Green Technologies for Reducing Slope Erosion

Requested by
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The Caltrans Division of Research and Innovation (DRI) receives and evaluates numerous research problem statements for funding every year. DRI conducts Preliminary Investigations on these problem statements to better scope and prioritize the proposed research in light of existing credible work on the topics nationally and internationally. Online and print sources for Preliminary Investigations include the National Cooperative Highway Research Program (NCHRP) and other Transportation Research Board (TRB) programs, the American Association of State Highway and Transportation Officials (AASHTO), the research and practices of other transportation agencies, and related academic and industry research. The views and conclusions in cited works, while generally peer reviewed or published by authoritative sources, may not be accepted without qualification by all experts in the field.

Executive Summary

Background

As climate change alters precipitation patterns, departments of transportation will increasingly face the problem of slope failures, which already cost California millions of dollars in repair work annually. Caltrans hopes to prevent these failures by implementing the latest vegetative and soil-based solutions for reducing the volume of highway stormwater runoff on slopes and in water conveyance systems.

Caltrans staff requested a Preliminary Investigation to identify innovative strategies for reducing the risk of roadside slope erosion. We reviewed recent research, national guidance and related efforts of other state DOTs, focusing on Low Impact Development technologies; emerging "green" solutions; and biotechnical guidance related to slope design, soil engineering, and vegetation selection and management.

Summary of Findings

We scanned state, national and some international sources to identify green slope erosion control practices and interviewed representatives of several state DOTs that appear to be leaders in this area. We have organized our findings in the following sections: **State Practices, National Guidance, Related Research,** and **Resources**. Key highlights of our research include:

State Practices

- Caltrans has conducted extensive research in this area, and discussions with other states suggest that California is at the forefront of erosion technology research and implementation.
- The Texas Department of Transportation (TxDOT) is a national leader in the use of compost to prevent soil erosion. Washington State DOT (WSDOT) also relies heavily on this approach.
- WSDOT also makes heavy use of soil bioengineering techniques, and its Roadside Manual has a comprehensive soil bioengineering section: http://www.wsdot.wa.gov/publications/manuals/fulltext/M25-30/Roadside.pdf, Chapter 740.
- Florida is unique in its heavy use of polyacrylamide erosion control methods to supplement soil bioengineering and other methods. Its Stormwater Management Academy at the University of Central Florida (http://www.stormwater.ucf.edu/default.asp) is very actively researching the use of polymers and has developed a comprehensive manual on their use with other erosion control techniques (http://www.stormwater.ucf.edu/FLErosionSedimentManual_6_07.pdf).

National Guidance

- AASHTO provides a comprehensive list of state stormwater best management practices manuals: http://environment.transportation.org/environmental_issues/construct_maint_prac/compendium/manual/3_7.aspx (scroll to the bottom).
- AASHTO's National Transportation Product Evaluation Program (NTPEP) 2008 report reviews rolled erosion control products.

Related Research

- A number of states have carried out research and implementation related to the use of bioengineering, compost and other green methods for slope erosion control.

Related Resources

- The International Erosion Control Association is holding a conference February 16-20, 2010, that may be valuable.
- Promising technologies include the Vetiver system, using a noninvasive clump grass for low-cost erosion control, and the GreenArmor system for long-term root reinforcement.

Gaps in Findings

Because Caltrans is a leader in erosion control and stormwater management, it was difficult to find innovative green solutions not already used by California. The states we talked to use a combination of engineered structures and typical bioengineering methods described in numerous state DOT erosion control manuals. There are a large number of vendors who offer "green" products to enhance or improve these bioengineering methods, some of which California has begun exploring already. A more in depth review of research on specific plants, products or approaches for California situations may be needed to fully understand the gaps and opportunities.

Next Steps

Caltrans might consider the following:

- Attending the conference of the International Erosion Control Association in February 2010.
- Further discussion with Washington and Florida on their use of bioengineering and polymers, respectively.
- Follow up with the contacts below who were recommended during the course of this research:
    - Contact: Jerry S. Fifield, HydroDynamics Incorporated, hdi@ecentral.com, (303) 841-0377 (recommended by Josh Boan of Florida DOT (FDOT) and author of Florida's Erosion and Sediment Control Designer and Reviewer Manual).
    - Al Rattie, US Composting Council (www.compostingcouncil.org), aarconsulting@aol.com, (215) 258 5259. Barrie Cogburn of TxDOT recommends Mr. Rattie for insight into which states are using compost and in what quantity.
    - Dennis Markwardt, director of Vegetation Management, TxDOT, (512) 416-3093. Recommended by Barrie Cogburn of TxDOT, Mr. Markwardt has specifications for grass seeding blends tailored to every geographic region of the state.
- Follow-up research on the effectiveness of specific plants or "green" products for targeted climates and locations in California.

