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Greenroads:
A sustainability performance metric for roadway design and construction

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16. ABSTRACT

Greenroads is a performance metric for quantifying sustainable practices associated with roadway design and construction. Sustainability is defined as having seven key components: ecology, equity, economy, extent, expectations, experience and exposure. By Greenroads standards, a sustainable roadway project is one that carefully an overtly integrates these components into the design and construction process to a substantially higher standard than current common practice. Greenroads Version 1.0 consists of 11 Project Requirements, 37 Voluntary Credits (worth 108 points) and up to 10 points worth of Custom Credits. Project-level sustainability performance can be assessed by meeting all Project Requirements and any number of Voluntary Credit points. Greenroads also sets “achievement levels” at different point values in order to provide recommended scoring levels. Greenroads is compatible with other existing systems that can and have been applied to roadways and can be adopted in a number of ways, however the most likely are: (1) as an external standard, (2) as a project accounting standard, and (3) as a tool for competitive advantage for both private industry and public agencies.

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Executive Summary

Greenroads (www.greenroads.us) is a performance metric for quantifying sustainable practices associated with roadway design and construction. This metric can be used to:

- Define what project attributes contribute to roadway sustainability
- Provide a sustainability accounting tool for roadway projects
- Communicate sustainable project attributes to stakeholders
- Manage and improve roadway sustainability
- Grant "certification" based on achieving a minimum number of points

Sustainability Defined

Greenroads defines "sustainability" as *a system characteristic that reflects the system's capacity to support natural laws and human values*. "Natural laws" refers to three basic principles that must be upheld to maintain earth's ecosystem as discussed by Robért (1997). These are summarized:

1. Do not extract substances from the earth at a faster pace than their slow redeposit and reintegration into the earth.
2. Do not produce substances at a faster pace than they can be broken down and integrated into nature near its current equilibrium.
3. Do not degrade ecosystems because our health and prosperity depend on their proper functioning.

"Human values" refers to equity and economy. Equity, which is essentially Robért's (1997) fourth principle, is interpreted as a primarily human concept of meeting their nine fundamental human needs: subsistence, protection, affection, understanding, participation, leisure, creation, identity and freedom (Max-Neef et al. 1991). Economy is broadly interpreted as management of human, manufactured, natural and financial capital (Hawken et al. 1999).

Beyond *ecology*, *equity* and *economy* we believe there are four other essential components to a sustainability definition. First, sustainability is context sensitive. Hence, for a particular project, the project's *extent* in space and time (i.e., its scope and life cycle) and performance *expectations* (i.e., design life, metrics of performance, and assessment of risks) must be part of the definition. Second, what transforms "sustainability" from concept to reality are *experience* (in the form of technical expertise and historical information that drive current decisions) and *exposure* (in the form of education and training) of the profession and general public to the idea of sustainability and its importance. In total, this sustainability definition has seven components: ecology, equity, economy, extent, expectations, experience and exposure.

Where Greenroads Fits

- **Regulation**. Greenroads is designed to work within the existing U.S. regulatory environment. Specifically, Greenroads is 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.
- **System boundaries**. Greenroads is a project-based system; it is applicable to the design and construction of new or rehabilitated roadways including expansion or redesign. Importantly, it does not directly deal with planning (e.g., alternative selection, etc.) or operations (e.g., vehicle fleet mix, fuel efficiency, etc.) components. While these are important, they are beyond the scope of a project-oriented metric.
- **Stakeholders**. There are a number of important stakeholders in U.S. roadways that may have interest in Greenroads including: road owners, funding agencies, design consultants, contractors, regulatory agencies, sustainability organizations and research organizations.

Greenroads Performance Metric

Greenroads is a collection of sustainability best practices that apply to roadway design and construction (Table 1). These best practices are divided into two types: required and voluntary. Required best practices are those that must be done as a minimum in order for a roadway to be considered a Greenroad. These are called "Project Requirements," of which there are 11. 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.

TABLE 1. Greenroads Listing by Category

No.	Title	Pts.	Description
Project Requirements (PR)			
PR-1	NEPA Compliance or Equivalent	Req	Conform to NEPA or equivalent
PR-2	Life Cycle Cost Analysis (LCCA)	Req	Perform LCCA for pavement section
PR-3	Life Cycle 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	Use LID stormwater management where applicable
PR-9	Pavement Maintenance	Req	Have a pavement preservation system
PR-10	Site Maintenance	Req	Have a roadside maintenance plan
PR-11	Educational Outreach	Req	Publicize sustainability information for project
Voluntary Credits			
Environment & Water (EW)			
EW-1	Environmental Management System	2	ISO 14001 certification for general contractor
EW-2	Runoff Quantity	3	Reduce runoff quantity
EW-3	Runoff Quality	3	Treat stormwater to a higher level of quality
EW-4	Stormwater LID/BMP Cost Analysis	1	Conduct an LCCA for stormwater BMP/LID selection
EW-5	Native Revegetation	3	Use native low/no water vegetation
EW-6	Habitat Restoration	3	Create new habitat beyond what is required
EW-7	Ecological Connectivity	3	Connect habitat across roadways
EW-8	Light Pollution	3	Discourage light pollution
	EW Subtotal:	**21**	
Access & Equity (AE)			
AE-1	Safety Audit	2	Perform roadway safety audit
AE-2	Intelligent Transportation Systems (ITS)	5	Implement ITS solutions
AE-3	Single-Occupant Vehicle (SOV) Reduction	5	Reduce SOV use through quantifiable methods
AE-4	Context Sensitive Planning	5	Plan for context sensitive solutions
AE-5	Pedestrian Access	2	Provide/improve pedestrian accessibility
AE-6	Bicycle Access	2	Provide/improve bicycle accessibility
AE-7	Transit Access	5	Provide/improve transit accessibility
AE-8	Scenic Views	2	Provide views of scenery or vistas
AE-9	Cultural Outreach	2	Promote art/culture/community values
	AE Subtotal:	**30**	
Construction Activities (CA)			
CA-1	Quality Process Management	2	ISO 9001 certification for general contractor
CA-2	Environmental Awareness Training	1	Provide environmental training
CA-3	On-Site Recycling Plan	1	Provide on-site recycling and trash collection
CA-4	Fossil Fuel Use Reduction	2	Use alternative fuels in construction equipment
CA-5	Equipment Emission Reduction	2	Meet EPA Tier 4 standards for non-road equip.
CA-6	Paving Emission Reduction	1	Use pavers that meet NIOSH requirements
CA-7	Water Use Monitoring	2	Develop data on water use in construction
CA-8	Performance-Based Warranty	3	Warranty on the constructed pavement
	CA Subtotal:	**14**	

No.	Title	Pts.	Description
Materials & Resources (MR)			
MR-1	Full Life Cycle Assessment (LCA)	2	Conduct a detailed LCA of the entire project
MR-2	Pavement Reuse	5	Reuse existing pavement sections
MR-3	Soil Rehabilitation	1	Use native soil rather than import fill
MR-4	Recycled Materials	5	Use recycled materials for new pavement
MR-5	Regional Materials	5	Use regional materials to reduce transportation
MR-6	Energy Efficiency	5	Improve energy efficiency of operational systems
	MR Subtotal:	**23**	
Pavement Technologies (PT)			
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	3	Use a quiet pavement to reduce noise
PT-6	Pavement Performance Monitoring	1	Relate construction to performance data
	PT Subtotal:	**20**	
	Voluntary Credit Total:	**108**	
Custom Credits (CC)			
CC-1	Custom Credits	10	Design your own credit
	CC Subtotal:	**10**	
	Greenroads Total:	**118**	

Greenroads may be used to certify (bestow official recognition) a project based meeting all the Project Requirements and achieving a particular number of Voluntary Credit points. There are four certification levels (Figure 1):

- 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)

FIGURE 1. Certification level graphics.

Importantly, each Greenroads Project Requirement and Voluntary Credit can be traced back to at least one relevant sustainability component. This is important because it provides a transparent basis by which a Greenroads Project Requirement or Voluntary Credit can be considered to contribute to "sustainability" as Greenroads defines the term. This tracing back of best practices to sustainability is done, to the extent possible, using existing empirical research with an emphasis on the transparency. If a practice is not well-understood or there is evidence a material or method may compromise performance, it is mentioned and discussed.

Interoperability with Other Systems

Over the past few years a number of sustainability-related initiatives, coalitions, rating systems and procedures that have gained significant traction in the transportation field. Typically, these address a specific component of sustainability (e.g., access or ecology) and have some form of guidance or scoring that provides guidance for owner-agencies wishing to adopt the process or assess their projects. As the number of these separate systems continues to grow it is important to understand how Greenroads might work with these systems. In essence, Greenroads is an overarching sustainability metric while often (but not always) these systems address components of sustainability (e.g., ecology or economy) or subsets of roadway design/construction (e.g., site planning, access). A list of the more prominent systems includes:

- **Complete Streets**. A coalition whose goal is to help with the adoption of street policies focused on access for all ages, abilities and transportation modes.
- **Sustainable Sites Initiative**. An effort to create voluntary national guidelines and performance benchmarks for sustainable land design, construction and maintenance practices.
- **Civil Engineering Environmental Quality Assessment and Award Scheme (CEEQUAL)**. A United Kingdom-based assessment and award scheme for improving sustainability in civil engineering projects. The goal is to award projects that go beyond environmental regulatory minimums.
- **Low Impact Development (LID)**. A planning and design approach with a goal of maintaining and enhancing the pre-development hydrologic regime of urban and developing watersheds

- **Context Sensitive Solutions (CSS)**. A collaborative process that involves all stakeholders in developing transportation solutions that fit within their context. This is an overarching process that stresses communication, consensus, flexibility and creativity in generating transportation solutions.
- **Smart Growth**. A network of organizations that advocates growth that restores vitality to center cities and older suburbs through collaboration, mixed-use development, preserving open spaces, and providing transit and pedestrian access.
- **Resource Conservation Challenge (RCC)**. A U.S. Environmental Protection Agency (EPA) led effort designed to conserve natural resources and energy by managing materials more efficiently.
- **Eco-Logical**. A conceptual approach to developing infrastructure that stresses reduced impact on ecosystems.
- **LEED for Neighborhood Development**. Integrates principles of smart growth, urbanism and green building into neighborhood design.

As a minimum, achieving goals set forth in sustainability-related approaches such as these should be reflected in Greenroads scores. For instance, a city's Complete Streets program that promotes multimodal access should also receive points in Greenroads. Table 2 shows how these systems relate to specific Greenroads Project Requirements and Voluntary Credits.

TABLE 2. Greenroads Project Requirements and Voluntary Credits Most Applicable to Other Systems

Effort	Most Likely PRs and VCs	Other Possible PRs and VCs
Complete Streets	AE-4	AE-3, AE-5, AE-6, AE-7, AE-8, AE-9
Sustainable Sites	PR-10, EW-5, EW-6, MR-3	PR-2, PR-3, PR-6, PR-7, PR-8, PR-11, EW-2, EW-3, AE-4, AE-9, CA-3, MR-1, MR-2, MR-3, MR-4, MR-5, PT-4
CEEQUAL	PR-1, PR-7	PR-2, PR-3, PR-5, PR-6, PR-8, PR-9, PR-10, AE-4, AE-8, all EW, CA-2 through CA-6, all MR, PT-1, PT-2, PT-5
LID	PR-4	PR-7, PR-10, EW-2, EW-3, EW-5, EW-6, PT-2
CSS	AE-4	AE-1, AE-2, AE-3, AE-5, AE-6, AE-7, AE-8, AE-9
Smart Growth	AE-4	PR-4, EW-2, EW-3, EW-6, AE-1, AE-3, AE-5, AE-6, AE-7, AE-8, AE-9
Eco-Logical	EW-6, EW-7	EW-2, EW-3, EW-5, AE-4, AE-8
RCC	CA-3, MR-2, MR-4	MR-3, MR-6
LEED for Neighborhood Dev.	EW-6, EW-7	EW-8, AE-5, AE-6, AE-7, AE-8, AE-9, MR-6, PT-4

Avenues for Adoption

Sustainability metrics like Greenroads are likely to be adopted on an individual organization basis rather than as a regional or national standard. Interactions with owner agencies, consultants and contractors over the last two years have begun to reveal the most likely avenues for adoption:

- **External standard**. Some owner organizations are seeking ways to legitimize, improve, or market their sustainable approaches to roadway design and construction.
- **Project accounting standard**. Some owner organizations are seeking sustainability accounting tools to help monitor, judge and improve their approach to sustainability.
- **Competitive Advantage**. Some organizations, often design consultants and contractors, use Greenroads to gain a competitive advantage. Competitive advantage also extends to public owner agencies. Beginning in 2010, the Washington State Transportation Improvement Board (TIB), an independent state agency that makes and manages street construction/maintenance grants based on revenue from 3 cents of the statewide gas tax, will include specific sustainability items (15 points) on its 100 point evaluation criteria for their urban arterial and corridor programs (Washington TIB 2009). Whether or not cities and counties receive these grants depends directly on how their project's evaluation criteria score.

Greenroads Use to Date

A number of organizations have begun to use Greenroads (on a trial or experimental basis) decided to investigate its potential for use. These investigations generally take one of two forms:

- **Case studies**. A retrospective application of the Greenroads performance metric to projects that are already complete or substantially complete. Essentially, this amounts to asking the question, "How would the project have done if it had been scored using Greenroads?" These investigations provide information on what current practice is able to achieve without special attention to Greenroads. Therefore, they can help an organization establish benchmark or baseline scores for typical projects and they can help with Greenroads calibration so that achievement levels are neither too easy nor too hard to reach.

- **Pilot projects**. An application of Greenroads to projects that have not yet been designed or are in early design (30% complete at the most). Pilot projects are different from case studies because pilot projects consider Greenroads best practices in the design and construction decision-making process; thus Greenroads has some influence over how a project is designed and constructed. In this way, pilot projects provide data on the cost and reason for pursuing or not pursuing Project Requirements and Voluntary Credits. They can also serve as usability tests in an effort to make Greenroads easier to use.

