CHAPTER 3: DESIGNING FOR ENVIRONMENTAL STEWARDSHIP IN CONSTRUCTION & MAINTENANCE

State transportation agencies have been devoting increasing attention to the relation of design considerations to DOTs’ ability to effectively steward the environment in construction and maintenance. Raising the bar on environmental performance in construction and maintenance requires cooperation with design and attention to a host of factors at an early stage in the process (planning or design) when appropriate design changes can be made and increased funding may be sought. State DOTs increasing emphasis on and guidance for designers is evident in the proliferation of design manuals that are available. AASHTO maintains a list of links to state DOT manuals on their website, at design.transportation.org. Almost every DOT has a manual for drainage and water quality considerations in design. The most widely available guidance is not duplicated here. Rather, this section focuses on more recent and emerging stewardship practices in design that assist construction and maintenance staff in delivering positive environmental outcomes.

3.1 Beyond Mitigation: Projects to Achieve Environmental Goals

As part of their stewardship commitments, environmental planning, or process improvement efforts, some state DOTs have begun to systematically encourage and include non-compliance-related enhancements in project design and construction.

Environmental Betterments and Dual Purpose Projects

Dual Purpose Projects at Caltrans
Caltrans has explored “dual purpose” projects to achieve both environmental and transportation objectives. To further explore opportunities for enhancement as well as avoidance and minimization of environmental impacts, Caltrans is working with The Nature Conservancy of California to overlay the road network with priority habitat conservation areas statewide. A previous effort co-sponsored by Caltrans examined statewide wildlife habitat connectivity needs and associated opportunity areas for conservation. Caltrans has pursued other types of “dual purpose” community and environmental benefit projects where opportunities arose.

NYSDOT’s Guidelines and Procedures for Environmental Betterments
NYSDOT’s environmental initiative guidelines and procedures encourage DOT Regional Design Groups to look for opportunities for joint development with municipalities, other agencies, and private developers whereby design, construction, land acquisition and maintenance responsibilities can be mutually and equitably shared, while accomplishing community goals. The guidelines allow specific environmental elements or facilities requested and funded by others (e.g., municipalities, other agencies, and environmental groups) to be incorporated in DOT capital and maintenance projects as “Environmental Betterments,” wherever practicable. Such elements or facilities include landscaping, park amenities, historic building preservation, noise barriers, created wetlands, stream
restorations, stormwater basins, habitat improvements, and new municipal sanitary sewer lines, storm sewer lines and water mains that provide an environmental benefit. Such “environmental betterments” are intended to benefit from the “economies of scale” possible on large public works projects and the particular equipment and skilled personnel available in such cases, that could cost sponsors and stakeholders less than individual projects designed, constructed, and let by themselves. NYSDOT’s Stewardship Initiative calls for the following practices or features to be incorporated into DOT capital and maintenance projects, as appropriate:

1. Practice of context sensitive design.
2. Street ambience enhancements (e.g., benches, decorative paving, bollards, period lighting fixtures).
3. Restoration of historic highway related features (e.g., historic lighting fixtures, stone walls, guiderails).
4. Measures to retain the integrity of historic parkways and bridges.
5. Increased wild flower plantings.
6. Additional landscaping to enhance the appearance of noise barriers.
7. Increased landscape plantings to improve roadside appearance and streetscapes.
8. New or rehabilitated fishing access and trail head parking areas.
9. New or rehabilitated boat and canoe launch sites.
10. New or rehabilitated historic markers and interpretive signing.
11. Increased signing of important waterways and watersheds.
12. New or rehabilitated scenic overlooks.
13. Retrofits of existing highway drainage systems with created wetlands and stormwater management facilities.
15. Plantings, boulders, deflectors and other techniques to improve fisheries habitat.
17. New or rehabilitated wildlife viewing sites.
18. Wildlife habitat improvements.
19. Mitigation and enhancement for past wetland impacts.
20. Restored and enhanced wetlands.
21. Acquisition of endangered species habitat.
22. Acquisition for preservation of regionally important wetlands and upland habitat.
23. Acquisition of scenic easements.
24. Improvements to highway entrances of public parks, wildlife management areas,
and historic sites.

25 Replacement of fixed-time traffic signals with vehicle activated signals.

As part of NYSDOT’s proactive outreach effort, Regional Design offices have invited local municipalities, environmental groups and agencies to combine their funded and designed environmental elements or facilities with ongoing DOT projects. In some cases, NYSDOT has provided added design services to assure that the community’s “environmental betterment” work is appropriately integrated into the transportation project plans and specifications. NYSDOT can also provide contract letting and construction inspection of the Environmental Betterment work at no charge to the municipality, other agency or environmental group.

Since NYSDOT’s Environmental Initiative is a component of the Department’s Capital Program Update process, Regional Planning and Program Managers are required to include Environmental Initiative projects on their updated program. Regions identify those projects that have environmental or context sensitive design work which goes above and beyond regular mitigation or permit requirements and track those elements as a project attribute in the Department’s Project and Program Management Information System (P/PMIS). Various work types allow environmental initiative projects to be grouped by a specific activity, as outlined in NYSDOT’s Environmental Initiative Statement and description of the Dedicated Environmental Benefit Projects. This overview also outlines NYSDOT’s further rationale for investment in such public goods:

**Example 1: NYSDOT Initiative - Environmental Benefit Projects**

NYSDOT will fund and implement a number of environmental benefit projects that are well-suited to the Department’s mission and capabilities. To program environmental enhancements on property owned by the New York State Department of Transportation will be a simple, straightforward and visible demonstration of environmental commitment. These projects will be designed to:

**Improve water quality** because studies done by the New York State Department of Environmental Conservation (DEC) have shown that non-point source runoff is now the major cause of water pollution. Non-point source pollution enters a water body from diffuse origins on the watershed and does not result from discernible, confined or discrete convergences such as a pipe or ditch. NYSDOT, with its extensive network of state highways, is in an excellent position to assist in improving New York’s water quality. Since, non-point source water pollution control is most practically achieved through the construction of stormwater control measures that NYSDOT routinely incorporates into its projects. NYSDOT will also retrofit existing highway drainage systems by designing and building:

1 Created wetland and stormwater management structures
2 Bioengineered streambanks.
3 Specialized water quality inlet structures

**Restore wetlands** because the initial construction of New York State’s transportation infrastructure caused negative impacts on wetland acreage, function and value. During the last two decades, the New York State Department of Transportation has gained extensive experience both in delineating state and federal wetlands and in avoiding, minimizing and mitigating adverse impacts to wetlands. NYSDOT will continue to use this new knowledge to go beyond regulatory state and federal no-net-loss goals by helping to increase New York State’s wetland acreage and function by:

1 Improving or restoring wetlands affected by federal-aid highway projects that were done
before regulatory mitigation was required.

2 Constructing additional wetland acreage in projects beyond that required for state and federal wetland permits.

3 Working cooperatively with The Nature Conservancy and the resource agencies to preserve important existing wetland sites.

4 Creating new wetlands to control non-point source pollution as well as to provide other wetland functions, such as wildlife habitat.

**Protect fish and wildlife** because fisheries habitat in New York State has been degraded by the channelization and siltation of state waterways, and DOT has the capability to deliver restoration measures in an efficient and practical manner. The New York State Department of Transportation will protect wildlife by planting specialized food and cover crops along state highway rights-of-way and by providing more and safer wildlife crossings under state and local highways. For example, NYSDOT will design and install:

1 Boulders and stone weirs to improve fisheries habitat
2 Culverts for wildlife crossings
3 Plantings for wildlife habitat

**Promote eco-tourism** because people travel on state highways. And, through access to nature, people develop a deeper sense of why the environment warrants protection. Eco-tourism is a growing and sustainable part of New York State’s economy. Because a large part of the eco-tourism experience depends on the appearance of state roadsides as well as access to natural features, the New York State Department of Transportation will develop:

1 New or rehabilitated fishing access and trailhead parking areas
2 Historic markers and other interpretive signing
3 Improved bikeway and pedestrian facilities
4 New scenic overlooks

**Enhance transportation corridors** because as a state agency, the New York State Department of Transportation’s customers include the traveling public and the people who live and work in New York State’s transportation corridors. They deserve improvements in the quality of their lives that can be achieved through:

1 Providing streetscape amenities
2 Wild flower plantings
3 Landscaping to enhance the appearance of noise barriers
4 Reestablishing street trees in historic districts
5 Rehabilitating comfort stations and rest areas

The New York State Department of Transportation will continue to make every effort to:

Reduce environmental toxins by:

1 Using salt and sand for highway anti-icing and de-icing as judiciously as possible
2 Sweeping roadsides better and more often
3 Reducing herbicide applications
4 Cleaning up wastes previously generated on NYSDOT projects and at NYSDOT facilities

**Improve air quality** because up to half of the air pollutants emitted in New York State are emitted by single occupancy vehicles; that is, by cars with only a driver. To reduce these
emissions, the New York State Department of Transportation will:

1. Implement Transportation Demand Management practices
2. Encourage alternatives to single-occupancy vehicle commuting
3. Expand Ozone Alert Day initiatives
4. Promote the use of alternative fueled vehicles
5. Provide facilities for pedestrians and bicyclists
6. Support mass transit

**Increase the use of recycled materials** because New York State’s environmental policy calls for recycling as the first choice in dealing with solid waste. As a leader in this policy initiative, the New York State Department of Transportation will pilot and promote the use of recycled:

1. Tires in highway embankments
2. Glass, plastics, and aggregate in pavement mixes
3. Plastic, rubber, and aggregate in noise walls

**Preserve and enhance our New York State heritage** because our historic and our natural heritage belongs to all New Yorkers. Because of the nature of its work, NYSDOT is in a unique position to enhance this heritage by:

1. Preserving historic structures
2. Promoting state bicycle routes and greenways
3. Increasing highway tree plantings and other landscaping
4. Providing streetscape amenities
5. Increasing roadside plantings and maintenance for aesthetic improvement

Through active integration of environmental concerns into the Department’s daily operations and coordination with regulatory agencies, environmental groups, municipalities and concerned citizens, the Initiative will attain the goals set forth above.

**Maintaining or Improving the Natural Environment as Transportation is Built**

An increasing number of DOTs are incorporating ecosystem conservation into their planning processes; the General Accounting Office noted that DOTs in Oregon, South Dakota, Colorado, and North Carolina “reported extensively considering ecosystem conservation in transportation planning using several approaches. The Oregon Department of Transportation has included a policy in its long-range plan to, among other things, maintain or improve the natural and built environment, including fish passage and habitat, wildlife habitat and migration routes, vegetation, and wetlands. The long-range transportation plans of Colorado and North Carolina each contain specific references to goals or policies to conserve ecosystems, while South Dakota’s plan contains a more common, less specific goal aimed at protecting the environment.”

**Cultural Resource Enhancement Efforts**

Efforts to preserve and enhance public enjoyment of cultural resources are included among Context Sensitive Design/Solutions initiatives at state DOTs. Such efforts often include such environmental stewardship practices and improvements as:
1 Extending trails or sidewalks to allow public access to historic sites and areas
2 Visual screening of sensitive sites and structures
3 Scenic easements to protect cultural resources from inappropriate development
4 Special signage design/placement
5 Preservation of historic landscape elements and visual contexts
6 Preservation of the historic contexts of cultural resources through historical studies and publication of public interpretive materials

AASHTO’s Environmental Stewardship Demonstration Program profiles these and other project and programmatic cultural resource stewardship projects, about which further information is available on-line:

1 Bell Farm Bridge (KY)
2 Pioneer Street Bridge (VT)
3 Bridge Over Virgin River, East of Hurricane (UT)
4 WV Route 9 Environmental Commitments (WV)
5 AHTD Historic Bridge Management System (AR)
6 Section 106 Programmatic Agreement (VT)
7 Section 106 Programmatic Agreement (DL)
8 Farmland Mitigation (CA)
9 Community Sensitive Design Development (WI)
10 Connecticut Farm Map (CT)
11 Cultural Resource Partnership with Indiana University (PN)
12 Section 106 and 4(f) Programmatic Agreements for Historic Canal Bridges (NY)

AASHTO’s Center for Environmental Excellence maintains background information about information about Section 106 of the National Historic Preservation Act and Section 4(f) of the Department of Transportation Act on-line along with Recent Developments, Documents and Reports, Success Stories, and Related Links. A notable practice and use as a design resource in the state of Minnesota is MN/Model- A Predictive Model of Precontact Archaeological Site Location for Minnesota.

Often cultural resources enhancements are included in general project costs. Other times, such enhancements are funded as separate Transportation Enhancements (TE) activities,
which are federally funded, community-based projects that expand travel choices and enhance the transportation experience by improving the cultural, historic, aesthetic and environmental aspects of transportation infrastructure. Transportation Enhancement funds are apportioned to the state DOTs through a minimum 10 percent set aside of each state’s STP funds. TE projects must be one of 12 eligible activities and must relate to surface transportation. For example, projects can include creation of bicycle and pedestrian facilities, streetscape improvements, refurbishment of historic transportation facilities, and other investments that enhance communities and access. The National Transportation Enhancements Clearinghouse contains descriptions and photos for a full range of such efforts, as well as links to learn the basics of the TE program, view a Guide to Transportation Enhancements, access state-specific information, order free documents, or assistance. Federal legislation related to TE is accessible through the Federal Highway Administration (FHWA) TE Web site. In addition to a project list, NTEC maintains a state program policy and procedures database that is updated periodically as changes occur. Some state DOTs are more active in implementing the TE program and using TE dollars than other states. Several states, including Wisconsin, Massachusetts, and Alaska, have funded numerous TE-eligible projects using funding sources other than the TE set aside. The following trail extension project profiled by NTEC is a prime example of a cultural resource enhancement project, in the sidewalk/trail extension category, undertaken with DOT support:

New Hampshire Lincoln-White Mountain Trail

Figure 1: Lincoln, NH White Mountain Trail

New Hampshire DOT facilitated construction of over 2.5 miles of sidewalk and multi-use path through what was once an ailing mill town in New Hampshire’s majestic White Mountains. The town of Lincoln now bustles year round with tourists bound for hiking, biking or skiing, after town officials recognized its strategic importance as a gateway to the White Mountains, and focused efforts on better connecting the community with recreational opportunities in the area. The path was built over the former site of a penstock, a sluice used to transport water to the mill, between the Pemigewasset River and Route 112. Residents of the town can now safely travel adjacent to Route 112 by foot, and bicyclists coming down from the Noon Mountain ski area or through Franconia Notch can use the path to enter town. Parts of the path abut the White Mountain National Forest, where pedestrians and bicyclists can take in the beauty of the mountain scenery and, in the autumn, enjoy the region’s spectacularly colored foliage.
3.2 Context Sensitive Design/Solutions

The Context Sensitive Design (CSD) process, also called Context Sensitive Solutions (CSS), identifies the physical, visual, and social context in which a project is situated. Establishing the existing context is done through observation and analysis along with interviews and discussion. CSD/CSS fosters the use of:

1. Strong stakeholder involvement programs.
2. Collaborative and interdisciplinary approaches to decision-making.
3. Understanding of the aesthetic and other contexts within which transportation occurs.
4. Consideration of human and natural environmental effects of transportation.
5. Selection of design criteria appropriate to a specific project’s safety, operational, and environmental needs.

The American Society of Civil Engineers (ASCE) defines CSS as “a collaborative, interdisciplinary approach, involving all stakeholders to ensure that transportation projects are in harmony with communities and preserve environmental, scenic, aesthetic, and historic resources while maintaining safety and mobility.” In sum, a CSD project is highly responsive to the environmental conditions, both cultural and natural, in which it occurs.

As noted by the TxDOT/Texas Transportation Institute project, “Guidelines for Aesthetic Design in Highway Corridors: Tools and Treatments for Texas Highways,” the goal of aesthetics design in the highway environment is to create a pleasurable experience for the user and a positive contribution to the visual character of the community, while attending to safety and efficiency needs. This can be approached through visual quality and four related information factors: complexity, coherency, legibility, and anticipation.

Context sensitive solutions also minimize impacts to sensitive areas during design. Ideally, the highway project is planned to fit the particular topography, soils, drainage patterns, and natural vegetation as much as practicable. To this end, designers collect information and/or map surface waters, natural drainage ways, and direction of drainage patterns. Examples of stewardship practices DOTs have taken in design to avoid environmental impacts include:

1. Asymmetrical widening to avoid wetlands, critical slopes, active slide areas, or the locations of endangered plant species.
2. Alignment or profile shifts.
3. Design deviations.
4. Installing guardrails to avoid slope flattening that will encroach upon sensitive areas.
5. Building retaining walls to minimize the fill footprint.
6. Minimizing clearing limits to avoid impacting buffers.
7 Reuse of existing bridge abutments to help avoid disturbance to native vegetation and endangered species.

8 Use of materials that blend with the natural setting of the area.

9 Use of timber bridge rail, timber guardrail, and timber handrail in some cases rather than guardrail and concrete barrier walls.

The 1998 State DOT “Thinking Beyond the Pavement Workshop,” identified the following recommended actions for states which may be considered practices that achieve environmental stewardship:

1 Adopt Federal language from 23 U.S.C. 109 in their own policies to include environmental, scenic, aesthetic, historic, community, and preservation criteria in projects, along with safety and mobility.

2 Advance the philosophy of context sensitive design in the strategic plans of AASHTO committees.

3 Review procedures, organizational structure, and staffing to encourage and institutionalize context sensitive design.

4 Develop educational programs for staff and consultants that develop the necessary attitudes and skills to carry out context sensitive design, including highway design, communication skills, and process improvements.

5 Provide the tools necessary for context sensitive design, including 3D presentation tools.

AASHTO Environmental Stewardship Demonstration projects highlight success stories in implementation of CSS/CSD initiatives in Kentucky, Utah, North Carolina, and Wisconsin.

State DOT CSD/CSS Policies, Plans, Guidelines, Agreements, Training, and Examples

Caltrans’ Context Sensitive Design approach implements the Director’s Policy on Context Sensitive Solutions and the Deputy Directive on Accommodating Non-Motorized Travel. Caltrans’ Highway Design Manual Philosophy and Application of Standards provide for the use of nonstandard design when such use best satisfies the concerns of a given situation through an exception process. Practices and design opportunities for downtown areas are included in the agency’s booklet on Main Streets: Flexibility in Design and Operations. Caltrans has also produced internal articles on “Innovation: Context Sensitive Solutions” and Context Sensitive Design Powerpoint Presentation and case studies on U.S. Hwy. 50 Operational Improvements Project in Placerville and The Donner Park Overcrossing.

Connecticut DOT has promoted context sensitive design through statewide awareness training, training courses for its managers, and development of an ongoing training course for engineers through collaboration with the University of Connecticut’s Engineering Department. ConnDOT sponsored a regional context sensitive design workshop with CSS leaders and 300 participants from 18 states and the District of Columbia, comprised of 85 percent transportation professionals and with 15 percent representing stakeholder interests outside transportation. An Executive Summary is
available on-line. ConnDOT also is utilizing a Connecticut Farm Map in CSD/CSS. 

**Florida DOT’s Public Involvement Handbook**, updated in 2003, addresses CSD/CSS issues.

**The Kentucky Transportation Cabinet** has held extensive training workshops in context sensitive design, geared toward all participants in the project development phases. The **Kentucky Transportation Center** maintains CSD/CSS case studies, and the **KYTC Context Sensitive Design Workshop** is available on-line as is Kentucky Streetscape Design Guidelines for Historic Commercial Districts. KYTC’s premier CSD/CSS project is the Paris Pike which created a 4 lane road with curvilinear alignment, timber guardrails, grass shoulders, large trees and rock fences retained along roadside, and stone veneer on headwalls and bridges. KYTC stripped, stockpiled, and returned the silt loam topsoil to its original thickness after grade and drain work was completed.

**The Maryland State Highway Administration** developed a “Thinking Beyond the Pavement” strategic plan to guide CSD/CSS implementation, conducted charettes to identify project development process strengths, designed a project evaluation instrument, and established teams to review and implement project improvement strategies. MDSHA developed a process to move beyond a “traditional” engineering approach to transportation projects and developed a new means of roadway improvement design that captures the broader effects of transportation safety and mobility decisions on 1) specific community needs, 2) on the land use decisions that are likely to follow, and 3) the cumulative impact on air/water quality and quality of life. The result of this mission was a new planning/design process subsequently used in scores of projects and communities and published in When Main Street is a State Highway. MDSHA replaced what they called a “cookie-cutter” approach to roadway design work with a method that better reflected each community’s unique character and living environment. Participating communities are given a clear understanding of the choices involved and the information necessary to make effective, long-term decisions. The approach has now been used in over 50 constructed projects and no project has had to be redesigned because of opposition or lack of understanding for its need.

The process has also formed the basis for organization-wide training whereby highway engineers have been empowered to go beyond “standards-driven” design solutions. MDSHA has been called upon to deliver training using this approach to other DOTs and to partners in Architecture, Planning, Urban Design and Historic Preservation nationally. MDSHA has developed an internal orientation course for CSD/CSS and MSHA’s project development process, a Resource/Reference Guide for project managers, introductory and advanced-level project management courses, and advanced level, topic-specific project management courses, as well as a support system for project managers that include mentors and other resources.

In support of CSS/CSD and the governor’s Smart Growth Initiative, MDSHA’s Neighborhood Conservation Program (NCP) provides funding for projects that stimulate growth and investment in older communities. The NCP projects are initiated by a community contact to MDSHA requesting assistance in addressing traffic issues with regard to pedestrians, transit riders, bicyclists and motorists. The program gives priority to improvements along state highways located within designated neighborhoods and part of Priority Funding Areas where the improvement will ignite economic growth, contribute to other revitalization efforts and promote neighborhood conservation. A key
component of the NCP is total participation throughout the process by the affected community. The community and MDSHA form a partnership to gather information, define the concerns to be addressed through the project, and then create viable alternatives. MDSHA provides the technical expertise while community representatives assure that the functioning needs of the town are met through design plans and implementation. Working together, the team develops plans for improvement that will create more livable, convenient and enjoyable communities. More than $124 million is funded for NCP projects through fiscal year 2006 for improvements such as roadway reconstruction, roadway signing, lighting and traffic controls, constructing curb and gutter, sidewalks and transit shelters, improvements to existing storm drainage lines, streetscape design, and pedestrian and bicycle accommodations and safety. Mn/DOT’s policy is to use a “Context Sensitive” approach to create excellence in transportation project development—an approach that incorporates design standards, safety measures, environmental stewardship, aesthetics, and community sensitive planning and design. Mn/DOT Technical Memorandum No. 00-24-TS-03 outlines the department’s commitment to CSD. Mn/DOT is incorporating context sensitive design into all aspects of transportation project development—planning, design, construction, and operations through new policies, extensive research, and training programs. Mn/DOT has developed many implementation resources, including the use of visualization technologies to support CSD. Mn/DOT produced Context Sensitive Design, the Road Best Traveled and an Executive Summary that serves as a good introduction to CSD principles and design practices. Also, Mn/DOT’s entire CSD/CSS workshop is available on-line, addressing CSS issues in sessions as follows:

1. Session 2: Mn/DOT Introduction
2. Session 3: What is Context?
3. Session 4: Introduction to Design Workshop
4. Session 5: Design Workshop Session A: Defining the Context
5. Session 6: District Engineers Panel
6. Session 7: The “Think” Method of Design
7. Session 8: Design Workshop Session B
8. Session 9: Walking Tour of Excelsior Boulevard
9. Session 10: Creative Engineering
10. Session 11: Design Workshop Session B Continued
11. Session 12: Edge and System Relationships
13. Session 14: Design Workshop Session C
14. Session 15: Public Involvement
15. Session 16: Putting It All Together
16. Session 17: Design Workshop Session D
One of Mn/DOT’s premier CSD/CSS examples is the 47-mile Minnesota Highway 38 Edge of the Wilderness National Scenic Byway, which offers a winding route around lakes and wetlands. The project involved partnerships with federal, state and local parties to guide the design process. More than 90 percent of the highway would have been altered to increase the design speed to 55 miles per hour, which would have required some cut and fills over 25 feet high and clearing limits as great as 190 feet. It was agreed that the existing horizontal and vertical alignment would be maintained as much as possible unless spot upgrading could significantly improve safety. Six foot paved shoulders with a continuous rumble strip to lessen the roadway footprint on the land, and guardrails occasionally extended to further protect in-place resources. Additional design flexibility included shallow ditch bottoms at higher vertical alignment points and increasing the back-slope steepness to minimize vegetation and visual impacts. Special care was taken to choose appropriate native turf establishment. Roadside maintenance practices have encouraged the re-establishment of native vegetation. Under the direction of a Leadership Board, the corridor continues to be maintained, redesigned, and reconstructed following best-practice environmental design principles.

A recently completed University of Minnesota research project, entitled Attributes and Amenities of Minnesota’s Highway Systems that are Important to Tourists, studied eleven scenic byways in Minnesota, including Highway 38. The research examined user preferences for physical characteristics, aesthetics, and amenities of each roadway segment. Early focus groups provided a framework for the study and results revealed that road travelers are able to differentiate between physical and socially derived attributes and amenities, roads do have strong character and can strongly influence user trip satisfaction.

The Montana Department of Transportation (MDT) and the Western Transportation Institute hosted a Context Sensitive Design Workshop with attendees from 38 states and South Africa. MDT’s premier CSS project is Highway 93, which will include 42 wildlife crossings, including culverts, bridges, and two overpasses. The Memorandum of Agreement (US Highway 93 from Evaro to Polson) MTDOT, FHWA, and the Confederated Salish and Kootenai Tribes is available on-line.

Utah committed to a culture change process as part of implementing Context Sensitive Solutions at UDOT. The effort is focused on addressing the transportation need and being an asset to the community that is compatible with the natural and built environment. UDOT provides guidance for implementing these principles on their website. The initiative has focused on community outreach and project development and includes assessment of stakeholder attitudes and internal practices, an implementation and staff training plan, and post-implementation assessment. UDOT also created a
Directorate position for Context Sensitive Solutions, to provide leadership and coordination for the agency’s CSS Program. Other position responsibilities include development of long-range plans for the CSS Program.

Nevada’s Governor stated “because [highways] affect our ecosystems and the way our neighborhoods and places of business connect to each other, they influence the quality of life of every citizen in the state;” in response Nevada DOT (NDOT) developed a Pattern and Palette of Place: A Landscape and Aesthetic Master Plan for the Nevada State Highway System that provides guidance for aesthetic treatments for city streets, rural roads, gateways, rest areas, and various other circumstances. In many cases it also provides guidance through examples of various levels of aesthetic treatments, from no cost to high cost. The document also discusses the process of developing a project that is aesthetically pleasing and fits into the context of its environment.

New Jersey DOT has implemented a training program for highway engineers and other transportation professionals, along with stakeholders in New Jersey host communities, to ensure Context Sensitive Design Awareness in New Jersey. This program emphasizes the use of effective public involvement techniques, implementation of design flexibility, and the concept and importance of “Placemaking.” NJDOT’s premier CSD/CSS project is Route 35 Coopers Bridge over the Navesink River between Red Bank and Middletown, which was dedicated in 2000 after five years of planning and redesign by a partnership between the communities and NJDOT.

New York DOT gives internal awards for Context Sensitive Solutions. The agency’s philosophy aims for projects that are in harmony with the social and natural environment and community needs, and show measurable success in improving the community’s environmental, scenic, aesthetic, historic, and natural resources, above and beyond mitigation requirements. To that end, NYSDOT has developed a number of resources to implement CSD/CSS including: NYSDOT Engineering Instruction 01-020, NYSDOT CSS Implementation Plan, and a review of Context Sensitive Solutions in New York Construction News. NYSDOT also provides its staff a Place Audit: An Assessment Exercise from the Project for Public Spaces to help assess a site’s current and potential performance.

North Carolina DOT worked with the Center for Transportation and the Environment to develop CSD/CSS Presentations used in training NCDOT engineers and project managers. Also, the University of North Carolina Highway Research Center developed a document entitled Visualization: Guidance for the Project Engineer, which provides an overview of visualization capabilities and techniques, a discussion of cost benefits and development time, and a survey of the state-of-practice of state DOT visualization techniques.

Oregon DOT developed CSD/CSS guidelines for Historic Downtown Main Streets: Strategies for Compatible Streetscape Design. The Portland, Oregon Traffic Calming Program is also available on-line. Context sensitive design guidance for natural resources is under development; ODOT plans to apply such practices and standards programmatically in rehabilitation of Oregon bridges.

Texas DOT developed a Landscape and Aesthetic Design Manual, which provides in-depth information and guidance on landscape and aesthetic design and includes details about selecting and using specific aesthetic treatments, as well as design planning and evaluation for common structural elements as well as common transportation features like interchanges, highway corridors, entrance and exit ramps, and more.
Complimenting the Landscapes and Aesthetic Design Manual, TxDOT and the Texas Transportation Institute developed Guidelines for Aesthetic Design in Highway Corridors: Tools and Treatments for Texas Highways, a reference to assist TxDOT designers and consultants in selecting and specifying appropriate aesthetic treatments for transportation projects. The project developed Technical Data Descriptions with fundamental information about the character, advantages, disadvantages, costs, and maintenance implications of aesthetic treatments or elements designers may consider for use on highway projects. The aesthetic treatments or elements addressed in the Technical Data Descriptions include:

**Example 2: Aesthetic Treatments Discussed in TxDOT Guidelines for Aesthetic Design - Site Amenities & Public Art**

**Concrete (Poured-in-Place) - Coatings and Coloring**
1. Sealer Stains
2. Acid Stains
3. Integral Color
4. Color-Hardened Concrete
5. Thin-Set Surface Coatings

**Concrete (Poured-in-Place) - Textures**
6. Sandblasting
7. Colored, textured Concrete
8. Form Liner Finishes

**Veneers**
9. Brick and Stone
10. Tile

**Concrete (Modular) - Walls**
11. Concrete Masonry Units
12. Modular Block

**Paving**
13. Brick and Concrete Pavers

**Traffic Barriers**
14. Movable Concrete
15. Interior Planter Support System

**Asphalt - Textures**
16. Patterned Asphalt

**Asphalt - Color**
17. Surface-Coated
18. Integral Color

**Pedestrian Barriers**
19. Railings
VTrans or the Vermont Transportation Agency has focused the agency’s CSD/CSS efforts on Historic Bridge Program, Danville Project, the Shelburne Road Project, and Vermont Byways. The Danville Transportation Enhancement Project is a partnership among VTrans, the Vermont Arts Council and the Town of Danville, Vermont to integrate artistic enhancements into the redevelopment of a portion of U.S. Highway Route 2 through the village center, to “enhance the essence of a small, close-knit rural community by providing a safe, attractive and comfortable pedestrian environment in the Village of Danville while celebrating its unique historic, built and natural features.” The project provided better sight lines and improved vehicular and pedestrian safety while respecting the aesthetic and socio-economic fabric of the community. VTrans is also in the process of developing a statewide layer of critical wildlife corridors, the first products of which will be developed by late 2004, in addition to undertaking research to minimize human and beaver conflicts.

Washington State DOT’s approach to CSD/CSS helps implement the WSDOT Livable Communities Policy. WSDOT Roadside and Site Development and WSDOT Design Visualization Services provide implementation tools. WSDOT has emphasized learning from others both nationally and internationally, through sponsorship of a 2002 Regional U.S.-Canadian CSD Workshop and the CSD-100 International Symposium Main Street America Meets Main Street Europe. The agency provides Geometric Design Practices for European Roads on the WSDOT Context Sensitive Design website. In 2003 WSDOT published “Building Projects that Build Better Communities - Recommended Best Practices.”

WSDOT’s Roadside Manual includes guidance on “Design Enhancements,” which WSDOT defines as “the incorporation of manmade elements in the landscape to accomplish goals such as expression of community character, marking a community entrance, providing corridor continuity on a scenic or recreational highway, and as mitigation for visual impacts.” Examples of such enhancements occur on tunnel portals, bridges, noise walls, community entrances, rest areas, and park and ride lots and may consist of a landform, water feature, wall or barrier texture, color, pavement type, brick variation, site furnishings, or a combination of elements, including incorporation of impressions into a wall, barrier, or bridge structure.

WSDOT’s Washington State Roadside Manual also calls for the following questions to be answered at the 30 percent review point:

1. What is the purpose of design enhancement?
2. What is the community character?
3. What is the historical significance?
4. What is the cultural significance?
5. How does enhancement contribute to corridor continuity?
6 Who is the audience?
   o Driver & passengers
   o Transit and rail users
   o Pedestrian or recreational users
   o Community/neighborhood residents

1 How long will the design enhancement be viewed?
   o Is it on a bridge portal that is seen for long moments on approach?
   o Is it on the side of the road and seen only briefly?
   o Is it at an intersection where drivers will be stopped at a light?
   o Is it at a park and ride lot or safety rest area?

1 Is the design enhancement in a publicly accessible area (such as a viewpoint,
   park, or plaza)?

2 How great is the potential for vandalism on the site?

3 Will the design enhancement create a distraction or act as a fixed object that can
   be a hazard?

4 Will the design enhancement block sight lines (to signs, merging traffic, etc.) or
   infringe on safety?

5 Will the design enhancement be lighted?

6 Will lighting create a distraction or glare problem?

7 Can the lighting be developed to enhance visibility for both road users and
   pedestrians?

8 How high is the chance that the design could become an attractive nuisance?

9 What are the dimensions of the design enhancement?

10 Does its scale relate to its context?

Incorporation of art into the design of a facility is an option for some projects, including a
repeating element or pattern along the length of a corridor, which can include wall
textures, luminaire design, railing design, or site furnishings such as bicycle racks, street
tree grates, trashcans, or benches. The WSDOT Traffic Manual, “Signs” has a section on
Community Entrance Markers (under “Miscellaneous Signing”) that provides guidelines
on these elements.

WisDOT’s Community Sensitive Design Development has resulted in a
Policy/Philosophy Statement for CSD in WisDOT, revision of the WisDOT Facilities
Development Process to include public involvement opportunities earlier and more often,
development of policy and guidance on formats for Public Involvement meetings and
coordination and extensive outreach to internal and external stakeholders in the
development of policy changes. Design criteria tables and guidance were expanded to
incorporate the full range of flexibility provided in the AASHTO “Green Book”
Whereas WisDOT FDM design criteria formerly fell in the middle to upper range of the AASHTO design criteria, the revised design criteria include AASHTO minimum design criteria available with justification addressing safety, traffic operations and social and environmental effects of a project. Design Standards and Planting and Aesthetic Design components of the manual received particular attention. The WisDOT Local Cost Share Policy is being revised to incorporate more aesthetic elements into projects by expanding the list of eligible items to include low cost treatments such as textured and colored concretes and to incorporate budgets that can be used to fund “non-standard” treatments outside the list of eligible items.

WisDOT has developed CSD training workshops for over 400 WisDOT staff and other stakeholders. Outreach has included such groups as local government officials, environmental groups, state and federal agencies, Wisconsin Transportation Builders Association, Wisconsin Association of Consulting Engineers, and special interest groups. At the training sessions, attendees are provided with a CSD training manual and copies of the WisDOT FDM revisions, developed by WisDOT Roadway Development Engineers. They also receive a copy of the FHWA publication “Flexibility In Highway Design.” To support CSD/CSS work in each district, WisDOT also established “aesthetic contacts,” given more in-depth training by WisDOT landscape architects. The aesthetic contacts assist district engineers in refining visual impact ratings, determining aesthetic budget estimates, and developing aesthetic design treatments.

WisDOT has also assembled resources on context sensitive solutions that are available to state transportation agencies on-line, or are in process.

**Roadway Aesthetic Treatments Photo Album Workbook - Federal Lands Highway**

The Federal Lands Highway Divisions have extensive experience with aesthetic treatments on highway projects. In an effort to document innovative practices being applied across the nation, a Technology Deployment project was initiated to collect information about aesthetic treatments used in highway construction. The product of this effort is a compact disc with approximately 200 examples of innovative aesthetic treatments. The Roadway Aesthetic Treatments Photo Album Workbook. The workbook has been showcased at previous annual meetings of the American Association of State and Transportation Highway Officials and the Transportation Research Board. The Aesthetic Treatments Photo Album was produced during FY 2000 and updated in FY 2002, providing an extensive reference guide of innovative aesthetic treatments that have been applied on transportation projects nationwide for bridges, walls, barriers, soil and rock cut and fill slopes with a focus on roadway case studies. For each aesthetic treatment example as much of the following information as possible is included:

1. Agency Name
2. Brief Project and Aesthetic Treatment Description
3. Reason(s) Aesthetic Treatment Used
4. Contact Person Name and Address
5. Color Photographs
7. Construction Specification
Example 3: Federal Lands Highway Special Aesthetic Treatment Categories

1 - Rock Cut Slope
   Rock staining
   Rock sculpting
   Fresh and weathered
   Half casts

2 - Soil Cut Slope
   Serrated Soil
   Creation of natural looking land forms
   Special vegetative treatments

3 - Fill Slopes
   Rock 1.25H : 1V
   Re-vegetated
   Reinforced slopes

4 - Retaining Walls
   Form liner treatments
   Painted or stained face
   Natural stone facing
   Simulated stone facing
   Custom treatments
   Bush Hammer finished concrete
   Vegetation planted facing
   Shotcrete facing
   MSE w/ Precast Facings
   Segmental block walls
   Welded wire faced
   Timber faced

5 - Rockfall - Barriers, Fences, Draped Mesh
   Weathering steel guardrail
   Steel backed timber
   Stone masonry or simulated stone
   Concrete core w/stone or timber facade
   Gabion Barriers
   GM rail w/aesthetic treatment
   Brugg or other proprietary fence
   DOT’s own fence
Colored vinyl coated chain link or gabion mesh fences or slope screening

6 - Bridges
Colored or stained concrete
Stone masonry or simulated stone
Form liner treatments
Custom treatments
Timber

7 - Bioengineering Treatments
Waddles
Bio-logs
Live stakes and Live planted walls
Logs and boulders on slope
Bounded fiber matrix
Organic based fertilizer
Riprap barbs

Matings

Context Sensitive Design/Solutions References and Resources
State products for developing Context Sensitive Solutions are listed within state initiatives under Context Sensitive Solutions. The following technical assistance and guidance is available on a national basis.
Flexibility in Highway Design (FHWA Pub. No. FHWA-PD-97-062). In an effort to highlight Flexibility in Highway Design for the environment, FHWA produced this document which includes an Overview of the Highway Planning and Development Process as well as the following design guidelines: Highway Design Standards, Functional Classification, Design Controls, Horizontal and Vertical Alignment, Cross-Section Elements, Bridges and Other Major Structures, and Intersections.

1 Federal Highways Traffic Calming Website is dedicated to all the known and electronically publicized transportation programs and studies that pertain to traffic calming. As traffic calming needs often differ, techniques include police enforcement and public education only in some areas. In others, it means the employment of speed humps while in others it means the possible use of a wide array of techniques and devices. This web site is dedicated to all the known and electronically publicized transportation programs and studies that pertain to traffic calming. FHWA Community Impact Assessment Quick Reference for Transportation from the Federal Highway Administration. Also, FHWA - Citizen’s Guide to Transportation Decision Making.

2 The National Transportation Enhancements Clearinghouse is an information service sponsored by the Federal Highway Administration and the Rails-to-Trails Conservancy. Transportation Enhancements are community-focused activities related to surface transportation that involve consideration of environmental, cultural, economic, and social conditions. The site provides an explanation of the Transportation Enhancements program (a federal-aid reimbursement program) and how it is implemented at the state level. It provides professionals, policy
makers and citizens with timely and accurate information necessary to make well-informed decisions about transportation enhancements, including landscaping and scenic beautification. The site includes a compilation of Web sites, virtual libraries, databases and other Internet resources that provide information on contacts, reports, legislation, policies, implementation or other issues relating to activities that can be funded as Transportation Enhancements.

3 Thinking Beyond the Pavement: A National Workshop on Integrating Highway Development with Communication and the Environment, University of Maryland.

4 A Policy on Geometric Design of Highways and Streets, AASHTO.

International Scanning Tour on Highway Geometric Design Practices for European Roads. (FHWA-PL-01-026) The objective of this scanning tour in June, 2000 was to review and document procedures and practices in highway geometric design and context sensitive design in several European countries. This “Report” gives a brief discussion on practices the scan tour participants found most significant.

1 A Guide to Best Practices for Achieving Context Sensitive Solutions, Transportation Research Board. NCHRP 20-07, Task 128 identified, described, and disseminated information on the best examples of highway projects contributing to enhanced community livability. The final report was published by AASHTO and is entitled, How Transportation and Community Partnerships Are Shaping America Part II: Streets and Roads. The publication is out of print but black and white copies are available from AASHTO. NCHRP Project 16-04 on Design Guidelines for Safe and Aesthetic Roadside Treatments in Urban Areas is due to be completed in late 2005. Objectives of the project are to develop 1) design guidelines for safe and aesthetic roadside treatments in urban areas and 2) a toolbox of effective roadside treatments that balance pedestrian, bicyclist, and motorist safety and mobility and accommodate community values. The guidelines will be based on an evaluation of the effects of treatments such as trees, landscaping, and other roadside features on vehicle speed and overall safety. The guidelines will generally focus on arterial and collector-type facilities in urban areas with speed limits between 25-50 mph.

2 Project for Public Spaces, Context Sensitive Solutions has published Getting Back to Place: Using Streets to Rebuild Communities.

3 Building Roads in Sync with Community Values, Public Roads Magazine.


1 Traditional Neighborhood Development: Street Design Guidelines, Institute of Transportation Engineers, 1999.

2 The National Main Street Program is designed to improve all aspects of the downtown or central business district, producing both tangible and intangible benefits. Improving economic management, strengthening public participation, and making downtown a fun place to visit are as critical to Main Street’s future as recruiting new businesses, rehabilitating buildings, and expanding parking. Building on downtown’s inherent assets — rich architecture, personal service and
traditional values and most of all, a sense of place — the Main Street approach has rekindled entrepreneurship, downtown cooperation, and civic concern.

3 National Park Service–Rivers, Trails and Conservation Assistance Program (RTCA), is a community resource of the National Park Service and works in urban, rural, and suburban communities with the goal of helping communities achieve on-the-ground conservation successes for their projects. They help communities help themselves by providing expertise and experience from around the nation. From urban promenades to trails along abandoned railroad rights-of-way to wildlife corridors, their assistance in greenway efforts is wide ranging. Similarly, their assistance in river conservation spans downtown riverfronts to regional water trails to streams.

5 Walkable Communities

6 Traffic Calming.org

7 Context Sensitive Design for Major Urban Thoroughfares, a joint project of the Institute of Transportation Engineers and the Congress for the New Urbanism begun in 2003 will: 1) Present a new design framework developed in this effort specifically for use in urban projects, 2) Detail a design process to implement that framework based on current AASHTO, FHWA, ITE, and other design standards, criteria, and practices, 3) Incorporate optimal existing guidelines for the total public right-of-way, including but not limited to the pedestrian realm, intersections, bicycle facilities, transit, access management, and on-street parking. The project has received support from EPA and FHWA as well.

3.3 Avoiding Impacts to Historic Sites

Prior to construction, compliance with Section 106 of the National Historic Preservation Act should have resulted in the identification of “historic properties” subject to possible effect by construction. A “historic property” under the Act is a district, site, building, structure or object included in or eligible for the National Register of Historic Places. Historic buildings and archaeological sites are the best-known kinds of historic properties, but expansive urban and rural districts, landscapes, roads and trails, natural areas of traditional cultural importance, and even highways themselves may be eligible for the Register. Compliance with Section 106 involves consultation with the State Historic Preservation Officer (SHPO), Indian tribes, and other parties, as well as surveys to identify historic properties and determine effects on them. It usually results in a written agreement – either an exchange of letters or a Memorandum of Agreement (MOA) – specifying how any adverse effects will be avoided or mitigated. Measures commonly agreed to include:

1 Physical avoidance of properties in construction work
2 Realignment and other redesign of projects to avoid or reduce impacts
3 Adaptive use of historic buildings, structures and other properties for new purposes consistent with their character
4 Relocation or removal of historic buildings and structures from project areas
5 Incorporation of historic elements into new design
6 Retention of historic setting
7 Mitigation of road noise
8 Reduction in traffic speeds.
9 Retention of historic elevations, lane widths, shoulders and road curvature.
10 Avoidance of new visual elements, such as curbing, lighting, or signage, that may detract from historic character.
11 Landscaping to preserve rural feeling and association where appropriate.
12 Recording/Research, which may include: drawings, photography, records research, and informant interviews, as well as historical, architectural, and archaeological studies
13 Placing information kiosks/signage in highly visible areas with roadside turnoffs to provide public access. Use in conjunction with recordation and research.

It is very important to ensure that the terms of agreements resulting from Section 106 review are reflected in construction specifications, contracts, and related documents, and that construction personnel are made aware of the need to comply with such terms. AASHTO and NCHRP 8-40 sponsored a study in 2001 focusing on “the improvement of existing procedures for evaluating cultural resource significance through the use of information technology.” The first phase of the study involved the collection of information on how state DOTs and SHPOs use (or do not use) information technology in making decisions on resource significance. The study made the following findings:

1 Most SHPOs and DOTs have not completed a standard set of historic contexts for their states; and, if the contexts exist, they exist only on paper.
2 Many SHPOs and DOTs do not have their resource inventories in a computer database.
3 There are competing state, regional, and national efforts in terms of computerized cultural resource database development.
4 When databases do exist, they were not developed to be used as a tool for evaluating significance. Rather, the majority is used to describe and locate resources on the landscape regardless of whether or not they are listed in or eligible for listing in the National Register.
5 The majority of the DOT and SHPO staffs rarely use their databases or historic contexts to evaluate properties to determine their eligibility for the National Register. Rather, they rely on their own personal experiences and knowledge, and those of their cultural resource consultants.
6 DOT and SHPO staff are generally not satisfied with the tools that they have to make and justify their decisions on the significance of properties, and they would like to see increased sharing of information and approaches among agencies and states.

The situations described above can complicate the identification and evaluation of properties and reduce the efficiency of historic property studies, and increases costs.
Archaeological Sites

Archaeological sites – that is, physical remains of past human activity, on or in the ground – are among the most common kinds of historic property with which DOTs have to deal. Archaeological sites are valuable for the information they contain, which can be used by archaeologists to reconstruct the past. They also may have cultural significance to Indian tribes and other descendant communities, which may sometimes conflict with the interests of archaeologists. They may also have public interpretive value. The following recommendations have been developed with regard to stewardship of archaeological sites, including the artifacts and other objects they contain, and districts or complexes of archaeological sites in construction areas:

1. Utilize covenants and easements to ensure avoidance of physical impact, where possible. Easements may be donated to a third party, which then assumes preservation responsibility. Avoiding impacts in this way not only preserves sites for the future, but can save money that would otherwise be spent on archaeological excavations. For example, by preserving nearly 12 acres of archaeological site within the ADOT right-of-way, it is estimated that ADOT saved $2 million in archaeological costs. The preserved sites are treated with respect in the interests of those who ascribe cultural value to them, and may be available for future archaeological research. ADOT has partnered with the city, county, and several Native American tribes to seek funding that will allow expansion of this preserve and its incorporation into a cultural and natural resource park (a grant application is pending).

2. In planning avoidance of impact, be sure to consider more than only direct physical impacts. There is little point in investing to preserve a site from direct impacts if it is only going to be lost to indirect effects such as induced development. Some sites may also be subject to non-physical impacts, such as visual and auditory impacts, if they have cultural or interpretive values that can suffer such impacts.

3. In providing for physical impact avoidance, be sure to establish where the edge of the archaeological site is closest to the construction area, and maintain a buffer zone of at least 50 feet between the edge of the construction zone and the edge of the site. Fencing, earthen berms, or other permanent barriers can be used to ensure avoidance in conjunction with a buffer zone.

4. Consider adding 12-24 inches of topsoil to “cap” sites by intentional burial. Through consultation with concerned parties, make sure that this approach is generally regarded as appropriate to the kind of site involved. Archaeological and geophysical testing may be necessary prior to capping to assess whether compaction, subsidence, chemical leaching, or other effects may occur.

DOTs have developed a variety of ways to steward cultural resources and historic sites in the course of design and construction:

1. Pre-construction surveys indicated that TxDOT’s Mission Refugio project would require the exhumation of a number of historic human burials, and plans had been
agreed to for handling them. When more burials than anticipated were discovered, TxDOT expanded the scope of its public involvement process and contacted other possible stakeholders, including the Refugio county judge, Refugio government officials, a local history museum, and community members. Many of these stakeholders helped TxDOT identify historic features and artifacts.

Figure 3: Arkansas SHDT Historic Bridge and Native Stone Retaining Wall

1) When the Arkansas State Highway and Department of Transportation (AHTD) took on the expansion of a one-lane bridge over the Mulberry River in the Ozark National Forest, they chose to construct a rock retaining wall, made with native stone quarryed from near the construction site. Using local stone to build the structure was lower in cost than some traditional systems, and was much cheaper than a masonry face. It also enabled the wall to fit in with the natural surroundings. The team chose a mechanically stabilized earth (MSE) wall system, using geogrid reinforcements for the taller walls, covered by the locally quarried stone. It required no special equipment or labor, and provided more flexibility without distress. AHTD widened the existing gravel road to two travel lanes with shoulders; constructed a bridge over Indian Creek; developed drainage improvements; and designed functional, yet aesthetic, retaining walls for the project. Native stone also provided natural water drainage. Concrete would have enabled water to seep into the walls when the Mulberry River flooded, causing a buildup of hydrostatic pressure through water retention. Retaining walls are now free-draining, eliminating the need for a human-engineered drainage system.

Figure 4: NHDOT Smith Millennium Covered Bridge

1
1) NHDOT continues to maintain just over 50 covered bridges. Hundreds more used to exist. Old bridges have been carefully rehabilitated under a state law allowing NHDOT to use State Bridge Aid money for this purpose. With an 80 percent share from the state and 20 percent from the town, each new covered bridge is rebuilt to retain its historic character while meeting legal load and height standards. The $3 million Smith Millennium Covered Bridge (Long Truss with integrated arches spans 163 feet over the Baker River in Plymouth) can handle two 18-wheel tractor-trailer trucks passing each other. It combines the historically proven qualities of a wooden covered bridge with more modern amenities, such as a fire detection system, lighting for the interior travel way and an exterior sidewalk. A picture is included to the right. This and other new covered bridges in New Hampshire are the result of state and community partnerships that led to the rebuilding of local landmarks, thus restoring part of the state’s heritage that are also highly functional parts of the state’s transportation system. They are structures that both honor the past and look to the future.

