LOVER'S LANE
KILLINGWORTH, CONNECTICUT

EASTERN CONNECTICUT
ENVIRONMENTAL REVIEW TEAM REPORT

EASTERN CONNECTICUT
RESOURCE CONSERVATION & DEVELOPMENT AREA, INC.

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PREPARED BY THE
EASTERN CONNECTICUT ENVIRONMENTAL REVIEW TEAM
OF THE
EASTERN CONNECTICUT
RESOURCE CONSERVATION AND DEVELOPMENT AREA, INC.

FOR THE

INLAND WETLANDS AND WATERCOURSES COMMISSION
KILLINGWORTH, CONNECTICUT

REPORT #611

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ACKNOWLEDGMENTS

This report is an outgrowth of a request from the Killingworth Inlands Wetlands and Watercourses Commission to the Connecticut River and Coastal Conservation District (CRCCD) and the Eastern Connecticut Resource Conservation and Development Area (RC&D) Council for their consideration and approval. The request was approved and the measure reviewed by the Eastern Connecticut Environmental Review Team (ERT).

The Eastern Connecticut Environmental Review Team Coordinator, Elaine Sych, would like to thank and gratefully acknowledge the following Team members whose professionalism and expertise were invaluable to the completion of this report.

The field review took place on Tuesday, November 28, 2006.

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I would also like to thank Martin Klein, first selectman, Town of Killingworth, Cathie Jefferson, wetland officer, Town of Killingworth, and Florence Marrone, interested landowner, for their cooperation and assistance during this environmental review.

Prior to the review day, each Team member received a summary of the proposed project with location and soils maps. During the field review Team members were able to view additional information and discuss the project. Some Team members made separate or follow-up visits to the site. Following the review, reports from each Team member were submitted to the ERT coordinator for compilation and editing into this final report.

This report represents the Team's findings. It is not meant to compete with private consultants by providing site plans or detailed solutions to development problems. The Team does not recommend what final action should be taken on a proposed project - all final decisions rest with the town. This report identifies the existing resource base and evaluates its significance to the proposed use, and also suggests considerations that should be of concern to the town. The results of this Team action are oriented toward the development of better environmental quality and the long term economics of land use.

The Eastern Connecticut RC&D Executive Council hopes you will find this report of value and assistance in reviewing future options for the maintenance or continued use of Lover's Lane.

If you require additional information please contact:

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INTRODUCTION

INTRODUCTION

The Killingworth Inland Wetlands and Watercourses Commission have requested Environmental Review Team (ERT) assistance in reviewing Lover's Lane.

Lover's Lane is a paved asphalt town road that has been constructed through a wetland area. The road is located north of the Route 80/81 rotary and is used as a short cut between Route 81 and Route 148 (Tooley Road).

OBJECTIVES OF THE ERT STUDY

The town has requested the ERT to review the road and the surrounding area because of long term problems with road flooding and settling. The town would like to have a natural resource inventory and assessment conducted so they may determine what is the best option for the roadway and what if any maintenance options are available or suitable. Discussions over time have included:

- Do nothing but add pavement as needed and, continue to close the road when flooded and during the winter months;
- Close the road permanently;
- Bridge the length of the peat bog area (construction costs estimated in 2004 to exceed 2 million dollars); or
- Construct a small bridge or culvert with approach filling (estimated cost in 2004 $200,000 to $400,00)

The town has requested natural resource information as well as comments on environmental impacts, planning, and traffic and access issues.

THE ERT PROCESS

Through the efforts of the Killingworth Inland Wetlands and Watercourses Commission this environmental review and report was prepared for the Town of Killingworth.

This report provides an information base and a series of recommendations and guidelines which cover the topics requested by the town. Team members were able to review maps, plans and supporting documentation provided by the town.

The review process consisted of four phases:

1. Inventory of the site's natural resources;
2. Assessment of these resources;
3. Identification of resource areas and review of plans; and
4. Presentation of education, management and land use guidelines.

The data collection phase involved both literature and field research. The field review was conducted Tuesday, November 28, 2006. The emphasis of the field review was on the exchange of ideas, concerns and recommendations. Being on site allowed Team members to verify information and to identify other resources.