Contacts

During the course of this Preliminary Investigation, we spoke with the following individuals:

State agencies

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State Practices

California

Caltrans has a comprehensive toolbox of erosion control methods, and discussions with other states suggest that California is at the forefront of erosion technology research and implementation. Toolbox methods range from the use of mulch, compost and netting to jute, coir and cellular confinement.

Erosion Control Toolbox
http://www.dot.ca.gov/hq/LandArch/ec/index.htm
This online toolbox provides information about erosion control standards and guidance for Caltrans landscape architects.

Soil Stabilization Projects
http://www.dot.ca.gov/hq/env/stormwater/ongoing/soil/index.htm
This page on the Caltrans web site gives an overview of soil stabilization studies.

Below are details about some of the most pertinent research projects produced by Caltrans.

Roadside Erosion Control & Maintenance Study Annual Report June 2005 through May 2006, California Department of Transportation, 2006.
http://ntlsearch.bts.gov/tris/record/tris/01139153.html
From the abstract: "This report describes research conducted to improve vegetation establishment and water quality along California roadways in efforts to comply with the Clean Water Act. Areas of focus include: measuring the effectiveness of hydroseeded plant species in controlling runoff; examining rainfall regimes and how they affect seed germination and plant establishment; determining the effects of compost soil amendment on native vegetation cover; selecting appropriate species for highway plantings; erosion control, vegetation establishment; and vegetation management."

The Use of Mycorrhizal Fungi in Erosion Control Applications, Keith M. Vogelsang, James D. Bever, Margot Griswold, Peggy A. Schultz, California Department of Transportation, June 2004.
http://www.dot.ca.gov/hq/LandArch/research/docs/final_report_65A070.pdf
This report examines how mycorrhizal fungi interact with different host plants and what the potential is for mycorrhizal fungi to serve as a plant restoration and soil stabilization tool along roadside slopes. The report also examines the potential for other sources of inoculum, such as properly salvaged topsoil, for improving plant establishment and soil stabilization in a potentially more cost-effective manner.

Caltrans Erosion Control New Technology Report, California Department of Transportation, June 2003.
http://www.dot.ca.gov/hq/env/stormwater/special/newsetup/_pdfs/erosion/CTSW-RT-03-049.pdf
This report examines practices and products developed for stormwater management, with a focus on erosion control practices and products applicable to upland areas. These practices and products stem from methods, typically of a biotechnical nature, rather than application of a specific product. The evaluation focuses on the capability of each product or practice in protecting surface soils from erosion or containing sediments generated upslope of the point of installation. In all, 37 practices and 262 erosion control products are evaluated.

Caltrans Statewide Erosion Control Review, California Department of Transportation, February 2002.
http://www.dot.ca.gov/hq/env/stormwater/special/newsetup/%5Fpdfs/erosion/CTSW-RT-01-067/CTSW-RT-01-067.pdf
This report provides a statewide review of common erosion control problem sites for the California Department of Transportation and highlights the need for specialized approaches to the varying soils and climatic conditions in the state.

Other States

To investigate innovative green practices in erosion control, we contacted several state agencies to discuss their current practices: Florida, North Carolina, Oregon, Texas and Washington. These states were contacted based on suggestions from Caltrans and recommendations from AASHTO committee and subcommittee members.

- Each state is using a number of bioengineering methods to one degree or another, including:
  - Native plant cutting and seed collection.
  - Live staking.
  - Erosion control blankets.
  - Live cribwalls.
  - Live fascines.
  - Brush layering.
  - Branchpacking.
- Washington is making heavy use of bioengineering as well as compost.
- Texas is a leading user of compost for erosion control on slopes, using 3 million cubic yards since 2001 and actively creating a market by informing potential producers of their demand.
- Oregon has typically used silt fences, but is transitioning to compost.
- Because it is frequently subjected to storms, Florida appears to be at the forefront of research into stormwater management and erosion control techniques. It favors the use of polymers in combination with soil bioengineering techniques, and its Stormwater Management Academy at the University of Central Florida has developed a comprehensive manual of polymer-enhanced techniques.

