of information you are using.

RESEARCH

Reused materials are a valuable and cost-effective resource that may be used to help reduce the ecological impacts and lifecycle costs of roadway construction. In many forms of roadway infrastructure (especially pavements) existing materials can be reused for their original intended purpose if they meet minimum engineering standards. Badly deteriorated hot mix asphalt (HMA) pavement, for example, may be ground up in place, stiffened with a binding agent and recompacted to form the base material for a new pavement. This process is typically referred to as cold in-place recycling.

For the built environment, materials reuse typically refers to the idea of carefully deconstructing a building instead of demolishing it. Deconstruction means disassembling a building in such a way that the materials can be reused for new construction (BMRA, 2010). Thus, items like floor joists, windows, doors, plumbing fixtures and siding that still have remaining life can be reused for new construction rather than demolished and either sent to landfill or recycled as more basic materials (e.g., wood, steel, etc.). For instance, an assembly of materials like a door (possibly consisting of wood, aluminum, brass, glass, plastic and more) can be reused rather than disposed of or separated into its constituent components for recycling.

Pavement Reuse Defined

Pavement Reuse: the process by which pavement materials within the project limits are either maintained in place (such as existing pavement structure) or disturbed/removed but are not transported outside the project limits.

By this definition Greenroads distinguishes "reuse" from "recycle" because recycling is defined more broadly as the process by which materials within or external to the project limits are diverted from final disposal (i.e. landfill) and are reprocessed or repurposed for use in the project. The essential difference between "recycling" and "reuse" is that recycling involves reprocessing/repurposing and, usually, substantial transportation (usually to and from the reprocessing facility). Also, a recycled material need not originate from the project in question. Therefore, material reuse as defined by Greenroads offers the same sustainability benefits of recycling (see MR-4 Recycled Materials for a discussion of benefits, current waste streams and diversion rates) with the added benefit of reduced transportation and an associated reduction in energy, emissions and cost.

This credit focuses exclusively on reuse of pavement materials because of (1) the dominance of pavements materials on roadway projects, and (2) the ability to reuse large percentages of existing pavement structures. First, pavements are the most prevalent structure in roadway construction, accounting for about 70% of state and local roadway expenditures (BTS, 2008). On most projects (except for perhaps bridges and tunnels) they make up a majority of the material by weight. Second, it is quite common to undertake a roadway construction project that keeps in place the entire existing pavement structure (essentially 100% reuse). This can occur in roadway expansion projects, projects that reprocess existing materials in-place and, importantly, routine preservation projects that either add to the existing structure or only replace the top few inches of an existing pavement structure. For the purposes of Greenroads, these types of preservation "overlays" and "mill-and-fill" (remove a thin layer of pavement and replace with a comparable thickness) jobs are deemed to have reused the entire remaining pavement structure. In this way, the pavement reuse credit can serve as a reward for an owner that pursues a preservation program designed to maintain pavement network condition through timely periodic surface overlays or treatments rather than wholesale remove-and-replace procedures.

Pavement Reuse Methods

This section briefly overviews some of the more common pavement reuse methods that meet the Greenroads "reuse" definition. These are:

- Surface treatments
- Overlay / Mill and Fill
- Hot in-place recycling (HIR)
- Cold in-place recycling (CIR)
- Full-depth reclamation (FDR)
- Crack-and-Seat of PCC pavements
- Rubblization of PCC pavements

In the cases of CIR, FDR, crack-and-seat and rubblization the existing material is effectively downcycled; that is it is reused for a lesser purpose (as an aggregate material instead of a bound concrete material). In all cases, these methods are considered "reuse" as defined by Greenroads because no existing material leaves the project site.

Surface Treatments

Pavement surface treatments are materials placed on the existing pavement surface in order to correct minor surface defects, improve wear course characteristics (i.e., friction) and provide a waterproof covering. Surface treatments are generally quite thin (e.g., less than 1-inch thick) and can consist of a number of different treatments including:

- **Fog seal (Figure MR-2.7)**. A light application of a diluted slow-setting asphalt emulsion to the surface of an aged (oxidized) pavement surface.

- **Slurry seal (Figure MR-2.8)**. A homogenous mixture of emulsified asphalt, water, well-graded fine aggregate and mineral filler used as a maintenance treatment or wearing course. Microsurfacing is an advanced form of slurry seal that uses the basic ingredients and combines them with polymer additives to achieve better engineering properties.
- **Chip seal (Figure MR-2.9 and MR-2.10)**. Also known as a seal coat or bituminous surface treatment, a chip seal is a thin protective wearing surface applied to a pavement surface. At its most basic, a chip seal consists of a layer of asphalt (often applied as an emulsion) applied to the existing pavement surface in which a single layer of aggregate is embedded. More exotic chip seals can use several layers (e.g., double chip seal), different stone sizes (e.g., racked-in seal), and be combined with other surface treatments (e.g., cape seal – combined with a slurry seal) (Gransberg & James, 2005).

Figure MR-2.7: No fog seal (left), fog seal (right).

Figure MR-2.8: Microsurfacing (from the Washington State Department of Transportation).

Figure MR-2.9: Chip seal asphalt emulsion application.

Figure MR-2.10: Chip seal aggregate application.

Overlay / Mill & Fill

Overlays (Figure MR-2.11) are operations where either PCC or HMA is placed over an existing pavement. Overlays can be used to add additional structure to the existing pavement (called “structural overlays”) or can be used to provide a new pavement surface free of defects (called “non-structural overlays”). A “mill and fill” is a variation of an overlay where the existing pavement surface is partially removed by a pavement milling machine (cold planer, Figure MR-2.12) before the overlay is applied. This is usually done to either:

1. Remove existing surface defects in order to improve overall pavement quality, or
2. Maintain existing pavement elevations after the overlay is complete.

In many instances (especially the second) the milling depth is the same as the subsequent overlay depth. For HMA pavements, overlays and mill-and-fills are the most common form of pavement preservation and can constitute the majority of HMA placed for most owners (as opposed to new pavements). PCC overlays can consist of bonded or unbounded overlays. Bonded overlays, often referred to as "whitetopping" when placed on existing HMA pavements, consist of a thin PCC layer (usually 2 to 7 inches) that is bonded to the existing underlying pavement. An unbounded overlay is a PCC layer placed over an existing pavement without bonding. Since there is no bonding, the new PCC layer essentially performs like an independent structure and therefore must be thicker; often the minimum thickness for an unbounded overlay is 5 to 7 inches.

Figure MR-2.11: 1.8-inch overlay.

Figure MR-2.12: Milling machine.

Hot In-Place Recycling (HIR)

HIR involves in-place reprocessing of the top of an existing HMA pavement. The process is accomplished by heating the existing pavement surface to aid in remixing, additive addition and removal of defects. Despite its name, Greenroads considers HIR to be reuse since the existing material does not leave the project site. There are generally three methods of HIR:

- **Heater scarification**. Heats the pavement surface (typically using propane radiant heaters), scarifies the pavement surface using a bank of non-rotating teeth, adds a rejuvenating agent to improve the recycled asphalt binder viscosity, then mixes and levels the recycled mix using a standard auger system. The recycled asphalt pavement is then compacted using conventional compaction equipment.
- **Repaving**. Heats the pavement surface (typically using propane radiant heaters), removes (by scarification and/or grinding) the top 1 to 2 inches of the existing HMA pavement, adds a rejuvenating agent to improve the recycled asphalt binder viscosity, places the recycled material back on the remaining existing pavement using a primary screed, and may simultaneously place a HMA overlay.
- **Remixing (Figures MR-2.13 and MR-2.14)**. Similar to repaving but adds new virgin aggregate or new HMA to the recycled material before it is replaced.

Figure MR-2.13: HIR heating equipment.

Figure MR-2.14: HIR equipment heating and removing the top layer of existing HMA.

Cold In-Place Recycling (CIR)

CIR (Figure MR-2.15) involves milling and crushing the existing HMA pavement, mixing in measured amounts of emulsified liquid asphalt and lime slurry, and placing and compacting the reprocessed material to construct a new roadway base. Following CIR, the base is overlaid with HMA or, in some cases, a chip seal. The depth of milling is generally 2 to 4 inches and, importantly, does not extend beyond the existing HMA layer.

Figure MR-2.15: CIR process train (photo from the Washington State Department of Transportation).

Full Depth Reclamation (FDR)

FDR (Figures MR-2.16 and MR-2.17) involves pulverizing the full existing pavement structure and a portion of the underlying subgrade and combining the resultant material with water and/or a stabilizing agent to form a uniform stabilized base course (ARRA, n.d.). Typical FDR depths are 6 to 9 inches (ARRA, n.d.). After FDR, it is typical to pave either a thin HMA pavement or chip seal.

Figure MR-2.16: Road reclaimer used in FDR (photo from Grace Pacific, Inc.).

Figure MR-2.17: Finished FDR material before overlay (photo from Grace Pacific, Inc.).

PCC Crack-and-Seat

Crack-and-Seat is a method for rehabilitating failed plain jointed PCC pavement that involves breaking up the existing PCC pavement into small pieces (typically 1 to 4 foot pieces), seating those pieces with a heavy proof roller and then overlaying the cracked and seated PCC with new HMA. This method avoids removing the old PCC; instead using it as a high quality base material. Typically, PCC is cracked using a drop hammer truck (Guillotine Breaker, Figure MR-2.18) that repeatedly drops a heavy weight onto the pavement surface.

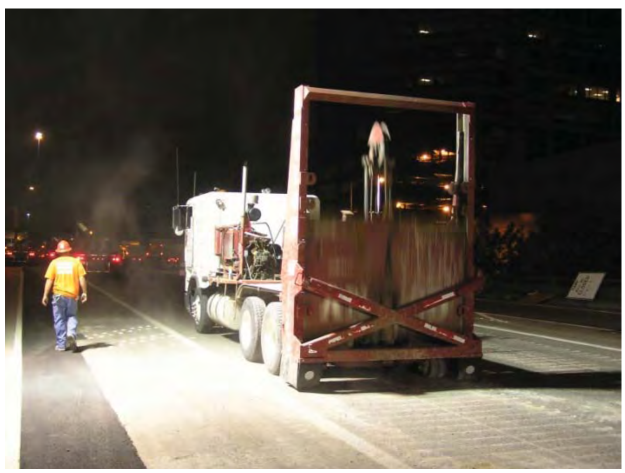

Figure MR-2.18: Guillotine breaker used for crack-and-seat.

Crack-and-seat projects have performed relatively well to date. For instance, Rajagopal et al. (2004) showed that the crack-and-seat technique reduced reflection cracking over at least a 9-year period for the conditions analyzed.

PCC Rubblization

Rubblization is a method for rehabilitating failed PCC pavement (typically plain jointed PCC pavement) that involves rubblizing the existing PCC pavement (particles sizes of 2 to 15 inches in diameter depending upon the specific method used) and then overlaying the rubblized PCC with HMA pavement. This method avoids removing the old PCC; instead using it as a high quality base material. Rubblization is typically accomplished by one of two methods:

- **Resonant breaker (Figure MR-2.19)**. A machine that strikes the pavement at a high frequency (around 44 Hz, the resonant frequency of the PCC pavement) and low amplitude (0.5-0.75 inches) using the resonant frequency to fracture the existing PCC into small-diameter particles. The breaking shoe can be 2 to 12 inches wide.

- **Multi-head breaker (Figure MR-2.20)**. A machine that strikes the pavement with a series of drop hammers (1 to 5 foot drop height) and uses the impact energy to fracture the existing PCC pavement into small-diameter particles.

Figure MR-2.19: RMI resonant breaker (photo from Resonant Machines, Inc.).

Figure MR-2.20: Antigo multi-head breaker (photo from Antigo Construction, Inc.).

Limited evidence suggests that rubblized pavements, if constructed properly, can perform well. Wolters et al. (2005) examined rubblized pavements in 2005 that were 3-8 years old and found them to be in good condition with the exception of those sections that did not have well drained base layers.

GLOSSARY

CIR	Cold in-place recycling (sometimes CIPR)
Cold In-Place Recycling	In-place reprocessing of a portion of existing HMA pavement (usually the top 204 inches) into a high quality base material by milling, crushing and stabilizing. Usually this base is then covered by a thin HMA layer or surface treatment.
Crack-and-Seat	Method for rehabilitating failed plain jointed PCC pavement that involves breaking up the existing PCC pavement into small pieces (typically 1 to 4 foot pieces), seating those pieces with a heavy proof roller and then overlaying the cracked and seated PCC with new HMA.
Downcycling	The recycling of a material to a material of lower quality or reduced functionality.
FDR	Full depth reclamation
Full Depth Reclamation	In-place reprocessing of a HMA pavement structure (including the granular base course and some subgrade material) into a high quality base material by pulverizing and stabilization. Usually this base is then covered by a thin HMA layer or surface treatment.
HIR	Hot in-place recycling (sometimes HIPR)
HMA	Hot mix asphalt
Hot In-Place Recycling	In-place reprocessing of a thin top layer (usually less than 2 inches) of an existing HMA pavement by scarification, rejuvenation and repaving.
Mill and Fill	A variation of an overlay for existing HMA pavements where the existing pavement surface is partially removed by a pavement milling machine before the overlay is applied.
Overlay	A layer of either PCC or HMA that is placed over an existing pavement. Overlays can be used to add additional structure to the existing pavement (called "structural overlays") or can be used to provide a new pavement surface free of defects (called

	"non-structural overlays").
PCC	Portland cement concrete
Recycle	A process that diverts materials within or external to the project limits from final disposal in a landfill by reprocessing or repurposing them for use in the project.
Reuse	A process that maintains materials in place (such as existing pavement structure) or disturbs or removes them by means that does not include transport outside the project limits.
Rubblization	Method for rehabilitating failed PCC pavement (typically plain jointed PCC pavement) that involves reducing the existing PCC pavement to small particles (2-15 inches in diameter depending upon the specific method used) and then overlaying the rubblized PCC with HMA pavement.
Surface Treatment	Materials placed on the existing pavement surface in order to correct minor surface defects, improve wear course characteristics (i.e., friction) and provide a waterproof covering.

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EARTHWORK BALANCE

GOAL

Reduce need for transport of earthen materials by balancing cut and fill quantities.

CREDIT REQUIREMENTS

Minimize earthwork cut (excavation) and fill (embankment) volumes such that the percent difference between cut and fill is less than or equal to 10% of the average total volume of material moved. For purposes of this credit, use the method and definitions detailed in Chapter 8 (Earthwork) of the Road Design Manual from the South Dakota Department of Transportation (SDDOT), or equivalent, to compute cut and fill volumes. Include miscellaneous additional cut and fill such as outlet ditches and muck excavations (see definitions in Chapter 8 of the Manual) and account for moisture and density as well as shrink and swell.

Balance cut and fill material volumes:

A = Volume of Cross Section Cut
B = Volume of Cross Section Fill
C = Volume of Miscellaneous Cut
D = Volume of Miscellaneous Fill

For points, show that design volumes **AND** actual construction volumes meet:

$$\frac{(A+C)-(B+D)}{\frac{1}{2}(A+C+B+D)} \times 100\% \leq 10\%$$

Note that for purposes of this credit, all volumes are positive quantities. SDDOT's Chapter 8 is available here:
http://www.sddot.com/pe/roaddesign/plans_rdmanual.asp

Details

- Projects with minimal earthwork or with no earthwork do not qualify for this credit. "Minimal earthwork" means that the total excavated cut or imported fill volume is less than one full dump truck volume, based on the smallest dump truck used on the project.
- Where soil stabilizer materials or other soil additives are used, include the volume of those materials in the total imports. Mechanical stabilizers such as rock bolts and geotextile fabric materials do not need to be included in volume calculations.
- Removed topsoil materials must be included in calculations.
- Unused cut or imported fill materials placed in stockpiles that serve no purpose on the project must be treated as exported materials and may not be used to count toward the final "balanced" section for purposes of calculating this credit. Sometimes this practice is called "soil banking" since these materials are often placed in embankments that may be used at some later time, often on different nearby sites. This practice often helps successfully avoid import of new materials, so it still may qualify for 1 point.
- Structural aggregate for base courses in pavements, foundations, or

MR-3

1 POINT

RELATED CREDITS

- ✓ PR-8 Low Impact Development
- ✓ MR-2 Pavement Reuse
- ✓ MR-4 Recycled Materials
- ✓ MR-5 Regional Materials

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Economy
- ✓ Extent
- ✓ Experience

BENEFITS

- ✓ Reduces Fossil Fuel Use
- ✓ Reduces Air Emissions
- ✓ Reduces Greenhouse Gases
- ✓ Reduces Solid Waste
- ✓ Reduces Manmade Footprint
- ✓ Reduces First Costs
- ✓ Reduces Lifecycle Costs

superstructures such as bridges need not be included in the total volume calculations.
- Structural backfill and drain rock specifically intended for utility trenches and stormwater infrastructure need not be included in the total volume calculations.
- Rock (Stable Rock, defined by the Occupational Health and Safety Administration) cuts sourced within the project boundary that are intended for use as structural aggregate within the project boundary do not count toward the total cut volume of materials.

DOCUMENTATION

- Copy of the grading plan. The grading plan must report total cut and fill quantities, total miscellaneous cut/fill, and show that they are within 10% of one another.
- Calculate and report actual construction earthwork volume for the project. This calculation shall show the following:

  - Actual cut and fill volumes during construction.
  - Actual volume of unused embankment materials (include excess import and excess cut materials)
  - Actual volume of earthwork material imported to the project site.
  - Actual volume of earthwork material exported from the site.
  - Show that:

$$\frac{(\boldsymbol{A}+\boldsymbol{C})-(\boldsymbol{B}+\boldsymbol{D})}{\frac{1}{2}(\boldsymbol{A}+\boldsymbol{C}+\boldsymbol{B}+\boldsymbol{D})}\times 100\% \leq 10\%$$

APPROACHES & STRATEGIES

- Use a project design that balances cut and fill volumes. This assumes that cut material from one area of the project site is suitable for use as fill material in another. This may not always be possible.
- Use soil improvement or stabilization techniques in an effort to avoid removing existing soil.

  - Apply binding agents, additives and other processes to unsuitable soils such that they become suitable for use. This often involves improving their bearing capacity so they can accept overburden or structures.
  - Use in-situ mitigation techniques to solve problems with unsuitable soils through ground improvement solutions such. Usually this involves forms of compacting, preloading, installed drains (to lower moisture levels) or other similar methods.
  - Improve load bearing capacity of soils by placing geosynthetics over them. This can force the potential bearing capacity failure surface to develop along alternate, higher strength surfaces.

- Use recycled material from other structures (e.g., crushed recycled concrete material – RCM or reclaimed asphalt pavement – RAP).
- Use design software and computer aided drawings (CAD) to calculate the design volumes of earthwork to be reported in relation to this credit. Note that these drawings and calculations will be superseded by final volume calculations in the field in the event that they differ.

Example: Sample Calculation

The South Dakota Department of Transportation Road Design Manual, Chapter 8, contains a detailed example of balancing cut and fill volumes using computer software, titled "Example of Earthwork Quantities with Moisture & Density Control (Undercut)" (p. 8-6). The example below shows how the calculation can be done by hand for this credit. There are a number of additional sample calculations in the referenced chapter.

Variable	Description	Volume (cy)
A	Normal cross-section excavation	54,889

A	Adjustment for moisture and density	9,233
C	Miscellaneous extra excavation (unstable material below undercut)	805
B	Normal cross-section embankment	49426
B	Adjustment for moisture and density	11079
D	Miscellaneous additional embankment (unstable material below undercut)	1490
D	Adjustment for moisture and density	298
A+C	**Total volume of excavated materials**	**64927**
B+D	**Total volume of embankment materials**	**62993**
½ (*A+B+C+D*)	**Average total volume of materials**	**63557**

$$\frac{64927-62993}{63557}\times 100\% = \mathbf{3.04}\% \leq 10\% \therefore \text{ Project qualifies for 1 point}$$

Example: O'Hare Airport Modernization Program - Phase 1

The Chicago O'Hare Airport Modernization Program (OMP), which was ongoing as of early 2010, made a substantial effort to be more sustainable in their approach to airport design and construction. One of the features of their sustainability efforts is balanced earthwork. Phase 1 moved 15 million cubic yards of soil under a "balanced earthwork plan" that reportedly saved over $100 million by reducing truck trips and fees for dumping at landfills.

Figure MR-3.1: Runway 10C-28C Paving and Electrical (West): Excavation in Area G5 (Photo Courtesy Chicago O'Hare Moderization Program)

Figure MR-1.2: June 2010 Runway 10C-28C Paving and Electrical (West): Placing and compacting Bit concrete base course on taxiway (Photo Courtesy Chicago O'Hare Moderization Program)

Example: Wattstown Business Park Road Extension

The Wattstown Business Park Road Extension Project in Coleraine, Ireland implemented a balanced cut and fill strategy that allowed all of the excavated materials to be re-used on site including excavated topsoils in order to minimize waste and hauling. The vertical alignment of the road was also kept to a minimum in order to minimize earthwork.

Figure MR-3.3: Wattstown Business Park (CEEQUAL,n.d.)

Example: Kicking Horse Canyon – British Columbia Ministry of Transportation

The Kicking Horse Canyon project near Golden, British Columbia, is a 26 km corridor upgrade that began construction in 2002. One of the project goals was to minimize the need for earthwork along the entire corridor in order to reduce greenhouse gas emissions from hauling trips (and to save money) in accordance with objectives of the British Columbia Ministry of Transportation (BCMoT) Climate Action Program. This balanced earthwork program also included addressing safety concerns on the project, which called for improvements to slope stability on roadway excavations as well as avalanche control and rockfall protection in several locations along the corridor's new alignments.

Slope stabilization on Phase 2 of the project was accomplished in some steep areas using 11,000 m^3 of high tensile strength steel mesh that also allowed for seeding to grow, which can add stability to upper soil layers (BCMOT, n.d.). The mesh is tied to rock layers below the slope to stabilize the hillside (see Figure 4). Rockfall areas are protected by approximately 20,000 m^3 of drapery mesh (BCMOT, n.d.). Excess fill soils were also stockpiled within the corridor for future lanes of highway (BCMOT, 2006). Construction of Phase 3 East - Brake Check to Yoho National Park (underway) is also following a balanced earthwork design program (see Figures MR-3.6 and MR-3.7).

Figure MR-3.2: Tecco® high-strength steel mesh used for slope reinforcement. (BCMOT, 2010)

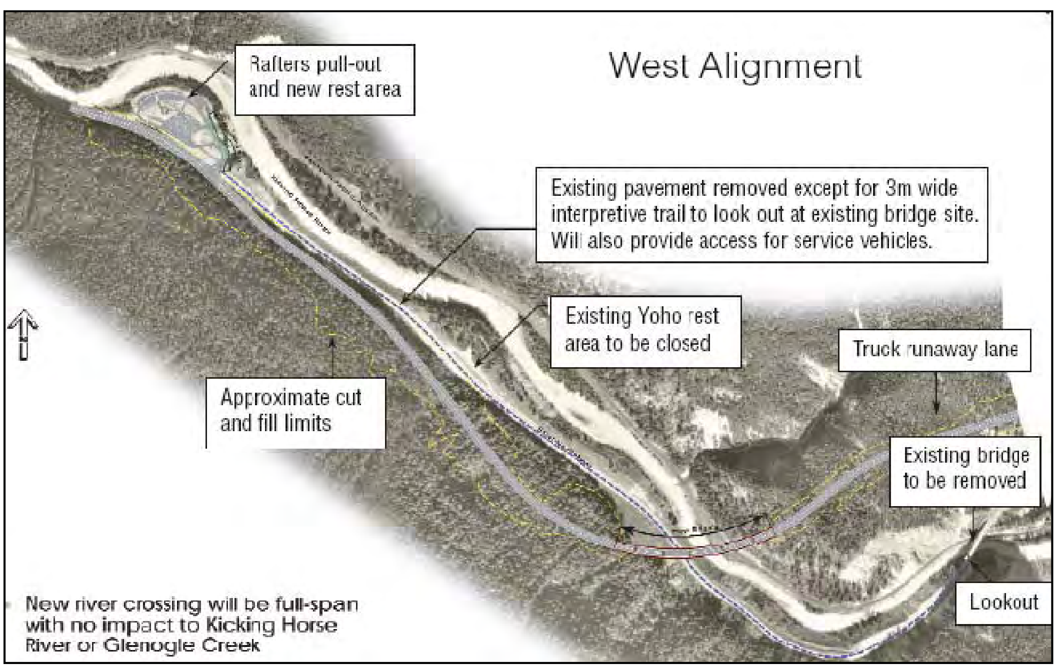

Figure MR-3.3: West Alignment of Phase 2, Kickinghorse Canyon, showing approximate cut and fill boundary for corridor segment (BCMOT, 2006)

Figure MR-3.4: Phase 3 of The Kicking Horse Project: Excavation on north side of the highway (BCMOT, 2010)

Figure MR-3.5: Phase 3 earthwork on east side of highway (BCMOT, 2010)

Example: Software Tools for Designers

The most straightforward means of balancing earthwork is to design and construct the project such that the volume of cut within the project is equal to the volume of fill. For designers and contractors there are numerous software packages that can provide exact and/or estimated earthwork quantities. The following are examples of software packaging that can be used to achieve balanced cut and fill.

- Trakware Inc. Earthworks Software
- Pizer Inc. EARTH Software
- Trimble Inc. Paydirt Software
- Vertigraph Inc. SiteWorx/OS
- Roctek Inc. WinEx Master Software

POTENTIAL ISSUES

1. When using stabilization material it is possible that the life cycle inputs for such material (e.g., energy use and emissions associated with their manufacture, transport and use) may be greater than that associated with moving soil associated with unbalanced earthwork.
2. Subsurface conditions may not be well known for the project site. Therefore, a balanced earthwork design that assumes a certain soil type and characteristics may not be feasible if, during earthwork, different soil types, moisture conditions or other characteristics are found.
3. Geosynthetics and stabilization additives may add significant cost over conventional methods.
4. Contractor familiarity and experience with alternative methods and materials can be highly variable.
5. Some roadwork does not lend itself to a balanced earthwork plan. For instance, work in an urban area may not work because the primary concern is typically maintaining existing elevation. Therefore, if a thicker pavement section is placed, some earth must be removed.
6. In a waterway corridor (area near a river or other waterway) balanced earthwork may not be sufficient. It is more important to ensure that earthwork does not reduce either the flood storage or flood carrying capacity of the waterway area (City of Brisbane, n.d.).
7. Rain events or prolonged wet periods can render on-site material unsuitable for fill until it is sufficiently dried. There may not be enough time in the construction schedule to allow adequate drying time.
8. Designers may neglect to consider or poorly estimate shrink or swell of soil material.
9. Earthwork on a phased project may not be completed by the same contractor.
10. Efforts across phases may be difficult to coordinate without clear documentation of intent of stockpiled materials.

RESEARCH

Most roadway construction involves some earthwork (moving of soil mass from one location to another). Earthwork can represent a significant project expense, especially in roadway projects. Because of the cost of landfill and truck transport most roadway designs seek to minimize earthwork as much as possible. When other ecological costs are added (i.e., landfilled waste, fuel use, truck emissions) the incentive to minimize earthwork grows. Thus, the goal is to minimize the earth moved and to minimize the distance it is moved. Ideally, a balanced earthwork project is one that matches cut and fill volumes and therefore does not required cut export or fill import. This section reviews typical methods used to achieve balanced earthwork.

Balancing Earthwork

The most straightforward means of balancing earthwork is to design and construct the project such that the volume of cut within the project is equal to the volume of fill. In rural projects this can often be accomplished by choosing the appropriate gradeline (roadway profile) so that cut volumes are roughly equal to fill volumes. For urban environments, this may be more difficult as urban projects are often severely constrained by right-of-way or required to match existing abutting elevations (e.g., other streets, parks, drainage conveyances, etc.). For designers and contractors there are numerous software packages that can provide exact and/or estimated earthwork quantities.

Once in construction, a balanced earthwork design may not be achievable for several reasons. First, earthwork often involves unknown quantities. Although geotechnical engineers can attempt to characterize existing soil with test pits, soil borings and laboratory tests, these characterizations are usually only done on a few locations within the project site and cannot guarantee the condition of untested locations. Therefore, it is possible that unexpected soil is encountered that when excavated is unsuitable for use as fill elsewhere. Second, environmental conditions can change causing previously acceptable soil to become unacceptable. For instance precipitation can substantially alter the moisture content of in-situ material making it unsuitable for use as fill elsewhere. Finally, design estimation may be inaccurate or, more likely, changes to the design during construction may add cut or fill quantities such that the overall effect is unbalanced earthwork.

Unsuitable Material

One of the most common impediments to balanced earthwork is in-situ material that is either (1) unsuitable to be used as fill elsewhere, or (2) unsuitable to be used as a foundation for other items such as structures (bridges, walls, etc.) and pavements. The most straightforward option in these cases is often to remove the unsuitable material and replace it with suitable fill. While this is feasible, it may result in unbalanced earthwork. It may be advantageous to treat the in-situ soil rather than remove and replace it. This section discusses several treatment options.

Traditional Soil Stabilization

Soil stabilization is the process of improving the engineering properties of soils through the use of additives that are mixed into the soil (Army, Navy, Air Force, 1994). These improved engineering properties can include:

- Reduced plasticity
- Drying
- Reduced swelling
- Improved stability

Stabilization can be done by mixing soils of two different gradations to achieve desirable qualities (mechanical stabilization) or by adding binding materials (additive stabilization). This section briefly reviews three common soil stabilization additives. The Army, Navy and Air Force *Soil Stabilization for Pavements* (1994) offers a means to choose between portland cement, lime and asphalt as soil stabilization additives.

- **Portland cement.** When added with water, portland cement hydrates and binds adjacent soil particles together resulting in a stiffer and perhaps stronger stabilized material. Portland cement can generally be used with well-graded granular materials with sufficient fines to mix with the portland cement (Army, Navy, Air Force, 1994).
- **Lime.** Added in the form of quicklime (CaO), hydrated lime ($Ca[OH]_2$) or lime slurry. Lime does three basic things: drying (through hydration with existing water in the soil), modification (Ca ions migrate to clay particle surfaces and displace water making the soil more granular), stabilization (increases the pH of the soil causing clay particles to break down). The National Lime Association (2004) states, "When added with In general, fine-grained clay soils (with a minimum of 25 percent passing the #200 sieve (74mm) and a Plasticity Index greater than 10) are considered to be good candidates for stabilization."
- **Asphalt emulsions.** Most suitable for silty sand and granular materials since these are more likely to have all particles fully coated by the emulsion.

Ecological Impacts of Soil Stabilization

Mroueh et al. (2001) reviewed several different combinations of industrial byproducts for use in earthwork. Results generally show that soil stabilization (as Mroueh et al. describe it this involves cement stabilization) generally has a higher environmental loading than simple soil replacement in most all areas (e.g., fuel use, energy, CO, particulate, SO_2, CO_2, VOC) except the amount of natural materials used.

GLOSSARY

Additives	Manufactured commercial products that, when added to the soil in the proper quantities, improve some engineering characteristics of the soil such as strength, texture, workability, and plasticity (Army, Navy, Air Force 1994).