3.4 Designing to Accommodate Wildlife, Habitat Connectivity, and Safe Crossings

Wildlife issues are on the rise for state DOTs. Wildlife related concerns include habitat fragmentation and connectivity for wildlife, loss of habitat, increasing numbers of threatened and endangered species, and secondary and cumulative impacts. The federal Endangered Species Act prohibits harm to or take of any listed species or adverse modification of designated critical habitat. Some of the existing regulations can be reviewed at the Overview of the U.S. Fish and Wildlife Service and recent developments at AASHTO’s Center for Environmental Excellence website. Other sites which provide regulatory information include the USFWS’ Digest of Federal Resource Laws of Interest to the U.S. Fish and Wildlife Service, Executive Orders, FHWA’s Summary of Environmental Legislation Affecting Transportation, December 1998 and the Center for Wildlife Law’ Federal Wildlife and Related Laws Handbook, Statute Summaries. Maintenance and construction staff are responsible for ensuring that no threatened or endangered species within areas they are working are injured or destroyed or their habitat impacted without proper permits. DOTs are implementing stewardship practices specific to certain threatened and endangered species as well as practices designed to benefit wider groups of species and ecosystems more proactively. This sections specifically focuses on what DOTs are doing to improve habitat connectivity and the ability of wildlife to safely cross roads.

State transportation agencies currently employ a mix of underpasses, bridge extensions, culvert installations, and culvert modifications, and associated fencing and ecowalls to facilitate wildlife movement. Effective wildlife fencing and crossing structures can significantly reduce many harmful impacts of roads on wildlife populations, though such measures can contribute to habitat fragmentation. More and more DOTs are exploring wildlife passages and culvert retrofits as means to enhance wildlife passage. In a few cases overpasses are being built. From a wildlife conservation perspective, the impacts addressed by these stewardship measures include habitat loss, habitat fragmentation, degradation of habitat quality, road avoidance zones, increased human activities, direct mortality, reduced biodiversity, genetic isolation, chemical contamination, changed
hydrology for fisheries, reduced access to vital habitat, disruption of processes important to animal life cycles, and disruption of the food chain. Rigorous evaluation of the success of these measures has been implemented more slowly as funding for such work after the conclusion of construction is harder to find and frequently involves partnerships with others. In a 2002 survey by the author, 17 of 50 state DOTs said they were beginning to systematically incorporate wildlife crossings into roadway designs, but only a couple state DOTs had wildlife crossing policies, and only two states reported they had prioritized barriers for correction based on benefit evaluation. NCHRP 25-27, starting in 2004 and concluding in 2007, will investigate what guidelines are currently used by DOTs to determine wildlife crossing dimensions or design, the decision process, and any tools or aids that are used in that process. As of early 2002, only five state DOTs reported providing some direction to designers in this regard. In dissecting existing decision processes, NCHRP 25-27 will seek to understand the various factors used to decide what type of crossing will be employed as well as the extent to which long-term maintenance costs (annuities) of a highway structure guide selection (e.g. steel arch culvert vs. precast concrete girders with concrete deck). Ultimately the project will produce design guidance and a decision support tool for DOTs, as well as measures of cost and effectiveness.

Identifying Locations for Wildlife Crossings

The locations of wildlife crossings and/or problem areas are critical for effective mitigation of the barrier effect caused by highways; however, few methodological approaches to identify and prioritize these key areas have been explored. Researchers from Madrid University found that 70 percent of collisions occurred on just 7.7 percent of the roads in the area they studied. Collisions tended to occur where animals found it easier to cross roads in the absence of human habitation; fences or large, steep embankments deter animals from crossing roads and funnel animals to easy crossing points. Habitat availability on either side of the road is another factor in where animals choose to cross.

Only three state DOTs in the U.S. reported using modelling tools to identify habitat linkages as of 2002, and only one state did so for a large number of species on a statewide basis. Six states had embarked on or participated in statewide efforts to determine connectivity needs as of early 2002. Several more have begun to do so over the past two years.

Planning for wildlife crossings can be very involved; however, much can be accomplished using rapid assessment techniques, available information, and expert panels. The Forest Service’s national expert on wildlife crossings advocates a simple rapid assessment approach that has proven effective in a variety of circumstances, is fast, and affordable: 

1. Select highways to be examined.
2. Select species for analysis.
3. Use available, spatially specific information, especially that available digitally in geographic information systems (GIS).
4. Use a team of local biologists. Teams can often examine 100 miles/day.
Nature Conservancy, American Wildlands, and the Rocky Mountain Elk Foundation have attempted to fill this gap by conducting workshops, often with DOT sponsorship. Biologists, researchers, and regulatory specialists come together in a workshop setting to make decisions on conservation and connectivity needs based on analysis of best available environmental data. With recent requirements of all states to identify priority conservation areas, new opportunities for interagency identification and prioritization of wildlife crossing needs are emerging.

NCHRP 25-27 will survey state transportation agencies to determine what information is used to determine location and number of wildlife crossings on planned sections of highway-improvement project, whether models are developed around political, project, or ecological boundaries, and whether connectivity needs are assessed at the project level, political/statewide level, or the level of ecoregions surpassing political boundaries.

**Monitoring Wildlife Crossings**

Performance evaluation of crossing structure depends upon adequate monitoring. Future design benefits from such information as well. Most monitoring efforts to evaluate wildlife crossings have been short-term and focused on discerning whether target species are using the crossings. Monitoring programs have largely been aimed at single-species or have been confined to certain taxonomic groups; consequently, such programs may fail to recognize the requirements of other non-target species and ecological processes. Further, studies have generally failed to address the need for wildlife adaptation to environmental change. How well crossings ultimately perform depends on how well they accommodate changes in wildlife species distributions, abundance and behavioral profiles. Wildlife crossings are expensive measures, but a large void exists in devising cost-effective designs based on ecological and engineering criteria. Also, the current information base on wildlife crossing performance is geographically limited.

While nine of 50 state transportation had modified culverts for enhancement of connectivity across roads as of 2002, only four of these monitored such crossings with feedback to DOT designers and/or the state or federal wildlife agency. Eight of 50 state DOTs reported monitoring specially constructed wildlife underpasses, with feedback to design and wildlife agencies. Though DOTs more commonly employed bridge extensions to facilitate wildlife passage, usage by wildlife was much less frequently monitored than with other crossing technologies.

According to research by the Western Transportation Institute, evaluation of a wildlife crossing structure installation may involve consideration of the following issues:

1. Motorist safety and animal-vehicle collisions
2. Ecological impacts of mortalities and the “barrier effect” due to roads and traffic on individual animals, on a specific species, on populations of animals, on ecological communities and biodiversity, or on ecosystem processes and functional landscape integrity.

NCHRP 25-27 will add to this knowledge base by collecting details about types and methods of wildlife crossing monitoring in use, how often monitoring occurs, and the length of time for which it has occurred. The project will seek to detail the ecological criteria currently used to judge whether wildlife crossings are functional or effective, whether targets are established in advance, criteria are based on single target species, observed frequency of use by target or multiple species, population- or ecosystem-level...
data collection and analysis, or accident reduction.

**Wildlife Crossing Research, Resources, and Techniques**

This section reviews environmental stewardship practices and features that are being incorporated in many transportation projects across the country, including the restoration or preservation of habitat as mitigation and the addition of wildlife underpasses, overpasses, bridge extensions, enlarged culverts, and fencing by many states dealing with the realities of wildlife conservation and motorist safety. These practices were initially presented in NCHRP Report 305 on Interaction Between Roadways and Wildlife Ecology and are summarized herein. Habitat-related mitigation and conservation measures are some of the most effective measures and are used to address the broader ecological concerns associated with reductions in habitat and wildlife connectivity. Model stewardship practices in this area will also be briefly reviewed. Existing crossing techniques can also be viewed at the Wildlife Crossing Toolkit developed by the U.S. Forest Service. Their website offers a searchable database of case histories from a wide variety of locations, time periods and wildlife species where people have attempted to solve issues resulting from wildlife/highway interactions. Research by the Western Transportation Institute found that the physical dimensions of the underpasses had little effect on passage because animals in the Banff National Park in Canada may have adapted to the 12-year old underpasses; however, structural attributes were more important on newer structures. Furthermore, the level of human activity in the vicinity was an important factor suggesting that mitigation strategies need to be proactive at the site and landscape level to ensure that crossing structures remain functional over time, including human use management. The Western Transportation Institute is developing a vehicle-animal collision “toolbox” of countermeasures, which will provide detailed information to support application choices and decisions, and performance measurement.

The remainder of this section consists of summary excerpts from NCHRP Synthesis Report 305 on Interaction Between Roadways and Wildlife Ecology and practices adapted from that discussion with regard to wildlife crossings, except where otherwise noted.

**Fencing**

Fencing is a common practice used throughout the world to keep animals off highways. Twenty-eight states report using fencing to protect wildlife. The most frequent application is to keep deer off of roads. Deer are locally overabundant in a number of states, and fencing has proven to be an effective way to keep deer off the roads. Clevenger () reported an 80 percent reduction in ungulate-vehicle collisions on the Trans-Canada Highway in Banff National Park after fencing.()

1 **Design fencing applications for target species.** Typical fencing applications are rectangular mesh or chain link fence from 2.6 to 3.0 m (8.5-10 ft) high. Florida and some European countries use strands of barbed wire along the top of the fence to discourage animals from climbing over the fence. Also used is finer mesh wire of from 2 x 2 cm (0.78 in.) to 4 x 4 cm (1.57 in.) buried 20 to 40 cm (7.87-15.75 in.) with a height extending from the ground of from 0.5 to 1 m (1.64-3.28 ft).
2 Keep local wildlife interactions in mind when designing fences. For example, in California fencing application in areas with kit fox and coyotes provide a gap under the fence just large enough for the kit fox to negotiate at full run so that the latter can escape predators such as the coyote.

3 For reptiles and amphibians, bend the upper edge of the finer mesh at a 90-degree angle to provide a lip to prevent animals from climbing over the fence. In Waterton Park, Canada, a temporary silt barrier type fence was used to direct frogs into polyvinyl chloride (PVC) drop traps so that volunteers could move them across the highway to a pond during the few-week-long migration period. Europeans have used a PVC barrier with an angled lip to keep reptiles and amphibians off the highways as well as a fabricated galvanized steel rail with a barrier lip along the upper edge. Iowa DOT has placed finer mesh fence at the bottom of regular fence to prevent smaller wildlife such as turtles, snakes and other small animals from getting on the Eddyville Bypass and Highway 63 at the Bremer-Chicksaw county line. This fencing approach has been commonly used in Europe to keep smaller animals off highways.

4 Bury fine-meshed fencing at the bottom in use with pipe culverts for small animal connectivity or in association with other ROW fences. This practice has been successfully used under highways in Europe in culvert pipes with diameters approximately 0.4 m to 2.0 m (1.31-6.56 ft). California used a unique fencing application for desert tortoise approximately 6 km (3.7 mi) east of Kramer Junction on Highway 58 in San Bernardino County. A finer [1.27 cm (0.5 in.)] mesh section of wire fence, approximately 50.8 cm (20 in.) in height, was installed along the bottom of a typical 1.22-m (4-ft) right-of-way fence. The finer mesh fence was buried approximately 15 cm (5.9 in.) to prevent animals from going under. This portion of the fence was held in place using three strands of wire. The fencing application was done on an approximately 35.42- km (22-mi) section of four-lane highway. The fencing angled into the road at a series of culverts and bridges that were constructed for wildlife connectivity.

5 Fence installation decisions should account for the potential for wildlife to be trapped between the fences should they find a way to enter the rights-of-way under, over, or around the fence ends. Because fencing is not totally exclusionary, Bissonette and Hammer studied two highway sites in Utah to compare the use of one-way gates and earthen ramps. They found that earthen ramps were used from 8 to 11 times more than one-way gates. Irrespective of the species, fencing without provisions for movement across the road can cause disruption of connectivity resulting in isolation of populations. This can be especially problematic for species with low populations, where the possibility of extinction can result.

Culverts
Properly designed culverts can enable wildlife to cross roadways by passing under an intersecting roadway through a culvert. A culvert is a conduit covered with embankment around the entire perimeter. It may or may not convey water. Small conduits for amphibians are sometimes called tunnels. The following table is from the U.S. Forest
## Table 1: U.S. Forest Service Wildlife Crossing Toolkit Guide to Culverts

<table>
<thead>
<tr>
<th>Category</th>
<th>Definition</th>
<th>Shape</th>
<th>Typical Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Box Culvert</td>
<td>Culvert has four sides, including bottom. Sometimes square or rectangular</td>
<td>Square or Rectangular</td>
<td>Precast concrete</td>
</tr>
<tr>
<td></td>
<td>corrugated metal pipe culverts without bottoms are called box culverts, but</td>
<td>Multiple Chamber</td>
<td>Cast-in-place concrete</td>
</tr>
<tr>
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<td>in this toolkit they are referred to as bottomless culverts.</td>
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<td>Box culverts may be arranged in a horizontal series of small culverts to</td>
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<td>form multiple chambers.</td>
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<td>Culvert (Continuos)</td>
<td>Culvert is continuous in circumference. The lower portion may or may not</td>
<td>Slotted Drain</td>
<td>Corrugated metal pipe</td>
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<td>be buried. Sometimes simply called pipe. European badger culverts are</td>
<td>Pipe-Arch</td>
<td>Metal plate</td>
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<td>sometimes called ecopipes.</td>
<td>Elliptical (Squash Pipe)</td>
<td>Cast-in-place concrete</td>
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<td>Slotted drain culverts are continuous except for a break in the upper</td>
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<td>Bottomless Culvert</td>
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<td>rounded or square top and natural surface bottom. Also called open-bottom</td>
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From Forest Service Wildlife Crossings Toolkit on-line at http://www.wildlifecrossings.info/cst2.htm

### Modified Drainage Culverts

Drainage culverts can be modified to accommodate wildlife, a practice increasingly implemented by state DOTs and for which the Netherlands is renowned. Small mammals and amphibians are able to move through the culverts on shelves and floating docks or through wildlife tunnels built parallel to the wet culvert. NCHRP Synthesis Report 305 identifies the following stewardship practices with regard to modified drainage culverts:

1. **Addition of a 0.46 m wide × 0.30 m high (18 in. × 12 in.) elevated concrete walkway can allow animals to move through a culvert even when water is present.** Such modified culverts were successfully tried on US-98 in Texas for bobcats.

2. **A central “sacrificial” culvert with other culverts placed on both sides but at a higher elevation for drainage and connectivity can diminish blockage by large mammals.**
accommodating both terrestrial and aquatic organisms depending on water levels in the area of the culverts. When placed at the proper elevation, they can serve both types of organisms. Drainage culverts are typically used where highway causeways or fill sections transverse wetlands with fluctuating water levels such as wet prairies and marsh. They are also used on intermittent streams and floodplain areas that may inundate during wet periods. Aquatic species such as amphibians and fish use them when they are wet and terrestrial species including reptiles and small mammals use them when they are dry. Pictures of Florida DOT drainage/wildlife culverts, Massachusetts amphibian tunnels, Dutch structures, and wildlife using the culverts mentioned above, as well as other projects around the world can be seen at FHWA’s wildlife crossings website; however, Evink notes that few states have researched the effectiveness of these structures. Nevertheless, it is known that

1. Culverts should be sized for use by multiple species, wherever possible.

**Stream Culverts and Bridges**

Like drainage culverts in upland areas, oversized culverts can be designed and placed at the proper elevation over waterways to provide passage for a large number of aquatic and terrestrial species.

1. **Use the natural stream bottom rather than a concrete or metal bottom.**
2. **Provide shallow water or even dry edges along the stream edge in the culvert or bridge to allow the greatest number of species to move through.**
3. **Allow extra height for larger mammals, such as deer, bear, and other species that ordinarily follow riparian corridors for movement and pass safely under roads.** A wide variety of designs are possible depending on the site-specific construction environment – concrete box culverts, and round, oval, and elliptical pipe culverts.
4. **Provide cover as well as substrate on the inside of the culvert, similar to that of the exposed stream, to expand utility of the culvert**. Proper sizing of the culvert depends on site-specific considerations and hydraulics, but including the natural streambed and as much adjacent upland as possible proves most successful.

**Wildlife Underpass Bridges and Dry Culverts**

Upland culverts are one of the most frequently used structures for wildlife crossings and have proven successful for accommodating a wide variety of species. Pipe culverts and box culverts have proven effective for small animals. California is using culverts for San Joaquin kit fox. Illinois, Kansas, Montana, New Hampshire, New Jersey, Oregon, Texas, Utah, and Virginia are using culverts for other small mammals. Arkansas, Colorado, New Jersey, Wyoming, Utah, Michigan, Washington, and Kansas report using larger culverts for deer and other wildlife. A range of culvert sizes, from 1.22 m × 1.22 m (4 ft × 4 ft) in Arkansas up to 2.44 m × 7.32 m (8 ft × 24 ft) in Florida and from 1.5 to 10 m (4.92–32.81 ft) in New South Wales, Australia, have been successfully used for various species of terrestrial mammals and reptiles.
2 Use frequently placed culverts [150–300 m (492.13–984.25 ft)] of varying size in close proximity to shrub or tree cover. Clevenger and Waltho found that for a variety of culvert sizes for small and medium-sized mammals, passage was positively correlated with traffic density, road width, road clearance, and culvert length. They also found that all species with the exception of coyotes and shrews preferred small culverts with low openness ratios. There appeared to be some evidence of predation at crossings so the thought was that the smaller culverts provided comfort to the prey species. Weasels and shrews preferred culverts with nearby cover. The researchers felt that drainage culverts could be used to mitigate the harmful effects of high-speed roads.

Wildlife underpasses are bridges and/or large culverts over dry land and sometimes land and water, constructed expressly to facilitate wildlife movement in important corridor areas. The length and height of these large culverts or bridges varies with the wildlife expected to use them. Twenty-three states report using underpasses for wildlife. The Western Transportation Institute is cataloging existing uses of and research on underpasses and culverts to provide further guidance to DOTs on stewardship practice in this area.

Extended Bridges and Existing Structures

One of the most successful and cost-effective means of providing for wildlife movement down riparian corridors is the extended bridge. Twenty-four states report using extended bridges for wildlife movement and wetland protection.

1 Provide adequate area for both water movement with associated organisms and dry habitat for terrestrial species movement.

2 Consider the characteristics of the area when trying to determine the appropriate length of the bridge. In cases where there is an important corridor for movement of rare or protected wildlife species, bridging the entire floodplain may be necessary. At the other end of the spectrum, where the floodplain is being used by habitat-limited species, a combination of smaller structures and fences may be possible.

3 When choosing a combination of bridge and fill, consider what reptile and amphibian species will likely move up the fill slope onto the road. Standard fencing will not stop this movement so that very expensive barrier walls and associated guard rails may be necessary to prevent significant kills of these species during periods of the year when they are moving around in large groups.

4 Consider the cost of mitigation for wetland takings by opting for a fill section. By the time the costs of shorter bridges or culverts, fill acquisition, barrier walls for reptiles and amphibians, guardrails, and fencing are factored in, along with the cost of wetland mitigation, the cost of a more substantial bridge, preferred for habitat connectivity, may already have been approached.

Viaducts

Viaducts are a potential solution for the entire spectrum of species moving through an area, as these long bridges can leave wetlands, rivers, and variable topography and geology below largely intact. Typically, this approach is most cost-effective where there
is topographic relief, such as in mountainous areas, is sufficient to make bridging necessary for a significant span of a waterway, canyon, or valley; use of spanned lands by wildlife is typically a secondary benefit. () Design of viaducts for wildlife connectivity and habitat enhancement is increasing, especially in Europe.

Wildlife Overpasses
Although wildlife overpasses are largely a European phenomenon, Florida, Hawaii, New Jersey, and Utah reported overpasses being used by wildlife and the Montana Department of Transportation and the Connecticut DOT are installing wildlife overpasses on Highway 93 and Route 6, respectively. The New Jersey overpasses, among the first in the United States, were completed in 1985 at a cost of $12 million. The overpasses were designed to provide connectivity across I-78 (a six-lane highway) at an approximately 2-mile stretch that crossed the Watchung Reservation in Union County. Specifically, one was constructed solely for wildlife use (especially deer). Another one was constructed for shared wildlife and vehicular use; however, it has since been closed to traffic. A third overpass was constructed as a shared use between wildlife, vehicular traffic, and a bridle path for horses. The Utah overpass was constructed principally for deer. The Florida overpass on I-75 in Marion County just north of County Road 484 is a multi-use overpass designed to accommodate a recreational and equestrian trail, as well as for wildlife use. Two overpasses were built over the Trans-Canada Highway in Banff National Park and are being used by a variety of wildlife.()

1. **Allow the widest width possible.** Wildlife overpasses can vary in width from 3.4 m (11.15 ft) to 870 m (2,853.6 ft). Wider passages are more effective at allowing animals to cross and animal behavior on wider structures is more normal than on narrower ones.

2. **Establish or preserve suitable habitat at and leading to the overpasses.** Where this has been accomplished, it has been found that the overpasses were effective for a wide variety of animals including invertebrates.

Other Structural and Non-Structural Measures for Wildlife
Signage and deer reflectors are common approaches to informing motorists when they are entering an area where the danger of wildlife collision is high, though the effectiveness of these methods has not been demonstrated. However, a few methods have been documented to work: ()

1. **Use a series of solar-powered, battery-operated, motion sensors to determine animal presence and trigger low-voltage, LED-illuminated warning signs that reduce the posted speed limit to 40 km/h (25mi/h) and alert motorists to the presence of approaching wildlife.** This method has been successfully used in Switzerland, though the location on the road was also adjacent to a large wildlife overpass over a major nearby freeway.

2. **Install vertical pipes perpendicular to bridge railings to keep bird flight patterns above the elevation of traffic.** Florida reported installing PVC pipe approximately 3 m (9.84 ft) in height perpendicular to the railing on the San Sebastian Bridge. The poles were spaced approximately 3.7 m (12 ft) and kept birds hovering over the bridge from dropping down into traffic crossing the bridge, reducing bird kills.
State DOT Initiatives to Address Wildlife Habitat Connectivity Needs in Planning and Design

Maine DOT Initiatives to Limit Disruption of Habitat and Transportation Related Wildlife Mortality

Maine DOT chairs a multi-agency task force looking into how to prevent collisions between vehicles and animals, predominantly moose and deer. This task force, initiated in 1999, comprises members from Maine Department of Inland Fisheries and Wildlife, Maine Secretary of State, Maine Turnpike Authority and Maine Department of Public Safety. A focused, statewide campaign begun in 2001 to make the public aware that moose and deer crashes are likely to happen on any road in Maine and providing tips for drivers to avoid or lessen the severity of these crashes. This public information campaign was expanded in April 2004 to include a new brochure with safe driving tips distributed statewide to all towns, libraries, schools, state parks, tourism centers, and other distribution points. News media alerts are distributed to all radio and TV stations, and to newspapers throughout the state each spring, in time to alert the traveling public that May and June are the most dangerous months of the year for moose/vehicle collisions. In 2004, Maine DOT’s efforts were publicized by statewide media outlets and picked up by other news outlets including the Washington Post and Chicago Tribune. Public outreach also includes a module on large animal collisions that continues to be part of driver education programs throughout the state. In addition, the task force produced a safety video in 2001 and distributed the video to all driver educators in Maine.

Maine is increasing the number of available moose hunting permits in areas with severe/high crash locations. Maine DOT is supplementing these efforts by examining and testing measures to prevent collisions by either warning motorists or warning/excluding animals from roadsides. Some of these measures include alternative striping, reflectors, signs (with and without additional warning lights), and fencing. The Department is also looking at increased roadside clearing widths, to make moose visible from greater distances, allowing drivers more time to react and therefore prevent or lessen consequences of collisions. Roadside vegetation management practices, such as the composition of seed mixes and preventing sprouting of roadside woody plants, are also being examined to eliminate choice food sources close to highways. Maine DOT is investigating habitat conditions, especially at historically high crash locations, to better predict likely cross locations and to choose and install appropriate prevention measures in the most effective locations.

On the planning end, Maine DOT has initiated meetings and invited representatives from resource agencies to join them in speaking with officials from New Brunswick and Quebec who are facing the same issues with wildlife and the traveling public. These meetings have helped Maine DOT understand issues in a regional context, learn from the experience of experts in those fields, and further develop Maine DOT strategies that will benefit the traveling public while responsibly addressing wildlife issues related to transportation. Maine DOT is also actively participating in a “Beginning With Habitat” initiative for Habitat and Transportation with Maine Audubon, The Nature Conservancy, Maine State Planning Office, Maine Department of Environmental Protection, Maine Department of Conservation, and Maine Department of Inland Fisheries and Wildlife.
The group is looking into comprehensive awareness and protection measures for all types of wildlife and identifying transportation-related actions to benefit habitat statewide. Maine DOT is also developing a process to screen future projects for valuable wildlife habitat and has funded research into developing crossing measures for smaller animals, amphibians, and other species. Maine DOT develops mitigation for projects specifically looking for opportunities to protect, improve, or restore significant wildlife/fisheries corridors and habitats. Recently, as part of a cooperative assessment of the Sunday River watershed, a restoration plan was developed providing a number of projects that could be implemented by various partners. Maine DOT will construct a tributary restoration project during 2005 in the lower Sunday River watershed. Other agencies and groups are organizing to implement additional projects from the watershed plan.

**Caltrans Interchange Removal and Partnership to Identify and Address Habitat Connectivity Needs**

Due to the rising importance of the wildlife connectivity issue and implications for future construction, Caltrans participated in a statewide symposium/workshop with scientists, activists, and planners from resource agencies and conservation organizations to identify “Missing Linkages” in fall 2000. The meeting report identifies 232 critical habitat linkages in the state, 59 percent of which are threatened. Connectivity areas identified in the report ranged from narrow choke points, like the Coal Canyon underpass, later removed by Caltrans, to long stretches of rivers and broad swaths of redwood forest. More than half of the linkages were deemed to be high priorities because of development threats and good opportunities for conservation.

The interchange Caltrans decided to remove was located where two intersecting state highways divided several protected natural areas, including greater diversity of vegetation types than any other area of comparable size in the United States. By closing the ramps, removing the pavement and lighting, rearranging fencing, and restricting access, Caltrans created a wildlife crossing with substantial height, width, ample natural lighting, and openness. In addition, Caltrans worked with State Parks to find funding to purchase approximately 685 additional acres of conservation lands adjacent to the freeway and interchange, ultimately linking the Tecate Cypress Reserve, the Cleveland National Forest and the Irvine Company’s Gypsum Canyon Preserve and lowering development pressure in the area.

Caltrans determined that the site has great mitigation value for transportation impacts, but no agreements exist with other resource agencies to obtain credits at this point. Instead, Caltrans still considers the site an excellent example of leadership and interagency cooperation, which “indirectly facilitates other transportation efforts.” Wildlife passage features were incorporated into current and future state highway improvements nearby, benefitting both federally listed species and non-federally listed species with large habitat ranges.

Caltrans plans to utilize the products of the state’s collaborative “Missing Linkages” project to assess viable communities, habitats, and wildlife movement corridors throughout the state. This resource will be used to help environmental impacts wherever possible, and as a guide for addressing habitat and wildlife connectivity needs when the state implements conservation measures. Generation of the statewide conservation and connectivity maps is providing the foundation for interagency buy-in, acknowledgement, and utilization of a common set of environmental priorities. The mapped priorities are expected to streamline interagency coordination and negotiation on a project-by-project basis.
basis, reduce conflict, and facilitate achievement of mutual stewardship objectives among Caltrans, FHWA, federal and state resource and regulatory agencies, non-profit conservation organizations, and environmental advocates. The Nature Conservancy (TNC) is now assisting Caltrans in comparing the 20-year transportation plan to priority conservation areas, to minimize potential impacts and to identify opportunities where Caltrans mitigation projects could achieve the greatest environmental benefit and make a tangible contribution to achievement of interagency, public and private conservation objectives.

**Florida DOT Partnership to Determine and Prioritize Connectivity Needs and Contribute to “Green Infrastructure”**

The State of Florida issued a report in 1994 that identified the state’s highest priority wildlife habitat, which is the basis for a successful current state-funded effort to protect priority habitat conservation areas. The Florida Game and Fresh Water Fish Commission completed a land cover map of Florida’s 34 million acres and performed modeling to identify the long-term habitat needs of many focal species on public and private lands. Florida DOT helped support the development of the extensive wildlife occurrence and habitat geographic information system database, which is used in roadway alignment analysis and impact assessment. The database includes: 1) a statewide vegetation map with 22 land cover classes; 2) habitat maps for over 150 individual wildlife species, constructed by modeling habitat requirements, radio-telemetry range data, museum records, and other surveys, and 3) statewide maps of strategic habitat conservation areas, defined as lands which have a high priority for protection and acquisition, but are not in public ownership.

Because significant efficiencies and ecological gains can be made by coordinating wildlife crossing installation with statewide efforts to map conservation areas and large scale linkage needs, FDOT and the Florida Game and Fresh Water Fish Department developed a decision-based geographic information system (GIS) computer model for FDOT road improvement projects associated with road mortality of wildlife and other environmental impacts. This system is integrated with other state environmental initiatives such as the greenways and CARL (Conservation and Recreation Lands) programs. An interactive CD-ROM allows the user to perform multiple scenarios and develop their own priorities, and contains all necessary data and information to perform analyses. The computer model program enables FDOT to appropriately schedule future projects according to critical environmental and transportation improvement needs.

In 2000, the Florida Department of Transportation DOT initiated a cooperative effort with the Florida Fish & Game Commission to prioritize and begin to address black bear roadkill problem areas on a statewide basis, to focus and direct investments in habitat conservation and connectivity improvements, and to streamline project approvals. Bear roadkill data were re-analyzed to rank road segments by the percent of total statewide roadkills and percentage of kills in the past ten years. This ranking was then combined with habitat information, including percent of road buffer encompassed by conservation lands and strategic habitat conservation areas. The ranking is providing guidance in siting wildlife underpasses on a statewide basis. Fifteen black bear roadkill problem areas were identified, comprising 40 percent of the total transportation-related bear mortality in the state. The core habitat systems surrounding these problem areas also provide important habitat for many species of mammals, amphibians and reptiles. At least as important as the priority crossing and connectivity needs, the analysis revealed
that land management and conservation are critical in enhancing the black bear’s potential for long-term survival in Florida. The results were shared with the state’s Conservation and Recreational Lands program to help justify the purchase of a 22,260-acre tract associated with the Aucilla River Project in the Big Bend area of north Florida, a top three conservation priority as a result of the study.

As part of Florida’s DOT’s updated environmental policy, approved in February 2002, FDOT committed to cooperate in the state’s Greenways Program of land acquisition and management through identification and prioritization of important habitat connections. The objective of the statewide greenways program is to establish an ecological network of green infrastructure to reduce wildlife mortality and restore connectivity to the landscape by restoring natural processes as they originally occurred across the landscape (e.g., wildlife movement and migration, flood, and fire). Where alternative mitigation strategies permit, FDOT will support land acquisition activities to help achieve this ecological infrastructure, and will utilize methods to preserve, enhance, and protect trees and other vegetation as valuable natural resources consistent with ecosystem management principles. So far, over one million acres have been preserved through this program, which has garnered the support of a diverse array of citizens, land managers, and state policy-makers.

**New Hampshire DOT’s Pilot Project for Identifying Habitat Connectivity and Wildlife Crossing Needs**

The New Hampshire Department of Transportation (NHDOT) is engaged in a pilot project effort with the New Hampshire Audubon Society, the New Hampshire Fish & Game Department, and others to develop a methodology for predicting wildlife movement in the state. The effort is an outcome of a discussion on how NHDOT and these partners could cooperatively address wildlife and transportation issues. The partners hope to develop a geographic information system (GIS) layer of important wildlife habitat areas and locations of frequent wildlife crossings to be used as a planning and design tool for future projects.

The pilot effort focuses on Route 4, one of the state’s major east-west routes. When sections of Route 101 were widened to four lanes, NHDOT extended bridges to improve habitat linkages. NHDOT is now interested in further increasing the level of connectivity. To this end, NHDOT has contacted Fish & Game Conservation Officers, local road agents, conservation commission members, and NHDOT maintenance patrol foremen to collect anecdotal evidence of crossings and road kills and record that information in a database. In the future, roadkill data will be collected by maintenance staff. Concurrently, the New Hampshire Audubon Society is reviewing mapping of the corridor to identify prospective habitat units, for purposes of predicting where wildlife crossings are likely to occur. The partners will pool efforts to see how well the field data correlates with the mapping predictions. The goal is to develop a predictive model that can be used elsewhere in the State.

To further improve habitat linkages, NHDOT is also supporting efforts to develop an inventory of contiguous habitat areas, to be taken into consideration when siting new alignments, bridge extensions, and crossing locations. The New Hampshire Fish & Game Department has decided that investing in habitat preservation in key areas can be a higher priority than adding or enhancing crossing structures. The New Hampshire Ecological Reserve Project, a partnership between The Nature Conservancy and the University of New Hampshire, is working with the New Hampshire Department of
Environmental Services and the Fish & Game Department to develop criteria for the identification of priority conservation parcels. This will generate information that NHDOT can use in planning and project development, and will also guide state investment through the New Hampshire Land and Community Heritage Investment Program.

**Maryland SHA’s Net Gain Wetland Mitigation Policy & Contribution to Regional Restoration/Connectivity Goals**
The Maryland State Highway Administration (SHA) has made a commitment to mitigate for historical impacts to wetlands from transportation projects, with an overall “net gain” wetland mitigation policy. The MDSHA is working with local jurisdictions and watershed groups around the state to realize watershed goals and restore stream segments, and contribute to the state’s green infrastructure at the same time. Maryland has two million acres of ecologically significant land that has not been developed, of which almost three-quarters are unprotected. The state designated the GreenPrint program to preserve the state’s remaining natural resources and to create an extensive, intertwined network of conservation lands. The purpose of the program is threefold:

1. Identify, using the most up-to-date computer mapping techniques, the most important unprotected natural lands in the state;
2. Link, or connect, these lands through a system of corridors or connectors; and
3. Save those lands through targeted acquisitions and easements.

GreenPrint databases and watershed plans are available to Maryland State Highways’ planning, environmental, and design staff to reference in avoiding, minimizing, and mitigating for unavoidable impacts from transportation. The State Highway Administration is currently undertaking internal discussions to maximize use of this resource.

MDSHA is contributing to watershed restoration and regional habitat connectivity through 23 separate stream restoration projects across the state, with funding matched by local project sponsors. MDSHA has plans to restore approximately nine miles of streams and install a number of stormwater retrofits to improve water quality and stream habitat over the next three years.

**VTrans Habitat Connectivity Training**
The Vermont Agency of Transportation (VTrans) began offering Habitat Connectivity Training in 2002, which has been very popular. The training is offered to VTrans staff to help them understand the importance of habitat and consider it while doing their work as transportation professionals. In particular, the training fosters an awareness of habitat and encourages a lively dialog about how transportation can fit into the landscape while still considering habitat and connectivity and incorporating that into the planning and design of projects. Solutions that are discussed range from big-picture land use discussions to the details of engineering a bridge or culvert to allow wildlife passage to the merits of including warning signs to alert drivers of wildlife hazards and many things in between. Engineers, planners, environmental specialists, biologists, maintenance staff, landscape designers, project managers, have joined bridge and roadway designers in the training program. Consultants and DOT staff from neighboring states have also attended. Much of the discussion engages transportation professionals in discussions about the
challenges they face when planning, designing, constructing, and maintaining a transportation infrastructure.

**VTrans Habitat Linkage Area Assessment**

In a collaborative effort with the Vermont Department of Fish and Wildlife, VTrans has sponsored development of a GIS habitat database, called the Habitat Linkage Area Assessment. This tool will be used for making decisions for addressing habitat connectivity on VTrans projects and also help the two agencies identify priority areas for consideration for habitat connectivity investments. The project utilizes landscape features as its base and is augmented by years of existing data collected on wildlife crossing areas, recorded roadkill locations, anecdotal reports of crossing areas, land ownership, conservation lands, and other data layers. The database identifies areas that range from high priority to low priority in terms of habitat linkage areas and relationship to the Vermont transportation infrastructure.

The Habitat Linkage Area Assessment efforts rests upon VTrans’ Operations and Maintenance Division, which collaborated with the Environmental Section and the Vermont Department of Fish and Wildlife in developing a method for collecting roadkill information from District Maintenance Crews. The method utilizes an existing database called MATS that the Maintenance and Operation Division was already using to manage their resources. An existing but unused field was modified, with the guidance of VT DF&W, as a field for recording roadkill data. The Maintenance field crews keep a log in their trucks. When they identify a road kill that is included as a target species in the database they record it (species, location/mile marker, date, and route). These roadkill data sheets are collected on a monthly basis and then entered into the database. This information is shared with the VT DF&W and is included as a field in the Habitat Linkage Assessment described above.

**Maintenance and Management of Created, Modified, or Restored Habitat**

Most state DOTs try to find a land management agency to provide maintenance for mitigation/conservation habitats. A few have sought to perform mitigation (modification or restoration) on public lands that are already being managed by a resource agency. While some federal resource agencies encourage this approach, others disallow it. Universities, conservation groups, resource agencies, and even private groups where consistent with the objectives of the mitigation have become involved in maintenance of habitat by taking possession or easement of land from the state DOTs. Few transportation departments are maintaining habitat except for wetland mitigation sites, though creative conservation partnerships have been developed in a number of states through in lieu fee arrangements. Texas, Tennessee, Kentucky, North Carolina, and Florida are among the DOTs allowed to provide funding instead of mitigation. Habitat management is frequently the responsibility of the agency or partnering organization holding title to the land or conservation easement.

In most cases, when a state uses a habitat strategy as a conservation or mitigation measure, the maintenance plans for these habitats contain a monitoring requirement. These requirements vary in length and design, but states are often required to maintain sites to varying performance levels (such as a percent survival of desired species and exotic/invasives free) for some period of time (commonly 3 to 5 years). Specific management plans including funding can also be a requirement. Such a monitoring
program is designed to:

1. Specify recommended mitigation and ensure that it is included in the final design process.
2. Monitor the implementation of the mitigation through design, construction, and operation.
3. Resolve issues that are contingent on the outcome of design as it progresses to more detailed stages.
4. Report on progress toward implementation of mitigation measures to responsible parties.

Biologists from resource and conservation agencies associated with CDOT’s Shortgrass Prairie Initiative crafted recommended Baseline/Annual Reporting Requirements that would provide an effective yet practicable framework for adaptive management and annual reporting:

1. Type of plant communities/habitats present:
2. Size/extent of each present plant community or habitat group.
3. Description of plant communities present and estimated percent cover.
4. General condition of each plant community/habitat type (estimated percent weed cover, estimated weed sp. relative abundance, estimated percent bare ground, etc.).
6. Brief description of land use on-site and in surrounding areas documented in initial baseline. Report changes over the past year.
7. Recommendations for management of parcel (i.e., grazing, controlled burns, plantings, etc.) to achieve conservation goals.
8. Success of recommendations from previous year and suggested modifications.
9. Observations on wildlife diversity, activity, and general trends. i.e. field notes. Surveys and quantitative data are not required.
10. Photo points at established permanent locations according to protocols to be developed in the management plan. The on-site managers and regulatory oversight agreed that new aerial photos would be acquired as they become available.

3.5 Culverts and Fish Passage

As long linear ecosystems, rivers and streams are particularly vulnerable to fragmentation. A number of human activities can disrupt the continuity of river and stream ecosystems, the most familiar of which are dams. There is growing concern about the role of road crossings – and especially culverts – in altering habitats and disrupting river and stream continuity. On U.S. Forest Service and Bureau of Land Management land in Washington and Oregon alone, there are over 10,000 culverts on fish-bearing
Based on an estimate from GIS analysis over 28,500 road and railroad crossings affect Massachusetts streams. Over half of the culverts assessed on U.S. Forest Service and Bureau of Land Management (BLM) lands in Oregon and Washington are considered barriers to juvenile salmonid fish passage. Fish habitat and fish passage improvement projects undertaken by DOTs include installation of baffles or weirs in culverts, construction of berms or detention facilities, and installation of deck curbs, new culverts or jump pools for fish passage.

**Forms of Stream Crossings**

Stream crossing methods include bridges, fords, open-bottom or arch culverts, box culverts, and pipe culverts. Depending on the type of crossing, its size, method of installation, and maintenance, a road crossing may have many or relatively few adverse impacts on a river or stream ecosystem. It is generally believed that culverts are more detrimental to streams than are bridges; consequently, wildlife regulatory agency biologists routinely recommend installation of a bridge instead of a culvert. Culverts, however, are more economical than bridges; they often cost less to install, require less maintenance, and have a longer effective life. Culvert crossings tend to provide very little or no habitat within the culvert. Some habitat can be provided if the culvert is sufficiently embedded such that the substrate in the culvert resembles the natural streambed. Open-bottom or arch culverts and bridge crossings often maintain natural streambeds, although some habitat may be lost to footings, piers, and abutments. Resource agencies often prefer that structure types should be considered for use in the following order of preference:

1. Bridge (with no approach embankment into the main channel).
2. Streambed simulation strategies using a Bottomless Arch or embedded culvert designs.
3. Streambed simulation strategies using embedded round metal or concrete box culvert designs.
4. Non-embedded culvert; placed at less than 0.5 percent slope.
5. Baffled culvert (various designs); placed at 0.5 percent to 12 percent slope or a structure with a fishway.

**Bridges versus Culverts**

Providing for larger structures that mimic natural streambeds requires a greater capital investment, but the return on such an investment can be accrued over the long term with reduced maintenance and/or replacement costs. NCDOT hypothesized that the impact of culverts on the stream bed is not uniform, but varies due to its design, and size and site specific factors and that construction and renovation practices may be refined to minimize the impact of crossing structures on surface waters and achieve a delicate balance between construction and maintenance costs and ecosystem integrity. Consequently, NCDOT is undertaking research, due in late 2005, that will compare the relative impact of culverts and bridges, and specific design attributes on freshwater mussel populations, in the interests of refining standard culvert designs to be more environmentally beneficial and acceptable to wildlife agency
biologists.

Through an initial assessment of the 51 study sites, the research team has observed that while each of the culvert sites is unique, a pattern seems to be emerging regarding their impacts on stream morphology. Many of the sites that seemed greatly affected by the installation of a culvert usually had one or more of the following characteristics.

1. When the culvert was installed, many streams appeared to have been straightened and deepened in order to increase flow speed so that the culverts would be self cleaning. This altered habitats, destroyed stream sinuosity, and created long, slow pools that invite beaver dams.

2. When a culvert’s width was near or less than the bankfull width, then the downstream bank incision usually was greater than upstream. Inversely, when a culvert was wider than the bankfull width, then the stream was able to use its floodplain and thus minimize the high velocities associated with the concentrated flow from most culverts.

3. When a culvert was installed in a stream with a coarse substrate, the stream banks seemed to resist the higher velocities below a culvert.

The team will identify crossing structure design attributes that may alter the physical or biological impact on streams and suggest where certain culverts are more appropriate for certain stream types. The study will be complete, and the final results documented for NCDOT and the project technical committee’s review, by June 2005.

**Potential Adverse Impacts of River and Stream Crossings**

If not properly designed, crossing structures can block animal movements, delay migration (a process made worse where there are many crossings), and cause physiological stress as animals expend energy passing both natural and artificial obstacles. If crossing structures are not large enough, or lack banks or other dry passage, riparian wildlife may choose to cross over the road surface rather than pass through the structure. As barriers to animal movement, stream crossings for roads can reduce access to vital habitats. To the extent that road crossings act as barriers to animal passage, they can fragment and isolate populations, increasing vulnerability to genetic change and extinction due to chance events. Local extinctions can result from demographic chance events (e.g., change in sex ratio), natural disturbances, or human impacts. Barriers to movement can block the exchange of individuals among populations, eliminating gene flow and disrupting the ability of “source” populations to support declining populations nearby. Barriers to dispersing individuals also eliminate opportunities to re-colonize vacant habitat after local extinction events.

Culvert and embankment fill can cover up fish habitat on channel beds and banks. Flow concentration can raise velocities and increase erosion and sediment production and downstream deposition in the stream, increased slopes and flow velocities can block fish passage, and long culverts can discourage fish from entering if no light can be seen at the opposite end. Improper design or scour can result in a perched culvert which blocks fish passage.

Potential adverse effects of river and stream crossings that should be considered ineffective design for fish and wildlife include: ()
1 Habitat Loss and Degradation
2 Alteration of Ecological Processes, including passage of large woody debris
3 Inlet or outlet drop. Elevation drops at either the inlet or outlet of a crossing structure can represent physical barriers to many animal species. Piping (water flowing through the fill material rather than the culvert) and scouring can result in culverts that are perched above the stream channel making passage impossible for most aquatic species.
4 Physical barriers. Animal movement can be blocked by clogged or collapsed culverts. Also, weirs or baffles associated with crossing structures can create barriers for some species.
5 Excessive water velocities. Water velocities can be too high to pass fish or other organisms during some or all of the year.
6 Absence of bank-edge areas. Passage by weak-swimming organisms can be inhibited or prevented by the absence of bank-edge areas within crossing structures.
7 Excessive turbulence. Flow contraction at the inlet can create turbulence that inhibits or prevents animal passage.
8 Insufficient water depth. Absence of a low-flow channel can result in water depths too shallow to allow passage for fish or other organisms.

Stream Crossing Design Considerations

Collecting Adequate Survey Information
Adequate survey information should be collected, to help ensure proper design and avoid costly mistakes:

1 The original site survey should have at least three durable reference points for location of all other site features and establishing additional references. Remote projects that are surveyed, then delayed for years, may lose reference points to vandalism, storm events or road maintenance activity. Site topography may also change, especially in stream channels due to flood events. Lost references have to be replaced. Existing culvert inverts and drill holes can be useful project references.

2 Preconstruction Survey. An early review of project plans in the field with the contract administrators and designers can help prevent surprises later on by answering specific questions and verifying that the design still fits if some site
changes have occurred.

- Enough references and data points should be surveyed to be able to locate the structure and reestablish the road surface and embankment geometry.

- Assure the road surface is adequately described by existing survey information; otherwise, survey additional points to assure that super elevation, vertical curves, curve widening, or any other critical geometric elements can be reestablished. A straight road segment is easy to recreate with a minimum of survey data, but others such as a super-elevated “S” curve are not.

- Examine site plans and design elevations carefully. The project site may not seem to match the site plan or stream profile. If survey points near the existing or new structure are not marked and the channel is very rough, this may lead to confusion and uncertainty as to design elevations and assumptions. A stream classification system may be helpful in describing channel conditions. This could be due to the software used to generate the contour map. Rough channels can be confusing unless it is known exactly what points were surveyed in the channel. The “stream channel elevation” used to design the new structure invert can vary a foot or even more depending on where the survey rod was placed originally. Was it held on top of a boulder or between boulders? Are boulders dominant? Do they seem to define elevation more than the spaces between boulders? Some additional surveying may be needed. The designer and administrator should communicate and verify design assumptions on the ground and during the contract as necessary to reduce potential questions such as these, and to prevent inappropriate “last minute” changes during construction. This is especially important when the decision affects the new structure elevation, orientation or gradient. Confusion may arise during construction surveys over contract drawings, survey points, elevations and design assumptions.

**Designing for Target Species**

When designing fish passage facilities, species of fish present, life stages to be impacted, and the migration timing of affected species/life stages should be considered. For example, in looking at non-anadromous trout in Virginia, researchers determined that culverts can be the best way to cross trout streams in Virginia, provided certain actions are taken. ()

1. The culvert should be on the same slope as the streambed.
2. The slope of the stream should be less than 3 percent.
3. The flow velocity should not exceed 1.2 meters (4 feet) per second under normal flow conditions.
4. The culvert barrel should be properly countersunk at the outlet.
5. In addition, newly installed culverts should not use baffles to control stream flow, and concrete aprons should not be used at culvert outlets.
If these actions are not possible or feasible, then bridges should be constructed. While in this case design is simplified by focus on one species, passage design for multiple species is normally based on the weakest species or life stage present that requires upstream access and should accommodate the weakest individual within that group. For fish, swimming ability is highly variable among species. While information exists on the swimming ability of stronger, migratory fish species, very little is known about the remaining. Even less is known about the swimming abilities of non-fish species that inhabit rivers and streams, including aquatic salamanders, softshell and musk turtles, aquatic reptiles that rarely travel over land and are not strong swimmers (relative to migratory fish), though movement and population continuity is essential to the survival of their populations. As a group the most vulnerable animal species in the U.S. are freshwater mussels. Over 70 percent of the 297 species native to the U.S. and Canada are endangered, threatened or of special concern. Although adult mussels have a very limited capacity for movement, dispersal typically occurs when larvae (glochidia) attached themselves to host fish or salamanders. Therefore, survival and persistence of freshwater mussel populations is dependent on the capacity of host fish usually small, sedentary, and weak swimming, and therefore, highly vulnerable to movement barriers. Many weak swimmers and crawling species take advantage of boundary zones along bank edges and the stream bottom where water velocities are much lower than in the water column. In addition to aquatic organisms, rivers and streams are used as travel corridors by riparian wildlife. To address these issues,

1. Maintenance of unfragmented stream bottom and bank edge habitats is the best strategy for maintaining continuous and interconnected populations for these species.