Florida

FDOT's Environmental Process/Natural Sciences Manager Josh Boan recommended contacting Steve Iwinski, an erosion control consultant (Applied Polymer Systems, http://www.siltstop.com/) and senior associate member of the Stormwater Management Academy at the University of Central Florida (http://www.stormwater.ucf.edu/default.asp), which conducts stormwater management research, education and training programs.

The academy assisted in the development of Florida's Erosion and Sediment Control: Designer and Reviewer Manual (June 2007, http://www.stormwater.ucf.edu/FLErosionSedimentManual_6_07.pdf), which is recommended by both Mr. Boan and Mr. Iwinski as a state-of-the-art guide to erosion control methods. Mr. Iwinski emphasizes the manual's detailed guidance on the use of polymers for soil stabilization. Polymer additions can assist in the temporary or permanent establishment of grass by binding the seed, fertilizer, mulch and soil together until germination occurs. (See pages III-4, IV-33, Appendix III.) When polymers are added in correct amounts to sediment-laden waters, suspended colloidal particles combine, resulting in an increased mass more resistant to being washed away by water flow. Dosages must be closely tailored to site conditions. (See Appendix III.) This manual provides instructions on using polymers to enhance typical control techniques, which it also covers in detail, including establishing and maintaining vegetation; the use of mulches and compost; rolled erosion control products; runoff control structures; sediment containment structures; and temporary construction site best management practices. The manual contains detailed drawings and step-by-step instructions for each method as well as appendices with design examples.

Mr. Iwinski markets and strongly advocates the use of polymer products tailored to soil type and water chemistry as a green solution to prevent erosion and encourage vegetation growth. Products include polyacrylamide erosion control powders, emulsions and logs, which decrease sediment removal and increase soil permeability to water and shallow plants. He considers Florida to be at the forefront of stormwater management and erosion control research.

North Carolina

North Carolina has used compost blankets on failing slopes for a few years, but the solution is considered expensive and a last resort. North Carolina relies primarily on engineered structures for erosion control. It has also used brush layering, fascines, bonded fiber matrices, live staking with coir fiber matting and various other methods: http://www.ncdot.org/doh/operations/dp_chief_eng/roadside/soil_water/special_provisions/.

Oregon
Oregon DOT (ODOT) is currently transitioning from the use of silt fences to compost. Silt fences are difficult to implement and more costly than compost, and Oregon's funding is limited. Chapters 3 of its 2005 Erosion Control Manual (ftp://ftp.odot.state.or.us/techserv/Geo-Environmental/Environmental/Procedural%20Manuals/Erosion%20Control%20Manual/Chapter%203.pdf) describes ODOT's use of natural vegetation, seeding, mulch, hydraulic application, sod, matting, plastic sheeting and dust control to prevent soil erosion. For more information, see http://www.oregon.gov/ODOT/HWY/GEOENVIRONMENTAL/erosion_control.shtml and

http://www.oregon.gov/ODOT/HWY/GEOENVIRONMENTAL/erosion_control_manuals.shtml.

In addition, the Oregon Department of Environmental Quality produced the Erosion and Sediment Control Manual in 2005. Chapter 5 covers a range of bioengineering and vegetative approaches: http://www.cicacenter.org/pdf/ORESCManual.pdf.

Texas
Texas relies heavily on the use of compost for erosion control and because of its practices is the biggest market in the United States for compost. Since 2001, TxDOT has used 3 million cubic yards of compost for erosion control practices. While TxDOT considers wood fiber blankets and spray-on mulches useful for erosion control, its focus is on changing the fundamental nature of the soil to improve its quality. Using compost has the added benefit of reducing the amount of waste being put into the watershed, and because of its compost program Texas' water quality has improved dramatically in the last decade. Challenges include acclimating contractors to the use of compost and actively seeking out potential producers who might otherwise landfill their waste. The following article describes the spearheading of erosion control by Barrie Cogburn, who was interviewed for this investigation: http://www.tfhrc.gov/pubrds/04mar/03.htm. See also:

- **TTI/TxDOT Hydraulics, Sedimentation, and Erosion Control Lab**
  http://tti.tamu.edu/facilities/facility_detail.htm?loc_id=3222&fac_id=10.
  This lab operates a full-scale outdoor evaluation facility for the performance testing of selected erosion control materials in order to maintain TxDOT's Approved Products Program for erosion control: http://tti.tamu.edu/groups/aem/docs/draft_protocol_manual.pdf.