Stabilization	Process of blending and mixing materials with a soil to improve certain properties of the soil. Can be done mechanically (blending gradations of soils) or by using additives (Army, Navy, Air Force 1994).

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RECYCLED MATERIALS

MR-4

1-5 POINTS

GOAL

Reduce lifecycle impacts from extraction and production of virgin materials.

CREDIT REQUIREMENTS

Use recycled materials as a substitute for virgin materials. The fraction of recycled materials used can be calculated using one of four options below:

1. **Consider only the pavement binder materials**. This typically means the cement or asphalt in the pavement section. No other materials (e.g., aggregate in the pavement, granular base, fill, walls, bridge, signs, other structures, etc.) are considered.
2. **Consider only the hot mix asphalt (HMA) or portland cement concrete (PCC) pavement materials**. This encompasses the material in Option 1 plus the aggregate as well as any other additive materials. No other materials (e.g., granular base, fill, walls, bridge, signs, other structures, etc.) are considered.
3. **Consider all pavement materials including granular base layers**. This encompasses the material in Options 1 and 2 plus the granular base layers (either unbound or bound with a binding agent such as lime, cement or asphalt emulsion) as well as any other added materials. No other materials (e.g., fill, walls, bridge, signs, other structures, etc.) are considered.
4. **Consider all project materials**. This encompasses the material in Options 1, 2 and 3 plus, as a minimum, all materials in the fill and wall structures of the project. Other structures (e.g., bridges) and material (e.g., signs, traffic control devices, etc.) may be considered if desired.

Calculate the average recycled material content by weight using one of the above four methods and Equation MR-4.1. Table MR-4.1 shows the point scale.

Table MR-4.1: Points for Average Recycled Content (Percent by Weight of Materials)

Points Earned	1	2	3	4	5
Percent recycled material required for Options 1 and 2	10%	20%	30%	40%	50%
Percent recycled material required for Options 3 and 4	20%	30%	40%	50%	60%

Use Equation MR-4.1 to compute the average recycled content (ARC) that will be achieved by the pavement section or by the binders.

$$ARC\ (\%) = \frac{\sum r_n}{\sum W_n} \times 100\% \quad \text{(Equation MR-4.1)}$$

Where:

- r_n is the total weight of recycled materials for that individual material or assembly
- W_n is the total weight of each individual material or assembly
- **n** represents the number of materials used in the pavement section

Details

It may be difficult to measure the recycled content of a material in place. For the

RELATED CREDITS

- ✓ PR-2 Lifecycle Cost Analysis
- ✓ PR-3 Lifecycle Inventory
- ✓ MR-1 Lifecycle Assessment
- ✓ MR-2 Pavement Reuse
- ✓ PT-3 Warm Mix Asphalt

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Economy
- ✓ Expectations
- ✓ Experience

BENEFITS

- ✓ Reduces Raw Materials
- ✓ Reduces Air Emissions
- ✓ Reduces Greenhouse Gases
- ✓ Reduces Solid Waste

purposes of this credit, it is sufficient to use the approved mix design or specified amount of recycled material as an estimate of the fraction of recycled material. Therefore, if paving rubberized HMA (RHMA) and the asphalt rubber mix design specifies 20% crumb rubber modifier (CRM) by weight then this number can be used as the percent recycled material in the binder provided that standard quality control and quality assurance testing shows the produced material meets the mix design specifications.

Similarly, if the PCC mix design specifies 20% recycled concrete aggregate (RCA) as a minimum then this number can be used as the percent recycled material in the PCC provided that standard quality control and quality assurance testing shows the produced material meets the mix design specifications. If a minimum recycled content is specified but a contractor chooses to use more than the minimum amount, records showing the actual recycled content must be submitted if credit for the actual amount is to be given. Otherwise, the minimum specified shall be assumed to be present in the material.

DOCUMENTATION

- A spreadsheet that clearly notes which calculation method is used and lists: total weight of each material used, total weight of recycled materials, and computed ARC for the project.
- Copy of the approved mix design for the pavement materials and (if options 3 or 4 are chosen) copies of the specifications for the additional materials that state the required or minimum recycled content if available.
- Supporting test documents (usually from quality assurance or quality control testing) such as plant proportioning records, mix tickets, and manufacturer's documentation for products (steel, rebar, etc.) that state the actual recycled material content (if no minimum is specified or if the contractor chooses to use more than the specified minimum).

APPROACHES & STRATEGIES

- Specify the total percentage of recycled material to be used in the mix design and the type of allowable waste materials in the contract documents. Many state departments of transportation (DOTs) already allow a certain percentage of recycled content in their standard specifications for certain material mixtures such as PCC or HMA. (See the Figures and explanations provided in the "Research" section of this credit.)
- Update agency standard specifications to specify a certain percentage of recycled material.
- During construction, keep updated records of all materials and recycled materials used on the project.
- Build a basic spreadsheet or other mechanism to track weights of materials for the project. Use the spreadsheet to compute the sum of weight of the recycled materials, compare it to the sum of the weight of all materials, and compute the average percent recycled content.

Example: Calculation for a Rubber-Modified Hot Mix Asphalt

Description: A 1.5 mile, one-lane HMA construction project uses CRM as a binding material additive. By mix design, the CRM is 20% of the binding material by weight. No other recycled materials are used. The HMA mix design calls for 9.2% binder by total weight of mix.

Calculation logic: Since the binder material only constitutes 9.2% of the total mixture weight, even if it were 100% recycled material it would still not qualify for any points in this credit if methods 2, 3 or 4 are used for the calculation. Therefore, use Option 1.

Calculation:

$$ARC\% = \frac{weight\ of\ CRM}{weight\ of\ binder} \times 100\% = \frac{20}{100} \times 100\% = 20\%$$

This project would qualify for **2 points** according to Option 1**.** Note that it is not necessary to weigh the CRM and asphalt binder since that is normally not done. In this case the mix design, if followed, is sufficient.

Example: Calculation for HMA using Reclaimed Asphalt Pavement (RAP)

Description: A 1.5-mile urban arterial preservation project consists of removing and replacing (mill-and-fill) the top 2 inches of pavement with HMA. The design for the HMA is as follows: 5.4% binder content; PG 70-22 asphalt binder. The project uses 2,720 tons of HMA of which 630 tons is reclaimed asphalt pavement (RAP). No other recycled materials are used.

Calculation logic: Since RAP is included in the mixture and no recycled material is included in the binder, the highest percentage of recycled material would be obtained by using Option 2 for the calculation.

Calculation:

$$ARC\% = \frac{630\ ton}{2720\ ton} \times 100\% = 23\ \%$$

This project would qualify for **2 points** according to Option 2.

Example: Calculation for PCC Using Type 1-SM Cement

Description: A 0.75-mile long road is being constructed to consist of two 12-ft wide lanes and no shoulders. The pavement structure is 8 inches of PCC placed on top of 10 inches of granular base material. The PCC mix design is as follows:

- Type 1-SM (slag modified) cement: 565 lbs/yd^3.
  - The cement manufacturer provides documentation that shows Type 1-SM cement contains 80% Type 1 portland cement and 20% ground granulated blast furnace slag (GGBFS).
- Course aggregate #1: 631 lbs/yd^3 of1.5 to 0.75-inch aggregate
- Course aggregate #2: 1,354 lbs/yd^3 of 0.75-inch to #4 aggregate
- Course sand: 682 lbs/yd^3
- Fine sand: 464 lbs/yd^3
- Water: 237 lb/yd^3
- Water/cement ratio: 0.42
- No other recycled materials are used in the pavement structure.

Calculation logic: Since the GGBFS is only in the binding agent, Option 1 will give the highest percentage.

Calculation: Start by computing the volume of PCC pavement to be placed.

$$(0.75\ miles)\left(\frac{5{,}280\ ft}{mile}\right)(2\ lanes)\left(\frac{12\ ft}{lane}\right)(8\ inches\ deep)\left(\frac{1\ ft}{12\ inches}\right)\left(\frac{1\ yd^3}{27\ ft^3}\right) = 2{,}347\ yd^3$$

Next, determine the total weight of cementitious material and the total weight of GGBFS.

$$Total\ cementitious\ material = 2{,}347\ yd^3 \times 565\ \ lb/yd^3 = 1{,}326{,}055\ lb$$

$$Total\ GGBFS = 2{,}347\ yd^3 \times 565\ \ lb/yd^3 \times 0.20 = 265{,}211\ lb\ cementitious\ material$$

Then, compute the average recycled content for the cementitious material.

$$ARC\% = \frac{weight\ of\ GGBFS}{weight\ of\ cementitious\ material} \times 100\% = \frac{265{,}211}{1{,}326{,}055} \times 100\% = 20\%$$

Note that the result, 20%, logically matches the percentage of GGBFS in the cement. Therefore, an alternate way of doing this calculation is to use the mix design ratio, which is computed as follows:

$$ARC\% = \frac{weight\ of\ GGBFS}{weight\ of\ cementitious\ material} \times 100\% = \frac{20}{100} \times 100\% = 20\%$$

This project would qualify for **2 points** based on Option 1.

Example: Calculation for an Aggregate Base Using 100% Recycled PCC

Description: A 1-mile highway rehabilitation project is going to use crushed recycled PCC from a nearby pavement demolition site as the base material. The existing highway is consisting of four 12-foot wide lanes. Existing shoulders are to be left in place. The surface course is 9 inches of PCC, the base course is 6 inches of crushed recycle concrete material (RCM). No other recycled material is used. The density of the PCC is 150 lb/yd^3 and the density of the RCM base course is 132 lb/yd^3.

Calculation logic: Since the recycled material is in the base course, Option 3 should be used.

Calculation: Start by computing the volume of PCC pavement to be placed.

$$(1\ mile)\left(\frac{5{,}280\ ft}{mile}\right)(4\ lanes)\left(\frac{12\ ft}{lane}\right)(9\ inches\ deep)\left(\frac{1\ ft}{12\ inches}\right) = 190{,}080\ ft^3$$

Compute the weight of new PCC pavement:

$$Weight\ of\ new\ PCC = 190{,}080\ ft^3 \times 150\ \ lb/ft^3 \times \frac{1\ ton}{2{,}000\ lbs} = 14{,}256\ tons$$

Compute the volume of RCM base course:

$$(1\ mile)\left(\frac{5{,}280\ ft}{mile}\right)(4\ lanes)\left(\frac{12\ ft}{lane}\right)(6\ inches\ deep)\left(\frac{1\ ft}{12\ inches}\right) = 126{,}711\ ft^3$$

Compute the weight of RCM base:

$$Weight\ of\ RCM\ PCC = 126{,}7111\ ft^3 \times 132\ \ lb/ft^3 \times \frac{1\ ton}{2{,}000\ lbs} = 8{,}363\ tons$$

Compute the average recycled content:

$$\left(\frac{8{,}363\ tons}{8{,}363\ tons + 14{,}256\ tons}\right) \times 100\% = 37\%$$

This project would qualify for **2 points** by Option 3. Note that by volume the recycled content is 40% but the density difference results in a 37% recycled material content.

Example: Calculation for Rubber-Modified Hot Mix Asphalt with RAP

Description: 5 miles of a 6-lane Interstate highway will be overlayed with a rubber modified HMA in one 0.75-inch lift. Lanes are 12 feet wide. The asphalt binder contains 20% CRM by weight of binder. The HMA mixture contains 15% of RAP by total weight of mixture and has a density of 2.05 tons/yd^3 in place after compaction. The target asphalt content is 9.1%. A small section of pavement is failing structurally and must be replaced. The replace section involves:

- 1,200 yd^3 PCC surface course with the following mix design:
  - Type 1 cement: 565 lbs/yd^3
  - Course aggregate #1: 631 lbs/yd^3 of1.5 to 0.75-inch aggregate
  - Course aggregate #2: 1,354 lbs/yd^3 of 0.75-inch to #4 aggregate
  - Course sand: 682 lbs/yd^3
  - Fine sand: 464 lbs/yd^3
  - Water: 237 lb/yd^3
- 1,000 yd^3 of crushed base material that is 50% RAP by total weight, with the rest being virgin crushed rock.
- The density of the HMA is 145 lb/yd^3 = 1.96 tons/yd^3
- The density of the PCC is 146 lb/yd^3 = 1.97 tons/yd^3
- The density of the virgin base course is 135 lb/yd^3.
- The density of the RAP base course is 136 lb/yd^3.

Calculation logic: This scenario involves recycled material in the binder, HMA and base material. Since there is no base layer being placed, Option 3 is not applicable, but Options 1, 2 or 4 could be used.

Option 1 Calculation

Weight of rubber-modified HMA pavement to be placed.

$$(5\ miles)\left(\frac{5{,}280\ ft}{mile}\right)(6\ lanes)\left(\frac{12\ ft}{lane}\right)(0.75\ inches)\left(\frac{1\ ft}{12\ inches}\right)\left(\frac{1\ yd^3}{27\ ft^3}\right)\left(\frac{1.96\ tons}{yd^3}\right) = 8{,}624\ tons$$

Weight of rubber-modified binder at 9.1% binder content by total weight of mix:

$$Total\ binder\ volume = 8{,}624\ tons \times 0.091 = 785\ tons$$

Weight of CRM at 20% by weight of binder:

$$CRM\ volume = 785\ tons \times 0.20 = 157\ tons$$

Weight of PCC binder in pavement repair section:

$$Weight\ PCC\ binder = (565\ lb/yd^3)(1{,}200\ yd^3)\left(\frac{1\ ton}{2{,}000\ lb}\right) = 339\ tons$$

Percent recycled material in the binder:

$$ARC\% = \frac{weight\ of\ CRM}{wt\ of\ RHMA\ binder + wt\ of\ PCC\ bindder} \times 100\% = \frac{157\ tons}{785\ tons + 339\ tons} \times 100\% = 14\%$$

Note that it is generally assumed that the binder content of the RAP contributes to the mixture binder. Therefore, if the binder content of the RAP is determined then it can be counted as recycled material in the binder. In this case, as is often the case in RAP additions, the binder content of the RAP is essentially ignored.

The project would qualify for **1 point** according to Option 1.

Option 2 Calculation

Weight of RAP to be placed (15% of volume of rubber-modified HMA to be placed:

$$RAP\ Volume = (8{,}624\ tons)(0.15) = 1{,}294\ tons$$

Weight of the PCC to be placed:

$$PCC\ Volume = (1{,}200\ yd^3)\ (1.97\ tons/yd^3\ ) = 2{,}364\ tons$$

Percent recycled material in the HMA and PCC:

$$ARC\ (\%) = \frac{\sum r_n}{\sum W_n} \times 100\% = \frac{1{,}294\ tons\ RAP + 157\ tons\ CRM}{8{,}624\ tons\ RHMA + 2{,}364\ tons\ PCC} = 13\%$$

The project would qualify for **1 point** according to Option 2.

Option 4 Calculation

This method includes the small pavement repair section materials.

Compute the weight of materials in the pavement repair base:

$$RAP\ in\ base = (0.50)(1{,}000\ yd^3)\left(\frac{27\ ft^3}{yd^3}\right)(136\ lb/ft^3)\left(\frac{1\ ton}{2{,}000\ lbs}\right) = 918\ tons$$

$$Virgin\ base = (0.50)(1{,}000\ yd^3)\left(\frac{27\ ft^3}{yd^3}\right)(135\ lb/ft^3)\left(\frac{1\ ton}{2{,}000\ lbs}\right) = 911\ tons$$

$$Total\ base\ weight = 918\ tons + 911\ tons = 1{,}829\ tons$$

Percent recycled material in the HMA, PCC and base:

$$ARC\ (\%) = \frac{\sum r_n}{\sum W_n} \times 100\% = \frac{1{,}294\ tons\ RAP + 157\ tons\ CRM + 918\ tons\ RAP\ in\ base}{8{,}624\ tons\ RHMA + 2{,}364\ tons\ PCC + 1{,}829\ tons\ base} = 18\%$$

The project would not qualify for any points according to Option 4.

Best Option

Choose either Option 1 or 2. The project qualifies for **1 point** with both of these Options. Depending on the type of project and the extent of the work, one of these methods may require less paperwork or be significantly less complicated to compute.

POTENTIAL ISSUES

1. Workability, compaction and other performance qualities change as amounts of recycled materials included in the material change.
2. Additional testing and inspection is often required for higher compositions of recycled materials for some cases and may represent an added cost.
3. Weather, performance, location and availability issues may limit the amount of recycled content that can feasibly be included in project materials.
4. Transport of recycled materials is sometimes costly, depending on availability and distance of transport. Occasionally this cost exceeds the total benefit of using the recycled material.

RESEARCH

Recycled materials present a valuable, common, and cost-effective material resource that may be used to help reduce the ecological impacts life cycle cost or roadway construction. In many forms of roadway infrastructure (e.g., pavements, base material, walls, etc.) recycled materials can be used in place of virgin materials without degrading final product performance. Ultimately, this reduces the need for production of virgin material, including extraction, processing and manufacturing, which eliminates related costs, waste disposal, emissions and energy use. A number of life cycle assessments (Carpenter et al., 2007; Chui et al., 2008; Horvath, 2003; Mroueh et al., 2001; Rajendran & Gambatese, 2007) have quantitatively shown at least some, if not all, of these benefits.

This research section outlines overall raw materials use, waste generated from that use, the unsustainable nature of this use or waste, current recycling practices, and waste materials that are typically used in a roadway construction project.

Raw Materials Use

Raw material (non-food and non-fuel) use in the U.S. has grown tremendously over the last century and continues to grow as infrastructure and manufacturing require ever more amounts to meet current demand (Figure MR-4.1).

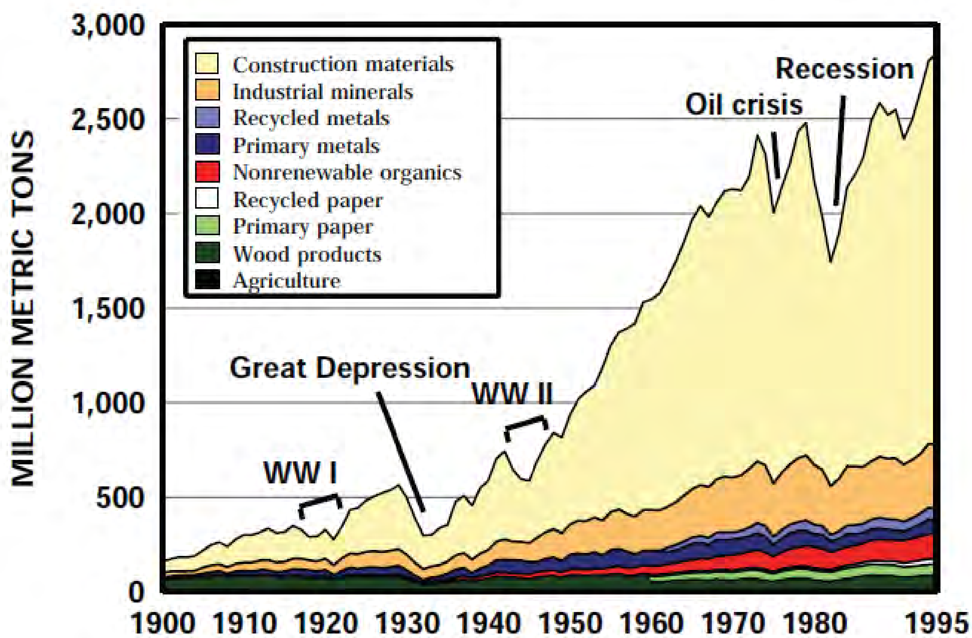

Figure MR-4.1: Measurement of the amount of raw materials consumed in the United States. (From Matos & Wagner, 1998)

Consumption in 1995 was 2.8 billion metric tons, over 17 times more than consumed in 1900. Noticeably, construction materials have been the largest contributor to the growth in materials production; especially since World War II.

Not only has the amount of raw materials consumed grown but the composition of those raw materials has changed significantly too (Figures MR-4.2 and MR-4.3). Of note, while in 1900 about half of the raw materials consumed (by weight) were from renewable resources (e.g., wood, agricultural products), only about 8% of the total raw materials consumed were from renewable sources (Matos & Wagner, 1998). Since the 1970s, U.S. raw material consumption has leveled off a bit (growing at rate of 1% from 1970 to 1995). However, worldwide consumption continues to grow at 1.8%, almost double the U.S. rate (1.8% (Matos & Wagner, 1998).

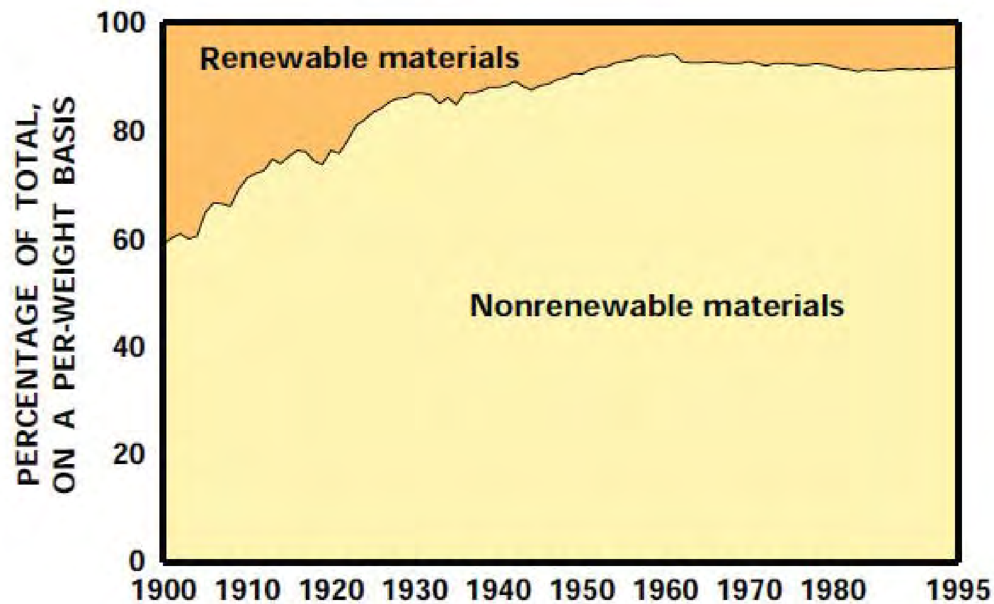

Figure MR-4.2: Measurement of the amount of renewable and nonrenewable materials consumed in the United States. (From Matos & Wagner, 1998).

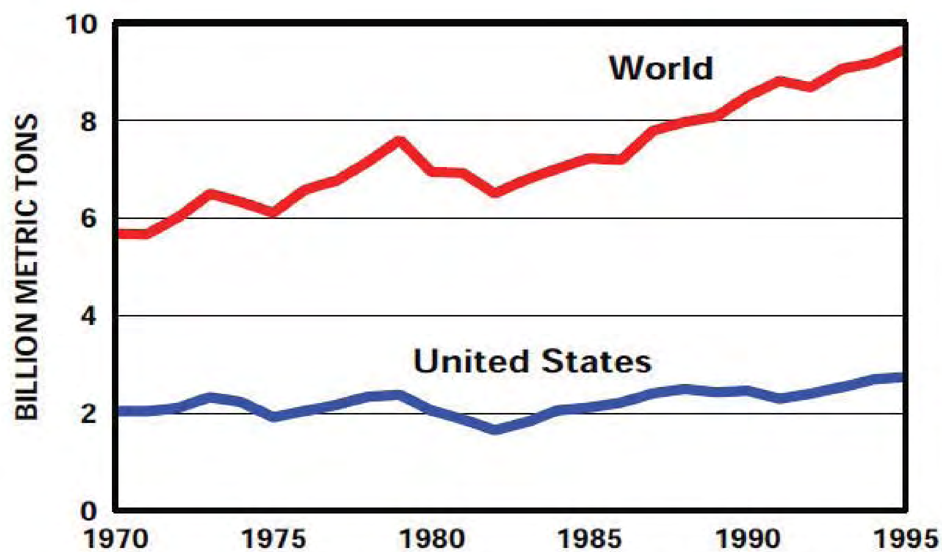

Figure MR-4.3: Measurement of the amount of materials consumed in the United States and the world. (From Matos & Wagner, 1998)

In sum, this level of domestic and worldwide raw materials extraction is generally thought to be unsustainable for a number of reasons (Fiksel, 2006):

- Depletion of non-renewable resources. These resources (e.g., oil, gas, coal, etc.) can be extracted at any time but cannot be replenished (at least not on a typical human time scale).
- Over exploitation of renewable resources (e.g., timber). Renewable resources are often referred to as “natural capital” because they can be replenished over time as long as the existing stock is not exhausted.
- Life cycle impacts associated with materials extraction, transportation and use.

Waste

The other end of a typical linear manufacturing flow is waste. After materials are extracted and used they eventually end up as waste. Worldwide, general estimates are that industrialized countries (loosely defined as those being members of the Organization of Economic Cooperation and Development – OECD) generate waste at about 12 lbs per day per capita while developing countries can be as low as about 2 lb per day per capita. Estimates of waste stream composition in the U.S. vary but they are generally similar to Figure MR-4.4. The contribution of construction and demolition waste (the type of waste associated with roadway construction) is generally estimated at between 20 and 40% of the total waste stream (Cascadia Consulting Group, Inc., 2004; GDRC, n.d.). This fraction is second only to organic (e.g., food, etc.) waste. In absolute numbers, a 2003 EPA estimate put construction and demolition waste from buildings (not including roads) at about 170 million tons or about 3.2 lbs/day per capita. Information on roadway construction and demolition waste is essentially speculative, but it is not unreasonable to assume that the total amount would approach that for buildings. More detail about infrastructure construction waste is given in Project Requirement PR-6 Waste Management Plan.

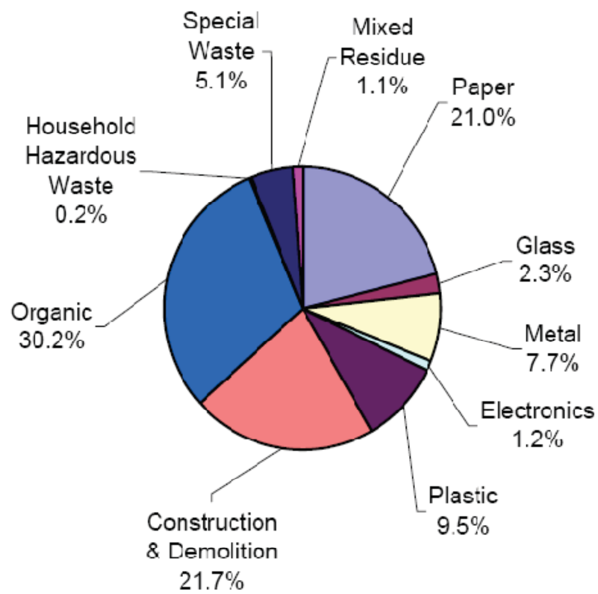

Figure MR-4.4: Material classes in California's overall disposed waste stream, 2003. (Cascadia Consulting Group, Inc., 2004)

Current Materials Extraction and Disposal Patterns are Generally not Sustainable

One simple measure of sustainability often sited is an ecological footprint, which in this case refers to the amount of nature's productive capacity (in terms of land area) needed to support our human demands. Wackernagel (2001) estimates the amount of biologically productive capacity available worldwide at 2.1 hectares per capita. He also estimates human demand on average across the planet at 2.8 hectares per capita. Thus, by this estimate current human activity cannot be supported by nature indefinitely. The numbers are worse for industrialized countries: 12.3 hectares for the U.S., 6.3 for Germany and 5.9 for Japan (Wackernagel, 2001).

Recycling

One means to reduce the required raw materials and waste stream volumes are to recover, process and repurpose waste materials as a substitute for raw materials. Generally, this is referred to as recycling. Generally, "recycling" implies some sort of waste stream recovery or diversion as well as some sort of applied process to condition the recovered material into a usable form. This is distinct from "reuse," which in Greenroads refers to a material that is either used again with no processing or at least is used again with no significant transport outside of site boundaries. McDonough & Braungart (2002) go further and make a clear distinction between "recycling" (reusing the material for the same purpose for which it was originally made) and what they term "downcycling" (reusing the material for a lesser purpose than for which it was originally made) arguing that recycling is superior to downcycling.

Quantification of Recycling

Recycling rates are variable worldwide and in the U.S. according to geographic region and material. In terms of municipal solid waste (this excludes industrial, hazardous and construction waste) Americans recycled about one-third of all generated waste in 2008 (EPA, 2009). Figure MR-4.6 gives a breakdown of the recycling rates for certain MSW products.

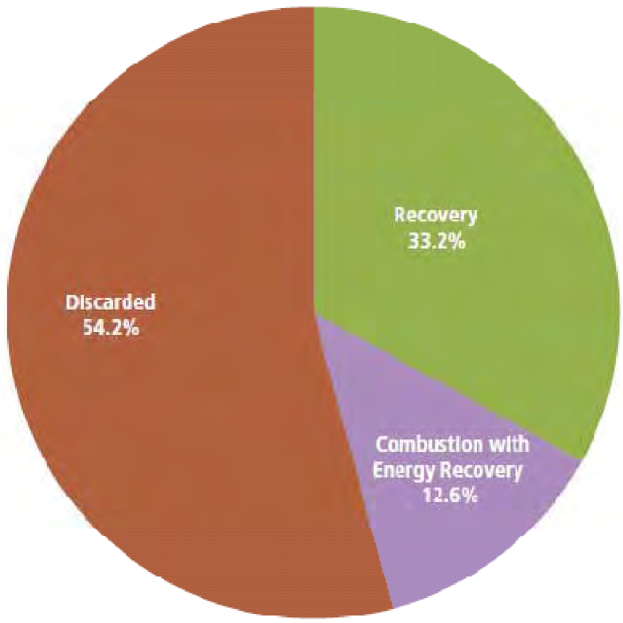

Figure MR-4.5: Management of MSW in the U.S., 2008 (EPA, 2008).