In early 2009, Greenroads undertook an early experiment to see if the Washington State Department of Transportation's (WSDOT) entire roadway network could be rated using the Greenroads sustainability performance metric. This experiment used data from WSDOT's pavement management system to score WSDOT's roadway network based on the Greenroads metric. While only some Voluntary Credits could be scored (9 of 37) using pavement management data, the experiment showed that existing data can be used to develop minimum baseline scores and Greenroads scores can be tracked as pavement condition is currently tracked by most owner agencies. Of the 13,630 sections of roadway analyzed, the average Greenroads score was 12.68 (Figure 2 shows a histogram of Greenroads scores).

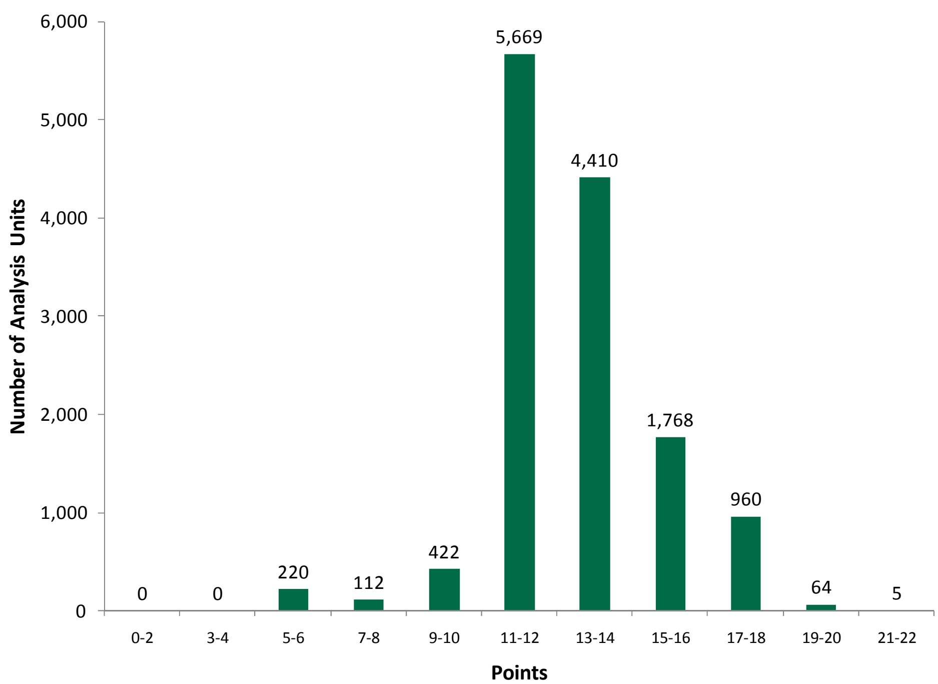

FIGURE 2. Histogram of points by frequency of Analysis Unit.

1 Introduction

The use of sustainable practices in civil infrastructure can often be difficult because (1) decision makers do not have adequate information to make informed decisions on these aspects, and (2) there is no quantitative means of assessment in this area. “Greenroads” is the overarching term for a project to research and implement a sustainability performance metric for roadway design and construction. In broad terms, this metric awards points for more sustainable practices and functions as a means to quantify sustainability in roadway design and construction. This quantification can be used to:

- Define what project attributes contribute to roadway sustainability
- Provide a sustainability accounting tool for roadway projects
- Communicate sustainable project attributes to stakeholders
- Manage and improve roadway sustainability
- Grant “certification” based on achieving a minimum number of points

The Greenroads sustainability performance metric (hereafter referred to as “Greenroads”) is a publically available system that can be used by anyone. However, the Greenroads logo, name, and the rights to grant official certification remain with the research and implementation team alone.

This report describes Greenroads efforts from the project’s inception in early 2007 through October 2009. Work on Greenroads is ongoing and expected to continue through 2012. This report specifically describes the Greenroads performance metric including its development, function and use to date. The full Greenroads Version 1.0 manual is still under development and will be issued as a supplement to this report when it is complete in the first quarter of 2010. Current Greenroads status and other resources are available on the official project website: www.greenroads.us.

1.1 Greenroads Developers

Greenroads is being developed jointly by the University of Washington (UW) and CH2M HILL. Research at the University of Washington is conducted as contracted research, while work at CH2M HILL is conducted and billed wholly within CH2M HILL. UW and CH2M HILL are operating under a Memorandum of Understanding (MOU) that provides the framework for combining efforts. Essentially, this MOU states that each party agrees to work together on Greenroads and that any intellectual property developed remains the property of the developing organization.

1.2 Greenroads Website

All Greenroads work – including news, supplemental information, and copies of presentations given – is documented on the official website, www.greenroads.us, which was developed as part of this research effort.

2 Sustainability Defined

Greenroads defines "sustainability" as *a system characteristic that reflects the system's capacity to support natural laws and human values*. "Natural laws" refers to three basic principles that must be upheld to maintain earth's ecosystem as discussed by Robért (1997). These are summarized:

1. Do not extract substances from the earth at a faster pace than their slow redeposit and reintegration into the earth.
2. Do not produce substances at a faster pace than they can be broken down and integrated into nature near its current equilibrium.
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"Human values" refers to equity and economy. Equity, which is essentially Robért's (1997) fourth principle, is interpreted as a primarily human concept of meeting their nine fundamental human needs: subsistence, protection, affection, understanding, participation, leisure, creation, identity and freedom (Max-Neef et al. 1991). Economy is broadly interpreted as management of human, manufactured, natural and financial capital (Hawken et al. 1999) . By this definition economy refers to project finance but it also refers to items such as forest resources management and carbon cap-and-trade schemes.

In total, this definition contains the key elements of *ecology*, *equity* and *economy* and is essentially consistent but more actionable on a project scale than the often quoted United Nations 1987 Brundtland Commission report excerpt: "…development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (A/RES/42/187). It is also compatible with the Millennium Ecosystem Assessment (2005) and other local definitions such as the Oregon Sustainability Act of 2001 (ORS 184.421).

Beyond *ecology*, *equity* and *economy* we believe there are four other essential components to a sustainability definition. First, sustainability is context sensitive. Hence, for a particular project, the project's *extent* in space and time (i.e., its scope and life cycle) and performance *expectations* (i.e., design life, metrics of performance, and assessment of risks) must be part of the definition. Second, what transforms "sustainability" from concept to reality are *experience* (in the form of technical expertise and historical information that drive current decisions) and *exposure* (in the form of education and training) of the profession and general public to the idea of sustainability and its importance. In total, our sustainability definition has seven components: ecology, equity, economy, extent, expectations, experience and exposure.

To date, roadways typically approach sustainability in a piecemeal manner. Typical means have been through regulation (describing minimum acceptable standards); political or mandated processes for ensuring environmental justice, cultural and aesthetic considerations; project evaluative procedures (e.g., benefit-cost), external budgetary constraints and political or economic pressures. Although there are processes that attempt to integrate these efforts on a project level (e.g., the National Environmental Policy Act – NEPA and state equivalents, cost/benefit analyses, etc.) and Context Sensitive Solutions/Design (CSS/CSD) (Neuman et al. 2002) none yet are purposefully organized around the definition of sustainability presented here.

3 The Building Industry's Leading Metric: LEED™

In all, there may be more than 60 green rating systems for buildings in the U.S. developed by various public and private entities (Intelligent Design 2007). Among these systems, the U.S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED™) has garnered the most attention and is arguably the most successful. LEED™ is briefly reviewed here in an attempt to (1) quantify its popularity and growth, and (2) review its major strengths and criticisms in order to address these in Greenroads development.

Developed by the USGBC in the mid 1990s, LEED™ is a rating system for the design and construction of sustainable buildings. LEED™ standards are divided into categories with each category containing a certain number of mandatory prerequisites and optional credits. Projects can earn points through design and construction decisions/actions and then become certified based on the number of credits earned. Importantly, the project team decides which and how many credits to apply for and provides the required documentation. Once the building is complete, it is “commissioned” where LEED™ credits are verified through an official process.

3.1 Popularity and Growth

As of 15 October 2009 there are more than 25,000 registered LEED™ projects and more than 3,800 certified projects worldwide (USGBC 2009a). This compares to about 100 registered projects and 12 certified projects in 2000 (Scheuer and Keoleian 2002). This rapid growth has been attributed to its relative simplicity, substantial infrastructure and, most importantly, a growing nationwide consumer interest in sustainability.

3.2 Advantages

The USGBC markets LEED™ as advantageous for the following reasons:

- **Superior buildings**. LEED™ requirements create a better environment that can improve occupant comfort, health and productivity. Notably, Kats et al. (2003) concluded productivity and health benefits constituted 70 percent of the financial benefits of a LEED™ certified building. However, valuing benefits like worker productivity can be difficult and subjective (Kats et al. 2003).
- **Reduced environmental impact**. LEED™ requirements result in a building that creates less waste and is more efficient in energy and water use (Schendler and Udall 2005).
- **Positive return on investment**. LEED™ certified buildings have a lower life cycle cost. It is generally argued (Kats et al. 2003;Dorsey and Sieving 2003) that energy efficiency, worker productivity and other LEED™ features offer life cycle savings of about 10 times their initial cost premium. Again, some benefit valuation is highly subjective.
- **Marketing**. Consumer interest in sustainability and environmental issues makes LEED™ certification a marketing tool for showing “environmental commitment and leadership” and “sending a strong message to employees and the wider community that you care about their health” (USGBC 2003).

LEED™ has been successful because of this benefit mix. Building owners receive a better building with less environmental impact that provides a positive return on investment. Marketing these benefits can result in premium prices for certified buildings.

3.3 Criticisms

Major LEED™ criticisms are:

- **Certification is expensive and bureaucratic**. Certification can cost between $1,750 and $22,500 in fees (USGBC 2009b) plus time and resources. LEED™ reviews can be overly focused on unimportant details and overly bureaucratic (Schendler and Udall 2005).
- **LEED™ can shift design focus from good design to obtaining LEED™ credits**. Potential marketing aspects of certification begin to drive design.
- **The credits are not weighted to reflect environmental impacts and importance**. Low impact actions that require little effort (e.g. installing a bicycle rack) are valued the same as high impact, high effort actions (e.g., installing a million dollar HVAC heat recovery system) (Schendler and Udall 2005). Consequently, most certification efforts concentrate on low-budget, low-impact credits to achieve certification (Matthiessen and Morris 2007). A National Institute of Standards (NIST) report concluded that LEED™ ratings do not compare to life cycle assessment results and when "…considered in a life cycle perspective LEED™ does not provide a consistent, organized structure for achievement of environmental goals." (Scheuer and Keoleian 2002).
- **Initial costs for LEED™ projects are higher**. Most estimates (e.g., Kats et al. 2003; Dorsey and Sieving 2003; Matthiessen and Morris 2007; Steven Winter Associates 2004) put initial costs at between 0 and 8 percent more than similar non-LEED™ buildings.

Criticisms of LEED™ are generally focused on initial cost and the sometimes tenuous relationship between credits and sustainability and the resulting impacts these two items can have on design and construction decisions.

4 Fit, Boundaries and Philosophy

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

4.1 Regulatory Fit

Greenroads is designed to promote sustainability best practices within and beyond existing federal, state and local regulations. Specifically, Greenroads is 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.

4.2 System Boundaries

Greenroads is a project-based system; it is applicable to the design and construction of new or rehabilitated roadways including expansion or redesign. Specifically, it applies to (1) the design process and (2) construction activities within the workzone as well as material hauling activities, production of portland cement concrete (PCC) and hot mix asphalt (HMA). This means that some typical items associated with roadways are considered in specific ways that merit explanation:

- **Roadway planning**. Decisions regarding the location, type, timing, feasibility or other planning level ideas are excluded. 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 performance metric. We believe planning efforts are better measured by adherence to more general community or organizational performance metrics that often go beyond the boundaries of a single roadway project.

- **Materials manufacturing or refining**. Items such as cement and asphalt manufacturing/refining are only considered in life cycle inventories (LCI) or analyses (LCA). This means that specific improvements in these processes may not be captured by Greenroads depending upon the data source(s) used for the required pavement LCI or voluntary roadway LCA.
- **Structures**. Bridges, tunnels, walls and other structures are considered only as a collection of materials. Points can be awarded for materials used; however the structural design, aesthetics and other non-material qualities are excluded. A future system focused on structures could be incorporated into Greenroads but none currently exist.
- **Paths and trails**. If directly associated with the roadway (e.g., adjoining foot/bicycle path or sidewalk), they are considered. Independent paths and trails (e.g., a conversion of a rail right-of-way to a bicycle path) are excluded but could be addressed within something like the Sustainable Sites Initiative (www.sustainablesites.org).
- **Maintenance and preservation**. Maintenance and preservation actions have a large impact on overall roadway sustainability. Greenroads considers them in LCA, and awards points for having formal procedures in place to ensure their execution. However, since they necessarily occur after certification, they are not judged at the time they are actually performed. Such an idea could be incorporated into a future Greenroads metric that specifically addresses maintenance and preservation.
- **Roadway use**. Traffic has a profound impact on sustainability. Design decisions that affect how a facility is used by traffic are given credit but judgments on direct use issues such as fleet composition, emissions ratings and vehicle fuel sources are not considered since they cannot be adequately predicted or verified at substantial project completion. These issues may be best left to planning level efforts as they are more universal in nature and not specific to one particular project.

4.3 Stakeholders

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 related sustainable technologies.

Upon the release of Version 1.0 these types of stakeholders will be sought out to comment and revise the metric for a planned Version 2.0 release in the future.

4.4 General Philosophy

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

- **Straightforward and understandable**. Non-experts should be able to understand the metric. Simplicity is valued over excessive detail because it is more understandable. Best practices, as described in Greenroads, 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**. Best practices are based on a preponderance of empirical evidence and, to the extent possible, should be evaluated using existing tools and techniques.
- **Credit commensurate with impact**. Best practices should be weighted in relation to one another commensurate with their impact on sustainability.
- **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.
- **Continual evolution**. Over time, better ideas, more complete knowledge and technology advances will require Greenroads to be updated and changed.
- **Minimal bureaucracy**. Obtaining points/certification requires documentation. To the greatest extent possible, 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 performance metric that awards credit for these items alone essentially becomes a marketing tool that is technically redundant and administratively burdensome.

5 Greenroads Overview

The Greenroads performance metric is a collection of sustainability best practices that apply to roadway design and construction (Table 3). These best practices are divided into two types: required and voluntary. Required best practices are those that must be done as a minimum in order for a roadway to be considered a Greenroad. These are called “Project Requirements,” of which there are 11. 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.