Texas is also successfully recycling tire bales to construct embankments and stabilize slopes, significantly improving their stability. More information about these practices is available from these sources:

- **Geotechnical Investigation and Analyses: Slope Failure Repair Utilizing Baled Tire Fill**, March 2003: ftp://ftp.dot.state.tx.us/pub/txdot-info/gsd/pdf/tbfreport.pdf.
- **Presentation: Beneficial Use of Scrap Tire Bales in Highway Projects**, 2002: ftp://ftp.dot.state.tx.us/pub/txdot-info/gsd/pdf/baledtires.pdf.
- **Design Guidelines, Specifications,** 2002-2003:
  - ftp://ftp.dot.state.tx.us/pub/txdot-info/gsd/pdf/stbguide.pdf.
  - ftp://ftp.dot.state.tx.us/pub/txdot-info/gsd/pdf/tbspec132.pdf.
  - ftp://ftp.dot.state.tx.us/pub/txdot-info/gsd/pdf/tbtypical.pdf.
  - ftp://ftp.dot.state.tx.us/pub/txdot-info/gsd/pdf/tbsummary.pdf.
  - ftp://ftp.dot.state.tx.us/pub/txdot-info/gsd/pdf/yrr_oct.pdf.

Washington
Washington integrates soil bioengineering into its specifications for roadside materials: http://www.wsdot.wa.gov/publications/manuals/fulltext/M25-30/Roadside.pdf (Chapter 740). Washington uses soil bioengineering as a tool for remediation and restoration of degraded slopes, often in combination with a geotechnically engineered system. Techniques include the use of live fascines, live staking, brush layering, brush mattresses, live cribwalls, vegetated geotextiles, live gabions and erosion control blankets. WSDOT's Soil Bioengineering web site (http://www.wsdot.wa.gov/Design/Roadside/SoilBioengineering.htm) includes a number of useful references, including:

- A comprehensive list of related publications:
  http://www.wsdot.wa.gov/publications/fulltext/Roadside/TitleRef.pdf.

- **Biotechnical Stabilization of Steepened Slopes**, 1994.
  http://www.wsdot.wa.gov/publications/fulltext/Roadside/TRBBiotechstabmod7-27.pdf.
  In this case study, a live brush layer is used to repair and stabilize an unstable cut slope along a highway in Massachusetts.
- **Soil Bioengineering for Upland Slope Stabilization**, 2001.
  http://ntl.bts.gov/lib/18000/18500/18567/PB2002100538.pdf
  This report describes soil bioengineering methods for slope and shallow rapid landslide stabilization along different roadside environments.

Washington also makes heavy use of compost and hydroseeding using a mechanical bonded fiber matrix that is sprayed onto wood fibers in order to hold slopes until grass can provide permanent stability. It also uses biodegradable coir blankets and compost socks to break up slope lengths and reduce water velocity. Of these, WSDOT considers hydroseeding to be the most cost-effective method. Other resources include:

- Vegetation restoration: http://www.wsdot.wa.gov/Design/Roadside/vegetation.htm (Chapter 810).
- Roadside materials specifications with a 2010 bioengineering update:
  http://www.wsdot.wa.gov/Design/ProjectDev/specifications (Section 9-14).
- WSDOT's erosion control web site:
  http://www.wsdot.wa.gov/Environment/WaterQuality/ErosionControl.htm.

National Guidance

We highlight below recent AASHTO design guidance and laboratory results related to stormwater management and erosion control.

Design Guidance for Stormwater and Erosion & Sedimentation Control
AASHTO Center for Environmental Excellence, 2010.
http://environment.transportation.org/environmental_issues/construct_maint_prac/compendium/manual/3_7.aspx
This page includes links to state stormwater best management practices manuals with design elements for minimizing the volume of runoff, preventing downstream erosion, stabilizing disturbed soil areas and maximizing vegetated surfaces. It includes a discussion of low impact design—such as bioretention, dry wells, filter strips, grassed swales, infiltration trenches and inlet pollution traps—and links to the following EPA resources:

- **Low-Impact Development Design Strategies: An Integrated Design Approach**:
  http://www.epa.gov/owow/nps/lidnatl.pdf.
- **Low-Impact Development Hydrologic Analysis:** http://www.epa.gov/owow/nps/lid/lid_hydr.pdf.