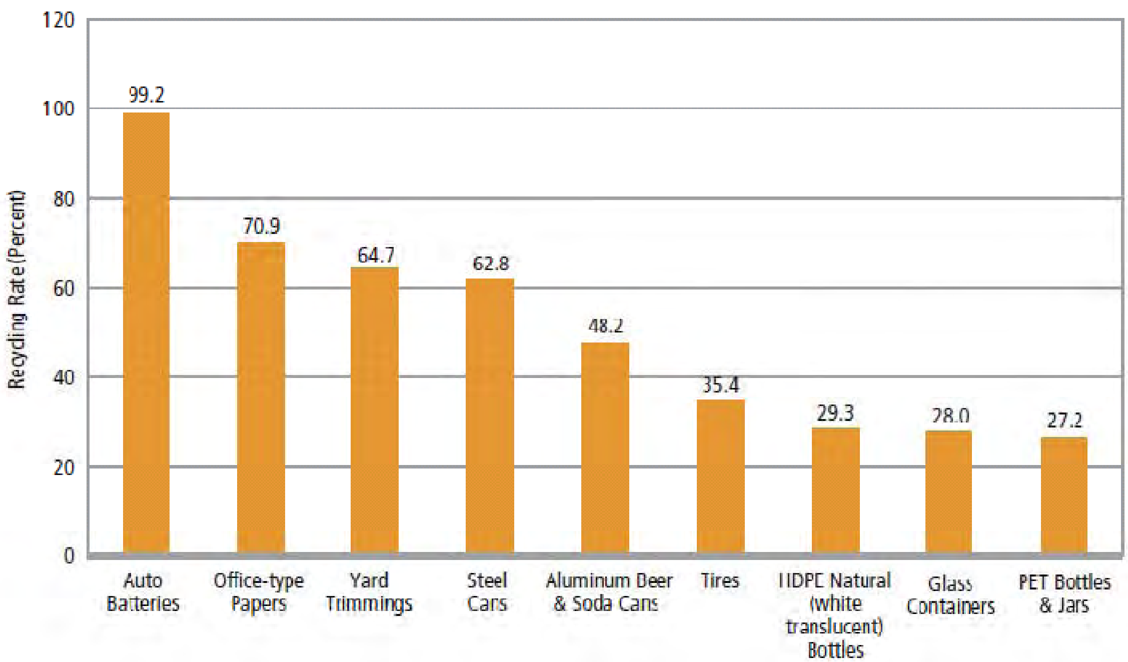

Figure MR-4.6: Recycling rates of selected products, 2008 – does not include energy recovery by combustion. (EPA, 2009)

Data on recycling in the construction and demolition field is less exact; however some numbers exist for certain materials. Recycling rates for hot mix asphalt (HMA) and portland cement concrete (PCC) are quite high. The most common citation in the HMA industry is that about 80% of the HMA waste stream is recycled (Bloomquist et al., 1993). PCC recycling rates are similar, if not higher. Data from the Washington State Department of Ecology (DOE) show that PCC and HMA together are the largest contributors to the diverted waste stream (waste that is either recycled or reused and thus, kept out of landfills). About 30% of all diverted waste in Washington State (by weight; 2.3 million tons combined) was PCC and HMA (Washington DOE, 2007). Ferrous materials at 1 million tons were second.

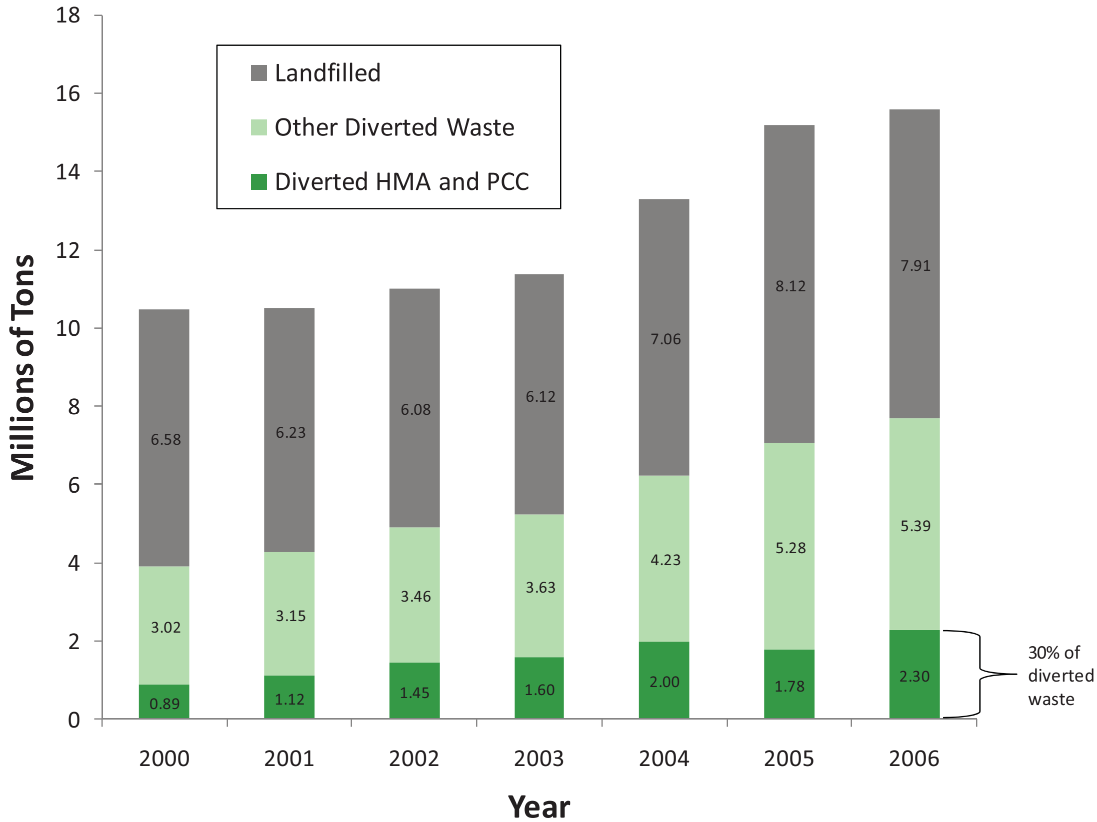

Figure MR-4.7: Disposition of generated waste in Washington State (data from Washington DOE, 2007).

Using Recycled Materials in Roadway Construction Materials

A substantial fraction of roadway materials are recycled (about 80% in the case of HMA). Much of this is used in roadway construction and, thus, replaces at least some virgin raw material. Additionally, other waste materials outside of construction and demolition waste can also be used in roadway construction materials. This section briefly reviews the major materials in a pavement structure and the types of recycled materials used in each.

With all of these materials, one of the primary issues to overcome is the general non-uniformity of recycled materials. Their variability is often greater than that of the virgin raw materials which they replace, and this variability can make quality control more difficult. Often, this issue leads to a limit or maximum fraction of recycled materials that is allowed in a construction material. In other instances a maximum fraction is specified so as to prevent a substantial undesirable change in material properties from that of a material made entirely from virgin raw materials.

Recycled Materials in Granular Base, Subbase and Fill

Recycled materials can be used in granular material and in some instances can impart desirable qualities. Table MR-4.2 list typical materials that can and have been used in granular or stabilized base materials.

Table MR-4.2: Some Examples of Base and Sub-Base Assemblies (FHWA, 1997)

Assembly	**Possible Recycled Materials**
Granular Base and Embankment Fill	
Granular Base	Blast Furnace Slag Coal Boiler Slag Mineral Processing Wastes Municipal Solid Waste Combustor Ash Nonferrous Slags Reclaimed Asphalt Pavement Reclaimed Concrete Steel Slag Waste Glass
Embankment or Fill	Coal Fly Ash Mineral Processing Wastes Nonferrous Slags Reclaimed Asphalt Pavement Reclaimed Concrete Scrap Tires
Stabilized Base	
Cementitious Materials	Coal Fly Ash Cement Kiln Dust Lime Kiln Dust Sulfate Wastes
Aggregate	Coal Bottom Ash Coal Boiler Slag
Flowable Fill	
Cementitious Material	Coal Fly Ash Cement Kiln Dust Lime Kiln Dust
Aggregate	Coal Fly Ash Foundry Sand Quarry Fines

According to rough estimates by the U.S. Geological Survey (2000), about half (53%) of recycled HMA is used as a granular base material. While this is counted as “recycling” it may be more appropriately classified as downcycling since using reclaimed asphalt pavement (RAP) as a granular fill does not take advantage of the asphalt binder in the mixture; the most expensive (in terms of cost and ecological impact) component. The predominant belief is as RAP content increases to higher levels, the shear strength of the base material decreases and other material properties change too (McGarrah, 2007). Because of this, many states limit the RAP content in base materials to 50% or lower (McGarrah, 2007).

Similarly, according to rough estimates by the U.S. Geological Survey (2000), about two-thirds (68%) of recycled PCC is used as a granular base material or other rock-like material such as fill or rip-rap. The Michigan Department of Transportation has found that portland cement concrete has shown to have similar properties to that of aggregate when used in base (Venner, 2004). Most states use or at least allow crushed recycled concrete material (RCM) as base material (Figure MR-4.8).

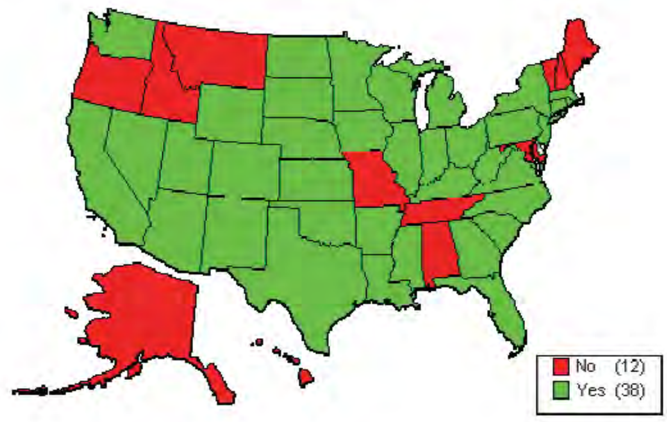

Figure MR-4.8: States recycling PCC as aggregate base (from FHWA, 2004).

Recycled Material in Hot Mix Asphalt

Recycled materials can be used in HMA and in some instances can impart desirable qualities. Table MR-4.3 list typical materials that can and have been used in granular or stabilized base materials.

Table MR-4.3: Some Examples of Base and Sub-Base Assemblies (FHWA, 1997)

Assembly	Possible Materials
Hot Mix Asphalt (HMA)	
Asphalt Binder	Modifiers Recycled asphalt binder from RAP
Aggregate	Blast Furnace Slag Coal Bottom Ash Coal Boiler Slag Foundry Sand Mineral Processing Wastes Municipal Solid Waste Combustor Ash Nonferrous Slags Reclaimed Asphalt Pavement Roofing Shingle Scrap Scrap Tires Steel Slag Waste Glass

By far, the most common recycled material in new HMA is RAP (reclaimed asphalt pavement, or "old HMA"). In the U.S. the qualities of RAP are generally assumed to be identical to that of virgin raw materials and thus no additional testing on HMA mixtures that contain RAP is required. However, in both gradation and asphalt quality RAP is different than virgin aggregate and asphalt. Therefore, as percentages get higher, they tend to affect overall mixture behavior, which necessitates special testing. As a result, most agencies set limits for the amount of RAP allowed but require no special mix design if you use RAP. A survey by the National Asphalt Pavement Association (NAPA, 2008) identified allowable RAP percentages and typically RAP inclusion rates in the U.S. Results are summarized in Figures MR-4.9 and MR-4.10.

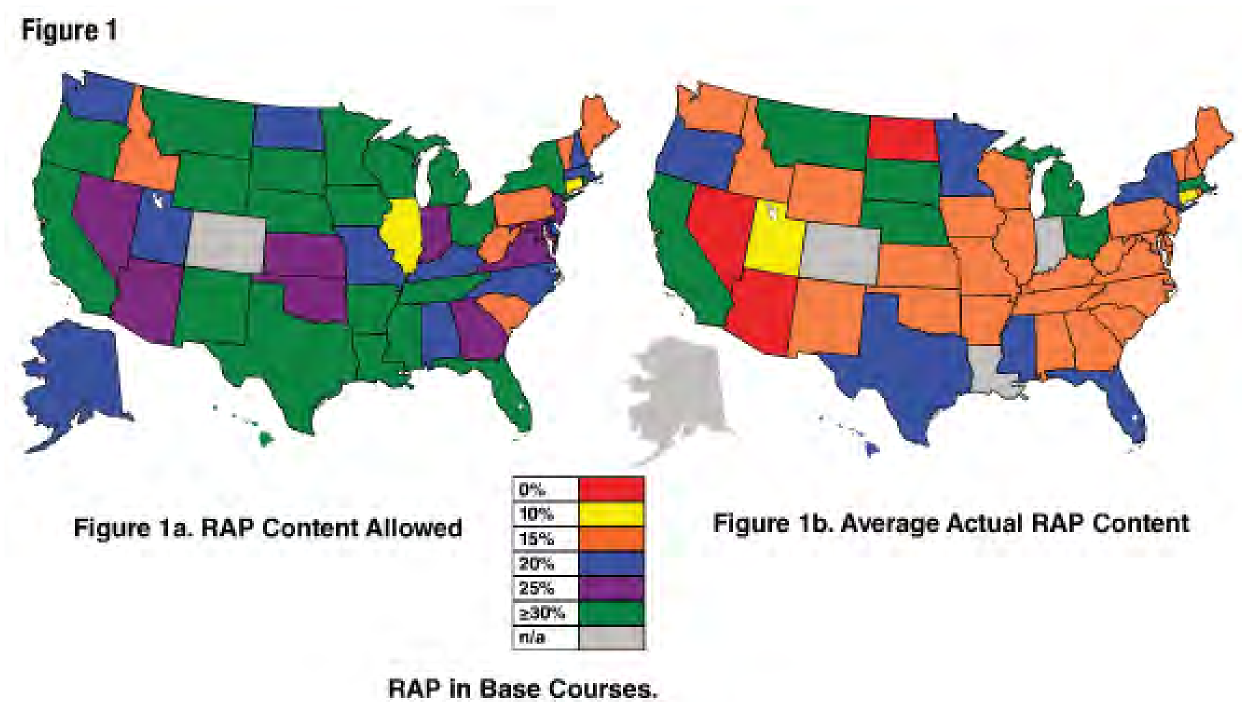

Figure MR-4.9: RAP use in HMA base courses (from Newcomb & Jones, 2008).

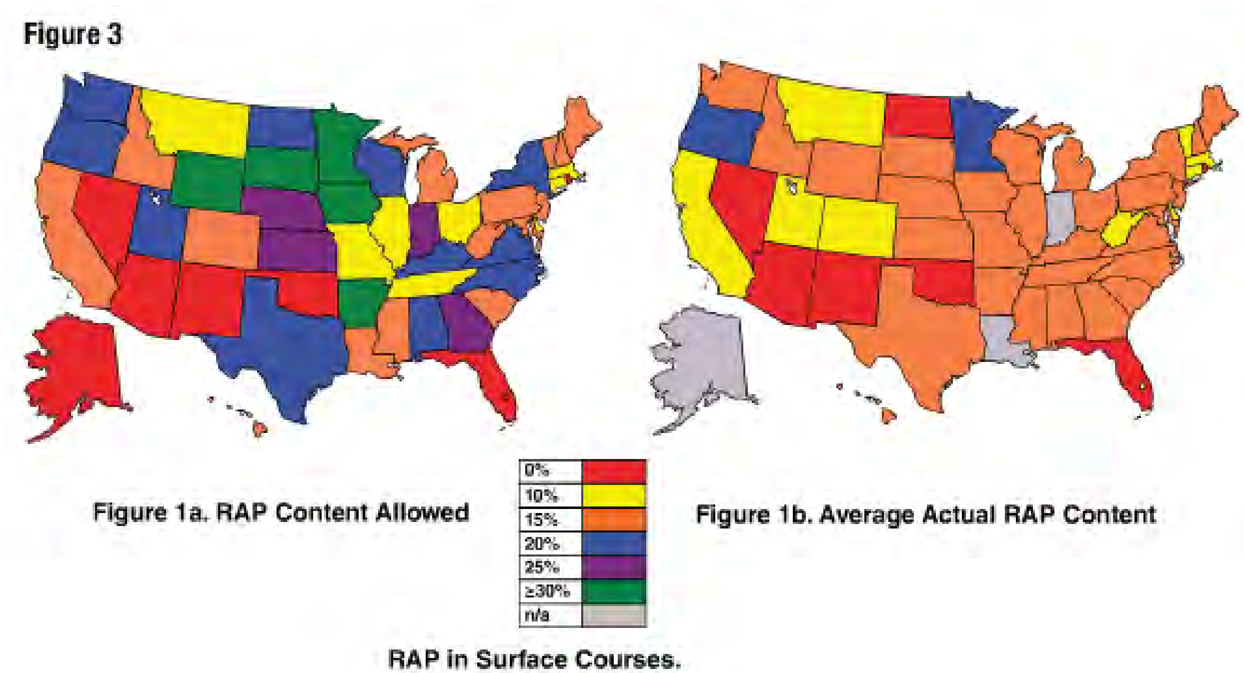

Figure MR-4.10: RAP use in HMA surface courses (from Newcomb & Jones, 2008).

Note that in almost all cases the average RAP content in HMA mixtures is somewhat less than the maximum allowed.

Recycled Material in Portland Cement Concrete

Recycled materials can be used in PCC and in some instances can impart desirable qualities. Table MR-4.4 lists typical materials that can and have been used in granular or stabilized base materials.

Table MR-4.4: Some Examples of Portland Cement Concrete (PCC) Assemblies (FHWA, 1997)

Assembly	Possible Materials
Portland Cement Concrete (PCC)	
Cementitious Material	Coal Fly Ash Silica Fume Ground Granulated Blast Furnace Slag
Aggregate	Reclaimed Concrete Waste Glass Foundry Sand

Only about 9% of RCM is used in new PCC (USGS, 2000) and few states do it (Figure MR-4.11). When used in new PCC, RCM has several key properties that distinguish it from virgin aggregate (Celeen, 2007):

- Lower specific gravity. Specifically, it is about 5-10% lower.
- High absorption. The constituent cement paste is more absorptive than virgin aggregate. Typical absorption for virgin aggrgate is in the 1-2% range while RCM may be from 2-8%.
- Lower slump. This really means lower workability. Likely this is due to the more angular shape of the RCM.
- Alkalia-silica reactivity (ASR) potential. This is really dependent on the old concrete's susceptibility to ASR. RCM will not necessarily be susceptible to ASR but one should check on the old concrete source since the recycled stuff is likely to have the same issues.
- Drying shrinkage. About 40-100% more for RCM due to the mortar and cement paste in the RCM.

In general there seems to be an unofficial "30% rule" that when natural sand is used, it is generally accepted that up to 30% of natural crushed coarse aggregate can be replaced with coarse recycled aggregate without significantly affecting any of the mechanical properties of the concrete. Some agencies go above this rule but it is still often followed (Celeen, 2007).

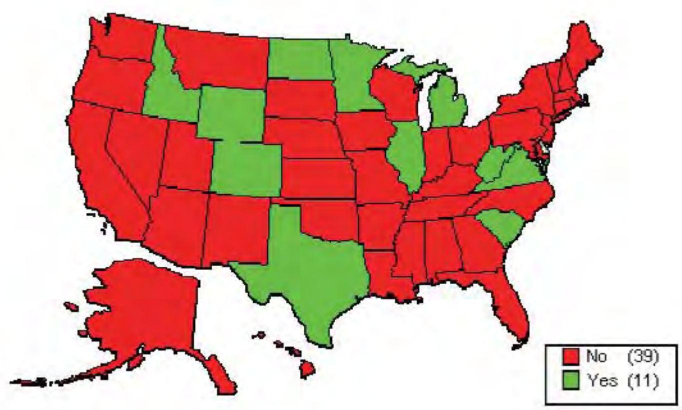

Figure MR-4.11: States recycling PCC as aggregate new PCC (from FHWA, 2004).

Coal fly ash and ground granulated blast furnace slag (GGBFS) are the most recycled materials used in PCC for roadway applications. Headwaters Resources (n.d.) reports that all 50 states allow fly ash in PCC. In pavement use, typically fly ash replacement is limited to 15-25% of the cementitious material by specification (FHWA, n.d.). Ground granulated blast furnace slag limits are similar.

GLOSSARY

Diversion	Avoiding placement in a landfill through recovery processes such as recycling or reuse

Downcycling	Recovering a portion of a used product or material in a manner that reduces the original value of the product or material after being reintroduced into the manufacturing or construction process (McDonough and Braungart 2002)
HMA	Hot mix asphalt
PCC	Portland cement concrete
RAP	Reclaimed asphalt pavement
RCA	Recycled concrete aggregate (see also RCM)
RCM	Recycled concrete material (see also RCA)
Recycling (recyclable, recycled)	Recovering a portion of a used product or material from the waste stream and processing such that those same materials can be reintroduced into the manufacturing or construction process (CIWMB 2009)
Reuse (reusable)	Recovering a portion of a used product or material from the waste stream that requires minimal, if any, processing to be reintroduced into the manufacturing or construction process
Waste	Any material that must be hauled off-site for disposal or reprocessing, or, if disposed within the project right-of-way (ROW), is not intended for engineered use on-site

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REGIONAL MATERIALS

GOAL

Promote use of locally sourced materials to reduce impacts from transportation emissions, reduce fuel costs, and support local economies.

CREDIT REQUIREMENTS

Make an itemized list of all materials, parts, components and products intended for permanent installation on the project including weights, total costs, shipping costs, and location of purchase and/or source of these materials. Using a spreadsheet or table is recommended for documentation of this credit. Show that your project meets the requirements of Option 1 or Option 2 below.

Option 1. Choose local materials and product suppliers.
Compute the total cost of all materials, parts, components and products used for project construction including all shipping and transport costs based on the project bid list. Compute the percentage of this total cost that has been paid to materials suppliers, processors, distributors and producers **within a 50 mile radius** of the geographic center of the project. Points are awarded according to the minimum percentages shown in Table MR-5.1.

Option 2. Minimize travel distance for project construction materials.
Disaggregate each material, part, component or product into its "basic materials" by weight and express as a percentage of the sum of these weights. Compute the cumulative fronthaul distance traveled for each basic material from point of origin to the final endpoint on the project. Note this distance includes all intermediary points, such as assembly or distribution, between the original source and the final placement on the project. Report the total distance in terms of total freight miles (road, air, rail or barge) traveled for each basic material. Show that at least **95%** of these basic materials **by weight** have traveled less than the maximum haul distances shown in Table MR-5.1.

Table MR-5.1: Point Scale*

Credit MR-5 Points	1	2	3	4	5
Option 1 by % of total cost	60	75	84	90	95
Option 2 by maximum fronthaul distance (miles)	500	337.5	225	150	100
Both options assume exponential difficulty associated with achieving this credit.					

Details

A "basic material" used in the project may include (but is not limited to): any and all binders (asphalt, cement products, etc.), aggregate, base and subbase or embankment materials, metal, finished plastic and wood or whole components assembled with these materials. The rule of thumb for determining "basic" is that it cannot be taken apart without changing the chemical composition of the material component itself. For example, typical new asphalt pavement is made of two basic materials: rocks and an asphalt binder. However, existing asphalt pavement is a basic material when used as recycled asphalt pavement (RAP). This is because it is difficult to separate the asphalt binder from the rocks.

Generally, the "origin" or "source" of a basic material means where it came out of the Earth or was initially fabricated. "Fronthaul" means traveling from the origin of

MR-5

1-5 POINTS

RELATED CREDITS

- ✓ PR-2 Lifecycle Cost Analysis
- ✓ MR-1 Lifecycle Assessment
- ✓ MR-2 Pavement Reuse
- ✓ MR-3 Earthwork Balance
- ✓ MR-4 Recycled Materials

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Equity
- ✓ Economy
- ✓ Extent

BENEFITS

- ✓ Reduces Fossil Fuel Use
- ✓ Reduces Air Emissions
- ✓ Reduces Greenhouse Gases
- ✓ Improves Local Economies
- ✓ Reduces First Costs
- ✓ Reduces Lifecycle Costs

the basic material and any of the places it has traveled on its way to the final destination in the project. This includes any material that is sourced at the site and taken offsite for reprocessing, such as recycling, later to return at the site in a different form. By contrast, the term "backhaul" is typically used to describe materials taken away from the site, usually destined for landfill, but sometimes is just an empty truck returning to its point of origin for another load. The distance traveled by emptied vehicles leaving the site (backhaul) need not be considered for purposes of this credit. Also, waste materials not intended for reuse or recycling on the project (i.e. they are transported offsite and do not come back) need not be included in calculations. Materials that qualify for credit MR-2 Pavement Reuse may not be counted toward this credit. However, recycled materials that originate from the project site and are transported offsite for reprocessing before being returned to the site are considered. Be sure to track weights of any added or lost materials during such a recycling process.

Two options are available for this credit and projects may elect to demonstrate either of them, whichever is most beneficial. Note that a 50 mile radius has a 100 mile diameter, so the highest potential points available in both Options are essentially consistent. Also, most pavement and structural materials are high in weight, and constitute the majority of most roadway project materials by cost. However, most high value items, such as binders, may not be as easily locally sourced, and represent a limited amount of the total material weight. In some cases, both Options may earn the same number of points, but in most cases one will govern depending on the project location. Also, depending on the location and the types of materials used on the project, one option may be substantially easier to document and track than the other. Option 1, for example, addresses where the project money for materials actually goes. For large projects this may be a less complex approach and simply requires tracking material costs according to the project bid list and picking a nearby materials contractor. On the other hand, Option 2 for this credit intends to minimize the total transportation (and therefore fuel costs, energy and emissions) associated with transportation of materials to the site. This may be easier for smaller projects with limited complexity of materials, or for projects that are not near urban centers. For consistency between all projects, map and compute haul distances using the Google Maps tool (http://maps.google.com). For products that are shipped by air, barge, or rail, use weights and distances reported by shipping agency or organization.

DOCUMENTATION

Option 1

- A spreadsheet including an itemized list of all purchased basic materials used on the project and the billing address of the source for each.
- A computation of the total percentage of basic materials sourced within a 50 mile radius of the project.
- A map showing the geographic center (in latitude and longitude) of the project. This may, in many cases, be a milepost or station. The map must show:
  - The name and location of the project.
  - The geographic center of the project. Show the latitude and longitude or mile marker.
  - A clearly drawn circle with a radius of 50 miles drawn to scale.
  - A scale.
  - Labels or icons for each basic material with a billing address that lies within the 50 mile radius.

Option 2

- A spreadsheet showing:
  - The name and location of the project.
  - An itemized list of each basic material and its weight.
  - Cumulative fronthaul distance for each basic material.
  - A list of the locations that the basic material visited during fronthaul.
- A computation showing 95% of the total material weight meets the maximum haul distance requirements to qualify for points in Table MR-5.1. Fuel receipts, mix tickets, dump tickets, and similar supporting documents may be requested to verify spreadsheet calculations.

APPROACHES & STRATEGIES

- Establish a documentation pipeline for materials extraction and fabrication before construction starts.
- Ensure that a local materials clause is written into the special provisions in the construction contract.
- Make sure that the project has local contractors that can perform the work.

Example: Option 1 Calculation – New Roadway in Suburban Neighborhood

A small new road is being constructed in a suburban neighborhood development. The HMA aggregate is mined at the location of the asphalt plant, which is 35 miles away from the project. The asphalt binder is sourced from an out of town supplier that is located 220 miles away from the project site, and the marking paint was shipped from 86 miles north of the geographic center of the project. No electrical or stormwater infrastructure materials are included in the scope of work, because these utilities are already in place.

The bid list costs for all material components or products on the project are:

	HMA Aggregate	Asphalt	Aggregate Base	Paint for Markings
Weight (ton)	21,200	896	17,300	0.21
Distance (mi)	25	220	25	86
Unit Cost ($/ton)	$7.50	$100	$7.50	$153,377
Total Cost ($) with shipping	$159,000	$89,600	$129,750	$32,080

The total cost for materials is **$410,430**. The total cost of the items that originate from within a 50 mile radius of the geographic center of the project (the HMA aggregate and aggregate base) is **$288,750**. This equates to **70.3%** of the materials by cost being located within a 50 mile radius, which would allot **1 point** to the project.

Example: Option 2 Calculation – Rural Overlay with Stormwater Treatment

A new project to overlay two miles of a rural county road will be occurring in the next few months. Stormwater is to be treated in linear ditches along the roadway using compost amended soil provided from a farmer whose plot is approximately 120 miles from the project, where it is produced and mixed. The HMA aggregates are being trucked into a mobile plant located 45 miles from the quarry and 35 miles from the project. The asphalt binder is being trucked via tanker from the nearest refinery which is located 295 miles away to the mobile plant. Paint for markings is provided from the nearest city center which is 410 miles west of the project.

	Aggregate for HMA	Asphalt Binder	HMA	Compost	Soil	Compost Amended Soil	Paint for Markings
Weight (ton)	5,200	200	-	350	325	-	0.25
Distance (mi)	45	295	35	0	0	120	410
% of Total Weight	85.6%	3.3%	*88.9%*	5.8%	5.3%	*11.1%*	0.0%

The total distance travelled by the aggregate from source to plant to project site (front haul only) is 80 miles and this material accounts for 85.6% of the total weight of materials for this overlay. However, since this is less than 95% of the total weight of materials, the critical material component is actually the compost amended soil. The total distance traveled by the compost amended soil is 120 miles, meaning that 96.7% of the total materials by weight have traveled 120 miles or less from point of origin to the project site. This qualifies the project for **4 points** according to table MR-5.1.

For this example, note that the total distance travelled by the asphalt binder from source to plant to project site is 330 miles, but this only accounts for 3.3% of the total weight of materials. The paint materials also did not contribute measurably to the total weight of materials transported to the site. These products are likely to have high unit cost, making it unlikely the project would score as highly according to the Option 1 method.

Example: Case Study - I-5 James to Olive Project (Mixed Pavement)

The I-5 James to Olive project was constructed in downtown Seattle in 2005. This project consisted of constructing 2 miles of 13 inch concrete pavement over 3 inches of HMA. The HMA was supplied approximately 30 miles from the job site by road. Aggregates for HMA were mined at the batch plant location. Steel was supplied from a local supplier that was approximately 35 miles from the job site. Portland cement concrete aggregates were quarried within a radial distance of 30 miles from the project, but were trucked 25 miles to a concrete batch plant located 12 miles from the project by road. Asphalt was trucked from out of town 150 miles away to the HMA plant. Portland cement concrete and ground granulated blast furnace slag (GGBFS) were produced 5 miles from the concrete batch plant and in a 10 mile radius from the project site.

For Option 1 the materials cost breakdown would look like:

Material or Component	**Aggregate for HMA**	**Asphalt Binder**	**Aggregate for PCC**	**Cement Binder**	**GGBFS**	**Steel**
Weight (ton)	2,400	100	7800	3250	1950	35
Radial Distance (mi)	30	150	30	10	10	35
Cost of Materials ($/ton)	7.50	100.00	7.50	50.00	30.00	650.00
Cost	$18,000	$10,000	$58,500	$162,500	$58,500	$22,750

The total cost for these materials was **$330,250**. The total cost of materials that were located within 50 miles was **$320,250** which amounts to **96%** of the materials cost. This would score **5 points** towards this credit.

For Option 2 the materials breakdown would look like:

Material or Component	**HMA Aggregate**	**Asphalt Binder**	***HMA***	**Aggregate for PCC**	**Cement Binder**	**GGBFS**	***PCC***	**Steel**
Weight (ton)	2400	100	*2500*	7800	3250	1950	*1,000*	35
Travel Distance (mi)	30	180	*30*	37	17	17	*12*	35
Total Weight (ton)			*2500*				*13000*	*35*

The total weight of the materials is **15,535 tons.** The asphalt binder, which traveled farthest (180 miles from source to plant to project site), accounts for 0.6% of the total weight of pavement assembly materials. The remaining **99.3%** of materials traveled less than 100 miles to their final destination on site. This method would also score **5 points**.