TABLE 3. Greenroads Listing by Category

No.	Title	Pts.	Description
Project Requirements (PR)			
PR-1	NEPA Compliance or Equivalent	Req	Conform to NEPA or equivalent
PR-2	Life Cycle Cost Analysis (LCCA)	Req	Perform LCCA for pavement section
PR-3	Life Cycle 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	Use LID stormwater management where applicable
PR-9	Pavement Maintenance	Req	Have a pavement preservation system
PR-10	Site Maintenance	Req	Have a roadside maintenance plan
PR-11	Educational Outreach	Req	Publicize sustainability information for project
Voluntary Credits			
Environment & Water (EW)			
EW-1	Environmental Management System	2	ISO 14001 certification for general contractor
EW-2	Runoff Quantity	3	Reduce runoff quantity
EW-3	Runoff Quality	3	Treat stormwater to a higher level of quality
EW-4	Stormwater LID/BMP Cost Analysis	1	Conduct an LCCA for stormwater BMP/LID selection
EW-5	Native Revegetation	3	Use native low/no water vegetation
EW-6	Habitat Restoration	3	Create new habitat beyond what is required
EW-7	Ecological Connectivity	3	Connect habitat across roadways
EW-8	Light Pollution	3	Discourage light pollution
	EW Subtotal:	**21**	
Access & Equity (AE)			
AE-1	Safety Audit	2	Perform roadway safety audit
AE-2	Intelligent Transportation Systems (ITS)	5	Implement ITS solutions
AE-3	Single-Occupant Vehicle (SOV) Reduction	5	Reduce SOV use through quantifiable methods
AE-4	Context Sensitive Planning	5	Plan for context sensitive solutions
AE-5	Pedestrian Access	2	Provide/improve pedestrian accessibility
AE-6	Bicycle Access	2	Provide/improve bicycle accessibility
AE-7	Transit Access	5	Provide/improve transit accessibility
AE-8	Scenic Views	2	Provide views of scenery or vistas
AE-9	Cultural Outreach	2	Promote art/culture/community values
	AE Subtotal:	**30**	
Construction Activities (CA)			
CA-1	Quality Process Management	2	ISO 9001 certification for general contractor
CA-2	Environmental Awareness Training	1	Provide environmental training
CA-3	On-Site Recycling Plan	1	Provide on-site recycling and trash collection
CA-4	Fossil Fuel Use Reduction	2	Use alternative fuels in construction equipment
CA-5	Equipment Emission Reduction	2	Meet EPA Tier 4 standards for non-road equip.
CA-6	Paving Emission Reduction	1	Use pavers that meet NIOSH requirements
CA-7	Water Use Monitoring	2	Develop data on water use in construction
CA-8	Performance-Based Warranty	3	Warranty on the constructed pavement
	CA Subtotal:	**14**	

No.	Title	Pts.	Description
Materials & Resources (MR)			
MR-1	Full Life Cycle Assessment (LCA)	2	Conduct a detailed LCA of the entire project
MR-2	Pavement Reuse	5	Reuse existing pavement sections
MR-3	Soil Rehabilitation	1	Use native soil rather than import fill
MR-4	Recycled Materials	5	Use recycled materials for new pavement
MR-5	Regional Materials	5	Use regional materials to reduce transportation
MR-6	Energy Efficiency	5	Improve energy efficiency of operational systems
	MR Subtotal:	**23**	
Pavement Technologies (PT)			
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	3	Use a quiet pavement to reduce noise
PT-6	Pavement Performance Monitoring	1	Relate construction to performance data
	PT Subtotal:	**20**	
	Voluntary Credit Total:	**108**	
Custom Credits (CC)			
CC-1	Custom Credits	10	Design your own credit
	CC Subtotal:	**10**	
	Greenroads Total:	**118**	

5.1 Achievement/Certification Levels

Greenroads may be used to "certify" (bestow official recognition) a project based on total points achieved. Depending upon the appetite of the project and its owners, 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 (Figure 3):

- 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)

FIGURE 3. Certification level graphics.

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.

Certification Review Process[1]. Greenroads certification is an online process at www.greenroads.us. Projects register at the Greenroads website (www.greenroads.us) and submit documentation and questions via an online interface. A Greenroads certification team works with a project by answering questions online and verifying documentation to ensure credit requirements are met. Ultimately, a project is certified by the Greenroads certification team based on documentation and narrative submitted by the project. The certification workflow works like this:

1. A project chooses to pursue Greenroads certification and signs up online.
2. The project team communicates online which credits will be pursued and, for those pursued, enters a short narrative describing the project portion that will achieve the credit.
3. The project uploads supporting documentation (or enters a link that points to such documentation that is housed elsewhere on the Internet) for each credit that is being pursued.
4. The Greenroads certification team may comment informally on attempted credits to provide clarification or answer any questions the project team has.
5. Once documentation for all pursued credits is entered the Greenroads certification team reviews these credits and provides a preliminary ruling on whether each credit is

[1] Note: as of 31 October 2009, this online system is not fully operational.

achieved; and, if a credit was not achieved, they will provide an explanation of what additional items must be accomplished or submitted to achieve the credit.

6. The project addresses any comments from the Greenroads certification team and then enters a final submission for certification. At this point, the project team and Greenroads certification team should have had enough communication about the project that the final rating decision should be already known on an informal basis.
7. The Greenroads certification team makes a final certification determination and officially certifies the project.
8. Greenroads sends an official letter to the project notifying it of the level of Greenroads certification.

5.2 Tracing Greenroads Credits to Sustainability Components

Each Greenroads Project Requirement and Voluntary Credit can be traced back to at least one relevant sustainability component (Figure 4). We call this “mapping”, and believe it is important because it provides a transparent basis by which a Greenroads Project Requirement or Voluntary Credit can be considered to contribute to “sustainability” as Greenroads defines the term. This mapping involves subjective judgment as to which components map to which items. While elimination of this subjectivity would be ideal, more complex systems for mapping would likely just obfuscate rather than eliminate this subjectivity. Further, mapping of an item back to sustainability and its seven components must, where at all practical, be done using empirical evidence with proper citation. 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.

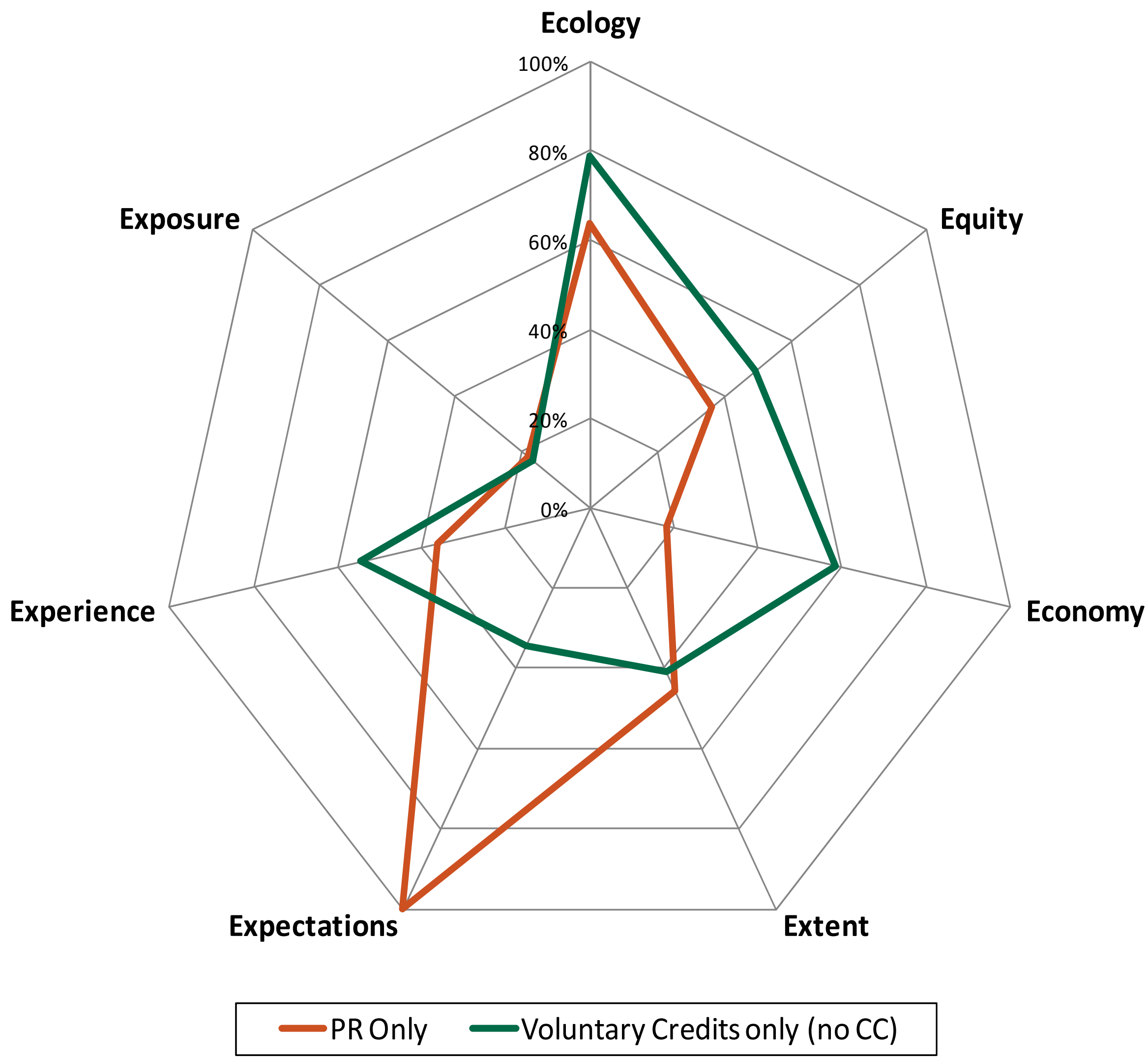


FIGURE 4. Greenroads sustainability footprint. This spider graph that shows the percentage of total Project Requirements or Voluntary Credit points that are traceable back to each sustainability component; most are traceable to several components. An example of how to read this graph: the sustainability component "ecology" shows that 80% of the Voluntary Credit points and 63% of the Project Requirements can be traced to it.

6 Weighting Voluntary Credits

6.1 Reasons for Weighting Greenroads

Whether explicitly stated or not, the fundamental goal of any sustainability performance metric is a logical judgment as to the sustainability of the final product and perhaps a more sustainable final product. Therefore, it would seem imperative that the best practices a performance metric will likely encourage should ultimately result in a more sustainable final product. However, in the building industry reviews of this idea are mixed at best. Criticisms of LEED™ (based on LEED™ for New Construction versions predating the current version 3.0) suggest that achieving LEED™ certification may not achieve a more sustainable building (see Section 3.3). Notably, LEED™ for New Construction (NC) version 3.0, which was introduced in April 2009, is a weighted system as are several other LEED™ systems.

We believe that there is value in properly weighting a sustainability performance metric so that the accomplishment of each sustainability best practice is acknowledged at a level commensurate with its impact on sustainability. This requires two important components: (1) a precise and actionable sustainability definition and (2) a logical scheme that establishes the relative impact of each best practice on sustainability. We believe these two items must be explicit and transparent so that system users can gather adequate information on the system in order to intelligently use, judge and improve it. Although our weighting may be controversial, it does provide a starting point for a sustainability discussion that may prove beneficial to the transportation community. Also, as demonstrated by objections to LEED™, an unweight system invites substantial criticism for its lack of weighting.

6.2 Weighting Logic

This section describes the logic used in weighting Voluntary Credits (Table 1). Since Project Requirements are all required and have no point value they are not weighted. Custom Credits, as they are developed, will be weighted using the logic for Voluntary Credits developed here.

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 for several key reasons. First, 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). Second, traditionally accepted quantitative methods, e.g., life cycle assessment (LCA), life cycle cost analysis (LCCA), benefit-cost analysis, do not adequately address all sustainability components. Therefore, they alone cannot be used for weighting. Third, 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. For instance, treating stormwater runoff may be considered vital based on LCA results; however it receives less emphasis in Greenroads because many stormwater treatment actions are already mandated by U.S. regulation and thus need not be repeated in Greenroads. Fourth, 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. For instance, collecting construction water use data can help determine when and how water is used in roadway construction. It can be argued, though, that the actual act of data collection does not contribute to sustainability.

6.2.1 Weighting Framework

Voluntary Credit 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. We feel this range allows Voluntary Credit weights to reflect a range of sustainability impact but limits the impact of potential missteps such as (1) erroneously high or low weighting based on what later proves to be faulty, incomplete or refuted data, (2) valuing some items so low in relation to others that a particular sector of roadway design and construction is not allowed to participate in a meaningful way, and (3) establishing a relationship between sustainability components through weighting that overwhelmingly favors one component even though all seven components are inherently difficult to value using a common metric.

In the following sections we will argue that individual construction activities during initial construction have the lowest impact 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 we present in this paper. Importantly, Voluntary Credit weights are based on the relationship of their associated prevailing broad concepts (e.g., how construction compares with materials manufacture). The actual level of achievement necessary to qualify for a Voluntary Credit (e.g., 50 percent of the off-road construction fleet) 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 system details.

6.2.2 Ecology Weighting

Sustainability is a human concept. We believe this creates a bias towards human values in any performance metric, including Greenroads. Thus, it is difficult to value ecological components 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 an extremely broad sense and in the absence of any more precise data, 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 Costanza et al. (1997) high end estimate to at least partially account for their admitted underestimation. While other philosophical work might put this multiple as high as infinite, such an estimate does not serve a useful purpose when applied to a performance metric.

Ecosystem services. 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. We acknowledge that this may be controversial but we consider it a first-order approximation necessary to weight a performance metric. This value may be further modified by other logic described in this section.

6.2.3 Equity Weighting

Equity, as it is reflected in Greenroads can be addressed by portions of what is commonly called context sensitive design (CSD) or context sensitive solutions (CSS) (Neuman et al. 2002). To our knowledge, nobody has attempted to place a monetary value on CSD/CSS however, there is substantial evidence (e.g., Neuman et al. 2002; FHWA 1997; APTA 1999; AASHTO 2000; AASHTO 2004) 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). It does not contain significant guidance on ecological specifics but rather a framework in which to consider them. 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 (Neuman et al. 2002) 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 VCs two points.