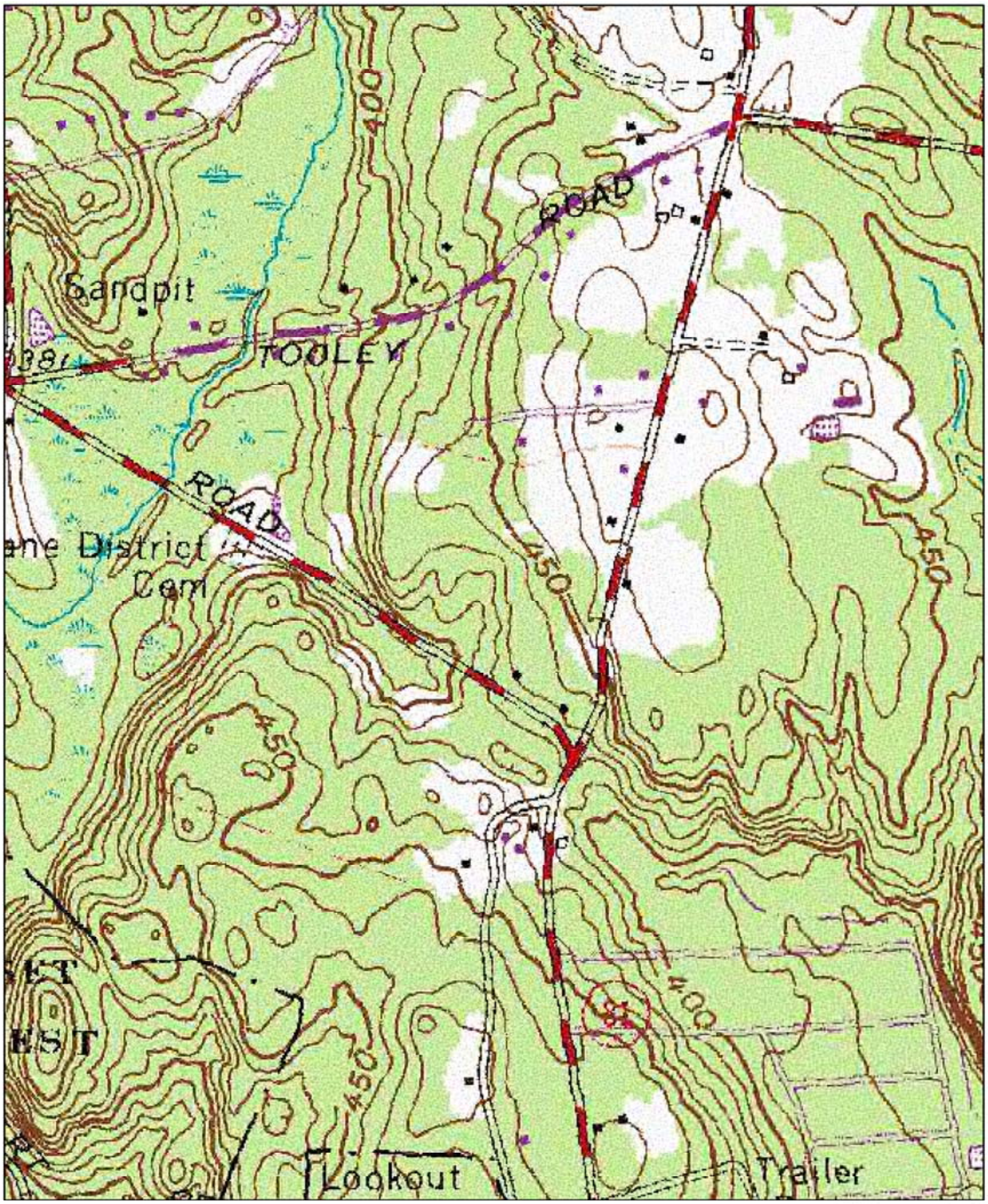
Once Team members had assimilated an adequate data base, they were able to analyze and interpret their findings. Individual Team members then prepared and submitted their reports to the ERT coordinator for compilation into this final ERT report.

Water running over road surface in area of pipes under the road. (11/28/06)

Many layers of asphalt.