Example: Case Study - Mountlake Terrace Freeway Station, Mountlake Terrace, WA

The Mountlake Terrace Freeway Station project began construction in May 2009 to provide I-5 median access to the recently constructed Mountlake Terrace Transit Center. Currently, buses must merge across I-5 to exit and use surface streets to reach the transit center. The freeway station will allow buses to load and unload riders without straying from the HOV lanes. The covered freeway station will connect to the transit center through a pedestrian bridge, and is designed to increase bus speed and reliability. The roadway project consists of underground utility work for infrastructure improvements, sound walls, and also standard pavements.

Option 1 is used to compute the points for this project. The computation is shown in the table on the following page. The project qualifies for **4 points**, with **94%** of materials by cost being sourced from within a 50 mile radius of the project site.

Materials and Components	Quant.	Unit	Unit Cost ($)	Total ($)	% of Total Cost	Origin	Miles to Site	Within 50 miles?
Conc. Class 4000 for retaining wall	2800	cy	576	1,612,800	30.5	Seattle	20	Yes
HMA Cl 1/2 in PG 64-22	15520	ton	83	1,288,160	24.4	Bremerton	38	Yes
Conc. Class 4000 for station	1407	cy	706	993,342	18.8	Seattle	20	Yes
St. Reinf. Bar for retaining wall	229970	lb	1	229,970	4.4	Seattle	18	Yes
Prestressed Conc. Girder W74G	663	lf	285	188,955	3.6	Spokane	299	No
Crushed Surfacing Base Course	7060	ton	25	176,500	3.3	Monroe	26	Yes
Gravel Backfill for Wall	6060	cy	29	175,740	3.3	Monroe	26	Yes
Quarry Spalls	8686	ton	20	173,720	3.3	Monroe	26	Yes
36in - Cl V. Reinf. Conc. Storm Sewer Pipe	1149	lf	113	129,837	2.5	Spokane	299	No
36in - Ductile Iron Storm Sewer Pipe	456	lf	210	95,760	1.8	Marysville	21	Yes
24in - Corrugated Polyethylene Culv. Pipe	2291	lf	41	93,931	1.8	Edmonds	2	Yes
Profiled Plastic Wide Lane Line	16040	lf	4	64,160	1.2	Edmonds	2	Yes
Cement Conc. Pavement	221	cy	287	63,427	1.2	Seattle	17	Yes
			Total Cost	**$5,286,302**	**% by Cost in 50 mile Radius:**			**94.0%**

POTENTIAL ISSUES

1. As written, this credit currently does not include contribution from **backhaul** distances of emptied vehicles because they carry zero materials. Additionally, there is high variability in vehicles used for transport which makes tracking distances (in a meaningful way) travelled based on gas mileage or engine efficiency quite tedious. These two issues may be addressed more comprehensively by pursuing the MR-1 Life Cycle Assessment credit.
2. As written, this credit currently does not track **waste** products leaving the site. This value of such an activity can be addressed in the Custom Credits category. However, material gathered on site and taken offsite for reprocessing (e.g. fill material, recycled asphalt pavement from milling waste, etc.) needs to be considered and has been noted. This recycling activity assumes the initial production stage occurs at the site, goes through additional production at the processing facility, and is later constructed back at the site in a different form.
3. As written, this credit does not require projects to include distances traveled from the extraction sites of raw materials used to make basic material products such as asphalt binder (petroleum extraction).

RESEARCH

Using local materials on projects can not only lower the transportation costs of the project, but will also reduce the amount of emissions associated with transport by reducing transport distances for hauling materials. This practice can therefore decrease the overall greenhouse gas emissions and energy use associated with road construction.

Reducing haul distances decreases emissions and fossil fuel use. According to most lifecycle assessments completed for pavement construction, transportation of materials accounts for 7-38% of energy use and 4-10% of CO_2 emissions on typical roadway projects modeled (Muench & Anderson, Submitted). This means transportation of materials uses about 8 times the energy and produces twice as many CO_2 emissions as the construction processes for the road. Therefore, limiting haul distances has a sizable impact on energy and greenhouse gas emissions, as well as reducing emissions of many other harmful air pollutants from burning fossil fuels that are detrimental to human health (Bilec et al., 2006). (See also Project Requirement PR-3 Life Cycle Inventory).

Local economies also benefit from projects using local materials. Using local suppliers creates or maintains jobs, establishes community identity (Sustainable Sites, 2009), and often supports local small business owners. Typically many paving companies that bid large scale road projects are located less than 100 miles away from a project due to local specification restraints on material properties (e.g. standard binder grades and aggregate quality), and because transportation of heavy materials is fuel-intensive and expensive. Also, most public work paving projects use local material suppliers due to the cost implications of competitive bidding. That being said, using local contractors and suppliers will not always result in the lowest bid. The cost of social externalities for the resultant transportation emissions is not normally included in a bid and can be significant (Bilec et al., 2006).

Both the Leadership in Energy and Environmental Design (LEED™) Rating System and the Sustainable Sites Initiative award credit for minimizing transport distance. In LEED, the radius that determines a "regional" product is established at 500 miles from the site. LEED has experienced issues with their specification due to incorrect reports of haul distances during extraction and manufacture provided by contractors. This is largely a communication issue between the contractor, materials supplier and the project team attempting a LEED certification (Davis Langdon, 2004). There is also some difficulty in understanding the LEED credit calculation requirements for computing supply-chain responsibility by cost: many building products are extracted or produced in one location that may be outside the radius, and then they are assembled locally (Davis Langdon, 2007). In Sustainable Sites (2009), the radius varies depending on the type of product from 50 miles (soils and aggregate) to 500 miles (for specialty products). For this credit, a 50 mile radius is used and calculations are done by weight, because soil and aggregates represent the largest percentage of materials on most paving projects, are typically supplied locally due to cost-effectiveness, and weights of these materials are already tracked. Additionally, weight of materials directly corresponds to total fuel use and thus bid cost for the most common hauling equipment used in construction.

GLOSSARY

Backhaul	The return trip after a good has been delivered
Basic material	A material component that cannot be taken apart without changing the chemical composition of the material component itself
Fronthaul	The trip associated with delivery of a good
Haul distance	The distance a good travels to get to the location of intended use
Waste	Unwanted material produced as a result of construction activity

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ENERGY EFFICIENCY

MR-6

1-5 POINTS

GOAL

Reduce lifetime energy consumption of lighting systems for roadways.

CREDIT REQUIREMENTS

Install lighting systems with luminaires that meet or exceed the 2009 Energy Star standard for roadway lighting and are compliant with all safety requirements applicable to the roadway project. The 2009 Energy Star Standard is available at: http://www.drintl.com/htmlemail/ESOutdoorDraft2_01Jul09.pdf.

Points are awarded based on the fraction of total luminaires installed on the project with energy efficient fixtures that are 2009 Energy Star compliant in the following manner:

- 1 point: 20%
- 2 points: 40%
- 3 points: 60%
- 4 points: 80%
- 5 points: 100%

Details

Lighting facilities and systems must be appropriate for the project. This means that installing pedestrian safety lighting on a project with no pedestrian accessibility will not be awarded credit. Similarly, lighting for new and/or improved driveways and parking lots are subject to the credits only if they are included within the project scope and budget boundaries. Projects that do not include lighting within their scope cannot achieve this credit.

DOCUMENTATION

Provide a copy of the specification and/or cut sheets of the luminaires being installed on the project. Show that these are Energy Star 2009 compliant. Show that the lighting design complies with all applicable safety regulations for the project.

RELATED CREDITS

- ✓ EW-8 Light Pollution
- ✓ AE-3 Context Sensitive Solutions
- ✓ AE-5 Pedestrian Access
- ✓ PT-4 Cool Pavement

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Economy
- ✓ Extent

BENEFITS

- ✓ Reduces Fossil Fuel Use
- ✓ Reduces Air Emissions
- ✓ Reduces Greenhouse Gases
- ✓ Increases Service Life
- ✓ Reduces Lifecycle Costs

APPROACHES & STRATEGIES

- Install luminaires that are 2009 Energy Star compliant.
- Use **light emitting diode (LED)** lamp technologies.
- Consider not installing lighting systems where average daily traffic counts do not warrant lighting installation for a particular roadway configuration, or where pedestrian safety is not an issue.
- Review and apply Chapter 2 of the AASHTO Roadway Lighting Design Guide to achieve a Master Lighting Plan.
- Perform a lighting analysis of the project lighting system according to the American Association of State Highway and Transportation Officials (AASHTO) Roadway Lighting Design Guide method or the Illuminating Engineering Society of North America (IESNA) Roadway Lighting standard "RP-8-00" method. These methods can help determine if **solid state lighting** technologies will be appropriate for the project. Design tables for the referenced **luminance** or **illuminance** methods are noted in Table MR-6.1. Note that a combination of luminance and illuminance methods may be appropriate for some projects, and that some projects include multi-pavement types, which must be considered in the analysis. The analysis should include consideration of initial lumens, lamp lumen depreciation factor, and dirt depreciation factor.

Table MR-6.1: Lighting Analysis Methods

Reference Source	Luminance	Illuminance
AASHTO Roadway Lighting Design Guide	Table 3-5a	Table 3-5a
IESNA RP-8-00, Roadway Lighting	Table 2	Table 3

Example: Solid State Lighting Case Study - I-35 Bridge in Minneapolis, Minnesota

Replacement of the I-35 Bridge in Minneapolis, which tragically collapsed in 2007, was used as an opportunity by the U.S. Department of Energy and Minnesota Department of Transportation to demonstrate the use of solid state roadway lighting on a high profile project. LEDs were used with the goal of providing adequate uniform lighting while reducing operational energy use and maintenance requirements. (Pacific Northwest National Laboratory: PNNL, 2009) An aerial photo of the bridge at night is shown in Figure MR-6.1 and Figure MR-6.2 (next page) shows a pair of luminaires.

Figure MR-6.1: Aerial View of LED Lighting on I-35. Photo by Beta Lighting. (http://www.ledwaystreetlights.com/Benefits/pdf/case-study/ledway-I-35W-CaseStudy.pdf)

Figure MR-6.2: Lit LED luminaires at night on I-35. Photo by Figg Engineering Group. (http://www.ledwaystreetlights.com/Benefits/pdf/case-study/ledway-I-35W-CaseStudy.pdf)

Some highlights of the project include (PNNL, 2009):

- Bridge illumination was accomplished using 20 luminaires of two different designs.
- Operational energy requirements of the LED luminaires were estimated to be a minimum of 13% lower than those of Minnesota's standard 250-watt high pressure sodium luminaires.

More information about this project is available from PNNL and the U.S. Department of Energy at: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/gateway_i-35w-bridge.pdf

POTENTIAL ISSUES

1. A tradeoff exists between providing enough luminance for safety, limiting light pollution, and reducing or conserving energy.
2. Compliance with veiling luminance ratios may also be required in some jurisdictions.
3. In colder climates, LED lighting may not provide as much heat that assists with deicing of luminaires or traffic signals as do incandescent bulbs.

RESEARCH

With a large proportion of the world's electricity being produced by unsustainable methods, reduction of electricity consumption is an important goal in the pursuit of sustainable infrastructure. After construction is completed, the direct electricity consumption of virtually all roadways can be primarily attributed to roadway lighting systems. The U.S. Department of Energy estimates that roadway lighting systems consume 31 terawatt hours of electricity each year in the United States (US DOE, 2008).

Solid State Lighting

In recent years, lighting technologies have been refined to provide feasible alternatives to traditional methods that can provide comparable performance with significantly reduced energy use. Solid state lighting, which uses **light emitting diodes** (LED), can replace typical sodium or mercury luminaires above roadways to meet lighting needs. Notably, the **optical efficacy** (light output in lumens per watt of electricity) of LEDs has become comparable or better than current alternatives, and light from LEDs can be more effectively directed and therefore used to light an area with less energy (Wu et al., 2009). In addition, the increased lifespan of LEDs decreases the need for replacement and maintenance.

Solid state lighting is a technology still very much under development. Because of this, the efficiency of LED luminaires is continually increasing as devices are refined. In 2006, LEDs were developed that approximated the same optical efficacy as typical modern day mercury lamps, about 70 **lumens** per watt of electricity (Wu et al., 2009). In 2007, commercial luminaires were produced that could perform at 80 lumens per watt (Craford, 2008). Efficacy levels reached around 130 lumens per watt experimentally by 2008 and it is expected that a long term feasible maximum for LED efficacy is about 150 lumens per watt (Long et al., 2008; Schubert et al., 2006). In addition to energy savings, LED roadway lighting provides a longer lasting alternative to traditional luminaires, reduces the need for replacement and maintenance, and decreases material waste and pollution.

Energy Savings

LEDs with comparable levels of optical efficacy can provide significant energy savings over traditional light sources such as mercury and sodium bulbs. This is due to the increased ability to focus or aim LED light through design. Over 85% of the light from an LED may be directed to hit the roadway surface, while only about half of the light from conventional fixtures does so (Wu et al., 2009). Therefore, less total light output is required to illuminate the roadway surface, reducing energy use as well as light pollution and trespass.

In roadway lighting field tests, LED luminaires have shown energy savings between 30% and 75% (Wu et al., 2009; US DOE, 2008, Long et al., 2008). Decreased energy use also allows for reduction in the amount of copper wire used for electrical transmission (Huang et al., 2009). Assuming that the optical efficacy of LEDs will continue to improve and surpass that of mercury and sodium lamps, LED luminaires promise to be a very attractive alternative to traditional systems.

Increased Service Lifetime

In addition to reducing electricity consumption, LEDs have substantially longer functional lifetimes than sodium and mercury bulbs. LED luminaires can provide adequate light levels for about 50,000 hours (nearly six years), or about four times longer than current alternatives (Wu et al., 2009; McClear, 2007). This means decreased long term costs and less need for replacement, which is a difficult, dangerous, and sometimes fatal process, particularly on busy highways (New Jersey DOT, 2005).

Other Benefits

Rather than burning out like traditional bulbs, LEDs slowly lose brightness over time. This increases the safety of LED-lit roadways, eliminating periods of complete darkness between bulb failures and replacements. Finally, in contrast to some commonly used luminaires, LED luminaires contain no mercury, meaning reduced mercury pollution at the end of the useful lifetime of the light (Long et al., 2008). The U.S. Department of Energy (2008) estimates that if all high pressure sodium luminaires in the nation were replaced with LED luminaires, 8.1 terawatt hours would be saved annually at minimum, amounting to 5.7 million metric tons of atmospheric carbon dioxide.

Lifecycle Cost Savings

The most significant barrier to use of LED roadway lighting is the increased initial capital costs of such systems. However, decreased electricity and maintenance costs mean that these systems are capable of paying for themselves in the long term, even without considering environmental benefits. Studies of different technologies and methods on various roadway projects have found payback times ranging from 1.2 to 6.3 years

(Wu et al., 2009; US DOE, 2008). These durations will continue to decrease as LED technology becomes less expensive and more efficient.

What is Induction Lighting?

Induction lighting is another alternative to traditional lighting systems, and uses induced magnetic fields to cause mercury vapor to emit light. Because of the lack of filaments and electrodes, induction lights can have extremely long lifetimes of 100,000 hrs (Lippert, 2009). This is especially attractive for applications where maintenance is difficult or dangerous, such as roadway lighting. Induction lights can provide energy savings over typical luminaries while maintaining safe conditions (Dahua et al., 2008). However, large scale testing and comparison is still needed before this technology can be widely implemented.

GLOSSARY

AASHTO	American Association of State Highway and Transportation Officials
IESNA	Illuminating Engineering Society of North America
Induction Lighting	A type of lighting that uses induced magnetic fields to cause mercury vapor to emit light.
Illuminance	Quantity of light that reaches a given surface
LED	Light-emitting diode
Lumen	Unit of luminous flux
Luminaire	A complete lighting unit that includes light source, covering, mounting, wiring, etc.
Luminance	Quantity of light reflected by a given surface (measure of brightness)
Optical efficacy	Number of lumens an electrical light source produces per watt of energy used
Solid state lighting	A type of lighting produced by light-emitting diodes

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PAVEMENT TECHNOLOGIES

LONG-LIFE PAVEMENT

PT-1

5 POINTS

GOAL

Minimize life cycle costs by promoting design of long-lasting pavement structures.

CREDIT REQUIREMENTS

The first requirement AND EITHER of the following two requirements must be met to achieve points.

Requirement 1: Design at least 75% of the total new or reconstructed pavement surface area for regularly trafficked lanes of pavement to meet long-life pavement design criteria. Compute the total surface area of all trafficked lanes and show that a minimum of 75% of that area is designed for long-life. Do not include shoulders, medians, sidewalks and other paved areas in the computation. Long-life pavement is defined as a pavement structure that is designed using a minimum 40-year design life.

Requirement 2a: Meet the requirements of Figure PT-1.1.

OR

Requirement 2b: Pavement design is in accordance with a design procedure that is formally recognized, adopted and documented by the project owner.

Details

Generally, not all pavement sections on a project will be designed as long-lasting sections. Also, this credit is not applicable to roads that are not surfaced with hot mix asphalt (HMA) or portland cement concrete (PCC), such as gravel roads, dirt roads, and roads sealed with bituminous surface treatments.

Figure PT-1.1 Method. Requirements for subgrade California Bearing Ratio (CBR) and base material CBR can be taken as averages across the entire project where more than one test is done. If subgrade or base support is not measured by CBR, use the common conversion techniques in Table PT-1.1 or any local conversion that is commonly used in design and has a basis in empirical evidence. Soils testing data should support the conversion used.

Table PT-1.1: Commonly Accepted CBR Conversion Methods (AASHTO, 1993)

Conversion	Equation	Limitation
CBR - Resilient Modulus (M_R)	$CBR = \frac{M_R}{1500}$	Fine grained soils with a soaked CBR of 10 or less only
CBR - Resistance Value (R-value)	$CBR = \frac{555(R\ value) + 1155}{1500}$	Fine grained, non-expansive soils with a soaked CBR of 8 or less only

Design Procedure Method. The intention is to allow an owner agency to use its existing design procedure to design the pavement section as long as a sufficiently long design life is chosen (at least 40 years). Some common design procedures include (but are not limited to):

- **1993 AASHTO Method**. The method described in the 1993 version of the

RELATED CREDITS

- ✓ PR-2 Lifecycle Cost Analysis
- ✓ MR-2 Pavement Reuse

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Economy
- ✓ Extent
- ✓ Expectations
- ✓ Experience

BENEFITS

- ✓ Reduces Raw Materials
- ✓ Reduces Fossil Fuel Use
- ✓ Reduces Air Emissions
- ✓ Reduces Greenhouse Gases
- ✓ Reduces Solid Wastes
- ✓ Increases Service Life
- ✓ Reduces Lifecycle Costs
- ✓ Improves Accountability

AASHTO Guide for Design of Pavement Structures (1993) and computerized in DARWin, and AASHTOware product.

- **Asphalt Institute Method**. The method described in the Asphalt Institute's MS-1 Asphalt Pavements for Highways and Streets and computerized in the Asphalt Institute's publication, SW-1 Asphalt Thickness Design Software for Highways, Airports, Heavy Wheel Loads and other applications (1981).
- **Mechanistic-Empirical Pavement Design Guide (MEPDG)**. The method described in AASHTO MEPDG-1 Mechanistic-Empirical Pavement Design Guide, Interim Edition: A Manual of Practice (2008). This method is eventually intended to replace the 1993 AASHTO method.

Existing Pavements. Existing pavements that are to at least partially remain in place (in any condition) can also qualify for this credit. In these cases, evaluation for this credit shall be based on the final pavement structure, which may include (1) existing pavement remaining in place, and (2) any new pavement structure added. In this manner, a diamond grind of an existing PCC pavement or an overlay of an existing HMA pavement can qualify for this credit if the resultant pavement structure meets the criteria of this credit.

DOCUMENTATION

- A list of pavement sections to be built (or reconstructed) and their associated pavement material type, surface areas, equivalent single axle loads (ESALs), design thicknesses, subgrade CBR, and if design was intended to be long-life or not in accordance with the requirements of this credit. This may be included as part of the standard project documentation or as a separate document.
- A calculation to indicate the total percentage of trafficked lane pavement surface areas that are designed for long-life.
- A drawing or project map showing locations of pavement sections designed for long-life. These pavement sections should be highlighted on the plan, a scale should be on the plan, and the total surface area of each pavement section should be called out as a note on the plan.

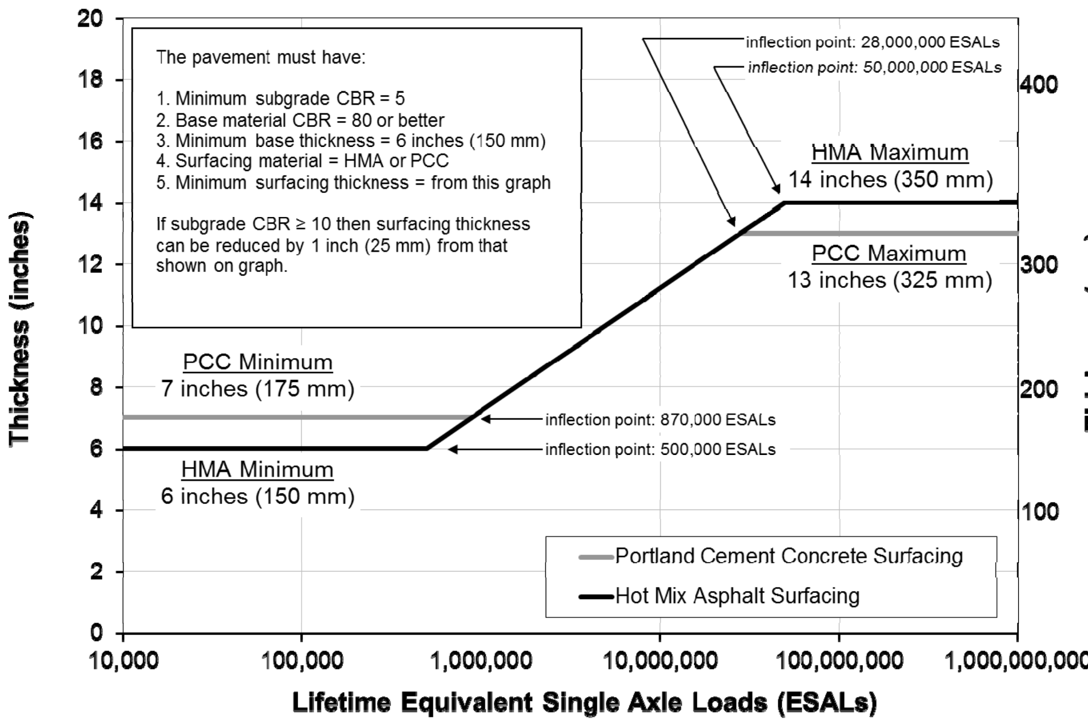

Figure PT-1.1: Long-life pavement design graph.

APPROACHES & STRATEGIES

- Consider designing long-lasting pavement that meets the requirements of this credit. Any number of pavement design methods can produce pavement sections that meet the requirements of this credit.
- Have a rehabilitation/preservation program that strives to keep existing pavements in satisfactory condition such that they may remain in place for overlays or diamond grinds. This allows simple rehabilitations such as diamond grinds and overlays to quality for this credit. Ultimately, this gives credit for a road being durable enough such that it does not need to be entirely replaced.

Example: Sample Calculation using Figure PT-1.1

A pavement is to be designed for a roadway that will have a loading of 5 million equivalent single axle loads (ESALs) over a 40-year period built on a subgrade with an average CBR of 11. ESAL calculation methods and definitions are found in the *AASHTO Guide for Design of Pavement Structures* (1993). Determine the required pavement thickness as follows:

a. Enter Figure PT-1.1 at 5 million ESALs. Note that the ESAL scale is a log scale so 5 million is more than half-way between 1 million and 10 million (Figure PT-1.2).
b. Find where 5 million ESALs intersects the plotted lines for HMA and PCC. In this case both plotted lines lie on top of one another.
c. Find where this point lies on the Thickness axis. In this case, it is 10 inches.
d. Since the average CBR is 11, the graph note allows the surfacing thickness to be reduced by 1 inch leaving a final surfacing thickness of 9 inches.
e. Note the 5 items the pavement must have as listed in the upper left corner of the graph (minimum subgrade CBR of 5, base material CBR of 80 or greater, minimum base thickness of 6 inches, surfacing material of either HMA or PCC, and a minimum surfacing thickness from the graph).
f. The final pavement should be 9 inches of HMA or PCC, placed on at least 6 inches of base course with a CBR of at least 80, placed on the subgrade.

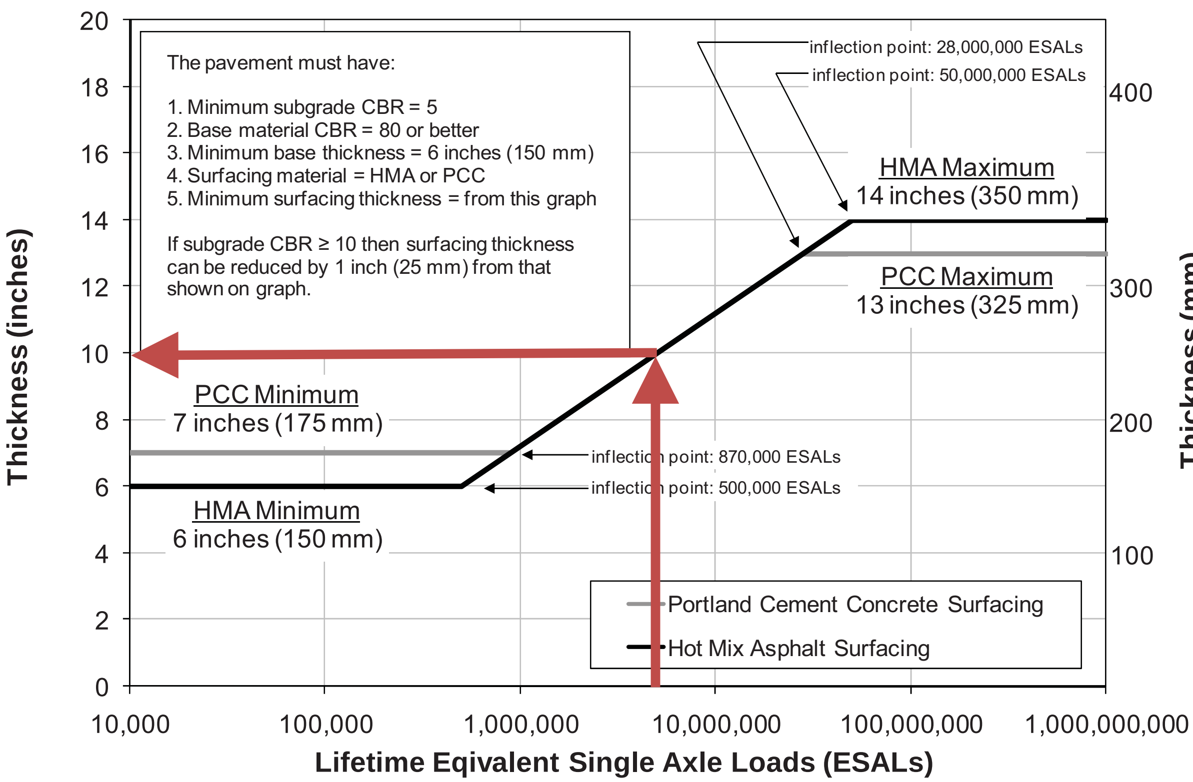

Figure PT-1.2: Example calculation.

Example: HMA Pavements

Currently, the Asphalt Pavement Alliance (APA) has a "Perpetual Pavement Award" given nearly annually to proven long lasting pavements. The APA defines a "Perpetual Pavement" as "…an asphalt pavement designed and built to last longer than 50 years without requiring major structural rehabilitation or reconstruction, and needing only periodic surface renewal in response to distresses confined to the top of the pavement." (APA, 2002). All pavements that receive the Perpetual Pavement Award are evaluated for structure, condition, maintenance and rehabilitation efforts to ensure they meet the APA requirements. Awardees for 2006, which can serve as examples of in-service long lasting pavements were:

- California Department of Transportation for a section of the San Diego Freeway (Interstate 405) between Harbor Boulevard and Beach Boulevard
- Minnesota Department of Transportation for Town Highway (TH) 61 between Wabasha and Kellogg
- Montana Department of Transportation for a 10-mile length of Interstate 90 over Homestake Pass
- Nebraska Department of Roads for a 5-mile section of State Highway 35 in Wayne County
- Tennessee Department of Transportation for a 14-mile section of State Route 14 in Tipton County
- Virginia Department of Transportation for a 6.5-mile portion of Interstate 81 in Frederick County

While these pavements are all generally higher volume, examples of a low-volume HMA long lasting pavement can be found in Muench et al. (2004). They investigated the WSDOT pavement network and found 1,339 lane-miles of low-volume pavement of which a majority (about 64%) had been in service for over 35 years without having undergone reconstruction. These pavements were also found to exist in all areas of the state and be in good condition.

Example: PCC Pavements

It may be more likely that a PCC pavement will be designed for at least 35 years. The NCHRP Report 1-32 lists 7 states in 1997 that already used PCC pavement design lives of at least 35 years. Even PCC pavements designed for shorter lives often last in excess of 35 years. For instance, most of the State-owned PCC pavements in Washington State were designed for 20 years but have lasted much longer: there are over 400 lane-miles of PCC pavement in Washington State that are already older than 35 years and are still functioning. There are many examples of this type of performance nationwide including:

- I-80 (Grundy County), I-70 (Clark County), I-290 (Cook County), I-80 (Grundy County) and I-74 (Peoria County) in Illinois (Winkelman, 2006).
- The Motorway E40 from Brussels to Leige in Belgium (Caestecker, 2006)
- US 40/ I-80 in Fairfield, CA (Rao, et al., 2006)

Additionally, many cities that surface their residential streets with PCC have experienced long-life. For example, the City of Seattle paved many urban streets with concrete before 1940 and many of those are still in service (Flynn, 2002). Some remain in their original state while others have been covered up by subsequent layers of HMA. However, in nearly all cases the original PCC pavement remains in some fashion.

POTENTIAL ISSUES

1. In many applications an adequate pavement design may not call for hot mix asphalt (HMA) or portland cement concrete (PCC) surfacing. These include gravel, dirt or bituminous surface treated (BST) roads. This credit does not apply to these roads even though these surfaces may be the most appropriate for the given project. However, the design approach is still applicable and appropriate for such projects.
2. Some commonly used pavement design methods may produce pavement thicknesses that do not meet the requirements of this graph. Such designs do not qualify for this credit even though they conform to common pavement design practice.
3. The idea that pavement design can be reduced to a single graph may be controversial among experts. However it is a necessary compromise in order to engage decision-makers who may otherwise arrive at inadequate pavement designs driven by budgetary constraints or unfamiliarity with the concepts of long-lasting design.

RESEARCH

A "long-lasting pavement" is one where the bulk of the pavement structure is designed to last for at least 35 years. The only required maintenance and rehabilitation actions are periodic surface renewals to address roughness and surface distress. This definition is taken largely from the Asphalt Pavement Alliance (APA, 2002).