Access and Equity (AE) Category. 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-4 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. We acknowledge that this may be controversial but we consider it a first-order approximation necessary to weight a performance metric.

6.2.4 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.

Data collection. Two Voluntary Credits are designed to encourage data collection in areas where little credible data exist (CA-7 and MR-1). Each of these is worth two points to provide extra incentive to collect such data.

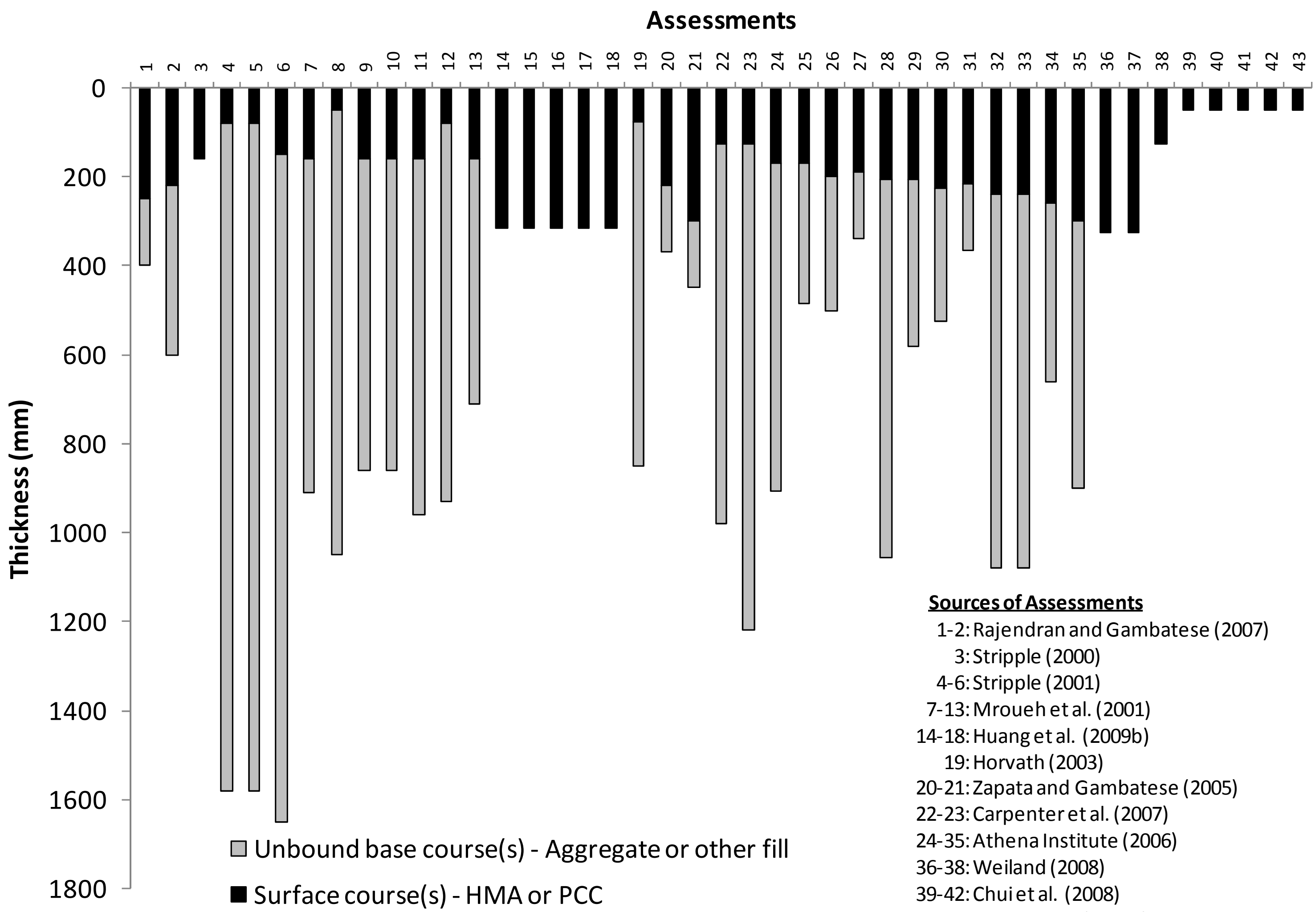
Organization-wide efforts. Two Voluntary Credits are designed to encourage organization-wide efforts (EW-1 and CA-1) that affect sustainability. Each of these is worth two points to provide extra incentive to undertake these broad-based efforts that extend beyond the project in question.

Achievement increments. If a certain achievement level is required to qualify for a Voluntary Credit and there is evidence to suggest that even higher levels are achievable (CA-4, CA-5, CA-8, MR-4 and MR-5), one additional point is awarded for each higher achievement level increment. For example, CA-4 requires alternative fuel to be used in 50% of construction equipment for one point and 75% for two points.

6.2.5 LCA-Based Weighting

For Voluntary Credits dealing with materials production, construction, transportation associated with the construction process and traffic use, weighting is based on 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 Greenroads Voluntary Credits.

With this idea we searched the literature for roadway-related LCA documents that contained adequate supporting information on (1) a system definition, (2) the pavement structure analyzed, (3) total energy use and/or total CO_2 production, and (4) a traceable method for performing the analysis. Based on these criteria we identified 12 roadway LCA papers consisting of 43 assessments of either actual or hypothetical roadways (Athena Institute 2006; Carpenter et al. 2007; Chui et al. 2008; Horvath 2003; Huang et al. 2009a; Huang et a l. 2009b; Mroueh et al. 2001; Rajendran and Gambatese 2007; Stripple 2000; Stripple 2001; Weiland 2008; Zapata and Gambatese 2005). Five papers addressed PCC pavements (10 assessments), while all 12 address HMA pavements (34 assessments). Figure 5 shows the described pavement structure for each assessment. Although each paper's focus, assumptions, data sources and system boundaries are different, we could still identify several reasonable trends on a per lane-km basis relating to (1) LCA/LCI scope, (2) energy use, (3) CO_2 production and (4) the fraction of energy and CO_2 attributed to different phases of roadway construction and use. Median values are used to minimize the influence of extreme outliers. We understand such generalizations might be considered flawed, however we believe that they are useful in providing straightforward and consistent weighting in a performance metric like Greenroads. The following sections describe our findings related to these 12 papers.



6.2.5.1

FIGURE 5. Structural composition of the LCA assessments examined.

6.2.5.2 General Conclusions

System Scope. Most papers (10) consider a roadway's pavement structure only and include its initial construction and construction-related maintenance activities over a defined analysis period of, typically, 40 to 50 years. Two papers also included automobile operation on the completed roadway and just one paper (Stripple 2001) also included items outside the pavement structure (e.g., land clearing, signage, etc.). These scope limits are probably driven by the availability of quality data or the defined scope of the paper.

Total Energy Use. Nine of the papers reported total energy use from a total of 35 assessments. The distribution of results (Figure 6) has a median value of 3.17 TJ/lane-km. The extreme outlier, Horvath (2003) at 10.72 TJ/lane-mile is also the only calculation based on an economic input output (EIO) model. Further analysis of the software used to generate this number (PaLATE) showed several errors in key data values, which in our opinion renders this number (but not the method) suspect. Based on these results it can be reasonably stated that energy expenditures per lane-km of pavement are typically on the order of 2-4 TJ depending upon the pavement section.

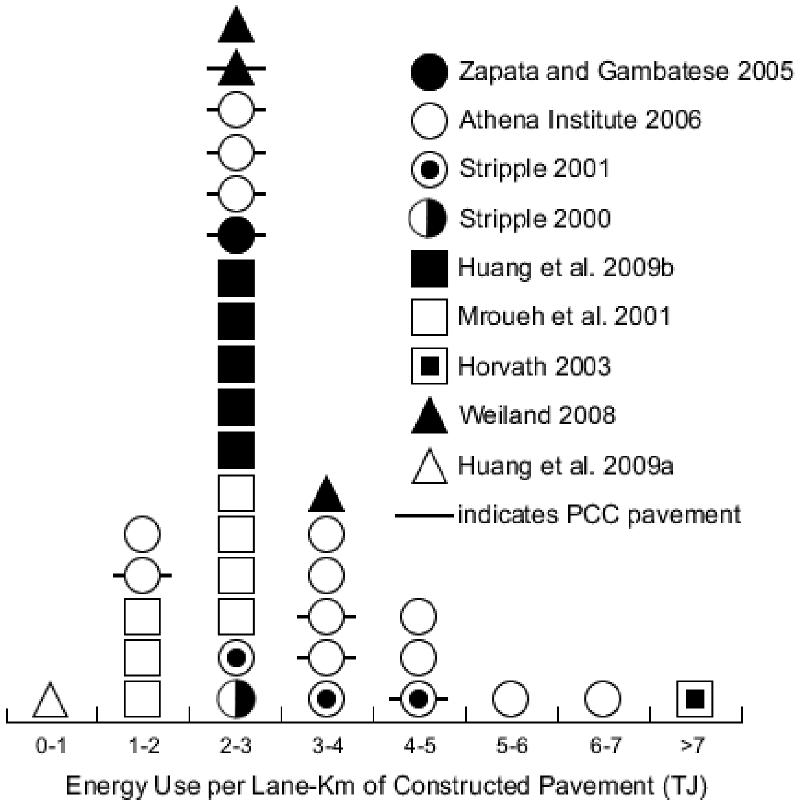


FIGURE 6. Histogram of energy use per lane-km of constructed pavement for 34 assessments in nine pavement LCA papers. Each symbol represents one assessment.

Total CO_2 Emissions. Six papers reported total CO_2 emissions from a total of 19 assessments. One paper reported global warming potential rather than total CO_2 emissions on another 12 assessments. The distribution of results (Figure 7) was more variable than for energy with a median value of 243 tonnes/lane-km. The three highest values came from examples in the two Stripple papers (2000 and 2001), which are also the only two papers to consider aspects of road construction beyond the pavement section and supporting materials (e.g., forest clearance, sign posts, etc.). Based on these results it can be reasonably stated that CO_2 emissions per lane-km of pavement are typically on the order of 100-500 tonnes depending upon the pavement section and LCA scope.

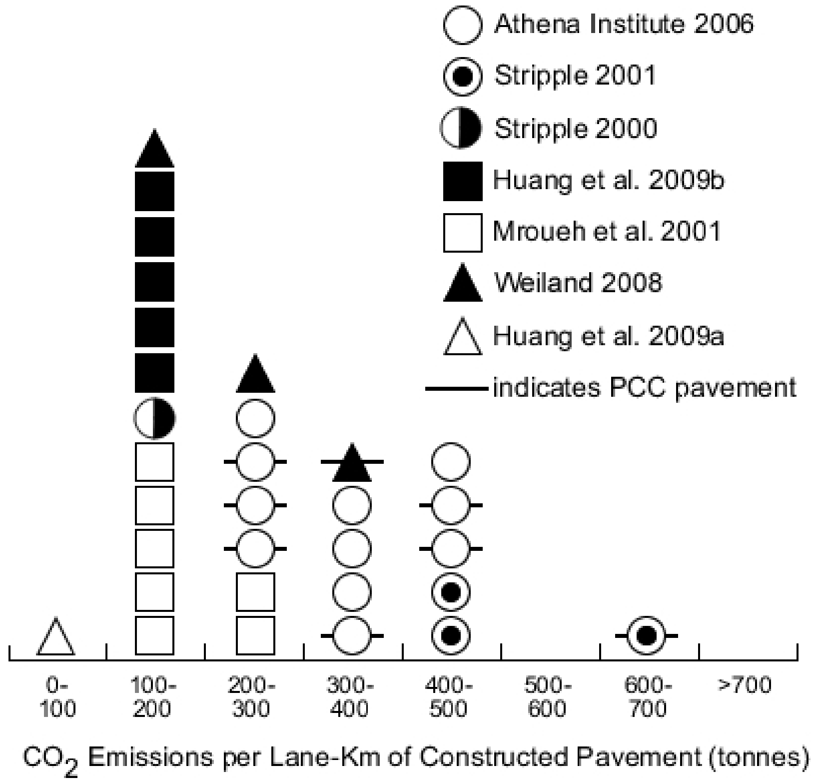


FIGURE 7. Histogram of CO_2 emissions per lane-km of constructed pavement for 32 assessments in seven pavement LCA papers. Each symbol represents one assessment.

Contribution of Roadway Construction Categories. Several papers (Table 4) broke down energy use and CO_2 emissions into what we interpret as three major construction components (materials production, pavement construction and transportation associated with construction) and two categories (initial construction and maintenance activities). Although the number of papers is limited, the percentages are reasonably consistent. Based on Table 2 we draw the following general conclusions: materials production accounts for about 75% of energy use and 60-70% of CO_2 emissions; construction accounts for less than 5% of energy use and CO_2 emissions; and transportation associated with 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.

Another useful way to visualize the Table 2 relationships is in terms of multiples:

- Energy use
  - Materials production uses about 25 times the energy as construction.
  - Transportation uses about 10 times the energy as construction.

    - Maintenance uses about one-third the energy of initial construction.
- CO_2 emissions
    - Materials production emits about 16 times the CO_2 as construction.
    - Transportation emits about eight times the CO_2 as construction.
    - Maintenance emits about one-fourth the CO_2 of initial construction.
- A combined average of energy and CO_2
    - Materials production has 20 times the impact of construction.
    - Transportation has nine times the impact of construction.
    - Maintenance has one-third the impact of initial construction.

We base our weighting of materials production, construction, transportation associated with the construction process and traffic use on the combined average reported here. We do not consider waste because outside of Rajendran and Gambatese (2007) there have been few attempts to quantify waste generation associated with roadway construction.

TABLE 4. Relative Contributions of Roadway Construction Categories and Maintenance

	Number of papers	Number of assessments	Average (percent)	Median (percent)	St. Dev (percent)	High (percent)	Low (percent)
Energy							
Materials Production	5	14	74	73	13	98	60
Construction	5	14	3	2	2	10	2
Transportation	4	12	21	21	11	38	7
Initial Construction	4	8	74	73	21	45	97
Maintenance	4	8	26	27	21	55	3
CO_2 emissions							
Materials Production	1	3	69	61	15	87	60
Construction	1	3	4	4	2	6	1
Transportation	1	3	8	9	3	10	4
Initial Construction	3	16	78	86	20	100	45
Maintenance	3	16	22	14	20	55	0

Relation of roadway construction to operations. Operations are defined as those equipment, actions and operations that happen on a routine basis necessary to ensure proper and safe roadway use. They include items such as lighting, traffic signals, de-icing, sanding, drawbridge actions, toll booths, etc. Stripple (2001) found that for the roadways analyzed the largest contributors to operations were traffic control (signals) and roadway lighting. Over a 40 year life cycle Stripple (2001) calculated that for traffic of 5,000 vehicles/day traffic control and lighting combined (extrapolating from his Table 5.2.1) was about equal to initial construction and maintenance energy use. For rural roads, where traffic control and lighting are sparse or do not exist, the energy in operations becomes essentially insignificant.