Avoiding Channel Constriction
Channel constriction is often evident from undersized culverts. Channel constriction results in increased water velocity within and exiting the structure, creating a barrier to upstream fish passage. Where the streambed is not composed of bedrock or properly aproned with riprap, streambed elevation can be reduced. Sometimes this reduction is in the form of a pool and does not alter the ability of fish to enter the culvert. More commonly the culvert outlet becomes “perched” above the lowered streambed, creating a barrier to the upstream migration of smaller, less aggressive swimming fish. The effects of increased water velocity due to channel constriction can also be compounded as a result of excessively high culvert gradient and/or flow augmentation via ditch lines with improper road drainage. To avoid channel constriction, the following stewardship practices are recommended:

1. Design and install road crossing structures that allow bankfull events to flow unimpeded. This requires larger culverts or alternative structures.

2. Where channel gradients exceed 2 percent, design structures for the upstream passage of fish, imitating natural roughness inside culverts.

Energy Dissipation at Culvert Exits
Energy dissipation at box culvert outlets is important for reducing harmful impacts to the receiving channel and for minimizing soil loss through scour and erosion. Dissipaters include riprap, vegetated ditches, concrete or steel baffles, and tiger teeth. Debris
racks should be installed only when regular maintenance is possible. Raised culvert inlets are raised by constructing a dike around the culvert, or by installing a culvert elbow. They keep water on the land longer and promote infiltration. These inlets increase vegetation vigor and diversity, reduce flash flooding, create sediment barriers, and raise water tables.

Currently the only options available to roadway designers are riprap basins or rigid concrete structures requiring significant additional costs for concrete and steel and right-of-way. The Nebraska Department of Roads is evaluating three different low-cost energy dissipating methods for concrete box culverts: a sill wall placed in the downstream apron of the box culvert, a vertical drop structure with stilling pool or sill, and the feasibility of using concrete forms to increase the hydraulic roughness of the interior walls and floor of a concrete box. Research results will be due in early 2005.

Other Hydraulic Considerations

242) Primary hydraulic considerations include the upper and lower flow limit. In general:

1 Acceptable hydraulic design of culverts includes selection of appropriate design flow from which the flow characteristics can be derived by hydraulic analysis. The low flow depth design should be based on the 2-year, 7-consecutive-day low flow discharge or the 95 percent exceedence flow for the migration period of the fish species of concern.

2 The high flow design discharge should be the flow that is not exceeded more than 10 percent ($Q_{10\text{ percent}}$) of the time during the months of adult migration.

Besides the upper and lower flow limit, other hydraulic effects need to be considered, particularly when installing a culvert:

1 Water surface elevations in the stream reach must exhibit gradual flow transitions, both upstream and downstream. Abrupt changes in water surface and velocities must be avoided, with no hydraulic jumps, turbulence, or drawdown at the entrance. A continuous low flow channel must be maintained throughout the entire stream reach.

2 In addition, especially in retrofits, hydraulic controls may be necessary to provide resting pools, concentrate low flows, prevent erosion of stream bed or banks, and allow passage of bedload material.

3 Culverts and other structures should be aligned with the stream, with no abrupt changes in flow direction upstream or downstream of the crossing. This can often be accommodated by changes in road alignment or slight elongation of the culvert. Where elongation would be excessive, this must be weighed against better crossing alignment and/or modified transition sections upstream and downstream of the crossing. In crossings that are unusually long compared to streambed width, natural sinuosity of the stream will be lost and sediment transport problems may occur even if the slopes remain constant. Such problems should be anticipated and mitigated in the project design.

Fish passage should be designed to be adequate for high and low discharge. When that cannot be accommodated, mitigation may be required.
Mitigating Fish Passage Effects through Culvert Design Modifications

Common DOT methods of assisting fish passage through culverts include lowering of culvert inlets, over-sizing and sinking a portion of the culvert to mimic streambeds. The Alberta Department of Transportation has identified the following methods, in order of preference:

1. Modify culvert design
2. Depress invert culverts
3. Replicate natural streams
4. Use baffled culverts

There are several alternatives for modifying a standard culvert design to satisfy fish passage requirements. Design options may vary as long as fish passage criteria can be met. Any culvert design should be thoroughly reviewed by a professional engineer to ensure that both fish passage and flood conveyance criteria are satisfied. The following is a representative list of possible modification options:

1. **Culvert size.** Culvert size may be increased to decrease water velocity.

2. **Culvert shape.** A different culvert shape (e.g., ellipse, culvert arch, or box culvert) may be chosen to achieve fish passage requirements.

3. **Invert level.** The invert level at an inlet or outlet is very important for managing flow effects at contractions (inlets), expansions (outlets), and flow regime in a culvert barrel. Invert levels affect habitat upstream and downstream of culverts. Lowering the invert may be necessary to allow the placement of natural substrate on the culvert bottom. Care should be taken to ensure a stable channel upstream and downstream of the culvert because erosion due to increased flow velocities can progress in both directions and create barriers to fish passage.

4. **Roughness.** Changes in culvert roughness may effectively decrease water velocities to acceptable levels. For example, corrugated circular culverts can be chosen with large, helical corrugations to provide greater overall roughness and provide for a larger low flow water depth suitable for fish. Concrete box culverts can be modified by using oversized aggregate or grouted riprap. The addition of energy dissipaters can control the hydraulic regime and thereby reduce velocities.

5. **Grade Control.** Artificial resting areas upstream or downstream of a culvert can mitigate many adverse conditions in the culvert barrel and at the inlet or outlet. Weirs or sills downstream of a culvert can be used to maintain adequate water depth and prevent scouring of a plunge pool. An upstream resting pool can trap sediment while allowing recuperation time for 7-10 migrants. Combined with proper instream cover, culverts may provide migrants some protection against predators.

Measures for Non-Embedded Culverts

Fish passage through existing non-embedded culverts may be improved through the use of gradient control weirs upstream or downstream of the culvert, interior baffles or weirs,
or in some cases, fish ladders. While these measures are not a substituted for good fish passage design for new or replacement culverts, the following guidelines can be adapted for target species and local conditions:

1 **Hydraulic Controls** - Hydraulic controls in the channel upstream and/or downstream of a culvert can be used to provide a continuous low flow path through culvert and stream reach. They can be used to facilitate fish passage by establishing the following desirable conditions: Control depth and water velocity within culvert, concentrate low flows, provide resting pools upstream and downstream of culvert and prevent erosion of bed and banks.

2 **Baffles** - Baffles may provide incremental fish passage improvement in culverts with excess hydraulic capacity that can not be made passable by other means. Baffles may increase clogging and debris accumulation within the culvert and require special design considerations specific to the baffle type. Culverts that are too long or too high in gradient require resting pools, or other forms of velocity refuge spaced at increments along the culvert length.

3 **Fishways** - Fishways are generally not recommended, but may be useful for some situations where excessive drops occur at the culvert outlet. Fishways require specialized site-specific design for each installation and resource agency specialists should be consulted.

4 **Multiple Culverts** - Retrofitting multiple barrel culverts with baffles in one of the barrels may be sufficient as long as low flow channel continuity is maintained and the culvert is reachable by fish at low stream flow. Additional culverts may be used to improve conveyance conditions for fish passage. For example, box culverts can be separated into multiple sections where part of the flow enters a plain section, and part of the flow is carried through a baffled section. Multiple culverts can also be “stacked” by placing the inverts at different elevations to provide sufficient fish passage conditions at different stream stages. However, the effectiveness of these types of solutions is questionable, because fish need to choose which section or culvert to enter. Fish have been observed choosing the culvert with the most flow and highest velocity; consequently, one large culvert may be preferable to two or more smaller ones. In general, it is better for fish passage to use fewer culverts.

**Other General Recommendations**

1 Trash racks and livestock fences should not be used near the culvert inlet. Accumulated debris may lead to severely restricted fish passage, and potential injuries to fish. Where fencing cannot be avoided, it should be removed during upstream migration periods. Otherwise, a minimum of 9 inches clear spacing should be provided between pickets, up to the high flow water surface. Timely clearing of debris is also important, even if flow is getting around the fencing.

2 Cattle fences that rise with increasing flow are highly recommended.

3 Natural or artificial supplemental lighting should be provided in new and replacement culverts that are over 150 feet in length. Where supplemental lighting is required the spacing between light sources shall not exceed 75 feet.
4 Comply with in-stream work windows in each watershed. Work in the active stream channel should be avoided during the times of year target species are present. Temporary crossings, placed in streams for water diversion during construction activities, should meet environmental stewardship guidelines or BMPs.

**Design Methods for New and Replacement Culverts**

High water velocity, shallow water depth within the culvert, excessive vertical drop at the culvert outlet and debris blockages are the most frequent causes of fish passage problems at culverts. These design methods can help prevent some of these problems: ()

**Active Channel Design Method**

The Active Channel Design method is a simplified design that is intended to size a culvert sufficiently large and embedded deep enough into the channel to allow the natural movement of bedload and formation of a stable bed inside the culvert. Determination of the high and low fish passage design flows, water velocity, and water depth is not required for this method since the stream hydraulic characteristics within the culvert are intended to mimic the stream conditions upstream and downstream of the crossing. This design method is usually not suitable for stream channels that are greater than 3 percent in natural slope or for culvert lengths greater than 100 ft.

Structures for this design method are typical round, oval, or squashed pipes made of metal or reinforced concrete.

1. **Culvert Width** - The minimum culvert width should be equal to, or greater than, 1.5 times the active channel width.

2. **Culvert Slope** - The culvert should be placed level (0 percent slope).

3. **Embedment** - The bottom of the culvert should be buried into the streambed not less than 20 percent of the culvert height at the outlet and not more than 40 percent of the culvert height at the inlet.

**Stream Simulation Design Method**

The Stream Simulation Design method is a design process that is intended to mimic the natural stream processes within a culvert. Fish passage, sediment transport, flood and debris conveyance within the culvert are intended to function as they would in a natural channel. Determination of the high and low fish passage design flows, water velocity, and water depth is not required for this option since the stream hydraulic characteristics within the culvert are designed to mimic the stream conditions upstream and downstream of the crossing.

This approach to culvert design both avoids flow constriction during normal conditions and creates a stream channel within culverts that resists scouring during flood events. Since the streambed longitudinal profile and cross section in the pipe are similar to the natural channel, water velocities and depths at flows up to bankfull are also similar, and the crossing should be essentially invisible to migrating aquatic organisms.

Culverts designed for stream simulation are sized wide enough to include either channel margins or banks. The most basic stream simulation culvert is a bottomless culvert placed over a natural streambed. Other culverts are filled with a sediment mix that emulates the
natural channel and adjusts similarly during most flows. In steep channels, the bed may be designed to resist erosion during very large floods. These culverts contain a streambed mixture that is similar to the adjacent stream channel.

Stream simulation culverts require a greater level of information on hydrology and geomorphology (topography of the stream channel) and a higher level of engineering expertise than the Active Channel Design method.

1. **Culvert Width** - The minimum culvert width should be equal to, or greater than, the bankfull channel width. The minimum culvert width shall not be less than 6 feet.

2. **Culvert Slope** - The culvert slope shall approximate the slope of the stream through the reach in which it is being placed. The maximum slope shall not exceed 6 percent.

3. **Embedment** - The bottom of the culvert should be buried into the streambed not less than 30 percent and not more than 50 percent of the culvert height. For bottomless culverts the footings or foundation should be designed for the largest anticipated scour depth.

Certain channel features cannot be duplicated directly or can be simulated only partially in a culvert. Examples include channel-spanning wood, embedded wood, bank vegetation, cohesive bank stability, debris jams and rigid bed forms. Bank vegetation stabilizes most natural streambanks. Large wood that spans the channel provides roughness and complexity, as do bedrock exposures and other rigid bedforms. Debris embedded in the natural channel may anchor bed material and in some cases control all of the elevation change. Bank vegetation cannot grow inside a pipe; trees will not fall into them; and large, woody debris is difficult and risky to install. While vegetation and large wood are often critical to channel stability, it is usually possible to replace these functions with large rock to create a stable streambed inside a pipe.

It is essential to understand what stream functions are critical at a site, as well as the consequences to the stream of placing a culvert and interrupting them to some degree. Riparian functions such as overbank flooding, side channel construction, and nutrient and debris exchange between stream and floodplain are not simulated within the culvert. The impact of floodplain contraction on up- and downstream floodplains may be reduced with a larger culvert, additional culverts in the floodplain, and/or overflow dips in the road. At any given flow, slope is an important factor affecting water velocity in culverts. Culvert size also affects velocities, especially when a structure is considerably undersized and a head (pooling above culvert) is developed.

1. If any of these functions cannot be adequately simulated by the design, other road alignments and/or crossing structures should be considered.

2. Gradients (slope) for non-embedded, non-baffled culverts should not exceed 0.5 percent unless a tailwater situation exists to backwater the culvert to a suitable depth for its length. Properly baffled or weir-ed culverts are appropriate for steeper gradients depending on design. Structures with fishways (i.e., fish ladders or culverts with weir-type baffles) generally will be required where culvert gradients exceed 5 percent and streambed simulation is not employed.

3. Corrugated metal culverts should generally be used over smooth-surfaced...
culverts. Deep corrugations are preferred over shallow corrugations.

4 Bottomless arches and all styles of embedded culverts should be placed at or near the same gradient as the natural streambed and should be at least as wide as the active stream channel (i.e., no lateral encroachment on the active stream channel). All embedded culverts (round or arch) must be embedded one foot deep or at least 20 percent of its height, whichever is more.

5 When deciding between bottomless arch and embedded culvert designs, the primary consideration is foundation substrate. If considerable bedrock is present, an open bottom arch is generally the appropriate choice; embedding a culvert would require extensive excavation. Where deep unconsolidated gravel and cobble is present, failure (undermining) of a bottomless arch foundation is a major concern.

6 Hydraulic controls may be required to 1) improve culvert entrance and exit conditions (e.g. using a beveled inlet configuration; providing resting pools at culvert entrance and exit), 2) concentrate low flows, 3) prevent erosion of stream bed and banks, or 4) allow passage of bedload material. The need for, and design of, these project features should be developed in consultation with the resource agency.

7 If water-crossing structures are placed in spawning areas, they should incorporate mitigation measures, as necessary, to achieve no-net-loss of spawning area.

8 Trash racks are discouraged at culvert inlets, but if necessary, these should be installed only above the high passage flow water level.

Hydraulic Design Method
The Hydraulic Design method is a design process that matches the hydraulic performance of a culvert with the swimming abilities of a target species and age class of fish. This method targets distinct species of fish and therefore does not account for ecosystem requirements of non-target species. There are significant errors associated with estimation of hydrology and fish swimming speeds that are resolved by making conservative assumptions in the design process. Determination of high and low fish passage design flows, water velocity, and water depth are required for this option. The Hydraulic Design method requires hydrologic data analysis, open channel flow hydraulic calculations, and information on the swimming ability and behavior of the target group of fish. This design method can be applied to the design of new and replacement culverts and can be used to evaluate the effectiveness of retrofits of existing culverts.

1 **Culvert Width** - The minimum culvert width should be 3 feet.

2 **Culvert Slope** - The culvert slope shall not exceed the slope of the stream through the reach in which it is being placed. If embedment of the culvert is not possible, the maximum slope shall not exceed 0.5 percent.

3 **Embedment** - Where physically possible, the bottom of the culvert should be buried into the streambed a minimum of 20 percent of the height of the culvert below the elevation of the tailwater control point downstream of the culvert. The
minimum embedment should be at least 1 foot. Where physical conditions preclude embedment, the hydraulic drop at the outlet of a culvert shall not exceed the limits specified above.

4 High Fish Passage Design Flow - The high design flow for adult fish passage is used to determine the maximum water velocity within the culvert.

5 Low Fish Passage Design Flow - The low design flow for fish passage is used to determine the minimum depth of water within a culvert.

6 Maximum Hydraulic Drop - Hydraulic drops between the water surface in the culvert and the water surface in the adjacent channel should be avoided for all cases. This includes the culvert inlet and outlet. Where a hydraulic drop is unavoidable, its magnitude should be evaluated for both high design flow and low design flow and shall not exceed 1 foot for adults or 6 inches for juveniles. If a hydraulic drop occurs at the culvert outlet, a jump pool of at least 2 feet in depth should be provided.

Structural Design and Flood Capacity
All culvert stream crossings, regardless of the design option used, should be designed to withstand the 100-year peak flood flow without structural damage to the crossing. The analysis of the structural integrity of the crossing should take into consideration the debris loading likely to be encountered during flooding. Stream crossings or culverts located in areas where there is significant risk of inlet plugging by flood borne debris should be designed to pass the 100-year peak flood without exceeding the top of the culvert inlet (Headwater-to-Diameter Ratio less than one). This is to ensure a low risk of channel degradation, stream diversion, and failure over the life span of the crossing. Hydraulic capacity must be compensated for expected deposition in the culvert bottom.

Culvert Evaluation for Fish Passage and Ranking for Remediation Efforts
Various methods for fish habitat and passage evaluation have been developed. The following sample ranking method assigns scores or values for the following five parameters:

1. Species Diversity - Number of target species currently present (or historically present which could be restored) within the stream reach at each crossing location. Score - For each federally or state listed salmonid species; Endangered = 4 points; Threatened or Candidate = 2 points; not listed = 1 point. Consult state resource agency or NOAA for historic species distribution and listing status information.

2. Extent of Barrier - Over the range of estimated migration flows, assign one of the following values from the “percent passable” results generated with FishXing. GREEN crossings are considered 100 percent passable for all fish, while RED crossings are considered 0 percent passable for all fish. Do this for adult anadromous, resident, and target species for each culvert. Score - 0 = 80 percent or greater passable; 1 = 79-60 percent passable; 2 = 59-40 percent passable; 3 = 39-20 percent passable; 4 = 19 percent or less passable; 5 = 0 percent passable (RED). For a total score, sum the values for all three.

3. Habitat Value - Multiply habitat quantity score by habitat quality score. Habitat
Quantity - Above each crossing, length in feet to a sustained 8 percent gradient or field identified limit of anadromy. Score: 0.5 points for each 500 feet of stream (example: 0.5 points for <500N; 1 point for 1,000N; 2 points for 2,000N; and 5.5 points for 5,500N). The maximum possible score for Habitat Quantity is 10.

4. Habitat Quality - For each stream, assign a score of quality after reviewing available habitat information. Consultation with local state resource agency biologists to assist in assigning habitat quality score is recommended. Score: 1.0 = Excellent - Relatively undeveloped, with pristine watershed conditions. Habitat features include dense riparian zones with mix of mature native species, frequent pools, high-quality spawning areas, cool summer water temperatures, complex instream habitat, floodplain relatively intact. 0.75 = Good - Habitat is mostly intact but erosional processes or other factors have altered the watershed with a likelihood of continued occurrence. Habitat includes dense riparian zones of native species, frequent pools, spawning gravels, cool summer water temperatures, complex instream habitat, floodplain relatively intact. 0.5 = Fair - Erosional processes or other factors have altered the watershed with negative affects on watershed processes and features, with the likelihood of continued occurrence. Indicators include: a) riparian zone lacking mature conifers, b) infrequent pools, c) sedimentation evident in spawning areas (embeddedness ratings of 3), d) summer water temperatures periodically exceed stressful levels for target species, e) sparse instream complex habitat, and floodplain intact or slightly modified. 0.25 = Poor - Erosional processes or other factors have significantly altered the watershed. There is a high likelihood of increased erosion and apparent effects to watershed processes. Habitat impacts include riparian zones absent or severely degraded, little or no pool habitat, excessive sedimentation evident in spawning areas (embeddedness ratings of 4), stressful to lethal summer water temperatures common, lack of instream habitat, floodplain severely modified with levees, riprap, and/or residential or commercial development.

5. Sizing (risk of failure) - For each crossing, assign one of the following values as related to flow capacity. Score: 0 = sized for at least a 100-year flow, low risk; 1 = sized for at least a 50-year flow, low/moderate risk; 2 = sized for at least a 25-year flow, moderate risk of failure; 3 = sized for at least a 10-year flow, moderate/high risk of failure; 4 = sized for less than a 10-year flow, high risk of failure; 5 = sized for less than a 5-year flow, extreme risk of failure.

6. Current Condition - For each crossing, assign one of the following values. Score: 0 = good condition; 1 = fair, showing signs of wear; 3 = poor, floor rusting through, crushed by roadbase, etc.; 4 = extremely poor, floor rotted-out, severely crushed, damaged inlets, collapsing wingwalls, slumping roadbase, etc.

For each stream crossing, enter criteria values into a spreadsheet, sum the ranking criteria values, and compute the total scores. Then sort the list of crossings by total scores to determine a first-cut ranking for the project area. The results of the ranking matrix provide a rough, first-cut evaluation. There are other important factors that should be considered when deciding the exact scheduling of remediation efforts. The following list provides guidance that should assist in rearranging the first-cut ranking. On a site-specific basis, some or all of these factors should be considered:

1. Presence or absence of other stream crossings - In many cases, a single stream
may be crossed by multiple roads. If migration barriers exist at multiple stream crossings, a coordinated effort is required to identify and treat them in a logical manner, generally in an upstream direction starting with the lowest crossing in the stream.

2 *Fish observations at crossings* - Sites where fish are observed holding during migration periods should receive high consideration for remediation. Identify the species present, count the number of fish, and record failed versus successful passage attempts. Consider the potential for predation and/or poaching. Sites with holding fish are areas where immediate recolonization of upstream habitat is likely to occur.

3 *Amount of road fill* - At stream crossings that are undersized and/or in poor condition, consider the volume of fill material within the road prism. This is material which is directly deliverable to the stream channel if the crossing were to fail. Also determine if there is a potential for water to divert down the road if the crossings capacity is overwhelmed.

4 *Remediation project cost* - The range of treatment options and associated costs must be examined when determining the order in which to proceed. In cases where federal or state listed fish species are present, costs must be weighed against the consequences of not providing unimpeded passage.

5 *Opportunity* - Road managers should consider upgrading all migration barriers during road maintenance activities. The ongoing costs of maintaining an undersized or improperly installed culvert may exceed the cost of replacing it with a properly sized and installed crossing. When undersized or older crossings fail during storms, road managers should be prepared to install properly-sized crossings that provide unimpeded passage for all species and life stages of fish.

**DOT Practice and Design Guidance for Culvert Installation, Design, and Prioritization for Fish Passage**

The following state agency links contain installation guidance and stewardship practices for the listed culvert and stream crossing measures. Practices cover the designs, construction and maintenance of both temporary and permanent stream crossings, including culverts:

1 Culvert Pipe with Access Road, MD
2 Culvert Installation, MD
3 Multi-Cell Culverts, MD
4 Depressed Culverts, MD
5 Pipe/Culvert Extensions, NCDOT, p. 22
6 Pipe/Culvert Installation, NCDOT, p. 26
7 Streambed Gravel, WA, p. 146
8 Culvert Baffles, MD
Several DOTs have developed programmatic approaches to Fish Passage improvements, as detailed below.

**Alaska Programmatic Agreement for Fish Passage Improvements**
The Alaska Department of Transportation and Public Facilities (ADOT and PF) and the Alaska Department of Fish & Game (ADF&G) developed a Memorandum of Agreement (MOA), signed in August 2001, to improve fish passage through culverts and to streamline the review process for the increasing number of fish habitat permits processed annually for culvert work. The MOA is the result of more than 15 years of fish passage research by state agencies and the University of Alaska Fairbanks, in addition to extensive discussions with fish and wildlife and transportation counterparts in Washington and Oregon State, the Federal Forest Service, and the National Marine Fisheries Service (now NOAA Fisheries). Prior to development of the MOA, permitting decisions were often ad hoc, resulting in inconsistencies, unpredictability, and unnecessary tension and conflict in the permitting process. Now, the MOA provides a consistent, state-wide basis for evaluating and approving culvert structures.

Alaska’s Memorandum of Agreement (MOA) applies to both new culvert installation and reinstallation of culverts during maintenance activities, where the ADF&G and/or the ADOT&PF have determined that culverts are the appropriate structure. Key to the agreement is a tiered approach to the culvert design. The level of information necessary for the permit depends on the “Tier.” Opting for Tier 1 requires simulation of a natural stream, but requires minimal interagency design review and permitting paperwork and leads to faster approvals. Under the MOA, ADOT&PF’s senior Regional Hydraulic Engineer reviews all proposed fish passage structures, including those proposed by Maintenance and Operations, for compliance with the design criteria contained in the MOA. ADF&G provides relevant information early in the design process, and if additional information from ADOT&PF is needed, requests such in a timely manner and in a consolidated form. The MOA also provides ADF&G reasonable opportunity to inspect culverts in the field and to review “as-built” plans prior to project shutdown, demobilization, or release of the contractor(s), in order to ensure that all culverts are installed in accordance with permit terms and conditions.

ADF&G and Alaska Department of Transportation and Public Facilities ADOT&PF believe the agreement is leading to more timely approval of permit applications for culvert installations, as well as improved passage for anadromous and resident fish populations through drainage structures, when migrating to spawning, rearing and over-wintering grounds. As their agreement represents current knowledge and state of the practice, ADF&G and ADOT&PF will meet annually to review the MOA and to amend it appropriately to accommodate new information and proven fish passage techniques.

**Maine DOT’s Fish Passage Policy and Design Guide**
In early 2002, the Maine Department of Transportation issued guidance establishing a policy, process, and design guide for fish passage at Maine DOT projects with water-crossing structures such as bridges, struts, culverts, pipes, or pipe arches. In the past, case-by-case evaluation of crossings and the associated regulatory approvals added unpredictability to project timelines and budgets. The new guidance establishes consistent expectations and procedures, facilitating planning and budget estimation. A second edition of Maine’s Fish Passage Policy and Design Guide (July, 2004) is now
available on-line.
To reach agreement on how best to achieve interagency goals, representatives from
Maine DOT and resource agencies met over several months to discuss the issues
involved with fish passage and establish a protocol considering the need for passage and
the feasibility of improvement, given site conditions and other potentially limiting
factors. The team developed guidance that provide a framework and tools to evaluate
crossing projects by balancing a variety of needs at a site (including regulatory
requirements and resource needs) while delivering safe, cost effective, and timely
projects.
When examining whether fish passage and associated habitat issues are compatible with
new stream crossing structures or improvements to existing structures, Maine DOT
considers the following goals:

1. Maintain or replicate natural stream channel or flow conditions, as appropriate.
2. Pass peak flows in accordance with Maine DOT drainage policy.
3. Comply with existing regulations on passing fish.
4. Consider potential impacts to rights-of-way, utilities and traffic.
5. Meet appropriate standards and safety requirements.
6. Provide reasonable life cycle costs.
7. Consider the least environmentally damaging solutions.

In addition to including a clear protocol for the nature and timing of agency coordination,
the new guidance facilitates Maine DOT use of new and developing technologies.
Currently Maine DOT addresses deficient culverts by rehabilitating a culvert through
insertion of a smaller diameter pipe inside the existing culvert, placing a concrete lining
at the inverts or throughout the entire length, or by replacing the culvert. This
rehabilitation allows a culvert to be repaired in place, usually with less streambed
disturbance and lower project cost than replacement would entail.

**Oregon DOT Culvert Retrofit and Replacement Program Agreement**
In 2001, the Oregon Department of Transportation (ODOT) and the state Department of
Fish and Wildlife (ODFW) signed a Memorandum of Understanding (MOU)
acknowledging that repairing or modifying ODOT-maintained culverts is a priority for
the agencies that will take decades to resolve. The Oregon Department of Fish and
Wildlife completed culvert inventories for the entire state of Oregon in 1999 and found
that 96 percent of the barriers identified were culverts associated with road crossings.
The project also identified high priority culverts for fish passage remediation.
ODOT has an ongoing program of culvert installation and maintenance, with the goal of
making all ODOT culverts passable to fish. After research monitoring results
demonstrated the effectiveness of baffle and weir designs in culverts, ODOT modified
their culvert replacement programs to use these designs, significantly reducing the cost of
improving fish passage at ODOT culverts. The designs improve fish passage by slowing
water velocity and raising stream elevations to reduce entry jump heights or backwater
culvert outlets. Use of retrofit designs are allowing culverts that are otherwise in good
physical condition to be retrofitted until their service integrity is compromised, at which
time they will be replaced with designs that more fully meet fish passage criteria and
standards. Use of retrofits will thus allow many more culverts to be remediated each year, increasing the scope and pace of ODOT’s contribution to salmon recovery in Oregon. The baffle and weir retrofits also provide ODOT an alternative to fish ladders, which have become increasingly problematic for ODOT from a maintenance standpoint. According to the MOU, ODOT will continue internal education regarding the needs and requirement of fish passage, and prioritize its resources and culvert modification needs on an annual basis, demonstrating good faith in addressing culvert passage problems. On replacement culvert projects, ODOT will strive to simulate a natural stream and will determine if changes in culverts result in flows detrimental to fish passage. ODFW is supporting ODOT’s efforts by providing the master inventory of culverts that do not provide adequate passage, along with technical assistance on educational activities, design, and construction techniques.

**WSDOT Fish Passage Improvements on a System and Project-by-Project Basis**

WSDOT is trying to tailor transportation investments in restoration and mitigation to mesh with state and community watershed restoration and enhancement goals. To that end, WSDOT has been pursuing watershed characterization research to better understand how watersheds store water naturally (e.g., wetlands, riparian areas, floodplains) and then identify where land use has resulted in the loss of natural storage capacity. So far, the agency has found that investments in watersheds with lower areas of impervious surface may yield greater marginal benefits than mitigation sited close to impact areas. Hence, WSDOT has directed mitigation investments to restoring natural, self-maintaining systems that provide many other valuable watershed functions such as groundwater recharge, water quality treatment and fish and wildlife habitat, along with aesthetic, recreational, and educational values to residents.

WSDOT’s watershed approach aims to direct transportation mitigation and conservation dollars toward high priority watershed needs, including recovery of native fish species. Access to good quality habitat is a key factor in the recovery of listed salmon stocks and culverts can create fish passage barriers that fragment habitat. Common problems with older culverts include high water velocity, inadequate water depth, and large culvert outfall drops. Once these problems are corrected, the benefits to fish habitat are real and immediate; in many cases, fish have been observed upstream of improved culverts within weeks of restoring access.

WSDOT’s environmental procedures manual describes their environmental retrofit program for construction and maintenance as retrofitting state highway facilities as appropriate to reduce existing environmental impacts. This commitment extends beyond the agency’s work in performing appropriate avoidance, minimization, and environmental mitigation as a part of all other highway system projects. The Washington State Highway System Plan update sets a 20-year goal for correction of all state highway culvert barriers. Expenditures for barrier removal in the current biennium are approximately $7 million, and estimates show that this spending level would have to double to complete correction of all culvert barriers on the highway system in 20 years. Consequently WSDOT has developed and funded a research strategy to improve understanding of how road crossings can become barriers to fish and the best approaches to correcting barriers, enabling retrofit projects to be prioritized so that those culvert barriers that promise to yield the greatest habitat benefits are corrected first.

The WSDOT fish passage barrier retrofit program is inventorying highways to locate impassable culverts, rating the potential habitat to be gained from fixing them, and
prioritizing the fixes. WSDOT and the Washington Department of Fish and Wildlife jointly manage a statewide database for this inventory with over 900 identified culvert barriers, many of which have been added under more stringent criteria adopted in the past few years. Culverts associated with 2,000 of the 7,000 miles in the state highway system have been inventoried. Since 1991, 27 barriers have been corrected in the course of highway projects, and another 42 barriers have been corrected through the special retrofit program. WSDOT maintenance personnel also correct or at least improve some fish barriers during routine culvert maintenance.

WSDOT’s Environmental Retrofit Program also includes:

1. Noise Barriers — Adding noise mitigation along state highways where neighborhoods are exposed to unacceptable noise levels as defined by federal statute.
2. Stormwater Discharge — Constructing new stormwater treatment facilities to treat runoff from existing untreated pavements.

**MDSHA Incorporates Stream Morphology Concepts in Culvert Design**

In 1992, the Maryland State Highway Administration (SHA) initiated new design procedures to limit the impact of constructing culverts and bridges in streams. Elements of the new procedures included studies to define the characteristics of Maryland streams regarding bankfull widths, depths, and discharges; training of engineers in basic and advanced courses in stream morphology; and updating the MDSHA culvert design manual to address consideration of stream morphology, fish passage, and other environmental features. The revised design procedure emphasized the need to identify all appropriate objectives at the start of the design process so the best overall solution can be determined. The design concept is to construct a stream system that is stable and that neither scour nor aggrades. Elements of this approach include maintaining the consistency of dimension, pattern, and profile of the stream with particular attention given to maintaining bankfull width and width/depth ratio. Initial efforts to construct culverts using stream restoration methodologies and to relieve the hydraulic load on the main channel culvert in some cases to limit downstream scour and erosion were quite successful; MDSHA concluded that it was practical to consider stream morphology concepts in culvert design.

**Alberta Transportation Practices and Measures for Protection of Fish & Aquatic Ecosystems**

Practices and measures for fisheries and aquatic ecosystems have been established in Canada, and include the following:

1. Crossings of a waterbody that provide fish habitat at any time of the year should be designed, constructed, operated and maintained such that no new barriers to fish passage, including physical, chemical or flow impediments (including maintaining minimum flows and depths), are created so that fish can pass and the ability for fish to pass is not reduced over time, unless authorized by the appropriate resource agency.

2. If highway construction must proceed during a period when fish are moving between different areas of their habitat, their safe passage shall not be restricted for an unreasonable amount of time. The relevant period should be determined by
a qualified fisheries biologist, for the target species/community, in consultation with the appropriate resource agency.

3 Fish screens, guards, netting or other barriers should be installed and maintained across any water intake withdrawing water from any waterbody that contains fish (e.g. for the purposes of water-taking, dewatering, bypass pumping, etc.) or across the entrance to any channel constructed for the purposes of conducting water temporarily from any waterbody that contains fish so as to prevent fish access until the water intake or diversion has been decommissioned.

4 Any area of a waterbody containing fish that is temporarily isolated by guards, screens or other barriers should be inspected for the presence of fish, and all fish should be captured using appropriate means and released unharmed in adjacent fish habitat beyond the barriers. This fish transfer should be conducted under the direction of a qualified fisheries biologist, with the appropriate permit.

5 Fish shall not be harmed in any manner unless authorized by the appropriate resource agency. Fish species, or parts or derivatives of fish species listed as extirpated, endangered or threatened shall not be killed, harmed, harassed, captured, taken, possessed, collected, bought, sold or traded except under a valid Permit.

6 No harmful alteration, disruption or destruction of fish habitat is permitted unless authorized the appropriate resource agency. Destruction of any part of the critical habitat of any listed endangered or threatened aquatic species, or an extirpated species where a recovery strategy recommends reintroduction of that species to the wild, is not permitted.

7 Where a harmful alteration, disruption or destruction of fish habitat is authorized by the appropriate resource agency. Appropriate compensation should be developed by a qualified fisheries biologist, to ensure no net loss of the productive capacity of the habitat occurs.

8 Where the use of explosives is required during construction in the vicinity of a waterbody that contains fish, they should be used in such a manner as to ensure no harmful effects to fish occur.

9 No substance of any type that is deleterious should be deposited in water frequented by fish, or be released or placed such that the deleterious substance could enter the water.

10 Plans and specifications for highway construction that may affect fish habitat should be provided to Ministry of Natural Resources and Fisheries and Oceans Canada, and modified as required.

11 Where a substance is released and/or deposited into water such that fish and/or their habitat could be harmed, it should be reported to the appropriate agencies (Ministry of Natural Resources, Fisheries and Oceans Canada, Ministry of the Environment).

12 Where a substance is released and/or deposited into water such that fish and/or their habitat are harmed or likely to be harmed, all reasonable measures to remedy
the situation should be undertaken as soon as possible.

Resource Agency and Other Design Guidance for Fish Passage

318) A number of agencies have guidance for design of culverts for fish passage, including:

1 Improving Stream Crossings for Fish Passage: Final Report (2004 NOAA Fisheries) Final report of a multiyear research project investigating passage conditions for anadromous salmonids at numerous steam crossings within Northwestern California. The project evaluated the effectiveness of current fish passage guidelines. A main focus of the study was relating observed migration of adult and juvenile salmonids fish passage to existing and proposed design flows. The study also evaluated the leaping success of different size classes of fish at various culvert outlets and examined hydraulic conditions within various culvert types.

2 California Salmonid Stream Habitat Restoration Manual, (2003) Commonly called “The Green Book” this California Division of Fish and Game manual details many aspects of stream restoration and watershed monitoring and is the de facto standard (in California) for in-channel and in-stream structures for fisheries habitat improvement. The 3rd Edition contains a new section: “Part IX Fish Passage Evaluation at Stream Crossings,” added to the manual in April 2003. The primary authors of this section were Ross N. Taylor and Michael Love. This section addresses fish passage evaluations at stream crossings (roads, bridges, etc.) and Data Collection for evaluations using the FishXing software.

3 Design of Road Crossings for Fish Passage (2003) Comprehensive engineering manual by the Washington State Department of Fish and Wildlife detailing the design of manual permanent, new, retrofit, or replacement road crossing culverts without harmful impact to salmonid migration.

4 Washington State DOT Fish Passage Barrier Removal Program


7 Geomorphologic Impacts of Culvert Replacement and Removal (2003) by the Oregon Department of Fish and Wildlife.

8 DRAFT National Inventory and Assessment Procedure For Identifying Barriers to Aquatic Organisms at Road-Stream Crossings USDA Forest Service, San Dimas Technology and Development Center.

9 Juvenile and Resident Salmonid Movement and Passage Through Culverts (1998) Washington State Transportation Center (TRAC), Univ. of Wash.

10 Stream Characteristics and Hydrology – Design for Fish Passage and Aquatic
Organisms (BLM)

11 FishBase is a Searchable relational database with information to cater to different professionals such as research scientists, fisheries managers, zoologists and many more. Available on CD and on the web, it contains over 28,000 fish species, data on habitat range, swim speeds, references, research photos and much more.

12 FishXing software and learning systems for the analysis of fish migration through culverts has added features for hydraulic analysis of culverts and expanded biological references, as of Spring 2004. FishXing gives detailed profiles of hydraulic conditions and fish performance inside a variety of culvert shapes.

13 HydroCulv is an Excel-based macro that performs culvert hydraulic calculations to determine water surface profiles through culverts based on culvert geometry data and boundary conditions. Output includes key results such as freeboard, head loss, inlet and outlet velocities, as well as depth and velocity profile information throughout each culvert. Profile plots are available for each pipe and boundary condition.

14 Flow Pro is a Windows-based program that computes steady-state water surface profiles for many prismatic open channel shapes, including circular, rectangular, trapezoidal, triangular, U-shaped, and tubular. It handles both subcritical and supercritical flow types, and flow through weirs, orifices, and underflow gates. Flow Pro also computes many useful flow and channel properties including critical depth and slope, hydraulic radius and wetted perimeter, normal depth, and channel roughness. It uses Manning’s equation and numerical integration, and accepts both English and SI units of measure.

15 CulvertMaster is a Windows-based program intended for use in design and analysis of culverts at road-stream crossings. The program uses FHWA Design of Highway Culverts (HDS-5) methodology to perform inlet control and outlet control computations, including pressurized flow conditions and hydraulic jumps. The software can model hydraulics for most commonly used culvert shapes. It allows the user to input the tailwater elevation or it can generate a tailwater rating curve based on a downstream cross-section. Additionally, the user is able to input road surface elevations to check overtopping conditions. CulvertMaster also contains a hydrology module that allows the user the ability to calculate peak design flows using the Rational Method or SCS Graphical Peak Method. It provides tabular and graphical output and can generate reports. The program accepts both English and SI units of measure.

16 HEC-RAS is produced by the Army Corps of Engineers, Hydrologic Engineering Center. The Hydrologic Engineering Center’s River Analysis System (HEC-RAS) is designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels. HEC-RAS allows the user to perform one-dimensional steady and unsteady flow calculations within a graphical user interface. The steady flow component of the modeling system is intended for calculating water surface profiles for steady gradually varied flow. The system can handle a full network of channels, a dendritic system, or a single river reach. The steady flow component is capable of modeling subcritical,
supercritical, and mixed flow regimes water surface profiles. The unsteady flow component was developed primarily for subcritical flow regime calculations.

17 WinXSPRO uses a resistance-equation approach (e.g., Manning’s equation) to single cross-section hydraulic analysis, and is capable of analyzing both the geometry and hydraulics of a given channel cross-section. WinXSPRO was specifically developed for use in high-gradient streams and supports three alternative resistance equations for computing boundary roughness and resistance to flow. The program allows the user to subdivide the channel cross-section so that overbank areas, mid-channel islands, and high-water overflow channels may be analyzed separately. The program also allows input of variable water-surface slope so that is may be varied with discharge to reflect natural conditions.

18 PEAKFQ from the U.S. Geological Service is a DOS based program that performs flood-frequency analysis based on the guidelines delineated in Bulletin 17B, published by the Interagency Advisory Committee on Water Data in 1982. The program is interactive and contains the code from the WATSTORE program J407. PEAKFQ uses the method of moments to fit the Pearson Type III distribution to the logarithms of annual flood peaks. The skew that is used may be a user-developed generalized skew for a region, from the Bulletin 17B skew map, computed from the data, or weighted between the generalized skew and station skew computed from the data. Adjustments can be made for high and low outliers and historic information. Qualification codes may be used to censor data from the analysis.

19 CTE Literature Survey on Impacts of Culverts on Anadromous and Non-Anadromous Fish Passage (December 2002)

20 FISHPASS program for culvert installations – Alaska Department of Fish and Game

21 Fish Protection Screens:

  o Hydraulic testing of static self-cleaning inclined screens – U.S. Bureau of Reclamation, Water Resources Research Laboratory

  o Juvenile fish screen criteria for pump intakes – National Marine Fisheries Service, Portland, Oregon

Post-Construction Evaluation and Long Term Maintenance and Assessment

Post-construction evaluation is important to assure the intended results are accomplished, and that mistakes are not repeated elsewhere. There are three parts to this evaluation: 1) Verify the culvert is installed in accordance with proper design and construction procedures. 2) Measure hydraulic conditions to assure that the stream meets these guidelines. 3) Perform biological assessment to confirm the hydraulic conditions are resulting in successful passage. Staff and resource agency biologists may assist in developing an evaluation plan to fit site-specific conditions and species. The goal is to generate feedback about which techniques are working well, and which require modification in the future. These evaluations are not intended to cause extensive retrofits of any given project unless the as-built installation does not reasonably conform to the
design guidelines, or an obvious fish passage problem continues to exist. Any physical structure will continue to serve its intended use only if it is properly maintained. Hence the following practices should be employed.

1. Ensure timely inspection and removal of debris for culverts to continue to effectively move water, fish, sediment, and debris.

2. Inspect all culverts should be inspected at least annually to assure proper functioning. Summary reports should be completed annually for each crossing evaluated. An annual report should be compiled for all stream crossings and submitted to the resource agencies. A less frequent reporting schedule may be agreed upon for proven stream crossings. Any stream crossing failures or deficiencies discovered should be reported in the annual cycle and corrected promptly addressed.

3.6 Stream Restoration and Bioengineering

The traditional approach to designing highway structures over water crossings has been based on channel hydraulics, with little consideration of stream stability, causing reduced meanders, costly upstream and downstream erosion problems, water quality impacts, barriers to fish passage, and altering associated wetland and floodplain function. Increasingly, engineers and environmental professionals are turning toward design procedures that minimize disruption of stable stream channels and design in accordance with the natural fluvial geomorphology of rivers. These principles can also be used to restore the physical, biological, and aesthetic characteristics of degraded rivers or help to maintain the natural stream properties for newly constructed projects.

Stream restoration and mitigation is a complex process that addresses the active channel as well as the floodplain and the vegetation along its edges. Geomorphically mature natural channels are dynamically stable and are characterized by an equilibrium of sediment supply and transport. The active channel, floodplain, slope and discharge of natural channels provide the velocity necessary to transport sediment generated in the basin. The aquatic community that resides in the natural channel and along its floodplain has evolved to exploit the features of the channel and to respond to the dynamic equilibrium that has been established. Healthy fish communities tend to exist in productive, dynamically stable channel systems. Such systems provide a suitable mix of habitat features: pools, riffles, bed materials, bank features, aquatic and stream bank vegetation, woody debris, etc. that provide for the basic life requisites of food, reproduction and cover. Therefore, dynamically stable natural channels provide good fish habitat that is sustainable over a wide range of hydrologic conditions. It is generally recognized that natural channels provide optimal sustainable fish habitat for the given natural climate, geology and terrain. Improving fish habitat in natural conditions may not be sustainable over the long term, although short-term improvements are feasible. Natural stream channels are the result of the gradual evolution of the natural landscape and exist in a state of dynamic equilibrium. Natural channels typically lie in valleys with floodplains that attenuate peak flood flows. Their geometry (e.g., channel depth, slope, width, sinuosity, meander wavelength and width-to-depth ratio) can be described by regime equations which depend on the geology and geography of the watershed. This provides a tool that can be used to design channel diversions or realignments in accordance with natural regime conditions and to design watercourse
crossings to accommodate natural channel processes.

When changes to the channel, floodplain, vegetation, flow or sediment supply significantly affect this equilibrium, the stream may become unstable and start adjusting toward a new equilibrium state. This transition may take a long time and may substantially change water quality, habitat and adjacent property. Stream restoration re-establishes the general structure, function and self-sustaining behavior of the stream system that existed prior to disturbance, so the stream does not aggrade or degrade and so that it provides the highest level of aquatic habitat and biological diversity possible. To accomplish this, restoration may involve:

1. Removal of the watershed disturbances that are causing stream instability.
2. Installation of structures and planting of vegetation to protect streambanks and provide habitat.
3. Reshaping or replacement of unstable stream reaches into appropriately designed functional streams and associated floodplains.

Bioengineering is the use of plant material, living or dead, to alleviate environmental problems such as shallow rapid landslides, and eroding slopes and streambanks. Plants are an important structural component of bioengineered systems, not just an aesthetic element. This approach to slope stabilization requires a true partnership between engineering geologists, maintenance personnel, civil engineers, and landscape architects. Bioengineering mimics nature by using locally available materials and a minimum of heavy equipment. Hence it can offer designers and roadside managers an inexpensive way to resolve local environmental problems. These techniques can also be used in combination with “hard” engineering techniques such as rock or concrete structures.

The following benefits of bioengineering, or soil bioengineering as it is commonly called, are outlined by:

1. Soil bioengineering work is often the only practical alternative on sensitive or steep sites where heavy machinery is not feasible.
2. Installation of soil bioengineered systems while problems are small will provide economic savings and minimize potential impacts to the road and adjoining areas. Erosion areas often begin small and eventually expand to a size requiring costly traditional engineering solutions.
3. Many designs can be implemented by hand crews.
4. Native plant species are usually readily available and adapted to local climate and soil conditions. Costs might be limited to labor for harvesting, handling, and transport to the project site.
5. Soil bioengineering projects may be installed during the dormant season of late fall, winter, and early spring. This is the best time to install plants and it often coincides with a time when other construction work is slow.
6. Years of monitoring have demonstrated that soil bioengineering systems provide limited initial benefits, but grow stronger with time as vegetation becomes established. Even if plants die, roots and surface organic litter continue to play an important role during reestablishment of other plants.
7 Once plants are established, root systems remove excess moisture from the soil profile. This often is the key to long-term soil stability.

8 Soil bioengineering provides improved environmental functions, such as slope stabilization, stormwater retention, and habitat values.

Nationwide, there is strong support for this natural stability approach from federal and state regulatory agencies involved in the review of highway projects.

Planning Considerations for Stream Restoration and Bioengineering

A literature review for Transportation and the Environment (CTE) and NCDOT by the NCSU Stream Restoration Institute for the Center found that despite research gaps in understanding the goals of restoration, spatial and temporal aspects of structure use and placement, and the reach level hydraulic effects of structures, most authors agree that the process and design of stream restoration should cover the following principle areas:

1. Analysis of channel history and evolution
2. Analysis of cause and effect of change
3. Analysis of current condition
4. Development of specific restoration goals and objectives prior to design
5. Holistic approach to account for channel process, riparian and aquatic function
6. Consideration of passive practices (such as fencing against livestock)
7. Natural channel design to restore function

WSDOT outlines the following stewardship practices when planning and designing bioengineering projects:

1. Evaluate soil bioengineering methods as a possible tool for remediation and restoration of degraded slopes. Soil bioengineering has unique attributes, but is not appropriate for all sites. In some cases a conventional vegetative treatment works with less cost, or it may be best to use a geotechnically-engineered system alone or in combination with soil bioengineering.

2. Evaluate projects that leave exposed slopes, and slopes requiring high maintenance for stabilization, for possible application of soil bioengineering technologies.

3. Include bioengineering technologies as an alternative when evaluating costs.

4. Include a slope stability analysis in plans for large erosional slopes.

Consider the natural history, cultural, and social issues of the surrounding landscape as well. A proposed soil bioengineering project within a forested landscape, for example, requires knowledge and understanding of:

1. Road construction methods and current maintenance practices.
2. Objective of the bioengineering project - repair, remediation, prevention, habitat, etc.
3. The area’s geologic and glacial history.
4. Its propensity for wild fires, wind storms, and floods.
5. Occurrence and trends of natural and management related erosion.
6. Sequence of vegetation removal and revegetation efforts.
7. Fire management history.
8. Soil types and properties
9. Hydraulic and hydrological erosion and scour characteristics.
10. How the area is used by contemporary people and how it has been used in the past
11. What resources (for example, water, native vegetation, non-native vegetation, fish, wildlife) are used by different groups of people
12. What stakeholders are interested in the area and its resources

The following basic planning considerations are good environmental stewardship practice when planning and designing stream restoration and bioengineering projects:

**Channel Features**
The channel must possess key habitat characteristics including food supply for production, appropriate areas for reproduction, areas for refuge and rest, and linkages between these areas. When designing a channel reach these habitat characteristics need to be considered in relation to the role of the reach in the stream habitat system. Features of the channel that should comply with channel regime relationships and replicate local natural analogues include:

1. **Channel morphology:** width, depth, pool area, riffle area, sinuosity, meander wave length, bed material, bank material and slope.
2. **Habitat substrate:** percentage area in boulders (substrate larger than 256 mm), percentage area in cobbles (64 to 256 mm), percentage area in gravels (2 to 64 mm), percentage area in fines (< 2 mm), percentage bed area vegetated; and
3. **Habitat structure:** type of instream cover, percentage of instream area covered, length of undercut bank, percentage of channel eroding, percentage bank area in debris cover, shading.
4. **Riparian Zone:** type of riparian vegetation, extent of riparian vegetation. The channel design should produce an overall channel form consistent with that which would evolve naturally under the same conditions. This can be accomplished by comparing stream classification attributes with representative stream reaches that are nearby. The use of natural analogues to determine channel characteristics is recommended wherever possible.