NTPEP Report 12001.7—Laboratory Evaluation Summaries of Rolled Erosion Control Products, Parts A and B, AASHTO, 2008.
http://www.ntpep.org/ProfileCenter/Uploads/NTPEP-ECP-Report-12001.7(final)(part_a).pdf
http://www.ntpep.org/ProfileCenter/Uploads/NTPEP-ECP-Report-12001.7(final)(part_b).pdf
These reports contain complete laboratory results for the first eight months of AASHTO's National Transportation Product Evaluation Program (NTPEP) Test Facility's study of rolled erosion control products submitted in 2003. Products were tested for slope erosion, channel erosion and vegetation enhancement.

Related Research

Extensive research is being done on slope erosion control. The following reports, papers and articles represent recent research on erosion control and slope stabilization strategies focused on vegetative or bioengineering approaches.

Steep Cut Slope Composting: Field Trials and Evaluation, Rob Ament, Montana Department of Transportation, in progress (expected end date: March 2011).
http://rip.trb.org/browse/dproject.asp?n=18605
http://www.mdt.mt.gov/research/projects/env/organic_matter.shtml
The purpose of this research is to optimize application rates using various compost materials and application techniques, and to increase performance using less compost on steep slopes. In addition, compost stabilization techniques limiting wind erosion will be evaluated.

Compost for Steep Slope Erosion, Sudhir Palle, Steve Higgins, Theodore Hopwood II, Kentucky Transportation Center, November 2008.
http://www.ktc.uky.edu/Reports/KTC_08_16_SPR_360_08_1F.pdf
This study was initiated to develop guidelines for erosion control measures for steep slopes. The study focused on evaluating and monitoring KY-31 fescue germination rates using two media treatments: 100 percent by weight compost and 70 percent compost with 30 percent soil with different seeding rates on a pilot project to establish vegetation on slopes with grades of 3:1 or steeper. The pilot program demonstrated that **weed infestation and erosion problems on slopes can be minimized by use of properly formulated compost with sufficient seed.** It also showed that the seeding rate of 1 pound per 1,000 ft^2 slope area currently employed by KYTC for erosion control was not sufficient for steeper slopes. Researchers recommend a seeding rate of at least 3 pounds per 1,000 ft^2 for long-term coverage.

Slope Stabilization Using Recycled Plastic Pins, Phase III, J. E. Loehr, John J. Bowders, Missouri. Department of Transportation, January 2007.
http://ntl.bts.gov/lib/30000/30600/30698/or07006.pdf
This report describes a three-phase study that develops and evaluates a new technique for stabilizing surficial slope failures using recycled plastic reinforcing pins. This report is the final technical report for the entire three-phase project, and describes activities for all phases. Researchers conclude that the use of plastic pins is effective for long-term slope stabilization and cost substantially less than most other competing technologies. The report describes optimum spacing for pins and other installation best practices.

Erosion Control Performance of Crimped Straw Mulch on Simulated Highway Roadsides, Ming-Han Li, Jett McFalls, Derrold Foster, Aditya B. Desai Raut, Transportation Research Board 86th Annual Meeting, 2007.
http://ntlsearch.bts.gov/tris/record/tris/01046378.html
From the abstract: "The objective of this study was to evaluate crimped straw mulch on its erosion control performance of sediment loss and vegetation establishment on the simulated highway environment. Results showed that sediment loss decreases with increasing weight of crimped straw mulch. On 3:1 slopes, **all rates of the crimped straw mulch could protect the soil surface either equal to or better than the proprietary products currently approved by TxDOT**. For slopes of 2:1, heavier applications of crimped straw mulch are needed to reach the protection level a TxDOT-approved product can provide. Vegetation density testing yielded inconsistent results with no clear trend, which is likely due to insufficient time for vegetation establishment and other experimental conditions."

"**Using Waste to Reduce Slope Erosion on Road Embankments**," J. de Ona, F. Osorio, *Transport: Proceedings of the Institution of Civil Engineers*, Vol. 159, 2006: 15-24.
http://www.atypon-link.com/TELF/doi/abs/10.1680/tran.2006.159.1.15?cookieSet=1&journalCode=tran
This paper presents the results of research carried out to study the viability of the application of sewage sludge compared with compost for erosion control and revegetation. Sludge is cheaper than compost and typically has been used for agriculture but not erosion control. Results showed that sludge reduced soil loss by 30 percent on average.

Coir Products for Soil Bioengineering Applications in Highway Construction, Calista Rohini Santha, Transportation Research Board 85th Annual Meeting, 2006.
http://ntlsearch.bts.gov/tris/record/tris/01021002.html

This study explores the use of soil bioengineering with coir, or coconut fiber, to establish sustainable vegetation surrounding highway construction products. Coir is strong, biodegrades slowly and is used in a variety of natural products for soil bioengineering. This paper describes these products and best practices for their application in the field.