This is in contrast to the historical practice of designing pavements for shorter lives (often 10 to 20 years) and then reconstructing the entire pavement structure at the end of life. Part of National Cooperative Highway Research Program (NCHRP) Project 1-32, *Systems for Design of Highway Pavements* (1997), consisted of a survey of U.S. state department of transportation (DOT) pavement design practices. This survey showed that most state DOTs use pavement design lives of 20 to 30 years (Figure PT-1.3). Based on the 35-year cutoff of this credit, most of these design lives do not qualify as "long-life." However, since 1997 the general trend has been to design pavements for longer life. For example, the Minnesota DOT has extended its PCC pavement design life standard from 35 to 60 years (Burnham et al., 2006).

Long-lasting pavements generally lead to higher initial costs (due to more material being used) but lower lifecycle costs because less rehabilitation and maintenance is needed over time. Both HMA and PCC surfaced pavements can be long lasting according to this description.

For low-volume HMA pavements Muench et al. (2004) performed a lifecycle cost comparison conforming to the guidelines of Walls and Smith (1998) between an archtype long-lasting low-volume pavement with one that was designed to be reconstructed after 25 years. They used typical Washington State Department of Transportation (WSDOT) design characteristics and found a cost savings over 50 years of about 25% for the long-lasting pavement.

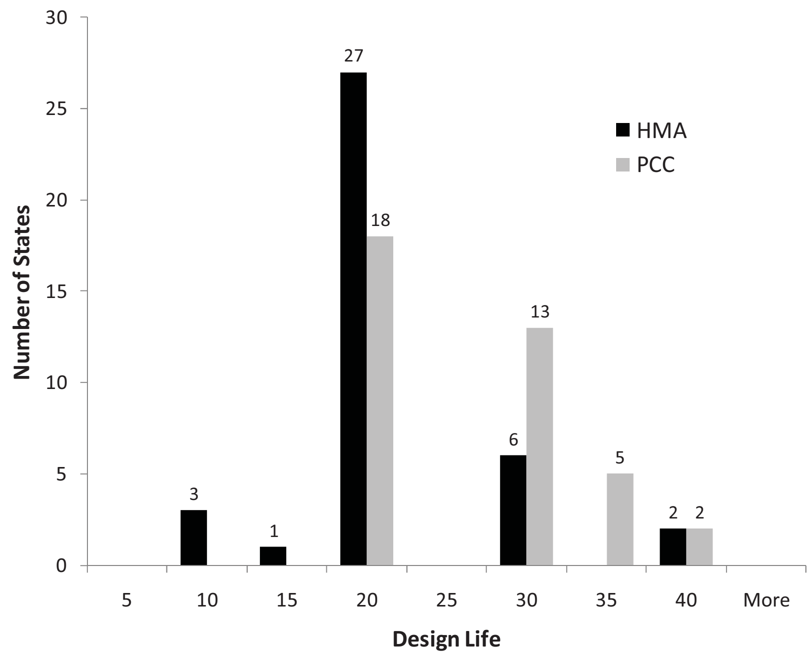

Figure PT-1.3: Pavement design lives taken from NCHRP Project 1-32 survey.

Looking at just the performance life of the pavement surface (often called the "wearing course," the Organisation for Economic Co-operation and Development (OECD) (2005) concluded that developing long-lasting surface courses that cost three times as much as traditional ones (e.g., the ones in use today) that would only require resurfacing every 30-40 years would generally be economically viable for traffic levels of at least 70,000 to 80,000 AADT in both directions. With discount rates below 6% they could be viable between 40,000 and 60,000 AADT in both directions. In general, economic savings increases as traffic levels increase and as discount rates decrease.

Development of Figure PT-1.1

Figure PT-1.1 was developed based on output from a number of generally accepted pavement design methods (AASHTO, 1993; Muench et al., 2007; Timm, 2007; Asphalt Institute, 1981; Nunn, 1998) and is an attempt to capture the basic pavement structure that is likely to result in long-life. Figure PT-1.4 shows how Figure PT-1.1 was developed using these design methods. Pavements designed according to Figure PT-1.1 are likely to be long-lasting pavements and thus result in lower lifecycle costs. Additionally, design thicknesses and subgrade requirements are straightforward.

The design assumptions that were used to develop Figure PT-1.4 are summarized here.

1993 AASHTO Rigid Design (AASHTO, 1993)

- Reliability = 75% for designs of 500,000 ESALs or less.
- Reliability = 85% for designs > 500,000 and < 20,000,000 ESALs.
- Reliability = 95% for designs of 20,000,000 ESALs or more.
- PCC modulus (E_c) = 4,000,000 psi
- PCC modulus of rupture (S'_c) = 700 psi
- Drainage coefficient (C_d) = 1.0
- Load transfer coefficient (J) = 3.2
- Modulus of subgrade reaction (k) = 200 psi/inch
- Base thickness = 6 inches of granular base material

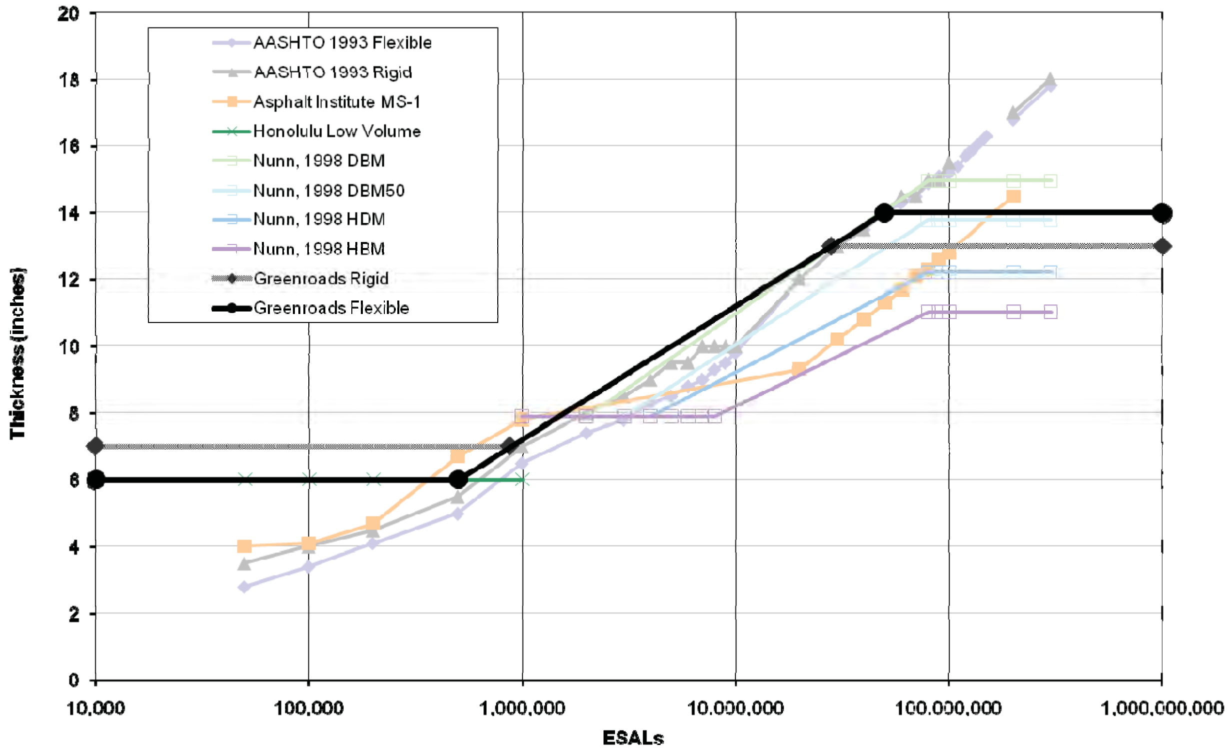

Figure PT-1.4 Development of graph using existing design methods.

1993 AASHTO Flexible Design (AASHTO, 1993)

- Reliability = 75% for designs of 500,000 ESALs or less.
- Reliability = 85% for designs > 500,000 and < 20,000,000 ESALs.
- Reliability = 95% for designs of 20,000,000 ESALs or more.
- Change in servicability over the pavement life (delta-PSI) = 1.5
- HMA structural coefficient (a-HMA) = 0.44
- Granular base material structural coefficient (a-base) = 0.13
- Granular base material resilient modulus (M_R) = 30,000 psi
- Base thickness = 6 inches of granular base material
- Subgrade CBR = 5, equivalent to a subgrade M_R = 7,500 psi

Asphalt Institute MS-1 (Asphalt Institute, 1981)

- Design table: HMA over 6 inches of untreated granular base material with MAAT = 60F
- Design Chart A-29 in MS-1

Low Volume roads (Muench et al., 2007)

- The plot for "Honolulu, low volume" comes from the City and County of Honolulu design standards that were developed as described in this paper.

TRL standards (as reported by Nunn, 1998)

The plots for the various "Nunn, 1998" come from the TRL standards.

- The full report (Report 250) can be found at: http://www.trl.co.uk/online_store/reports_publications/trl_reports/cat_highway_engineering/report_design_of_long-life_flexible_pavements_for_heavy_traffic.htm

- A version of the graph used (from Figure 8 on page 9 of 10) to get the values plotted above can be seen at: http://www.transport-links.org/transport_links/filearea/publications/1_764_PA3736_2001.pdf.

GLOSSARY

AADT	Annual average daily traffic
AASHTO	American Association of State Highway and Transportation Officials
ADT	Average daily traffic
APA	Asphalt Pavement Alliance
BST	bituminous surface treatment
CBR	California Bearing Ratio
DOT	department of transportation
ESAL	Equivalent single axle load
HMA	Hot mix asphalt
Long-life pavement	any pavement design that falls on or above the plotted line for the given pavement type and meets the criteria described in the PT-1.1 graph
M_R	Resilient modulus
NCHRP	National Cooperative Highway Research Program
PCC	Portland cement concrete
R-value	Resistance value

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PERMEABLE PAVEMENT

PT-2

3 POINTS

GOAL

Improve flow control and quality of stormwater runoff through use of permeable pavement technologies.

CREDIT REQUIREMENTS

Use a permeable (porous) pavement or pavers to control and treat at least 50% of the 90^{th} percentile average annual rainfall event post-construction runoff volume to 25 mg/L concentration of total suspended solids (TSS) or less.

Details

Low impact development (LID) stormwater controls must be considered in the scope and budget of the project for this credit to be applicable AND permeable pavement must be considered a feasible design best management practice within the stormwater management plan. This means that the feasibility study completed for PR-8 Low Impact Development must clearly show that permeable pavement (of any type) is appropriate for application on the project.

DOCUMENTATION

- Copy of the drainage or hydrology report and supporting calculations showing treatment area and percent treatment achieved. This document may be included as part of the submittal requirements for PR-8 Low Impact Development, but relevant permeable pavement calculations, areas, and treatment levels should be highlighted for this credit.
- Copy of the permeable pavement mix design. The mix design should have the following items highlighted:
    - Name of permeable technology, if used (e.g. pavers, turf, etc.)
    - Total tons of pavement on the project, including portland cement concrete and asphalt concrete (hot, warm and cold mix)
    - Total air voids in the mix (or manufacturer-tested voids specifications for pavers based on method of installation)
    - Total tons of permeable pavement used
- Copy of the maintenance plan in-place for the permeable pavement(s).
- Photo of the permeable pavement(s) installed on the project.

RELATED CREDITS

- ✓ PR-8 Low Impact Development
- ✓ EW-2 Runoff Flow Control
- ✓ EW-3 Runoff Quality
- ✓ EW-4 Stormwater Cost Analysis
- ✓ PT-4 Cool Pavement
- ✓ PT-5 Quiet Pavement

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Expectations
- ✓ Experience

BENEFITS

- ✓ Reduces Water Pollution
- ✓ Restores Habitat
- ✓ Creates Habitat
- ✓ Reduces Manmade Footprint
- ✓ Increases Aesthetics

APPROACHES & STRATEGIES

Following some of these key design and maintenance elements will promote maximum performance of permeable pavements. (Pennsylvania Department of Environmental Protection: PDEP, 2006)

Design Elements

- Use a mix design for the pavement with significant permeability (> 8 inches per hr).
- Use an open-graded subbase with minimum 40% void space (typically a washed aggregate).
- Design the pavement surface and stone bed to suitable for design traffic loads.
- Ensure placement on uncompacted sub-grade.
- Use nonwoven geotextile underlayments.
- Use level infiltration bed bottoms to prevent pooling.
- Do not place on trafficked slopes with grades over >5% (without careful design).
- Provide positive stormwater overflow from beds.
- Do not place bed bottom on compacted fill; fill with stone, as needed.
- Protect from sedimentation during construction.
- Line bed with nonwoven geotextile.
- Provide perforated pipe network along bed bottom for distribution.
- Allow three foot buffer between bed bottom and seasonal high ground water table and two feet for bedrock.
- Place infiltration beds on upland soils when possible.
- **Attempt to make periodic maintenance easy for owners in the design process**. Pavement areas should be accessible and slope gradually to accommodate standard maintenance vehicles.

Clog Prevention Maintenance

- Vacuum the pavement twice per year (or align with rainy season).
- Maintain planted areas adjacent to pavement.
- Immediately clean any soil deposited on pavement.
- Do not allow construction staging, soil/mulch storage, etc. on unprotected pavement surface.
- Clean inlets draining to the subsurface bed twice per year.

Winter Snow/Ice Removal

- Monitor the permeable pavement in the winter. Porous pavement systems generally perform better and require less treatment than standard pavements.
- Do not apply abrasives such as sand or cinders on or adjacent to porous pavement.
- Place snowplow blades slightly higher than for conventional pavements.
- Apply salt as necessary; however, keep in mind that salts will infiltrate, so organic deicers are preferable.

Maintenance Repairs

- **Do not seal-coat permeable pavement surfaces.**
- Patch damaged areas less than 50 square feet with porous or standard pavement.
- Patch damaged areas larger than 50 square feet with an approved permeable pavement.

Example: Types of Permeable Pavement

Porous Asphalt

Porous asphalt, developed about 1970, greatly resembles non-porous asphalt except the fines (very fine sand and dust) have been removed, leaving additional air voids where the fines would have been. This leaves space for water to flow through and collect. Large aggregate is also used to raise the void space. Asphalt is typically designed with a small amount of air voids, typically 4% of the total mix volume, in order to allow the binder to migrate a little. The binder remains somewhat soft long after pavement is laid, and sometimes moves into these voids, which is called migration. There were problems in the past with early porous asphalt, as the binder would migrate into the higher void spaces, blocking the travel path of the water. This has been ameliorated with the use of additives and additional binders. (North Carolina Department of Environment and Natural Resources, 2007; Hun-Dorris, 2005)

Additives and additional binders are often used to enhance the characteristics of porous asphalt. Polymers keep the binder from migrating into the void spaces. Polymer-reinforcing fibers assist with cohesion of the mix. (Hun-Dorris, 2005)

Figure PT-2.1: The appearance of porous asphalt is much the same as non-porous asphalt. The porous asphalt is placed over course of porous aggregate beneath a temporary geotextile fabric, which is to prevent clogging issues during construction. (Photo by K. Hansen, National Asphalt Pavement Alliance)

Porous Concrete

Porous concrete, much like porous asphalt, has the fines removed in order to create voids. It was also developed in the 70s. Portland cement concrete (PCC) is typically made with coarse aggregate (gravel), fine aggregate (sand), water, cement, and optional additives. In porous concrete, the fines are greatly reduced or entirely removed. Fifteen to twenty-five percent (15-25%) void spaces may be achieved, with an average flow rate of around 480 inches per hr. (Hun-Dorris, 2005) The appearance of porous PCC is generally rougher than nonporous. See Figure PT-2.2. Finishing during the construction process may create an impervious layer on the surface and attention needs to be paid to the process to prevent this from happening.

Figure PT-2.2: Porous concrete surface course in West Seattle, Washington. Quarter provided for scale. (Photo by J. Anderson)

Block Pavers

Concrete pavers, or porous paver blocks, are interlocking units which are partially pervious. Water drains through the areas between each block. These spaces can be filled with gravel or grass, and offer drainage and an attractive finish. Void space (open area) of pavers tends to be 13-15% (Hun-Dorris, 2005). Paver blocks are typically used in low traffic areas, such as walking paths or driveways, and are easy to install. See Figure PT-2.3.

Figure PT-2.3: A variety of permeable pavers, bricks, and non-porous asphalt. (Photo by Sean Thayer)

Other Permeable Pavements

Other permeable pavements include open graded aggregates, artificial turf and turf reinforcement.

Open graded aggregate. Open-graded aggregate is washed to remove fines and is typically made of single-sized, angular pieces. This allows for low settling compaction, and void spaces may constitute up to 40% of the material. Open-graded aggregate is extremely permeable. This kind of base has a strong tendency to segregate and steps must be taken through production, transport, and placement to offset this tendency. Regularly wetting the stone through the laydown and compaction processes keeps the material more stable.

Figure PT-2.4: Washed aggregate base with keys for scale.

Artificial turf. Artificial turf is typically the topmost layer of one or more other permeable layers, such as open graded aggregate. Artificial turf is rolled out in large sheets (see following photos) and pinned to the underlayer. The seams between lengths of turf are stitched. Artificial turf typically lasts for 12 to 15 years.

Figure PT-2.5: Permeable artificial turf (keys for scale). This material is typically laid over a base of washed open-graded aggregate.

Figure PT-2.6: Underside of permeable artificial turf, showing drainage holes.

Turf reinforcement. Similarly, turf reinforcement (commonly called "geogrid") is typically achieved via an open plastic grid or honeycomb matrix that is filled with gravel at the surface, placed on a well-draining aggregate, over a layer of geosynthetic filter fabric, and finally on top of a well-draining soil subbase. Usually these installations are most common in gravel parking areas or emergency accessways that need a bit of extra reinforcement in order to carry a (low volume) vehicle load. We do not expect many Greenroads projects to be made of turf or geogrids or gravel, but these methods are technically valid and may be appropriate for pedestrian areas within the project right-of-way. See Figure PT-2.7.

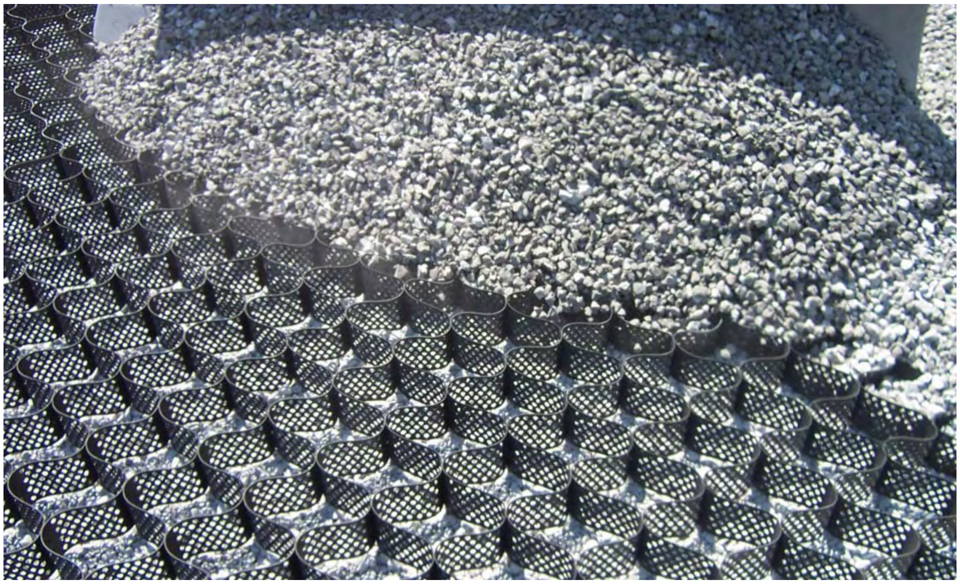

Figure PT-2.7: Turf reinforcing grid installed in gravel parking area in Pennsylvania to alleviate ponding issues. (Blair County Conservation District, n.d.)

Semi-Permeable Materials Not Suitable for Roadway Traffic

For purposes of this credit, we do not expect many Greenroads projects to be made of timber decking, wood mulch, shells or turf. These materials may be installed on a project as part of a low-impact development scheme (to reduce actual impervious surfaces, such as conventional concrete sidewalks); however, areas made with these materials do not count toward points in this credit.

Soft materials. Soft paving materials, such as wood mulch and crushed shells, are typically used for foot traffic. High void spaces allow for good permeability, and such materials tend to offer great aesthetic benefits.

Timber Decking. Decks allow for ease of walking through swampy or sandy areas while creating very low-environmental-impact structures. Wooden structures are also natural looking and aesthetically pleasing.

POTENTIAL ISSUES

1. Clogging of voids in the pavement. Routine maintenance is recommended to help prevent clogging and optimize infiltration rates.
2. Quality control and contractor familiarity varies widely with location, contractor and pavement type.
3. Pre-existing groundwater issues may not allow permeable pavements within certain distances of aquifers. However, quality treatment is provided by permeable pavements to some extent.
4. Long-term data is generally not available.
5. Permeable pavements may not be suitable for high volume traffic loads or arterials. However, shoulder areas and sidewalks may be appropriate applications to consider.

RESEARCH

Permeable pavement is a low-impact development technique that can be used as part of a comprehensive roadway stormwater management plan. The terms “permeable,” “porous” or “pervious” are used interchangeably to describe a pavement structural system that has more voids than a conventional paved surface such as concrete or asphalt. For stormwater design, permeable implies that the curve number (CN) for areas paved with these surface materials is lower than a conventionally paved surface. For composite mixes, such as asphalt and concrete, this generally means intentionally designing for a higher void ratio in the mix, i.e. fewer fine aggregates, larger coarse aggregate or introduction of air during mixing.

A permeable surface may also be achieved through a strategic layout of stone or masonry pavers and filling paver gaps with a well-draining material, which may be designed to withstand vehicular loading. This also provides an increase in overall void ratio over a large surface area. Further, artificial turf or grid reinforcement are other types of surfaces that may also be considered permeable “pavements,” but in general for roadways that carry high volumes of traffic, there is no long-term performance data to justify that they offer enough structural capacity to carry those loads. Generally, the latter applications will be seen most commonly in pedestrian areas or areas with very low traffic volumes.

How Do Permeable Pavements Work?

Due to the increased void ratio, water is conveyed through the surface and allowed to (1) infiltrate, (2) evaporate, whereas conventional surfaces will not do so. (NCDWQ, 2007) A permeable pavement surface therefore becomes an active participant in the hydrological cycle: rainfall and snowmelt are conveyed back through soils into groundwater. Therefore, permeable pavements can become part of a stormwater infiltration system if appropriately designed, constructed and maintained. This means that key elements of the pavement must be considered: (1) long-term hydraulic capacity of the material, and (2) infiltration capacity of the base material. (City of Seattle, 2008)

Permeable pavements allow rainwater, snowmelt and air to pass through the matrix, recharging the groundwater table and refreshing soil nutrients. This reduces total volume of runoff flows leaving the paved surface. The void space captures water and slowly releases it to infiltrate the subgrade. This filtration process reduces the total quantity and concentration (generally) of pollutants that would otherwise runoff the paved surface and require treatment, volume control and flow attenuation. Typical pollutants removed or improved are hydrocarbons and heavy metals, (Hun-Dorris, 2005) as well as a number of other chemical compounds that are considered deleterious. (Geosyntec Consultants and Wright Water Engineers, 2008)

The air voids also allow for evaporation, which offers a cooling process on the surface and to the stormwater runoff. This is especially beneficial in cities which experience extremely high temperatures in summer - traditional "blacktop" temperatures can make some public spaces unusable in warmer weather. (Hun-Dorris, 2005)

Existing Literature

Stormwater quality and quantity performance data is relatively sparse for permeable pavements, especially for long term data. “Long-term” performance data (6 years) is available from four different pervious paver and turf reinforcing grid systems installed in urban parking lots in western Washington from Brattebo and Booth (2003). These lots were originally tested by Booth and Leavitt (1999) in 1997. Site soils were sands with a high hydraulic conductivity to isolate the pavement hydraulic conductivity. These two studies showed significantly or completely reduced surface runoff for winter storm conditions even long-term, except in one condition measured in the revisit by Brattebo and Booth: a 72-hour storm produced about four millimeters of surface flow.

In the UK, a porous asphalt parking lot was tested in place and monitored for flow control performance over a 13-month period. The results indicated that the pavements reduced peak flows and increased time of concentration. (Abbott & Camino-Mateos, 2003) A relatively recent study of another porous asphalt parking lot in Rhode Island by Boving et al. (2008) investigated the potential for contaminants to leach from the lot into the groundwater table directly below the lot’s infiltration bed. They found a retention rate of more than 90% for metals, no bacteria, and a much lower rate for nutrients (27%). However, they detected polycyclic aromatic hydrocarbons (PAHs) at near minimum allowable levels.

Information on pavement structural performance in high-traffic volume roadway environments is very limited. Open-graded surface courses (OGFC) in Oregon have traditionally been installed to reduce noise and spray. However, they may theoretically also reduce surface flows via horizontal hydraulic conductivity, which occurs below the surface course and moves water to the shoulder areas, but this has not been well-studied. (City of Seattle, 2008)

However, the International Stormwater BMP (Best Management Practice) database (BMPDB) reports that, of six reporting permeable pavement sites, quality indicators for effluent heavy metal and total suspended solid concentration were as follows (shown compared to a detention pond) based on median values from mean effluent concentrations. For comparison, ranges are also provided.

Table PT-2.1: Constituent removal performance data for 6 permeable pavement installations and 25 detention ponds. (GeoSyntec Consultants and Wright Water Engineers, 2008)

Constituents	Unit	Value	Permeable Pavement Effluent (6 reporting)	Detention Pond Effluent (25 reporting)	Relative Removal (%)
Suspended Solids	(mg/L)	Median	16.96	31.04	183
		Range	5.90 – 8.72	16.07 – 46.01	-
Total Copper	(µg/L)	Median	2.78	12.10	435
		Range	0.88 – 8.78	5.41 – 18.80	-
Total Lead	(µg/L)	Median	7.88	15.77	200
		Range	1.64 – 37.96	4.67 – 26.87	-
Total Zinc	(µg/L)	Median	16.60	60.20	363
		Range	5.91 – 46.64	20.70 – 99.70	-
Total Phosphorus	(mg/L)	Median	0.09	0.19	211
		Range	0.05 – 0.15	0.12 – 0.27	-
TKN	(mg/L)	Median	1.23	1.89	154
		Range	0.44 – 3.44	1.58 – 2.19	-

In all six quality measures tested, permeable pavement installations treated effluent stormwater to a higher level of treatment than conventional detention ponds. Note that data for these statistics comes from 15 U.S. states and also the United Kingdom (UK) and Sweden, but neither the locations nor the types of these permeable pavements were specified, nor were the storm conditions when these data were measured. Additionally, data was not provided for influent treatment levels because it was not measured for the pavements or there were not enough samples for statistical analysis. However, the BMPDB maintains a working database and it is currently updating statistics for 2009.

Finally, studies on safety are also limited. One study of safety of surface course porous asphalt in Europe (where permeable pavements) are more common was inconclusive due to inconsistent reporting. (Elvik and Greibe, 2005)

Permeable Pavement Benefits

Permeable pavements offer many benefits, both aesthetic and practical. These include (Charles River Watershed Association: CWRA, 2008):

- Reduces stormwater runoff, total water volume, and flowrate
- Treats water runoff, including reduction of temperature
- Increases groundwater infiltration and recharge
- Provides local flood control
- Improves the quality of local surface waterways
- Reduces soil erosion
- Reduces the need for traditional stormwater infrastructure, which may reduce the overall project cost
- Increases traction when wet
- Reduces splash-up in trafficked areas
- Extends the life of paved area in cold climates due to less cracking and buckling from the freeze-thaw cycle
- Reduces the need for salt and sand use during the winter, due to little or no black ice
- Requires less snow-plowing
- Reduces groundwater pollution
- Creates greenspace (grass groundcover, shade from tree canopies, etc.)

- Offers evaporative cooling
- Porous pavements reduce the volume of stormwater, increase the recharge, control the peak rate, and offer a high outflowing water quality.
- Pollutants are removed: total suspended solids are reduced by 85%, NO_3 by 30%, and total phosphorous by 85%. (PDEP, 2006)

Cost Considerations

With a permeable pavement system, traditional stormwater systems may be reduced or bypassed entirely. This may reduce the total lifecycle cost of the project significantly. Cost depends on the system chosen, and varies widely. A washed aggregate gravel pathway that may be appropriate in some pedestrian areas will be extremely inexpensive and have extremely high hydraulic conductivities (Hun-Dorris, 2005).For surface courses, permeable asphalt is more expensive than traditional asphalt. The project specifics also significantly dictate the cost, and must be considered individually. (EPA, 2000)

- Porous asphalt, with additives, may cost more than standard asphalt on a unit area basis. Generally this depends on availability and contractor familiarity. (PDEP, 2006)
- Porous concrete as a material is generally more expensive than porous asphalt and requires more labor and experience for installation due to specific material constraints. (*ibid.*)
- Porous paver blocks vary in cost depending on type, manufacturer, order volume and site layout. (*ibid.*)

Design Elements

Design of permeable structures generally includes a permeable surface such as asphalt or portland cement concrete over a base of fines, which help to filter the water, and uniformly graded gravel, which stores the water as it infiltrates through the ground below the structure. An uncompacted soil base is highly recommended, and construction practices which emphasize this are critical for groundwater recharge. (CRWA, 2008)

The design of permeable pavements varies considerably due to location and cost considerations. However, three things must be considered regardless of which design is being considered: (1) the location and any unique features, hydrogeologic and geotechnical characteristics, local codes, etc.; (2) proper structural design; (3) and quality construction (Hun-Dorris, 2005). Soil beneath the permeable pavement structure must allow the accumulated water to drain, meaning these soils must not be overcompacted. Care must also be taken to ensure that debris and water drains away from the permeable structure, in all directions, to ensure that clogging does not become a problem.

Maintenance Requirements

Regular maintenance is recommended for permeable pavements. This may include re-sodding, laying gravel, and other small repairs. Other typical concerns for maintaining the permeable pavement are limited to aesthetics, snow and ice conditions and the prevention/repair of clogging.

Clog Prevention

More typically, maintenance of a permeable structure refers to vacuum sweeping, pressure washing, or air blowing to remove debris. Vacuuming is recommended (PDEP, 2006). Depending on the site, this may need to happen 2-4 times a year (CRWA, 2008). Clogging can be prevented or mitigated through proper routine maintenance of planted areas, cleaning up soil spills, thoughtful construction staging and storage of soils, covering permeable pavement installations during construction and cleaning drainage inlets at least twice a year or seasonally (PDEP, 2006). Proper design may prevent clogging, such as designing for drainage away from the porous section of pavement. This will keep debris from sweeping onto the pavement while allowing rain to infiltrate the soil below (PDEP, 2006).