Second area of flooding on north/westernn section of Lover's Lane.(11/28/06)

Lover's Lane Aerial Map



The Connecticut Environmental Review Team

This map was prepared by Amanda Fargo-Johnson for the Connecticut Environmental Review Team.
This map is for educational use only.
It contains no authoritative data.
August 2006.

Killington, CT

0 0.0375 0.075 0.15 0.225 Miles

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Lover's Lane Aerial Map

TOPOGRAPHY AND GEOLOGY

TOPOGRAPHY

Lover's Lane is an asphalt road that appears to have been laid without proper road-bed foundation across a peat bog. The bog formed in a hollow in an unnamed stream valley north of Killingworth center. The unnamed stream heads at a small pond about two miles north of Lover's Lane and flows south-southwesterly through a shallow, but narrow valley that has several hollows. The hollows all contain small bogs. Unlike the other hollows, a sand and gravel deposit and overlying swamp muck fill the Lover's Lane hollow (see Fig. 1). Indeed, a small gravel excavation is located just north of Lover's Lane and a small cemetery (usually sited on sandy soil) is located along the south side of Lover's Lane at the edge of the bog.

GEOLOGY

Bedrock is not exposed in the vicinity of Lover's Lane, but it is close to the surface on south-facing slopes of several hills west of the bog. The immediate area is underlain by the "granitic"-Monson Gneiss (Lundgren, 1979; Rodgers, 1985).

The bedrock is broken by several prominent sets of fractures and fracture zones that have topographic expression as linear valleys (Lundgren, 1979, p.33). The unnamed stream flows down one linear valley (Fig. 1) oriented N.20-30^{o}E (020-030^{o}). This orientation is similar to the dike of diabase a few miles to the west and northwest that intruded into fractures of the same orientation in the bedrock. The orientation of another prominent set of linear valleys is N.45^{o}W (315^{o}). Each of the hollows in the unnamed stream is located at the intersection of these fracture zones. A third prominent linear valley orientation is N.20^{o}W (340^{o}), which is parallel to the orientation of the layering in the area, particularly to the east and northeast.

During past ice ages, glaciers scraped across the landscape eroding the land as they went. Fractured rocks are more easily erodible and hence rocks in the fracture zones were eroded producing linear valleys. Where fracture zones intersected, bedrock hollows were eroded. Near the end of the last glacial episode (and probably previous episodes) glacial ice deposited till on the bedrock surface. A thin veneer of till covers most of the upland surfaces in the nearby vicinity (Flint, 1978). As the ice melted at the very end of the ice age, large blocks of left-over ice dotted the landscape, but particularly in the valleys. Small temporary ponds formed in the space left when the ice melted. This space quickly filled with mud and sand and finally gravel brought in by melt-water streams. Most of the hollows were also quickly filled with mud and swamp deposits. The bog at Lover's Lane contained a large block of left-over ice that prevented it being completely filled with sand and gravel deposited by melt-water streams that flowed around the ice. By the time the ice melted the melt-water streams had been diverted down neighboring valleys. Instead of filling with sand and gravel, the space formerly occupied by ice became a pond that filled in with peat (see Fig. 2). Thus, a small terrace of sand and gravel surrounds the bog (Figure 3).

Peat is a spongy vegetative material that initially contains a high percentage of water. With time the water is naturally expelled and the peat becomes more compact: it settles creating more room in the swamp for deposits of new peat. A load placed on top of the peat hastens the compaction. In addition, peat has a low bearing strength and is easily displaced by unequal application of a load. Apparently that has occurred at Lover's Lane (Fig. 4).

REFERENCES

Flint, R.F., 1978, The Surficial Geology of the Haddam Quadrangle, with map. State Geological and Natural History Survey of Connecticut Quadrangle Report 36, 27p.

Lundgren, L. Jr., 1979, The Bedrock Geology of the Haddam Quadrangle, with map. State Geological and Natural History Survey of Connecticut Quadrangle Report 37, 44p.