**Conveyance Capacity**
Flows that entrain sediment, cause bed and bank erosion, and flood the areas adjacent to the channel are important to aquatic habitat. Bankfull discharge is considered to be the flow that determines channel characteristics of width, depth, sediment size and sorting, and channel plan form.
Flows exceeding 1:10 and 1:25 year recurrence intervals are normally the flows that connect the channel to the riparian zone and affect the floodplain features of
wetlands, vegetation cover, and sediment deposition. Depending on the type of stream system, the floods greater than the 1:25 year and up to the 1:100 year flow fill the valley bottom, defining the limit of fluvial influence on the landscape. The active channel area should, wherever possible, provide conveyance up to the 2-year return period event. Additional conveyance should be supplied by the riparian zone or floodplain. When site conditions limit the use of a floodplain to convey flows, structural measures such as additional armoring, may be required.

Low Flows
Low flows are defined by the flow duration curve for the watershed. If the data for the derivation of the low flows are not available they can be developed from regional relationships for estimating low flows. Provided a natural channel can support sustainable fish habitat, design guidelines should be incorporated into the channel design based on target fish species. For example, intermittent streams would provide habitat for forage fish or spawning habitat for spring spawners such as arctic grayling or northern pike. Streams with permanent flow could be designed to support target sport fish or other target species.

379) Human uses

380) The way the stream is used by various groups of people today, and the ways in which it has been used in the past, are important variables to understand when planning a restoration or bioengineering project. Not only must human uses be considered in assessing the environmental impacts of such a project under NEPA, the National Historic Preservation Act, and other laws, but they may be critical to the design of the project itself, and they may offer particular opportunities for creative cooperative management. For example, a stream may be used by a Native American community as a source of fish, or by an Asian-American community as a source of natural medicines. If possible, it is important to avoid impacting such uses. Also, such communities may be stakeholders whose cooperation will simplify and improve the quality of a restoration project.

Information Requirements
Channel measurements include a site description, cross-sectional characteristics across the channel and valley, an assessment of bed and bank material, documentation of bank vegetative cover, channel profile and channel planform.

Site Description
The recommended procedure for characterizing the reach, the riparian zone, and the valley bottom is as follows: ()

1. Locate the reach to be designed on a map with a scale of 1:2000 for urban areas with contour intervals of 0.3 m. A 1:10,000 scale map should be used for rural areas. Also locate the reach on air photos with a scale of 1:2000, if possible. As air photos of this scale are unlikely to be available unless they are taken specifically for the project, it may be necessary to use smaller scale air photos.
2. Determine the upstream drainage area.
3. Locate the upstream drainage basin and document its condition in terms of
land use and level of disturbance. Identify any potential changes to it, including development, impervious surface development, channelization, drainage of wetlands, installation of stormwater ponds, or infiltration fields.

4 Locate the valley and document its width, terraces and breaks in the slope, and any evidence of floodlines.

5 Locate and identify any structures and other modifications to the channel, banks, and floodplain.

6 Locate and map out existing tree cover, shrubs, and understory cover. Locate any debris, stumps, or large boulders in the channel, banks, or floodplain.

Cross-Sectional Measurements
Measurements of channel and valley cross-sections should extend across the valley slope and include the following: ()

1 Stream width at the time of measurement of the flow.

2 Average depth and maximum depth at the time of flow measurement.

3 Bankfull width.

4 Average and maximum depth at bankfull discharge.

5 Stream entrenchment ratio.

Bed and Bank Material
Assessment of bed and bank material should be carried out by taking the following measurements: ()

1 Sieve particle size analysis for various samples taken from all representative material types in the section. If bed materials are too large for sieve analysis, characterize the grain size distribution by counting stones.

2 A sketch of the location and a description of the condition of each representative material type.

3 Visual estimates of the percentage of the bed’s area covered by boulders, cobbles, gravel and sands, and fines.

4 The area and nature of the vegetative cover on the bed.

5 The particle size data should be plotted as cumulative percent to calculate $d_{15}$, $d_{50}$ and $d_{84}$ of the particle size distribution.

Bank Vegetative Cover
Bank vegetative cover should be documented to include the following: ()

1 Density and height, using a gridded sampling frame to assess cover and to sample numbers of plants, for the smaller plants.

2 Plant species, associates, and each type’s percentage of cover should be noted.

3 In the case of trees, sampling should be carried out at regular intervals along the transect.

4 Location of snags and overhanging vegetation should be noted.
5 The height of vegetation and width of the vegetative buffers along the bank should be assessed.

Profile and Plan Measurements
For the design of a channel, the important variables required include the following: ()
1 For each station at which the cross-sectional data were gathered, the following should be measured according to a standard datum: water level, bed level, top of bank level, and levels of any terraces. Any historical high water marks should also be recorded.
2 The plan form of the channel should be mapped. The map should include the thalweg’s path, cut banks and point bars, mid-channel bars, riffles and pools, snags, and other obstructions.
3 Meander characteristics including wavelength, radius of curvature, and meander belt width and amplitude.
4 All elevations should be placed on the map so that the geometry of all features can be referenced.
5 Depressions, wetlands, and other water storage areas in the floodplain should be mapped.
6 Vegetative cover in the channel and snags should be mapped.
7 Bank vegetative cover, overhanging vegetation, and riparian and floodplain vegetation should be mapped.

Use Characterization
Through consultation with stakeholders, and sometimes appropriate background historical, sociological, ethnographic and archaeological studies, the following information should be gathered:
1 How has the stream and its elements (water, wetlands, channel, meanders, springs, stands of vegetation, fish populations, etc.) been used in the past, and by whom?
2 How are these elements used today, and by whom?
3 What expectations are there about future uses, and who holds them?
4 Who (if anyone) has legal (including treaty) rights to the stream or its resources?
5 Are the various stakeholders willing to participate in restoration and bioengineering?
6 Are there cultural, social, economic, or linguistic barriers to their participation? If so, how can these be overcome?
7 Are there particular areas along the stream, or particular elements within or along it, that require special consideration in planning because of their cultural importance of uses?

Design Steps
Many criteria need to be taken into account for the complex process of designing a channel realignment or channelized section. These include:

1. Discharge capacity (e.g., major flood)
2. Channel stability and sediment equilibrium (channel regime)
3. Riparian zone vegetation
4. Fisheries habitat (possibly species specific)
5. Recreational opportunities (active or passive)
6. Other current uses and use opportunities
7. Aesthetics (viewscapes)
8. Erosion protection

Since these objectives are not necessarily compatible, design conflicts can arise. For example, the objectives for fisheries habitat will affect requirements for vegetation and physical features, recreational and aesthetic objectives could affect topography and vegetation requirements, and the geomorphological features required to provide a stable stream may reduce its capacity during flood events. Physical constraints, such as urban encroachment, may exist and must be considered in the design process. Choosing the right design parameters involves careful consideration of all the objectives for the stream system and the constraints that exist within the valley. Tradeoffs may be necessary to reconcile differences to establish workable design parameters. The recommended design steps are outlined as follows:

1. **Step 1: Define Objectives for Design.** Identify the objectives to be met in the design. Multiple objectives may include conveyance, fisheries, habitat, recreation, aesthetics, and maintenance.

2. **Step 2: Define Existing Conditions.** The existing characteristics should be identified and detailed.

3. **Step 3: Define Expected Natural Regime.** Once the existing conditions are identified, the change in natural regime should be established.

4. **Step 4: Identify Inconsistencies.** The predicted regime and the existing regime should be compared to identify any inconsistencies and to determine if the stream is in equilibrium.

5. **Step 5: Design Parameters for Unconstrained Design.** Design parameters for the channel should be developed that will meet the objectives and provide stable, natural conditions.

6. **Step 6: Identify Constraints.** Identify the constraints to the channel such as property encroachments, roadways, etc.

7. **Step 7: Identify Tradeoffs.** The constraints and optimum conditions should be compared and the tradeoffs should be identified.

8. **Step 8: Develop Final Design Parameters.** The tradeoffs should be evaluated and decisions made about selecting design parameters. The design should be compared to the objectives and any shortcomings should be identified.

9. **Step 9: Evaluate Design.** The design parameters should be compared to the unconstrained condition (see Step 5) and the differences should be evaluated for acceptability.
**Climatic Conditions**
Climates near the ground can vary considerably within short distances. South facing valley walls, for example, receive more direct sun rays, which cause higher soil temperatures, increased evaporation, more rapid snowmelt in the spring, and generally drier conditions than on the more shaded north facing walls. This difference will influence erosion rates and the composition and vigor of revegetation efforts.

1. Consider precipitation types, amounts, seasonal variation, and duration.
2. Consider temperatures, including seasonal averages and extremes.

**Topography and Aspect**
1. Slope gradient.
2. Terrain shape (for example, gentle slope to valley or sharp peaks).
3. Elevation of project area.
4. Direction of sun exposure.

**Soils**
Identify conditions above, below, or within the project site that might have an effect on the project and incorporate these considerations into the design. Consult with the HQ Engineering Geologist to determine need for slope stability analysis. Some categories below will require soil testing to determine.

1. Substrate - take soil probe sample from potential site.
2. Soil types
3. Soil permeability
4. Moisture holding capacity
5. Nutrient availability

**Water**
Detailed analysis or work in streams or rivers will require consultation with a hydraulics engineer. Work affecting streams or rivers will require consultation with the DOT environmental office.

1. Water velocity: Lateral stream stability
2. Hydrologic regime: general and site specific.
3. If applicable, stream and fish types affected by the erosion site.
4. Location of natural drainage channels and areas of overland flow from road surfaces.
5. Areas for safe water diversion.
6. Condition of ditch line and culvert inlets and outlets.
**Erosion Process**

1. Evidence of past sliding: deep or shallow failure surface in vicinity.
2. Regional geomorphic trends or slope features (review aerial photos).
3. Type of mass wasting or surface erosion feature.
4. Source of eroding material: road fill slope, cut slope, landing, etc.
5. Trend of site: improving naturally, remaining uniform, or worsening.

**Vegetation**

Living vegetation is the most critical component of a bioengineered system. Existing vegetation and knowledge of predisturbance plant communities can inform the designer of project limitations, opportunities, and long-term ecological goals. Plants that can resist mechanical stresses of erosion, floods, and landslides, while developing a strong, stabilizing root system are best suited for soil bioengineering applications. The best indicator of which plant materials to consider for the soil bioengineering project is the plants growing on or adjacent to the project site. Deciding which plants to use is affected by the following factors:

1. Site characteristics (topography, elevation, aspect, soil moisture, nutrient levels).
2. Existing vegetation.
3. Intended role of vegetation in the project.
4. Growth characteristics and ecological relationships of the plants.
5. Availability.
6. Locations for plant and seed collection.
7. Plant species and amount growing within and adjacent to project site. It is especially important to identify colonizing species.
8. Logistical and economic constraints.

Plant materials are chosen from among those species available on the site or nearby. Alternatively, it might be possible to salvage like species from a similar area where vegetation is scheduled to be removed. Logistical concerns are important in the selection of plant material.

**Coordination and Communication on Bioengineering Projects**

The complexity of the project dictates the level at which the following environmental stewardship practices in bioengineering or stream restoration are performed. An interdisciplinary team is typically necessary for all steps.

1. Involve all associated disciplines early in the process.
2. Involve external stakeholders early and throughout the process, including all those who use the channel, wetlands, and associated resources.
3. Establish clear project objectives.
4 Conduct predesign field review.
5 Conduct plan-in-hand field review.

Available Guidebooks and Research in Progress

In October 1998, FHWA, AASHTO, and TRB sponsored a scanning review of European practice for bridge scour and stream instability countermeasures. Since that time, state DOTs have undertaken a number of research efforts to establish regionally appropriate guidelines. NYSDOT and NCDOT are among other DOTs that include recommendations for appropriate practices when working near streams in maintenance or construction manuals.

1 NCDOT has developed Guidelines for Relocations of Mountain Streams in North Carolina and jointly funded the Stream Restoration and Natural Channel Design Guidebook.
2 Mn/DOT has developed Guidance for Stream or Water Body Modification.
3 KYTC has put together a manual of BMPs for streamside areas.
4 WSDOT Roadside Manual Chapter 740 - Soil Bioengineering addresses definitions, planning, design, implementation, site evaluation, and eleven upland soil bioengineering techniques.
5 The Nebraska Cooperative Extension Service has published Bioengineering Techniques for Hillslope, Streambank, and Erosion Control.
6 The Stream Restoration: A Natural Channel Design Handbook prepared for the North Carolina Department of Transportation by the NCSU Stream Restoration Institute, is available on-line and contains River Cross Section Survey, Fact Sheets on River Courses, and Structure Details for Vanes and Rootwads in addition to:
   1. Introduction to Fluvial Processes
   2. Existing Condition Survey
   3. Gage Station Analyses and Bankfull Verification
   4. Restoration Priority Options for Incised Streams
   5. Reference Reach Survey
   6. Design Procedures
   7. Structures
   8. Vegetation Stabilization and Riparian Buffer Re-establishment
   9. Erosion and Sediment Control Plan
   10. Flood Studies
   11. Evaluation
   12. References

Materials for an accompanying four-day workshop held for 35 NCDOT staff are available from the NCSU Stream Restoration Institute, NCDOT, or CTE.

1 Maryland’s Waterway Construction Guidelines recommends that the planning and design of any stabilization, restoration, or in-stream construction project should include a set of clearly defined restoration objectives, a comprehensive
monitoring strategy, and an adaptive management plan. Objectives vary from aesthetic improvements to habitat enhancement to safety and installation of hydraulic structures and roadways. Identifying the objective of the project must be accomplished before the design process can begin. Regardless of the nature of the objective, it should include measurable performance criteria. Performance criteria are quantitative measurements that are made in the stream corridor and compared to the project’s objectives and can include parameters such as suspended sediment load and rate of lateral channel migration. A comprehensive monitoring strategy including appropriate baseline studies and timing, frequency, and location of field measurements, is necessary to assess the degree of project success or failure and to determine an adaptive management plan. Options for an adaptive management plan include adjustment or maintenance of individual measures, modification of project goals and objectives, and project redesign.

2 WSDOT’s Integrated Streambank Protection Guidelines (ISPG) Manual resulted from the 2002 finalization of an effort by WSDOT, the Washington State Department of Fish and Wildlife, the Washington State Department of Ecology, the U.S. Army Corps of Engineers, and the U.S. Fish and Wildlife Service. The ISPG contains chapters on the mechanisms and causes of streambank failure, the best method for selecting appropriate solutions, examples of appropriate solutions, and technical background material. WSDOT has worked with regulatory agencies and other stakeholder to make the ISPG an agreed-upon multi-agency standard, improving bank stabilization efforts while expediting project delivery. The ISPG is part of a series of manuals designed to protect and restore fully functioning marine, freshwater, and riparian habitat in the state and to encourage permit streamlining through the provision of proven, detailed, and well-illustrated technical solutions. Written by professional resource engineers and managers, these manuals – including the ISPG – are geared toward local, state, and federal agencies, elected officials, engineering design consultants, volunteer restoration groups, and riparian landowners. In 2003, WSDOT conducted training based on the ISPG statewide and throughout WSDOT.

3 In September 2004, Washington State completed Stream Habitat Restoration Guidelines including chapters on Stream Processes and Habitat Assessment, Developing A Restoration Strategy, Designing and Implementing Stream Habitat Restoration Techniques, and a variety of Techniques including:
  - Channel Modification
  - Levee Removal and Modification
  - Side Channel/off-Channel Habitat Restoration
  - Riparian Restoration and Management
  - Fish Passage Restoration
  - Nutrient Supplementation
  - Beaver Re-Introduction
  - Salmonid Spawning Gravel Cleaning and Placement
General Design and Selection Considerations for Instream Structures
Boulder Clusters
Large Wood and Log Jams
Drop Structures
Porous Weirs
Bank Protection Construction, Modification, and Removal
Instream Sediment Detention Basins

In addition to a Glossary, overviews of Hydrology, Hydraulics, and Fluvial Geomorphology, Construction Considerations, Placement and Anchoring of Large Wood, Typical Permits Required for Work in and Around Water, and Monitoring Considerations are also included.

Federal efforts have included the following:
1. EPA’s Principles for the Ecological Restoration of Aquatic Resources

The latter incorporates and reflects the experiences of the fifteen collaborating agencies and has received the endorsement of and awards from the American Society of Landscape Architects. It is more general than some of the other guidebooks available and is easily applicable nationwide in both urban and rural settings, to a range of stream types. The guide is divided into three principal parts. Part I provides back-ground on the fundamental concepts of stream corridor structure, processes, functions, and the effects of disturbance. Part II focuses on a general restoration plan development process comprised of several fundamental steps. For example, in analyzing stream restoration alternatives, a management summary of proposed activities should be prepared, including an overview of the following elements:

1. Analysis of the various causes of impairment and the effect of management activities on these impaired conditions and causes in the past.
2. Statement of specific restoration objectives expressed in terms of measurable stream corridor conditions and ranked in priority order.
3. Preliminary design alternatives and feasibility analysis.
4. Cost-effectiveness analysis for each treatment or alternative.
5. Assessment of project risks.
6. Appropriate cultural and environmental reviews and their results
7. Monitoring plan linked to stream corridor conditions.
8. Anticipated maintenance needs and schedule.

Part III briefly covers Restoration, Installation, Monitoring, and Management. The information lacks detailed design guidance for various stream restoration techniques, but
state environmental agencies and DOTs have begun to fill that gap, as will NCHRP 24-19, results of which are due in late 2004.

1. NCHRP 24-19 seeks to fill part of the gap in DOTs abilities to use and rely on environmentally sensitive bank and erosion control measures. Traditional channel- and bank-protection techniques have relied on countermeasures such as riprap, gabions, cable-tied blocks, or grout-filled bags, which may not offer sufficient in-stream functions, such as habitat diversity, fish passage, water quality, and energy dissipation. Environmentally sensitive channel- and bank-protection measures (ESCBMs), such as bioengineering, root wads, large woody debris, riparian vegetation, bendway weirs, and energy dissipaters, are being called for more frequently to protect transportation facilities from erosion, scour, and lateral migration. The CD will include for each ESCBM covered:

2. A review of the technical literature from foreign and domestic sources pertaining to environmentally sensitive channel- and bank-protection measures.

3. Performance data.

4. Examples, charts, tables, figures, drawings, and specifications.

5. Guidance pertaining to selection and application.

6. Critical evaluation of the extent and adequacy of existing information pertaining to the current state of practice for the selection and design of the measure.

7. Upcoming NCHRP projects will cover Riprap Design Criteria, Specifications and Quality Control and Hydraulic Loss Coefficients for Culverts.


9. Stream Corridor Inventory and Assessment Techniques


11. TR 1737-12, Using Aerial Photographs to Assess Proper Functioning Condition of Riparian-Wetland Areas


The following new state DOT research is in progress:

1. **Mn/DOT** is undertaking a “Scoping Study for the Development of Design Guidelines for Bioengineering in the Upper Midwest,” with research results due in early 2005.(\) The project will assess current design methods, clarify current practices, propose areas where better design guidance is needed and outline further research requirements.

2. **Georgia DOT** is investigating the feasibility of using recently developed stream restoration techniques, specifically in-stream structures, to restore the previous channel geometry and habitat continuity in the vicinity of bridges.\) The project will develop a database of the effectiveness of three different materials (rock, wood, and salvaged concrete slabs) for the restoration structures and restoration
failures in the region. Results are due in 2006.

3 **Florida DOT**, in conjunction with USFWS, is also collecting regional data; in particular the agencies are developing regional curves to characterize and stream channel hydraulic geometry (i.e., width, depth, and cross-sectional area) in relationship to bankfull discharge and watershed area and assist in natural channel design for FDOT projects. This study is expected to provide a model for future efforts to analyze streams statewide and result in improved guidelines for designing culverts and bridges to preserve natural bankfull channel dimensions and their associated floodplains and wetlands. Study results are expected in 2005.

4 **Nebraska DOR** is establishing guidelines about when and where to use vegetation to control erosion on streambanks, how to establish the vegetation, and what types of vegetation are most practical in any given situation. The research team also investigated combined erosion control methods to see if bioengineering can improve the stability and appearance of non-biological erosion control techniques in locations where vegetation by itself provides insufficient protection against erosion. MDT and FHWA are also undertaking research in alternative strategies in stream restoration.

### Bioengineering Technique Selection

Selection of the appropriate technique, or techniques, is critical to successful restoration. NCHRP 24-19 Environmentally-Sensitive Channel and Bank Protection Measures will provide guidelines for 44 bioengineering techniques, accompanied by 19 Special Topic guidance documents, and a total of 55 typical drawings in both AutoCAD and MicroStation formats. For each of the 44 different bioengineering techniques, the following information will be provided:

1. Description
2. Purpose
3. Planning
   - Useful For Erosion Processes
   - Spatial Application
   - Hydrologic / Geomorphic Setting
   - Conditions Where Practice Applies
   - Complexity
   - Design Guidelines / Typical Drawings
4. Environmental Considerations / Benefits
5. Hydraulic Loading
6. Combination Opportunities
7. Advantages
Bioengineering techniques are grouped into four major categories, viz., 1) River Training Techniques, 2) Bank Armor and Protection, 3) Riparian Buffer and River Corridor Treatments, and 4) Slope Stabilization. The CD will include a rule-based selection system that relates the hydraulic, geotechnical, and environmental constraints of each technique to site conditions and project constraints to aide the user in selecting an applicable measure. Also included will be reference material “hot-linked” within the various design criteria provided. The material will be considered state-of-the-art when it is due out in late 2004 and will cover the following practices:

**Example 4: Environmentally Sensitive Channel- and Bank-Protection Measures to be Included in NCHRP 24-19River Training**

1. Spur dikes
2. Vanes
3. Bendway weirs
4. Large woody debris structures
5. Stone weirs
6. Longitudinal stone toe with spurs
7. Longitudinal stone toe
8. Coconut Fiber Rolls
9. Vegetated gabion basket
10. Live cribwalls
11. Vegetated Mechanically Stabilized Earth
12. Live siltation
13. Live brushlayering
14. Willow posts and poles
15. Trench fill revetment
16. Vegetated floodways
17. Meander restoration

**Bank Armor and Protection**

1. Vegetation alone
2. Live staking
3. Live fascines
4. Turf reinforcement mats
5. Erosion control blankets
6. Geocellular Containment Systems
7. Rooted revetments
Bank Armor and Protection, cont.
1. Live brush mattresses
2. Vegetated articulated concrete blocks
3. Vegetated riprap
4. Soil & grass covered riprap
5. Vegetated gabion mattress
6. Cobble or gravel armor

Riparian Buffer and Stream Corridor Opportunities
1. Live gully repair

Vanes with J hooks
1. Cross Vanes
2. Boulder clusters

Slope Stabilization
1. Diversion dike
2. Slope drain
3. Live pole drain
4. Chimney drain
5. Trench drain
6. Drop inlet
7. Fascines with Subsurface Drain
8. Flattening
9. Stone - Fill Trenches

Special Topics
43. Bankfull Discharge
1. Bio-Adaptive Plant Response
2. Checklist/Guidelines for Effective Design
3. Combining Techniques
4. Designing Stone Structures
5. Ecological Aspects of Bridge Design
6. Geotextiles and Root Penetration
7. Harvesting/Handling of Woody Cuttings
8. Management of Conveyance
9. Optimal Compaction and Other Strategies
10. Physical Aquatic Habitat
11. Proper Functioning Condition
12. Resistive (Continuous) vs. Redirective (Discontinuous)
13. Revetments to Resist Wave Wash
14. Self-Launching Stone / Well Graded Stone
15. Sources, Species, and Durability of Large Wood
16. The Key to Stability is the Key
61) The Role of Geotextiles and Natural Fabrics

Bank Protection and Stabilization Techniques
Streambank stabilization affects many of the structural characteristics and functions of a stream. These impacts can be viewed as either adverse or beneficial, depending upon the perspective of the individual assigning values to the system. The prevailing philosophy in ecosystem management is that physical alterations of the structure and character of an ecosystem are most significant if they also impact process-based functions. Erosion
control measures are most likely to impact morphological evolution, sediment processes, and habitat, and are least likely to impact the stream’s hydrologic character and the chemical processes and pathways.

River functions most likely to be impacted by stabilization measures include stream evolution processes, riparian succession, sedimentation processes, habitat, and biological community interactions. Those least likely to be impacted include the functions related to hydrologic balance and chemical and biological processes.

Bank protection practices are designed to protect the stream bank from erosion or potential failure. Bank protection practices include practices that are structural in nature, as opposed to practices often grouped as bank stabilization, which tends toward less structural and more vegetation-reliant techniques such as bioengineering, to stabilize streambanks. Bank protection practices are used along stream reaches where eroding streambanks threaten private property or public infrastructure or where available space or highly erosive flows are a constraint.

The most common examples of bank protection practices are rootwad and boulder or riprap revetments. Fact sheets on Bank Protection Techniques, provided by the Washington Department of Fish and Wildlife, cover the following Structural Techniques:

1. Anchor Points
2. Roughness Trees
3. Log Toes
4. Roughened Rock Toes

Bank stabilization practices generally involve regrading the stream banks to a stable angle and geometry, followed by the use of vegetative plantings and biodegradable materials to stabilize the streambank and prevent future bank erosion. Widely used practices within this latter group include coir fiber logs, live fascines and willow plantings. A Caltrans Stormwater Fact Sheet on Stream Stabilization is available online. This source describes Best Management Practices that can reduce the discharge of sediment and other pollutants and minimize the impact of construction activities on watercourses.

A number of the following techniques are also used in river training or channel restoration, are reviewed here rather than in those later sections.

**Riprap**

Riprap usually refers to natural stone (i.e., cobbles, boulders, or broken stone), used for shoreline, streambank, or streambed armoring for erosion control. Riprap has many advantages over other bank protection techniques including: low cost, relatively simple construction techniques as necessary, easily repaired, ability of vegetation to grow between rocks, increasing stability of the bank and improving habitat value of the structure, and performance is not impaired.

Riprap structures can have ecological benefits and can even be used specifically to improve the quality of riverine habitat. Stabilizing stream channels with riprap can reduce sediment loads, improve water quality, and allow re-establishment of riparian vegetation. Stone used in riprap structures provides hard substrate habitat that can be important in some sand bed streams where it might be limited, and spaces between riprap stones provide velocity refuge and cover for aquatic invertebrates and small fishes.

Generally, streams with healthy riparian vegetation communities and the habitat features
associated with such communities (shade, relatively stable undercut banks, large woody debris, etc.) will be harmed ecologically from the addition of riprap structures. On the other hand, habitat may be improved on streams where natural hard substrate is rare or lacking. Systems with excessive erosion due to anthropogenic causes are most likely to benefit ecologically from riprap. According to the literature, the impacts for coldwater fisheries are predominantly adverse, whereas impacts for warmwater organisms are overwhelmingly beneficial. Although a number of variables are involved, this general trend appears to be related to the character of the habitat afforded by the riprap relative to the habitat it replaces and the other habitat in nearby reaches. In most of the warmwater systems studied, coarse hard substrate was very limited, so the addition of riprap provided a habitat niche that was rapidly exploited by a number of species. The Washington State Department of Fish and Wildlife produced a Literature Review of Revetments and found predominantly adverse effects in these cold water environments.

Design Considerations and Practices for Minimizing Environmental Impacts from Riprap

Careful planning can minimize impacts due to construction, and design features can often be incorporated into riprap structures to improve their habitat value. According to the U.S. Army Corps of Engineers, most of the impacts associated with armoring a streambank are the same regardless of whether the armor material is riprap, concrete, vegetation, or a synthetic product; material-related impacts are generally associated with the habitat characteristics of the structure, and the influence of the structure on riparian vegetation. Impacts associated with the use of riprap as an erosion control measure can be minimized by modification of structures and incorporation of the following environmental stewardship practices. Similar modifications can be employed to minimize the impacts associated with riprap used as toe protection in a slope stabilization project.

1. When used as an armor material, minimize riprap impacts by reducing the height of the protection, by increasing the slope of the embankment, and by sizing the riprap to afford adequate habitat within the aquatic environment.

2. Plant the interstices of a riprap revetment with woody vegetation.

Measures to reduce the impacts associated with flow deflection structures incorporating riprap include the following:

1. Carefully locate the deflection structures to minimize impacts to the riparian corridor.

2. Modify the structure design in order to generate desired habitat characteristics within the aquatic environment.

Structure designs that result in diverse conditions or that restore or generate necessary habitat can produce generally positive impacts. The size and gradation of stone for both flow deflection and armor structures can be adjusted to reduce impacts in some cases. Most impacts caused by energy reduction structures are related to the height of the structure. High structures significantly decrease the energy and water surface slope, induce sediment deposition upstream and scour downstream, and can present a barrier to the migration of aquatic organisms. These impacts can be minimized by the following measures:
1. Replace single structures with a series of low-head structures.
2. Incorporate structural modifications to improve sediment continuity and fish passage.

**Construction Practices to Minimize Adverse Environmental Impacts from Use of Riprap**

Construction methods used to place revetments should be carefully reviewed to ensure that they do not contribute to environmental degradation. Construction of a typical riprap structure requires extensive use of heavy equipment, and steps should be taken to minimize damage to riparian vegetation and instream habitats.

1. Plan movement of construction materials to minimize impacts to riparian vegetation outside the area of interest.
2. Conduct riprap placement so as to preserve existing trees along the bank that are not in danger of windthrow or toppling.
3. Regulate equipment operation on the upper banks to minimize soil compaction in the riparian zone, which leads to plant mortality.

Common methods of riprap placement include hand placing; machine placing, such as from a skip, dragline, or some form of bucket; and dumping from trucks and spreading by bulldozer. Hand placement produces the best riprap revetment, but it is the most expensive method except when labor is unusually cheap. Steeper side slopes can be developed with hand-placed riprap than with other placing methods.

1. Where steep slopes are unavoidable (when channel widths are constricted by existing bridge openings or other structures, and when rights-of way are costly) consider hand placement.
2. With machine placement release sufficiently small increments of stone as close to their final positions as practical.
3. Minimize rehandling or dragging operations to smooth the revetment surface, as this tends to result in segregation and breakage of stone, and can result in a rough revetment surface.
4. Avoid dropping stone from an excessive height as this may result in the same undesirable conditions.
5. Minimize riprap placement by dumping and spreading as a large amount of segregation and breakage can occur. In some cases, it may be economical to increase the layer thickness and stone size somewhat to offset the shortcomings of this placement method.

Timing of construction is important when managing for certain impacts.

1. Construction activities should generally be avoided when they will disrupt spawning or nesting activities of nearby sensitive species.
2. Designs that incorporate vegetation may require that the installation occur during the dormant season.
3. Construction activities should generally be abandoned when flows are sufficient to heighten the risk of catastrophic failure.
NCHRP 24-19 will outline environmental stewardship practices for implementing Cobble or Gravel Armor, Vegetated Riprap, and Soil and Grass Covered Riprap. Currently available on-line guidance includes:

1. **Riprap, MD**
2. **Imbricated Riprap, MD**
3. **Riprap, WSDOT**, p. 103
4. **Riprap, WA Fish & Wildlife**, p. 6.67
7. **Spruce Tree Revetments, AK**

**Gabions**

Gabions are stone-filled wire baskets that are used to protect the stream bank from erosive water currents. NCHRP 24-19 will provide guidance for the use of Vegetated Gabion Baskets and Vegetated Gabion Mattress. Meanwhile, guidance is available on-line on implementation of gabions from the Maryland Department of the Environment.

**Toe Protection**

Toe Protection consists of reinforcing bank toes with vegetation, bioengineering methods, or rigid engineering techniques to ensure the dynamic or rigid stability of the stream corridor. NCHRP 24-19 will have forthcoming information on Longitudinal Stone Toe with and without Spurs. Maryland and Alaska have online resources for toe protection as follows.

1. **Toe Protection, MD**
2. **Live Siltation, AK**

**Vegetated Concrete Blocks**

Vegetated Articulated Concrete Blocks or Cellular Concrete Blocks are precast perforated concrete blocks which stabilize slopes or streambanks but also allow vegetation to establish itself through openings in the block. NCHRP 24-19 will provide practice guidance for Vegetated Articulated Concrete Blocks. Meanwhile, practice guidance for implementation is available on-line from Florida:

1. **Cellular Concrete Blocks, FL**, p. 79
2. **Grid Confinement Systems, FL**, p. 75

**Live Crib Walls**

Live Crib Walls are hollow, box-like frameworks of untreated logs or timbers filled with riprap and alternating layers of suitable backfill and live branch layers and are used for slope, streambank, and shoreline protection. They are sometimes used in channel restoration or river training as well. Environmental stewardship practices for live crib walls and vegetated cribbing are available online in the form of fact sheets and guidelines from the following states:
Root Wads
Root Wads are a streambank protection technique that provides immediate riverbank stabilization, protects the toe of slope and provides excellent fish habitat, especially for juveniles. Root wads are particularly well suited for higher velocity river systems and riverbanks which are severely eroded. They provide toe support for bank revegetation techniques and collect sediment and debris that will enhance bank structure over time. Because of their size, root wads usually require the use of heavy equipment for collection, transport and installation. NCHRP 24-19 will cover rootwad revetments. Environmental stewardship practices for live crib walls and vegetated cribbing are currently available online in the form of fact sheets and guidelines from the following states:

1. Root Wads, MD
2. Structure Details For Vanes And Rootwads, NCDOT
3. Root Wads, AK

Live Staking
Live plants can be incorporated into a riprap structure to enhance its habitat and aesthetic value. Live staking (i.e., planting live woody vegetation) of the riprap interstices is common, and root wads can be incorporated into a riprap structure. The woody vegetation enhances the habitat value of the structure, and as an added benefit, it can also increase bank stability and reduce chances of structure failure. In areas where aesthetics are especially important, the stone above the normal high water level can be covered with soil and planted in grasses. Cuttings (live stakes) are the most beneficial means of adding vegetation to riprap structures.

1. Cuttings should be prepared from woody plants that root adventitiously (e.g. Salix spp.), obtained from as near the site as possible, and should be free from obvious signs of disease.

2. To root effectively, cuttings must have good soil/stem contact, (difficult to achieve in many riprap structures) and must be placed to a depth sufficient to access groundwater during drought.

3. Woody cuttings or posts can be placed through many riprap sections using a stinger mounted on an excavator. The stinger creates a pilot hole into which the cutting is inserted. A recently patented procedure allows the installation through riprap of plants that are encapsulated with soil, greatly improving survival, as a lack of soil contact within the riprap section is a leading cause of mortality for plants installed with a conventional stinger. Alaska has added information online under the heading of Dormant Cuttings.

Live staking BMP fact sheets and resources online include:

1. Live Stakes, MD
Large Woody Debris
Research on the effect of wood structures includes both biological and hydraulic study. Large organic debris or large woody debris has an important influence on stream process and morphology by hydraulically controlling areal sorting and storage of sediment, spacing of pool-riffle sequences and channel geometry. Two studies in wood placement examine the effect on trout habitat. Both papers report increases of trout fry and biomass associated with large woody debris. Hilderbrand et al. compared the effect of random design and human judgment-based placement of large wood structures. Their most significant finding was the 146 percent increase in pool area associated with systematic placement opposed to 32 percent pool area increase in random placement. The Washington Department of Fish and Wildlife has produced guidance on Anchoring and Placement of Large Woody Debris that is available on-line. Another Washington document also has guidance on Large Woody Material (p. 88).

Live Fascines
Live fascines are groups of dormant branches bound together to create a log-like structure that will root and grow, quickly providing plant cover. The bundle is used to revegetate and stabilize slopes, secure the toe of streambanks, or provide a transition from one revegetation technique to another (e.g., a brush mat to a live siltation). Bundles are planted in shallow trenches and provide immediate physical protection to a site before plant growth begins. Bundles create small shelves that collect native seeds and water. Environmental stewardship practice guidance on implementing these techniques will be available from NCHRP 24-19 and is currently available from the following states:

1. Bundles (Fascines), AK
2. Live Fascines, MD

Brush Layering or Branch Packing
Brushing Layering is a revegetation technique which combines layers of dormant cuttings with soil to revegetate and stabilize both streambanks and slopes. It is one of the best techniques for these purposes. Living and non-living brush layers provide fish habitat. Branches are placed on horizontal benches that follow the contour of the slope and provide reinforcement to the soil. Steep slopes and streambanks are better stabilized when a biodegradable revegetation fabric is used to hold the soil in place between the plant layers. Additional stability is provided when the front of the soil layer is seeded with grass while the woody plants are becoming established. This technique is sometimes used in channel restoration or river training as well. Branchpacking is another similar revegetation technique which consists of alternating layers of live branch cuttings and compacted backfill to repair small, localized slumps and holes. One of its advantages is that as the plant tops grow, the branchpacking becomes increasingly effective in reducing erosion and runoff. The trapped sediments then refill slumps or holes while the roots stabilize the surrounding area.
Environmental stewardship practices for brush layering are available online in the form of fact sheets and guidelines from the following states:

1. Brush Layering, MD
2. Brush Layering, AK
3. Hedge-Brush Layering, AK

**Brush Mattresses**

*Brush mattresses* are a revegetation technique that provides a protective covering to a slope as soon as it is installed. A brush mat can be constructed with dormant branches of willows and poplar that will root and grow. Alternatively, a brush mat can simply be constructed with any brushy, woody branches to provide effective slope protection from erosion. A brush mat is often combined with other revegetation and/or protection techniques which are used to secure the toe of the slope including root wads, live siltation, bundles, coir logs and spruce tree revetments. **Brush Matting/Live Brush Mattresses** will be covered in NCHRP 24-19. Environmental stewardship practice guidance on implementing these techniques is currently available from the following states:

1. Brush Matting, Alaska
2. Brush Mattresses, Maryland

**Coir Fiber Logs**

*Coir fiber logs* are constructed of interwoven coconut fibers that are bound together with biodegradable netting. Commercially produced coir logs come in various lengths and diameters, and the product needs to be selected specifically for the site. Fiber logs composed of other sturdy biodegradable materials may function equally as well. Applications for coir logs occur in many streambank, wetland and upland environments. The log provides temporary physical protection to a site while vegetation becomes established and biological protection takes over. The logs can provide a substrate for plant growth, protect plants growing adjacent to the log, can be used as a transition from one revegetation technique to another, and used to secure the toe of a slope. Both the upstream and downstream ends of the coir log(s) need to transition smoothly into a stable streambank to reduce the potential to wash out. **NCHRP 24-19** will offer environmental stewardship practice guidance on Coconut Fiber Rolls. Meanwhile, guidance is available on-line in the form of fact sheets and design specifications from the following states:

1. Natural Fiber Rolls, MD
2. Coir Logs, AK
3. Coir Log, WSDOT, p. 31
4. Coir Fabric, WSDOT, p. 29

**Ditch Lining, Turf Reinforcement Mats, and Geocellular Containment Systems**

*Ditch lining* provides a long/short-term erosion resistant lining of the ditch flow line and side slopes utilizing biodegradable or non-biodegradable geo-textile fabrics and/or
angular rock to stabilize ditches and channels from erosion and soil particle movement. NCHRP 24-19 will provide environmental stewardship practice for Turf Reinforcement Mats, Erosion Control Blankets (covered in this document under Erosion Control), and Geocellular Containment Systems.

Research on the use of compost blankets in stream rehabilitation projects has found that although flood events completely submerged the compost blankets and much of the staked vegetation, the compost blanket held in place while some of the woody vegetation was destabilized and/or washed won stream. It may be advantageous to have the compost contained (e.g., in a sock), because rising stream levels submerge the compost.

The Washington Department of Fish and Wildlife has produced guidance on Planting Considerations and Erosion Control Fabric that is available on-line.

Other available resources from North Carolina and Washington include:

1. NCDOT Slope Repairs Adjacent to Jurisdictional Waters, p. 33
2. Concrete Containment (1&2), WA, pp. 34, 37

**Other Vegetative Streambank Stabilization and Bank Protection Practices**

Shields et al studied the effect of specific woody vegetation combined with rock bank protection finding native woody species, especially willow, to be best adapted to streambank environments; however, success of vegetation was successful only in reaches where the streambed was not degrading and banks were stabilized by grading or toe protection. In a similar study, Shields et al combined stone placement with willow planting in a deeply incised sand channel. Stage-discharge, channel geometry and grain size were unaffected, though average depth of scour holes and pool habitat increased along with fish number and size, woody vegetation cover, mean depth and width. Additionally, they reported the occurrence of erosion beneath stones. Shields et.al. also conducted a study on the addition of spurs to stone toe protection indicating a modest increase in overall pool width and habitat availability, and local effects on depth.

Environmental stewardship practices in streambank stabilization and vegetation are included in on-line fact sheets and guidance from the following states:

1. Stream Bank Stabilization (Bio-engineering), WSDOT, p. 141
2. Grass Rolls, AK
3. Transplanting, AK
4. Vegetative Streambank Stabilization, FL, p. 51

**Bioengineering Techniques** provided by the Washington Department of Fish and Wildlife, cover the following:

1. Woody Plantings
2. Herbaceous Cover
3. Soil Reinforcement
4. Bank Reshaping

NCHRP 24-19 also has forthcoming guidance on Large Woody Debris Structures as well as a discussion using “Vegetation Alone” in protecting stream banks.
**Borrow**
This item consists of supplying, loading, hauling and satisfactorily placing additional material necessary to complete embankments to subgrade and other features of the work. Materials should be obtained outside the limits of the ROW.

1. Borrow, New Brunswick, p. 4-14

**Drains and Trenches**
NCHRP 24-19 project lists the following areas in slope stabilization to be discussed in the upcoming publication due in late 2004. Drainage practices discussed as part of this project, NCHRP 25-25(04) include:

1. Diversion dike
2. Slope drain
3. Live pole drain
4. Chimney drain
5. Trench drain
6. Drop inlet
7. Fascines with Subsurface Drain
8. Flattening
9. Stone - Fill Trenches

**River Training and Channel Rehabilitation Techniques**

**Grade Control Structures**
*Grade control structures* are designed to maintain a desired streambed elevation. They can be either used to raise the stream invert to reverse past channel incision or to maintain the channel invert at a current elevation. Common examples of grade control structures are rock vortex weirs and rock cross vanes and step pools.

Low-head stone weirs (LHSV) are boulder structures that extend across the entire bed of a stream channel, and have an effective height of less than 3 ft. The structures are primarily used to prevent streambed degradation, reduce the energy slope to control erosion, create backwater for reliable water surface elevations, and increase aquatic habitat diversity.

Unlike traditional grade control structures, which can adversely impact fish passage, habitat, recreation, and other environmental functions, LHSV are designed to provide stabilization and riffle and pool habitat, reoxygenate water, establish desired substrate characteristics, improve local bank stability, and enhance habitat diversity and visual appeal. LHSV structures are flexible in that their design characteristics can be altered to achieve specific objectives and to address unique site characteristics. LHSV structures are designed to remain stable under the full range of anticipated flow conditions, and to permit fish passage.

All LHSV structures obstruct the flow, creating a backwater area upstream that, at least
temporarily, serves as a pool and reduces upstream erosion. Most concentrate the energy losses in a scour hole or dissipation basin immediately downstream of the structure. They can be designed to arrest bed degradation, or can have virtually no effect upon this phenomenon. The extent to which these and other characteristics are manifested depends upon the structure dimensions, shape and orientation, material, and the character of the stream.

A common configuration for conventional LHSW structures is a V-shaped structure with the apex pointing upstream, a depressed central region to serve as a low-flow notch, and boulders or riprap as a foundation with the ends keyed well into the banks. The dimensions can be varied for effect, but the structure height is commonly set at about the bankfull elevation at the banks, and is generally 0-2 ft above the bed at the apex. The V-shape is intended to concentrate flows in the central portion of the channel and minimize the velocity gradient near the banks. The friction generated by the water flowing over the weir crest causes the streamlines to “bend” approximately perpendicular to the crest alignment. This phenomenon only persists for a narrow range of flow depths (generally less than one fifth the structure height), so on an LHSW with a sloping crest, the effect varies with discharge.

**Log and Check Dams**

Log and check dams are used to pool water and for grade control. The pooled water is used either to create aquatic habitats or to trap sediment runoff from work sites or drainage ditches along the roadside. Following are examples of these dams available online.

1. Log & Rock Check Dams, MD
2. Temporary Rock Sediment Dam Type “B”, NCDOT, p. 60
3. Rock Check Dam, WSDOT, p. 105
4. Step Pools, MD

**Flow Deflection/Concentration Practices**

Flow Deflection/Concentration Practices are designed to change the direction of flow or concentrate flow within the stream channel. The practices within this group may be used to deflect flow away from eroding stream banks, concentrate the flow in the center of the channel, redirect water in and out of meanders, or enhance pool and riffle habitats. Common practices within this group include rock vanes and log vanes.

**Stream Deflectors**

1. Stream Deflectors, MD
2. Wing deflectors
3. Single wing deflectors
4. Double wing deflectors
5. Linear deflector

**Vanes**
1 Cross Vanes MD
2 Rock Vanes MD
3 J-Hook Vanes MD
4 Log Vanes MD

Bendway Weirs
Bendway Weirs are an important tool in current multi-purpose erosion control, stream restoration, and habitat improvement projects. A series of upstream-angled low-elevation stone sills (Bendway Weirs) are designed to control and redirect currents and velocities throughout a bend (and the immediate downstream crossing) of a river or stream. The U.S. Army Corps of Engineers provides an Overview of bendway weirs, What Is A Bendway Weir?, How Do They Work?, Advantages, A Real-World Example, Design Considerations, History And Development, and Applications for Bendway Weirs (Case Studies) along with technical assistance contacts.

Following are some guidelines available online that cover Weirs and Sills:
1 Weirs, MD
2 Cross Vane Rock Weirs, NCDOT, p. 111
3 Sills, NCDOT, p. 110

NCHRP 24-19 Environmentally-Sensitive Channel and Bank Protection Measures will be forthcoming in providing guidelines for the following techniques in the area of River Training (Stream Restoration, Channel Relocation):
1 Vanes
2 Weirs
3 Spur Dikes
4 Bendway Weirs
5 Stone Weirs

Boulder Placement In-Stream for Habitat Creation
Maryland’s Fact Sheet on Boulder Placement describes guidelines for placing boulders in stream channels to encourage riffles and pools and to provide habitat and spawning areas for aquatic life. When properly utilized, boulder placements create small scour pools and eddies which can be used as rearing areas for various species of fish. They can also help restore meanders and pools in channelized reaches and to protect eroding streambanks by deflecting flow. Boulder placements are most effective when used in moderately wide, shallow, high velocity streams with gravel or cobble beds and stream reaches with pool densities less than 20 percent. See guidelines for further details. NCHRP 24-19 will also have information on Boulder Clusters available online in late 2004.

Other Flow Redirection Techniques
Flow Redirection Techniques provided by the Washington Department of Fish and Wildlife, cover the following:
Stream Restoration Evaluation and Monitoring

DOTs evaluate and monitor stream restoration efforts to help determine whether the design objectives have been met and in order to identify needed adjustments to design parameters, installation procedures and/or stabilization methods. The following areas are typically monitored:

1. Proper functioning of stabilization and grade-control structures.
2. Check channel stability by measuring dimension, pattern and profile; particle-size distribution of channel materials; sediment transport; and streambank erosion rates. This is usually accompanied by a reassessment of stream morphology, using permanent cross-section measurement areas.
3. Biological response (i.e., vegetation, macroinvertebrates and fish).
4. Whether the specific objectives of the restoration have been met.
5. On a site-specific basis, shading and temperature are occasionally monitored as well.

Resource agencies generally require photo-documentation to supplement the above. Monitoring often occurs at least once a year for five years after construction.

CTE and the NCDOT developed the evaluation and monitoring recommendations for stream restoration projects as noted in the Appendix:

3.7 Design Guidance for Stormwater and Erosion & Sedimentation Control

All projects should incorporate certain minimum design elements with respect to water quality concerns. Such design goals include the following:

1. **Minimize Impervious Surfaces**: The intent of this goal is to reduce the volume of runoff.
2. **Prevent Downstream Erosion**: Stormwater drainage systems should be designed to avoid causing or contributing to downstream erosion.
3. **Stabilize Disturbed Soil Areas**: Disturbed soil areas should be appropriately stabilized.
4. **Maximize Vegetated Surfaces Consistent with Existing Policies**: Vegetated surfaces prevent erosion, promote infiltration (which reduces runoff), and remove...
pollutants from stormwater. See the following section on design for sustainable, low maintenance roadsides.

NYSDOT’s Operations & Maintenance Manual for Stormwater Facilities contains the following general pre-construction stormwater facility design considerations:

1. Discuss proposed facilities with the Maintenance Environmental Coordinator and Residency personnel.

2. Make facilities visible. Visible structures get more attention.

3. Select low-growing suitable grasses to reduce mowing needs. Add nitrogen fixing plants such as clover to reduce fertilizing needs.

4. Incorporate reference points into basins and other features that require clean-out in regard to an absolute elevation. How would someone know how much sediment has accumulated? Percentage of capacity reduction is difficult to estimate.

5. Consider mosquito control such as introducing natural predators into a permanent pool (for example mosquito eating fish) or placing commercial mosquito traps. Non-native species should not have a means of escape.

6. Features to be maintained must be accessible. Consider access roads, ramps to basin bottoms, sturdy slopes.

7. Trash racks should be accessible at normal pool elevations.

8. Do not plant trees and shrubs on embankments, side slopes or dam areas.

9. Slopes that should be mowed should be 1 on 3 or flatter. If slope is higher than 5 feet, slope should be 1 on 4 or flatter. If steeper, explore other treatment options.

10. For non-vegetated covers, loose stone or rip rap, which encourages the growth of weeds, should be discouraged. Can consider using gabion lining.