Innovative Solutions for Slope Stability Reinforcement and Characterization, Volumes I-III, David White, Hong Yang, Mark Thompson, Vernon R. Schaefer, Iowa Department of Transportation, 2005.
http://www.ctre.iastate.edu/reports/slope_stability_vol1.pdf
http://www.ctre.iastate.edu/reports/slope_stability_vol2.pdf
http://www.ctre.iastate.edu/reports/slope_stability_vol3.pdf
These studies explore the use of the Borehole Shear Test for in situ testing of slope stability, identifying factors that affect slope stability and designing slope reinforcement using pile elements for cases where remedial measures are necessary. Results show that small-diameter pile elements can be used to stabilize shallow slope failures. The study includes a comprehensive literature review on the state of the knowledge of slope stability and slope stabilization.

"**Erosion Control with Recycled Materials**," Timothy Barkley, *Public Roads*, Vol. 67, No. 5, March/April 2004.
http://www.tfhrc.gov/pubrds/04mar/03.htm
This article describes Texas' award-winning erosion control program, which encourages the environmentally safe use of compost along the rights of way of federally funded highways. Compost has proven to be extremely effective in preventing soil runoff during and after roadway construction. In 1996, TxDOT Landscape Architect Barrie Cogburn and Texas Commission on Environmental Quality program specialist Scott McCoy conducted a compost demonstration project and encountered problems with wind blowing compost away. They countered this problem by blending compost with wood chips at 50 percent. This project led to frequent use of compost to stabilize slopes in Texas.

Evaluation of Organic Matter Addition and Incorporation on Steep Cut Slopes, Phase II: Test Plot Construction and Performance Monitoring, Stuart Russell Jennings, John D. Goering, Pamela Sue Blicker, Montana State University, April 2007.
http://ntl.bts.gov/lib/26000/26000/26094/final_report070001-8176.pdf
Erosion of steep highway cut slopes in Montana is oftentimes the consequence of poor vegetation development in nutrient-poor growth media resulting from highway construction where topsoil cannot physically be replaced due to slope steepness. Topsoil is often locally unavailable. The objective of this project was to develop techniques for using compost to reduce sediment yield and erosion from steep highway cut slopes by enhancing vegetation establishment.

This Phase II report describes the construction and performance monitoring of test plots from 2004 to 2006. Researchers describe the use of selected equipment to apply compost (pages 30-37) and the evaluation of compost and vegetation for countering soil erosion (pages 38-57). Researchers conclude (pages 58) that compost application to steep slopes is a viable technique for vegetation re-establishment and stormwater control, with experimental plots significantly outperforming control plots. Compost can be blanketed onto slopes or tilled into existing soil, and increases fertility and organic matter content for two years after addition. Vegetation performance was greatly enhanced on all treated plots and greatly reduced soil loss.

- Phase I of this project (http://www.mdt.mt.gov/research/docs/research_proj/organic_matter/final_report.pdf) involved a literature review and an evaluation of equipment for applying compost.
- Phase III (http://rip.trb.org/browse/dproject.asp?n=18605) is expected to be complete in March 2011. Its objective is to optimize compost application techniques to decrease the amount of compost required as well as to evaluate compost stabilization techniques that limit wind erosion prior to vegetation establishment. Principal investigator: Rob Ament, (406) 994-6423, rament@coe.montana.edu.

"**Use of Native Vegetation and Biostimulants for Controlling Soil Erosion on Steep Terrain**," F. A. Brindle, Eighth International Conference on Low-Volume Roads, *Transportation Research Record No. 1819A*, 2003: 203-209.
http://dx.doi.org/10.3141/1819a-30
http://ntlsearch.bts.gov/tris/record/tris/00942489.html
From the abstract: "This report describes the use of organic soil amendments and soil stabilizers on a large restoration project in northwest Oregon to provide soil conditions that would foster a healthy stand of native grasses

and forbes (broadleaf plants) while holding the soil in place until plant establishment could occur. The results of the field evaluation were favorable for the ability of the soil to resist water erosion through the initial rainy season and the native species establishment after application."