Rodgers, John, 1985, Bedrock Geological Map of Connecticut. State Geological and Natural History Survey of Connecticut, Natural Resource Atlas Series

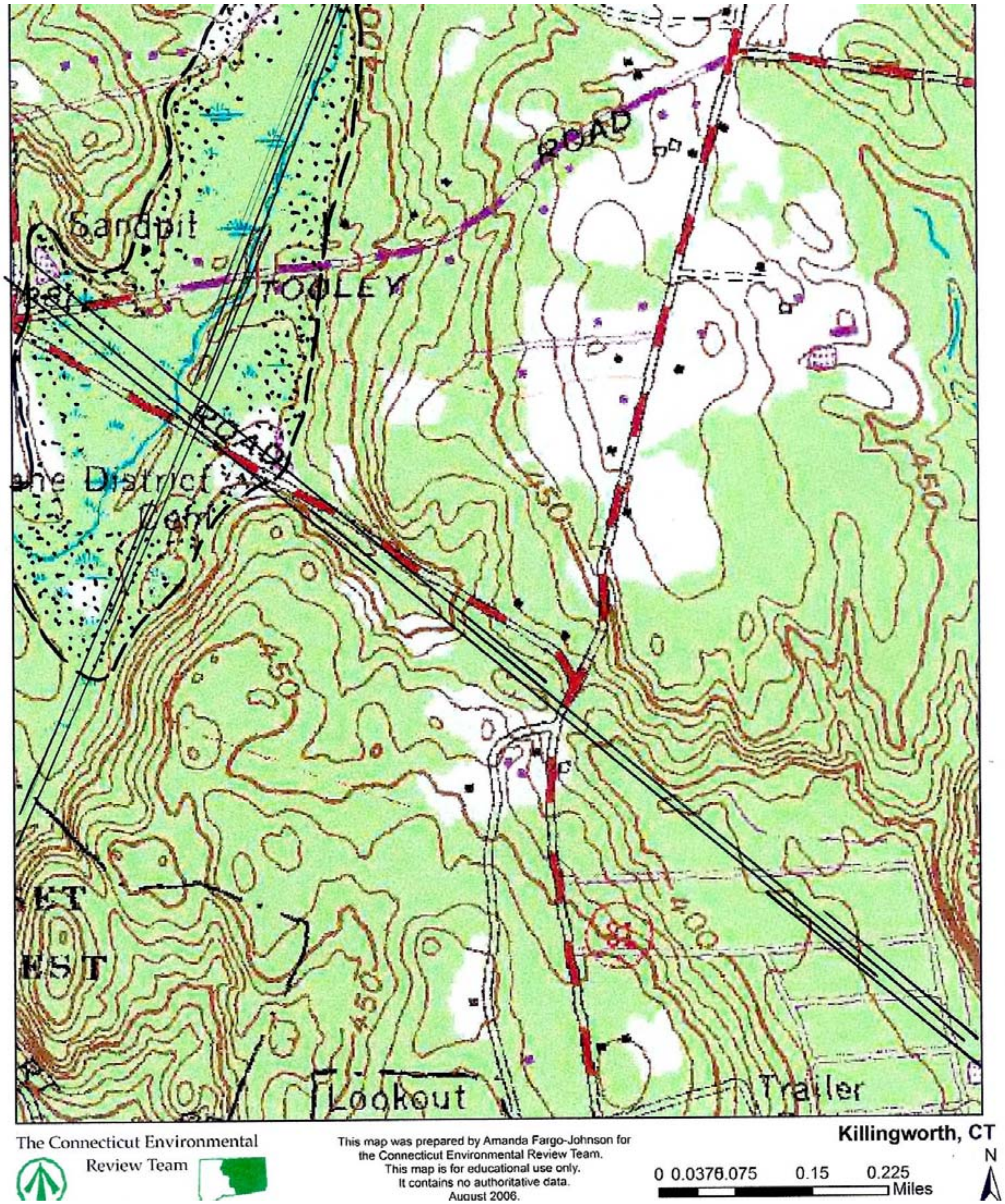


Figure 1. Topographic map showing distribution of sand and gravel deposit (after Flint, 1979) in bog-hollow of Lover's Lane. Stippled pattern indicates area of sand and gravel. Long parallel line segments are drawn along the axes of linear fracture-controlled valleys.