Relation of roadway construction to traffic use. If a roadway system is defined to include traffic travelling upon it then the traffic component is the dominant energy user and emissions producer. Drawing on a range of examined new construction roadways, Kennedy (2006) estimated the energy used by traffic over 20 years of use to be about 18 times greater than the energy used in initial roadway construction. Stripple (2001) estimated this to be on the order of 20 times over 40 years of use but also included maintenance. Based on these analyses, we consider a good rule-of-thumb to be: 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. Although this ratio has not been calculated for rehabilitation work (e.g., HMA overlays) we believe it would be substantially less given the generally lesser material volumes involved in typical maintenance work.

6.2.5.3 Weighting Applications

Operations vs. initial construction and maintenance. MR-6, which concerns energy efficiency in operations, only addresses lighting systems because Stripple (2001) found that they were the overwhelming contributor to operations energy. Traffic signals are excluded because in the U.S. the use of energy-efficient light emitting diode (LED) signals is already required by minimum U.S. federal efficiency standards (70 *Fed. Reg.* 60407). There are five Voluntary Credits that address energy use in initial construction (CA-4, MR-3, MR-4, MR-5 and PT-3) worth a total of 12 points (not counting additional incentive points), thus MR-6 should be worth a similar number of points. Therefore, MR-6 is assigned the maximum of five points.

Traffic use vs. initial construction. Using the previously established rule-of-thumb, the energy used and CO_2 generated over 1-2 years of traffic use is about equal to the energy used and CO_2 generated during initial construction. If, like a majority of the LCA papers analyzed, a 40-year analysis period is used this results in traffic use being weighted at 20 to 40 times initial construction. Lesser weights could be argued because design and construction only have limited control over operations (e.g., have limited influence on vehicle type, mix and amount) and operations cannot be verified at the point of substantial project completion (when the Greenroads score is calculated). Even so, it would be difficult to argue that this weighting should be less than the maximum five points. Therefore, AE-2, AE-3, and AE-7 as assigned the maximum of five points each.

Transportation associated with construction. Using the previously established rule-of-thumb, transportation associated with construction should be weighted at nine times construction. Since this factor of nine exceeds the maximum point value, MR-5, which addresses the transportation associated with construction, is assigned the maximum of five points.

Materials production. Using the previously established rule-of-thumb, materials production should be weighted at 20 times construction. MR-2 and MR-4 are weighted at the maximum of five points each. Using four examples Mroueh et al. (2001) found that soil stabilization methods employing cement had higher associated energy use and emissions than soil replacement methods. However, soil replacement generally used more natural material, slightly more land and created more noise. Roughly then, the choice of soil stabilization versus soil replacement (methods to achieve balanced cut and fill) involves trade-offs between higher energy and emissions versus higher materials use, land use and noise. Because of this, MR-3 is assigned one point.

Weiland (2008) found that for the specific example analyzed energy use and CO_2 emissions from materials production were roughly equally divided between asphalt/aggregate production and HMA production at the plant. Impact assessment categories of Acidification, Eutrophication, Human Health (HH), and photochemical smog all had greater contributions (but not substantially greater) from asphalt/aggregate than from HMA production. Therefore, since PT-3 only addresses HMA production at the plant and not asphalt/aggregate production it is assigned three points, rather than five, to reflect its contribution to materials production.

6.2.6 Noise-Based Weighting

Hofstetter and Müller-Wenk (2005) investigated different monetization approaches for the health impacts from road noise. They found that of their selected human health impacts for a 28 tonne truck operating for 1000 vehicle km, just over 37 percent were attributable to day-time noise while the rest came from various emissions. When viewed in terms of human health symptoms communication interference (from noise) was responsible for about 35 percent of the disability adjusted life years (DALYs) total while the rest came from various emissions-related symptoms. Although Hofstetter and Müller-Wenk (2005) certainly qualified their results, we use these rough numbers to assign noise one-third the impact of traffic-related emissions. Further, tire-pavement noise is the predominant source or road noise above about 50 km/hr (for automobiles) (Sandberg and Ejsmont 2002). Therefore, 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. Voluntary Credits that can be associated with traffic emissions reduction (AE-2, AE-3 and AE-7) total 15 points; therefore a possible weight for PT-5 is five points. However, noise reduction characteristics of quieter pavements tend to diminish over time (e.g., Sandberg and Ejsmont 2002; Bendtsen et al. 2008; Harvey et al. 2008) therefore the influence of a quieter pavement is likely somewhat less than initially calculated. Therefore, we assign PT-5 two points.

6.2.7 Urban Heat Island Effect 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." (US EPA 2009a). UHI can impact sustainability in the following ways (US EPA 2009a):

- **Energy consumption**. Higher temperatures increase artificial cooling (air conditioning) demand. Akbari (2005) claims that increased cooling demand can account for 5-10 percent of urban peak electricity demand.
- **Emissions**. Increased electricity demand results in more power plant operation and resultant air pollution and greenhouse gases.

- **Human health**. The UHI effect can contribute to "…general discomfort, respiratory difficulties, heat cramps and exhaustion, non-fatal heat stroke, and heat-related mortality." (US EPA 2009a).
- **Water quality**. Higher pavement temperatures can heat stormwater runoff. Higher water temperatures can, in turn, affect metabolism and reproduction of aquatic species.

In short, energy consumption is the driver for energy use and emissions while heat is the driver for human health and water quality. In looking at four cities (Sacramento, Chicago, Salt Lake City and Houston) Rose et al. (2003) found pavements 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 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). If the base values (i.e.., not counting additional incentive points) of those credits directly addressing water quality, energy and emissions (EW-3, CA-4, CA-5, CA-6, MR-2, MR-3, MR-4, MR-5, MR-6 and PT-3) are added they total 24 points. Multiplying this by one-quarter gives six. Thus, we assign the cool pavement VC, PT-4, the maximum of five points.

6.2.8 Long Life Pavement Weighting

Long life pavement generally results in lower life cycle costs, less material and fewer traffic interruptions over the life cycle of a pavement (Muench et al. 2004; FHWA 2002, Huang et al. 2009). While more work needs to be done in quantifying these reductions (e.g., like that described in Huang et al 2009), a value for PT-1, the long-life pavement VC, can be attempted by drawing the link between less material and fewer traffic interruptions to less energy and lower emissions. If the base values (i.e.., not counting additional incentive points) of those VCs directly addressing energy and emissions (CA-4, CA-5, CA-6, MR-2, MR-3, MR-4, MR-5, MR-6, PT-3 and PT-4) are added they total 25 points. Thus, we assign the long-life pavement VC, PT-1, the maximum of five points.

7 Interoperability with Other Systems

Over the past five years there have been a number of sustainability-related initiatives, coalitions, rating systems and procedures that have gained significant traction in the transportation field. Typically, these address a specific component of sustainability (e.g., access or ecology) and have some form of guidance or scoring that provides guidance for owner-agencies wishing to adopt the process or assess their projects. Most of these are being developed at the local or industry level ("bottom-up" approach) rather than a concerted national effort ("top-down" approach). While some may view this explosion of systems, metrics and advocacy as troublesome, it may well be the best approach. While top-down approaches are capable of focusing resources on key issues and problems, they generally involve a limited number of individuals in the problem definition phase and therefore do not have the diversity of viewpoints and creativity offered by bottom-up approaches. Some of the more popular sustainability-related systems are:

- **Complete Streets (National Complete Streets Coalition 2009)**. A coalition whose goal is to help with the adoption of street policies focused on access for all ages, abilities and transportation modes. Complete streets essentially addresses a subset of the Greenroads equity component (access) in more detail and is also broader in scope since it addresses policy regarding access.
- **Sustainable Sites Initiative (The Sustainable Sites Initiative 2008)**. An effort to create voluntary national guidelines and performance benchmarks for sustainable land design, construction and maintenance practices. The approach, based on ecosystem services, chiefly addresses ecology but also extends into economics.
- **Civil Engineering Environmental Quality Assessment and Award Scheme (CEEQUAL) (CIRIA and Crane Environmental 2008)**. A United Kingdom-based assessment and award scheme for improving sustainability in civil engineering projects. The goal is to award projects that go beyond environmental regulatory minimums. For roadway applications, CEEQUAL is quite similar to Greenroads in scope. Unlike Greenroads, CEEQUAL awards points for actions/decisions already required by U.S. regulation.
- **Low Impact Development (LID) (Low Impact Development Center 2008)**. A planning and design approach with a goal of maintaining and enhancing the pre-

development hydrologic regime of urban and developing watersheds. LID is essentially focused on stormwater treatment, a subset of ecology. A number of owner agencies (e.g., City of Seattle, City of Portland, etc.) have integrated LID solutions into their stormwater manuals as acceptable best practices and strongly encourage their use.

- **Context Sensitive Solutions (CSS) (Neuman et al. 2002)**. A collaborative process that involves all stakeholders in developing transportation solutions that fit within their context. This is an overarching process that stresses, among other things, communication, consensus, flexibility and creativity in generating transportation solutions. There are no checklists or benchmarks but CSS does stress using a clearly defined decision-making process. CSS can conceivably address anything within Greenroads and extend into the planning and operation phases of a roadway. Conceivably, Greenroads could be part of CSS or vice versa.
- **Smart Growth (Smart Growth Online 2009)**. A network of organizations that advocates growth that restores vitality to center cities and older suburbs through collaboration, mixed-use development, preserving open spaces, and providing transit and pedestrian access. Smart Growth primarily addresses planning concerns (e.g., development plans) but does include some roadway project specific ideas. It is most closely associated with equity although it does address some ecology and economic components.
- **Resource Conservation Challenge (RCC) (US EPA 2009b)**. A U.S. Environmental Protection Agency (EPA) led effort designed to conserve natural resources and energy by managing materials more efficiently. Through the RCC the EPA, among other things, takes part in partnerships, offers guidance, provides resources and promotes resource conservation. RCC largely addresses ecology.
- **Eco-Logical (Brown 2006)**. A conceptual approach to developing infrastructure that stresses reduced impact on ecosystems. It stresses (1) voluntary collaboration between agencies and involvement of project stakeholders, and (2) mitigation that addresses larger-scale ecosystems (ecosystem-based mitigation). The Eco-Logical approach, which addresses ecology, is broader in scope than Greenroads, which is limited to a single project.

- **LEED for Neighborhood Development (USGBC no date given)**. Integrates principles of smart growth, urbanism and green building into neighborhood design. The roadway component addresses equity issues as well as some ecology issues (materials, energy efficiency, and light pollution).

This many-systems entrepreneurial type of approach is typical of early innovation in many fields and is likely to continue. As the number of worthy individual efforts continues to grow it will become increasingly complex for owner agencies and other stakeholders to choose and combine these systems to accomplish their sustainability goals. As a minimum, achieving goals set forth in sustainability-related approaches such as those previously listed should be reflected in Greenroads scores. For instance, a city's Complete Streets program that promotes multimodal access should also receive points in Greenroads. Table 5 shows how these systems relate to specific Greenroads Project Requirements and Voluntary Credits.

TABLE 5. Greenroads Project Requirements and Voluntary Credits Most Applicable to Other Systems

Effort	Most Likely PRs and VCs	Other Possible PRs and VCs
Complete Streets	AE-4	AE-3, AE-5, AE-6, AE-7, AE-8, AE-9
Sustainable Sites	PR-10, EW-5, EW-6, MR-3	PR-2, PR-3, PR-6, PR-7, PR-8, PR-11, EW-2, EW-3, AE-4, AE-9, CA-3, MR-1, MR-2, MR-3, MR-4, MR-5, PT-4
CEEQUAL	PR-1, PR-7	PR-2, PR-3, PR-5, PR-6, PR-8, PR-9, PR-10, AE-4, AE-8, all EW, CA-2 through CA-6, all MR, PT-1, PT-2, PT-5
LID	PR-4	PR-7, PR-10, EW-2, EW-3, EW-5, EW-6, PT-2
CSS	AE-4	AE-1, AE-2, AE-3, AE-5, AE-6, AE-7, AE-8, AE-9
Smart Growth	AE-4	PR-4, EW-2, EW-3, EW-6, AE-1, AE-3, AE-5, AE-6, AE-7, AE-8, AE-9
Eco-Logical	EW-6, EW-7	EW-2, EW-3, EW-5, AE-4, AE-8
RCC	CA-3, MR-2, MR-4	MR-3, MR-6
LEED for Neighborhood Dev.	EW-6, EW-7	EW-8, AE-5, AE-6, AE-7, AE-8, AE-9, MR-6, PT-4

8 Avenues for Adoption

It appears that sustainability metrics like Greenroads are likely to be adopted on an individual organization basis rather than as a regional or national standard. While earlier work had suggested several avenues for adoption (Soderlund et al. 2008), interactions with owner agencies, consultants and contractors over the last two years has begun to reveal the most likely avenues for adoption: as an external standard, a project accounting tool, a list of ideas and competitive advantage.

8.1 External Standard

Some owner organizations are seeking ways to legitimize, improve, or market their sustainable approaches to roadway design and construction. For the most part, these organizations respond favorably to Greenroads being labeled a "rating system" and find value in the idea that their project would be "certified" by an external standard.

8.2 Project Accounting Standard

Some owner organizations are seeking sustainability accounting tools to help monitor, judge and improve their approach to sustainability. These organizations, which tend to be larger ones, are more likely to have broad programmatic sustainability strategies and goals that go beyond the project level. Therefore, a project-level system like Greenroads may have the most utility if it is able to (1) capture programmatic strategies in project-level accounting or (2) translate large programmatic strategies into project actions that are likely to be more impactful because individual communities may identify more with a single project in their immediate vicinity rather than a broad agency-wide goal.