"**Soil Bioengineering as an Alternative for Roadside Management: Benefit-Cost Analysis Case Study**," S. Hagen, S. Salisbury, M. Wierenga, G. Xu, L. Lewis, *Transportation Research Record No. 1794*, 2002: 97-104.
http://dx.doi.org/10.3141/1794-12
http://ntlsearch.bts.gov/tris/record/tris/00932126.html
From the abstract: "This case study applied a benefit-cost analysis to an experimental soil bioengineering demonstration project to evaluate the cost-effectiveness of soil bioengineering as an alternative to traditional roadside management. Traditional roadside management methods (geotechnical solutions) were used as the baseline, and soil bioengineering treatments were treated as an investment alternative. Cost savings, along with other environmental benefits, were assessed and compared with construction costs. The effects of life cycle, effectiveness and discounting were included in the analysis to ensure comparability between both treatments. The analytical results demonstrate that soil bioengineering methods, if technically feasible, could be adopted to produce equal or better economic and environmental results. The findings of the research project and the economic analysis indicate that soil bioengineering is an efficient and environmentally beneficial tool for roadside management."

Evaluation of Slope Stabilization Methods (US 40 Berthoud Pass), M. Banovich, W. Outcalt, Colorado Department of Transportation, 2002.
http://ntl.bts.gov/lib/19000/19800/19855/PB2003100815.pdf
http://www.dot.state.co.us/publications/PDFFiles/SlopeStabilization.pdf
From the abstract: "This report evaluates only the soil containment products used in test sections on US 40. The fertilizers, tackifiers and mulches originally used for this study are not evaluated. Based on observations of the surface conditions and quantities of plant material on the slopes: (1) It appears that all of the blankets and cellular confinement products provide reinforcement to the scarp forming area of the cut slopes; and (2) All of the cellular confinement materials and soil retention blankets were successful in holding and reinforcing the plants' root systems. This study found that all of the blankets and geocell products evaluated were effective in reducing erosion in this high-altitude environment. Any of the products tested will help to prevent the loss of the topsoil and to aid plant growth."

Erosion Control for Highway Applications, Phase I: Review and Synthesis of Literature
Marian Muste, Robert Ettema, C. Mutel, R. Gomez, P. Shafer, K. Yu, Iowa Department of Transportation, 2002.
http://ntlsearch.bts.gov/tris/record/tris/00940837.html
This literature review identifies and evaluates erosion control methods for highway applications.

Erosion Control and Stormwater Quality Guide, Colorado Department of Transportation, 2002.
http://ntl.bts.gov/lib/24000/24300/24336/swqGuide.pdf
The Erosion Control and Stormwater Quality Guide was developed to address the degradation of water quality associated with highway operations, and further the prevention or minimization of that degradation through the implementation of planning, proper construction and proper installation of best management practices for erosion and sediment control and stormwater quality management.

Polyacrylamide as a Soil Stabilizer for Erosion Control, K. N. Nwankwo, Wisconsin Department of Transportation, January 2001.
http://on.dot.wi.gov/wisdotresearch/database/reports/wi-06-98polyacryl.pdf
This report investigates the effectiveness of using a polyacrylamide soil stabilizer for controlling soil erosion on Wisconsin Department of Transportation (WisDOT) construction projects. *From the abstract:* "The performance of polyacrylamide in controlling erosion is based on the fact that it is a flocculant. It forms ionic bonds of small soil particles to make larger particles. This makes the soil more resistant to the erosive forces of dispersion and shear. Further, the polyacrylamide enhances the intrusion of water into the soil, resulting in increased soil moisture to promote seed germination, lower runoff, and less soil detachment from erosion. Comparison of the polyacrylamide (CFM 2000, PAM) with other erosion control products that are currently used by WisDOT shows that this product is effective in controlling erosion. In addition, it is relatively inexpensive when compared to erosion mat, is very easily applied, is not affected by weather conditions, and, when applied following the manufacturer's recommendations, is environmentally safe."

Erosion Control and Engineering Properties of Native Vegetation Compared to Bermudagrass, H. C. Landphair, J. R. Schutt, J. A. McFalls, Texas Department of Transportation, 2001.
http://ntlsearch.bts.gov/tris/record/tris/00819911.html
From the abstract: "This study hypothesized that the growth habit of native plants, which includes a tough, deep, fibrous root system, and a dense surface protecting cover, may make them better suited for slope protection and erosion control than most introduced grass species commonly used on the roadside. Furthermore, researchers hypothesized that these native vegetation associations would require less cultural maintenance than the introduced grasses and would be less subject to invasion of noxious weeds. The researchers compared the erosion control and surface soil-reinforcing properties of four native grass, wildflower, and forb mixes to common Bermudagrass. The performance testing procedures were in accordance with the test procedures developed by the Texas Department of Transportation and the Texas Transportation Institute (TTI) for the evaluation of rolled erosion control products. Tests were performed at the TTI's Hydraulics and Erosion Control Field Laboratory, College Station, Texas."