11. Consider effects of sediment removal from vegetated surfaces. Can vegetative cover recuperate on its own?

Aesthetic features of the stormwater management facilities requested by municipalities should be maintained by the requester. Commitments by municipalities must be made by signed resolutions. Almost every state DOT has a guide to development of such plans and design of stormwater BMPs. Detailed selection guidance and information on BMP effectiveness will be available from NCHRP 25-20(01) later this year.

**Federally Sponsored Stormwater BMP Manuals**


3. **Stormwater BMP Design Supplement for Cold Climates.** Prepared by the Center
for Watershed Protection for the U.S. EPA.

4 EPA’s Stormwater Website also contains comprehensive reference and guidance materials for construction site stormwater runoff control and post-construction stormwater management in new development and redevelopment, including guidance on implementation of water quality control measures or BMPs and resources on contractor certification and inspector training, construction review, and BMP inspection and maintenance.

State Sponsored Stormwater BMP Manuals
The U.S. EPA Region 10: The Pacific Northwest provides web links to Stormwater BMP manuals from various State agencies: According to a 2003 survey by the author, 54 percent of all the states have developed a Highway Runoff Manual; Caltrans, FDOT, Illinois DOT, MoDOT, Ohio DOT, and TxDOT completed revisions in the last two years. Almost 30 percent of state DOTs have developed manuals for stormwater management at non-highway facilities (AR, CA, FL, GA, IH, MO, MT, NH, NV, WA) and stormwater manuals for construction (AR, CA, FL, GA, IH, IA, IN, LA, MI, MO, MT, NM, OH, WA). Following is list of manuals available on-line:

California
1 California Stormwater Quality Association Stormwater BMP Handbooks
2 Los Angeles Stormwater Program (click “Publications”)
3 California Department of Transportation (Caltrans) Stormwater Quality Handbooks
4 Stormwater Quality Handbook - Project Planning and Design Guide
5 Caltrans Construction Manual includes details for a wide array of construction drawings and standard water quality best management practices.
6 Caltrans Maintenance Manual and Maintenance Stormwater Staff Guide

Georgia
1 Georgia Stormwater Management Manual

Idaho
1 Idaho Department of Transportation (IDT) Design Manual (July 2001)

Illinois
1 Illinois Department of Transportation. Erosion and Sediment Control NPDES for Standard Specifications for Road & Bridge Construction.

Maine
1 Erosion & Sedimentation BMP Manual

Maryland
1. **Maryland Stormwater Design Manual, Volumes I & II**

**Massachusetts**
1. Massachusetts Department of Environmental Protection Stormwater Handbooks

**Michigan**
1. DEQ Index of BMPs/Individual BMPs

**Minnesota**

**Missouri**

**Montana**
1. Montana Department of Water Quality – Stormwater Program – BMPs and Erosion Control Plans

**New Hampshire**

**New Jersey**

**New York**
1. New York State Stormwater Management Design Manual
2. NYSDOT Highway Design Manual

**North Carolina**
1. North Carolina Department of Environment and Natural Resources

**Ohio**
1. Ohio EPA Stormwater Program Index

**Oregon**
1. Department of Environmental Quality Guides

_Pennsylvania_

1 Pennsylvania Handbook of Best Management Practices

_South Carolina_

1 NPDES Stormwater Program Guide
2 Sediment, Erosion and Stormwater Management Program Index to Guides

_Tennessee_

1 Tennessee Department of Environment and Conservation Water Pollution Index to Guides

_Texas_

1 Texas Nonpoint Sourcebook

_Utah_

1 Utah Department of Environmental Quality Stormwater Program Index to Guides
2 West Valley City Stormwater Utility Best Management Practices
3 Utah DOT Roadway Drainage Manual of Instruction

_Virginia_

1 Northern Virginia Regional Commission Best Management Practices
2 Virginia Department of Conservation & Recreation BMP Guides
3 Virginia DOT Drainage Manual

_Washington_

1 WSDOT 2004 Standard Specifications for Erosion Control (Section 8-01)
2 WSDOT Standard Plans Section I - Erosion Control
3 WSDOT Temporary Erosion Sedimentation Control (TESC) Plan Template
4 WSDOT When is a TESC plan needed?
5 WSDOT 2004 Highway Runoff Manual
Wisconsin

1 Wisconsin Construction Site Erosion Control and Stormwater Management Procedures

Wyoming

1 Urban Best Management Practices for Nonpoint Source Pollution

State Stormwater BMP Manual Builder

The Stormwater Manager’s Resource Center has developed a “Manual Builder” on-line, a toolbox for developing a stormwater treatment practice (STP) design manual. It includes stormwater treatment plan design and construction criteria and provides schematics and graphics for each practice. It also provides information about maintenance requirements and the typical local review process for treatment plan design and construction. As manuals need to be customized to meet the needs of the state or community where they are being applied, the manual builder does not prescribe one specific set of criteria, but instead presents a series of options for stormwater managers to choose from. A good manual contains specific guidance on how to select, size, design, construct, and maintain practices at each development site. A typical manual will contain the following elements:

1 Basic Stormwater requirements.

2 Procedures for Reviewing Stormwater Plans. In this section, the manual outlines the process a community should go through to review the stormwater plan.

3 Basic Sizing Criteria. The manual needs to identify minimum sizing criteria for practices to meet groundwater recharge, water quality, channel protection, and flood control requirements.

4 List of Acceptable Practices. The manual should include a list of practices that can meet water quality requirements. An engineer can choose from this menu of practices to treat stormwater runoff from a new development.

5 Performance Criteria. The performance criteria provide required minimum elements and guidance to ensure that practices are designed and maintained to ensure practice longevity and performance.

6 Guidance on STP Selection. This section presents criteria to guide the design engineer to select the best practice for the site, based on characteristics such as soil type, site slope, and the local watershed conditions.

7 Stormwater Credits. Stormwater credits are reductions in stormwater volume requirements given in exchange for incorporating site design techniques that minimize the need for STPs on the site. Many manuals do not incorporate credits, because they can increase the burden of review on local governments substantially.

8 Design Examples. Design examples step the engineer through designs for a
representative group of STP design variations. They should illustrate how to select, size, and locate the practice on the site.

9 Construction Specifications. Construction specifications detail specific materials and construction standards that ensure that the practice will function as designed.

10 Checklists for Construction Inspection. These checklists outline what minimum elements are needed for each practice group during construction.

In addition to extensive design guidance available in both manual and on-line formats, a number of BMP selection and evaluation systems are emerging. NCHRP 25-25(01) is designing a BMP effectiveness and evaluation system that will be available in late 2004. MDSHA has developed an evaluation system for all stormwater facilities and criteria for improvements. In the late 1990s WSDOT and FDOT also developed systems for categorizing outfalls and, in the case of WSDOT, assessing which projects provide the best return on investment in terms of environmental effectiveness and pollution reduction. WSDOT’s system included a condition indexing methodology and support program that enables users to quickly evaluate and compare projects and generate benefit-cost ratios for projects.

3.8 Drainage Ditches, Berms, Dikes, and Swales

Ditches, berms, dikes and swales are temporary or permanent measures used to intercept and direct surface runoff to an overside/slope drain or stabilized watercourse, away from the road. Several variations of ditch treatments include raised curbs, berms, vegetated, rock-lined, and lead out ditches. Raised curbs, or berms, are used to prevent water from entering or exiting the roadway. Numerous lead out ditches are typically installed to remove water impounded by the curbs and release it where water can be handled appropriately, with minimal resource damage.

Ditch treatments can be used on roadsides, trails, parking areas, urban and rural settings, and any other place where managing runoff is important. A scoured, entrenched roadside ditch and the presence of gullies on the downslope side are indicators that a ditch treatment may be necessary. Ditches, berms, dikes and swales are usually implemented for the following purposes:

1 To convey flow around maintenance activities.
2 To divert flow away from maintenance stockpiles.
3 At the top of slopes to divert run-on from adjacent slopes and areas.
4 At bottom and mid-slope locations to intercept sheet flow and convey concentrated flows.
5 At other locations to convey runoff to overside/drains, stabilized watercourses, stormwater drainage system inlets (catch basins), pipes and channels.
6 To intercept runoff from paved surfaces.
7 Along roadways and facilities subject to flood drainage.

Vegetated ditches are ditches with vegetation to reduce water velocities, and erosion control grass mixtures are typically used to vegetate ditches. Vegetated ditches help improve the quality of stormwater that runs off a highway by slowing water velocities.
and trapping sediment, metals, nutrients, petroleum products, pesticides, bacteria and other contaminants.

**Lead out ditches** are built to carry water away from the roadway, onto grassed or forested areas, allowing infiltration and dispersion of water. *Rock or stone-lined ditches* reduce velocities and capture sediment in the interstices. Maintenance cleaning is required when trash or debris have accumulated.

**Temporary diversion dikes** are intended to divert overland sheet flow to a stabilized outlet or a sediment trapping facility during establishment of permanent stabilization on sloping, disturbed areas. When used at the top of a slope, the structure protects exposed slopes by keeping upland runoff away. When used at the base of a slope, the structure protects adjacent and downstream areas by diverting sediment-laden runoff to a sediment trapping facility. This practice is considered an economical one because it uses material available on the site and can usually be constructed with equipment needed for site grading. The useful life of the practice can be extended by stabilizing the dike with vegetation.

**Design and Construction Considerations and Practices for Ditches, Dikes, and Swales**

Caltrans has an excellent Fact Sheet on Earth Dikes/Drainage Swales and Lined Ditches available on-line, which provides implementation guidance, drawings, specifications, and maintenance considerations. The EPA and Florida DOT have online information on permanent diversions and diversions. Diversions are preferable to other types of constructed stormwater conveyance systems because they more closely simulate natural flow patterns and characteristics. Flow velocities are generally kept to a minimum.

Recommended environmental stewardship practices for implementation of ditches, berms, drains, swales, and diversions include:

1. Evaluate risks due to erosion, overtopping, flow backups or washout.
2. Consider outlet protection where localized scour is anticipated.
3. Examine the site for run-on from off-site sources.
4. Conveyances should be lined if high flow velocity is anticipated. Consider use of riprap, engineering fabric, asphalt concrete, or concrete.
5. Establish adequate vegetation as soon as possible after installation of a diversion.
6. Stabilize the drainage area above the diversion so that sediment will not enter and accumulate in the diversion channel.
7. Diversions should be constructed before clearing and grading operations begin. If used to protect a flat, exposed area, a diversion might be constructed as a dike or berm. Berms made of gravel or stone can be crossed by construction equipment.
8. Diversions should have stabilized outlets which will convey concentrated runoff without erosion. Acceptable outlets include paved flumes, stormwater conveyance channels, outlet protection, and level spreaders. Outlets should be constructed and stabilized prior to the operation of the diversion.
9. Disturbed areas draining into the diversion should be seeded and mulched prior to or at the time the diversion is constructed.
10 Permanent diversions should include a filter strip of close growing grass maintained above the channel. The width of the filter strip, measured from the center of the channel, should be one-half the channel width plus 15 feet (4.5 m).

11 Unless otherwise stabilized, the ridge and channel should be seeded and mulched within 15 days of installation in accordance with permanent seeding.

12 If the diversion dike is going to remain in place for longer than 30 days, it is very important that it be established with temporary or permanent vegetation.

13 The slope behind the dike is also an important consideration. If the channel slope is less than or equal to 2 percent, stabilization may not be required. If the slope is greater than 2 percent, the channel should be stabilized in accordance with BMPs for stormwater conveyance channels.

14 Whenever feasible, the dike should be built before construction begins on the project.

15 The dike should be adequately compacted to prevent failure.

16 The dike should be located to minimize damages by construction operations and traffic.

**Slope Diversions for Intercepting Stormwater**

Diversions are channels constructed across a slope with a supporting ridge on the lower side, to reduce slope length and to intercept and divert stormwater runoff to stabilized outlets at non-erosive velocities. On moderately sloping areas, they may be placed at intervals to trap and divert sheet flow before it has a chance to concentrate and cause rill and gully erosion. Diversions may be placed at the top of cut or fill slopes to keep runoff from upland drainage areas off the slope. They can also be used to protect structures, parking lots, adjacent properties, and other special areas from flooding.

Diversions are often constructed:

1. Where runoff from higher areas may damage property, cause erosion, or interfere with the establishment of vegetation on lower areas.
2. Where surface and/or shallow subsurface flow is damaging upland slopes.
3. Where the slope length needs to be reduced to minimize soil loss.
4. Below stabilized or protected areas. They should not be used below high sediment producing areas unless land treatment practices or structural measures, designed to prevent damaging accumulations of sediment in the channels, are installed with or before the diversions.

- Diversions should not be placed on slopes greater than fifteen percent.

**Level Spreaders**

Level Spreaders are outlets for dikes and diversions consisting of an excavated depression constructed at zero grade across a slope whereby concentrated runoff may be discharged at non-erosive velocities onto an undisturbed area stabilized by existing vegetation. Their purpose is to convert concentrated runoff to sheet flow and release it onto an area stabilized by existing vegetation. This practice applies only in those
situations where the spreader can be constructed on undisturbed soil and the area below the level lip is stabilized by natural vegetation. The water should not be allowed to reconcentrate after release.

1. Level spreaders should be constructed on undisturbed soil (not fill material).

2. The entrance to the spreader should be shaped in such a manner as to insure that runoff enters directly onto the 0 percent channel.

3. The level lip should be constructed on zero percent grade to insure uniform spreading of storm runoff.

4. The released runoff should outlet onto undisturbed stabilized areas in sheet flow and not be allowed to reconcentrate below the structure.

### 3.9 Design for Sustainable, Low Maintenance Roadsides

An ecologically based program of roadside vegetation design and management seeks to produce low-maintenance, self-sustaining plant communities. WSDOT defines sustainable roadsides as those roadsides that are designed and maintained with the intent of integrating successful operational, environmental, and visual functions with low life cycle costs. The use of native plants planted in the right location is integral to achieving such a sustainable system. This requires good stewardship practice in design:

1. **Include a Landscape Architect in the design development process** to improve the design, environmental and visual quality of the roadsides, and chances of planting success.

2. **Consider construction requirements such as site accessibility and constraints such as contract timing in design documents.**

3. **Ensure noxious weeds are addressed and not incorporated in plantings.** Check with the state’s noxious weed control board for a list of noxious weeds in the state if not available through the DOT.

4. **Review and comments on plans during the development of the plans, specifications and engineering (PS&E).** Maintenance review (such as by the maintenance supervisor in charge of the contract area) is essential because DOT maintenance crews often maintain landscape projects after installation.

5. **Have project partners review design documents and plant material selection prior to installation.** Some projects have special partnership arrangements, for example, the DOT might require the project sponsor or partner to maintain plant communities. Project sponsors have included cities, counties, tribes, transit agencies, and other agencies, who can often contribute labor, funding, and materials.

Integrated vegetation management plans, though oriented to Maintenance needs and covered in detail in that section, also provide guidance in design for sustainable, low maintenance roads. According to the interim report for NCHRP 20-5, 33-04, to be
published in late 2004, Alaska, Arkansas, Connecticut, Florida, Illinois, Indiana, Maryland, Pennsylvania, South Carolina, Texas, and Washington indicated that they have policies that include vegetation management considerations in project planning and design phases, and Florida, Indiana, Maryland, Ohio, and Pennsylvania have performance measures for roadside design.

**Pre-Construction Soil Considerations**

Sustainable, vigorous plant growth is difficult to achieve on degraded soils from which topsoil has been removed by construction or erosion. Studies have indicated that plant available levels of phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S), micronutrients, soil acidity or salt are unlikely to limit plant growth on barren materials. Low plant available nitrogen (N) and poor soil physical characteristics that result in poor root development and low water holding capacity remain the most likely and common reasons for poor plant growth, aside from insufficient water.

The observation that nutrient deficiency may be a cause of the decline of plant cover is thought to result from the absence of topsoil as a growth medium; during construction the topsoil is often buried beyond the reach of plant roots by fill material (crushed, unweathered, siltstones and metamorphic sediments). The loss of topsoil and humus removes the major source of available plant nutrients and reduces soil structure, nutrient retention capacity and microbial activity. Microbial activity is reduced because the loss of organic matter eliminates the food supply of plant decomposing microorganisms; with death, the microbial nitrogen is available for leaching from the plant-soil cycle. A continuing supply of plant-supplied carbon prevents this loss.

In nutrient deficient soils, mycorrhizal fungi typically function to increase nutrient acquisition by plants. This occurs when certain fungi colonize the plant root and form a mutual relationship called a mycorrhizal infection. In this beneficial infection the plant provides energy for the fungi while the fungi provide nutrients for the plant. The loss of the topsoil removes the fungal spores or hyphae which are required to begin the infection. The plant is then left without either the original nutrient rich topsoil or the mycorrhizae necessary to improve uptake.

Claassen et al. have performed a large percentage of the studies on topsoil usage and compost, with funding from FHWA and Caltrans. Their work and recommendations augment that of DOT handbooks, and are summarized in the remaining bullets in this section.

1. **Stockpile topsoil.** Topsoil harvest, stockpiling and reapplication is strongly recommended wherever possible as the best method for reestablishment of plant communities on disturbed soils. Equivalent levels of chemical fertilizer cannot substitute for the benefits provided by topsoil reapplication. Topsoil provides, in addition to available nutrients, slow release nutrient reserves, improved soil structure and water holding capacity, increased microbiological activity for nutrient cycling and retention, increased mycorrhizal infection, and a potential source of native seed.

Because of its high soil organic matter content, topsoil is an excellent method of providing the slow release, high N content needed to regenerate barren slopes, as it contains the well stabilized, slow release N needed to reestablish plant
Stockpiling of topsoils apparently has little or no negative impact on topsoil quality. Caltrans studies of stockpiled and reapplied topsoils found that storage of topsoil material in a stockpile for periods of up to five months is an acceptable method of handling these materials during construction; topsoil nutrient content and biological quality was not degraded. Infection potential of mycorrhizal fungi did not decrease during stockpiling. Topsoil reapplication improved plant growth by 250 percent after three years compared to fill slopes which had no topsoil, with equivalent application of all other nutrients, erosion control and seed materials.

Topsoil fraction had to exceed 20 percent of soil volume before significant improvements in plant growth and soil characteristics occurred. Higher rates are recommended in more severe environments. Plant and mycorrhizal production peaked in the 60 percent treatments. The researchers extrapolated these greenhouse results to field situations by recommending 10-20 cm (4-8 in) topsoil application over fill material, if available. If a volume of topsoil equivalent to less than 2 cm (1 in) topsoil is available, it should be concentrated in smaller volumes such as in furrows or roughened surface, rather than being spread thinly over the slope surface.

The soil material which should be harvested includes the “duff,” including decomposed, broken or chipped plant material and the mineral soil material down to the color change from the darker topsoil to the redder or grayer subsoil.

Use of moderate amounts of fertilizer can be used to increase the total amount of mychorrhizal infected plants roots. Moderate fertilization improved plant growth without decreasing mycorrhizal root production. Mineralizable nitrogen was shown to be predominantly derived from soil microbes. Chemical fertilizers cannot by themselves regenerate soils, but their moderate use in conjunction with topsoil application was shown to be beneficial in promoting both plant growth and increased total mycorrhizal infection. Rates of P amendment should be limited to the range of the 39 kg P/ha (35 lb P/ac) treatment because the mycorrhizal infection dropped off significantly when the P rates were doubled.

2 Develop a plan for stockpiling and redistribution within the contract’s order of work. Washington State DOT makes the following recommendations with regard to developing a plan for soil preservation; e.g. a plan to stockpile and redistribute existing topsoil within the contract’s order of work.

Perform a site analysis

Examine proposed planting areas for any apparent drainage problems. Note any underlying characteristics that might affect drainage (hardpan, compacted subsoil, clay layers, and so forth.). Plan to correct deficiencies or plant appropriate species.
- Analyze soil for susceptibility to erosion from stormwater runoff.
- Determine solar exposure of slopes (slope aspect) and its effect on soil and vegetation.
- Conduct a plant inventory or a germination test to determine seed bank to decide if topsoil stockpiling is practical. An examination of the site with an inventory of existing vegetation is necessary prior to determining when to use existing topsoil. Stockpiling of topsoil might not be advisable when noxious weeds and their seeds are present. Consult with a Landscape Architect for assistance. Imported topsoil can be used to provide a medium for plant growth when native soil has been removed or is highly disturbed.
- Determine where to stockpile soil on-site and the extent of clearing and grading.
- Set clearing and grubbing limits to minimize soil disturbance. In some areas grubbing is unnecessary. Stumps and root systems may be left in the soil to provide stability. Decomposition of trees varies in time depending upon species and climate, but all decomposition provides nutrients, organic matter, and habitat for microorganisms.

724) **Perform a soil analysis** (type, compaction, and fertility), including a soil test to determine nutrient content and pH of soil.

- Obtain a soil sample bag or a plastic bag capable of holding approximately one quart of soil.
- Select a representative area for the sample. If the soil seems to vary in color and composition within the project area, sample those soils also.
- Dig a hole 300 to 460 mm (12 to 18 inches) deep and set the material to the side. Scrape off a small amount of material from the top to the bottom of the side of the hole and place into plastic bag. Do not include any material taken from the hole initially. Refill the hole with the set aside material.
- Locate the test pit on the site map. If more than one sample is taken from the site, number the test pits to correspond with the samples taken.
- Seal the bag tightly and place in a manila envelope and write all the information on the paper surface: name, date of sampling, site location, and sample identification (such as test pit #1). Fill out Soil Test Form and include it with the sample; box or wrap sample for mailing; and send the soil sample to a soil chemistry lab.
- Consult with the Landscape Architect for specific amendment recommendations when test results arrive, if necessary.

724) **Analyze the soil for compaction.** Appropriate soil treatment is crucial for the success of roadside restoration (including erosion prevention seeding). Soil
Compaction can be tested using the bulk density test. Test the soil to a depth of 0.6 m (2 feet). If the density is greater than 80 percent, take steps to break up the compacted soil. Contact the regional Materials Engineer for assistance.

- Pay close attention to areas that have been, or will be, staging areas. These areas will have to be ripped to restore pore spaces between the soil particles. Rip compacted soils, ideally in two directions, to a minimum depth of 460 mm (18 inches) before planting. The roots of most plants are above this depth.

- Specify in all contracts that the contractor has the responsibility to restore the soil to a less than 80 percent density in all staging areas. Higher compaction rates are allowed in areas that are critical for road or structure stability. Include the costs of these procedures as part of the contract. The contract should not be closed until this step is completed.

1. **Revegetation success should not be based on short term growth increases in the first season or year**, but performance and biomass production in the 3-5 year range.

2. **Maximum slope design for topsoil application should be 1½:1 for fill slopes and 2:1 for cut slopes.** Placement to topsoil on steep slopes can lead to sloughing.

3. **Where topsoil is not available other amendments can be used, but the quantity and quality of the N materials applied is critical.** The N release should be **slow enough to keep plant-available N at modest levels**, but the total amount of N amended should be high enough so that the site does not run out of N before the plant community is well established. The N amendment should be **able to support three to five years’ plant growth**, for example. Controlled release of N is important because excessive N availability promotes weedy annual grass growth, drying out the site and crowding slow growing perennials. While the maintenance of moderate, sustained nitrogen levels may be achieved from commercial, slow release fertilizer sources, the inclusion of organic matter in the amendment is also important to improve the hard setting and poor water holding capacity of low organic content materials.

4. **Biomass associated with compost has been more effective than N amendments** that were evenly disturbed throughout the profile (0-30 cm) or applied deeply within the profile (20-30 cm). Studies of plant communities established on “problem soils” amended with commercial fertilizers have shown vigorous initial growth, but that vegetative cover often becomes sparse or nonexistent within several years. **In addition to transportation related studies, those of fertilized mine reclamation spoil observed that revegetated areas tended to be highly productive for two to five years followed by a sharp decline in plant growth and nutrient availability.** Reapplication of topsoil to subsurface materials enhanced reestablishment of vegetation by increasing nutrient availability, water holding capacity, and microbial activity. **Compost can be used to replace the organic matter and nutrients and can act as a surface mulch to**
Long-term nitrogen release rates from most yard waste compost materials approached the N release rates of moderately fertile soils. Composts were shown to be able to regenerate the N availability characteristics of low-nutrient substrates that have been stripped of topsoil organic matter. Well-cured composts and co-composts (biosolids blends) approached the N release rates of highly fertile soils. Compost application provides longer N release duration compared to chemical fertilizer and also provides organic materials for improved infiltration and microbial activity.

1 Potential compost sources and soils at the site should be analyzed before amendment, as compost products and the soils that are to be revegetated vary in fertility and water availability. Even after adequate N fertility amendment, some sites may still support insufficient plant cover if water or other nutrient deficiencies restrict plant growth. Improved soil and compost tests can guide selection of appropriate amendments to harsh and variable site conditions.

2 As compost materials are variable from producer to producer and variability in source material, processing method and curing time have significant effects on field performance, an interim recommendation is to apply in the range of 72 Mg/ha (dry weight) compost to extremely low-nutrient sites and in the range of 36 Mg/ha compost to low- or moderate- nutrient sites, or sites with shallow soils. Incorporate into the top 15 cm if possible. Plant-available N on drastically disturbed sites (on which the majority of the topsoil and organic matter has been removed) can typically be regenerated with a 500 to 1000 kg N/ha application of typical, common yard waste compost. This N application rate is roughly equivalent to 36 to 72 Mg/ha dry weight of compost (32, 143 to 64,286 lb/ac), or a volume of 85 to 170 m³ (45 to 90 cu yd/ac), or a thickness of 0.84 to 1.7 cm (3/8” to ¾”). This rate can be reduced for sites that are not as nutrient poor as drastically disturbed sites.

3 The compost material should be moderately to well cured, meaning 3 to 6 months curing after the thermophilic compost process is to support plant growth. Recognizing the variability of compost N release behavior, the site should be monitored to detect if plant growth is too slow so that supplemental N can be applied if needed.

4 Yard waste composts need to be aged in order to achieve desirable rates of nitrogen release. Caltrans research showed that nitrogen (N) release rates change with time with a long-term incubation experience, and that extended curing after thermophilic composting increases N release rate. Long-term N release rates were in the range of the reference topsoils. Finely screened (<9 mm) compost can be applied with hydroseeder equipment, but this application method benefits from the addition of other structural material (straw, coarse wood fibers) to improve erosion control on barren slopes. The findings support the use of compost as a primary erosion control and soil amendment. In addition, there is an environmental and social benefit derived from using these waste-stream materials for erosion control.
Avoid poorly composted or poorly cured materials, which will not be biologically stabilized and can have atypical effects. Information on checking compost processing is available at the Composting Council Research and Education Foundation and at website for the UC Workshop on Compost Use for Pest Management. Cautions regarding use of uncomposted materials, especially in coastal regions are also found online.

Give special consideration to certain categories of materials, for best utilization in field situations to avoid negative impacts on field sites.

- **Fibrous or poorly cured yard waste composts can have an initial period of N immobilization** when high carbon materials are being decomposed. This period may last from several months to several years. Additional available N may need to be added to support plant growth N during this period.

- **Fibrous or poorly cured yard waste composts may benefit soils in other ways than just N availability.** Composts are rich sources of other nutrients as well as organic materials that improve water infiltration into the soil and water retention within the soil. The continued decomposition of compost by soil microbes further helps build soil aggregates, which improves drainage and water retention. If weed seeds and pathogen propagules have been killed, uncured materials can be used as surface mulches, or incorporated if N immobilization is not a problem. Do not transport infested, uncomposted materials to uninfested areas.

- **Co-composted materials (biosolids blends) have much larger N release rates than yard waste composts.** Co-composts should be used at about one half to one quarter of the amount of yard waste compost or at sites with rapid plant growth to absorb the higher N release rates. Because of the slow rate of N release, most hard waste composts are expected to have small or non-existent potential to leach N to watercourses, even when using large amendment loadings.

- **Sites with residual fertility (topsoils not completely removed, or some soil material has been re-applied to the site) may not need compost amendment.** Additional N may accelerate weed growth. Surface applied wood chip mulches may provide erosion control, microbial activity and mulch effects (temperature and evaporation protection) without the additional fertility of a composts material.

- **Non-composted materials may produce phytotoxic compounds during decomposition.** Any unprocessed plant material amendments other than wood chips should be stabilized using EPA regulation (40 CFR, part 503c) thermophilic composting, which sterilizes against weed seed and pathogen propagules.

While composts are shown to be able to replace the N release function of native soil organic matter, the best method for revegetation is still to harvest, stockpile and reapply the native topsoil that was on the site before disturbance. The quality of the organic matter is better, the harvested soil has better aggregate
structure, the soil contains microbial inocula and site adapted plant seeds, and the costs are often less than regeneration of soil fertility from component parts. Extra steps may be needed to eliminate weeds, such as spraying, tillage or incorporation of topsoil beneath the surface.

**Plans, Specifications, and Estimate (PS&E) for Soil Preparation**

The challenge to the roadside designer is to specify the appropriate soil preparation for planting, to prevent soil erosion, and to achieve desired soil structure. Appropriate soil preparation, including possible amendments, is crucial for the success of desirable roadside revegetation.

1. Specify **soil amendments** to achieve revegetation and restoration requirements.

2. Specify **structural soils** if needed in urban environments. The Urban Horticulture Institute at Cornell University has developed a cost effective structural soil mix that can improve the survivability of street trees in urban environments. The mix is:
   - 80 percent angular stones ¾ to 1¼ inch in diameter.
   - 20 percent topsoil with organic matter content of 10 percent.
   - Soil stabilizer per the manufacturer’s specifications.
   - Potable water – enough to cause soil to coat the stones without having water run off.

Angular stones form a skeleton that provides the weight-holding capability for the mix. Specialized compaction tests are not needed with this mix. The water-storing polymers bind the stones together and stabilize the soil mix. In addition, this structural soil mix leaves a large volume of rooting space that allows the plants to get oxygen and water. More information can be found at the website for the **Society of Municipal Arborists**.

3. Specify wide-track construction equipment in contract documents when it is necessary to work in wet soils.

4. Specify stripping topsoil and stockpile for redistribution after completion of rough grading. This is the best source of native seeds but it is also a source of exotic invasive vegetation and noxious weeds. (The plant inventory and germination test performed during the site analysis determine what plants are growing in the soil.)

3. Assess the entire project for other places to use removed topsoil. Restoration sites are practical locations to place excess topsoil.

**Planning for Native Vegetation and Consistent Roadside Design**

A Federal Executive Memorandum on beneficial landscaping became effective in April of 1994, encouraging the use of native plants as much as practicable on all federal lands and in all federally-funded projects. In 2000, this EM was incorporated into **Executive Order 13148**, on the Greening of Government. That EO also required agencies to purchase “environmentally preferable and recycled content products, including compost...
and mulch, that contribute to environmentally and economically beneficial practices.”

The following considerations and specifications are recommended environmental stewardship practices in designing with native vegetation.

1. Use natural region maps commonly available from the State’s Natural Heritage Program instead of cold hardiness zones when designing with native plants. Visit native plant preserves that can serve as references for plantings. The State Natural Heritage Program can recommend sites.

2. Use seed mixes specific to the different conditions on the site. Dry conditions may be present on sandy slopes or forest edges and wet conditions in ditches, requiring different or adjusted mixes in these areas.

3. Eradicate weeds from planting site before planting.

4. Consult with Native American groups and others who use native (and other) plants for food, basketmaking, and medicine, to avoid adverse effect on their plant use and to develop partnerships where feasible.

5. Consider a line item for the contractor to control weeds and clean equipment.

6. Plant as much diversity as possible, unless an adjacent native seed source exists.

7. Match site microclimates with distinct seed mixes as much as practical.

8. Specify a locally-grown or collected source if possible. Most native species will establish more easily if locally grown or collected.

9. Order native seed when the contract is let to prevent unwanted substitutions.

10. Limit bids to experienced contractors and approved vendors for these projects.

11. Separate the planting contract from the general contract for best timing.

12. Extend the establishment period to three years.

13. Learn appropriate seed test criteria and seeding rates to avoid waste.

14. Plan for seed collection and plant salvage if native remnants will be disturbed by the project.

The following resources may assist designers. The Natural Areas Association, an international nonprofit with a mission to preserve natural diversity, provides information on appropriate management of natural areas. Nature Serve Explorer is an online encyclopedia for 50,000 plants and ecological communities of the United States and Canada. With the common or scientific name of a plant, it is easy to locate the life history, distribution map, and more. The Center for Plant Conservation site offers a State by State Directory of conservation contacts, and the Northern American Plant Society provides an easy way to contact state and provincial native plants plant societies. The Native Plant Initiative, an interagency coalition, has worked together to share information and resources to improve public awareness, educate their own forces, increase planting success, and more. Their Plant Conservation Alliance is online. USDA Natural Resources Conservation Service provides a national plants database. USFWS provides a national list of plant species that occur in wetlands.
WisDOT Uses STURRA to Fund the Ongoing Use and Preservation of Native Plants
WisDOT utilized the 1987 Surface Transportation and Uniform Relocation Assistance Act (STURAA) to fund the ongoing use and preservation of native plants. STURRA contains a mandatory requirement that native wildflower seeds or seedlings or both be planted as part of landscaping projects undertaken on the Federal-aid highway system. At least one-quarter of one percent of the funds expended for a landscaping project must be used for native wildflowers. WisDOT established a waiver which allows the agency avoid planting native wildflowers where doing so would be inappropriate, but bank the unused dollars for larger projects in the future. WisDOT also banks native plant communities where possible.

WSDOT’s Roadside Classification Plan
Roadside management at WSDOT encompasses roadside planning, design, construction and maintenance. The agency identified their primary challenge in roadside management as preservation and restoration of roadside character and to fulfill roadside functions, regardless of fluctuations in funding and personnel. To this end, WSDOT developed a Roadside Classification Plan that provides WSDOT employees a consistent policy to follow on roadside character classifications and appropriate treatment levels for revegetation. The RCP is extensive roadside vegetation management guidance that coordinates and guides all aspects of the management of Washington State highway roadsides. It includes treatment level guidelines for Forest, Open, Rural, Semiurban, and Urban roadside character classifications and treatment tools to restore roadside character in those environments, using native plants, Integrated Vegetation Management, and a long-term management approach to achieve sustainable roadsides.

Designing for Salt Resistant Vegetation
To ensure long-term survival of vegetation in high salt exposure environments, the Transportation Association of Canada makes the following suggestions:

1. Avoid planting sites in heavy runoff collection areas such as depressions.
2. Landscaping should be planted on the back side of ditches to permit maintenance access and ensure that salt laden roadway runoff is not directed towards plants.
3. In urban areas protect newly planted conifers by erecting burlap screens during the winter months.
4. In urban areas consider applying anti-desiccants and anti-transpirants to the tender shoots of sensitive plants.
5. Use species tolerant of salt laden runoff. The following categories of species may be considered:

Example 5: List of Salt Tolerant Trees and Shrubs

Salt Tolerant Trees

Common Horsechestnut (*Aesculus hippocastanum*)
Serviceberry (*Amelanchier canadensis*)
Maidenhair Tree (*Ginko biloba*)
Honey Locust (*Gleditsia triacanthos*)
Tulip Tree (*Liriodendron tulipifera*)
Colorado Blue Spruce (*Picea pungens glauca*)
Mugho Pine (*Pinus mugho*)
Austrian Pine (*Pinus nigra*)
Jack Pine (*Pinus banksiana*)
Hop Tree (*Ptelea trifoliata*)
White Oak (*Quercus alba*)
Red Oak (*Quercus rubra*)
English Oak (*Quercus robur*)
Black Locust (*Robinia pseudoacacia*)

**Moderately Salt Tolerant Trees**

Amur Maple (*Acer ginnnala*)
Manitoba Maple (*Acer negundo*)
Yellow Birch (*Betula alleghaniensis*)
Paper Birch (*Betula papyrifera*)
White Ash (*Fraxinus americana*)
Large-toothed Aspen (*Populus grandidentata*)
Trembling Aspen (*Populus tremuloides*)
Cottonwood (*Populus deltoides*)
Black Cherry (*Prunus serotina*)
Japanese Pagoda Tree (*Sophora japonica*)
Eastern White Cedar (*Thuja occidentalis*)

**Salt Intolerant Trees**

Balsam Fir (*Abies balsamea*)
Red Maple (*Acer rubrum*)
Sugar Maple (*Acer saccharum*)
Silver Maple (*Acer saccharinum*)
Eastern Redbud (*Cercis canadensis*)
Shagbark Hickory (*Carya ovata*)
Black Walnut (*Juglans nigra*)
Ironwood (*Ostrya virginiana*)
Norway Spruce (*Picea abies*)
Red Pine (*Pinus resinosa*)
White Pine (*Pinus strobos*)
Scot’s Pine (*Pinus sylvestris*)
London Plane Tree (*Platanus acerifolia*)
Douglas Fir (*Pseudotsuga menziesii*)
Basswood (*Tilia americana*)
Littleleaf Linden (*Tilia cordata*)
Hemlock (*Tsuga canadensis*)

**Salt Tolerant Roadside Shrubs**

Silverberry (*Elaeagnus commutata*)
Sea Buckthorn (*Hyppophae rhamnoides*)
Common Ninebark (*Physocarpus opulifolius*)
Choke Cherry (*Prunus virginiana*)
Staghorn Sumac (*Rhus typhina*)
Buffaloberry (*Shepherdia canadenis*)
Snowberry (*Symphoricarpus albus*)
Japanese Tree Lilac (*Syringa reticulata*)

**Moderately Salt Tolerant Shrubs**

Forsythia (*Forsynthia ovata*)
Red Cedar (*Juniperus virginiana*)
Mock Orange (*Philadelphus coronarius*)
Smooth Sumac (*Rhus glabra*)
Elderberry (*Sambucus canadensis*)

**Salt Intolerant Shrubs**

Grey Dogwood (*Cornus racemosa*)
Red-osier Dogwood (*Cornus stolonifera*)
Winged Euonymous (*Euonymous alatus*)
High-bush Cranberry (*Viburnum trilobum*)

### 3.10 Designing to Reduce Snow, Ice, and Chemical Accumulation

The environmental stewardship practices profiled in this section are intended to increase the roadway and bridge designer’s awareness and consideration of techniques, configurations, and design parameters to reduce the amount of snow and ice accumulation, and thus sand, salt, and other chemical applications.

**Designing Roads to Minimize Snow Drift**

Understanding the cause of snow drift accumulations and designing to minimize the causes can reduce the severity of an icing problem, thus lowering salt usage. A significant amount of the snow that needs to be removed from roadways is deposited through drifting. Throughout all phases of roadway development (route location, planning, preliminary design and detailed design) the designer has the opportunity to make decisions regarding the location, configuration, and design details of the facility, which will affect the potential for snow and ice accumulation and the actual application of salt throughout the life of the facility.

Benefit to cost ratios for permanent snow fences, based only on reduced costs for snow removal range from 10 to 35:1, depending on the quantity of blowing snow, according to the National Research Council. It costs 3 cents to intercept and divert a ton of snow with a snow fence over the life of the fence, and $3 to plow the same amount of snow. Wyoming DOT reports that with the installation of snow fences along Interstate 80, snow removal costs dropped as up to 50 percent and the accident rate during snowy, windy conditions fell by up to 70 percent.

Level of service and safety are often improved as well. The Alaska Department of Transportation and public works videotaped snow accumulation on test sections of roadway where it had installed snow fences in order to extend the season in which the roadway was opened. Snow accumulation on the roadway in areas protected by the fences ranged from zero to one meter, but the accumulation on the sections of road without fence protection reached nearly three meters. In the spring, crews took two to four days to clear unprotected sections, whereas only two hours were needed to clear protected sections. Other benefits included reduced labor costs, reduced wear and tear on maintenance equipment, and a safer work environment for road crews. Drifting problems can be increased by poor roadway and bridge design and decreased by good design. By promoting the infiltration of water under pavement, snowdrifts can contribute directly to pavement damage. In addition to serving as a water source, drifts can adversely drainage by blocking ditches, drains, culverts and wildlife crossings. Reduced wind speed areas caused by changes in grade, vegetation, plowed snow banks, safety barriers, and bridge...
abutments can cause snow accumulation affecting the roadway and/or bridge if the obstructions are close enough to the travel lanes. Drifting can also be controlled through the erection of drift control devices such as snow fence and snow ridges at the proper distance from the road.

1 As a guiding principle, designers should consider maintenance requirements when determining the location, concept designs, preliminary designs and final designs for roadway infrastructure. Research and case studies have confirmed that there is a direct relationship between certain roadway design parameters, and snow and ice accumulation. It is possible that the incorporation of features to minimize snow and ice build up into a roadway or bridge design will add to the capital cost. However, it is also clear, however, that from a broader life-cycle view, such initiatives are likely to increase safety and reduce maintenance costs throughout the life of a roadway. These trade-offs and value engineering on a life-cycle basis should be considered as an integral part of route location, preliminary design and detailed design.

The Transportation Association of Canada has outlined the following factors to consider in Roadway and Bridge Planning Design to minimize snow accumulation and salt usage:

Example 6: Factors to Consider in Roadway and Bridge Planning Design to Minimize Snow Accumulation & Salt Usage

Meteorological Data
Roadway maintenance staff are often familiar with local conditions and are a source of useful “hands on” information. The following meteorological data should be obtained as background information:

- Average daily and annual snowfall.
- Prevailing wind directions and speeds.
- Storm directions and the amount of snowfall typical to a winter storm.
- Mean monthly temperatures and expected winter extremes.
- Number of freeze/thaw cycles.

Surrounding Terrain

- The terrain surrounding a site will affect the amount of snow that can drift towards the roadway or bridge.

- In establishing the location of a new roadway alignment bear in mind that the upwind terrain is key. The distance from the alignment to any major upwind features (e.g., a ridge, a heavy tree line, a building line, etc.) is referred to as the “fetch”. The bigger the fetch, the larger the snowdrift potential and the larger the problem on the roadway or bridge.

- The surface of the upwind fetch area is also a major concern. A “smooth” area such as frozen water or short grass will not trap snow and hence will not assist in reducing drifting conditions. Rougher terrain, such as ploughed fields, crop stubble, long grass, shrubs or particularly mature trees with dense winter branch structure, will trap snowfall and may reduce the potential drifting conditions at the roadway or bridge.

Interchanges
Complex wind flows are associated with interchanges and usually it is necessary to conduct a model study to fully assess conditions.

- From the point of view of snow accumulation, a roadway with a higher level of service (LOS) should cross over roadway with lower LOS as prevailing winds would blow snow off major roadway.
- Open style abutments should be considered over closed abutments to reduce snow accumulation, although the higher cost of open style abutments, and their typically rural nature may dictate the use of closed abutments in many instances.

Roadway Shading / Exposure to Sun
In areas of high tree cover, consider:

- Winter altitude and azimuth (bearing, measured clockwise from true north) of the sun.
- Potential shadow effects of the tree cover which will affect the potential for ice melting on the road surface. Trees should be cleared back far enough to maximize the heating effect of the sun.
- Similar considerations should be given to site conditions where vertical walls are part of the roadway design. In this case, the vertical wall should be replaced with a sloped embankment if possible.

Elevated Road on Fill Section
With divided roadways and a median width which will allow the establishment of independent grades for the two directions of travel, it is desirable to set the elevation of the upwind lanes lower than those of the downwind lanes, or at least, at the same elevation as the downwind lanes.

- Preferably the top of pavement should be approximately 1 m above typical snow depths in the area.
- If possible eliminate the need for safety barriers, and therefore, the obstruction that causes snow drifting with slope flattening of fill side slopes. Ideally, side slope should be flattened to 7:1 for effective snow accumulation.
- Generally, a road cross-section totally on fill without significant terrain features upwind is more likely to blow clear of snow than any other design configuration.

Wide Ditches
Wide ditches provide storage for plowed snow which otherwise would be piled along the edge of the roadway and would promote more snow accumulations.

Use of Guide Rails
- Box beam / cable guide rails have the least obstruction and in theory, accumulate the least amount of drifted snow but in practice, plows push snow against box beam / flex beam to create a solid barrier therefore, for the purposes of snowdrifting / accumulation, assume all barriers are solid.
- Solid Jersey barrier is easiest to plow against.
- Tall solid barrier has increased drifting area and increased shaded area.
- Flex-beam guide rail, in theory, collects the largest amount of drifted snow.
- Reduce the need for barrier at side of roadway through slope flattening.

Berms for Snow Accumulation
- Locate berms unpwind of the roadway, setback 7 times the berm height.
To obtain the maximum snow collection capacity, maximize the berm height and ensure berm slopes are as steep as practical.

One tall berm is more efficient at accumulating snow than a number of rows of shorter berms.

To maximize the effectiveness of tree plantings, locate trees on a berm. However, the setback should be 15 times the combined height of the berm and coniferous tree planting.

**Backslope**

Flatten upwind backslope (ideally 7:1 or flatter) to minimize drifted accumulations on roadway.

- With roadways in cut sections, consider a wider cut on the upwind side than on the downwind side, ideally meeting the 7:1 minimum gradient discussed above. If the roadway cut is a source of material for other sections of the roadway, consider taking the majority of the material from the upwind side of the cut.

**Obstruction Close to Roadway**

- Obstructions that can cause snow accumulation problems are as follows: trees too close to road; mail boxes; utility poles; guide rails; plowed snow banks; and fence rows.
- Consideration should be given to eliminating / minimizing these obstructions if they are causing snow accumulation problems.
- Where possible locate obstruction on downwind side of roadway.
- As a general rule of thumb a 50 percent solid obstruction (snow fencing, vegetation) should be placed a distance of 15 times its height from the edge of roadway, on level ground. A solid obstruction (buildings, double vegetation) should be placed 10 times its height on level ground.
- Noise walls do not typically present a problem with snow accumulation as they usually are located in residential areas that limit snow movement towards the wall and the roadway, however snow drifting at end details should be considered.

**Vegetation Management**

With appropriate landscape design, many snow drifting problems could be solved or lessened. Similarly, improper design or placement of vegetation can aggravate a snow accumulation problem (particularly at interchanges).

- Before vegetation is removed for the construction of new roadways (or for existing roadway improvements) designers should evaluate existing site conditions in order to determine whether or not existing vegetation could prevent a snow related problem or could cause a future snow related problem. Preserving existing vegetation is more economical and time efficient than planting new vegetation. This approach also allows existing vegetation to be incorporated into new landscape plans.
- The objective of upwind snow fences (non-living or living) is to encourage a snow drift immediately downwind of the fence or vegetation with the result that little snow is left to drift onto the roadway.
- Upwind vegetation planting can have a similar effect to snow fences providing the configuration and location is appropriate and the planting is not close to the roadway.
- Plants with dense branch structure will hold snow to approximately one half its height. Trees and woody plants are better as they do not tend to bend as much under the weight of the snow.
• Corn stalks left in agricultural fields on the upwind side can slow wind speed and reduce drifting and blowing snow. Five or six rows of corn with a similar setback to that shown in Figure 13 will be effective in reducing snowdrifts.

• Uncut grass in the ROW is better than cut grass as it keeps snow from blowing with the exception of grass directly adjacent to the roadway, which ideally should be cut short to avoid drifts that would extend onto the roadway.

• If there is sufficient land area available, at least 60 meters, a snowbreak forest is a viable option. However, a much more economical solution for new roadways is to retain existing forest. This saves the time required for newly planted vegetation to reach their required height. Snowbreak forests also provide substantial benefits to wildlife and may be managed for timber production.

• As the transportation right-of-way is usually too small to accommodate the setback required for living snow fences, cornrow fences, snowbreak forests or even structural snow fences; it may be necessary to enter into land use agreements with private landowners.

Urban Considerations
In an existing urban environment, little can be practically done to reduce snow accumulation, as roadway rights-of-way are constrained and adjacent lands typically built-up; accumulated snow is removed as per the municipalities’ snow removal program.

• Snow storage in an urban environment is often a challenge and consideration should be given to providing larger cul-de-sacs, bicycle paths and wider curb lanes (especially across bridges) for temporary snow storage, where appropriate.

Drainage
Good roadway drainage will lead to reduced ice accumulation, and as such reduced salt usage (this includes intersecting roadways and accesses as well as the main roadway).

• Set maximum and minimum grade to help maintain an even distribution of salt, and to allow melted ice/snow to drain to catch basin.

• Optimize salt usage by using lower superelevation rates (to help maintain even distribution of salt).

• Use crowned roadways, and good crossfalls (2 percent-3 percent).

• Mark all culvert ends to make them easier to locate for cleaning and thawing activities.

Pavement Choice in Salt Vulnerable Areas
• Though open friction course asphalt or grooved concrete pavements will shed surface brine more quickly, they can reduce salt spray and therefore may be beneficial in proximity to areas that are vulnerable to the effects of salt spray.

SHRP Report H-381, Design Guidelines for the Control of Blowing and Drifting Snow, also describes how to design effective and economical measures for controlling blowing and drifting snow, including various snow fence designs to accommodate land use and right-of-way considerations; considerations for pavement design and appurtenances; proper siting of snow fence to compensate for terrain; and ways to use trees and plants as natural snow fences. The field research and sources of information are included too.

Designing Snow Fences
Highway segments with wide, open stretches are vulnerable to blowing snow accumulation on the surface and reduced visibility for roadway users. Traditional snow fences are designed to permit 40–60 percent airflow, slowing the wind and piling the snow safely downwind. The Strategic Highway Cooperative Research Program’s Snow Fence Guide provides construction plans and guidelines for placement of snow fence for maximum effectiveness and cost-efficiency, as well as ways to work with landowners to obtain cooperation with a snow fence program.

Consideration should be given to the use of roadside plantings or solicited cooperation from local municipalities to require land owners/developers to include plantings in their buffer zone plans to curtail drifting. Another means is to request farmers to leave corn stalks high where the land adjoins a state highway.