8.3 Competitive Advantage

Some organizations, often design consultants and contractors, use Greenroads to gain a competitive advantage. Design consults may use Greenroads as a reputable set of sustainability ideas from which they can choose to meet client needs. Contractors have expressed interest because they are looking to become familiar with sustainable practices and market their expertise. Recently, some public design-build contracts have begun to include sustainability components in the decision criteria. For example, a $67 million design-build contract was awarded for SR 519 in the downtown Seattle, WA area in 2008 (WSDOT 2008). Bids were judged on the following criteria (the highest "score" won):

$$\text{Score} = \frac{T \times \$10{,}000{,}000}{\$P}$$

Score = The Adjusted Proposal Rating

$P = The Total Proposal Price from the bid form

T = Technical Evaluation Score (A number between 0 and 1000)

Within the scoring system, CSS (200 points) and environmental compliance and innovation (75 points) were worth 27.5% of the 1,000 point technical evaluation score. Further, language in the environmental innovation section read:

> "Additional points will be awarded to Proposals that demonstrate additional innovative designs that lead to environmental betterments. The Proposer shall demonstrate how their innovative design ensures forward compatibility."

A metric like Greenroads could be used in the proposal process to both devise "innovative designs" and demonstrate how they ensure "forward compatibility".

Competitive advantage also extends to public owner agencies. Beginning in 2010, the Washington State Transportation Improvement Board (TIB), an independent state agency that makes and manages street construction/maintenance grants based on revenue from 3 cents of the statewide gas tax, will include specific sustainability items (15 points) on its 100 point evaluation criteria for their urban arterial and corridor programs (Washington TIB 2009). Whether or not cities and counties receive these grants depends directly on how their project's evaluation criteria score.

9 Greenroads Use

Greenroads has been in existence since Version 0.5 in mid-2007. Since then it has been expanded upon and has currently reached Version 0.95 with Version 1.0 expected before the end of 2009. Along the way, a number of organizations have decided to investigate its potential for use. These investigations generally take one of two forms: case studies and pilot projects.

9.1 Case Studies

A "case study" is a retrospective application of the Greenroads performance metric to projects that are already complete or substantially complete. Essentially, this amounts to asking the question, "How would the project have done if it had been scored using Greenroads?" These investigations provide information on what current practice is able to achieve without special attention to Greenroads. Therefore, they can help an organization establish benchmark or baseline scores for typical projects and they can help with Greenroads calibration so that achievement levels are neither too easy nor too hard to reach.

Even though Version 1.0 is not yet complete, Greenroads is participating in a number of case studies in the U.S. including four in British Columbia (administered by CH2M HILL), three in Oregon (for the Oregon Department of Transportation), one in California (for Caltrans), one in Idaho (for Western Federal Lands), one in Yellowstone (for Western Federal Lands) and several in Washington State (for WSDOT). These case studies are in various states of completion but none are entirely complete as of October 2009. There are several other case studies on which Greenroads is working that have yet to be properly reviewed or acknowledged by the owner agency. Most of these case studies are student projects at the University of Washington using publically available project documents. As they are completed, they will be posted at www.greenroads.us.

9.2 Pilot Projects

A "pilot project" is an application of the Greenroads performance metric to projects that have not yet been designed or are in early design (30% complete at the most). Pilot projects are different from case studies because pilot projects consider Greenroads best practices in the design and construction decision-making process; thus Greenroads has some influence over how a project is designed and constructed. In this way, pilot projects provide data on the cost and reason for pursuing or not pursuing Project Requirements and Voluntary Credits. They can also serve as usability tests in an effort to make Greenroads easier to use. Greenroads is participating in three pilot projects: on in Bothell, WA (SR 522), one in Sisters, OR (US 20) and one in Denver, CO (14^{th} Street). As they are completed, they will be posted at www.greenroads.us.

9.3 Other Work

In early 2009, Greenroads undertook an early experiment to see if the Washington State Department of Transportation's (WSDOT) entire roadway network could be rated using the Greenroads sustainability performance metric. Since most owner agencies, including WSDOT, track the condition of their pavements using some type of pavement management system it is conceivable that the same data contained in a pavement management system (route location, functional classification, pavement structure, pavement condition and any other designations) could be used to estimate the Greenroads score for an entire agency's roadway network at a very basic level. Certainly this approach is limited because pavement management systems do not track all aspects of a project that relate to Greenroads, however they do track some aspects (those related to pavement) and would be able to automatically calculate scores related to those aspects based on existing data in the pavement management system. Conceivably, then, Greenroads scores could be tracked just as pavement condition is currently tracked; the only burden would be an additional data field in an already-existing database. This section summarizes this early effort to score WSDOT roadways using the Washington State Pavement Management System (WSPMS).

9.3.1 Washington State Pavement Management System (WSPMS)

WSPMS is essentially a large MS Access database that tracks pavement condition and other related data (e.g., road features, geography, traffic, etc.) and is capable of rudimentary predictions of when pavement preservation efforts are required.

Within WSPMS, the 17,000 lane-miles of WSDOT roadways are broken down into discrete sections for analysis. Analysis Units are the smallest discrete pavement sections that can be characterized by similar qualities (e.g., structure, location, pavement condition, traffic). Analysis Units can vary in length from as short as 0.1 miles to as long as 10-20 miles. In the 2007 WSPMS there were 28,776 Analysis Units. These were filtered to remove all those that could not be processed for Greenroads scoring, which left 13,630 for Greenroads scoring.

9.3.2 Greenroads Evaluation

After making some general assumptions as to the makeup and materials in a typical WSDOT pavement section, these 13,630 Analysis Units were evaluated on nine Greenroads Voluntary Credits:

- AE-8 Scenic Views. Based on the location of scenic overlooks.
- MR-2 Pavement Reuse. Based on pavement structure records.
- MR-3 Recycled Content. Based on a statewide average of 15% for HMA.
- MR-5 Regionally Provided Material. Assumed to occur for all WSDOT projects.
- PT-1 Long-Life Pavement. Based on historical structure.
- PT-3 Warm Mix Asphalt. Based on one project in 2008 (the only one to date in WA).
- PT-4 Cool Pavement. Assumed for all PCC pavement surfaces.
- PT-5 Quiet Pavement. Based on test projects in 2006 and 2007 (I-5 and SR 520).

Additionally, of the 11 Project Requirements, four are typically met by state regulation or standard WSDOT practice and can safely be assumed as met:

- PR-1 NEPA Compliance or Equivalent. Required for all federally funded projects. State funded projects are subject to the State Environmental Policy Act (SEPA), which is equivalent.
- PR-7 Pollution Prevention Plan. Required by the state's Construction General Permit in association with the National Pollution Discharge Elimination System (NPDES).
- PR-9 Pavement Maintenance. WSDOT's WSPMS meets this standard.
- PR-10 Site Maintenance. WSDOT's maintenance division meets this standard.

9.3.3 Results

Of the original 28,776 Analysis Units, 13,630 were analyzed (47%). The average Greenroads points per Analysis Unit for these nine Voluntary Credits was found to be 12.68. The lowest was 5 points (all Analysis Units received credit for local materials) while the highest was 22. Figure 8 is a histogram of the results, while Figures 9 and 10 show the results by Voluntary Credit for both points and Analysis Unit.

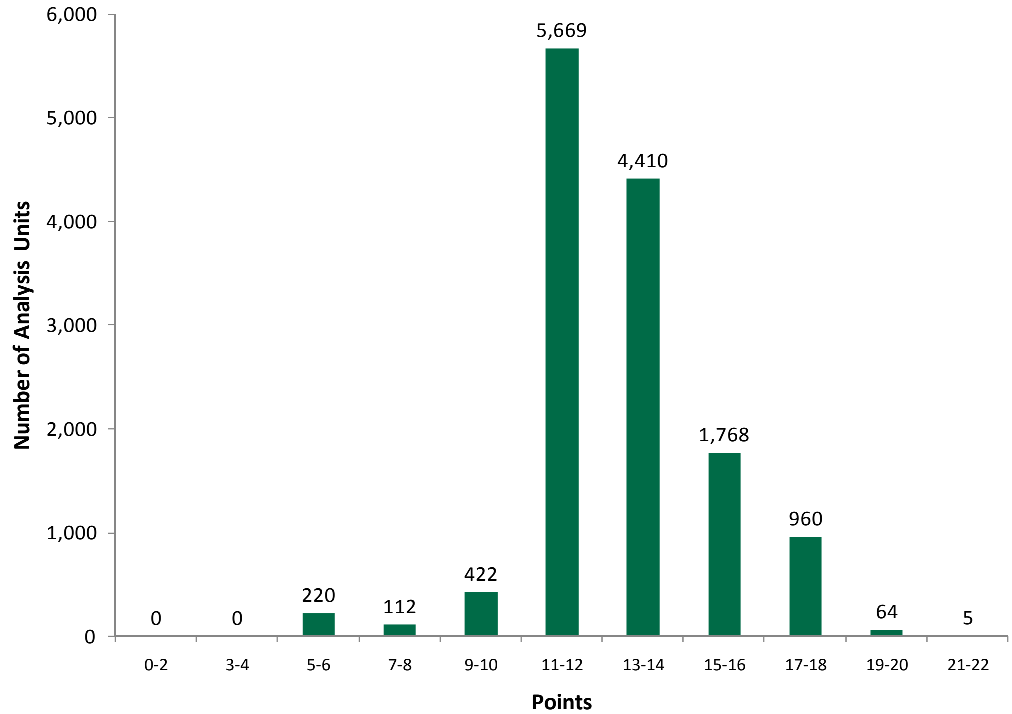


FIGURE 8. Histogram of points by frequency of Analysis Unit.

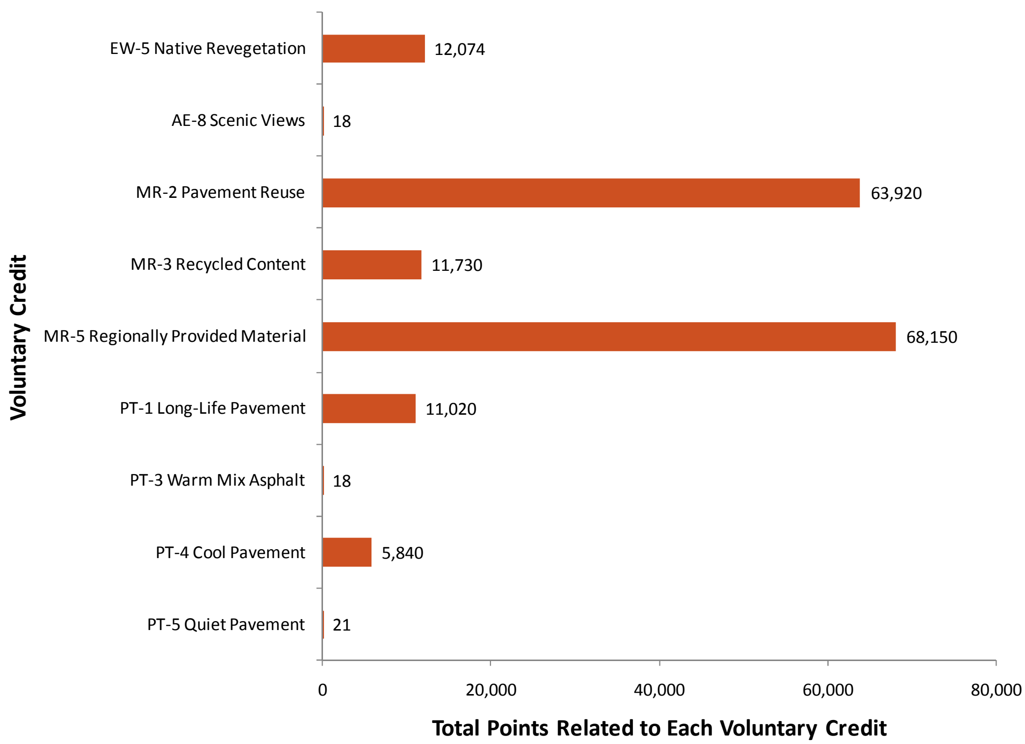


FIGURE 9. Points earned for each of the 9 Voluntary Credits analyzed.

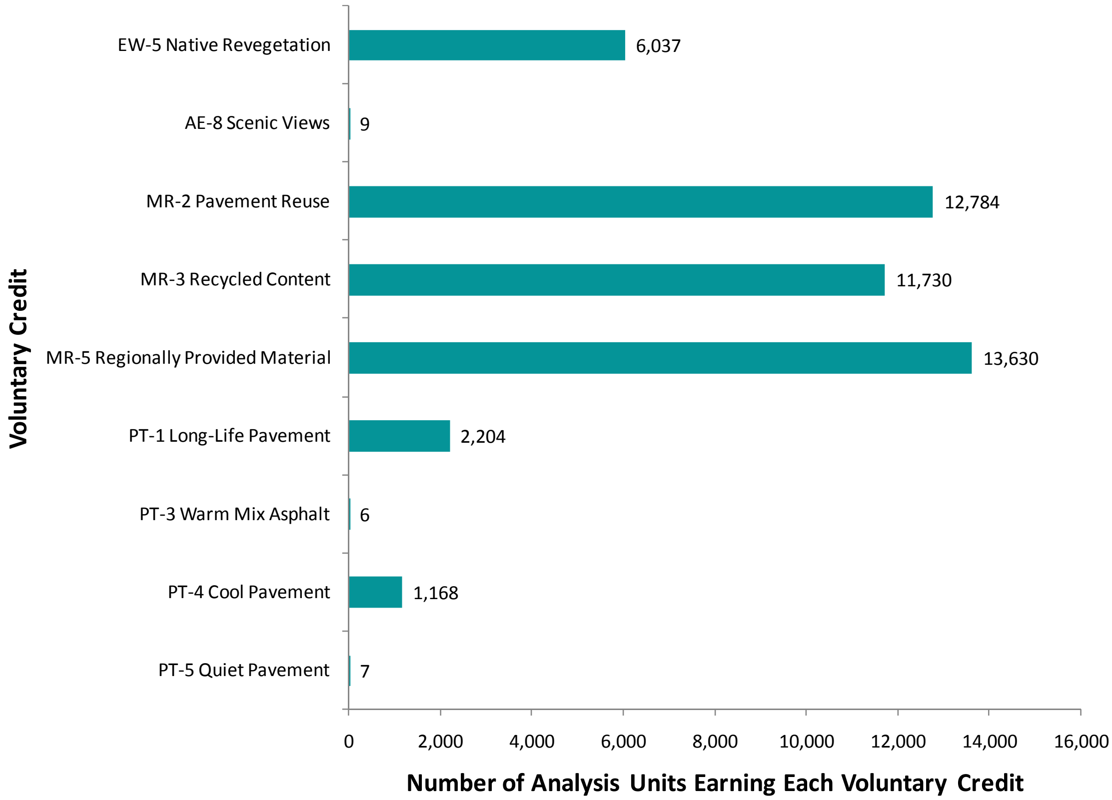


FIGURE 10. Analysis Units that earned each of the 9 Voluntary Credits analyzed.