Winter Maintenance

Winter maintenance for permeable pavements is simpler than that for typical pavements because the increased air voids and heat retention in the stone bed beneath the pavement tends to provide good snow melt, leading to reduced snow and ice problems. Abrasives that might promote localize clogging, such as sand, on or near the porous pavement should be avoided. Snow plowing may be used with caution, setting the blade about an inch higher than normal. Salt may be used; however, nontoxic organic deicers are preferred, as the contaminated water will go directly to the water table.

Repairs

Drainage structure repair has the highest priority, in order to keep the system working as designed. Pavement structural repairs will likely be limited primarily to areas that may have settled due to soft soils. These areas may be patched with standard or permeable pavement. Potholes will rarely be a problem, due to the lack of a freeze-thaw cycle as in typical pavements. Seal coats ought not to be used, as they would nullify the benefit of a permeable pavement.

GLOSSARY

OGFC	Open-graded friction course
Curve Number	A hydrological parameter that is used to model runoff
TKN	Total Kjeldahl Nitrogen
Permeable pavement	A pavement structural system that has more voids than a conventional paved surface such as concrete or asphalt

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WARM MIX ASPHALT

GOAL

Reduce fossil fuel use at the hot mix asphalt plant, decrease emissions at the plant, and decrease worker exposure to emissions during placement.

CREDIT REQUIREMENTS

Reduce the mixing temperature of hot mix asphalt by a minimum of 50°F from that recommended as the mixing temperature by the asphalt binder supplier. Mixing temperature shall be measured as the temperature of the mixture as it exits the mixing drum (for drum plants) or pugmill (for batch plants). This reduced temperature mix must comprise a minimum of 50% of the total project pavement (hot mix asphalt or portland cement concrete) by weight.

Details

This credit requires a recommended HMA mixing temperature to be provided by the asphalt binder supplier. This recommended temperature should be as if no WMA technology were to be used. If the recommended mixing temperature is provided as a range, use high end of the range for calculation of the required 50°F degree reduction.

Note that concrete products do not qualify for this credit.

Several additives and plant equipment options are available for WMA technology. All are acceptable. Based on regional availability, one additive or equipment type may be preferred over another.

DOCUMENTATION

- A copy of the WMA mix design should be submitted. The mix design should have the following items highlighted:

  a. Name of WMA technology used
  b. If an additive was used, percentage by weight of binder or by weight of mix
  c. Total tons of high-type pavement on the project, including Portland cement concrete and asphalt concrete (hot, warm and cold mix)
  d. Total tons of WMA pavement used
  e. WMA mix temperature as it exits the drum (drum plant) or pugmill (batch plant)
  f. Recommended asphalt binder mixing temperature from the asphalt binder supplier.
  g. Total fuel used in the burner per ton of WMA
  h. Total fuel used in the burner per ton of HMA if HMA was used. If HMA was not used, a general plant average is acceptable.

- A photo taken during placement of the mix, clearly labeled to identify the WMA.

PT-3

3 POINTS

RELATED CREDITS

✓ MR-4 Recycled Materials

SUSTAINABILITY COMPONENTS

✓ Ecology
✓ Equity
✓ Experience

BENEFITS

✓ Reduces Fossil Fuel Use
✓ Reduces Air Emissions
✓ Reduces Greenhouse Gasses
✓ Improves Human Health & Safety
✓ Reduces First Costs

APPROACHES & STRATEGIES

- Consider specifying a temperature reduction at the plant of a minimum of 50°F in the design documents and list all approved additives or methods allowed to achieve this temperature reduction.

Example: Case Study – Warm Mix Asphalt on I-90 in Vantage, WA

The Washington State Department of Transportation (WSDOT) recently completed a 10.6 mile mill-and-overlay project on the eastbound truck lane of Interstate 90 between Vantage and George, WA (WSDOT, 2008). Part of the project (approximately 5.0 miles) was paved using conventional HMA, while the remaining final 5.6 miles was paved using WMA. The same contractor, production plant, trucks and paving equipment were used for both mixes. Both mixes were placed in one two-inch lift and contained 20 percent recycled asphalt pavement (RAP), the maximum allowed by WSDOT without special testing. The mix design was half-inch Superpave with 5.2 percent PG76-28 binder. Sasobit® was added to the warm mix at 2.0 percent by weight of the binder. The Sasobit® additive was provided by Sasolwax, Inc. and produced at the Sasol South Africa plant in Sasolburg, RSA. The additive cost was roughly $25,000 (including shipping), or about two percent of the total $1.36 million paving portion of the project.

Based on field data collected, the WMA was mixed at 300°F and the HMA was mixed at 350°F. This resulted in a 23.5 percent reduction of diesel fuel use in the burner. The manufacturing processes for these two types of asphalt pavement were generally identical, save that the WMA includes the Sasobit® additive to allow a lower production temperature to be used in the burner. (It is worth noting that this temperature was much higher than the minimum temperature necessary for the additive, according to Sasolwax) (Sasol Wax Gmbh, 1997).

Other notes on this project:

- Field compaction test results (using standard WSDOT procedures) averaged 93.7 for WMA (11 lots with 5 random samples per 400-ton lot) and 93.6 percent for HMA (19 lots), with WMA allowing more time for the rollers to reach compaction.
- During placement, infrared photographs taken during observations indicated that temperatures were more uniform across the WMA mat than the HMA mat.

More information on that project can be found here: http://www.wsdot.wa.gov/Projects/I90/WGeorgePaving/

POTENTIAL ISSUES

1. Monitor the plant operations to ensure that the temperature is maintained at 50°F below the recommended mixing temperature.
2. Do not use recommended mixing temperatures that might result in asphalt binder thermal degradation, typically defined by the Asphalt Institute as temperatures above 350°F (175°C).

RESEARCH

Warm mix asphalt (WMA) is a relatively new technology to the United States' paving industry that shows great promise to reduce both the amount of energy used in constructing hot mix asphalt (HMA) pavements and the air emissions associated with pavement construction. WMA is commonly used in Europe, where non-renewable resources are strictly regulated and often heat and fuel energy required for conventional hot mix asphalt (HMA) are cost-prohibitive (D'Angelo et al., 2008). Lately, WMA has become an intriguing environmental marketing incentive, both popularized and heavily advocated, and the material is becoming more accepted due to the relatively new sustainability movement among engineering and construction professionals. Emphasis on climate change, energy conservation and human health impacts has brought WMA paving to the forefront of this newfound environmental movement. Recent field and laboratory studies (Hurley, 2006; Wasiuddin, Selvamohan, Zaman, & Guegan, 2007) conducted in the U.S. have produced positive results, indicating that WMA is a viable option to reduce the potential environmental and societal impacts associated with paving and construction.

Most of the warm mix asphalt studies and research cite several positive and few negative traits of the material. Particularly detailed research and references can be found in the Kristiandottir's thesis (2006) and Ghandi's dissertation (2008). Both of these researchers review the existing types of warm-mix additives available, discuss the engineering properties of the materials and additives in detail, and address potential applications such as cold weather paving and high recycled content mixes. The most common incentives cited are lower fuel consumption during the mix production and improved compaction and workability during placement of the mix (Kristjansdottir, 2006). Both of these traits allow for more uniform mat temperatures and extended compaction time.

However, long-term WMA performance data in U.S. applications is scarce because the technology is so recent. Noted drawbacks generally include slightly heightened concern for rutting potential, thought to be due to inadequate drying of the aggregates for use in the lower temperature mixes (Hurley, 2006; Kristiandottir, 2006; Wasiuddin, Selvamohan, Zaman, & Guegan, 2007; Ghandi, 2008) and, simply, cost (Muench, Kristiandottir, Pierce, & Willoughby, 2007).

More recently, interest in warm mix material has sparked field experiments for performance testing with using a higher content of recycled asphalt pavement (RAP) to alleviate stiff mixes (Mallick, Bradley, & Bradbury, 2007) and a noteworthy short-duration high-load study at the NCAT track (Prowell, Hurley, & Crews, 2007). Generally, the results show agreement with the benefits noted above for comparing performance of WMA with a similarly designed and placed mat of HMA.

Air emissions contribute to global warming, acid rain and smog formation throughout the lifecycle of a pavement. Additionally, studies have shown that asphalt paving may have detrimental effects on human health (Herrick, McClean, Meeker, Zwack, & Hanley, 2007; Gasthauer, Maze, Marchand, & Amouroux, 2008) due to the presence of volatile hydrocarbons (PAHs, polycyclic aromatic hydrocarbons) released when the asphalt is heated. For example, the most common gas emitted from bituminous pavements is naphthalene which is classified by the Environmental Protection Agency (EPA) as a carcinogen. Lifecycle emissions come from transportation sources, any construction or demolition equipment, stationary manufacturing equipment and any part of the manufacturing process that uses fossil fuels as an energy source (including electricity). Other substance emissions come from fumes of the pavement itself during both the manufacturing process and construction, which can adversely affect human health. Air emissions are thus highly regulated by the EPA. Of particular interest are emissions during the paving process, which are known to directly impact worker health (NIOSH, 1997).

Fossil fuel derivations, such as coal, diesel fuel, and gasoline are major inputs to all processes in the production of asphalt pavements. These fuels are used in many types of paving equipment during aggregate excavation, truck and rail transportation, manufacturing equipment (such as burners and crushers), paving construction (and deconstruction), and in disposal at landfills. Also, electricity and heat at the plant are generated using mostly non-renewable fossil fuel sources in most U.S. locations. This credit focuses on reducing lifecycle air emissions only from the mix production and placement processes by encouraging reduced fuel use at the plant through use of a temperature-lowering warm mix additive.

Lifecycle assessments (LCA) have been completed by various institutions attempting to identify and quantify air emissions and energy use for asphalt pavements (Zapata & Gambetese, 2005; Meil, 2007; Horvath, 2007). Zapata & Gambetese (2005) note that because existing LCAs vary in method, they tend to produce contradictory results according to their input variables and model assumptions. Further, reliable and publicly accessible data on environmental emissions or fuel consumption for any type of HMA pavement, including WMA, is rare, outdated or simply does not currently exist. However, the EPA published general emissions estimation techniques for standard hot mix plants based on average U.S. data collected for the 1997 industry census (EPA, 2000). Since air emissions increase with higher temperatures, and WMA allows for lower temperatures to be used in production, it follows that WMA applications will generally reduce emissions during the pavement production process.

GLOSSARY

EPA	Environmental Protection Agency
HMA	Hot mix asphalt
LCA	Lifecycle assessment
PAH	Polycyclic aromatic hydrocarbon
WMA	Warm mix asphalt

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COOL PAVEMENT

GOAL

Reduce contribution to localized increased air temperatures due to pavement reflectance and minimize stormwater runoff temperatures.

CREDIT REQUIREMENTS

Use a pavement surface with a minimum albedo of 0.3 (measured using ASTM E 903) for a minimum of 50% of the total project pavement surfacing by area.

OR

Use a porous pavement or pavers for a minimum of 50% of the total project pavement surfacing by area.

In either case, the surfaces intended for use by vehicles (e.g., roads, parking lots) must all be included in the calculation. Other surfaces (e.g., sidewalks) may be included if desired. A combination of materials may be used to meet the 50% area requirement.

Details

Calculate the percent of cool pavement (CP) surface area on the project using Equation PT.4.1.

$$CP\ (\%) = [(LSA + PSA)/A] \times 100\% \qquad \text{(Equation PT-4.1)}$$

Where:

- ***LSA*** is the total light-colored or high albedo surface area tested to have a minimum 0.3 albedo
- ***PSA*** is the total permeable or porous surface area
- ***A*** is the total paved surface area on the project.

Area calculations must be consistent across all credits requiring computations of this type (i.e. the total area, **A**, must match throughout). Note that combinations of materials may be used to achieve this credit.

DOCUMENTATION

Provide the following supporting information, as applicable:

- Copy or copies of albedo test results.
- Copy of the porous pavement mix design noting total air voids in the mix, or voids specifications for paver blocks based on method of installation.
- A photo of the pavement with cool pavement areas identified either with text describing them or graphics highlighting them.
- A plan showing the locations of the cool pavements on the project with cool pavement areas highlighted.

PT-4

5 POINTS

RELATED CREDITS

- ✓ MR-6 Energy Efficiency
- ✓ PT-2 Permeable Pavement

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Equity
- ✓ Economy
- ✓ Extent
- ✓ Expectations
- ✓ Experience

BENEFITS

- ✓ Reduces Fossil Fuel Use
- ✓ Reduces Air Emissions
- ✓ Reduces Greenhouse Gases
- ✓ Increases Aesthetics

APPROACHES & STRATEGIES

- Consider specifying a high albedo aggregate wearing course for the pavement section (especially for HMA), high albedo pavements (like PCC) or consider high albedo surface coatings.
- Consider porous or permeable pavement materials or products.

Example: Calculation

A 2-mile section of Interstate highway is reconstructed consisting of two 12-ft wide travelled lanes paved with PCC (albedo measured at 0.46) and an 8-ft wide outside shoulder paved with HMA (albedo of the HMA measured at 0.18). In this instance, the PCC counts as a cool pavement. The total cool pavement area is calculated using equation PT-4.1:

$$LSA = (2\ miles)(5280\ ft/mile)(12\ ft)(2\ lanes\ of\ PCC) = 253{,}440\ ft^2$$

$$PSA = 0$$

$$A = (2\ miles)(5280\ ft/mile)[(12\ ft)(2\ lanes\ of\ PCC) + (8\ ft)(1\ HMA\ shoulder)] = 337{,}920\ ft^2$$

$$CP\ (\%) = \left[\frac{253{,}440 + 0}{337{,}920}\right] \times 100\% = 75\%$$

This project would satisfy the credit requirements.

POTENTIAL ISSUES

1. Albedo is not the only indicator of a pavement's contribution to the UHI effect.
2. For a pavement in a rural area, it may not be appropriate to pursue this credit since the UHI effect is a distinctly urban phenomenon.
3. Pavement albedos change over time as they weather and age.
4. Pavement albedos also vary with surroundings such as time of day and shade cover.
5. Retention of heat in the pavement sections vary with thickness.
6. Permeable pavements can become less permeable over time without proper maintenance.

RESEARCH

The urban heat island (UHI) effect is "…a measurable increase in ambient urban air temperatures resulting primarily from the replacement of vegetation with buildings, roads, and other heat-absorbing infrastructure." (EPA 2009). This occurrence (Figure PT-4.1) is due to the reduction of natural vegetation, increased human activity and the absorption and radiation of solar energy in all built surfaces. Roofs, parks, water bodies and pavements all have different properties that determine how much of the sun's heat is absorbed and released, and they all interact together and with other systems in an urban area to produce a total Heat Island Effect (HIE). The UHI effect should not be confused with climate change (global warming); they are separate and rather unrelated items. The UHI effect is specifically a local temperature increase (generally the difference between urban and surrounding rural areas) while climate change refers to larger scale variations in global climate caused, in general, by greenhouse gas emissions resulting from human activity. Studies and simulations performed for 10 large cities in the U.S. indicate an average UHI effect of about 3.5°F (2°C), compared to surrounding rural areas (Pomerantz et al., 2000) and some cities are as much as 10°F (5.6°C) warmer than surrounding natural land cover (EPA 2008). UHI can impact sustainability in the following ways (EPA, 2009):

- **Energy consumption**. Higher temperatures increase artificial cooling (air conditioning) demand. Akbari (2005) claims that increased cooling demand can account for 5-10% of urban peak electricity demand. Figure PT-4.2 shows how energy loads can increase as temperature rises.

- **Emissions**. Increased electricity demand results in more power plant operation and resultant air pollution and greenhouse gas generation.
- **Human health**. The UHI effect can contribute to "…general discomfort, respiratory difficulties, heat cramps and exhaustion, non-fatal heat stroke, and heat-related mortality." (EPA, 2009).
- **Water quality**. Higher pavement temperatures can heat stormwater runoff. Higher water temperatures can, in turn, affect metabolism and reproduction of aquatic species.

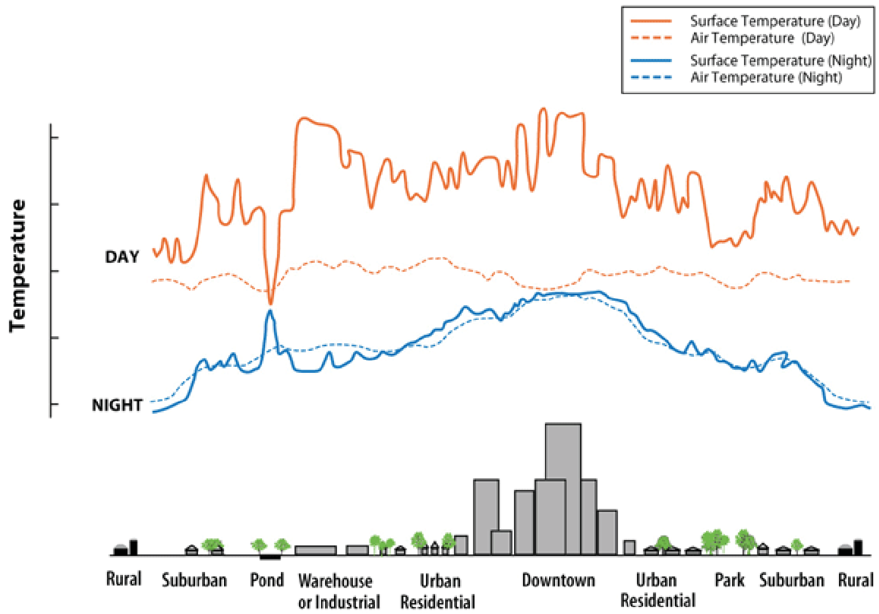

Figure PT-4.1: Urban Heat Island Effect (UHI). The graph shows how nighttime temperatures remain warmer in the urban areas due to the UHI (from EPA, 2009).

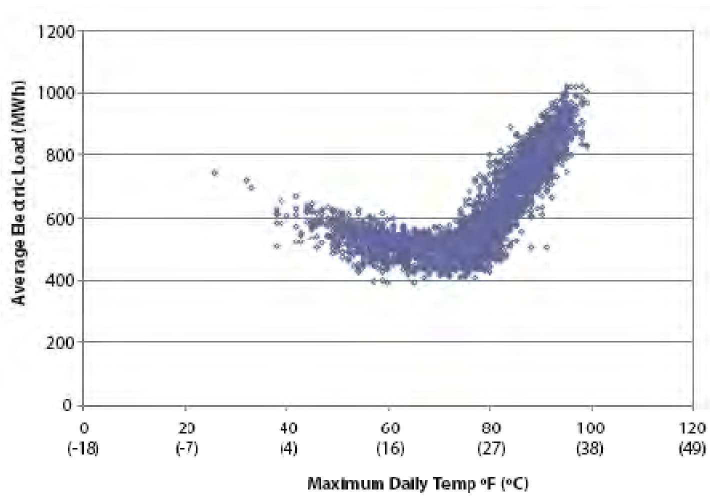

Figure PT-4.2: Increasing electrical loads with increasing temperatures.
This is an example of New Orleans from Sailor (2002).

Impacts

In short, UHI effect sustainability impacts are driven by energy consumption (for energy and emissions impacts) and heat (for human health and water quality impacts).

Energy

Increased local urban temperatures typically lead to higher electrical loads and more resultant energy use and emissions. For every 1°F (0.6°C) increase in summertime temperature, peak utility loads in medium and large cities increase by an estimated 1.5-2.0 % (EPA, 2008). A reduction of 1.8-3.6°F (1-2°C) in regional average temperatures can result in a 10% decrease of the peak energy demand, hence lessen annual energy cost and all impacts related to energy extraction. Rosenfeld et al. (1996) estimated that eliminating the UHI effect in Los Angeles (a reduction of 5.4°F (3°C)) could reduce peak power consumption by 1.6 GW resulting in a savings of about $175 million/year. Of note, Rosenfeld et al. (1996) estimated the contribution of cooler pavements (a theoretical increase of all pavement albedo by 0.25) to this total at $15 million/year.

Human Health

Higher urban temperatures lead to the formation of more smog. Specifically, the chemical reaction between sunlight, nitrogen oxides (NOx) and volatile organic compounds (VOCs) in the atmosphere that leads to the formation of particulate matter (PM) and ground-level ozone is a temperature sensitive reaction; production of PM and smog is increased with increased temperature. The impacts of this reaction on humans are significant and include breathing difficulties, headaches, fatigue and exacerbated respiratory problems. Thus, the UHI effect can increase PM and ground-level ozone in an urban area by raising the local temperature. In modeling the Los Angeles Basin, Rosenfeld et al. (1996) estimated that elimination of the UHI effect in Los Angeles (a reduction of 5.4°F (3°C)) could reduce smog exceedance by 12% (reduce the amount of time the area exceeds the California standard of 90 ppbv at the time of the study) resulting in a savings of about $360 million/year. Of note, Rosenfeld et al. (1996) estimated the contribution of cooler pavements (a theoretical increase of all pavement albedo by 0.25) to this total at $76 million/year.

Pavement Contribution to the Urban Heat Island Effect

Pavements are found to be a significant contributor to the UHI temperature increase because (1) they constitute a substantial portion of total urban land coverage and (2) pavements can store and radiate a significant amount of heat. In looking at four cities (Sacramento, Chicago, Salt Lake City and Houston) Rose et al. (2003) found pavements (roads, parking lots, sidewalks, etc.) make up 29-45 percent of the total land coverage, and about half the total UHI contributing surface coverage. Rose et al. (2003) further report that roads (the item most directly addressed by Greenroads) make up 33-59 percent of the total pavement coverage. Thus, as a gross approximation, road pavements constitute about one-quarter the total surface area contributing to the UHI (about 33-59% of one-half the UHI contributing surface coverage) in urban areas. The next section discusses the impact cooler pavements can have on the UHI effect.

Cool Pavement Impacts

Cool pavements are designed to reduce the absorption of the sun's energy and consequently radiate less heat to the surrounding environment. Solar energy is absorbed by the pavement surface and becomes stored as heat in the pavement. Paving materials can reach as much as 150°F (EPA, 2005) on sunny days, radiating this heat during the day and during the night back into the air as well as heat storm water that reaches the pavement surface.

In addition to the impacts mentioned in the previous section, studies in California (Pomerantz et al., 2000) have estimated that if the solar absorption of all pavements were reduced from 90% to 65%, the peak air temperature in an urban area would decrease by 1°F (0.6°C). This decrease is roughly equivalent to an albedo of 0.25 on 25% of all pavements in a certain urban area (Pomerantz et al., 2000). Experimentally and by calculation it is found that an increase in albedo of 0.1 produces a change in pavement surface temperature of about -7°F (-4°C) (Pomerantz et al., 2003). It may also be, although it has not been seen experimentally, that if pavement surface temperatures are decreased on hot days the resulting cooler pavements may also have longer lifetimes due to reduced thermal stresses.

Properties of Cool Pavements

Cool pavement strategies are those that seek to purposely reduce pavement's impact on the UHI effect by affecting how pavements absorb, store and radiate heat. Figure PT-4.3 illustrates the relationship of heat transfer mechanisms in a pavement structure.

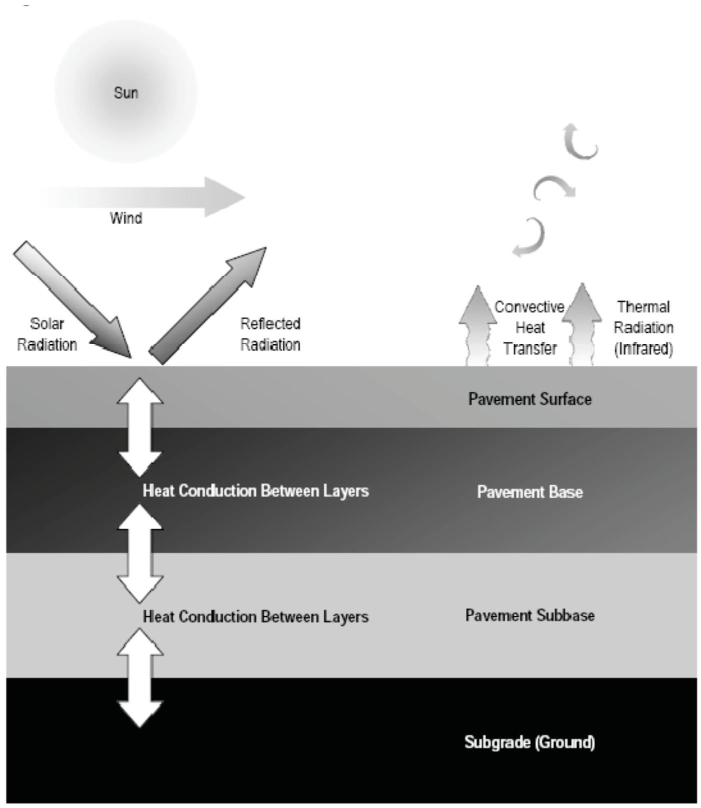

Figure PT-4.3: Heat related characteristics and processes in pavement (Cambridge Systematics, Inc., 2005).

There are two main types of cool pavement strategies:

1. **Reduce solar reflectance.** Use lighter-colored materials because they have higher solar reflectance (as measured by albedo) so they absorb less of the sun's energy and stay cooler.
2. **Improve cooling**. Use porous materials because they (1) allow for convective cooling because air can flow through the pavement voids and (2) allow for evaporative cooling because water can also enter the pavement voids in a rain event.

Reduce Solar Reflectance

Most studies mention the effect of heat island mitigation taking place in the top layer due to variations in solar reflectance and porosity. However, other studies have shown that a change in solar reflectance alone may not be the only important factor in determining the pavement surface temperature through a whole year. Factors such as pavement thickness, heat storage capacity, the material's thermal conductivity and density are also important considerations (Golden & Kaloush, 2006; Cambridge Systematics, Inc., 2005).

The solar reflectance of a pavement is correlated to a number of pavement properties including (Pomerantz et al., 2000):

- **Pavement age.** As a light pavement gets older it gets darker. For instance, concrete is darkened by the presence of iron oxide and dirt. As a dark pavement gets older it gets lighter. For instance, as the asphalt binder wears off the aggregate on the pavement surface the aggregate shows and the albedo of the pavement approaches the albedo of the aggregate. Also, the asphalt itself becomes lighter due to oxidation.

- **Aggregate color**. Pomerantz et al. (2000) examined several different chip seals and found that their albedo was approximately 50-80% that of its constituent aggregate.
- **Non-pavement factors**. Other factors such as wind, sea breeze, shadowing trees, buildings, and even vehicle shadows. Thus, the properties of the pavement are not the only properties that contribute to pavement solar reflectivity.

Figure PT-4.4 shows several different pavements and their corresponding albedo in the Phoenix, Arizona area (Cambridge Systematics, Inc., 2005).

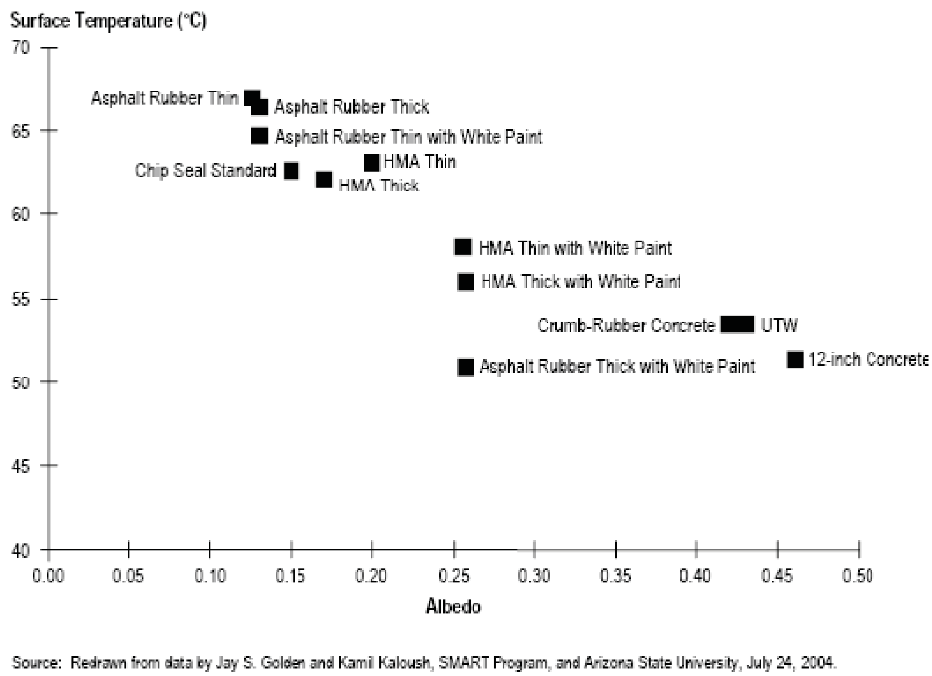

Figure PT-4.4: Surface temperature and albedo for selected types of pavements in Phoenix, Arizona (Cambridge Systematics, Inc., 2005).

Design Options. There are a number of ways to provide highly reflective pavement surfaces. This section lists a few of the more popular:

- Use a more reflective material such as portland cement concrete (PCC) for the pavement surface. The average of PCC albedo is usually higher than that of aged hot mix asphalt or bituminous surface treatments (Pomerantz et al., 2003). There are also a number of additives that can be used to further lighten surface color and increase reflectivity including slag cement, white cement and light fly ash.
- Use a lighter-colored aggregate. For bituminous mixtures (e.g., hot mix asphalt, HMA) the binder is usually quite dark. This can be at least partially offset by using a light-colored aggregate like limestone.
- Change the pavement's surface color. There are a number of existing techniques that can be used to color a pavement mixture or surface treatment. These usually involve pigment dyes mixed with thin surface treatments to be applied over the pavement structure.

Improve Cooling

Using porous pavement mixtures can also reduce a pavement's contribution to the UHI effect. HMA, PCC and block pavers can be used to make pavements porous (or permeable). Porous/permeable pavements are designed with a high air void content (usually 15-25% of the total volume), which results in interconnected voids and a pavement that is essentially permeable to water. These air voids also provide an opportunity for convective cooling (as air flows through them) and evaporative cooling (if they contain water, e.g., after a rain event).

Design options. There are essentially two main options to improve pavement cooling:

- Porous pavement. Build the entire pavement structure with a porous/permeable material (e.g., block pavers, permeable HMA or PCC). Generally this is done for stormwater treatment reasons; however a secondary benefit is a reduction in the pavement's contribution to the UHI effect.
- Permeable wearing courses. Build a normal impermeable pavement (e.g., traditional PCC or dense-graded HMA) and cover the surface with a layer of permeable material. While the entire pavement structure is not permeable, the surface is. There is some evidence to suggest that this helps pavements cool more quickly at night.

Additional Information

The U.S. Environmental Protection Agency (EPA) maintains an extensive website on the UHI effect (http://www.epa.gov/hiri). Of specific interest is the Cool Pavement Report (Cambridge Systematics, Inc.) available at: http://www.epa.gov/hiri/resources/pdf/CoolPavementReport_Former%20Guide_complete.pdf.

GLOSSARY

Albedo	A measure of a material's ability to reflect sunlight on a scale of 0 to 1. An albedo value of 0.0 indicates that the surface absorbs all solar radiation, and a 1.0 albedo value represents total reflectivity.
Urban Heat Island Effect	"…a measurable increase in ambient urban air temperatures resulting primarily from the replacement of vegetation with buildings, roads, and other heat-absorbing infrastructure." (EPA 2009).