If properly designed, tree plantings can be as effective as structural snow fences. The requirements for effective living snow fences are the same as those for structural snow fences:

1. Adequate snow storage capacity
2. Absence of openings or gaps
3. Adequate setback

Snow Fence Site Design and Placement Tools

_WYDOT and NYSDOT Software_

For nearly 30 years the Wyoming DOT (WYDOT) has been using snow fences to prevent blowing and drifting snow from covering roads and impairing motorists’ ability to see other vehicles, reducing maintenance costs and salt application and runoff to the environment at the same time. To ease the process of determining exactly which sections of road will be affected by blowing and drifting snow and where snow fences should be placed or the topography should be changed to keep roads clear, WYDOT developed software tools based on research conducted under the Strategic Highway Research Program (SHRP).

The research resulted in precise guidelines for placing snow fences for maximum benefit, using average snowfall, winter temperatures, wind speed and direction, and the project site’s topography. The WYDOT software handles virtually all the steps in the SHRP guidelines, from assembling the needed weather information to determining the location of a snow fence. The system has two components. The first is a set of computerized maps containing information on prevailing winds and average snow accumulations. The second component is a customized snow drift module that works with commercial roadway design software. The snow drift module, which uses the formulas in the SHRP guidelines, determines where snow drifts will form based on prevailing weather conditions and the project site’s topography. The module determines if the site’s weather conditions and topography will cause a snow drift to form on the road and plots the shape and location of the drift (Figure 6-1 below). If the user adds a snow fence upwind of the road, the module plots where the drift will form, showing at a glance that the fence will protect the roadway (Figure 6-2 below). Designers can also change the topography of the road to prevent a drift from forming.

NYSDOT has contracted with the State University of New York–Buffalo and Brookhaven National Laboratory to develop a similar software program that will allow roadway design engineers and maintenance engineers to enter readily available or easily
obtained information on weather and topography and then determine the best approach to snow drift control at the site—redesigning the highway cross-section, installing snow fences, or planting trees or other vegetation. The ability to look at different solutions makes the software particularly useful for states where the lack of public land and the relatively high population density can make it hard to find suitable locations for snow fences.

**Figure 5: Projected Snow Drift with and without Snow Fence in Place**


*Mn/DOT Snow Fence Design Module*

Mn/DOT funded a team of researchers and practitioners to develop a model to determine proper mitigation strategies, including appropriate living snow fence design. Entitled *Implementation of Climatological Summaries for Blowing Snow Control: Design, Training, and Website Development*, the project investigated several climatological factors such as snowfall season (onset and end date), snowfall amount and density, and wind frequency distributions.

To check for potential problems when designing a roadway or solve a drifting problem on an existing roadway, two parameters must first be quantified. These are the total seasonal snow transport, and the direction of greatest snow transport. Research results from a previous project provided the necessary climatological data to quantify these parameters on a site-specific basis. The three attributes that are required are: 1) length of snow season, 2) snowfall during the season, and 3) the potential snow relocation coefficient based on topography, wind speed, and vegetative cover. Data were analyzed using a database containing the climatic history of 370 locations, some dating back to the 1850s. With this information, a web-based snow-control design module was developed that allows users to obtain necessary climatological attributes for various road and snow fence designs. The web site is an interactive snow control design tool utilized by design/pre-design Mn/DOT personnel and natural resource managers. With it designers can utilize this site to:

1. Obtain necessary climatological information for GEOPAK,
2 Test for problems on an existing roadway and investigate possible solutions, and
3 Design a living or structural snow fence for a given problem area. The web
environment allows the user to select any location in Minnesota and in so doing;
necessary climate information will be given.

Plastic Snow Fence Research Results
Research on the configuration of the openings in plastic snow fence by the North Dakota
Department of Transportation indicated that the configuration did not have a bearing on
the amount of snow that accumulates in front of the fence; however, the Morton County
road crew who installed and maintained the fence made the following observations:

1 Plastic fence is easy to handle, not near as bulky as wood fence. A two-person
crew can handle the installation.
2 It is critical to have a good installation, solid end posts, and midway supports such
as lath. If end posts loosen, the fence will sag and become ineffective.
3 There is considerable variation in the quality of the fence, with some types tearing
more easily and some that are more difficult to handle.
4 More maintenance is required with plastic fences than with wood fences.
5 The effectiveness of plastic fence in holding back snow appears to be as good as
wood fence.
6 Costs of plastic fence vary considerably. Usually plastic fence is considerably less
costly than wood fence; however, a high-quality plastic fence may cost almost as
much as wood fence and should have a useful life considerably longer than a
wood fence, since wood slats and wire tend to break.

Living Snow Fence
All of the principles pertaining to snow fences apply to vegetative barriers as well, but
guidelines for plantings must consider the variability or irregularity of height and
porosity, and how these factors change with time. In addition, biological requirements
must be considered in the planting and maintenance of living snow fences, as well as
ecological factors that affect survival and growth. For these reasons, designing living
snow fences requires the knowledge of agronomists, foresters, landscape architects, and
engineers. Living snow fences include rows of trees and shrubs that, if planted in the
right location, can cause snow to accumulate in a more convenient area and can also
improve visibility during and after snowstorms. Considering direct and indirect costs,
living snow fences cost about the same as structural fences.

Living Snow Fence Placement and Design
The following guidelines for living snow fence placement and design were developed by
Mn/DOT:

1 To improve visibility and/or prevent drift accumulation on highway sections in
areas where there is 10,000 feet of “fetch distance” (open distance perpendicular
to the centerline), a living snow fence should be planted 250 feet from the
centerline. Note that normal rights-of-way are typically 75–100 feet from the
centerline, but that planting on existing rights-of-way may extend drift 
formation onto the road surface. In these situations, additional right-of-way 
should be purchased, or easements obtained, to plant the snow fence. In areas 
where the “fetch distance” is only a few thousand feet, a living snow fence 
planted 100 feet from centerline will still be effective. 

2 A strip of tall grasses 12 feet wide will actually trap the snow and hold it. Native 
grasses are an attractive addition to farmsteads and field borders because they 
remain upright during the winter and provide wildlife with excellent cover for the 
winter and nesting habitat in the spring. 

3 Proper design of a living snow fence involves three key elements: height, density, 
and length. 

4 Height: This affects the snowdrift length and depth. Snow storage capacity 
increases by more than four times when the height is doubled. Typically, 
vegetative barriers should be set back from the area to be protected 10–15 times 
the mature height of the vegetation. 

5 Density: This affects both windward and leeward snowdrift lengths and heights. 
The species, number of rows, and plant spacing determine density. Winter density 
of deciduous trees must also be considered. Density should be uniform with no 
openings and gaps. 

6 Length: This determines the maximum length of the area that can be protected. 
Less snow is stored at the ends of barriers, so the snow fence must extend 100 feet 
beyond the area to be protected. 

Strategies in the Use of Plant Materials 
There are two basic approaches to the use of plant materials to control blowing snow: 

1 Snow collection – Trapping incoming blowing snow with rows of trees or shrubs 

2 Snow retention – Holding the snow in place with grass, shrubs, or trees. These 
control measures will be referred to as retention plantings. 

The latter strategy is applicable where the source of the blowing snow is confined to the 
immediate vicinity of the road, such as embankment slopes, medians, and interchange 
areas. 

Selecting Plants for a Living Snow Fence 
Trees and shrubs suitable for drift control should have relatively dense foliage that 
extends to ground level. General recommendations include: 

1 Use dense foliage species that are fast growing; resistant to drought, frost, and 
disease; unpalatable to livestock and wildlife; tolerant of crowding without 
shedding lower branches; and should have a service life of 30 to 50 years. 
Secondary considerations include ornamental value and value for cover and food 
for wildlife. Coniferous species have the advantages of year-round dense foliage 
and relatively low palatability for wildlife. Deciduous trees and shrubs can also 
be used, but more rows are generally required and many species are browsed 
preferentially by livestock and wildlife.
2 Use plants that are adapted to site conditions such as soil pH, soil moisture extremes, and soil texture. County extension services can provide information regarding general conditions, but the advice of a forester or agronomist should be sought for recommended species for climate and soil conditions at specific sites.

3 Avoid self-pruning species.

4 Avoid plants for which a major insect or disease is known to cause problems with establishment and long-term survival. Most plants have characteristics that make them susceptible to one or more problems, such as insects, disease, and storms. Although in most cases pest- and weather-related problems are minor concerns, selecting a variety of plants with similar growth and site requirements can minimize the risk of a single problem destroying the snow fence planting.

5 Shrub rows between the road and tree plantings provide a temporary control until the trees become fully effective.

6 The best in-row spacing for coniferous trees is approximately 2.4 m (8 ft), with rows spaced 2.4 to 3 m apart (8 to 10 ft). Three rows are recommended to reduce the possibility of gaps forming when trees die.

The Minnesota Interagency Living Snow Fence Task Force developed “winning combinations” for snow fences, based on observations made during the winter of 1996–1997, site visits, past experience, and recent work understanding snow transport. The required fence height and setback for any of these combinations is based on the principal of snow transport. Design criteria can be obtained from the 1999 publication titled “Catch the Snow with Living Snow Fences,” published by Mn/DOT Office of Environmental Services. The five winning combinations for use as a living snow fence are:

1 Twin row tall grass native prairie snow catch
2 Twin shrub row
3 Deciduous tree windbreak
4 Vertical side community shelterbelt
5 Structural snow fence

Partnerships with Farmers to Leave Standing Corn
Iowa DOT is using standing-corn snow fences to save about 75 percent of the cost of erecting snow fences. In several Iowa counties, farmers are paid 50 cents more than market price to leave four to six rows of corn standing in areas where there are major problems with drifting snow on the roadway. This natural snow fence also helps improve visibility during snowstorms. Farmers benefit by a fair price for their corn, which is often picked by nonprofit groups in the spring. If the corn is given away at that time, the farmers may deduct the value of the corn as a charitable donation.() Minnesota DOT will pay $1.50 more than the current bushel price for cornstalks that farmers leave standing in their fields to act as living snow fences. Mn/DOT determined that one 40-foot-wide, quarter-mile-long snow fence is capable of capturing 11,800 tons of snow, minimizing snow and ice on roads and decreasing removal costs.()
Designing Drainage to Minimize Anti-Icing and Deicing Impacts to Natural Resources

The main purpose of any road drainage system is to safely convey runoff downstream to either a natural or man-made drainage system. Management measures should be implemented to ensure that this is done with minimal impact to the infiltration characteristics, water quality, erosion potential, and flood risk of the receiving drainage system. Training for drainage designers should include design options for managing the adverse effects of snow and ice control chemicals. Drainage designers need to consider the environmental setting into which their drainage system will be placed. The Transportation Association of Canada’s synthesis of best practice for doing so recommends the following:

1. At the onset of any drainage design, sufficient information should be collected to characterize the existing drainage system surrounding and downstream of the roadway.

2. A surface water assessment should be completed to identify all potential impacts to natural features as a result of the roadway. The assessment should include a review of the impacts of salt-laden surface water on potable water taken from groundwater sources, sensitive aquatic habitat, agricultural lands, wetlands, and wildlife. The requirements of the assessment are defined by the policy framework in the area where the drainage design is being completed. Specific site characteristics may require that other features be considered as well. The impact potential identified for all significant features assists in the selection of suitable mitigative measures.

Oregon DOT recommends review of the following environmentally sensitive areas and natural resources:

- Spawning streams and those inhabited by protected aquatic species, especially salmon and trout.
- Those receiving direct runoff from treated roads & highways where there would be less than 100:1 dilution.
- Those where a large volume of highway runoff can directly reach small, poorly flushed ponds, lakes and wetlands.
- Those where receiving water temperatures have warmed by the time highway runoff arrives.
- Those areas where shallow ground water is overlain by very coarse and permeable soils.
- Drywells, French drains, or similar facilities that allow surface water access to underground aquifers.

1. The relative importance of each feature as defined by low, medium or high potential for impact should be established. Further guidance on considering impacts to various classes of resources is included below. The potential for salt impacted drainage to affect each of these vulnerable areas should be assessed.
Groundwater
The suitability of groundwater for potable use and irrigation can be significantly impaired by the infiltration of salt captured by roadway runoff. For example, the Maine DOT noted that road salt is gradually accumulating in bedrock aquifers, causing some drilled wells to become unusable. The rate at which salt enters aquifers and how much salt is eventually discharged naturally from aquifers is unknown, making prediction of long-term impacts problematic. In 2004, Maine DOT decided to establish two sites where new highway construction is proposed for monitoring well installations over the next five years.

To determine the potential for impact from salt-laden runoff on groundwater, the following questions must be addressed:

1. Are there domestic wells near the roadway?
2. If there are wells, do they draw from a surficial aquifer?
3. Are the surficial soils permeable (sands and loams)?

Aquatic Habitat Impacts
Salt-laden runoff can potentially impact aquatic habitat in two ways: sudden pulses of chlorides during spring runoff, and continuous levels of chloride present in the groundwater discharging to the receiving stream. Although both types of impacts are a concern, the literature generally points to sudden pulses as the greater concern. With either type of impact, the existing literature is not clear on “how much is too much.” The following provides a guideline for assessing the potential impact:

1. High: The receiving watercourse has a permanent baseflow, and the catchment area of the road represents more than 10 percent of the catchment area of the stream.
2. Medium: The receiving watercourse has a permanent baseflow, and the catchment area of the road represents less than 10 percent of the catchment area of the stream.
3. Low: All other cases (i.e. receiving watercourses with no permanent baseflow).

Agricultural Land
Salt-laden runoff can impact crops in cases where there is the potential for water to pond on agricultural lands. This situation can arise where there is poor positive drainage or an outlet has been blocked by ice or debris. Guidelines for assessing potential impacts are as follows:

1. High: Agricultural land is adjacent to the road, and off road drainage has a high likelihood of ponding or blockage.
2. Medium: Agricultural land is adjacent to the road, and off road drainage has a low to moderate potential for ponding or blockage.
3. Low: Agricultural land is either outside the road runoff influence zone, or there is no agricultural land adjacent to the road.
Wetlands
Swamps, peat bogs, marshes, and other types of wetlands can be impacted where runoff is directed to natural roadside vegetation features. In these cases the runoff may enter the wetland as sheet flow or via a roadside ditch. With very high and prolonged chloride loading, changes in local plant composition may occur, with the possibility of a reduction in the overall value and diversity of the wetland. Small, perched wetlands that intercept the shallow water table or that are primarily surface water dependant may be most susceptible to chloride loading effects due to their small size and a reduced dilution potential. Large wetlands with extensive catchment areas and high dilution potential are likely more tolerant of chloride loading. Potential impacts may be classified as follows for wetlands located adjacent to the roadway:

1. High: No clear flow path evident through the wetland and/or small perched roadside wetlands present (<5 ha in size).
2. Medium: Poorly defined channel evident through the wetland and/or moderate sized wetland with better dilution potential (5 -20 ha in size).
3. Low: Clearly defined channel evident through the wetland and/or large wetland with good dilution potential (>20 ha in size).

Wildlife
Ponded runoff can serve as a salt source for wildlife. The attraction of the wildlife to the saltwater can be a safety hazard. Potential impacts may be classified as follows:

1. High: Roadway located in an area where large mammals (such as elk, big horned sheep, white-tailed deer and moose) are present and where roadside ponding is a current problem or has a high potential based on design limitations and topography.
2. Medium: Roadway located as above but roadside ponding is not a current problem or has only a moderate potential based on design limitations and topography.
3. Low: Roadway located as above but there is no existing or future roadside ponding problem, or large mammals are limited or absent in the area.

Structural Roadside BMPs to Control Deicing and Anti-Icing Chemical and Abrasive Laden Runoff
The range of potential impacts from salt-laden runoff offers considerable challenges to the designer. There are a number of practices that can aid in the management of runoff, however each practice may mitigate some types of impacts while accentuating others. For example, promoting rapid conveyance of runoff to a receiving watercourse will reduce the potential for impairment of potable groundwater while increasing potential impacts on aquatic environment. Special design modifications to traditional stormwater management measures may be warranted to protect vulnerable areas. Measures to protect salt vulnerable areas may include clay or geosynthetic liners in conveyance ditches and ponds, infiltration ponds, or use of storm sewers to transport drainage past vulnerable areas.

The Transportation Association of Canada (TAC) recommends consideration of eight
alternative management practices, which are often used to achieve other drainage objectives and may be used in combination to effectively minimize impacts related to salt rich surface drainage.

1 **Records should be kept on the chloride or conductivity levels and snow and ice control events to determine how the levels fluctuate around an event and whether BMPs are having the desired effect.** The analyst will want to be able to draw conclusions on whether or not the applications of best salt management practices are having an effect on the chloride levels in the aquatic environment. It will be important to determine whether or not drops in chloride levels can be attributed to improved practices and not just different weather conditions. This will require coordination with Maintenance.

TAC’s table below illustrates the merits of each management practice in addressing the potential impacts that can result from salt-laden runoff. Practices which benefit groundwater impacts are typically consistent with those that benefit agriculture, wetlands, and wildlife. However, most of these practices have the potential to negatively impact aquatic resources. Thus, measures should be selected as part of the overall management strategy formulated to achieve overall drainage and stormwater management objectives. In cases where objectives are conflicting, the practitioner must review each site on its own merits and set priorities such that the overall impacts are minimized. In addition to local policy frameworks, design information for these measures can be found in numerous technical documents relating to stormwater management.

<table>
<thead>
<tr>
<th>Management Practice</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Sheet Flow</td>
<td>Runoff conveyed across grass buffer strips or embankments.</td>
</tr>
<tr>
<td>2 V-ditch</td>
<td>Runoff conveyed by roadside ditch to receiving watercourse.</td>
</tr>
<tr>
<td>3 Storm Sewer</td>
<td>Runoff conveyed away from sensitive areas using storm sewer system (negligible infiltration potential).</td>
</tr>
<tr>
<td>4 Flat Bottom (Trapezoidal) Ditch</td>
<td>Runoff conveyed by roadside ditch with flat bottom ditch.</td>
</tr>
<tr>
<td>5 Flat Bottom (Trapezoidal) Ditch with Storage</td>
<td>Runoff conveyed by flat bottom ditch which includes on-line storage to trap sediment and reduce velocities and runoff rates.</td>
</tr>
<tr>
<td>6 Dry Basin (Pond)</td>
<td>Runoff directed to stormwater management basin designed to reduce runoff rates and promote sedimentation.</td>
</tr>
<tr>
<td>7 Wet Basin (Pond)</td>
<td>Runoff directed to stormwater management basin designed to reduce runoff rates, promote sedimentation and enlarge biological uptake.</td>
</tr>
<tr>
<td>8 Buffer Strip and Containment Berm</td>
<td>Berm designed to contain runoff within buffer strip, with positive outlet provided to prevent flooding and sustained water levels.</td>
</tr>
</tbody>
</table>

From Transportation Association of Canada, “Syntheses of Best Practices: Road Salt Management.”

**Table 3: BMP Characteristics and Impact on Minimization of Salt-Related Impacts - Transportation Assoc. of Canada**
### Snow Disposal and Snow Storage Site Design

At high latitudes, snow plowed from streets accumulates rather than melts. As plowed snow accumulates and exceeds available storage space along streets, it is hauled to central storage areas and placed as a compact snowfill. A portion of the applied grit and salt, as well as fugitive pollutants from vehicles, becomes incorporated into hauled snow. Heavy metals, inorganic salts, aromatic hydrocarbons, litter, debris, and suspended solids accumulate on road surfaces along with oil, grease, rust, hydrocarbons, rubber particles, and other solid materials deposited by vehicles. Runoff, snow, and melt water collect these pollutants, along with debris, and chloride, sodium, and calcium from winter road operations. Such contaminants become pollutants when they interfere with the normal life cycle functions of organisms living in or dependent on the water source.

The Alaska Department of Transportation and Public Facilities (ADOT&PF) is synthesizing best management practices (BMPs) for handling and treating the melt water snow storage areas, including performance requirements for runoff treatment in the

<table>
<thead>
<tr>
<th>Management Practice</th>
<th>Characteristics</th>
<th>Feature that May be Impacted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Groundwater</td>
</tr>
<tr>
<td>Sheet Flow</td>
<td>Disperses runoff</td>
<td>-</td>
</tr>
<tr>
<td>V-Ditch</td>
<td>Channels runoff</td>
<td>+</td>
</tr>
<tr>
<td>Storm Sewer</td>
<td>Channels runoff with little opportunity for infiltration</td>
<td>+</td>
</tr>
<tr>
<td>Flat Bottom Ditch</td>
<td>Channels runoff&lt;br&gt;Some attenuation of flow rate&lt;br&gt;Some sediment trapping&lt;br&gt;Some potential for infiltration</td>
<td>0</td>
</tr>
<tr>
<td>Flat Bottom</td>
<td>Channels runoff</td>
<td>-</td>
</tr>
<tr>
<td>Ditch with</td>
<td>Attenuates flow rate &lt;br&gt;Some sediment trapping &lt;br&gt;Some potential for infiltration</td>
<td></td>
</tr>
<tr>
<td>Dry Basin (Pond)</td>
<td>Attenuates flow rate &lt;br&gt;Sediment trapping &lt;br&gt;Potential for infiltration</td>
<td>-</td>
</tr>
<tr>
<td>Wet Basin (Pond)</td>
<td>Attenuates flow rate &lt;br&gt;Sediment trapping &lt;br&gt;Potential for infiltration</td>
<td>-</td>
</tr>
<tr>
<td>Buffer Strip and Containment Berm</td>
<td>Contains and disperses runoff</td>
<td>-</td>
</tr>
</tbody>
</table>

**Legend:**

+ The identified management measure may reduce the level of impact from salt-laden runoff (i.e. The level of impact potential for a feature may be decreased from high to medium, medium to low, etc.).
- The identified management measure may increase the level of impact from salt-laden runoff (i.e. The level of impact potential for a feature may be increased from low to medium, medium to high, etc.).
0 The identified management measure will have minimal effect on the level of impact potential.

From Transportation Association of Canada, “Syntheses of Best Practices: Road Salt Management.”
various water quality management jurisdictions and climatological regions, potentially applicable technologies/BMPs that have been used successfully in other locations and jurisdictions, the applicability of available technologies/BMPs, cost effectiveness of various potentially applicable BMPs, and research and development needs for BMPs. The Municipality of Anchorage (MOA) conducted a four-year study of snow disposal sites from 1998 through 2001, sponsored by the MOA Street Maintenance Department and the ADOT & PF, Central Region Maintenance and Operations that revealed three important factors related to how pollutants are released during melting: initial source of hauled snow, melt processes of stored snowfall, and shape of storage areas and the snowfills. The study concluded that: 

1. Chloride can be controlled passively only through detention and dilution.
2. Mobilization of metals and polynuclear aromatic hydrocarbons relates to chloride concentration, but a large fraction can be controlled with particulate capture.
3. Particulate loading in meltwater relates to the shape of the snowfill and the pad on which it is situated and can be controlled by manipulation of these elements.

**Control of Chloride through Detention and Dilution**
Chloride is not readily treated by simple technologies. Passive (non-chemical) treatment of chloride is best addressed through:

1. Control of street treatment processes (i.e., reducing use of salt).
2. Dilution of early meltwater discharges. The necessity for dilution and the potential for impact to other local resources from elevated chloride requires careful consideration to facility siting.
3. Application of snow disposal site location criteria. Analysis of Anchorage salt application practices suggested that total chloride loading could be reduced by as much as 60 percent through use of heated sand sheds.

**Control of Particulates and Subsequent Mobilization of Metals and PAHs**
As noted in the Alaska study, mobilization of metals and polynuclear aromatic hydrocarbons (PAHs) relates to chloride concentration, but a large fraction can be controlled with particulate capture. Furthermore, particulate loading in meltwater relates to the shape of the snowfill and the pad on which it is situated and can be controlled by manipulation of these elements. Turbidity of meltwater is a function of meltwater exposure to fine sediment:

1. Turbidity in snow disposal site flows is generated as meltwater exits and cascades off a snowfill, gathering sediment from the surface of the deflating mass.
2. Turbidity may be further increased as meltwater crosses a pad surface, particularly if pad surface soils are unprotected, waste soils are exposed, or flow velocities are increased.

**Environmental Stewardship Practices in Design and Operation of Snow Storage Sites**
The Transportation Association of Canada, the NHDOT, and the ADOT&PF have each compiled snow storage guidelines for design and operation, which are combined
Needs Assessment

1 Review potential sites considering:
   - Surface water quality and quantity (including potential assimilative capacity).
   - Site hydrogeology.
   - Location of groundwater recharge areas.
   - Location and nature of salt vulnerable areas including wetlands, sensitive vegetation, agricultural areas, drinking water supplies, shallow ponds, etc.
   - Location of sensitive land uses such as residential, institutional and recreational areas.

1 Review public, agency and staff concerns with existing sites and develop a list of potential concerns that should be resolved during the planning and design process.

2 Involve the public and government agencies in the site selection process.

3 The identification of potential temporary, contingency or emergency sites may focus on smaller more remote sites with natural features supporting basic siting criteria such as:
   - Soils with a low permeability
   - Natural slopes with a ponding area
   - Discharge to a high volume surface water receiver or sanitary sewer

Assessment and Evaluation

The assessment and evaluation process is iterative with increasing level of detail being used as sites are narrowed down. Many of the same criteria are used for the evaluation of existing and new snow disposal sites. The following criteria should be considered as part of the assessment and evaluation process.

1 Snow hauling distances
   - Snow hauling routes and site access
   - Past and current site land use
   - Current and future surrounding land use
   - Zoning
   - Size of the site

1 A snow disposal site must have an area sufficient to accommodate:
   - Anticipated volumes of snow
   - Site access/control facility
Drive paths for the heavy trucks allowing for simultaneous arrivals and departures
- Parking and re-fueling area for bulldozers, blowers, etc.
- Temporary storage for large debris
- Berms around the perimeter
- Meltwater collection/retention/settling ponds
- Maintenance access
- Monitoring stations/sites
- Consideration for other uses if included or desirable

1. Sub-surface conditions. Preference should be given to sites with low permeable soils with sufficient bearing capacity to handle year-round operation of heavy equipment.

- Protection of water quality may be the most important and difficult of issues to address. Map local and site hydrogeology within 300-meter (m) of site. Consideration should be given to:
  - Proximity to drinking and irrigation water sources (avoid possible contamination).
  - Proximity to surface water, downstream effects and the type of aquatic species present (avoid or minimize impacts).

1. Meltwater discharge location. If ultimate discharge is into municipal sanitary system, ensure the treatment system can handle the additional flow and contaminants. When discharging meltwater into a surface water body the receiver must provide enough dilution all year round to protect the aquatic eco system. The potential receiver should be evaluated both on its historical flow rate and volume fluctuations and potential for future fluctuations, particularly lower flow periods. Meltwater should not be discharged to salt vulnerable areas, including ground water recharge areas, and areas over shallow aquifers.

**Base Construction**

1. A good solid base is required to allow heavy trucks and graders to drive repeatedly over the wet ground without getting stuck or creating deep ruts that could divert or hold meltwater.

2. The base should have low permeability to protect groundwater resources.

3. The base must remain firm enough to support vehicle loads even after the frost has gone out of the ground.

4. The base should slope downwards to the north to take advantage of the sun melting the pile from south to north. The snow on the high (south) end melts first running under or around the piles to the meltwater collection facility. In this way,
contaminants (sand, silt, litter, etc) will remain up-stream of the pile and meltwater will not continuously flow across the materials previously released from the pile.

5 The Municipality of Anchorage and the Alaska Department of Transportation and Public Facilities have designed the base with “V” ditches under the pile to channel meltwater to a collection pond to take advantage of the melting process and inherently low-energy environment of a melting snowfall. The V-swale configuration promotes meltwater movement as saturated flow within a snowfill so that particulates are not mobilized during the early and middle stages of melt, providing as much as ten times the particulate control over conventional flat pad configurations. Flow directed along the trough of the V-swale ensures a single predictable discharge point so that flows can be further managed and directed to minimize erosion of pad and waste soils. The design also limits late-stage sediment mobilization by helping to short-circuit flows to armored channels.

Restriction of off-season pad use will minimize disturbance of pad soils and to allow revegetation.

**Siting Criteria**

1. Avoid meltwater discharge to potable water aquifers. The snow storage area should be at least 75 feet from any private water supply wells, at least 200 feet from any community water supply wells, and at least 400 feet from any municipal wells. Prohibit snow storage areas in wellhead protection areas.

2. Optimize opportunities for infiltration to shallow nonpotable groundwater systems.

3. Avoid meltwater discharge to ‘closed’ lakes and wetlands.

4. Avoid reduction of functionality of receiving wetlands.

5. Avoid meltwater discharge to streams having winter base flows less than 85 L/sec.

6. Optimize opportunities for a site orientation sloping down from south to north.

7. Snow disposal locations should allow melt water to flow at a low velocity to a water body.

8. Disposed snow should be stored near flowing surface waters, but at least 25 feet from the high water mark of the surface water.

9. Locate and operate snow disposal sites to minimize impacts to the natural environment and control nuisance effects, including noise, dust, litter and visual intrusion on adjacent landowners.

**Design Criteria**

1. A snow handling, storage and disposal design must be practical and must not impose undue maintenance requirements.

2. Drainage designs need to consider runoff and snow melt while snow is in the storage area. If snow is piled over the top of drainage inlets, the inlets will not
function. Rain or melting snow runs down the outside of the snow pile to low areas, forming ponds or flowing across the road.

3 Clearly delineate the actual snow disposal area in a manner that is clearly identifiable under adverse winter conditions, to ensure that the snow is placed in the proper location on the site.

4 Construct pad with a single or multiple V-swale configuration (minimum 45 m crest-to-crest swale width, 2 percent sideslope to central trough, and 1 to 2 percent longitudinal slope).

5 Orient V-swale longitudinal axes downhill from south to north.

6 Establish and flag setbacks from swale crests and facility perimeter.

7 Armor swale troughs and crests and all facility drainage channels and containment berms.

8 “Trackwalk” (imprint with crawler tractor treads trafficking directly upslope and downslope) and vegetate all non-armored pad surfaces with a mix resistant to an annual 2 to 5 cm sediment burial.

9 Construct dry detention ponds or other treatment to control chloride and sediment releases.

10 Install flow dispersion and energy dissipation controls at all outfalls to receiving waters.

Drainage and Meltwater Management

1 Manage the discharge of meltwater to comply with local water quality regulations and protect surface and groundwater resources.

2 Site meltwater should be directed away from the snow piles and dumping area to reduce ponding/rutting.

3 Use of setback staking and armored channels (oversized to provide room for icing) to direct and contain pad meltwater flows and limit turbidity.

4 Where local regulations permit dilution to meet regulated contaminant levels, uncontaminated site drainage and precipitation may be directed to the collection pond to provide dilution of the impacted meltwater. Otherwise, uncontaminated drainage should be isolated from the meltwater. The meltwater collection pond should be designed large enough to handle the expected meltwater volume, other site drainage, and the periodic additional load from precipitation events.

5 Incorporating shallow collection reservoirs reduces pad erosion and turbidity by effectively transporting meltwater over significant horizontal distances in a low-turbulence (pooled) environment. The meltwater collection pond should be designed with an impermeable base, a forebay to collect litter and settle coarse sediments and a larger secondary area to settle finer particles. An absorbent boom can be placed in the forebay to capture any oil and grease in the site drainage. The outlet should be controlled to regulate the release to the receiving water body. The point of discharge should be protected to prevent scour. Adequate access to
the pond needs to be provided to allow for periodic cleanout of sediments.

6 A silt fence or equivalent barrier should be securely placed between the snow storage area and the high water mark.

7 All required federal, provincial, regional and municipal approvals, permits and licenses will have to be applied for, obtained, and complied with.

8 A baseline condition evaluation (benchmarking) of the site and surrounding areas should be conducted for future monitoring comparisons.
   - Contaminant levels recorded once the site is operational will have to be compared to levels prior to the site opening to give a true indication of any environmental impacts.
   - Test sites and holes drilled to benchmark the site could be made permanent allowing future comparison data to be collected from the same locations.

3.11 Designing to Minimize Air Quality Problems

Air quality and pollution have been concerns in the United States for many years, especially in metropolitan areas.

AASHTO Center for Environmental Excellence Air Quality Resources

AASHTO’s Center for Environmental Excellence provides brief summaries of federal air quality requirements applicable to the transportation community including background information on National Air Quality Standards, Developing State Implementation Plans, Emissions Inventory, Control Strategies, Transportation Control Measures, Motor Vehicle Emissions Budget, Sanctions, Conformity, FHWA Resources, EPA Resources, and Links to air quality laws and regulations, guidance and Related Information. Recent Developments are provided as well as Documents and Reports, Success Stories, and Related Links. Most of these air quality resources are focused on the planning process. The following practices briefly review design measures to promote air quality and congestions mitigation and air quality (CMAQ) and sources of funding.

New England Governors & Eastern Canadian Premiers Greenhouse Gas Reduction Initiatives

The Conference of New England Governors and Eastern Canadian Premiers (NEG/ECP) adopted Resolution 25-9 on global warming and its impacts on the environment in 2000, “recognizing that global warming, given its harmful consequences to the environment and the economy, is a joint concern for which a regional approach to strategic action is required.” The Conference led to an Action Plan to “reduce the region’s emissions of heat-trapping gases and to build the foundation for a longer-term shift to cleaner and more efficient ways of using energy, as well as identifying and adopting adaptive measures.” Without the plan, a 30 percent increase in CO₂ emissions is forecast for New England between 2000 and 2020. National CO₂ emissions levels in the U.S. have been growing about 1.1 percent per year based on the U.S. Department of Energy’s
Energy Information Agency, with the largest emissions increases coming from the transportation sector.

Climate change is affecting governments and DOTs in a variety of ways. At the 2005 TRB meeting, Alaska DOT & Public Facilities reported the substantial increase in problems and expenditures that Maintenance is facing as a result of recent warming trends. Issues identified for New England states include an increase in weather extremes; stresses on estuaries, bays, and wetlands; changes in precipitation rates impacting water supply and food production; multiple stresses on urban areas; and recreation shifts. In addition, the composition of northeastern forests is anticipated to change dramatically, affecting biodiversity and forest industries. In addition to rising sea level and elevated storm surge levels—with associated problems of coastal erosion and saltwater inundation, rising ground-level ozone, warming would likely favor increased mosquito and tick populations, with associated public health as well as recreational impacts.

The NEG/ECP Climate Change Action Plan identifies steps to address those aspects of global warming which the governors decided are within the region’s control to influence. Specifically, the action plan includes:

2. Commitment to reach specified reduction targets for the region as a whole.
3. Commitment from each state and provincial jurisdiction to carry on its own planning for climate change gas reductions, with a coordinated process that includes disclosure of our progress, and a sharing of information including case studies of how various programs are working.
4. Plan for the adaptation of the region’s economic resource base and physical infrastructure to address the consequences of climate change.
5. Public education and outreach effort to ensure that the region’s citizens continue to be educated about global warming and climate change in order to better protect the earth’s natural climatic systems and natural environment.

The plan works within the context of other regional objectives, including:

1. Reducing other pollutant emissions that threaten human health and the natural environment.
2. Maintaining a reliable supply of reasonably priced energy within our region.
3. Reducing dependence on energy imports to the region, thereby keeping energy dollars in our regional economy.
4. Reducing our collective vulnerability to energy price shocks.
5. Providing ‘early adoption’ opportunities to enhance the competitive advantage of our region’s technology industries.

Some of the opportunities to promote greenhouse gas reductions and appropriate adaptation measures while meeting other governmental goals included:

1. Shifting to less polluting energy resources.
2. Maximizing the efficiency and effectiveness of energy conversion, transport, and consumption within the region.
3. Encouraging and aggressively promoting new technologies which reduce the use
of fossil fuels, thus reducing carbon emissions.

4 Taking actions to maintain a greater share of the region’s energy dollars in the regional economy leading to more productive reinvestment.

5 Taking actions to support agriculture, fisheries, aquaculture, timber, and other natural resource-based economic sectors to adapt to the climate impacts already being felt.

6 Encouraging similar sensible action by fellow states/provinces and federal governments.

7 Designing and building any new infrastructure to minimize the impacts of climate changes that are likely to occur, based on the extended residence time of gases already released into our atmosphere, and may occur due to inadequate greenhouse gas emission reductions elsewhere.

8 Preserving green spaces, including forests and farm lands.

9 Creating new jobs in the area of energy efficiency and renewables.

10 Contributing to the long-term economic and environmental sustainability and human health and safety of the states and provinces.

The New England governors and Eastern Canadian premiers recognized the following principles as guidelines for action on climate change in the region.

1 The need to identify constructive measures to reduce energy and non-energy related GHG emissions wherever possible, such as to: a) shift to lower and zero carbon energy sources, wherever economically feasible; and b) implement actions that result in higher efficiency in the transportation of passengers and goods.

2 Actions which will support and develop the states’ and provinces’ economy (so-called “no regrets” measures), when compared to other possible actions, and compared to the cost of inaction, including to: a) be cognizant of the energy supply needs of our region and find constructive measures with regional energy reliability in mind; and b) involve all segments of society—government, business, and citizens—in contributing to reductions in greenhouse gas emissions.

3 The need to foster long-term environmental and economic sustainability, in order to favor economic growth while decreasing total emissions of carbon and other climate change gases, such that states and provinces may: a) explore ways to adapt to the already changing climate, to take advantage of any benefits that might come from these changes, and to adapt our infrastructure and natural resource base accordingly; and b) to explore ways to adapt to climate change in ways that do not increase the production of greenhouse gases in the process, and to be mindful of the health and safety of citizens.

4 The need to work with our federal governments to seek additional solutions that can be addressed at a national level including emission standards, grant programs, and cooperative agreements. There is also a need to work with federal counterparts to improve the energy efficiency of vehicles for sale to the public.

The Conference’s goals are as follows:

1 **Short-term Goal**: Reduce regional GHG emissions to 1990 emissions by 2010.
2 **Mid-term Goal:** Reduce regional GHG emissions by at least 10 percent below 1990 emissions by 2020, and establish an iterative five-year process, commencing in 2005, to adjust the goals if necessary and set future emissions reduction goals.

3 **Long-term Goal:** Reduce regional GHG emissions sufficiently to eliminate any dangerous threat to the climate; current science suggests this will require reductions of 75–85 percent below current levels.

883) Action items include the following:

1 **Jurisdictions will establish a standardized inventory beginning with their 1990 GHG emissions levels, reported every three years.** The process of creating jurisdictional level inventories of existing emissions will assist jurisdictions in the identification of specific measures that will reduce greenhouse gas emissions. A full understanding of the present circumstances and a complete assessment of opportunities for action, in all sectors of the economy, are essential for states and provinces to address climate change issues effectively.

2 **Each jurisdiction will create plan, programs, and policies articulating measures to achieve GHG reductions in view of the regional short and mid-term targets.** Jurisdictions will report to the NEG/ECP annually on progress made regionally, recommend items for joint action and develop specific task forces to coordinate projects, review progress towards meeting GHG objectives, and produce an updated plan every three years, monitor the results of the actions and policies and share information on their effectiveness.

3 **Through promotion of public awareness, by 2005 the plan aims for the public in the region to be aware of the problems and the impacts of climate change and what actions they can take at home and at work to reduce the release of greenhouse gases, as well as adaptive measures they can undertake.** This effort encouraged dialogue among traditional conservation organizations, land managers, natural resource-based industries, recreational industries, major energy users, non-government organizations (NGOs) and interested citizens as to the implications of climate change.

4 **The region will reduce end-use emissions of GHGs through improved energy efficiency and lower carbon fuels within the public sector by 25 percent by 2012,** as measured from an established baseline. As the plan maintains that demonstrating energy efficiency, clean energy technologies and sustainable practices should be a fundamental task of government, the plan seeks to implement public sector energy reduction programs, including to institute policies to encourage the purchase of the most fuel-efficient vehicle available for each type of use and educate government employees about the specific operational changes they can undertake to reduce greenhouse gases and reduce fuel use. Examples include:

   - Promoting carpooling incentive programs and/or telecommuting policies for government employees
   - Educating building managers on measures to improve efficiency in heating, cooling, and lighting
o Providing office managers with information regarding energy-efficient office products and equipment.

o Establishing policies that all state and provincial expenditures related to energy conservation and efficiency, having simple payback periods of ten years or less, will be adopted whenever feasible.

o Establishing jurisdictional policies on sustainable building design to be applied to all state/provincial construction and renovation projects where such practices are feasible and cost-effective. Sustainable design practices include:
  ▪ using recycled, energy-efficient, and less toxic materials
  ▪ day lighting and other energy saving measures
  ▪ piloting on-site renewable energy projects
  ▪ separating and recycling construction and demolition debris.

o Creating a regional market for “Environmentally Preferable Products” (EPPs) by requiring their use at all state/provincial facilities. EPPs include materials with recycled content, those that minimize generation of toxic materials, and products otherwise designed to minimize the environmental impact from manufacture to disposal.

o Create a regional clearinghouse of “best practices” for the operation and management of public facilities so jurisdictions can share and benefit from each other’s experiences.

5 By 2025, increase the amount of energy saved through conservation programs by 20 percent (as measured in tons of greenhouse gas emissions) within the region, using programs designed to encourage residential, commercial, industrial and institutional energy conservation.

6 Understand and improve knowledge transfer on the impacts and costs of climate change, including documenting impacts, exchanging information and research, developing modeling capacities, identifying areas most susceptible to catastrophic events and proposing adaptation and mitigation strategies.

7 Expand the use of land conservation techniques such as conservation restrictions to protect green spaces, forest resources and soil carbon. Increase native tree planting programs, improving maintenance of existing trees, and monitoring the carbon uptake and release of planting programs over time to establish a better understanding of the long-term carbon benefits of such programs. Improve development practices to limit the destruction of existing trees and encourage/require the planting of native replacement trees when changing the nature of land use. Adding trees, where feasible, to urban areas to reduce heat island effect, thereby reducing the need for nearby building air conditioning.

8 Slow the growth rate of transportation emissions in the near future, to better understand the impacts of transportation programs and projects on overall emissions, and to seek ways to reduce these emissions. Work with federal
officials to improve the energy efficiency of vehicles for sale to the public.

- Promote the shift to higher efficiency vehicles, lower carbon fuels and advanced technologies through the use of incentives and education.
- Disclose GHG emission impacts from new publicly-funded passenger and freight transportation projects and alternatives.
- Promote compact development and transit/pedestrian development and other “smart growth” measures to encourage local communities to consider the energy impacts of development and infrastructure construction.
- Undertake programs designed to manage and reduce transportation demand in communities.
- Enhance mass transit infrastructure, intermodal connections, optimizing existing services and, where feasible, boosting ridership.
- Encourage shifts to lower-carbon fuels and advanced vehicle technologies for all transit services.
- Examine opportunities in freight transportation that would improve the energy efficiency of the movement of goods across the regions.
- Support the development of inter-connected regional, state, provincial, and local greenway and bicycle/pedestrian pathway systems to promote non-fossil transportation alternatives.

State DOTs in the Northeast are supporting the effort through inventory, electricity and space heating reductions, employee commuting, public involvement processes, and looking beyond operations. Some states are developing tools to measure the GHG emissions of transportation projects. The following have been reported as under consideration by DOTs in the region:

1. Centralized vehicle fleets that include:
   - Consistent collection and monitoring of fuel use and emissions data
   - Rightsizing (using the right size and type of vehicle for the job)
   - Timely and consistent maintenance schedules
   - Replacing the use of state employee personal cars for official state business with more fuel efficient and lower emission state fleet vehicles, without increasing the total vehicle miles traveled by employees during pick up and drop off of fleet vehicles and traveling to and from home

2. State contracts requiring the purchase or rental of the most fuel-efficient and lowest emission vehicles in each vehicle class for the state fleet.

3. Establishing the environmental and economic impacts of replacing the use of conventional diesel fuel for the state fleet with biodiesel blends, and beginning replacement when appropriate.

4. Promoting the use of telephone, video, and online conferencing to reduce trips.
5 A single (or compatible) maintenance, parts and equipment contract(s) for state motor vehicles and motorized equipment that require state of the art emissions, fuel efficiency, and overall environmental beneficial technologies and practices.

6 Maintenance procedures for heavy-duty vehicles that promote state of the art emissions control, fuel efficiency, and other environmentally beneficial technologies and practices.

7 Marketing the use of public transit and vanpools (when available), ridesharing, and non-motorized options such as walking and biking while on the job.

8 Establishing and actively promoting shuttle bus/van routes and schedules between key state facility destinations.

9 Expanding existing vehicle anti-idling education campaigns to state-owned facilities.

10 Locating new state facilities and services (such as copy centers, daycare, etc.) within close proximity and within mixed use growth centers, thus facilitating employee walking and biking while making short on the job trips.

**Promoting Carpooling and Transit**

Urban air pollution is a major and continuing concern for transportation agencies. Motor vehicles are a major contributor to this pollution. One possible means of mitigating the pollution caused by motor vehicles is to shift travel to alternate modes. Some states are very active in promoting alternate modes; in other, especially rural, states promotion of mode switching is minimal. Arizona DOT has a research project underway, with results due in late 2004, to compile practices in use by other state DOTs. DOT and MPO carpool and transit promotion activities are often funded under the CMAQ program.

**Georgia DOT HOV Land Promotion**

Georgia Department of Transportation (GDOT) in the Atlanta area used CMAQ funds to focus on HOV lanes and park and ride lots over lanes widening and another beltway. GDOT conducted a statewide kickoff of the media campaign to increase awareness of HOV lanes under construction in Gwinnett County, and to increase use of the existing HOV lanes and metrorail. The event attracted significant media coverage, including three Atlanta television stations. GDOT also ran radio ads on several stations throughout the year and has a campaign highlighting the need for and benefits of carpooling.

**Virginia DOT Commuter Choice Program**

The Virginia Department of Transportation has been praised by the EPA and the USDOT for its “Commuter Choice” program and contribution to improving air quality. VDOT has offered its employees bus, vanpool and carpool options since 1993 with its own “Commuter Incentive Program” (CIP), and is not only Richmond’s largest employer with such a program, but also the employer with the highest commuter participation. VDOT reports that the program is a very successful recruitment factor. To illustrate the benefits of joining its program, the EPA estimates that an employer with 1,000 employees could help take 175 cars off the road, which would save 44,000 gallons of fuel per year and reduce global warming emissions by 420 metric tons. The same employer also could
reduce its parking expenses by $70,000 and save participating employees $13,000 in
taxes and $160,000 in fuel, parking, and vehicle costs every year – employees pay no
federal income tax or payroll tax on commuter benefits. For VDOT’s headquarters
office, it’s estimated that the program saves more than 93,500 gallons of vehicle fuel per
year, and reduces air pollution by 4.25 metric tons of volatile organic compounds, 4.25
metric tons of nitrogen oxides, and 31 tons of carbon monoxide. VDOT’s CIP has grown
from 196 participants in August 1993 to 373 participants in 2003 - 27 percent of its
headquarters office workforce (69 vanpoolers, 262 bus riders and 42 carpoolers) - at an
annual cost to VDOT of $151,680. Eight percent (110 employees) of its Northern
Virginia work force participate (82 vanpool, 11 bus, 7 Metro train riders, and 10
Metro/bus) at an annual cost of $124,080.()

Transit Promotion Activities
NC DOT is studying feasibility of intercity rail from eastern to western NC, through the
state’s Triad of largest cities.() Transit promotion activities of other state DOTs can be
found through links to these sections online.

Promoting Telecommuting
The U.S. Congress’s 1999 National Air Quality and Telecommuting Act (H.R. 2094) set
up a pilot program in five metropolitan areas—Denver; Washington, DC; Los Angeles,
Houston, and Philadelphia—that would study the feasibility of addressing air quality
concerns through telecommuting. The pilot “e-commute” program ran from mid-2001
through early 2004, at which time scholars conducted an in-depth analysis of data drawn
from participants’ reports as part of a larger report to U.S. EPA.
A December 2004 investigation of Telecommuting and Emissions Reductions looked at
reports from 535 employees working in approximately 50 different companies in five
cities over a two-and-a-half year period, tracking employees over time and that the
frequency of reporting. The authors estimated that a 25-ton per year reduction in volatile
organic compounds could be achieved in a given metropolitan area with approximately
4,500 telecommuters working at home, on average, 1.8 days per week.()

Bicycling Promotion Activities
Bicycling promotion has begun to be incorporated into DOT planning and design, and
efforts to improve air quality in some cases. FHWA has Design Guidance for
Accommodating Bicycle and Pedestrian Travel and a US DOT Policy Statement
Integrating Bicycling and Walking into Transportation Infrastructure, which also asks
DOTs to “be committed to taking some or all of the actions listed below as appropriate
for their situation.” ()

1 Define the exceptional circumstances in which facilities for bicyclists and
pedestrians will NOT be required in all transportation projects.

2 Adopt new manuals, or amend existing manuals, covering the geometric design of
streets, the development of roadside safety facilities, and design of bridges and
their approaches so that they comprehensively address the development of bicycle
and pedestrian facilities as an integral element of the design of all new and
reconstructed roadways.
3 Adopt stand-alone bicycle and pedestrian facility design manuals as an interim step towards the adoption of new typical sections or manuals covering the design of streets and highways.

4 Initiate an intensive re-tooling and re-education of transportation planners and engineers to make them conversant with the new information required to accommodate bicyclists and pedestrians. Training should be made available for, if not required of, agency traffic engineers and consultants who perform work in this field.

The Design Guidance also offers sections on:

1 **Applying Engineering Judgment to Roadway Design**
2 **Further Information and Resources**
3 **General Design Resources**
4 **Pedestrian Facility Design Resources**
5 **Bicycle Facility Design Resources**
6 **Bicycle and Pedestrian Design Resources**
7 **Traffic Calming Design Resources**
8 **ADA Related Design Resources**
9 **Trail Design Resources**

**Virginia DOT Bicycle Facility Guidelines**

Virginia DOT’s Bicycle Facilities Guidelines contain the agency’s Policy on Participation in the Development of Bicycle, VDOT Bicycle Facility Participation Guidelines, AASHTO’s guidance, and the agency’s guidelines on Selecting Roadway Design Treatments to Accommodate Bicycles.