This effort showed:

1. Basic integration of Greenroads scoring into a pavement management system is possible. While not all the points for a roadway section may be captured a fair amount can be using existing data and systems.
2. WSDOT's network earns an average of 12.68 points per Analysis Unit as it exists now. While roadway projects are typically not conducted on single Analysis Units (they are often much longer), this suggests that, on average, WSDOT roadway projects would score about 12 points in Greenroads as a minimum.
3. Additional sustainable practices are needed to reach certification levels. While not all Greenroads Voluntary Credits were evaluated, it is likely that WSDOT roadways will not reach the certification level in Greenroads under current practice. However, 12 points per project as a starting point is likely quite high.

10 Summary

This report describes Greenroads, a performance metric for quantifying sustainable practices associated with roadway design and construction. Importantly, sustainability is defined as having seven key components: ecology, equity, economy, extent, expectations, experience and exposure. By Greenroads standards, a sustainable roadway project is one that carefully and overtly integrates these components into the design and construction process.

Greenroads is a straightforward performance metric that can help produce more sustainable roadways. Version 1.0 consists of 11 Project Requirements, 37 Voluntary Credits (worth 108 points) and up to 10 points worth of Custom Credits. Project-level sustainability performance can be assessed by meeting all Project Requirements and any number of Voluntary Credit points. Greenroads also sets “achievement” or “certification” levels at different point values in order to provide recommended scoring goals. Greenroads is compatible with other existing systems that can and have been applied to roadways and can be adopted in a number of ways, however the most likely are: (1) as an external standard, (2) as a project accounting standard, and (3) as a tool for competitive advantage for both private industry and public agencies.

Sustainability has become an important topic in engineering and construction, of which roadway work is a substantial part. Greenroads can potentially provide a common performance metric for considering sustainability in roadway design and construction. Fundamentally, such a metric can help people make better roadway sustainability decisions and improve over time.

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Appendix A: Evaluating Greenroads Scores for Washington State Using WSPMS 2007

Introduction

The Washington State Pavement Management System (WSPMS) serves as a tool to help determining when and what kind of measures should be taken for pavement preservation. It runs as an Access database and contains data about pavement dimensions, bases conditions, materials, construction projects descriptions, traffic, etc.

Greenroads is a sustainability performance metric for the design and construction of roadways. It is essentially a collection of sustainability best practices that apply to roadway design and construction. Greenroads awards points for sustainable design/construction choices and certification can be awarded based on total points. Fundamentally, Greenroads provides a means of quantifying roadway sustainability. This type of quantification allows sustainability to be judged, assessed and, ultimately, improved.

The goal of this project is to use the 2007 WSPMS data set to provide an estimate of a Greenroads score for every Analysis Unit in the system (over 20,000 total). While existing WSPMS data does not contain all the information necessary to make a complete Greenroads evaluation, much of the data can be used to develop reasonable proxies that, when totaled will give a reasonable estimate of the average Greenroads score for a Washington State Department of Transportation (WSDOT) owned roadway.

WSPMS

In WSPMS, there are several ACCESS databases, Analysis, BASESURV, CPMSPROJ, PROJECTS, RoadLog, Scheme, and WSPMS. The “Analysis Table,” which contains 28,776 Analysis Units, and is located in the Analysis database is the best for preliminary data preparation. An Analysis Unit is the smallest section used to characterize a roadway section in WSPMS. These Analysis Units are lengths or roadway (lengths vary from 0.1 miles to over 20 miles) that have similar characteristics including structure, condition, traffic and other features. Table 1 shows what useful information can be found in the Analysis Table.

Table A1. Applicable Attributes in the Analysis Table*

Item	Attribute	Description and function
1	SR	State Route number
2	BSARM	Beginning State accumulated route mileage, used to locate the unit and calculate length
3	ESARM	End State accumulated route mileage
4	Lane width	Lane width, used to calculate dimension of the unit
5	Surface type	Illustrate pavement type of the surface, used to evaluate cool and long life pavement
6	Bridge or not	Distinguish the bridge sections that aren't considered as regular pavements
7	Base thickness	Used to calculate the ESALs and evaluate long life pavement
8	ADT	Used to calculate the ESALs and evaluate long life pavement
9	ADT Growth	Used to calculate the ESALs and evaluate long life pavement
10	Single unit	Used to calculate the ESALs and evaluate long life pavement
11	Double unit	Used to calculate the ESALs and evaluate long life pavement
12	Trains	Used to calculate the ESALs and evaluate long life pavement
13	Truck Growth	Used to calculate the ESALs and evaluate long life pavement
14	HisESAL	Used to evaluate long life pavement

*There are total 54 attributes in the table.

Data Filtering

The 28,776 Analysis Units were then filtered to eliminate those that were not useful for this analysis. The filtering steps were:

1. Eliminate data of which rows with ESAL, TruckGrowth or HisEASL equal zero. These might be omissions while recording data. (These are processed in EXCEL.)
2. Eliminate data of which rows with base/surface thickness equal zero. These might be omissions while recording data. (These are processed in EXCEL.)
3. Eliminate data of which section it is bridge while evaluating long life pavement. This can be done by checking "Contract Exception Code Table" in "WSPMS" database and attribute "Exception Code" in "Analysis Layer Table". When "Exception Code" is 34 or 42, the data should be eliminated.
4. Eliminate data of which section grinding took place. Grinding made the long-life pavement calculation difficult so it was eliminated for this exercise.

5. Eliminate data with “Last Year” equal zero. If the “Last Year”, which refers the last construction year of the unit, equal zero, the ESALs cannot be calculated correctly. It will result in infeasibility of correctly issuing credit of long life pavement. (These are processed in EXCEL.)

After applying these rules, 13,630 qualified Analysis Units remained for Greenroads scoring.

General Guides/Assumptions

The remaining Analysis Units were then subject to the following general assumptions in order to create the data necessary for Greenroads scoring.

1. Use BSARM/ESARM to locate the units.
2. Assume that there is only one lane in each section to simplify the complication that different conditions on different lanes.
3. Minimum subgrade CBR = 5; base material CBR = 80 or better: requirement of long life pavement
4. All paving projects in Washington State use regional (provided within 50 miles/ton) provided materials.

Greenroads Evaluated Items

There are 11 Project Requirements and 37 Voluntary Credits (divided up into 5 categories and worth a total of 108 points) available in Greenroads. According to the sorted information offered from WSPMS database, only the following 9 Greenroads Voluntary Credits are feasible to evaluate.

- **EW-5 Native Revegetation, 3 points**. If the unit is in rural area, it is assumed to have native landscaping. This likely overcounts native vegetation because, anecdotally, WSDOT highways have invasive plants such as Scotch Broom and Himalayan Blackberry growing alongside the roadway.
- **AE-8 Scenic Views, 2 points**. If there is scenic viewpoint along the road, it gets credit for scenic view. This is likely limiting as there are many scenic views that do not have viewpoints to recognize them.

- **MR-2 Pavement Reuse, 5 points**. If the Analysis Unit is not listed as reconstructed or new construction it earns 5 points. Since WSPMS is fairly accurate in archiving older pavement layers, this total is probably quite close to reality.
- **MR-3 Recycled Content, up to 5 points**. All HMA pavements are assumed to have an amount of RAP in them equivalent to the average RAP use rate of 15% in Washington State as reported by a National Asphalt Pavement Association (NAPA) survey (Newcomb and Jones 2008). 15% corresponds to 1 point.
- **MR-5 Regionally Provided Material, 5 points**. All pavements are assumed to use materials from within 50 miles of the Analysis Unit. Likely, this overcounts points as some pavements probably contain materials from greater than 50 miles away, however this cannot be verified with WSPMS.
- **PT-1 Long-Life Pavement, 5 points**. This is done by calculating the forecasted ESALs of a section of pavement and examining its corresponding thickness to see if it meets the graph in PT-1. This is a reasonable approximation of points; however the forecast ESALs may not be a reliable indicator of traffic...
- **PT-3 Warm Mix Asphalt, 3 points**. Only one WMA project had been done on WSDOT roads at the time of analysis (I-90 near George, WA in 2008).
- **PT-4 Cool Pavement, 5 points**. All PCC surfaces were assumed to earn this credit.
- **PT-5 Quiet Pavement, 3 points**. At the time of analysis (late 2008) there were two quiet pavement projects (I-5 southbound near Lynnwood, WA and SR 520 both directions just east of Lake Washington).

In total, there are 36 Greenroads Voluntary Credits that were analyzed in this effort. Other Greenroads points that may be applicable to Washington roadways are not examined as there is no information in WSPMS upon which to determine which Analysis Units should receive them.

Additional Items Estimated

In addition to the 9 Voluntary Credits evaluated, there are several more items that can be reasonably estimated. First, of the 11 Project Requirements, four (PR-1, PR-7, PR-9 and PR-10) are typically met by state regulation or standard WSDOT practice. Two others (PR-2 and PR-5) are sometimes met depending upon project location and type. Therefore, we estimate that 4 Project Requirements are met for all projects.

Results and Comparison

Of the original 28,776 Analysis Units, 13,630 were analyzed (47%). The average Greenroads points per Analysis Unit for these 9 Voluntary Credits was found to be 12.68. The lowest was 5 points (all Analysis Units received credit for local materials) while the highest was 22. Figure 1 is a histogram of the results, while Figure 2 and Figure 3 show the results by Voluntary Credit for both points and Analysis Unit.

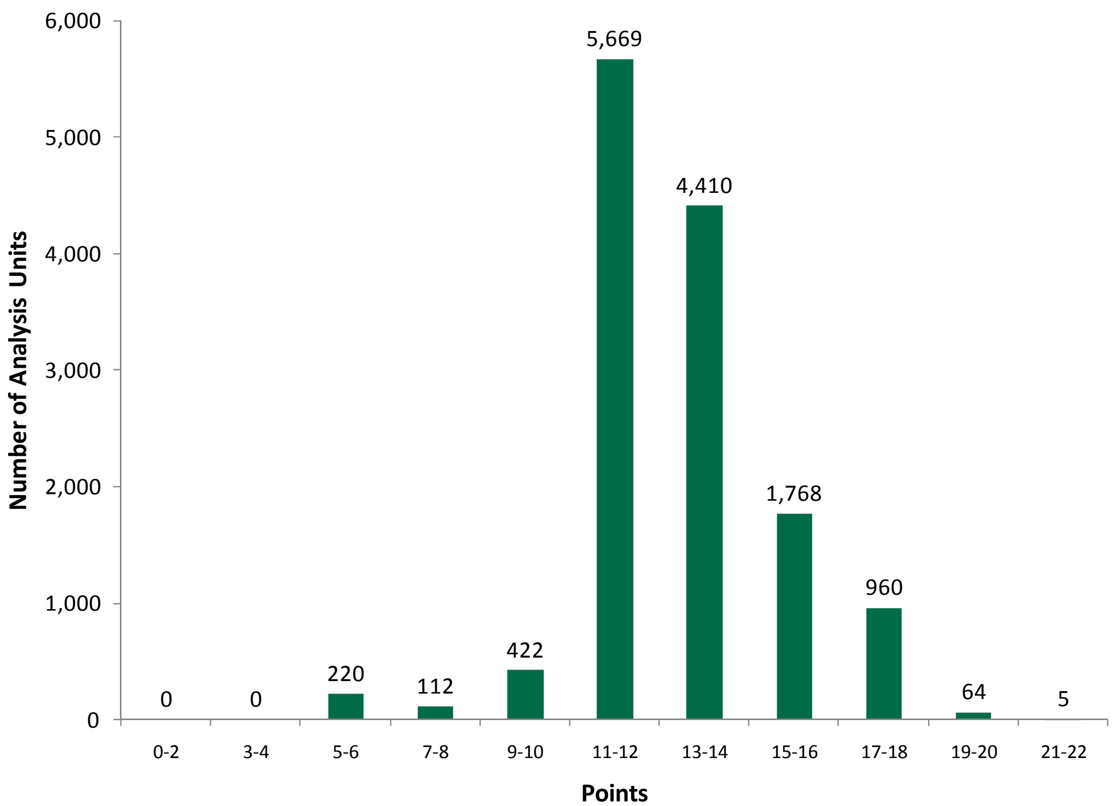


FIGURE A1. Histogram of points by frequency of Analysis Unit.

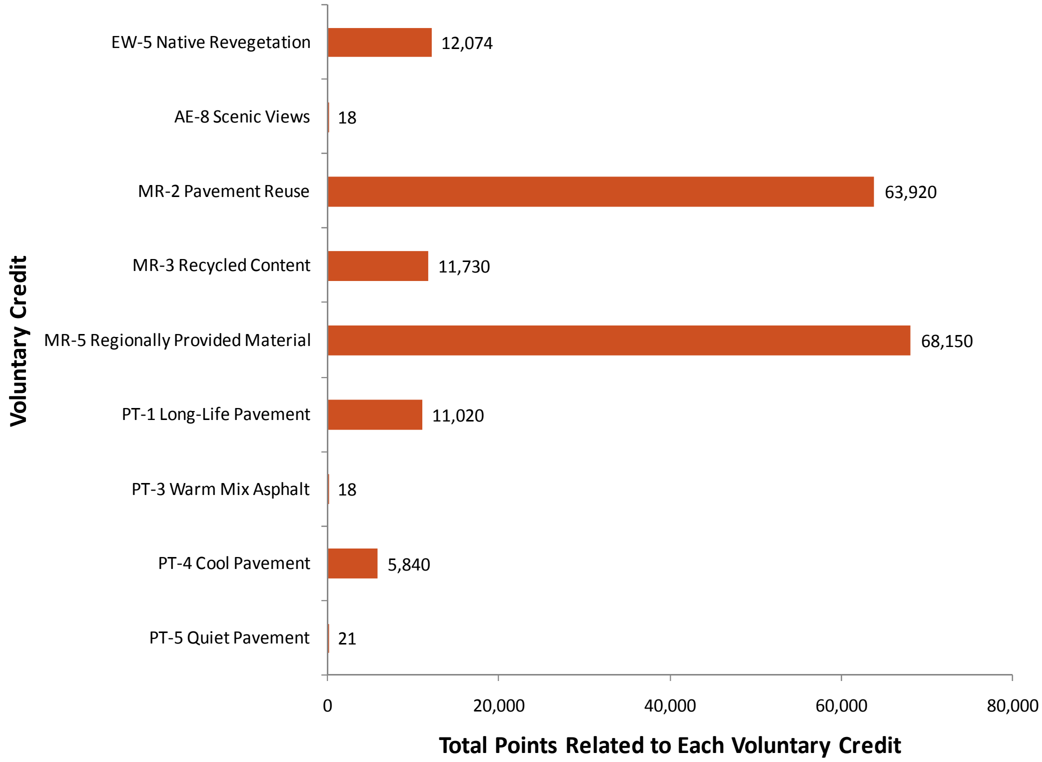


FIGURE A2. Points earned for each of the 9 Voluntary Credits analyzed.