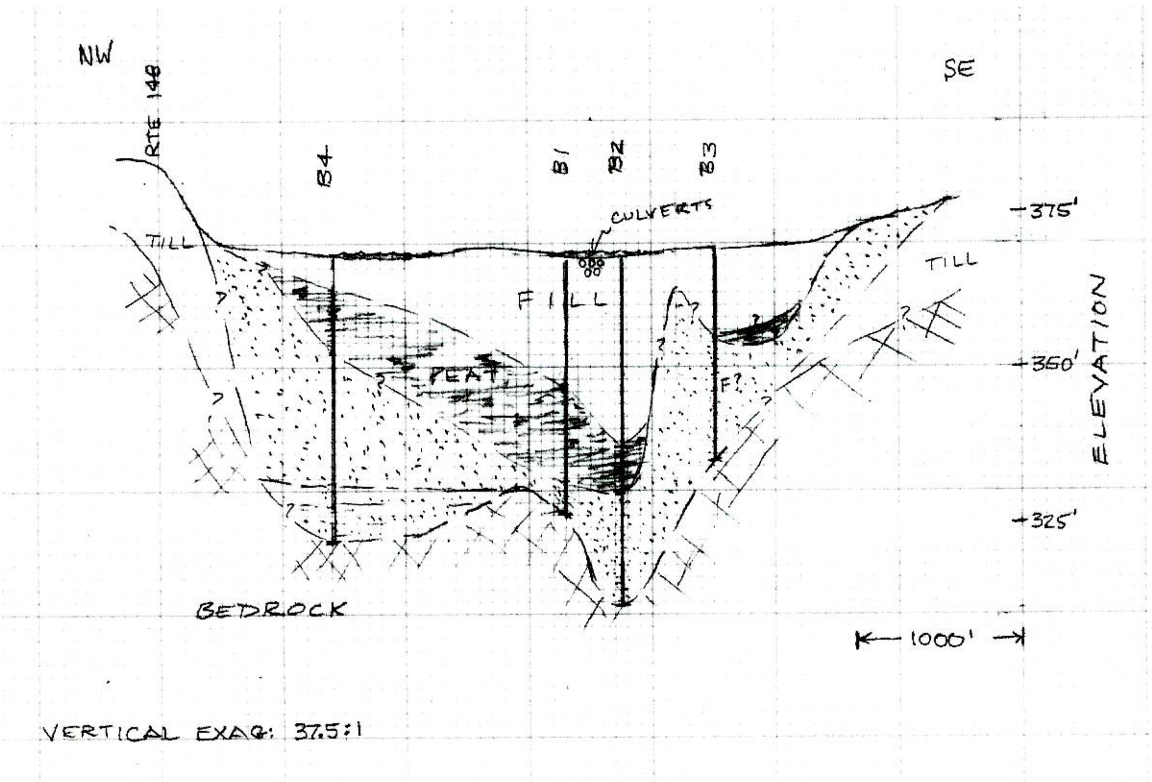


Figure 2. Geologic cross section along the western portion of Lover's Lane was constructed using descriptions of borings by C. Welte, Geotechnical Engineering. The locations of the borings are schematic (not accurately located on engineer's field sketch). Depth of boring inferred to be limited by bedrock (ledge) although this was not stated in the drill logs. Lowest part of boring B-3 interpreted as fill by engineer; geology of site indicates that some natural material must be present in the boring. This reviewer has reinterpreted the lower half of the material encountered as being natural. "Ridge" of sand between B2 and B3 inferred based on topography of site. Bedrock scour basin at bottom of B4 interpretative. Lip (high) to east, that contains fine-grained pond deposits in the lower part of B4, could have been provided by left-over ice rather than bedrock. Note unequal vertical and horizontal scales.

Figure 3. Flat terrace on east side of bog. Although its elevation is only a few feet higher than the bog, it is inferred to be a Pleistocene (ice-age) ice-contact deposit rather than modern river alluvium (Flint, 1978).

Figure 4. Lovers Lane bog-crossing, looking east. Several small culverts underlie the road opposite sign on right. Note unequal water levels on the upstream (left) vs. downstream side of road. Note also level of road varies, presumably a function of roadbed subsidence caused by compaction and/or displacement of underlying peat.