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QUIET PAVEMENT

PT-5

2-3 POINTS

GOAL

Improve human health by reducing tire-pavement noise.

CREDIT REQUIREMENTS

Design at least 75% of the total new or reconstructed pavement surface area for regularly trafficked lanes of pavement where the speed limit meets or exceeds 30 miles per hour (mph) with a surface course that produces tire-pavement noise levels at or below those listed in Table PT-5.1, which describes test vehicle speed parameters and the points corrsponding to the level of noise reduction achieved. Test the pavements according to the on board sound intensity (OBSI) method desribed by the current version of AASHTO TP 76. Compute the total surface area of all trafficked lanes that meets or exceed speed limits of 30 mph and show that a minimum of 75% of this area meets the tabulated criteria for tire-pavement noise. Do not include shoulders, medians, sidewalks and other paved areas outside of the travelled way in the computation.

Table PT-5.1: Testing Speeds and Maximum Average OBSI Noise Levels

		Maximum Average Noise Level	
Facility Posted Speed Limit	**Test Speed**	***2 points***	***3 points***
55 mph or more	60 mph	99 dBA	95 dBA
30 to 54 mph	35 mph	91 dBA	88 dBA
less than 30 mph	Does not qualify for credit		

Details

- One OBSI measurement should be done for each roadway section. A roadway *section* is defined as having the following attributes:
    - The same speed limit over its entire length
    - A straight section at least 500 ft long (the test requires 440 ft)
    - The same nominal surfacing material over the entire length

  Therefore, in some instances a project will need to conduct several OBSI measurements depending upon the number of sections identified. Portions of roadway that do not meet the section definition (usually this means portions that do not contain at least a 500 ft straight section) shall be deemed to have met the criteria for 2 points providing the project has at least one section that has been tested and meets the criteria for 2 points.

- OBSI testing need only be done on one lane of a given roadway in one direction. For instance, on a four-lane divided highway testing need only be done on one lane for one direction only.
- OBSI testing may be completed at any time on the final pavement surface.
- The noise level to compare with Table PT-5.1 values is the weighted average of all tested sections (weighted by the length of each section). For a section that does not have a straight portion of at least 500 ft, but does meet the other two section definition requirements, the OBSI measurement value shall be assumed equal to the 2-point value in Table PT-5.1.

RELATED CREDITS

- ✓ PR-5 Noise Mitigation Plan
- ✓ PT-2 Permeable Pavement

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Equity
- ✓ Experience

BENEFITS

- ✓ Improves Human Health & Safety
- ✓ Increases Aesthetics

DOCUMENTATION

- A list of pavement sections to be built (or reconstructed) and their associated surface material type, AASHTO TP 76 test results, and surface areas, and if design was intended to be quiet or not in accordance with the requirements of this criterion. This may be included as part of the standard project documentation or as a separate document.
- A calculation to indicate the total percentage of trafficked lane pavement surface areas surfaced with quiet pavement.
- A drawing or project map showing locations of quiet pavements. These pavements should be highlighted on the plan, a scale should be on the plan, and the total surface area of each pavement section should be called out as a note on the plan.

APPROACHES & STRATEGIES

- Refer to Sandberg and Ejsmont (2002), which is an excellent overview of quiet pavement options, fundamentals and research, including a comprehensive list of 33 different pavement design guidelines for reducing tire-pavement noise. Where noise reduction levels are mentioned they refer to a newly constructed quiet pavement surface and relate it to a more standard surface; often the surface that was previously used or previously measured. These noise reduction levels are difficult to compare fairly from one test/experiment to another because the reference noise level is different in many cases.
- For concrete pavements, refer to Rasmussen et al. (2008) for typical measurement values and methods to reduce tire-pavement noise.
- Use open-graded hot mix asphalt (HMA) and portland cement concrete (PCC). In general, open-graded pavements have shown noise reductions from 3-8 dBA although numbers vary greatly depending upon materials, design and measurement techniques (Sandberg & Ejsmont, 2002). The following mixture qualities generally lead to less tire-pavement noise:

  - **High porosity**. This means a high level of interconnected air voids on and near the surface. Typically effective air void content ranges are 15-30% with air void contents above 20% being better.
  - **Smaller maximum aggregate sizes**. Sizes under 0.4 inches tend to work well with even smaller sizes working even better.
  - **Smooth surfaces**. Especially important in the range of “Megatexture” and “Macrotexture.” Megatexture refers to pavement surface elevation changes on the order of 2-20 inches in wavelength, which is often perceived as uneven waviness or rough surface imperfections. Macrotexture refers to pavement surface elevation changes on the order of 0.2-20 inches, which is in the range of maximum aggregate size.
  - **More coverage**. Open-graded material placed outside the travelled lanes can reduce tire-pavement noise propagation by its sound absorbing characteristics. (Sandberg & Ejsmont, 2002)

- Use texturing methods for PCC. In general, transverse tining (the most popular texturing method in the U.S.) produces the loudest surfaces with alternative methods such as longitudinal tining, carpet drags and diamond grinding producing quieter surfaces. (Sandberg & Ejsmont, 2002)
- Use fine surface treatments with aggregate on the order of 0.05 to 0.25 inches. This surface texture generally can also reduce noise. Examples cited in Sandberg and Ejsmont (2002) included a number of proprietary materials (e.g., EP-Grip, Epoxy-Durop, Pavetex, ITALGRIP, Novachip, Colsoft, Safedress, Masterpave, Tuffgrip, Hitex, Smatex, UL-M, Euroduit, Ultraflex, Microduit, Microflex, Microchape, Microvile, Microvia, Mediflex, Miniphone, Citychape, Colrug, Viaphone, Tapiphone) and showed noise reductions in the range of 1-6 dBA.

Example: Sample Calculation

An existing four-lane divided freeway is to be resurfaced with asphalt rubber open-graded friction course (ARFC). Ten lane-miles of freeway (5 in each direction) with 12-foot wide lanes are to be resurfaced. Also, two 14-foot wide off-ramps, each 2,000 feet (ft) long, and the existing 10-ft wide shoulders are to be resurfaced with dense-graded HMA (not a quiet pavement). The posted speed limit for the freeway is 65 mph while the posted speed limit for the off-ramps is 40 mph.

$$ARFC\ Area = (10 \text{ lane-miles}) \times \left(5{,}280 \frac{\text{ft}}{\text{mile}}\right) \times (12 \text{ ft lanes}) = 633{,}600 \text{ ft}^2$$

$$Dense\ Graded\ HMA\ Area\ = (2{,}000 \text{ ft offramp})\times(2 \text{ offramps})\times(14 \text{ ft wide}) = 56{,}000 \text{ ft}^2$$

$$Total\ Area\ Paved\ =\ 633{,}600 \text{ ft}^2 + 56{,}000 \text{ ft}^2 = 689{,}600 \text{ ft}^2$$

$$\%\ of\ Surface\ with\ Quiet\ Pavement\ = \frac{633{,}600}{689{,}600} = 91.2\%$$

The area of the shoulders is excluded because it is not in the regularly trafficked lanes. OBSI tests after construction were done at 60 mph in accordance with AASHTO TP 76 on the inside northbound lane. The entire job consisted of one defined section. Within that section there were several curves but at least one straight stretch of over 500 ft. Results showed that the measured OBSI sound level on this section was 96.5 dBA. No tests were run on the ramps because they were not surfaced with quiet pavement and were excluded from the quiet pavement surface area calculation.

This project would earn 2 points because the minimum area requirement of 75% was met (91.2% was achieved) and the maximum sound level as measured by OBSI of 99 dBA was not exceeded.

Example: States with Quiet Pavements

Some of the largest users of quiet pavement in the U.S. are Arizona and California A few specific examples are:

- The Arizona DOT has placed over 4.2 million tons of rubberized asphalt (much of which is asphalt rubber friction course – ARFC – used for noise reduction) since 1988 (see map of 1988-2001 locations at: http://www.asphaltrubber.org/ari/Performance/ADOT_Projects_1998-2001.pdf). Surface lives are typically 10-12 years (Morris and Carlson, 2001) with noise typically in the 96-101 dBA range depending on conditions and age.
- Caltrans has placed a significant amount of open-graded friction course throughout the state. Specific locations of sections to be researched in the Caltrans Quieter Pavement Research Plan can be found at: http://www.dot.ca.gov/hq/esc/Translab/ope/QuieterPavements.html. The longest continually monitored quiet pavement in the U.S. is a section of I-80 near Davis, CA (http://www.dot.ca.gov/hq/env/noise/pub/IH80_davis_ogacpvmntwtudy_7yrrpt.pdf).
- The Washington State Department of Transportation (WSDOT) has several pavement surfaces under evaluation (http://www.wsdot.wa.gov/Projects/QuieterPavement). PCC locations are at: http://www.wsdot.wa.gov/NR/rdonlyres/5F022BDB-B9B3-437F-9016-2F1624EA0589/0/QuieterconcreteinWA.pdf . Open-graded HMA surfaces at: http://www.wsdot.wa.gov/Projects/QuieterPavement/Maps.htm.

Other states and areas also have active quiet pavement use and research programs including Georgia, Alabama, Florida, New Jersey, New Mexico, Minnesota, Kansas, United Kingdom, Belgium, the Netherlands, Denmark, Germany, Austria, Sweden and more.

POTENTIAL ISSUES

1. Without adequate prior testing on the surface course mix design, there is some risk that the constructed surface course will not meet the required maximum average noise levels for this credit.
2. In general, open-graded surface courses have shorter performance lives than traditional surfacing. Therefore, life-cycle costing of the roadway surface should be carefully considered and the potential for shorter service life should be considered.

3. While other methods may be successful, open-graded surface courses have been the most thoroughly researched and are reasonably well understood although there are still many unknowns.
4. Fine surface treatments can improve pavement surface texture, but in general these are surfaces used for primary purposes other than noise reduction. They often have noise reduction values associated with them but these values often have not been adequately tested or independently verified.
5. Measurement of noise "reduction" can be inconsistent. Usually noise reductions are reported in relation to (1) an established reference pavement, (2) a comparable dense-graded pavement, or (3) the previous pavement surface. In all cases these references are usually not well defined or their definitions vary from location-to-location. For instance, several European countries have standard reference pavements from which reference noise levels are measured, but these reference pavements vary from country-to-country. Because of this reference level dilemma, two pavements with the same measured tire-pavement noise may be reported as having entirely different noise reductions.

RESEARCH

This credit focuses on roadway noise from traffic that is generated from a roadway project after construction is complete. In particular, certain roadway surfacing materials can be used to reduce tire-pavement noise. For purposes of this credit, surfacing methods that reduce average tire-pavement noise below defined On-Board Sound Intensity (OBSI) levels (shown in Table PT-5.1) are defined as "quiet pavements." It is worth noting that the aesthetic terms "quiet" and "noise" are based entirely on subjective human perceptions and depend on a number of variables. However, the decibel criteria used in this credit is necessary to distinguish and recognize roadway projects where teams intentionally approach long-term noise mitigation through pavement design.

Noise mitigation efforts and alternatives for minimizing temporary construction noise and long-term traffic noise are addressed in Project Requirement PR-5 Noise Mitigation Plan (NMP) and also generally in the first Project Requirement, PR-1 Environmental Review Process. Quiet pavements may be a viable strategy for operational noise mitigation for the roadway project, and may be included in both the NMP and documentation for the project environmental review process. Details and basic definitions of noise, how it is measured, and discussion of adverse human health impacts are provided in PR-5 and are not repeated here.

The following discussion focuses on details of roadway traffic noise and various methods of designing the pavement section to be quieter than conventionally designed pavements. Other traffic noise mitigation efforts, such as permanent sound walls or other common techniques, are not addressed by this credit.

Traffic Noise

Noise from a roadway is generated largely by the traffic activities taking place on the road. Noise generated from traffic depends on traffic volume, traffic speed, vehicle mix, engine types, tire types, vehicle condition, roadway geometry and physical features also depends on the characteristics of the surrounding environment such as topography, development and population density. Traffic noise can be disturbing either as a constant noise such as a steady stream of traffic such as from a highway or as single events such as passby of a truck, bus or even a car. Some typical noise levels you might expect if you were standing 50 feet away for different vehicle classes traveling at 55 mph (Michael Minor & Associates, n.d.):

- Passenger cars: 72-74 dBA
- Medium trucks: 80-82 dBA
- Heavy trucks: 84-86 dBA

Traffic noise generated from vehicles can be further categorized into four major sources (Bernhard et al., 2005): 1) engine and drive train noise, 2) exhaust noise, 3) aerodynamic noise and 4) tire-pavement interaction noise. Above about 30 mph tire-pavement noise is the predominant source (Bernhard & Wayson, 2005).

Pavement Surface and Noise Generation

Tire-pavement noise is influenced by both the tire and pavement type and condition (Sandberg & Ejsmont, 2002). While it may not be realistic to regulate tire types and condition for a particular project, pavement type can be specified in project design. Some of the characteristics of a pavement surface that can influence noise generation are (Sandberg & Ejsmont, 2002): texture of the surface, skewing (orientation of pavement texture), thickness of the pavement, porosity, tire-pavement adhesion and elasticity of the pavement surface. Also, as the pavement ages these characteristics often change which can cause changes in noise reduction properties (Munden, 2006).

Pavement Surface Noise Measurement

Tire-pavement noise can either be measured from the side of the road as a vehicle passes by or from a point (or points) very near a standard tire as it drives down the road. There are a number of variations of noise measurements that can be made in these two manners but In the U.S. the on-board sound intensity (OBSI) measurement method (Figure PT-5.2) enjoys growing popularity and is the measurement upon which this credit is based. This method is most useful for comparing pavement surfaces and is relatively portable and cost-effective. Since the OBSI method measures noise very near the tire, OBSI readings are not equivalent to noise readings alongside the roadway. However, the two can be roughly correlated (Figure PT-5.3). Additionally, OBSI measurements can vary by season (summer gives slightly lower values – Illingworth & Rodkin, 2005), weather (wet pavements are noisier) and location (measurements may vary along the roadway surface by about 2 dBA: Bennert et al., 2004).

Figure PT-5.2: OBSI measurement device (picture from Illingworth & Rodkin, Inc.)

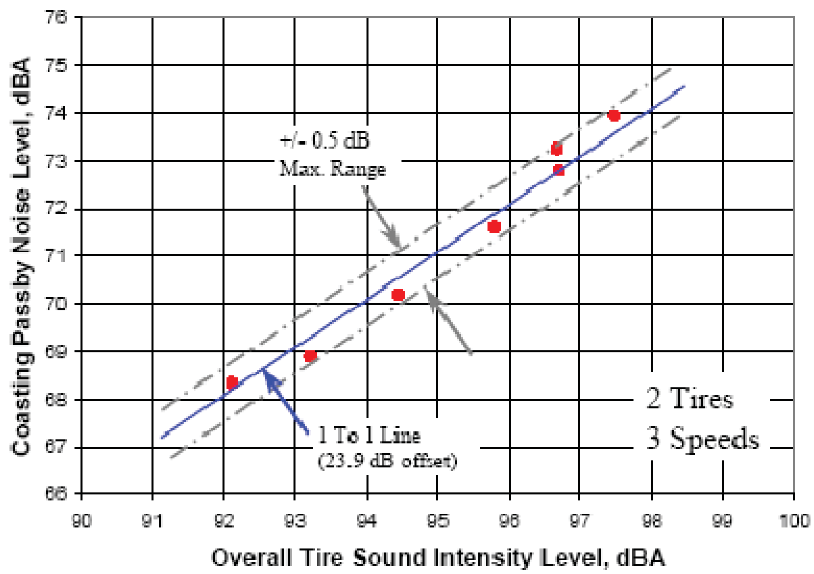

Figure PT-5.3: Relationship between pass-by (roadside) measurements and OBSI measurements for one particular study (graph from Donovan & Rymer, 2003).

Pavement Surface Design Options

A number of design options have been shown to produce lower tire-pavement noise. The primary considerations in choosing an option are (1) amount and duration of noise reduction, (2) pavement durability and (3) cost. This section briefly discusses major options available to the pavement designer.

Open-graded Quiet Pavements

The most recognized option is an open-graded mixture of HMA or PCC used for a pavement surface course. Open-graded refers to a general lack of fine aggregate material in the mixture resulting in interconnected air voids. As a rough rule-of-thumb, mixtures with an air void content above 15% can generally be considered to be open-graded and have interconnected air voids. The interconnected air voids tend to reduce noise by (1) reducing the generation of noise, and (2) absorbing generated noise in the air void structure of the mixture (Sandberg & Ejsmont, 2002).

Noise reduction ability is generally reported in the 3-9 dBA range but can vary widely depending upon the reference pavement used for comparison and environmental and geometric conditions. Figure PT-5.4 shows some noise levels measured in the U.S. and Europe.

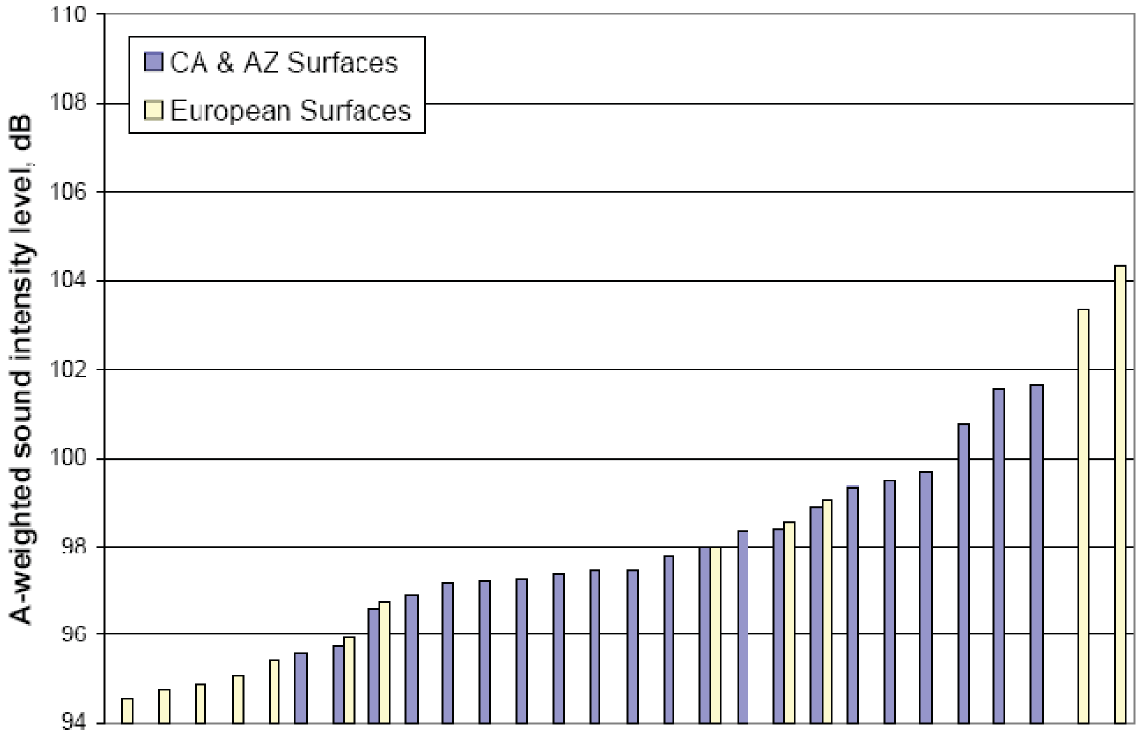

Figure PT-5.4: Comparison of sound intensity levels for various types of HMA open-graded surface courses in California, Arizona and Europe at 97 km/hr (60 mph). (From Donovan, n.d.)

In general, open-graded pavement surfaces have equal or shorter service lives than a standard pavement surfaces. Specifically, open-graded pavements may have maximum service lives in the 8 to 10 year range with the length of effective noise reduction being somewhat less. Bendtsen et al. (2008) report that the time history of quieting effect on noise levels of various European open-graded pavements varies widely but that on average one should expect noise level increases per year as seen in Table PT-5.2. Harvey et al. (2008) studied 54 California quiet pavement HMA surfaces and found that for any specific material older pavements were generally louder than younger ones. However, the older pavements still tended to produce less tire-pavement noise than similar non-quiet pavements.

Table PT-5.2: Overall Time History of Noise Increase (in dBA per year) of Pavement Service Time for Various Pavement-Traffic Conditions (From Bendtsen et al., 2008).

	Light Vehicles		**Heavy Vehicles**	
Surfacing	*High speed traffic*	*Low speed traffic*	*High speed traffic*	*Low speed traffic*
Dense HMA	0.1	0.1	0.1	0.1
Porous Open-graded HMA	0.4	0.9	0.2	-

Studded tire wear is a major concern in the longevity of open-graded pavements. Observations in Washington State indicate a near total loss in noise reduction in just over two years for an experimental asphalt rubber friction course (similar to those paved in Arizona) placed on I-5, and Bendtsen et al. (2008) also describe durability under studded tire traffic as a major concern noting that wear increases by a power of 2 with an increase in speed. Clogging of the interconnected air voids can also be a problem. For higher-speed facilities (on the order of 60 mph) a self-cleaning effect has been found (Ongel et al., 2008) resulting from the combination of water (contributed by rainfall) and a suction effect created by tire-pavement contact. However, on some pavements Ongel et al. (2008) did not see a cleaning effect where one was expected because of high-speed traffic. Finally, Chiba et al. (2008) found that in Japan snow removal equipment and tire chains tended to damage open-graded pavement surfaces and cause a loss of permeability after about 2 years. This seems to have led to an increase in noise level but measured noise levels after 6 years were still slightly below that for a conventional pavement surface.

Costs for open-graded pavement surfaces are typically reported as above those for traditional surfacing and can command a premium on a per-ton basis of 20-200% depending upon mix type, location and availability.

PCC Surface Texturing

Quiet pavement options for PCC can involve open-graded PCC but can also involve various means of texturing the PCC surface. Surface texturing can have a significant effect on tire-pavement noise and there are certain techniques that are better than others. Table PT-5.3 lists surface texturing and typical noise levels. Of note, transverse PCC joints also contribute significantly to noise levels.

Table PT-5.3: Typical PCC Surface Texturing and Average Noise Levels. Measured by Rasmussen et al. (2008).

Technique	Typical Noise Level	Notes
Transverse tining	104 dBA	Small, shallow grooves across the pavement surface transverse to the direction of traffic. The most popular means of PCC pavement texturing in the U.S.
Longitudinal tining	102 dBA	Small, shallow grooves across the pavement surface in line with the direction of traffic.
Carpet drag	100.5 dBA	Uneven texture created by dragging a piece of artificial turf across the pavement surface.
Diamond Grinding	99 dBA	Removes the surface with a gang-mounted spindle of saw blades. The resulting surface typically has a grooved appearance with the spacing and depth of grooves being controlled by the technique used.

PCC texturing life depends on traffic and the presence of studded tires. Tining can last in excess of 6 years (WSDOT, 2006) if no significant stud traffic exists while experience in Washington State has shown tining to last only 3-6 years (depending upon traffic levels) because of studded tire wear. The durability of carpet drag surfaces is not yet well understood. Finally, The American Concrete Pavement Association expects a typical diamond grind to last 14 years while results from Idaho (where studs are allowed) point to 10 years and results from California (where studded tire wear is insignificant) point to 16-17 years (Cotter, 2007).

PCC texturing is generally not as quiet as open-graded options but most techniques can achieve some noise reduction when compared to transverse tining. Rasmussen et al. (2008) point out that construction technique and details can also influence texturing effects on noise. Noise reduction strategies that rely on diamond grinding usually design the original pavement thicker than needed to compensate for the loss in thickness resulting from each grinding. While this technique works, it may not be sustainable beyond 2-3 grinding operations. Finally, studded tire wear can greatly reduce the life expectancy of any surface texturing technique.

With the exception of diamond grinding, PCC surface texturing is a standard procedure and thus, does not command a premium. Diamond grinding costs can vary widely depending upon quantity, aggregate hardness, contractor availability and geometry. Some example 5-year average costs provided during the open comment period for Version 1.0 are:

- Washington: $\$9.45/yd^2$
- Kentucky: $\$2.67/yd^2$
- Washington: $\$2.27/yd^2$

Other Techniques

Other surfacing techniques that are not engineered primarily for noise reduction have been shown to be somewhat quieter than conventional methods. Proprietary thin surfacing and stone matrix asphalt (SMA, which is a gap-graded mixture) are the two most commonly cited surfaces. Both work by creating a negative texture (where a majority of the surface texture is at the same height with small air void indentations) and/or using smaller maximum aggregate sizes (e.g., 3/8 inch or smaller in HMA). One concern with these types of surfacing methods is that they may lose their noise reduction capabilities more quickly than pavements specifically engineered to reduce noise. Harvey et al. (2008) found that Caltrans RAC-G mixes (a gap-graded mixture) increased noise levels over the first several years to where there were comparable to a typical 1/2-inch dense-graded HMA.

Prices for these surfacing methods vary widely. Proprietary mixtures are generally not predictable while SMAs may cost 20-30% more than traditional dense-graded HMA surfacing on a per-ton basis.

GLOSSARY

AASHTO	American Association of State Highway Tranportation Officials
dB	Decibel
dBA	A-weighted decibels
Ft	foot (feet)
HMA	Hot mix asphalt
Mi	mile(s)
Mph	miles per hour
Noise	Unwanted sound
OBSI	On-Board Sound Intensity
PCC	Portland cement concrete
SMA	Stone matrix asphalt

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PAVEMENT PERFORMANCE TRACKING

PT-6

1 POINT

GOAL

Allow for more thorough performance tracking by integrating construction quality and pavement performance data.

CREDIT REQUIREMENTS

Use a process that allows construction quality measurements and long-term pavement performance measurements to be spatially located and correlated to one another. This implies four requirements:

1. Construction quality measurements must be spatially located such that the location of the quality measurement is known to within 25 ft of the actual location where the material or process that was measured is actually located.
2. Pavement condition measurements must be taken at least every 2 years and must be spatially located to a specific portion of roadway or location within the roadway.
3. An operational system, computer-based or otherwise, that is capable of storing construction quality measurements, pavement condition measurements and their spatial locations.
4. The designated system must be demonstrated in operation, be capable of updates and have written plans for its maintenance in perpetuity.

Details

This generally means spatially locating construction quality measurements in a permanent location system and maintaining those records indefinitely. Examples of construction quality records include but are not limited to:

- Density tests
- Water content tests
- Air content tests
- Slump tests
- Compressive strength tests
- Asphalt content tests
- Gradation tests

Examples of pavement condition measurements include, but are not limited to, the extent and severity of:

- Cracking
- Permanent deformation (rutting)
- Bleeding or flushing (in relation to hot mix asphalt pavements)
- Faulting (in relation to portland cement concrete pavements)
- Joint spalling (in relation to portland cement concrete pavements.

DOCUMENTATION

- A signed letter from an owner official stating that the performance tracking system is operational and has been populated with the required data.

RELATED CREDITS

- ✓ PR-4 Quality Control Plan
- ✓ PR-9 Asset Management Plan
- ✓ CA-1 Quality Management System

SUSTAINABILITY COMPONENTS

- ✓ Extent
- ✓ Expectations
- ✓ Experience
- ✓ Exposure

BENEFITS

- ✓ Increases Service Life
- ✓ Reduces Lifecycle Costs
- ✓ Improves Accountability
- ✓ Creates New Information

APPROACHES & STRATEGIES

Develop and implement a pavement performance tracking system. Off-the-shelf systems that meet the credit requirements are difficult if not impossible to find.

Example: Sample Systems

Two examples of systems that could accomplish the intent of this credit are:

HMA View. A web-based system developed at the University of Washington between 2000 and 2004 (White et al., 2002). No significant development has happened since about 2005 and it is not ready for commercial use. However, it does demonstrate that such a system can be created and does work. It is capable of maintaining construction quality and pavement condition records in the same database. The spatial location feature was never fully developed. The system was used for a time by the Washington State Department of Transportation (WSDOT) and the Maryland State Highway Administration (SHA).

Pavement Interactive (PI) Maps. An system in proof-of-concept stage developed in 2008-9 and accessible at: http://maps.pavementinteractive.org. PI Maps is a tool for storing and sharing spatial data. It is currently in a public beta testing period, so the functionality may change from time to time. PI Maps uses the Google Maps API to allow viewing and input of points, lines, and polygons. PI Maps runs on Google App Engine, so it takes advantage of Google's robust storage and server infrastructure, which allows users to have confidence in their data's well-being.

Google My Maps or Windows Live Local Application. At the very simplest level, a Google My Maps (http://maps.google.com) could be created and a placemarker could be used to designate testing with the associated text used to describe the test and test result. Pavement condition could be described in association with a line that is drawn over the particular section of roadway being documented. While this system is simple it could quickly become unwieldy for larger organizations such as large cities, counties and states.

POTENTIAL ISSUES

1. The general trend in road construction is to dispose of construction records after a prescribed amount of time. Usually this time is set by legal obligations, but for this credit, records would not be able to be disposed.
2. There are no existing commercially available systems for accomplishing the actions of this credit. Where no system exists, implementing this credit (i.e. creating a system from scratch) will likely be very difficult. The project team has to develop a system or the owner must want to develop or operate a system like this independent of the Greenroads credit. However, long-term benefits of such a system may outweigh the costs of designing and implementing one.
3. It is difficult to define the concepts of performance and quality in simple terms. Tying construction quality and pavement performance data together can involve some very specific ideas.
4. The location of the construction quality test should be the final location of the material or process associated with the test and not the laboratory or testing location.
5. Currently there is no major organization that integrates construction quality control data with long-term pavement performance data. As a result, it is difficult to trace pavement performance issues back to construction quality.

RESEARCH

Many other industries (e.g., computers, automobiles, etc.) are able to trace each element of their final assembly back to original construction. The ability to accomplish this would improve pavement performance through a better understanding of how construction quality influences long-term pavement performance and allow existing data to be better used to evaluate the performance of new materials, concepts and design methods. Due to the limited research in this area for pavements, this section is necessarily short.

Current Means of Performance Tracking

Almost all agencies that track pavement performance do so by measuring surface defects and their qualities including such items as: cracking (longitudinal, transverse, reflective, alligator), rutting, raveling, faulting, spalling, roughness, etc.). However, databases that contain this information do not, as a general rule contain construction information and therefore are unable to link pavement performance with construction data. Typically construction data is saved for a finite amount of time (e.g., 3 or 5 years) and then discarded.

The Problem with Unlinked Data

Hudson et al. (2002) describe the problem when referring to their interview results with several state departments of transportation (DOTs):

> "One of the main challenges discovered in all the states visited is the absence of a convenient link between essential data on materials characteristics used in each project on the one hand and PMS [Pavement Management System] data including performance data on the other. This is most often caused by the fact that the first group of data (information on design, testing, inplace properties, thickness, and QA data) is commonly stored in flat files, difficult to access and sometimes incomplete…Performance data can only be linked to materials and construction data when use is made of a common locator reference."