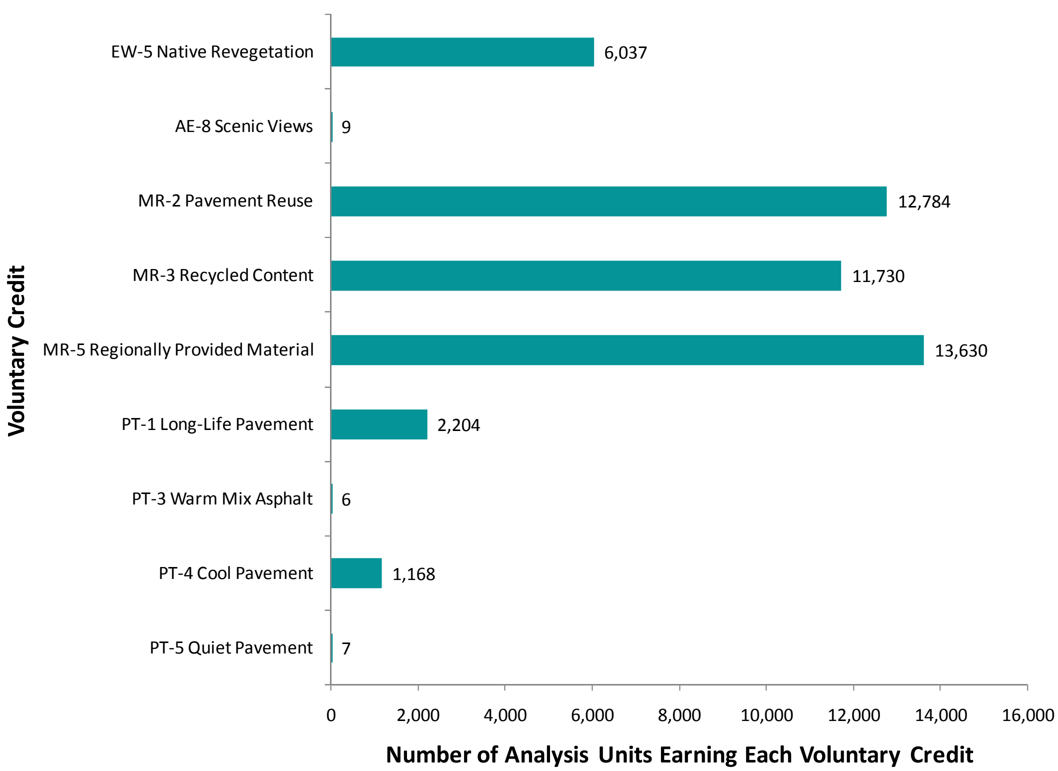


FIGURE A3. Analysis Units that earned each of the 9 Voluntary Credits analyzed.

Detailed Evaluation Process

EW-5 Native Revegetation

1. This is done by checking the Analysis Table, attribute FC.
2. Count for native landscaping where it is rural area (FC: R1-R5).

AE-8 Scenic Views

1. This is done by checking RoadLog ACCESS database.
2. The unit earns credit when there is/are one or multiple viewpoint(s) in that section of road.
3. Scenic views are in both sides of roads, so there will be two units (increasing and decreasing) in the same spot that there is a scenic view. Roads only have one side are exception.

MR-2 Pavement Reuse

1. This is done by checking Analysis Layer Table.
2. Only "Analysis unit" with resurfacing/reconstruction/new construction are qualified for being assessed. (Analysis_Layer_Table.ConType=10, 11,12, 20, 21, 22)
3. Rule out units which have grinded over 20 % of its thickness. This is processed in EXCEL.

MR-3 Recycled Content

1. This is done by checking Analysis Layer Table.
2. The assumption is that all HMA has the average RAP content of 15% as reported by Newcomb and Jones (2008).
3. Check SurfType. If it is "A," the unit gets 1 point.

MR-5 Regionally Provided Material

1. I assume that all paving projects in WA are using regional (provided within 50 miles/ton) provided materials. Hence every single unit is assigned 5 points.

PT-1 Long-Life Pavement

1. The data are from Analysis Table.
2. Long life pavement must have at least 5 inches of base material.
3. Calculate annual EASL for traffic year by following equations (Pavement Guide):

$$Annual\ ESALs = 365[0.40(single\ units) + 1.00(double\ units) + 1.75(trains)]$$

$$TotalEASLgrowthrate = (1+G)(1+0.016)-1.0$$

4. Calculate ESALs for 50 years (the threshold being perceived as long life).
5. Base on following graph, we can calculate the required surface thickness.
6. The procedures are all done in EXCEL.

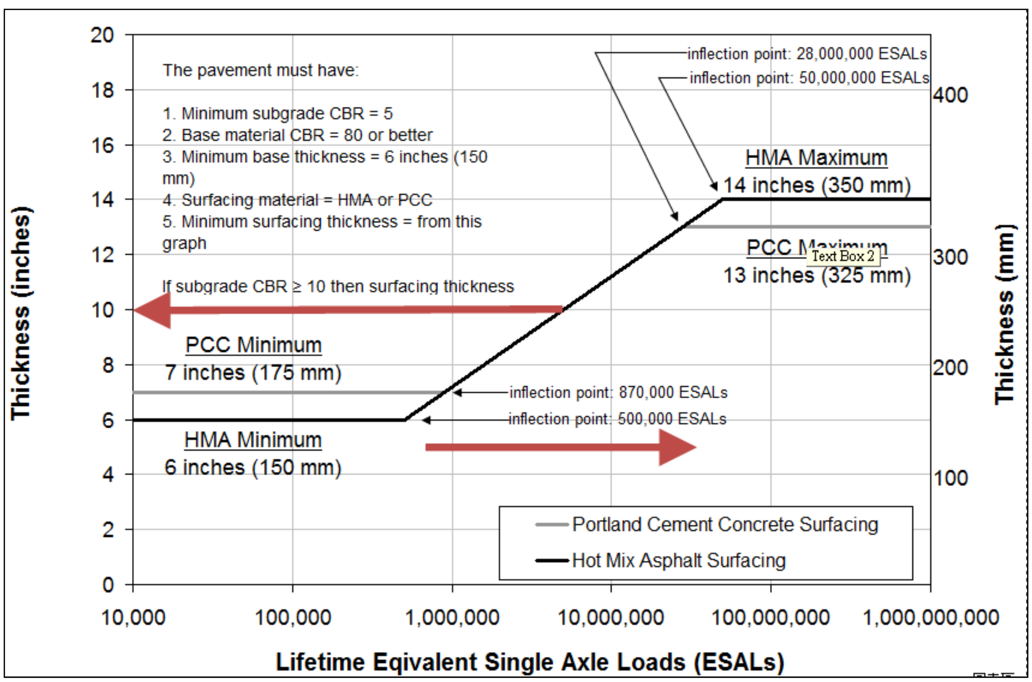


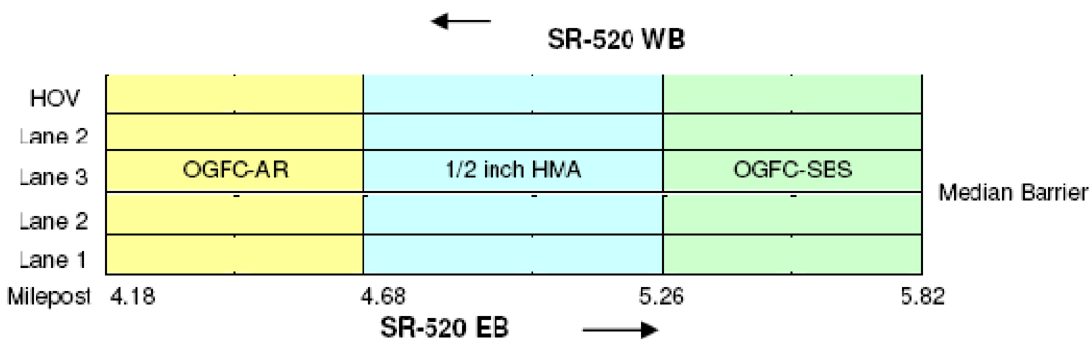
FIGURE A4. Corresponding thickness and ESALs for Longlife pavement.

PT-3 Warm Mix Asphalt

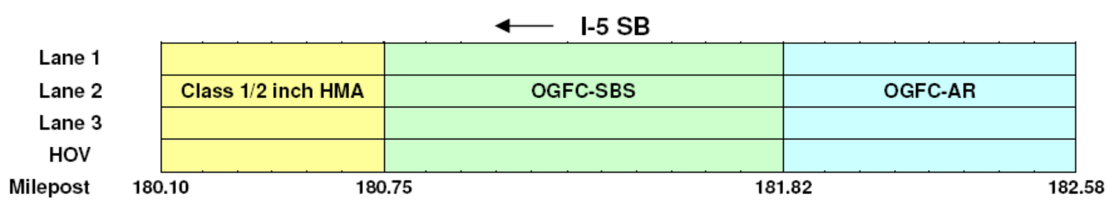
1. We know the location of the only project in WA.
2. I90, West of George Paving. 5.6 (MP 142.85-148.45) of 10.6 miles project length are paved in June, 2008.

PT-4 Cool Pavement

1. PCCP is considered as cool pavement. This is done by checking Analysis Table, attribute SurfType. If it is “P,” the unit can get the credit.
2. Besides all PCCP units, there are two HMA projects in WA:
   a. SR-520 MP 4.24 to MP 5.82 (both sides)

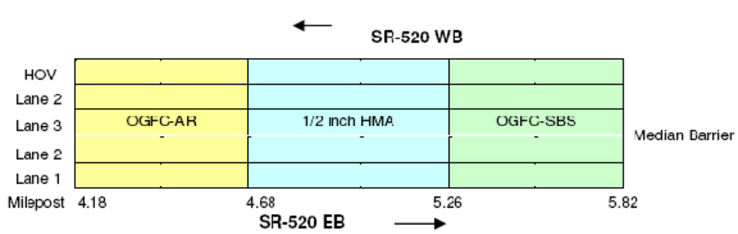


   b. I-5 MP 180.10 to MP 189.30 (decreasing)

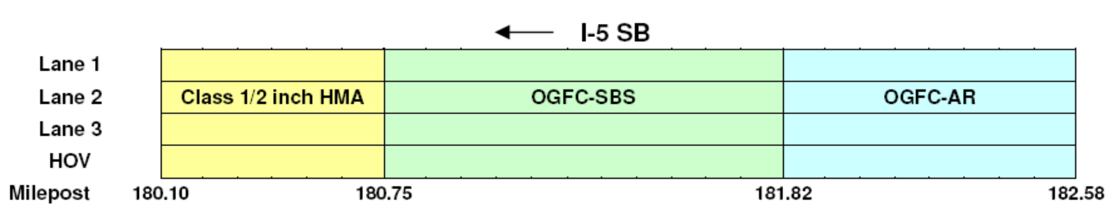


PT-6 Quiet Pavement

1. There are two HMA quiet pavement projects:
   a. SR-520 MP 4.24 to MP 5.82 (both sides)



   b. I-5 MP 180.10 to MP 189.30 (decreasing)



<u>ACCESS Database: WSPMS&GREENROADS</u>

In the ACCESS database, there are nine tables and eleven queries.

- Tables
    i. Analysis Layer Table: Analysis Layer table from WSPMS
    ii. Analysis Table: Analysis table from WSPMS
    iii. Contract Exception Code Table: Contract Exception Code table form WSPMS
    iv. ConType Table: Concrete Type table from WSPMS
    v. ID with credits in categories: every qualified analysis units and their respectively credits in different GREENROADS categories.
    vi. Project Table: Project table form WSPMS
    vii. Road Log Table: Road Log table from WSPMS
    viii. Scenic View Table: a table from query "Scenic Views"
    ix. Special Layers Table a table from query "Special Layers"
- Queries
    i. Average Credits for all SR: average earned credits from all state routes
    ii. Average Credits for specific SR: enter the desired route number then get the average earned credit for that route.
    iii. Credits for specific ID: enter the desired ID then get the average earned credits for that unit.
    iv. Concrete (cool) pavement: finding out all the pavement that surface type is concrete.
    v. ID counts for each SR: this query counts qualified unit numbers for all routes, which are used to calculate the average credits for each route.
    vi. Layer Thk: thickness of each layer
    vii. Layer Thk MatReuse: Every "Analysis unit" with resurfacing/reconstruction/new construction (Analysis_Layer_Table.ConType=10, 11,12, 20, 21, 22)
    viii.Scenic Views: Units with scenic views
    ix.Special Layers: Unit where grinding took place (Surface Type is Z2 or Z3)
    x. Total credits for each SR: total earned credits for every single state route.

EXCEL: Analysis Table

In the EXCEL file, there are three worksheets, Analysis_table_with_Thk, Grinding and Thk, MatReuse ID. The first one is the main worksheet in which we processed data filtrations and calculations about ling life pavement, pavement reuse, etc.

The latter two worksheets are exported from the queries of ACCESS database and are used to evaluate long life pavement and pavement reuse.

References

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