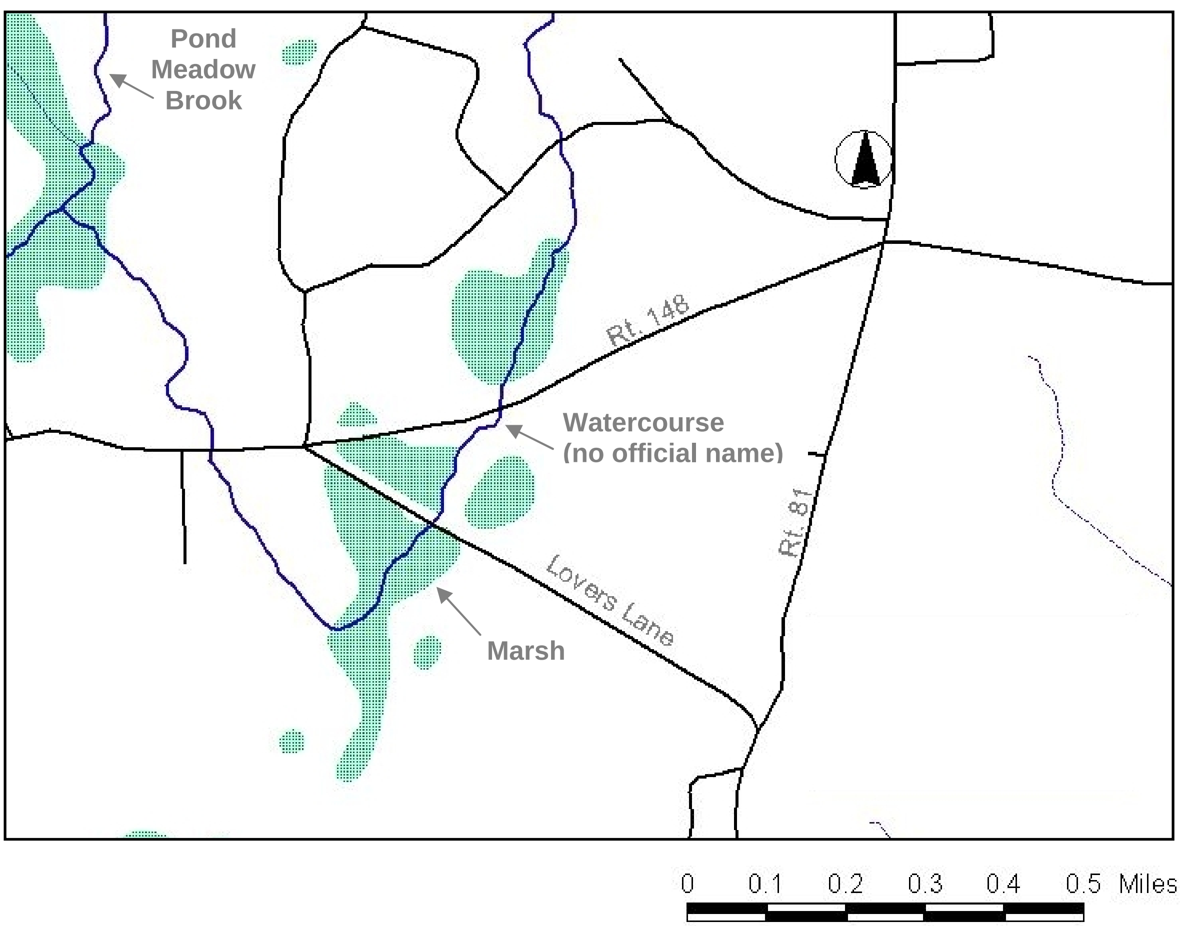
Connecticut River and Coastal Conservation District Review

The following are general comments and recommendations regarding conditions of Lover's Lane in the Town of Killingworth. Information used in this report includes the USDA/NRCS official digital soil survey maps (http://websoilsurvey.nrcs.usda.gov/app/); the USDA/NRCS Soil Survey Division Official Soil Series Descriptions; CT DEP GIS data layers (on-line at http://dep.state.ct.us/gis/Data/data.asp); published papers and reports (see attachments in the Appendix); and a site visit conducted on November 28, 2006. This review is advisory in nature and is intended to assist the Town of Killingworth when considering options to improve, permanently close, or continue existing practices on Lover's Lane.