The General Solution

Provide a pavement performance database that is linked spatially to a pavement construction database. This means that both performance and construction data must be available electronically. Whereas 10 years ago this was not likely (construction files were often paper files), today it is more likely since most files are now stored electronically. Ideally, linking and storage could be accomplished in a web-based system (White et al., 2002). To improve efficiency, White et al. (2002) proposed that construction data be initially recorded in electronic form and geotagged at the construction site. This would typically involve hand-held data entry devices and GPS units. At the time (2002) these types of GPS units were less common, however now they are relatively cheap and are routinely included in personal electronics such as smart phones.

Demonstration of a Pavement Performance Tracking System

Both Hudson et al. (2002) and White et al. (2002) describe the system developed primarily by White et al. called "HMA View" that allows integrated performance data to be uploaded, displayed and analyzed on the web. Figure PT-6.1 shows the basic architecture of what became HMA View (at the time it was simply known as the "hot-mix database"). This basic architecture (minus the mobile field setup) was demonstrated on a limited basis with the Maryland State Highway Administration (MDSHA) and the Washington State Department of Transportation (WSDOT) in the mid-2000s but has not been receiving new data since 2005 and has not been operational since about 2007. Currently, there are no plans to re-start the system or refine it.

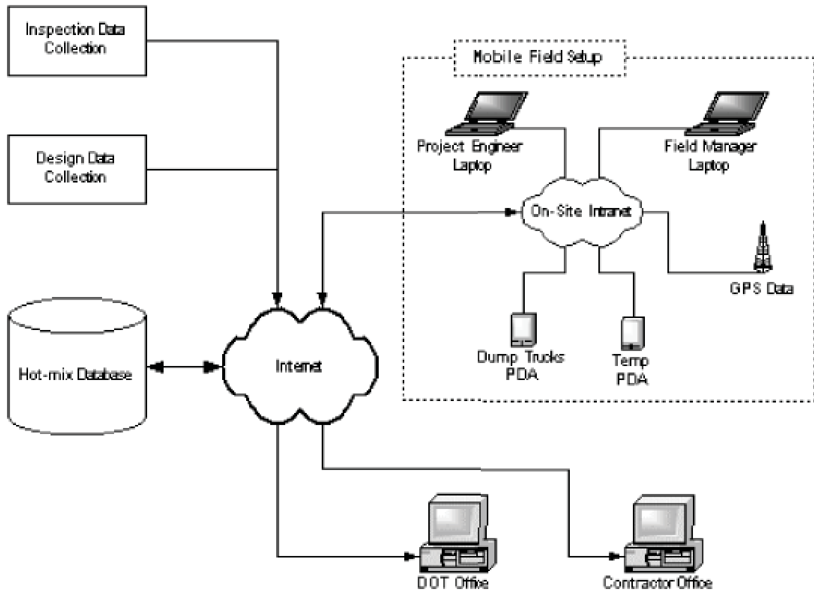

Figure PT-6.1: Overview of content acquisition and delivery for HMA View (from White et al., 2002).

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CUSTOM CREDIT

[YOUR TITLE HERE]

GOAL

Recognize innovative sustainable roadway design and construction practices.

CREDIT REQUIREMENTS

1. Come up with an idea for a design or construction best practice for roadways that is not currently included in Greenroads and is more sustainable than standard or conventional practices (be prepared to justify why).
2. Download and complete the Greenroads Credit Template. Be sure to follow the guidelines provided in the body of this document on how to fill in the areas of the Template and format your information.
3. Use the weighting scheme developed for Greenroads (see the Introduction to this Manual) to determine how many points the credit is worth. Justify your response with empirical data or match a currently existing weighting scheme.
4. Submit the template for peer review by the review team and make adjustments if requested or as needed.

In this section (yes, this one; the one called "Credit Requirements" at the top there in the "White on Green Header" font style), you must:

1. Answer the question here: What measureable thing in general needs to be done to meet the goal you state?
2. Hint: Sometimes it is easy to display what needs to be done in a bulleted or numbered list. (You can use styles called "Bullet" or "List Number;" try it out.)

You can also use the Styles command to choose Template styles as shown below, like:

Body Text style. This style can be *italized*, **bolded** and <u>underlined</u>, if you wish.

Details

This section, called "Details," may not be necessary for all credits (for example, no more explanation than what is noted above is needed), but should answer the question: what specification currently exists (national, international, state, local) that can be used/met to meet the credit goal above, if any? Use a bolded "**OR**" between different options, if any. You might want to include any equations here.

Note: Do not specify technologies or brands or dimensions (unless it matches or mimics an existing accepted standard). For the main text in this section, use Body Text Indent Style. Similar to above, you can use Body Text Indent style. This style can be *italized*, **bolded** and <u>underlined</u>, if you wish. The default indent increment is 0.2 inches, which also applies to numbering and lettering and bullets.

DOCUMENTATION

- Copy of the specification XX. Be very specific and indicate where such a document may be found in a standard set of plans and specifications, or if it needs to be created and submitted separately. Photos are an example of a separate item.
- This is "Bullet" style.
- **NOTE THAT EVERYTHING IN THE FIRST THREE SECTIONS CAN FIT ON THIS 1 PAGE.**

CC-#

1-5 POINTS

RELATED CREDITS

- ✓ List related credits as XX-# Title or None

SUSTAINABILITY COMPONENTS

- ✓ *Choose which apply then delete this line*
- ✓ Ecology
- ✓ Economy
- ✓ Equity
- ✓ Extent
- ✓ Expectations
- ✓ Experience
- ✓ Exposure

BENEFITS

- ✓ *Choose from list (pick from bracketed items), then delete*
- ✓ Reduces [Water, Fossil Energy, Raw Materials] Use
- ✓ Reduces [Soil/Solid Waste, Wastewater, Air] Emissions
- ✓ Optimizes Habitat & Land Use
- ✓ Improves [Human Health & Safety, Access & Mobility, Business Practice]
- ✓ Increases [Lifecycle Savings, Lifecycle Service, Awareness, Aesthetics]
- ✓ Creates [New Information, Energy]

APPROACHES & STRATEGIES

Explain some common approaches and strategies in this section. This is where practical experience comes in very handy, especially when it can be explained in a few short words. The heading above is in the style called "Heading Blue Line." There should be a page break before this section, even if the first page of the credit overlaps onto a second page (see last sentence on first page though).

- Bullet style is often an easy way to display approaches and strategies in this section.

    - You can use Bullet Indent style to note subtopics under each strategy or approach, too.

Below is an example of a table for text or numbers. Table borders should be outlined with simple boxes using the official Greenroads color of gray (if you should need to know the color palette to make adjustments - which you should not - please contact your Greenroads reviewer). Important items in the table can be bolded or italicized manually for emphasis, such as headings. Text in the tables is style No Spacing. Note that all tables have a 0.2" bottom separation from text on the bottom, which is accomplished by adding a carriage return (a blank line) in the No Spacing style, followed by Body Text, Body Text Indent (if table is indented), or one of the heading fonts for a new section.

Table XX-#.1: Table of Values or Text Items

Item 1	Sample text or numbers in No Spacing style	XX.XX
Item 2	Sample text or numbers	XX.XX

A line underneath tables should have no text and be in style No Spacing,

Note: If this is an indented table, use Body Text Indent following the single No Spacing line (just like this paragraph and the preceding line).

Example: Case Study [or Calculation]

This section can be used to demonstrate how a credit was achieved. It is optional, but a good idea, especially if you are profiling something you did on your own project that supports the case for award of this credit. If numbers are used to compute a credit, this is where examples are worked. (Be sure to title the header appropriately. Note also that you can have more than one example too!) This is "Body Text Indent" style. The heading style for the Examples section is called Indented Heading Orange Line.

- This is "Bullet Indent" style.
- Avoid highlighting specific products where possible.

Here is an example of a photo (they can be bigger or placed in pairs in table cells). It is embedded in a table cell that is aligned for the width of the headed section and centered in the cell. Figures are labeled similar to tables, with the style called Caption, but the Figure and the Figure caption are centered below image in the same cell.

Figure CC-#.1: A snowy stock photo. (Windows 2000)

POTENTIAL ISSUES

1. Write "None" here or provide a short summary of what might go wrong when trying to implement the credit (based on the research or pilot projects). If you have misgivings about this credit, or are aware of any tradeoffs that have been encountered along the way, put them on the table by including them here.
2. Explanation of another potential issue if any. This is "List Number" style.

RESEARCH

The Greenroads Rating System is a collection of best practices for design and construction of roadway projects. Greenroads supports sustainable performance and design goals that go beyond most existing federal, state, and local regulations. If you find yourself writing a Greenroads credit, what you write should fit within this framework.

Credit Writing 101

Greenroads understands that we have not been able to recognize all possible sustainable innovations and best practices because roadway projects are very diverse and specialized. This credit category, Custom Credits, is designed to represent user contributions to the ongoing development of Greenroads via cutting edge research and innovative design and construction practices.

Before You Write

Before you write the credit (and as you are writing it) consider whether or not this credit should even exist. Could it be replaced by another credit that makes more sense? Should it be fundamentally different? Is it needed at all? We are hoping that the credit writer exercises her/his expertise here and gives this some good thought. A Custom Credit must demonstrate beneficial impacts on the overall sustainability of the roadway system and demonstrate at least one of the seven components of sustainability: *Ecology, Equity, Economy, Extent, Expectations, Experience and Exposure.* If you are wondering what those ideas are all about, read the introduction to the Greenroads Manual one more time and get familiar with the philosophy that underlies all of the credits and requirements in the system.

Writing a Good Credit

Ultimately, Greenroads credits have the following characteristics.

- **Straightforward and understandable.** Simplicity is valued over excessive detail because it is more understandable. Credits are often simplistic interpretations of complex ideas; they are bound to contain some controversy, however the interpretation should hold true to the fundamental idea and intent.
- **Supported by empirical evidence and existing evaluative techniques.** Credits should be thoroughly researched, based on empirical evidence when available, and, to the extent possible, capable of evaluation using existing tools, techniques and documentation. Greenroads does not seek to develop evaluation tools or subsets of metrics at the credit level.
- **Commensurate with Impact.** High investment long-term impact items are given more credit than low investment short-term impact items. The weighting scheme is explained later in this document.
- **Flexible and dynamic.** The system shall continually evolve. Over time, better ideas, more complete knowledge, and technology advances will require Greenroads to be updated and changed.
- **Supported by existing project documents where possible.** Most credits, with very few exceptions, should be able to be clearly specified and incorporated into a project using typical contract documentation such as plans, specifications and design reports. Any additional documents should be simple and inexpensive to produce (and digital wherever possible) and also may use other standard reports such as standard construction quality control reports, change orders, etc. No new or unfamiliar types of documentation should be necessary to satisfy credit intent.
- **Verifiable by a design professional or inspection agency.** The Greenroads system shall presuppose the integrity of individuals, unless proven otherwise, and hold accountable the professionals involved.

Once you have your idea ready to put into words, download this Greenroads Credit Template and start editing it in place. If you have read this far, you have probably noted the suggestions for what to include in previous parts of the template as far as content, as well as suggestions for formatting and presenting your ideas.

The necessary sections of a Greenroads credit are listed briefly in Table CC-X.2. Each part listed below is essential to making the credit complete.

Table CC-X.2: Greenroads Credit Structure

MAIN BODY	OPTIONAL	FRONT PAGE SIDEBAR
Credit Title		Credit Number
Goal		Points
Credit Requirements	Details	Related Credits
Documentation		Sustainability Components
Approaches & Strategies	Examples	Benefits
Potential Issues		
Research	Glossary	
References		

The remainder of this document provides guidance regarding content and intent of each of the sections listed above. Additionally, there are formatting suggestions for the Research section.

Credit Title

Name your credit in three words or less.

Goal

State the overall goal of the credit.

- This should be no more than two full sentences, written concisely, in plain language and in imperative tense.
- The overall goal of the credit should be written in the simplest terms possible to make it clear to even the casual observer what is desired. It should be free of technical jargon or long, rambling sentences. For instance, the goal for the Roadway Safety Audit credit would be better as "Reduce roadway crashes and fatalities" rather than "Improve the safety of the roadway corridor through a multi-disciplinary audit whose purpose is to reduce pedestrian, bicycle and motor vehicle safety issues related to public mobility." It is obvious that the first is more simple and straightforward. The subtleties of credit may not be obvious by the goal statement but the goal should be crystal clear.
- If the credit is based on some other standard method of practice or documentation (like the AE-1 Roadway Safety Audit credit is based on *NCHRP Synthesis 336*) then it is helpful to look in that document for a simple goal statement. (See also “Research” below.)

Credit Requirements

Write the simple text describing what must be done.

- If you think there should be different point values associated with doing different steps, specify how many points that activity is worth. For example, the MR-4 Recycled Materials credit is worth up to 5 points, but it is awarded in 10% increments each worth 1 point.
- The credit requirements should be written in clear, simple terms to make it obvious what must be done to earn the credit or credits. Again, simplicity is the key. The litmus test is that a decision-maker (e.g., politician, executive, department head, etc.) without detailed knowledge of transportation design or construction should understand what must be done. They may not understand the details but they should have a general idea about what action must be taken to achieve the credit.
- Do not develop standards of practice, measurement techniques or any other regulatory-like text. Rather, use existing standards that have been proven robust and worthy and then ask Greenroads applicants to comply

with something that exceeds those standards by some measurable increment or verifiable accomplishment. In most cases there is a standard somewhere that works well or is well-worded. The advantage of using these standards is that they are generally well thought-out and vetted for possible legal, design, regulatory, etc. conflicts. For example, Project Requirement PR-8 Low Impact Development uses existing guidelines from the Washington State Department of Ecology. In this instance, the guidance used applies specifically to one state but may be easily reworded to be generally applicable to any type of project or location.

Details (Optional)

Provide further explanation of the credit requirements.

- This text adds details, such as definitions, to the Credit Requirements where necessary, or shows an equation, if any. Note in this section when a particular credit may be inappropriate or not applicable.
- Be sure to note instances where a credit may not be appropriate or applicable. Credits should reward intents which fall within context-sensitive design. For example, a project team might try to earn the AE-7 Transit Access credit by putting a bus stop and shelter on a rural forest road, miles from the nearest city, claiming potential for future growth. Or, perhaps the AE-8 Scenic Views credit should only apply to non-urban environments. It is important to clearly identify these issues in the text of the credit on the front page: providing these disclaimers is ultimately a courtesy to future users of the credit.

Documentation

Provided a bulleted list of the items required to prove that the credit was completed and that the goal was met.

- The purpose is to use standard project documents to verify that the intent of each Greenroads credit is being met. Projects applying for Greenroads certification will provide the following documentation:

  a. Full project plans and drawings (90% minimum for initial review).
  b. Project specifications (90% as above).
  c. Project design report (where available).
  d. A link to an online gallery with photos of the construction process.
  e. A checklist showing which credits are being attempted, and where evidence of each credit may be found in the above documents. (This is to streamline the review process for certification.)

- Any additional documentation is discouraged. The idea is to use documentation that already exists in a typical roadway design and construction project. Credits should be able to be represented within the plans, specifications or design report (bid document, etc.) or with a photograph. For example, the compliance with NEPA (a requirement) uses a checklist which can be attached as an Appendix to the design report or Xeroxed onto a sheet of the drawings.
- However, some Construction Activities credits may require additional documentation, such as compaction test reports or mix designs. Note that these types of reports are commonly available on infrastructure projects, and should be able to be submitted scanned or otherwise digitized. Do not ask for a City Inspector or engineer to write an essay describing the construction process. Instead, you may request a copy of a daily report (if absolutely necessary to verify your credit intent was met).
- The web-based system for Greenroads will allow documentation to be submitted via the web (e.g., file attachments, links, etc.). No paper or physical documentation (e.g., a paint sample) will be accommodated. File format should be Adobe PDF for documents and universal image formats (GIF, JPG) for photos.

Approaches & Strategies

Suggest things that may be done to achieve the credit requirements.

- In this section, you should identify any potential credit synergies, especially if you have listed them as “Related Credits” in the front page sidebar. For example, a project using porous asphalt or concrete should be able to satisfy the intent of the **Permeable Pavement** credit and also meet at least one of the points for **EW-3 Runoff**

Quality with minimal to moderate additional effort. Where some technologies are unfamiliar, these types of relationships are very important to note for project teams to consider going beyond their standard designs to make the overall roadway system more comprehensive.

- Most of the time, an actual example is the best way to portray an idea or strategy. Consider using the optional Examples section as many times as necessary to illustrate your idea more clearly.
- Also, photos and tables are encouraged.

Examples (Optional)

Give an example.

- Examples can have different levels of quality. The following is a list that goes from highest quality to lowest quality of examples.

a. An example that **has actually been done** on a project successfully **and you can show evidence** (e.g., pictures, documents, etc.) that it has.
b. An example that **has actually been done** on a project successfully **but you cannot show any evidence** of it other than the description. You should still have strong evidence that is has actually been done.
c. An example that **is planned to be done** on a project **and you can show evidence** (e.g., project documents) that it is.
d. An example that **is planned to be done** on a project **but you cannot show any evidence** that it is. You should still have strong evidence that is actually planned.
e. An example that is **made-up but realistic**. It has not been done on any project to your knowledge.

Potential Issues

State any typical problems or situations that may have been identified in the research or any potential problems that could be foreseen.

- This is also a good place to state any misgivings you may have or comments about potential misinterpretations for the credit. Also, be sure to state any uncertainties that result from underlying assumptions made about particular project types, places, agencies, etc.
- From the research, you should be able to note problems that were encountered during construction or limitations of a type of material, etc. It is important to identify these for the Review Team to understand the full depth of the issue you are trying to present. Also, use your imagination to identify things that could possibly go wrong if a design team or construction crew is trying to implement the credit. Things that can be overlooked or misinterpreted are important to note.

Research

Research your topic and write about it.

- In general, start with a need or purpose statement, discuss current available knowledge, and present perceived costs and benefits.
- In this section you should briefly describe the empirical evidence and existing research that suggests this credit is feasible and contributes to sustainability. This section is crucial and should likely involve the bulk of your time writing a credit. However, the key word here is the word "briefly" and the key concept is "contributes to sustainability." If empirical evidence is unavailable, be sure to note this here.
- The point of this section is to demonstrate that significant sleuthing was completed in order to support each credit. So, if you have a popular topic, you might find quite a bit of existing research. (If this is the case, sometimes it is easier to present each document in a table with a brief summary in a second column.) If you have a recent technology you might not find anything. Do the best you can and please be sure to cite your documents so we can always go back and check them later. What we're looking for here is a few short paragraphs that summarize the existing research on your topic in a clear and concise manner that will be understandable to someone using the Greenroads system.

Evidence Guidelines

We have high standards for vetting and approving Greenroads Custom Credits. Following are some guidelines for research that will help back up each credit.

Research and evidence should be properly documented and referenced. Evidence should be referenced to the report, study, etc. where it was originally investigated. References should be included in this section (at the end) just as they are included at the end of a refereed journal article. APA citation format is preferred. (Additionally, a digital library will be implemented on the Greenroads website to manage and maintain all of these supporting documents.)

Research and evidence should be credible. Different sources of evidence have different sources of credibility. A general list of most credible to least credible is as follows in Table CC-#.3 (this is not strictly true but can serve as a good guide).

Table CC-#.3: Table of Values or Text Items

BEST	Peer-reviewed journal article, published peer-reviewed conference paper, or other independent research. Keep in mind that these often come from larger study reports. If this is the case, find the larger study report. Certainly, these things can be outright wrong too, but the probability of any blatant errors is substantially reduced due to the review process.
STRONG	Public agency report or study. Again, these can be wrong or incomplete or biased but the possibility of any blatant errors is substantially reduced because they tend to be reviewed.
GOOD	Substantiated commercial or trade organization work. This is similar to the "STRONG" work above but comes from a sponsor (e.g., company or trade organization) with an obvious interest in the results and how they come out. For instance a trade organization that sponsors a professor to do a study that proves their material is superior falls into this category.
FAIR	Trade publications or other news items written for the general public. Due to time/space constraints these items can often gloss over the important details because they are written for a more general audience. This writing style is fine and effective but not ideal for this evidence section. Often you can find the more detailed work on which such pieces are based.
POOR	Unsubstantiated claims. These can come in the form of statements by commercial entities with a vested interest in the evidence (either pro or con), blogs, YouTube or other video, claims overheard in conversation, marketing claims and the like. The key is *unsubstantiated*.

Anecdotes are insufficient. Something that happens once or twice is not evidence that its occurrence is well-established. Often anecdotes can, however, provide leads to better evidence (see above list from BEST to POOR), so further digging might help.

Research and evidence should be corroborated. There should be more than one credible independent source for your supporting evidence. Two papers by the same research team involving the same study are not considered "independent." See Table CC-#.4.

Table CC-#.4: Rules of Thumb for Corroborating Evidence

No. of Independent Sources	Credibility of Evidence
3 or More	Three independent sources all arriving at similar conclusions is likely to mean that the efficacy of a concept, idea or practice is well-established.
2	There is evidence that the efficacy of a concept, idea or practice is established but it may not be fully vetted.
1	It is possible that a concept, idea or practice is proper and understood but there is not yet enough evidence to say it is well-established.

Dissenting views should be included. Sometimes there is quality evidence for more than one interpretation of a particular thing. If there are dissenting views they should all be listed and discussed in the comments section of the credit. It is better both for the end user and the credit developer to be aware of these than not. Issues arise when there are one or more pieces of fair/good/best evidence with opposing views or different interpretations. For instance, there may be three studies that give one point of view and two studies that give an opposite point of view. In these cases, it is up to the credit writer to use his/her best judgment to determine the quality of the evidence and render a decision. (If the decision is that there may not be enough evidence to suggest a credit contributes to roadway sustainability, then it is best to remove that credit.)

Glossary

Include definitions of unfamiliar terms.

- This is where definitions of jargon or non-plain English language terms should be defined.

References

Cite your sources.

- At the end of the credit, provide a list of all the references used.

Credit Number

Assign a Greenroads credit number.

- Credits are numbered on a project basis for purposes of your Custom Credit application. For example, if you are applying for your project to earn two different Custom Credits, the first template will be numbered CC-1 [Your Title 1] and the second will be CC-2 [Your Title 2].

Points

Determine the type of credit and how many points the credit is worth.

- Custom Credits are variable in point value and may be worth 1 to 5 points depending on their overall impact on comprehensive roadway sustainability.
- As far as credit weighting and the valuation system used in Greenroads credits (including supporting research), we have written about this in excruciating detail. We will spare that detail here and give you basic hints on how to choose the point value for your credit.
- There are three general types of Greenroads requirements and credits shown and described in Table CC-#.5 (next page).
- For Greenroads, the default minimum for any practice is 1 point, and the default maximum is 5 points, but your credit can float anywhere including or in between those values.
- A good way to approach weighting your own credit is to look for similar credits already included in Greenroads. Try to identify characteristics that might warrant different point values for your own credit. Table CC-#.6 may offer some insight (next page).
- Ultimately, the Review Team will validate this point value in line with the existing weighting and reserves the right to modify this point value as appropriate. For more information, there is also a brief discussion on this weighting taxonomy in the Introduction to this Manual

.

Table CC-#:5: Hints about Assigning Greenroads Points

Type	Credit Characteristics	Example
Binary	This is the simplest type of Greenroads credit. The project team either meets the requirements (1) and gets points, or does not (0) and does not get points.	The entire Project Requirements category is a good default example of the binary approach: if any requirement is unmet, no certification is possible. There are a number of Voluntary Credits that also use this binary approach, such as the CA-1 Quality Management System credit.
Incremental	This is an extension of the higher level of the binary credit. Still awarded in the all-or-nothing (binary) fashion, these credits are earned based on specified percentages of achievement. In general, the increment is linear or exponential depending on the level of difficulty perceived or effort required to complete such a task.	A good example of this type of credit is MR-4 Recycled Materials, where 1 point is awarded based on every 10% added.
Buffet	These credits allow you to pick and choose from a number of different specified practices or technologies in order to earn between the minimum and maximum points for that activity. In general, these types of credits recognize that there are a number of good practices in existence, but not all of them are feasible, cost-effective, or easy to implement at once, and it would be rare that any single roadway project would find all of them appropriate. However, implementing more than one might result in a more sustainable roadway overall.	A good example of a Buffet style credit is AE-2 Intelligent Transportation Systems because you can pick a number of categories and applications that may be appropriate to your project.
Foundation	These credits build on one (or more) particular credit as an extension of an existing best practice. In order for this credit to be awarded, this prerequisite credit step must be completed and achieved. This type of credit is infrequent and often difficult to implement, measure or otherwise specify. Use sparingly.	The AE series (AE-4, 5, 6, and 7) credit set is a good example of a Foundation credit. Credit AE-3 Context Sensitive Solutions must be achieved in order to qualify for these 4 credits. Generally, though, all 11 Project Requirements are also examples of Foundation credits with 0 point value.

Table CC-#:6: Hints about Assigning Greenroads Points

Points	Credit Characteristics
1	Default point value. Short term impacts. Generally low cost or easy process with little to no additional effort needed. Might be regulated in most states but not all. Most construction credits fall here based on life cycle assessment data.
2	Incentive based (for data collection) or influential at organization or agency level. Access and mobility improvement credits.
3	Most ecology and water credits fall here, including context sensitivity, noise and human perceptions of environmental quality. Moderate effort to implement, possible extensions to scope of work to achieve.
4	Usually a combination of 1, 2 and 3 point credits, or this can be achieved through credits with incremental points.
5	Influences phase most cited in life cycle assessments for roadways: materials use or traffic operations. Long term or permanent impacts. Could be high cost, or high level of perceived difficulty due to needed changes in scope or being against existing regulation or standard.

Related Credits

Identify credit synergies.

- List any credits that might be part of a related practice or activity. Use the format "XX-#: Credit Title" and Side Checkmark style. Note that it is a good idea to discuss these in the Approaches & Strategies section as well.

Sustainability Components

Identify sustainability components.

- Pick the major sustainability components that are supported by this credit. There are seven to choose from:

✓ **Ecology**
✓ **Equity**
✓ **Economy**
✓ **Extent**
✓ **Expectations**
✓ **Experience**
✓ **Exposure**

- This section of the sidebar helps identify what resources and principles of sustainability apply to a particular credit. Pick at least one resource and one principle from the lists below that are influenced, supported or enhanced by your credit. It is likely that the credit will have more than one sustainability components. However, it is rare that a single credit will address all sustainability components.
- Note that, while we recognize that all projects take time (Extent) and cost money (Economy), these two principles should not be noted for every credit unless there is a significant impact due to implementation of the credit itself on time or money. For example, the Long Life Pavement credit directly considers the principles Extent and Expectations, whereas the Energy Efficiency credit probably falls under both Economy and Ecology.

Benefits

Highlight direct and indirect benefits.

- The major benefits that represent influenced resources and needs met by your activity or practice. There are 16 to choose from:

✓ **Reduces Water Use**
✓ **Reduces Fossil Energy Use**
✓ **Reduces Raw Materials Use**
✓ **Reduces Air Emissions**
✓ **Reduces Wastewater Emissions**
✓ **Reduces Soil/Solid Emissions**
✓ **Improves Human Health & Safety**
✓ **Improves Access & Mobility**
✓ **Improves Business Practice**
✓ **Increases Lifecycle Savings**
✓ **Increases Lifecycle Service**
✓ **Increases Awareness**
✓ **Aesthetics**
✓ **Optimizes Habitat & Land Use**
✓ **Creates New Information**
✓ **Creates Energy**

- Essentially this section of the sidebar answers the question: **What is achieved or improved by attempting to satisfy the credit requirements?** A user can look briefly at the front page of the credit and have a quick understanding of the beneficial consequences associated with implementing the credit.
- These benefits can be qualitative or, more often, quantifiable attributes of the credit. For example, is air quality improved? Is there a novel impact on life cycle service or savings? For any benefit where the relationship is not immediately obvious, please provide some supporting research to make that connection clear. Sometimes these benefits may be indirectly achieved or difficult to quantify, but these should still be noted in the sidebar. An example is achieving AE-5 Pedestrian Access which has the direct benefit of improved access and mobility, but also the indirect benefit of reduced greenhouse gas air emissions.

Application Review Process

Your team's credit application will be reviewed by Greenroads developers based on the following criteria.

1. Greenroads Credit Template is substantially completed.
2. Goal statement is clear and concise.
3. Credit Requirements are clear, concise, and actionable.

4. Documents needed are clear and concise and easy to produce.
5. Potential Issues and associated sustainability tradeoffs are stated.
6. At least one strategy and one example are provided.
7. Research is thoroughly referenced or has clearly denoted limitations.
8. Research clearly exemplifies one or more component of sustainability.
9. Research clearly exemplifies one or more benefit due to the suggested practice and notes any tradeoffs associated with implementation of such practice.
10. All sources used are listed.

- You will be notified of comments and questions by a member of the Review Team.
- After that, your credit will be submitted to a panel of professionals for review and comment. This might be a long process, and it will likely be iterative and require interaction between Greenroads Reviewers and your project team.

What Happens Next?

- If your application is accepted, your custom credit will be put in the Greenroads bank of ideas and published online at http://www.greenroads.us in a form similar to other existing credits. It will be reassigned a number based on other Custom Credits that have also been approved. It will be made available to other projects to use following approval. Therefore, please take care to preserve proprietary knowledge where necessary.
- If your application is not accepted, you are welcome to revise and resubmit, or write an entirely new credit.

Formatting for the Research Section in the Template

This is an example of the standard style, in paragraphs, of Body Text. Be sure to define terms or professional jargon used to make your case in the glossary. Present any **vocabulary term** in boldface and define it in the Glossary.

This is Research Heading style

Body Text, List Number, Bullet

This is Research Heading Indent style

Body Text indent, List Number Indent, Bullet Indent

> *This is Research Blockquote. Use it when displaying large amounts of directly quoted or verbatim text from other references.*

Final Comments

Be sure to change both headers and footers to include your credit title and credit number. This template is designed to print double sided and bound (or hole-punched) on the left side of the front page of each credit.

GLOSSARY

This section is optional. Define words that might be unfamiliar to a wide audience of Greenroads users in this section. Vocabulary is defined in a 2 column table, terms on left (2” column), defined on right (the remaining width). Do not use captions for this table. Orange text is called “Vocabulary” style and the definition is in the style called “No Spacing.” All tables have a 0.2” bottom separation from text on the bottom, which is accomplished. No intro text in given in this section below the header, so delete this paragraph when writing your own credit. This glossary contains an example of the word **sustainability**.

Sustainability	A system characteristic that describes the system’s capacity to support natural laws and human values

REFERENCES

For this section, use American Psychological Association (APA) reference style and apply References style.

There are many resources available online to help you format your references. Here is a good one with many examples from the Online Writing Lab at Purdue University: http://owl.english.purdue.edu/owl/resource/560/01/

Here is an example of how to format the above reference from the web correctly:

Purdue University Online Writing Lab (2009, Nov. 11). *APA Formatting and Style Guide – The OWL at Purdue.* Retrieved November 25, 2009, from http://owl.english.purdue.edu/owl/resource/560/01/.

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