Soil Bioengineering: An Alternative for Roadside Management, USDA Forest Service, 2000.
http://www.wsdot.wa.gov/publications/fulltext/Roadside/SoilBioEng.pdf
This report provides alternatives for slope and shallow rapid landslide stabilization along different roadside environments. Three different combinations of soil bioengineering techniques were used to stabilize upland slopes at three roadside sites. Results indicate soil bioengineering is an effective means of upland slope stabilization on erosional slopes and shallow rapid landslides, and is practical and economical. Composted biosolids improved soil workability and enhanced the native plant community during the first year.

Related Resources

Below are links to a sampling of organizations, case studies and industry web sites related to highway erosion control.

- **The International Erosion Control Association**
  http://www.ieca.org/
  The International Erosion Control Association (IECA) claims to be the oldest and largest erosion control association, and its web site includes industry news and links to articles and other information. The IECA will be holding its annual conference in Texas February 16-20, 2010, (http://www.ieca.org/conference/annual/ec.asp) and manages a journal, *Erosion Control* (http://www.erosioncontrol.com/index.aspx). Relevant committees include:
    - Erosion & Sediment Control: http://www.ieca.org/resources/TS6ErosionSedimentControl.asp.
    - Vegetative Establishment: http://www.ieca.org/resources/TS3VegetativeEstablishment.asp.

- **The Vetiver Network International**
  http://www.vetiver.org/
  This organization promotes the use of Vetiver (*Chrysopogon zizanioides*), a nonfertile and noninvasive Indian clump grass, for low-cost erosion control and other sustainable environmental practices. Because vetiver grass roots have a high tensile strength, the grass can increase shear strength of soil by a factor of 40, and so can provide significant slope protection: http://www.vetiver.org/g/slope_protection.htm. It has been used in California and appears to have widespread use internationally in China, Australia and elsewhere. See:
    - **The Vetiver System's Role in California: Infrastructure Protection, Soil Erosion Prevention and Comprehensive Water Pollution Control** (a case study on its use in Santa Barbara, CA), http://www.vetiver.org/US_California%20Vetiver%20brochure%2009%20v1.pdf.
    - **The Role of Vetiver Grass In Erosion Control and Slope Stabilization Along the Highways of Thailand**, http://www.vetiver.org/TVN_IVC2/CP-2-1.PDF.
    - **Road Stabilization and Erosion Control Using the Vetiver System in the Democratic Republic of the Congo**, http://www.vetiver.org/ETH_WORKSHOP_09/ETH_S3a.pdf.

- **GreenArmor and Flexterra Flexible Growth Medium**
  http://www.greenarmorsystem.com/
  http://flexterra.com/
  This system claims to protect against elevated levels of hydraulic lift and shear force using a net of UV-

stabilized, thermally fused nylon filaments, which are sprayed with Flexterra Flexible Growth Medium to encourage turf establishment and long-term root reinforcement. For an article on its use in Texas in 2007, see http://www.cenews.com/magazine-article-cenews.com-june-2007-project_case_study__right_of_way_revegetation_challenge-5073.html.

- **Center for Watershed Protection**
  http://www.cwp.org/
  http://www.cwp.org/Resource_Library/Controlling_Runoff_and_Discharges/esc.htm
  This organization partners with small watershed organizations and provides resources on watershed protection, including erosion and sediment control.

- **The Low Impact Development Center**
  http://www.lowimpactdevelopment.org/
  http://www.lowimpactdevelopment.org/green_highways.htm
  This organization is dedicated to the advancement of low impact development technologies, and features several highway green infrastructure projects for stormwater management.

- **U.S. Environmental Protection Agency Compost Use on State Highway Applications**
  http://www.epa.gov/waste/conserve/rrr/composting/highway/
  This web site provides a listing of state landscape and environmental officers, summaries of state DOT use of compost and compost specifications.

- **American Forests, Green Infrastructure**
  http://www.americanforests.org/resources/urbanforests/greeninf.php
  This web site describes the importance of balancing gray and green infrastructure—buildings and roads vs. trees, shrubs and grass.

- **Erosion Control Technology Council**
  http://www.ectc.org/case_studies.asp
  The mission of the Erosion Control Technology Council is to become the leading authority in the development of standards, testing and installation techniques for rolled erosion control technologies.