**NCDOT Commitment to Integrating Bicycle and Walking into Transportation System and Long-Range Plan**

The NC Board of Transportation adopted *Bicycling & Walking in North Carolina, a Critical Part of the Transportation System* in 2000. Although NCDOT already incorporated bicycle and pedestrian elements — including bike lanes and sidewalks — into many of its highway projects, this resolution demonstrated NCDOT’s further strong commitment to integrating these elements into its long-range transportation system. The resolution also encourages cities and towns across the state to make bicycling and pedestrian improvements an integral part of their transportation planning and programming. In addition to offering the potential for cleaner air, NCDOT noted that:

1 Increasing bicycling and walking offers the potential for cleaner air, healthier people, reduced congestion, more liveable communities, and more efficient use of road space and resources.

2 Cashes involving bicyclists and pedestrians represent more than 14 percent of the nation’s traffic fatalities.

3 FHWA in its policy statement “Guidance on the Bicycle and Pedestrian
Provisions of the Federal-Aid Program” urges states to include bicycle and pedestrian accommodations in its programmed highway projects.

4 Bicycle and pedestrian projects and programs are eligible for funding from almost all of the major Federal-aid funding programs.

5 TEA-21 calls for the mainstreaming of bicycle and pedestrian projects into the planning, design and operation of our Nation’s transportation system.

Following the resolution, a team of NCDOT personnel reviewed and implemented guidelines to successfully integrate bicycle and pedestrian planning into the daily operations of the department. The effort builds on NCDOT’s longstanding commitments in this area. In 1978, NCDOT adopted the nation’s most comprehensive set of bicycle policies in response to enabling legislation in the Bicycle and Bikeways Act of 1974. These policies were unique at that time in that they detailed how the state DOT would institutionalize bicycle provisions into everyday departmental operating functions. They declared “bicycle transportation to be an integral part of the comprehensive transportation system in North Carolina” and formalized the inclusion of bicycle provisions in highway construction projects. In 1991, the policy document was updated to clarify responsibilities regarding the provision of bicycle facilities upon and along the 77,000-mile state-maintained highway system. The newer policy details guidelines for planning, design, construction, maintenance, and operations pertaining to bicycle facilities and accommodations. All bicycle improvements undertaken by the NCDOT are based upon the NCDOT Bicycle Policy. According to that policy, the Board of Transportation found that bicycling is a bona fide highway purpose subject to the same rights and responsibilities and eligible for the same considerations as other highway purposes and endorsed the concept of providing bicycle transportation facilities within the rights-of-way of highways as appropriate. The following practices and guidelines were outlined:

Planning and Design

1 The intent to include planning for bicycle facilities within new highway construction and improvement projects is to be noted in the Transportation Improvement Program.

2 During the thoroughfare planning process, bicycle usage shall be presumed to exist along certain corridors (e.g., between residential developments, schools, businesses and recreational areas). Within the project planning process, each project shall have a documented finding with regard to existing or future bicycling needs. In order to use available funds efficiently, each finding shall include measures of cost-effectiveness and safety-effectiveness of any proposed bicycle facility.

3 If bicycle usage is shown likely to be significant, and it is not prohibited, and there are positive cost-effective and safety-effective findings; then, plans for and designs of highway construction projects along new corridors, and for improvement projects along existing highways, shall include provisions for bicycle facilities (e.g., bike routes, bike lanes, bike paths, paved shoulders, wide outside lanes, bike trails) and secondary bicycle facilities (traffic control, parking, information devices, etc.).
4 Federally funded new bridges, grade separated interchanges, tunnels, and viaducts, and their improvements, shall be designed to provide safe access to bicycles, pursuant to the policies of FHWA.

5 Barriers to existing bicycling shall be avoided in the planning and design of highway projects.

6 Although separate bicycle facilities (e.g., bike paths, bike trails) are useful under some conditions and can have great value for exclusively recreational purposes, incorporation of on road bicycle facilities (e.g., bicycle lanes, paved shoulders) in highway projects are preferred for safety reasons over separate bicycle facilities parallel to major roadways. Secondary complementary bicycle facilities (e.g., traffic control, parking, information devices, etc.) should be designed to be within highway rights-of-way.

7 Technical assistance shall be provided in the planning and design of alternative transportation uses, including bicycling, for abandoned railroad rights-of-way. This assistance would be pursuant to the National Trails Act Amendment of 1983, and the resultant national Rails to Trails program, as will the Railway Revitalization Act of 1975.

8 Wherever appropriate, bicycle facilities shall be integrated into the study, planning, design, and implementation of state funded transportation projects involving air, rail, and marine transportation, and public parking facilities.

9 The development of new and improved bicycle control and information signs is encouraged for the increased safety of all highway users.

10 The development of bicycle demonstration projects which foster innovations in planning, design, construction, and maintenance is encouraged.

11 Paved shoulders shall be encouraged as appropriate along highways for the safety of all highway users, and should be designed to accommodate bicycle traffic.

12 Environmental Documents/Planning Studies for transportation projects shall evaluate the potential use of the facility by bicyclists and determine whether special bicycle facility design is appropriate.

13 Local input and advice shall be sought, to the degree practicable, during the planning stage and in advance of the final design of roadway improvements to ensure appropriate consideration of bicycling needs, if significant.

14 On highways where bicycle facilities exist, (bike paths, bike lanes, bike routes, paved shoulders, wide curb lanes, etc.), new highway improvements shall be planned and implemented to maintain the level of existing safety for bicyclists.

15 Any new or improved highway project designed and constructed within a public-use transportation corridor with private funding shall include the same bicycle facility considerations as if the project had been funded with public funds. In private transportation projects (including parking facilities), where state funding or Department approval is not involved, the same guidelines and standards for providing bicycle facilities should be encouraged.
Construction

1 Bicycle facilities shall be constructed, and bicycle compatibility shall be provided for, in accordance with adopted Design Guidelines for Bicycle Facilities and with guidelines of the American Association of State Highway and Transportation Officials.

2 Rumble strips (raised traffic bars), asphalt concrete dikes, reflectors, and other such surface alterations, where installed, shall be placed in a manner as not to present hazards to bicyclists where bicycle use exists or is likely to exist. Rumble strips shall not be extended across shoulder or other areas intended for bicycle travel.

3 During restriping operations, motor vehicle traffic lanes may be narrowed to allow for wider curb lanes.

Maintenance

1 State and federally funded and built bicycle facilities within the state right-of-way are to be maintained to the same degree as the state highway system.

2 In the maintenance, repair, and resurfacing of highways, bridges, and other transportation facilities, and in the installation of utilities or other structures, nothing shall be done to diminish existing bicycle compatibility.

3 Rough road surfaces which are acceptable to motor vehicle traffic may be unsuitable for bicycle traffic, and special consideration may be necessary for highways with significant bicycle usage.

4 For any state-funded bicycle project not constructed on state right-of-way, a maintenance agreement stating that maintenance shall be the total responsibility of the local government sponsor shall be negotiated between the Department and the local government sponsor.

5 Pot-holes, edge erosion, debris, etc., are special problems for bicyclists, and their elimination should be a part of each Division’s maintenance program. On identified bicycle facilities, the bike lanes and paths should be routinely swept and cleared of grass intrusion, undertaken within the discretion and capabilities of Division forces.

Operations

1 Operations and activities on the state highway system and bicycle facilities shall be conducted in a manner conducive to bicycle safety.

2 A bicyclist has the right to travel at a speed less than that of the normal motor vehicle traffic. In exercising this right, the bicyclist shall also be responsible to drive his/her vehicle safely, with due consideration to the rights of the other motor vehicle operators and bicyclists and in compliance with the motor vehicle laws of North Carolina.

3 On a case by case basis, the paved shoulders of those portions of the state’s fully
controlled access highways may be studied and considered as an exception for usage by bicyclists where adjacent highways do not exist or are more dangerous for bicycling. Pursuant to federal highway policy, usage by bicyclists must receive prior approval by the Board of Transportation for each specific segment for which such usage is deemed appropriate, and those segments shall be appropriately signed for that usage.

4 State, county, and local law enforcement agencies are encouraged to provide specific training for law enforcement personnel with regard to bicycling.

5 The use of approved safety helmets by all bicyclists is encouraged.

Parking

1 It is the policy of the Board of Transportation that secure and adequate bicycle parking facilities shall be provided wherever practicable and warranted in the design and construction of all state-funded buildings, parks, and recreational facilities.

Maryland DOT Bicycle Safety and Operations Guidelines

In 2002, the Maryland DOT published Guidelines Related to Bicycle Safety and Operations on Roadways in Maryland. The guidelines seek to allow bicyclists to operate, as they feel appropriate, on all roads were they are not specifically prohibited. Among the other guidelines:

1 Wide curb lanes for bicycle use are preferred on all closed section roadways. The width of a wide curb lane typically ranges from 13 to 16 ft, measured from the lane line to the curb face (or the edge line on open section roadways). In situations where 14 ft or more of pavement width exists, the roadway should be striped with a longitudinal white line 11 ft from the rightmost lane line to create either an otherwise unmarked “BICYCLE AREA”, a fully marked and signed BICYCLE LANE, or a shoulder.

2 BICYCLE LANES should be one-way facilities and carry bike traffic in the same direction as adjacent motor vehicle traffic. On one-way streets BICYCLE LANES should generally be placed on the right side of the street. (For further commentary on placement of BICYCLE LANES, see page 22 of the AASHTO Guide.)

3 For roadways with no curb and gutter, the minimum width of a BICYCLE LANE should be 4 ft. For roadways with curb or guardrail, the recommended BICYCLE LANE width is 5 ft from the face of the curb or guardrail to the BICYCLE LANE stripe.

4 If parking is permitted, the BICYCLE LANE should be placed between the parking area and the travel lane and have a minimum width of 5 ft.

5 Since bicyclists usually tend to ride a distance of 32-40 in. from a curb face, it is very important that the pavement surface in this zone be smooth and free of structures. Drain inlets and utility covers that extend into this area may cause bicyclists to swerve, and have the effect of reducing the usable width of the lane. Where these structures exist, the BICYCLE LANE width may need to be adjusted.
TAC Bicycle Traffic Pavement Marking Guidelines

Updated in December 2004 with expected final completion and approval in 2006, the Transportation Association is producing Bicycle Traffic Pavement Marking Guidelines. Numerous jurisdictions have recognized the need to provide national guidance on the effective use of pavement markings and colored pavements to guide cyclists in many situations, including in shared-use lanes, in contra-flow, two way on one side traffic, and through intersections and interchanges (including roundabouts). Looking at best practices in North America and Europe, the oversight committees noted that pavement markings take many forms and functions and are not always intuitive and easily understood by motor vehicle traffic and cyclists. Furthermore, it seemed that the use of pavement markings has been discretionary, without clear guidelines, numerical evaluation processes or ranking systems to help determine when benefits can be achieved. The project is developing guidelines and recommendations on the design and application of pavement markings for bicycle traffic on Canadian roads. It will provide recommendations on the most effective configuration of pavement markings, use of materials, installation, maintenance and cost, in addition to determining numerical evaluation processes and ranking systems.

ITS Facilitated Air Quality Improvement in Ohio and Kentucky

In the Cincinnati, OH, metropolitan area the Ohio Department of Transportation and the Kentucky Transportation Cabinet developed the Advanced Regional Traffic Interactive Management and Information System (ARTIMIS) to help with incident and congestion management. Using fiber-optic cable and telephone lines, 80 closed-circuit television cameras and 1,100 loop detectors, installed along 142 kilometers (88 miles) of freeway, relay information about traffic congestion and incidents to a control center. Through 40 changeable message signs, ARTIMIS distributes information on traffic problems and alternate routes from the control center to motorists. The system also includes a traveler advisory telephone service and a motorist assistance program with five service patrol vans. Estimates show that the system saves $15.9 million per year in reduced traffic delays, fuel consumption, and crashes.

Funding for Air Quality Improvement: The Congestion Mitigation & Air Quality Program (CMAQ)

The most well known program supporting air quality improvement is the Congestion Mitigation and Air Quality Program. In 1990, Congress amended the Clean Air Act (CAA) to bolster America’s efforts to attain the National Ambient Air Quality Standards (NAAQS). The amendments required further reductions in the amount of permissible tailpipe emissions, initiated more stringent control measures in areas that still failed to attain the NAAQS (nonattainment areas), and provided for a stronger, more rigorous linkage between transportation and air quality planning. In 1991, Congress adopted the Intermodal Surface Transportation Efficiency Act (ISTEA). This law authorized the CMAQ program, and provided $6.0 billion in funding for surface transportation and other related projects that contribute to air quality improvements and reduce congestion. The CAA amendments, ISTEA and the CMAQ program together were intended to
realign the focus of transportation planning toward a more inclusive, environmentally-sensitive, and multimodal approach to addressing transportation problems. The CMAQ program, jointly administered by the FHWA and the Federal Transit Administration (FTA), was reauthorized in 1998 under the Transportation Equity Act for the 21st Century (TEA-21). The TEA-21 CMAQ program provided over $8.1 billion dollars in funds to State DOTs, MPOs, and transit agencies to invest in projects that reduce criteria air pollutants regulated from transportation-related sources over a period of six years (1998-2003).

The percentage of CMAQ funds obligated for transit was higher than that of any other category in FY 1999, the last year for which a report is available. The total CMAQ funds obligated toward transit accounted for 51.6 percent of the total amount of funds obligated nationwide, a 70 percent increase in CMAQ share from FY 1998 (from 30.1 percent to 51.6 percent). Traffic flow improvement projects were the second largest category at 23.3 percent, a 50 percent decrease in CMAQ share from FY 1998.

Comparing findings from almost 140 CMAQ-funded projects, for which actual impacts had been quantified, the study ranked the project types by the cost per pound of combined pollutants reduced as follows:

<table>
<thead>
<tr>
<th>CMAQ Strategy</th>
<th>Cost Per Pound of Emissions Reduced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspection and maintenance</td>
<td>$0.95/lb.</td>
</tr>
<tr>
<td>Regional rideshare programs</td>
<td>$3.70/lb.</td>
</tr>
<tr>
<td>Charges and fees</td>
<td>$5.15/lb.</td>
</tr>
<tr>
<td>Vanpool programs</td>
<td>$5.25/lb.</td>
</tr>
<tr>
<td>Miscellaneous TDM</td>
<td>$6.25/lb.</td>
</tr>
<tr>
<td>Conventional fuel bus replacement</td>
<td>$8.05/lb.</td>
</tr>
<tr>
<td>Alternative fuel vehicles</td>
<td>$8.09/lb.</td>
</tr>
<tr>
<td>Traffic signalization</td>
<td>$10.05/lb.</td>
</tr>
<tr>
<td>Employer trip reduction</td>
<td>$11.35/lb.</td>
</tr>
<tr>
<td>Conventional transit service upgrades</td>
<td>$12.30/lb.</td>
</tr>
<tr>
<td>Park-and-ride lots (rideshare and transit)</td>
<td>$21.50/lb.</td>
</tr>
<tr>
<td>Modal subsidies and vouchers</td>
<td>$23.30/lb.</td>
</tr>
<tr>
<td>New transit capital systems/vehicles</td>
<td>$33.20/lb.</td>
</tr>
<tr>
<td>Bicycle and pedestrian programs</td>
<td>$42.05/lb.</td>
</tr>
<tr>
<td>Shuttles, feeders, and paratransit</td>
<td>$43.75/lb.</td>
</tr>
<tr>
<td>Freeway/incident management</td>
<td>$51.20/lb.</td>
</tr>
<tr>
<td>Alternative fuel buses</td>
<td>$63.20/lb.</td>
</tr>
<tr>
<td>HOV facilities</td>
<td>$88.10/lb.</td>
</tr>
<tr>
<td>Telework</td>
<td>$125.90/lb.</td>
</tr>
</tbody>
</table>

Therefore, among the top 10 strategies, **the most cost effective** alternative mode strategies are:

1. Regional ridesharing programs (including carpool matching)
2. Pricing programs (including parking pricing and congestion pricing)
3. Vanpool programs
4. Miscellaneous TDM programs (efforts to promote alternative modes)
5. Conventional transit service improvements (new lines, more frequency)
6 Employer trip reduction.
The analysis showed that as a group, traffic flow projects received 33 percent of all funds, but resulted in a cost per pound reduced of $42.70. Rideshare programs accounted for only 4 percent of all funds, yet reduced a pound of emissions for $10.25. Likewise, miscellaneous TDM programs accounted for 3 percent of all CMAQ funds but reduced a pound of emissions for $7.66. Transit service improvements and new services (not including alternative fuels) as a group, were somewhere in the middle, receiving 28 percent of funding and reduced a pound of emissions for $29.80.

State DOT CMAQ Measures and Strategies
959) State DOTs undertake a variety of CMAQ strategies, including the following measures and examples: 

1 Washington State DOT provides assistance to urban areas subject to Commute Trip Reduction regulations requiring employer’s to reduce trips and VMT to their worksites.

2 New York and New Jersey have statewide TDM policies that provide an overall framework for the role of alternative modes in state programs.

3 The state of Florida has a TDM policy within its statewide long-range plan. This also provides a framework for the technical and financial assistance Florida DOT provides to regional and local Commuter Assistance Programs. Florida DOT also supports research into alternative mode effectiveness and program evaluation.

4 Georgia DOT funds an independent evaluation of all alternative mode strategies in the Atlanta area to account for CMAQ funds spent and assess emission reductions toward the region’s attainment strategy.

5 Several states maintain specific offices or staff positions for TDM coordination.

6 States in the Northeast tend to promote the use of their established transit networks as the primary alternative mode, while western states tend to support carpooling and vanpooling. Several states also have statewide telework initiatives.

Strategies to Enhance the Role of State DOTs in Supporting Cost-Effective Alternative Mode Strategies
Some state DOTs are supporting cost-effective alternative mode strategies in ways that go beyond the pass-through of federal funds. Many of these strategies are focused on improving the coordination between various stakeholders, including state air quality agencies, regional planning organizations, and local service providers. Per Arizona DOT’s report on the topic, such support may include technical assistance, research, funding, and integration: 

1 State DOTs can provide technical assistance and objective guidance on how to project in advance and evaluate after implementation, the travel impacts of alternative mode strategies, since VMT reduction is at the heart of emission analysis. This can be made easier for other agencies through the development of software and on-line reporting that allows users to input simple data enabling the calculation of travel and emission impacts. State DOTs can take
a leadership position in: 1) setting state-wide policy of the role of alternative modes in addressing air quality and other policy issues, 2) forming ideas on alternative mode projects, 3) providing insights in realistic emission reduction potential, 4) provide insights on funding restrictions applicable to these types of strategies, 5) communicating and coordinating with state air quality or health agencies, and 6) obtaining information from other states and national sources of information on alternative modes. To accomplish such assistance, ADOT is considering assigning a person from its headquarters staff (help-desk) and district offices to maintain the information and knowledge in this area and be the liaison to regional agencies and other state and federal agencies, or possibly utilizing several staff to provide guidance, answer questions, and perhaps maintain a page on ADOT’s website.

2 State DOTs can foster and undertake research into the cost effectiveness of alternative mode strategies implemented within their state and help develop better methods and procedures for quantifying the impacts during project planning, funding, and reporting. Washington state and Florida DOT each have ongoing, dedicated research programs to evaluate alternative mode programs and provide guidance to district offices, regional agencies, localities, service providers, and others. Each maintains a TDM resource center for this purpose. Washington state biennially reports on the progress of its Commute Trip Reduction mandate to the state legislature, including what are the most effective strategies and how much it is costing employers to comply. The University of South Florida maintains the National TDM and Telework Clearinghouse for FDOT and FTA.

3 While most alternative mode strategies are planned and implemented at the regional and local levels, state DOTs can also fund or facilitate several support activities to bolster efforts within the state. For example, some state DOTs (Connecticut, Michigan, New Mexico) coordinate fleet purchases of vanpools to lower the cost to the end user. Some underwrite vanpool insurance or purchase ridematching software and maintenance agreements. Other states fund alternative mode pilot projects (Massachusetts, Oregon, and New York) to test new and innovative concepts that do not get funded under CMAQ, but are worth exploring. Finally, some states fund statewide activities to provide services not being undertaken at the local level. Some state DOTs have performed ridematching and information services in parts of the state not covered by existing programs. Others have funded statewide initiatives (rideshare week, bike-to-work week) or air quality public education campaigns (like Clean Across Texas, www.drivecleanacrosstexas.org).

4 Finally, state DOTs control the management and operation of transportation facilities that affect how and when people travel and use their cars. Three notable facilities are HOV lanes, park-and-ride lots, and bicycle facilities on state roads. These facilities increase the convenience of ridesharing and using transit (park-and-ride), increase safety (bicycle lanes), and can provide travel time savings (HOV lanes) to alternative mode users. FHWA is redefining TDM as less of a planning function, and more of a set of strategies to be integrated into the management and operations of transportation facilities to improve the overall
efficiency and effectiveness of the system. One major study of the HOV system in Los Angeles County pointed to the effectiveness of the HOV system, but the ongoing need to better coordinate HOV operations with ridesharing services and traveler information.

5 **Alternative modes are often a key part of the mitigation strategy for a major reconstruction project.** However, states often perform this integration late in the planning process, not providing sufficient time or funding to realize the potential impacts of shifting travelers to alternative modes, routes, or time of day. Some states, including California, have built transportation management planning functions into the overall planning process for reconstruction projects. State DOTs can develop clear guidelines for identifying candidate alternative modes and integrating alternative modes into this process.

6 **State DOTs can develop statewide policies regarding alternative modes and their role in addressing air quality objectives** as well as other issues such as congestion, growth management, asset management, etc. This also provides the DOT a better foundation for commenting on CMAQ project selection decisions.

**Tree Shading for Emissions Reduction**

While cars sit in the sun, gasoline evaporates from fuel tanks and worn hoses. These evaporated materials are principle components of smog. In 1999, the U.S. Forest Service and the University of California at Davis completed a pilot study to measure the difference in parking lot microclimate and parked vehicle emissions resulting from the presence or absence of shade tree cover. Results indicated that shade tree cover in parking lots reduced motor-vehicle hydrocarbon and nitrogen oxide emissions from cars parked in those lots. In this study, conducted in Sacramento California, interior vehicle temperatures averaged 45°F cooler in the tree-shaded vehicle when compared with temperatures inside unshaded vehicles. Furthermore, increasing parking lot canopy cover from 8 percent to 50 percent would reduce total vehicle-generated hydrocarbon emissions by two percent and nitrogen oxide emissions by just under 1 percent in similar climates. In addition, this study noted that there was a user preference for shaded parking spaces.

Shade also extends the life of asphalt pavement. Trees in parking areas provide shade, visually reduce the impact of large pavement areas, and reduce heat gain.

1 Use perimeter trees and shrubs to screen the parking area from nearby residential uses, while allowing for visibility by security personnel.

2 Design for a minimum of 50 percent canopy cover over parking areas.

3 Select tree species that do not drip pitch or attract aphids.

4 Where trees are planted near a bus route, or bus parking, limb trees to eight (8) feet above the ground.

5 Use planting areas to divide paved surfaces into smaller, more defined parking areas.

6 Consider end islands to delineate aisles and intersections and to protect the end
vehicles. End islands should have raised curbs.

7 An alternative to planting in linear parking islands is the design of large concentrated planting islands within parking lots. This can allow plant communities to establish in these islands. They can also be stormwater infiltration areas.

8 Keep landscaping as low-maintenance as reasonably possible.

9 In high snow load areas, end islands may cause difficulties with snow removal. In these areas, large central planting islands may be more appropriate. Consider snow storage needs and adjacent vegetation in high snow load areas.

10 In arid climates, irrigation may be necessary for plant survival.

11 These areas benefit most from tree shading of parking stalls in the summer due to higher temperatures.

12 Consider the use of structural soils under paved surfaces to allow root penetration without damage to the pavement and to retain parking spaces while increasing soil volume for trees in parking islands. This will benefit both the tree and long-term maintenance of the parking lot. Additional information can be found at the Department of Horticulture at Cornell University.

13 Interior planting islands should have drainage provided and depth to allow tree root growth at least 3 feet deeper than paving grade.

14 Plant trees to align with the painted parking stall lines to prevent their damage by car bumpers.

15 Car bumpers overhang tire stops and curbs. Consideration should be made in the design of sidewalks and planting areas for this overhang.

### 3.12 Design and Specification for Recycling

*The Growing Need for and Importance of Waste Minimization and Recycling*

Recycling means reintroducing waste material into the production process, to supplement primary resources. The use of waste as a raw material saves resources and primary raw material, reduces air and water pollution, and extends limited landfill life. Recycled products can also save financial resources through lower material costs and lower disposal costs. In some cases, using recycled products can improve material performance as well. Consequently, using recycled materials is a key aspect of more efficient and environmentally sensitive highway design and construction.()

Recycling also saves energy. A quantitative assessment of environmental impacts on life cycle of highways found that most energy is consumed in the manufacturing stage of construction materials, with consumption of 1,525 tons of oil equivalent (TOE)/functional unit (1 km and 4 lanes of highway).() Energy consumption in the maintenance and repair stage was also fairly high among the life cycle stages; the next highest consumption was for the construction and demolition stage. Through the whole life cycle of 20 years, 2,676 TOE of energy/functional unit was consumed, and this
corresponds to SO2, NOx, and CO2 emissions of 62.1 tons, 17.1 tons, and 2,438.5 T-C, respectively.

The United States spends approximately $13 billion annually (1999 dollars) on highway construction and repairs, requiring nearly 350 million tons of both natural and manufactured construction materials. Approximately 4.1 billion metric tons of non-hazardous solid waste materials are generated annually. The majority of these materials are being landfilled in many states; however, landfills and access to materials are increasingly limited by growing environmental regulations and permitting requirements, restrictive zoning laws, land uses, and other economic considerations. Community opposition has restricted the expansion of and forced the closure of existing landfills, quarries, and gravel pit operations. The latter has created localized shortages of construction aggregates and borrow materials in some areas, further adding incentive to explore alternatives in order to alleviate such shortages and to conserve natural resources.

**Common Recycling Applications in the U.S. and Europe**

Research into new and innovative uses of waste materials is continually advancing. Many highway agencies and private organizations have completed or are in the process of completing studies and projects concerning the feasibility, environmental suitability, and performance of using recycled products in highway construction. Reduction of waste material at its source and reuse of construction waste complement recycling efforts. Recycled materials are typically used in such applications as bituminous pavements, Portland cement concrete (PCC) pavements, road base, embankments and fills, flowable fills, landscaping, bicycle paths, parking lots, and appurtenances such as signs, fencing, barriers, traffic delineators, etc. Some of the most notable uses of recycled materials in the highway environment over the last 20 years have included recycled asphalt pavement (RAP), reclaimed concrete pavement, coal fly ash and blast furnace slag. A few states and local governments have passed legislation to promote recycling in road construction. In some case beneficial use determination processes (BUDs) evaluate uses though a wide range of approaches are used; California, Illinois, Massachusetts, New Jersey and Pennsylvania are working to standardize the BUD process and create reciprocity. State DOTs and state environmental protection agencies (State EPAs) are also trying to balance the desire for increased use of recycled materials with concerns about potential environmental impacts of leaching from recycled materials.

*FHWA* produced a review of the use of recycled materials in highway construction in the early 90s, a summary of which is included below.

**Table 4: FHWA Summary of Known Uses in Waste Applications**

<table>
<thead>
<tr>
<th>Millions of Metric Tons Annually</th>
<th>Current and Past Highway Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Produc ed</td>
<td>edRecycl ed</td>
</tr>
<tr>
<td>Blast Furnace Slag</td>
<td>ag</td>
</tr>
<tr>
<td>Material</td>
<td>LCP (%)</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>Municipal Waste Combustion Ash</td>
<td>7.3</td>
</tr>
<tr>
<td>Plastic</td>
<td>14.7</td>
</tr>
<tr>
<td>Reclaimed Concrete Pavement</td>
<td>3</td>
</tr>
<tr>
<td>Reclaimed Asphalt Pavement</td>
<td>91</td>
</tr>
<tr>
<td>Roofing Shingle Waste Industry-Produced Re-roofing Waste</td>
<td>0.4</td>
</tr>
<tr>
<td>Scrap Tires</td>
<td>2.3</td>
</tr>
<tr>
<td>Steel Slag</td>
<td>7.5</td>
</tr>
<tr>
<td>Waste Rock</td>
<td>954</td>
</tr>
</tbody>
</table>

NCHRP Synthesis of Highway Practice 199, *Recycling and Use of Waste Materials and By-Products in Highway Construction* developed a methodology for assessing the suitability and practicability of specific waste management materials.
true free market situation because of their excellent performance and competitive costs. Other materials are used more locally in response to more specific local market forces. There is little federal government involvement, except for construction procurement guidelines for materials like coal fly ash. Rather, the situation is driven at the state level. For example, the State of Pennsylvania has adopted legislation to promote recycling in the highway environment. RMRC’s Report for the International Scan Tour on Recycling Techniques, is available on-line.

**General Recommendations for DOTs with Regard to Recycling and Waste Management**

The International Scan Tour Report generated a number of recommendations for AASHTO’s Standing Committee on the Environment and Subcommittee on Materials that are pertinent to recommended practices for state DOTs: 

1. Include a recycling strategy in the sustainability aspect of strategic plans and long range research priorities.
2. Create a framework to consider the use of recycled materials in project planning, alternatives analysis, and mitigation analysis.
3. Encourage long term materials supply plans and recycled materials availability plans.
4. Develop clear engineering and environmental guidelines at the State and Federal level that are available for suppliers and decision-makers.
5. Develop courses on recycling.
6. Evaluate contractors with respect to use of recycled materials or environmental protection during contract performance reviews.
7. Develop and implement the use of warranty and performance based specifications.

The following practices are also recommended to facilitate environmental stewardship in materials management:

1. Materials should be used in the most effective way possible.
2. Structures should have long lives.
3. Materials should be recyclable.
4. Consumption of energy in the construction development should be optimized.
5. Alternatives for conventional resources should be considered.

**Life Cycle Cost-Benefit Analysis**

The most recent TRB research needs meeting called for an expansion of life cycle analysis to reduce waste, prevent pollution, and encourage recycling. FHWA’s Highway Economic Requirements System (HERS) is an example of a tool that supports tradeoffs between preservation and improvement projects. The HERS application is based on the Highway Performance Monitoring System (HPMS) database,
and is intended to replace HPMS as the source of biennial federal needs studies submitted to Congress. The HERS algorithms address both highway capacity and pavement preservation needs. Thus, state application of HERS or HERS/ST are uniquely suited to asset management studies that are more comprehensive than those addressed by individual management systems (e.g., pavement management and congestion management) and can explore tradeoffs between system preservation and system improvement or expansion.

**Areas for Recycling Applications**

Areas for recycling applications in maintenance, many of which are applicable for other parts of the organization, are described in detail in Section 10.13.

**Specifications for Recycled Materials in Transportation Applications**

Available AASHTO or DOT specifications for the recycled materials covered in ensuing sections are included as web links within those sections, and more specifications are being developed all the time. The Recycled Materials Resource Center (RMRC) has a project underway to Develop and Prepare Specifications for Recycled Materials in Transportation Applications. Participants in the project—Caltrans, FDOT, Illinois DOT, Mass Highway, Michigan DOT, Mn/DOT, NHDOT, NJDOT, NYS DOT, NCDOT, Ohio DOT, PennDOT, TxDOT, and WisDOT—identified the recycled materials of greatest interest to DOTs and assisted in the development of specifications. Six material/application combinations are underway. The first of these, a specification for glass cullet use as an aggregate base course, was published in 2001 (M-318-01). This past year, a second specification, “M-319-02, Reclaimed Concrete Aggregate for Unbound Soil-Aggregate Base Course,” was published in the 22nd edition of the AASHTO’s *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*. A third specification, “Use of Recycled Concrete as an Aggregate Substitute in PCC Pavements,” is under review by the AASHTO Technical Section. A specification for coal fly ash in embankments has been tabled by the Technical Section, while a draft specification for reclaimed asphalt pavement as an aggregate in asphalt concrete has been prepared for submission to the Technical Section. The last specification on the use of roofing shingle scrap as an aggregate for asphalt concrete is in preparation.

1. Final Glass Cullet specification - AASHTO Designation: M 318-01
2. Final Specification for Recycled Concrete as Aggregate in PCC Pavements
3. Final Specification for Reclaimed Concrete Aggregate for Unbound Soil-Aggregate Base Course: AASHTO Designation: M 319-02
4. Draft Coal Fly Ash Specification

See also:

1. AASHTO Standard Spec for Compost for Erosion/Sediment Control - *Compost Blankets*
2. AASHTO Standard Spec for Compost for Erosion/Sediment Control - *Filter Berms*

As of February, 2004, specifications under development via RMRC projects include the
projects listed in the Appendix. RMRC keeps an updated list at their RMRC Resources and Specifications site.

3.13 Designing to Minimize Noise

Noise may be defined as unwanted or excessive sound that is bothersome to human beings and wildlife. The 1998 International Labor Office encyclopedia lists the construction industry as the fourth noisiest industry sector.

State and federal agencies and the transportation industry as a whole have employed a wide variety of methods to minimize noise from construction and highway operations. Though some noise regulation exists, many of the most innovative and comprehensive noise control practices have evolved outside of the regulatory context.

Noise Effects and Regulation

Noise levels affect the quality of life in neighborhoods and communities and therefore affect the degree of public satisfaction with the transportation system. Fish and wildlife are also affected by noise.

Any type of rehabilitation that adds lanes, significantly changes alignment or increases capacity requires a noise study. The key component of the study is the modeling of the new acoustical landscape by using actual project design data and plugging it into a noise modeling software package that predicts the changes to the acoustical environment caused by the rehabilitation. The generally accepted definition of excessive noise is an increase of 10 dBA or greater. A 3dB reduction approximates doubling the distance from a line source (i.e. traffic) noise source. FHWA Noise Abatement Criteria establishes 67 dBA “not (as) an absolute value or design standard, (but) only a level where noise mitigation must be considered.”

Effects of Highway Noise on People

Noise can disturb sleep and relaxation, interfere with an individual’s ability to perform complicated tasks, be a source of annoyance, influence mood and stress levels, and otherwise detract from the quality of life. Economic effects of noise include impacts to property values, impaired health, and lowered working efficiency. Recent studies have concluded that day-night average sound level is still the most adequate noise descriptor for use in environmental impact analyses to assess the annoyance and overall impact of noise from general transportation, including civilian and military aircraft operations.

In Europe, a substantial amount of research has been performed on effects of noise on people and the European Union has begun to take the topic very seriously. European researchers say most of the high burden by environmental noise arises from transportation on road, on rail and in air and estimate the costs of noise pollution as up to 2 percent of the European gross domestic product. Adverse effects of roadway or traffic noise have been determined to include interference with communication, noise-induced hearing loss, annoyance responses, and effects on sleep, the cardiovascular and psychophysiological systems, performance, productivity, and social behavior. It was found that in the European Union about 40 percent of the population is exposed to road traffic noise with an equivalent sound pressure level exceeding 55 dB(A) daytime, and 20 percent are exposed to levels exceeding 65 dB(A). When all transportation noise is considered, more than half of all European Union citizens are estimated to live in zones
that do not ensure acoustical comfort to residents. At night, more than 30 percent are exposed to equivalent sound pressure levels exceeding 55 dB(A), which are disturbing to sleep.() The same researchers determined that noise pollution is an important issue in cities of developing countries as well, where traffic and alongside densely-traveled roads equivalent sound pressure levels for 24 hours can reach 75–80 dB(A). In contrast to many other environmental problems, noise pollution continues to grow and can result in direct, as well as cumulative, adverse health effects, according to the World Health Organization.() As a result of these concerns, the European Union has developed a Noise Research Strategy Plan with goals for 2020 to halve the perceived level of noise from road traffic. To this end, the EU is examining new or improved solutions and system approaches to deal with the following forms of roadway noise: ()

1. Rolling noise (the predominant issue at mid and higher vehicle speeds), and in particular low noise tires and quiet, maintainable road surfaces. In this report, rolling noise is addressed under “Roadway or Traffic Noise Control.”

2. Propulsion noise comprising engine, transmission and exhaust noise (a significant element during acceleration of heavy trucks, especially in urban traffic). In this report, vehicle/equipment operating noise is addressed under “Construction Noise Control.”

3. Traffic management, i.e. sophisticated management systems, (to make possible road traffic with reduced noise emission). (Not addressed in this report.)

An overview of European activities and working groups related to noise research and policies can be found at www.europa.eu.int/comm/environment/noise/.

Effects of Noise from Roads on Birds and Terrestrial Wildlife

Over 75 percent of roads and streets in the United States are under the jurisdiction of local governments. The Federal jurisdiction is mainly limited to National Parks, National Forests, and other government-owned land. FHWA has taken the view that “generally in these areas, there are no permanent residents and, therefore, no noise problem of any extent.”() While roads on federal lands are lower in density, and thus may have lower effects on people, the effect of roadway noise on wildlife is beginning to be explored. In general, animals respond to noise pollution by altering activity patterns and with an increase in heart rate and production of stress hormones.() Sometimes animals become habituated to increased noise levels, and apparently resume normal activity; however, birds and other wildlife that communicate by auditory signals may be at a disadvantage near roads.() Highway noise can also disrupt territory establishment and defense and communication, with Endangered Species Act implications in a few cases. The greatest effects of transportation on wildlife have been documented from off-road vehicles() and overhead flights. ()() A wider list of Scientific Literature References for Anthropogenic Noise Impacts to Wildlife was recently posted on Re:NEPA, FHWA’s knowledge exchange listserv.

The effects of highway noise on bird populations have been studied in the U.S., particularly in California, and with regard to multiple species’ breeding success in the Netherlands. Three papers published in the Journal of Applied Ecology describe changes in breeding patterns and densities for 43 species of birds in the Netherlands. Researchers examined pairs of nesting sites, with one near a busy road and one distant from it. Sixty percent of the species analyzed showed evidence of reduced densities close to the roads. The distance over which the effect was observed depended how busy the roads were:
10,000 cars a day affected birds up to 1.5 km from the roads; 60,000 cars a day affected birds up to 2.9 km from the road. For a zone of 250 m from the road the reduction of the density varied from 20 to 98 percent. When noise conditions were held constant, however, there was no difference in bird densities between plots with high and low visibility of cars. Visibility of cars, direct mortality and air and water pollution were considered unimportant. A California study on traffic noise impacts on Least Bell’s Vireo Habitat recommended speed reductions and temporary noise barriers for approximately 600 m (2,000 ft) on each side of CA-83. Nevada had successfully employed simple plywood tilted away from the road at a ten-degree angle to lessen noise reverberation between the barriers. The FWS rejected Caltrans’ proposed noise barriers but offered a mitigation alternative unrelated to the noise impact and the highway agency agreed to fund a project to control the arundo plant within the expected noise-impact area. Also known as giant reed, the arundo plant invades and destroys the native willow riparian habitat of the least Bell’s vireo. FWS indicated this measure would provide more long-term benefit to the vireo. The California Least Bell’s Vireo roadway noise study revealed that neither Caltrans nor the FWS had a centralized list of noise-mitigation projects for endangered species. Nonetheless, the issue of noise mitigation for endangered species has been considered on at least one temporary and seven permanent noise-mitigation highway projects in California. The CA-83 study also brought into question the validity of the FWS’s loudest-hour noise-impact criterion of 60 dB. Biologist John Rieger developed the criterion for a California highway project in 1987-88. Rieger assumed that if he found an area where least Bell’s vireo nests existed near the highway, the noise level on that stretch of roadway must be acceptable to the bird. Finding ten least Bell’s vireo nests along Route 76, he calculated the loudest-hour sound level at the location of each nest. The highest and lowest numbers were discarded, and the remaining were averaged—yielding a result of 61 dB. Rieger never intended this number to set a precedent or become a standard for noise-impact mitigation for endangered species, yet both resulted. In fact, with each noise-impact study that has used it, a 60-dB criterion has become more firmly established as the standard of use. This noise analysis relies on sound-level and loudest-hour equivalent sound level computations, both of which were developed in relation to human hearing. Current noise analysis procedures and criterion may not accurately estimate the impact of noise on the least Bell’s vireo and other songbirds. In addition, the CA-83 study raised the issue of money—how much should be spent on noise mitigation projects for endangered species. Rieger, now a manager at Caltrans, has estimated that $9 million has either been spent on or committed to noise mitigation projects for endangered birds in Caltrans District 11.

**Effects of Noise from Pile Driving during Construction**

While pile driving effects on some bird species, such as marbled Murrelets, have been explored, the primary concerns of pile driving during construction have been effects on people. Pile-driving is one of the noisiest construction operations. As an integral component of many overwater and in-water structures, pilings provide support for the decking of piers and docks, function as fenders and dolphins to protect structures, support navigation markers, and are used to construct breakwaters and bulkheads. Bridges, ferry terminals, and other structures commonly have driven-pile foundations. Piles are usually driven into the substrate using one of two types of hammer: impact hammers and vibratory hammers. Impact hammers consist of a heavy weight that is repeatedly...
dropped onto the top of the pile, driving it into the substrate. Vibratory hammers utilize a combination of a stationary, heavy weight and vibration, in the plane perpendicular to the long axis of the pile, to force the pile into the substrate. The type of hammer used depends on a variety of factors, including pile material and substrate type. Impact hammers can be used to drive all types of piles, while vibratory hammers are generally most efficient at driving piles with a cutting edge (e.g., hollow steel pipe) and are less efficient at driving displacement piles (those without a cutting edge that must displace the substrate). Displacement piles include solid concrete, wood, and closed-end steel pipe. While impact hammers are able to drive piles into most substrates (including hardpan, glacial till, etc.), vibratory hammers are limited to softer, unconsolidated substrates (e.g., sand, mud, gravel). Since vibratory hammers do not use force to drive the piles, the bearing capacity is not known and the piles must often be “proofed” with an impact hammer. This involves striking the pile a number of times with the impact hammer to ensure that it meets the designed bearing capacity. Under certain circumstances, piles may be driven using a combination of vibratory and impact hammers. The vibratory hammer makes positioning and plumbing of the pile easier; therefore, it is often used to drive the pile through the soft, overlying material, after which an impact hammer may be used to finish driving the pile to final depth. Overwater structures must often meet seismic stability criteria, requiring that the supporting piles are attached to, or driven into, the underlying hard material. This requirement often means that impact driving is necessary.

Injuries associated directly with pile driving are poorly studied, but include rupture of the swimbladder and internal hemorrhaging. Sound pressure levels (SPL) 100 decibels (dB) above the threshold for hearing are thought to be sufficient to damage the auditory system in many fishes. Impact hammers may be more harmful than vibratory hammers because they produce more intense pressure waves and because the sounds produced do not elicit an avoidance response in fishes, which exposes them for longer periods to those harmful pressures. Small fish are more prone to injury by intense sound than are larger fish of the same species (Yelverton et al. 1975). Of the reported fish kills associated with pile driving, all have occurred during use of an impact hammer on hollow steel piles. SPLs are positively correlated with the size of the pile, as more energy is required to drive larger piles. Wood and concrete piles appear to produce lower sound pressures than hollow steel piles of a similar size, and wood, concrete and small diameter steel may not present a problem.

The degree to which an individual fish exposed to sound will be affected is dependent upon a number of variables, including: species of fish, fish size, presence of a swimbladder, physical condition of the fish, peak sound pressure and frequency, shape of the sound wave (rise time), depth of the water around the pile, depth of the fish in the water column, amount of air in the water, size and number of waves on the water surface, bottom substrate composition and texture, effectiveness of bubble curtain sound/pressure attenuation technology, tidal currents, and presence of predators. Most of the work relating to noise impacts on fish has been done with explosives, which produce pressure waves with different shapes and intensities and frequencies than pile-driving. In 2005, NCHRP will undertake research to determine by laboratory work and field validation the nature and degree of impacts to fish over the potential range of sound pressure levels that can occur during aquatic pile-driving operations. This research will also develop and validate sound pressure guidelines for protecting sensitive Atlantic, Pacific and freshwater fish species over the potential range of sound pressure levels that can occur during
aquatic pile-driving operations in fresh and salt water. For the time being, DOTs rely on conservative assumptions and guidelines provided by the National Marine Fisheries Service, now called NOAA Fisheries, which provided the referenced information in this section on pile-driving and effects on fish species.

**Noise Regulation**

The National Environmental Policy Act (NEPA) of 1969 provides broad authority and responsibility for evaluating and mitigating adverse environmental effects including highway traffic noise. NEPA directs federal agencies to use all practical means and measures to promote the general welfare and foster a healthy environment. The Federal Aid Highway Act of 1970 specifically addresses abatement of highway traffic noise and mandated FHWA to develop noise standards for mitigating highway traffic noise. Under this mandate, FHWA has promulgated noise-level criteria for various land use activities. The law further provides that FHWA not approve the plans and specifications for a federally aided highway project unless the project includes adequate noise abatement measures to comply with the standards. FHWA has developed and implemented regulations for the mitigation of highway traffic noise in federally-aided highway projects, but states retain significant discretion in deciding what is reasonable and feasible. The regulations contain noise abatement criteria which represent the upper limit of acceptable highway traffic noise for different types of land uses and human activities; however, they do not require that the abatement criteria be met in every instance. Rather, they require that every reasonable and feasible effort be made to provide noise mitigation when the criteria are approached or exceeded. Noise descriptors are used to describe the time-varying nature of noise and are used in abatement procedures. The L10 is the noise level exceeded 10 percent of the time in the noisiest hour of the day. Leq is the constant, average sound level, which over a period of time contains the same amount of sound energy as the varying levels of the traffic noise.

The FHWA noise regulations give each state department of transportation flexibility in determining the reasonableness and feasibility of noise abatement and, thus, in balancing the benefits of noise abatement against the overall adverse social, economic, and environmental effects and costs of the noise abatement measures. The state DOT must base its determination on the interest of the overall public good, keeping in mind all the elements of the highway program (need, funding, environmental impacts, public involvement, etc.). FHWA developed a Method to Determine Reasonableness and Feasibility of Noise Abatement at Special Use Locations, which outlines a procedure that employs a systematic approach to the determination of reasonableness of abatement for special land uses. The development process for a Reasonableness Matrix for special land uses is explained and an overview of a finalized policy, along with details of the policy development methodology, is presented.

FHWA and state DOTs have advocated a three-part approach to effective control of the undesirable effects of highway traffic noise: control of land use near highways on a local level, quieter vehicles, and mitigation of noise on individual highway projects.

Expected noise reduction performance benefits of proposed mitigation measures are weighed against cost implications, and noise mitigation measures are implemented only when justified based on careful consideration of all relevant technical, cost, and policy issues.
Designing for Roadway/Traffic Noise Source Control

Roadway or traffic noise is generated by the vehicle engine and emission of exhaust, aerodynamic sources, and tire/pavement interactions. For vehicle speeds over 50 miles per hour, the tire pavement interaction dominates this mix and the source level is dependent on the vehicle type, tire type, and speed.

Sound walls are the only solution currently approved by FHWA for addressing noise impacts; however, a sound wall attenuates noise only within the acoustical shadow of the wall and benefits only those directly behind it. Caltrans has built more than 600 miles of sound walls at an average annual cost of $60 million. As of 2004, sound walls cost more than $1,300,000 per mile. Noise walls also tend to be very expensive per residence. For example, the 1990 construction cost for a noise wall on I-40 in Knoxville, TN was estimated at $25,000/affected home, as walls would have needed to be over 20 ft. high to be effective. More recently on I-285 in Atlanta the criteria for a noise wall was $50,000 or less per affected home and a noise level of 69 dB(A) or more. For U.S. 441 in West Boca, FL, the requirements to construct a noise wall included a noise level of 67 dB(A) or more, a cost of less than $30,000/affected home and a noise reduction of at least 5 dBA.

Pavement Alterations to Reduce Roadway Noise

The only component of traffic-related noise under the control of DOTs is the acoustical property of the pavement. Quieter highways have the potential to reduce noise levels at the source, reducing the need for expensive sound walls, and benefiting a larger percentage of the community; however, more scientifically based criteria for designing quiet pavements are still needed. A 2005 NCHRP study will undertake the development of adequate quiet pavement design criteria by performing a nationwide survey of both asphalt concrete (AC) and Portland cement concrete (PCC) pavements, using innovative sound measurement technology to develop a nationwide index that ranks various pavement acoustical properties from the quietest to the loudest.

NCHRP Synthesis 268: Relationship Between Pavement Surface Texture and Highway Traffic Noise presented a comprehensive synopsis of pavement/tire noise as it relates to roadways along with detailed information on acoustic definitions and concepts, the theory of tire/pavement noise generation and current mitigation practice, measurement techniques, interior vehicle noise, reported noise emission results for pavement type and texture, effects of pavement wear, surface friction, and maintenance and safety considerations. The study concluded that, “In general, when dense-graded asphalt and PCC pavements are compared, the dense-graded is quieter by 2 to 3 dB(A),” a reduction that corresponds to doubling the distance from the noise source or reducing the traffic speed by 25 percent. In particular the report found that, “open-graded asphalt show(ed) the greatest potential for noise reduction for passby noise. Reduction when compared to dense-graded asphalt ranged from 1 to 9 dB(A).” A 9dB(A) reduction corresponds to a reduction in traffic noise by almost 50 percent. Even dense graded hot mix asphalt surfaces (DGAC) have been found to be quieter than PCC pavements. Stone-matrix asphalt (SMA) has also been found to be a relatively quiet surface. England is moving forward with a 10-year plan to install quieter surfaces (SMA or OGFC) on 60 percent of main trunk roads.
**Open Graded Asphalt Concrete (OGAC) for Noise Reduction**

Caltrans and TxDOT are actively involved in quiet pavement studies focusing on open graded asphalt concrete. TxDOT refers to these as Porous or Permeable Friction Course (PFC). TxDOT’s first PFC was placed in 1999, and, since that time, approximately 25 PFC projects have been constructed in Texas. PFC mixtures are gaining popularity due to their ability to reduce the risk of hydroplaning, reduce the amount of splash and spray, reduce pavement noise, improve visibility of traffic striping in wet weather, and improve ride quality.

In research supported by the U.S. DOT Volpe Research Center Acoustics Facility (VCAF), near-field measurements (at the tire) and wayside measurements are each being used to evaluate AC and PCC pavements on California State Route 138. This study, unique in scale and scope, has placed commonly utilized AC pavements (30mm DGAC, 30mm OGAC, 75mm OGAC, 30mm Rubberized OGAC, and 30mm Bonded Wearing Course) in one location, exposing them to the same environmental and traffic conditions. All tested pavement courses will be placed over a 30 mm DGAC leveling course. VCAF is measuring noise pressure levels at 25 ft, 50 ft, and 200 ft from the edge of the pavement for 5 years, with existing traffic and a controlled test vehicle and applying a modified Statistical Pass-By (SPB) to evaluate the different pavements and account for multiple vehicle types, tires, and speeds. So far, Volpe has found that the quietest pavements are OGAC and RAC type O, though noise suppression effectiveness of pavements is vehicle dependent, with a lower effect shown for heavy trucks.

**Caltrans recently completed a three-year study** to determine if the noise attenuation benefits of open graded asphalt concrete (OGAC) decreased over time. A 9-kilometer portion of pavement on Interstate-80 near Davis California was rehabilitated in June 1998. The new pavement cross section consisted of a 60 mm dense graded asphalt concrete (DGAC) leveling course that was overlaid with 25 mm of OGAC. Noise measurements a month prior to the pavement rehabilitation established the baseline condition. Additional measurements were made immediately after placement of the DGAC leveling course, and after the completion of the OGAC overlay. Immediately after application of the DGAC base roadside noise levels declined by 3 to 4 dBA from the baseline condition. After application of the OGAC, roadside noise levels declined by about 5 dBA over the baseline condition. Noise levels continued to be 4 to 6 dBA lower than the baseline condition over the entire period of the study.

NCHRP has research planned for FY 2005 on cold weather performance of new generation open-graded friction courses (NGOGFC). While there are numerous reported benefits of NGOGFC or PFC mixtures, safety and winter maintenance concerns are often cited as the primary objections to increased use. The research will examine whether attributes of new generation OGFC (NGOGRC) will translate into better performance in winter conditions. In addition to the safety issues, concerns have also been raised about the increased maintenance cost of these mixtures due to the need for additional salt and/or sand treatment. Many agencies, particularly the European ones, have adopted innovative methods of maintaining NGOGFCs to ensure free drainage to surface water. It is also known that several agencies are revising their design criteria to improve the performance of NGOGFC. The use of modified binders and additives has improved the durability of NGOGFCs, but has not solved the potential icing problem. Research is needed to determine the liability versus benefit of using NGOGFC in geographic regions that are susceptible to numerous freeze/thaw cycles. Although no
performance problems such as raveling have been reported with NGOGFC, there are still concerns that these mixes could experience the performance problems associated with the old OGFC mixes if the NGOGFC mixes are used in climatic regions susceptible to numerous freeze/thaw cycles. The concerns are the most likely reason that NGOGFC mixes are predominately used in warmer, more arid climates such as the southern and western regions of the United States.

There are numerous differences between NGOGFC (or PFC) and first generation OGFC. NGOGFC contains approximately 20 percent more asphalt (by volume) than conventional OGFC. NGOGFC is designed to have a minimum of 18-percent air voids, whereas conventional OGFC was not designed based on air voids. Conventional OGFC mixture typically contained between 10- and 15-percent air voids. At the lower air void range, moisture could get trapped within the void matrix of the conventional OGFC. The void structure of NGOGFC allows the mix to be more permeable and less likely to trap water, which could potentially freeze. NGOGFC contain fibers and is heavily modified with polymers unlike conventional OGFC mixes. In addition, NGOGFC mixtures are more open graded than the conventional OGFC mixtures. The open texture allows NGOGFC to get flushed out by high-speed traffic, therefore reducing the potential to get clogged over time. NGOGFC mixtures are typically placed more thickly than conventional OGFC (1.5 to 2.0 inches as opposed to 1.0 inch). The thicker, more open matrix allows the NGOGFC to drain more water off the roadway more quickly than conventional OGFC. Research on NGOGFC indicates that the mixes typically last between 10 to 14 years, which is significantly longer than the first generation OGFC mixtures, which typically lasted between 5 and 7 years. The NCHRP project will provide recommendations for DOTs on how to maintain NGOGFC in different environmental zones, including the issue of how to avoid clogging or unclog voids due to sanding operations, provide recommendations on design requirements for NGOGFC, and identify topics that should be studied further.

*Rubberized Pavements*

Acoustics tests on Asphalt-Rubber open graded mixes or Porous Friction Course (PFC) are occurring in Arizona, California, and Texas. As described above, Asphalt-Rubber OGFC is part of Caltrans five year study of noise reduction from various pavement types. In Arizona, resurfacing of the old concrete US 60 with AR OGFC during a major design/build widening project generated a 9.5 dBs reduction and much public feedback, including requests for further resurfacing efforts. ADOT has committed to undertake a $100 million AR OGFC resurfacing effort if the public extends a special freeway tax. ADOT is currently running noise studies on many of its older AR pavements to determine the reduction capabilities of the material over time.

As part of the state’s “smoothness” campaign for the state’s roadways, TxDOT undertook a noise study as part of a resurfacing of the I-35 in San Antonio, where a 1.5 inch Porous Friction Course that was placed over the existing concrete surface. PaveTex Engineering conducted noise measurements prior to and after the new surface was applied and documented an average reading on the new PFC surface of 10dB quieter than an adjacent section of the old concrete pavement.

A joint study prepared for the Sacramento County Public Works Agency, Transportation Division by the Sacramento County Department of Environmental Review and Assessment and consultants in acoustics and noise control engineering found an average four decibel reduction in traffic noise levels as compared to the conventional asphalt
overlay used elsewhere. This noise reduction continued to occur six years after the paving with rubberized asphalt, at which time the study was concluded. The sponsors found this degree of noise attenuation to be significant, as it represented a 60 percent reduction in traffic noise energy, and a clearly perceptible decrease in traffic noise. This degree of traffic noise attenuation from rubberized paving has similar to the result documented in several non-related studies conducted in recent years at various other locations, both nationally and internationally.

The Netherlands has five years of experience with second generation porous asphalt surface courses with rubberized asphalt binders, ranging from test sections to large scale use. The new concept consists of a double-layered porous asphalt construction, made up of a bottom layer of coarse porous asphalt (single-grained gradation, aggregate size 11 - 16 mm) and a top layer of fine-graded porous asphalt (aggregate size 4 - 8 mm). The binder in both layers consists of rubberized asphalt. The fine texture of the top layer causes a reduction of traffic noise, from 3 to 4 dB(A) at 50 km/h up to 5,5 dB(A) at 100 km/h (and 7 to 12 dBA quieter than PCC pavements). The bottom layer has a higher discharge capacity compared to conventional porous asphalt, which makes the sideways drainage of water, even on wide roads, considerably better. Pollution, dirt and silt on the road surface are kept from entering into the construction due to the “sieve” behavior of the top layer. In the Netherlands, a vacuum cleaning method consisting of water under pressure (up to 120 bar) is sprayed onto the surface to remove nearly all of the accumulation. The rotating movement of the spray nozzles makes sure that water enters the top layer from all directions. Directly behind the spray bar the water, containing dirt, is sucked up and recycled before again entering the circuit. Cleaning the two-layered porous asphalt in this way is much more effective compared to conventional porous asphalt, because the dirt is concentrated in the upper part of the top layer. On the older road sections with Twinlay, the bottom layer appears to be clean after being in use for several years, which assures the horizontal drainage of water through this layer.

Depending on the severity of pollution, cleaning is required once or twice a year. Like conventional porous asphalt the two- layered construction requires adjusted salting operations, as salt can more easily be carried off with meltwater.

Further information on recycling rubber into pavement technologies, and the performance thereof, is reviewed in Chapter 5, Pavement, Materials, and Recycling.

Portland Cement Concrete Treatments for Noise Reduction

The United States has experience with tined (Arizona, California, Colorado, Iowa, Michigan, Minnesota, New Jersey, North Dakota, Virginia, and Wisconsin) and textured (Michigan) surfaces of PCC pavements to address roadway noise. For PCC pavements, Caltrans is partnering with the Western States-American Concrete Pavement Association on the Interstate-280 pavement rehabilitation project in San Mateo County. In this project the noise production from the old longitudinally tined pavement will be compared to noise production from a PCC pavement with diamond grinding, a PCC pavement with texture grinding, and a PCC pavement overlain with 30 mm of open graded rubberized AC. Noise measurements will be made for three to five years to assess the longevity of noise reduction. As of June 2002, several AC pavements had been placed on a test section of the roadway; plan sheets of the study location are available here. In a comparison study, Volpe has helped Caltrans compare 3 PCC test sections (longitudinal tining, burlap dragged, and broomed tining) and helped Arizona DOT compare three as well (uniform longitudinal tining, uniform transverse tining, and randomly spaced
New Research Areas in Noise Source Reduction

New noise research areas being considered include: developing a better understanding of the attributes of pavement that reduce noise generation for different types of vehicles, evaluating pavement performance with age, and developing maintenance techniques that preserve the noise reducing characteristics of the pavement and developing quieter tires without compromising safety.

To date, little data have been developed on how the transmission of pavement noise will be influenced by the porosity and/or rigidity of the internal pavement structure, though the Recycled Materials Resource Center is supporting research in this area. Several recent European research projects examining the issue of the high pitched whine and/or low-pitched rumble commonly associated with PCC pavements have indicated that the construction of porous pavements may provide one method for absorbing noise. While many of these pavements have shown significant initial noise reductions when installed, the propensity of these pores to ‘clog’ with debris over time is a cause for concern as this may lead to a reduction in performance with time. Preventative anti-clogging measures may be required. Two approaches for increasing the porosity of PCC and its noise reduction properties exist. The first approach (used in some applications in Europe) involves increasing the porosity of the hydrated cement paste component of the material (typical techniques include the use of air-entraining/entrapping agents, gap-graded aggregates, or mixtures with low sand content while the second involves the use of “aggregate” with a higher than typical porosity. In addition to dissipating the noise that is generated by tire-road interaction by increasing the energy dissipated by moving air (friction), it is anticipated that the use of a low stiffness ‘aggregate/fiber’ inclusions may provide an effective means to reduce the stiffness of the pavement and increase the viscous-dampening capacity of the concrete. This is similar to the methodology that is used in machinery vibration isolation pads. By increasing the impedance incompatibility between the concrete components, the sound transmission path can be interrupted which could possibly increase the dampening capacity of the pavement. While little has been reported on the use of inclusions to absorb sound, some work has been performed to investigate the influence of lightweight aggregates and rubber particles on the elastic modulus. With around 280 million tires being dumped annually in the U.S., scrap tires may be a potential source of flexible inclusions for PCC. This project has been funded by the Recycled Materials Resource Center and research results are due in the next year or two.

The substantial variation found with pavement type/treatment has also prompted FHWA initiation of the Quiet Pavement Pilot Program (QPPP), which will evaluate quiet pavements in terms of noise reduction benefits and longevity, while ensuring safety, and identify pavement specifications and maintenance requirements necessary to maintain the noise reduction benefits. The program will also help introduce quiet pavements as a feature in highway noise prediction models. States with preliminary quantification of quiet pavement benefits qualify for the program. ADOT has already completed an agreement with FHWA and enrolled in the program. Caltrans is working on an agreement. QPPP will collect data over the life of quiet pavement applications included in the program, including pavement parameters and specifications, pavement control
parameters, noise data near roads and in communities, and proper noise reductions to include in a noise prediction model. The program will also determine the need for FHWA policy change and key factors that would be included.

**Traffic Noise Barriers**
Noise emanates directly from primary noise sources such as exhausts and encased engines and from tires, where noise emissions depend upon the pavement type. Secondary noise sources arise due to reflections from pavement and vertical surfaces such as highway noise barriers. Noise barriers can be quite effective in reducing noise for receptors within 120 feet of a highway and are still effective in providing noise reduction beyond that distance. Ten decibel sound reductions are considered attainable, but noise barriers must be high enough and long enough to block the view of a road. Noise barriers do little residences on hillsides extending above a barrier. Also, openings in noise walls for driveway connections or intersecting streets greatly reduce the effectiveness of barriers.(

Drawbacks of noise walls include cost, impacts to viewsheds, shading, and the ability of noise barriers to reflect sound energy from an elevated location and spread the highway noise over a wider area. Absorptive sound barriers offset this effect. A number of new sound barriers made with polycarbonate or molded or molded crumb rubber panels have been developed to increase absorption. While such materials exhibit a much better performance than concrete with respect to sound absorption and transmission loss, at this point polycarbonate or rubber sound barriers are performing less well in terms of other criteria including cost-effectiveness, technology maturity, durability, cost and convenience in installation, cost and convenience in maintenance and repair, and aesthetics. Crumb rubber coating retrofit options are discussed below under retrofit practices. In the meantime, some states dealing with strong public criticism regarding noise increase at a distance from new wall installations has led to temporary suspension of Type II programs.

Sound refraction is influenced by the effective sound speed as a function of height above the ground surface. Current highway prediction methods assume a neutral, homogeneous atmosphere; however, prevailing atmospheric conditions can cause receivers beyond those adjacent to a highway to be exposed to highway noise otherwise considered inaudible using standard prediction methods. This effect may not only increase audibility of highway noise but can produce noise levels that exceed the applicable noise impact criteria. When the effective sound speed increases as a function of height, as is the case for downwind and temperature inversion conditions, sound refracts downwards. When the effective sound speed decreases as a function of height, as is the case for upwind and temperature lapse conditions, sound refracts upwards.

Arizona DOT is conducting research, due in 2005, to determine the extent of variations in highway noise propagation and the impact on noise exposure attributable to atmospheric conditions, and recommend procedures to ensure that state agencies base their respective noise mitigation studies and decisions on the best noise measurements possible.(

**Current Noise Wall Expenditures and Materials**
State and local governments spend more than $100 million each year on noise walls and other methods to avoid or mitigate the noise impacts of highways. California has built more than 600 miles of sound walls costing more than $60 million. In July 2000, $226 million was allocated to deliver 63 sound wall projects located throughout the state.
FHWA has developed increasingly accurate models that enable States to reduce their costs substantially through better modeling and prediction of noise impacts and better design of noise walls and other mitigation. A detailed listing of noise barrier data may be found in FHWA’s “Summary of Noise Barriers Constructed by December 31, 2001.”

Noise Wall Retrofit Practices
Most highway sound barriers are built with pre-cast concrete or concrete blocks and have very high acoustic reflectivity (90 percent and above) and low sound absorption for the frequency band of highway noise between 125 Hertz and 400 Hertz. Consequently, the effort to develop new materials for building better noise-reduction sound barriers has increased in recent years, though progress has been limited.

Noise Reducing Noise Wall Coatings
Arizona DOT is exploring crumb rubber based coating, a porous mix of multi-sized crumb rubber particles “glued” with certain polymers/paints, which can be sprayed on to new or existing concrete sound barriers. With near zero porosity, molded rubber has good acoustic absorption capacity. Due to the frequency content of highway traffic noise, changing the size distribution of rubber particles may provide a mechanism to better achieve the noise reduction effect. Crumb rubber is durable, and most industrial polymers/paints can have a minimum life of years and above. Crumb rubber is low cost. Spraying provides a quick, inexpensive and easy way to “manufacture” the coating layer. The repair of coating layers should also be simple because of the spray nature.

Innovative Top Treatments for Noise Walls
ADOT is also exploring retrofitting existing noise walls with innovative top treatments, such as angled tops, irregular top edge, T-top treatments, and other applications that can reduce noise levels and eliminate the need for costly wall height increases or wall replacement. ADOT is exploring these strategies to avoid some of the undesirable impacts of noise walls such as blocked views, large shadows, and upward noise refraction. Innovative noise barrier designs and treatments have been successfully utilized in Europe for a number of years. This report is also due in 2005.

Receptor Controls
In circumstances where source and path noise control measures are not feasible or sufficient, receptor control measures may be necessary.

Local and State Land Use Planning
FHWA and federal agencies have tried to address receiver controls proactively by recommending that local governments use their power to regulate land development in such a way that noise-sensitive land uses are either prohibited from being located adjacent to a highway, or that the developments are planned, designed, and constructed in such a way that noise impacts are minimized. Some State and local governments have enacted legislative statutes for land use planning and control. As an example, the State of California has legislation on highway noise and compatible land use development. This State legislation requires local governments to consider the adverse environmental effects of noise in their land development process. In addition, the law gives local governments broad powers to pass ordinances relating to the use of land, including among other things, the location, size, and use of buildings and open space.
To aid in the consideration of highway traffic noise in land use planning activities, the FHWA has produced the following report: The Audible Landscape: A Manual for Highway Noise and Land Use. Entering the Quiet Zone: Noise Compatible Land Use Planning is a brochure issued by FHWA that can be used by DOTs. It 1) summarizes the general nature of highway traffic noise, 2) provides examples of Noise Compatible Land Use strategies either constructed or planned, and 3) encourages a proactive posture by local decision makers, developers and citizens to share in and actively influence land use next to highways.

Physical and Procedural Receptor Controls
Window openings are typically a building’s weakest link for noise infiltration. For this reason, acoustical window treatments can significantly reduce the outside-to-inside noise contribution. In some cases (factors include numbers of affected residents, the configuration of work sites, and the proximity of nearby abutters), window treatments may be more cost-effective and viable than noise barriers or curtains. FHWA has published a resource on “Insulation of Buildings against Highway Noise;” the Full Document is available on-line. Effective public outreach and participation are also a best practice for receptor noise control, as it can greatly increase the community’s understanding and tolerance of noise.

The following receptor controls were used on the Boston Central Artery project, and are considered best practices in the field:

1. Community Participation — open dialog to involve affected residents
2. Window Treatments — reinforcing the building’s noise reduction ability
3. Noise Complaint Process — ability to log and respond to noise complaints
4. Temporary Relocation — in extreme otherwise unmitigatable cases

Window Treatments
The most extensive example of window treatment controls in the literature comes from Boston’s Central Artery Project. In response to the need for more noise mitigation than accomplished with only source and pathway controls, in 1997 the Central Artery Project elected to implement an acoustical window treatment program. The program was initially intended to reactively address continuing nighttime noise complaints for which the Project developed an Off-Site Noise Mitigation Policy establishing eligibility criteria for abutters to receive window treatments. In 1998 however, as a direct result of community suggestions, the Project expanded the acoustical window treatment program to proactively treat bedroom windows in residences that were likely to be adversely affected by nighttime construction noise. Noise models were used to predict which residences would be eligible based on anticipated work schedules and established criteria policies. As a result, some 300-400 bedroom windows were proactively approved and treated, at a cost of about $400,000. This window treatment program continues to this day, and is expected to treat another 200 windows in anticipation of future work at an additional cost of $100,000.

Noise Reduction Resources, Research, and Research Needs
The national pooled-fund study, HP&R 0002-136, Evaluation of Performance of Experimental Highway Noise Barriers summarizes the findings of the multiyear study and presents some additional analyses of previously collected data. The other two reports
in the study are FHWA-RD-90-105, Parallel Barrier Effectiveness, Dulles Noise Barrier Project, and FHWA-RD-92-068, Parallel Barrier Effectiveness Under Free-Flowing Traffic Conditions.

AASTHO has produced a Guide on Evaluation and Attenuation of Traffic Noise, containing guidelines for the abatement of traffic-generated noise through highway design procedures and techniques. It discusses 1) the nature of noise, 2) a systems approach for addressing noise, 3) the highway noise study, 4) noise attenuation measures, and 5) noise barrier design considerations.()

The Organization for Economic Cooperation and Development (OECD) produced a Roadside Noise Abatement report reviewing current state-of-the-art and national experience with noise abatement techniques for new and existing roads. It presents the regulations and limits prevailing in the different OECD countries and provides the criteria used in measuring, evaluating, and predicting noise. Low-noise road pavements and noise barriers, walls and screens are assessed in detail. The report also describes the impact of road layout -tunnels, cuttings, embankments on noise levels.()

To reduce adverse noise impacts on communities, researchers are developing analysis techniques, abatement methods, and land use tools to better evaluate the effects of highway traffic and construction noise. Major issues requiring research are 1) ways in which atmospheric conditions impact traffic noise prediction, 2) relationship of pavement type and texture to noise, and 3) multi-modal transportation noise prediction methodology.()

Future research will provide additional model validation and improvements to the model’s graphical user interface. Existing traffic noise prediction models, including the FHWA Highway Traffic Noise Model, do not account for atmospheric variations. Information related to the problems of highway construction noise and the consideration of visual quality during noise barrier design will also be updated and enhanced.

3.14 Lighting Control/Minimization

Roadway lighting is an important part of a highway system. It contributes to a safe environment and facilitates traffic flow for the traveling public during evening or nighttime driving. Lighting shows drivers changes in direction, obstacles, and roadway surface conditions. Exterior lighting may also have a significant impact on economic development. At present, roadway lighting standards are based almost exclusively on traffic safety.

Public and DOT Interest in Lighting Control/Minimization

The impact of roadway lighting practices on the surrounding environment is of increasing concern to the public and DOTs, out of concern for impacts on wildlife as well as energy efficiency and cost. Light pollution is an unwanted consequence of outdoor lighting and includes such effects as skylight, light trespass, and glare. “Skylight” is a brightening of the night sky caused by natural and human-made factors. “Glare” is an objectionable brightness or reflection of light and a driving hazard especially bothersome for older drivers. “Light trespass” is the actual light that falls off the right-of-way and can be measured and quantified. In fact, many professional lighting designers have been obliged to go out at night and take measurements of the light that is falling off the right-of-way and onto a concerned citizen’s property. Cities and states in some cases have responded
with lighting ordinances and requirements regarding certain types of fixtures, minimum and maximum lighting levels, lumen/acre limits, and lighting elimination in some cases. Legislation has been adopted in Arizona, California, Connecticut, Colorado, Maine, New Mexico, Texas, Georgia, and New Jersey. Such legislation has been proposed or introduced in New York, Iowa, Massachusetts, Michigan, New Hampshire, Maryland, Pennsylvania, Rhode Island, Virginia, and Wyoming. A number of North American transportation jurisdictions have initiated the process of re-evaluating all aspects of roadway lighting systems to respond to the increasing public demands to provide safe, efficient and cost-effective systems. The benefits of adopting new design methods and technologies such as small target visibility (STV) method for design, counter-beam technologies in tunnels and new techniques for dynamic management of roadway lighting systems are widely recognized by North American transportation and illuminating engineering communities.

**Environmental Impacts of Overlighting**

Environmental impacts of lighting are of increasing concern to biologists and members of the public concerned about wildlife. In the 1970s, research into light’s effect on organisms’ “biological clocks” and nocturnal behavior patterns led biologists to take a closer note of artificial lighting’s effect on a range of organisms. Over the past 25 years, much of this work has focused on small amphibians, reptiles, and birds. Many animals rely on celestial light for visual orientation and/or the timing of periodic behavior. Artificial light that interferes with these essential behavioral systems is termed photo-pollution. It has been estimated that between 35-50 percent of atmospheric light pollution is caused by roadway lighting. Unlike chemical pollutants, errant artificial light is not toxic. Nevertheless, it can have profound effects on the survival of animals that rely on accurate light information to initiate or guide critical biological activities. For example, trees under streetlights have been observed to retain leaves longer into the fall in temperate climates and disruption of plant growth by sodium vapor lights has been recorded in several studies. European research results reveal that road illumination has a statistically significant negative influence on the breeding habitat quality of certain birds, reaching over several hundreds of meters; in particular, the research suggested that the negative influence of illumination exceeded the attractiveness of favorable habitat or the negative influence of roadway noise. Nocturnal insects are also extremely sensitive to outdoor lighting because they have evolved special adaptations of photoreception. In many cases insects become disoriented by the effects of outdoor lighting and are no longer able to perform their basic functions of nutrition and reproduction, leading researchers to conclude that outdoor lighting may be a serious threat to insects, though newer alternatives to the high pressure mercury vapor lamps are better for insects. Light cues also figure prominently in the reproductive behavior of sea turtles. Errant lighting on or near nesting beaches introduces misinformation to turtles during vital phases of the reproductive process. Large predators such as wolves and mountain lions are reported to avoid illuminated areas.

**Recent and Upcoming Guides in Lighting Design**

In the last two decades, research into lighting concepts, along with major advancements
in computer simulation and design software, has led to the development of new techniques and methodologies for the design of efficient, effective, safe and environmentally responsive roadway lighting systems. These advancements were acknowledged in the millennium edition of the *Lighting Handbook* of the Illuminating Engineering Society of North America (IESNA). In addition, the United States Federal Highway Administration has completed a study on lighting design concepts and the American Association of State Highway and Transportation Officials is currently updating its *Informational Guide for Roadway Lighting*. The AASHTO guide provides guidelines for when lighting should be installed, traffic volumes, and other criteria for locating lighting. IESNA has also recently approved a revision to its *American National Standard Practice for Roadway Lighting* (RP8). The National Standard primarily deals with appropriate levels of lighting for different installations. The revision includes three methods for designing continuous lighting systems for roadways: illuminance, luminance and small target visibility (STV). Advanced technologies in lighting hardware have been applied in most of the industrialized countries of Europe. Some DOTs have updated their own manuals based on these new standards and resources. For example, Oregon DOT produced a *Traffic Lighting Design Manual* in January 2003, which drew on RP8 and implemented some lighting reductions, including a study on whether light removal would be possible.

In August 2005, the Transportation Association of Canada expects to complete a Roadway Lighting Guide. The guide will incorporate two decades of research into lighting concepts combined with major advancements in computer simulation and design software have resulted in new techniques and methodologies for design of efficient, effective, safe and environmentally responsive roadway lighting systems. Advanced through the Traffic Operations and Management Standing Committee (TOMSC) of the Transportation Association of Canada, the guide completely revises the TAC’s 1983 Guide for the Design of Roadway Lighting, a national guide providing a general outline of engineering practices, warrants, planning methods, design techniques and the design criteria for roadway lighting systems. The project has utilized the expertise and experience from a variety of international sources in formulating the contents of the new Guide for the Design of Roadway Lighting. The final approved draft of the TAC’s guide to Illumination of Isolated Rural Intersections is also due in 2005.

**Common Lighting Approaches and Deciding How Much Light Is Enough**

High pressure sodium (HPS) lights are the most commonly used type of roadway lighting in the U.S. They have the inherent advantages of long life, and hence less maintenance, low cost, energy efficiency and good long range optical control. Low pressure sodium (LPS) and metal halide (MH) are also used to provide roadway lighting. All of these sources are energy efficient. Newer sources such as inductive fluorescent, compact fluorescent and light emitting diodes may be practical sources in the future. There are many valid reasons where lighting is not only needed, but required. It is important to understand the lighting objectives and how much is enough, in order to balance the need for lighting while minimizing light pollution and increasing energy efficiency. A number of social and economic benefits are attributable to roadway lighting, including but are not limited to:

1. Facilitation of traffic flow,
2 Reduction of nighttime accidents,
3 Aid to police protection,
4 Promotion of roadside businesses, and
5 Safety for pedestrians and bicyclists.

Initial practices in assessing lighting needs include:
1 Identification of community objectives and whether the street in question needs lighting.
2 Identification whether other ways exist to accomplish the goals without installing lighting (including marking, mechanical structures, etc.)

Once lighting is deemed necessary, the following inquiry is recommended practice:
1 Are minimum lighting levels being used to accomplish the objectives?
2 Is the current or proposed lighting installation energy efficient?
3 Are all attempts being made to minimize light pollution? One of the most common recommended practices in terms of minimizing light trespass has been use of full cut-off fixtures. A “full cutoff luminaire” is one that allows no direct light emissions above a horizontal plane through the luminaire’s lowest light-emitting part.
4 Have maintenance and component life been considered? Have easy mechanisms for opening, removing lamps and ballasts, and cleaning been considered? Will special tools or equipment be needed?
5 Is the lighting installation cost effective?
6 Have lighting controls such as motion sensors or timers been considered?
7 Is a lighting curfew (turning lights off after a certain time) appropriate?
8 Are pole heights and pole spacings appropriate? Use an appropriate light for the location. In different locations, different pole heights are appropriate.
   - The “cobra head” type of luminaire seen on many streets and roadways is often found on a higher pole, spreads light further, and is often not fully shielded
   - Architectural or decorative types of luminaires might have a scale that requires shorter pole heights.
   - When existing utility poles are used, careful attention to luminaire selection is important so that it is suitable for the pole heights.
   - The height of street lighting poles will impact how uniform the light levels are in the street and surrounding area. This issue can be especially important in a retrofit installation where existing pole mounting locations are going to be used with no additional poles.
9 Almost all lamps used in street lighting require a ballast to provide the proper voltage and current to the lamp. Are efficient ballasts going to be used? Even the most efficient lamp and ballast can be made very inefficient by using luminaires that trap light inside. A luminaire that emits less than half of the light generated by the lamp and ballast should be avoided.
Further recommendations by biologists investigating the impacts of lights on wildlife include the following:

1. Lighting should be restricted where protection of biodiversity is a high priority, such as in unusual ecological habitats, and in certain agricultural and horticultural settings.
2. To limit artificial lighting, light sources should be turned off whenever illumination is not essential.
3. Lamp housings should be sealed tight, and located away from structures that may trap insects.
4. Low-pressure sodium lamps should be used in preference to other kinds of lamps.

**Arizona DOT Research to Improve Lighting Practices**
ADOT has undertaken research on whether it is possible and desirable to improve lighting design practices, with particular attention to observers greater response to the yellow light portion of the spectrum. Nighttime visibility has been shown to be influenced by the lamp type used for roadway lighting, because the lamp’s spectral output can influence sensors in the retina that are active at night. ADOT undertook a research project to determine the status of the subject and to find what can be done or needs to be done to better define the issues of useful lighting and to assess potential benefits. Both IESNA and CIE have established committees to review available knowledge of the subject and develop related technical publications.

ADOT outlined the following questions with regard to current roadway lighting practice:

1. Do different lamp color (or spectral power distribution) characteristics affect visibility and safety in a real roadway environment in a way that has a meaningful or measurable effect on driver performance?
2. If a different choice in light source spectral distribution from that most commonly used now does result in potential driver performance improvement, what would be the tangible benefits be: reductions in crashes, light pollution, energy use?
3. What would the drawbacks be: increased light pollution, more maintenance, higher initial costs?
4. Certain local regulations require the use of a specific lamp type, which has raised controversy. Can ADOT conform to regulations requiring the use of a particular lamp type while meeting desired goals?
5. Can and should ADOT make a change from its current designs to light sources with different color rendering characteristics, such as metal halide, or low pressure sodium?
6. Can and should ADOT recommend changes to standards writing bodies from their current design standards to lower lighting levels, or to higher lighting levels?
7. What maintenance issues are involved in changing lamp type?
8. Does the current state of research justify an immediate change to lighting design practice or is more research needed to see if the current results are in fact meaningful?

**Comparison of Lighting Sources, Issues, and Costs**
The Arizona DOT developed a side-by-side comparison for the three sources for the...
lighting of a major roadway, using identical design specifications or each of the three. Each design was optimized for maximum pole spacing. The results by lamp type and pole spacing were:

1. 400 watt High Pressure Sodium (HPS) 276 ft.
2. 180 watt Low Pressure Sodium (LPS) 176 ft.
3. 400 watt Metal Halide (MH) 246 ft.

Primarily as a result of these pole spacings, HPS provided the lowest initial system cost. MH had a 7 percent higher initial cost than HPS, while LPS was 41 percent more expensive than HPS. Power costs for HPS and MH were essentially identical, but were 24 percent lower for LPS. Considering overall operating costs, including maintenance, MH was 7 percent more expensive than HPS, while LPS was 12 percent less expensive. These values were based on a cost of 8 cents per kilowatt hour. Life cycle costs, based on a 30 year life, were 7 percent higher for MH versus HPS, and were 17 percent higher for LPS versus HPS. Florida DOT also investigated (LPS) lighting, as an alternative to (HPS), which is the most widely used type of lamp for street lighting. However, other drawbacks were noted by FDOT:

1. The large fixtures required for LPS typically did not meet Florida wind loading criteria, and the fixtures deteriorated relatively quickly in the salt-air environment of coastal roadways resulting in higher maintenance;
2. Both initial and operational costs for LPS lights are substantially higher than for HPS lights;
3. The distribution of lighting is more difficult to control (more lights are needed for uniform distribution);
4. Replacement cycles for LPS lights are more frequent than for HPS lights (i.e., shorter operational life); and
5. LPS have environmental concerns that require special disposal procedures.

While initial costs for LPS lights are higher than for HPS lights, electricity costs are generally lower, because LPS lamps are more efficient (more lumens per watt). In practice, operational costs may vary, depending on how the lights are used in a particular utility’s lighting system. Regardless of overall costs, there are some drawbacks to LPS usage. Principal among those are the large fixtures required to house the lamps. These fixtures are susceptible to damage during high winds, require more maintenance, and typically have more omni-directional broadcast properties than conventional light fixtures (i.e. more difficult to control light distribution).

**Florida DOT’s Coastal Roadway Lighting Manual**

Florida DOT has undertaken lighting research primarily because the state’s beaches serve as important nesting habitat for several species of threatened and endangered sea turtles. Artificial light on or near nesting beaches can negatively affect the nesting process by interfering with normal nocturnal behaviors and spatial orientation of sea turtles, a problem to which streetlights contribute. Consequently, FDOT contributed to development of a Coastal Roadway Lighting Manual. Guidelines and alternative lighting recommendations contained in the manual were the collaborative effort of a Technical Working Group of lighting experts, traffic engineers, public safety personnel, utility
customer service managers, biologists, and regulatory agency personnel. The partners had found that the previous lack of basic guidelines for streetlight management often resulted in duplication of effort, inadequate resolution of identified problems, delays in implementation of effective solutions, and/or unnecessary expense and an adversarial climate between those requiring that lighting be modified and those responsible for affecting a solution. The intent of streetlight management was to 1) confine light to the area of its intended use; 2) reduce the amount of light emitted to the minimum required to effectively achieve its intended purpose, and/or, 3) use light sources that minimize the potential for wildlife and hatchling disorientation.

When a lighting system is incorporated into a roadway improvement project, the FDOT Project Design Engineer refers to the Plans Preparation Manual for information on how to justify and design the system to applicable safety standards. Design elements include distance between poles, pole height, light source, wattage, illuminance, and clear zone requirements. The proximity of proposed lighting systems to environmentally sensitive areas is not always considered. However, the Project Design Engineer can request a design exception if variances from minimum safety standards are needed to reduce the potential for lighting impacts. This requires coordination with the Federal Highway Administration. To better address wildlife needs, FDOT lighting specialists now draw from the following list of options to reduce roadway lighting impacts in the following section.

**Lighting Environmental Stewardship Practices**

Best practices to reduce glare and improve visibility included: ()

1. If using cobrahead fixtures, use a flat-glass cobrahead instead of the typical horizontally mounted high-output lamp in the cobrahead-style fixtures, where the glass refractor lens on the lamp-head creates direct glare that is accentuated during extreme weather conditions such as rain, sleet, snow, and fog. This fixture still has bright spots under the pole that create glare, but is a better alternative.

2. Install lights at uniform heights, which helps the eye avoid having to adjust to extreme ratios of alternating higher and lower lights.

3. Avoid use of “offset fixtures,” mounted at an angle, with much of the resulting light wasted, going into the sky where it can affect nearby residential neighborhoods as well as the flight patterns of migratory birds. Some studies suggest that street and roadway lighting cause as much as 50 percent of the skyglow in our major urban areas. Many cities have already adopted ordinances against light trespass and light pollution from homes and businesses.

4. Utilize full cutoff fixtures to direct light and reduce light trespass.

5. Ensure lighting is energy efficient.

6. Install improved reflector systems and vertical lamps to put light more accurately in areas where light is desired. Vertically lamped fixtures can be mounted in a median and serviced from one side. Usually, one fixture can replace two or more cobrahead fixtures used in traditional designs. With an optimized fixture design, one can lower mounting heights and still meet required lighting levels. This type of installation usually has a lower first cost and, because it mandates fewer poles and fixtures, a much lower maintenance cost. Energy consumption is usually lower.

8 Realign the fixture (change angle of mounting arm or rotate fixture head) so the source of light is not directly visible outside the ROW.

9 Apply a shield to a drop globe fixture.

10 Change an open bottom or drop globe fixture to a cutoff fixture.

11 Apply a shield to a cutoff fixture.

12 Reduce the mounting height of the fixture.

13 Reduce the lamp wattage.

14 Change the lamp socket position in the fixture to compress the lighting footprint.

15 Change to a fixture with a different type of reflector providing a more favorable lighting footprint.

16 In addition to other shielding and light reduction measures: Install a flat 2422 acrylic amber lens in a cutoff fixture with an HPS lamp of 70 watts or less (e.g., GELS 70W M250).

17 Turn the light off.

18 Remove the fixture.

19 Relocate the fixture to block light from extending to sensitive resources.

20 Change to an LPS fixture (if the light is customer-owned).

21 Create a vegetated berm/buffer or other light shield between the roadway and the sensitive resource.

Electric utilities can generally provide the following options:

1 Seasonally turn the lights off.

2 Relocate or redirect the light fixture.

3 Change a drop globe fixture to a cutoff style fixture.

4 Remove the fixture.

5 Lower mounting height.

6 Reduce wattage.

7 Selectively install amber-colored filtering lenses (on cutoff fixtures of 70-watts or less and only in addition to other modifications).

8 Install a light shield.

An overview of roadway lighting fixtures is available at the MetroLux Lighting website.

FDOT’s Embedded Roadway Lighting Study
In order to further study alternative roadway lighting systems, FDOT funded a demonstration project in 2001 that utilized embedded roadway lighting products. Consultants contracted by FDOT researched available lighting products, designed and installed a system, and are currently maintaining it. A roadway section was selected because there was a history of hatchling disorientations on adjacent beaches, there was a vegetative screen between the road and the beach, the roadway is not heavily traveled in the summer months, and the community was particularly sensitive to the needs of sea
turtles. The purpose of the project was to determine if innovative lighting techniques could illuminate pavement markings without impacting sea turtles on adjacent beaches. The modification involved deactivating the existing overhead street lighting, placing amber lenses on existing pedestrian pathway lights, and installing low bollard mounted luminaires along the pedestrian and bicycle ways. As a safety countermeasure, an embedded pavement lighting system was installed in the roadway. In general, area lighting levels and uniformity were reduced by the elimination of the overhead lighting. The remaining pedestrian area lights provided adequate illumination levels along the pedestrian pathway. Visibility in the travel lanes and in the bicycle lanes appeared to have been adequate for the traffic conditions of the roadway. The embedded roadway lighting and the low bollard luminaires served principally as delineation aids."

**Caltrans Light Minimization Efforts**

In response to the energy crisis in California, Caltrans voluntarily adopted requirements for lighting controls by zones, maximum lighting power, and shielding of luminaires. Luminaires were required to be off during the day and all luminaires greater than 100 watts to be IESNA cutoff type or full cutoff. Caltrans is exploring designs that yield peak candlepower in the range of 65° to 72° yield, as those are the most economical roadway/outdoor layout. Avoidance of light above 80° from vertical was also recommended, as such light never reaches the ground, causes direct glare, and generates the most number of complaints.

**Tennessee DOT Light Reduction and Maintenance Cost Savings**

Tennessee DOT recently took a closer look at lighting opportunities and tradeoffs and found opportunities for significant payoff. A value engineering proposal for a new intersection designed with off-set style cobrahead lighting mounted in the right-of-way outside the safety shoulders was revised to use a vertically mounted lamp in an optimal, architecturally designed roadway fixture directed from a 40-ft. pole placed on the median barrier. True cut-off fixtures were installed, eliminating light trespass and light pollution; power consumption stayed the same in terms of first-cost dollars and cents. The change provided the state with several important benefits:

1. Skyglow and light trespass were greatly reduced. People in surrounding residential neighborhoods were pleased with the reduction in stray light and fewer impacts to the natural environment were likely.
2. Lighting levels on the roadway were increased, creating a safer highway and a safer intersection.
3. Fewer fixtures and poles were required, reducing anticipated maintenance costs.
4. Savings included more than 5 miles of trenching and backfilling and more than 5 miles of cable that no longer needed to be provided.
5. Sixty-one pole foundations, poles, and fixtures were eliminated. The new median lighting system involved installation of 26 poles and fixtures mounted on median barrier walls.
6. Considering maintenance, the cost of the lighting project was considerably reduced.

Tennessee DOT implemented alternatives to traditional roadway lighting practices that created visibility, maintenance, and safety problems, as well as escalating installation
TennDOT used many of the best practices listed in the earlier section on roadway lighting fixture options.

### 3.15 Design for Sustainability and Energy Conservation

Energy conservation decisions can be a factor in mode choice decisions made in Planning, as part of Major Investment Studies, or in Project Development as part of the alternatives analysis process for projects for projects undergoing Environmental Assessments and Environmental Impact Statements. Within construction and operations, DOTs also have choices with regard to operation of construction equipment (addressed in Chapter 4) and design of facilities.

A number of excellent green building resources are available. Building Green is an independent research organization which does not accept advertising, and which won the Architects, Designers, Planners for Social Responsibility (ADPSR) Lewis Mumford Award for Environment for 2004.

1. **Environmental Building News** is independently published and advertising-free publication in print since 1992, with research and reporting uncompromised by corporate or industry sponsorships.

2. **BuildingGreen Suite** integrates articles, reviews, and news from Environmental Building News (EBN) with product listings from the GreenSpec products directory and project case studies from the High-Performance Buildings Database.

1084) Articles, products, and case studies, and further links are available in the following areas:

1. **Land Use and Community**
   - Regional Integration
   - Property Selection

1. **Site and Water**
   - Water Efficient Appliances and Equipment
   - Land Development
   - Landscaping
   - Plumbing Fixtures
   - Site Selection
   - Stormwater
   - Water Collection and Conservation

1. **Energy**
   - Energy Efficient Appliances and Equipment
   - Energy-Efficient Building Envelope
New York City Transit’s Green Building and Design for the Environment Programs

The New York City Transit (NYCT) agency is a national leader in very long-term facility and capital planning in conjunction with environmental conservation; sustainable development supports the concept that economic and social development is complementary to environmental protection. It involves both long and short-term planning to increase community and business growth and productivity without diminishing the health and productivity of supporting and surrounding natural systems. NYCT’s Green Building Program is among the most notable of any transportation agency in the country. NYCT’s program, Design for the Environment (DfE), ensures that all building and construction projects (ranging from building designs to subway expansion) are reviewed and approved to meet sustainability standards that include energy efficiency; indoor environmental quality; water and natural resources conservation; and pollution prevention. Some project examples address:

1. **Harnessing renewable energy** – The Gun Hill Bus Depot (the Bronx) contains one of the largest solar energy facilities on the East Coast. Renovations at the Stillwell Avenue terminal (Coney Island-Stillwell Av station in Brooklyn) will include 60,000 feet of integrated photovoltaic paneled roof. This is expected to produce 210 kilowatts of solar power.

2. **Conserving water** – The Corona Subway Yard and Maintenance Facility
(Queens) is being designed to use rainwater and recycle wash water in its subway car wash.

3 Recycling materials and reducing landfill needs – The Roosevelt Avenue subway station (Queens) rehabilitation has diverted more than 85 percent of demolition waste (e.g., concrete, steel, wood) from landfill to recyclers.

NYC Transit has implemented many programs that promote sustainability. In December, 2003, NYC Transit became a Full Signatory member of the International Association of Public Transport (L’Union Internationale des Transports Publics, or UITP) Charter on Sustainable Development, building on agency commitments on which NYCT took action in the late 1990s. In 1999, the NYCT Department of Capital Program Management (CPM) became the first department of an American public agency and the first transit organization in the world to have an environmental management system certified to the International Organization for Standardization (ISO) 14001 EMS.

The following recommendations come from the Nova Scotia Department of Transportation and Public Facilities EMS: ()

Design for Efficient Heating, Ventilation, and Air Conditioning of Facilities
1. Consider alternative heating sources such as ground-source heat pumps, geothermal heat pumps, solar or other renewable energy sources.
2. Design buildings to allow for the use of outdoor air for cooling/heating as temperatures allow.
3. Design HVAC systems to allow for changes of heating/cooling and ventilation to match building occupancy times. Any manual over-rides of the system should be designed to automatically return to the original schedule at the end of the over-ride period.

Design for Lighting Conservation
1. Consider daylighting during design; make it possible to turn off or dim interior lights to take advantage of daylighting.
2. Include occupancy sensors wherever possible so that lights are not left on in unoccupied areas.
3. Plan for task lighting in each work area.

3.16 Safety Rest Areas, Traveler Services, and Parking Area Design
Washington State Roadside Manual describes environmental stewardship practices for roadside facilities such as safety rest areas, roadside parks, points of interest, and traveler information centers. Recommended practices include: ()
1. Use context sensitive design principles in planning and funding of projects. See the FHWA Context Sensitive Design website for more information on context sensitive design.
2. Preserve existing landscape features to the greatest extent possible.
3 Select vegetation to minimize water usage.
4 Encourage the use of recycled materials and offer recycling opportunities to the greatest extent practical.
5 Encourage nonprofit groups to coordinate recycling programs for aluminum cans and newspaper whenever possible.
6 Consult Maintenance personnel during the design phase of any parking facility to determine their concerns and respond to their suggestions.

Planning for Conservation in Rest Area Design

An Environmental Management System roadmap (RMS) developed for AASHTO’s EMS Workshop for State DOTs recommends the following stewardship practices in rest area planning. The main objective of the process is to consider environmental issues and opportunity areas in the design process and then to establish a process to routinely and consistently identify and implement pollution prevention and energy efficiency (P2/E2) opportunities in the operation and maintenance of rest areas. To do this, it is helpful to identify environmental issues and opportunity areas and prioritize. For example, desired environmental benefits and fiscal gains could include the following objectives:

1 **Reduce energy costs.** Rest areas average around $10,000/year for electricity and $7,000 for natural gas.

2 **Control chemicals/materials used in maintenance (e.g., cleaning products) and switch to “green” cleaners wherever possible.** Each rest area requires 500 gallons per year of cleaners and 1,000 pounds per year of herbicides and pesticides.

3 **Reduce water consumption.** Each rest area (lavatories, drinking water, and cleanup) uses an average of 1,000,000 gallons per year of water, DOT cost for treating well water or purchasing water averages $1.75 per 1,000 gallons.

4 **Reduce the number of and the potential for wastewater treatment upsets** per month at each area’s treatment facilities (e.g., discharge parameters not met).

A substantial amount of pollution prevention and energy efficiency (P2/E2) information has been developed by USEPA and Defense Department agencies. Among the DOTs, PennDOT has prepared a P2/E2 Guide identifying and characterizing the costs and benefits of various P2/E2 options. The Washington State Roadside Manual describes environmental stewardship practices for parking area design as such:

1 Provide areas for snow storage requirements in parking area design.

2 Adjust design to comply with local regulations and requirements.

3 Design aisles and breaks in planting strips to provide for easy maintenance. Aisles should be wide enough to allow access by street sweepers. High points in corner areas will allow water to drain away from these locations so they do not collect water and leaves.

4 Ensure environmental quality by addressing air, drinking water and noise
concerns, watershed restoration, and preservation of habitats and public green spaces.

5 Use transportation facilities to enhance community aesthetics by incorporating unique local features (scenic views, community neighborhoods, historic districts, cultural and natural resources, etc.) and providing focal points for communities through those facilities such as multimodal stations, pedestrian plazas, and parkways.

Vegetated/Bioinfiltration Swales in Parking Facility Design

1 Integrate vegetated/bioinfiltration swales into the facility to collect and detain stormwater. These can be designed within planting islands and around the perimeter. These swales also serve as water quality filtration strips and can be an amenity on the site. Long, linear swales break up the large expanse of pavement, collect stormwater, and allow for tree planting. A minimum width of 10 feet is recommended for these planted swales. If curbing is not placed around the swale, stop blocks should be used for each parking space surrounding the swale to prevent vehicles from entering the swale. Rip soils in planting islands before adding soil amendments and plant materials and/or install subsurface drainage. See the EPA Bioretention website for information on design of planting islands within parking areas.

2 Use on-site stormwater drainage to provide water for plants. For example, plant trees on the edges of swales in parking islands. Trees should be spaced a minimum of every 75 feet on center within the parking lot, and aligned with stall lines. If curbing is used around swales, regular gaps in the curbing should be provided to allow stormwater runoff to drain into the swale. The elevation of the swale in relation to the pavement should be low enough for water and debris to drain into the swale without continuous maintenance. However, these locations will require periodic maintenance to clear debris build-up.

Permeable Pavements
Consider vegetated pervious open grid-type parking stalls to allow infiltration of stormwater. These are most effective for peripheral or overflow parking. Alternative modular paving systems that can support long-term parking are available.

Porous Concrete Pavement
No-fines porous concrete pavement is an emerging technology that has been used in the eastern United States and in Europe for years. Costs are slightly higher (approximately 25 percent more) than for conventional Portland cement concrete pavement. However, because porous concrete pavement infiltrates water at 270 to 450 inches per hour per square foot (3-5 gallons per minute per square foot), stormwater detention facilities are usually not needed to mitigate those surfaces, thereby reducing costs for stormwater mitigation. Porous concrete pavement uses large aggregate and Portland cement with an additive to slow the rate of evaporation of the mix during placement. The thickness of the pavement is greater than conventional concrete and is laid over an aggregate subbase in order to provide structural stability. Because of the large pore spaces (15 to 25 percent of the
total volume), porous concrete pavement is more resistant to frost heave than conventional concrete pavement. With regular (4 times per year) vacuuming or blowing to remove fine materials that can clog the pore spaces, these systems can continue to infiltrate stormwater and last as long as conventional concrete pavement systems. Higher installation and maintenance costs might be balanced by savings in stormwater storage and treatment costs. Because these systems infiltrate water at high rates, they are not appropriate where pollutants, such as fluid drips are likely to occur and where ground water tables are close to the surface. The large pore spaces may cause problems with people in spiked heels, or people with pointed-tip canes. For this reason the use of this system may be more appropriate on outlying areas. Information on pavements can be found in WSDOT’s online engineering publication, the WSDOT Pavement Guide.