Current Site Conditions

Lover's Lane bisects an approximately 35 acre peat marsh. A perennial watercourse flows south through the marsh after passing under Route 148. This watercourse makes a U-turn after it exits the southern portion of the marsh to flow north where it re-cross Route 148 to join with Pond Meadow Brook.

Figure 1. Watercourse and marshes in the area of Lover's Lane (from CT DEP GIS datalayer from USGS data, at a scale of 1:24,000).

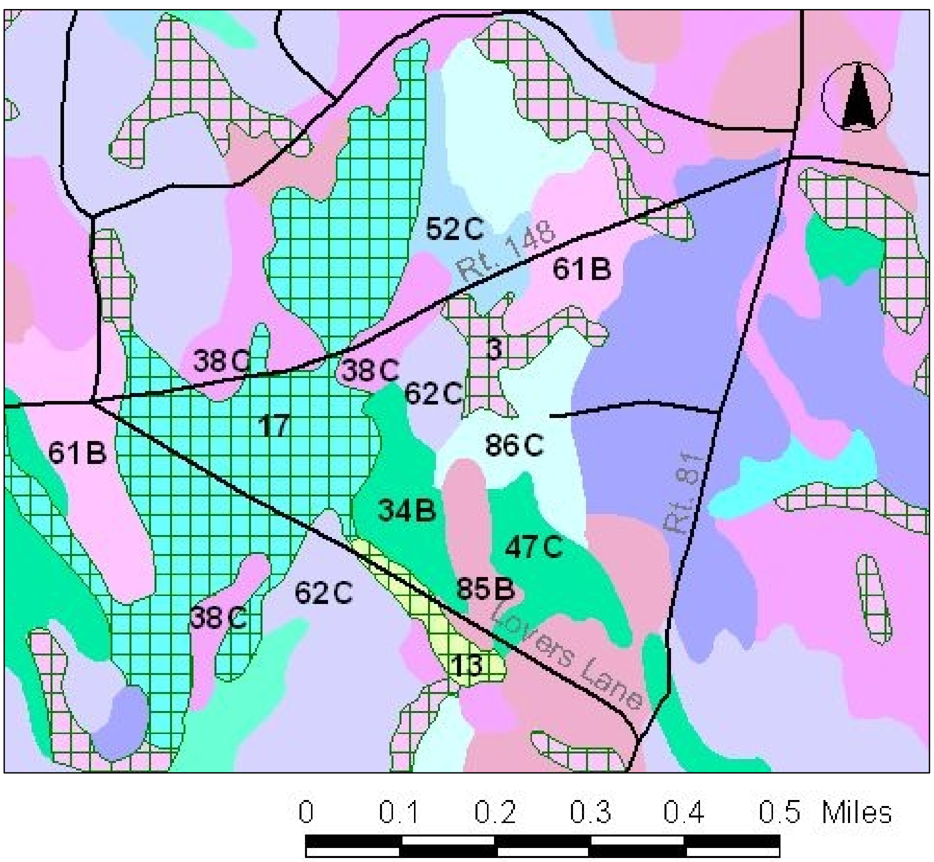


SOILS

Five inland wetland soils distributed across two map units and eight upland soils distributed across eight map units are shown in the vicinity of Lover's Lane. Five of the soil types have a restrictive layer, or compact hardpan, at depths ranging from 10-40 inches and a seasonally high water table (denoted in the table legend by an *). Mapping of the soil map unit boundaries is shown in Figure 2. Soils in the marsh at Lover's Lane is shown as Timakwa and Natchaug. The Timakwa series consists of very deep, very poorly drained soils formed in woody and herbaceous organic materials over sandy deposits in depressions on lake plains, outwash plains, till plains, moraines, and flood plains. The Natchaug series consists of very deep, very poorly drained soils formed in woody and herbaceous organic materials overlying loamy deposits in depressions on lake plains, outwash plains, till plains, moraines, and flood plains.

The soil map data are from the USDA/NRCS soils GIS coverage and are at a 1:12,000 scale, with the smallest area (polygon) delineated of approximately 3 acres. Caution should be taken when using soil survey mapping for site-level planning since at this scale soils in a single mapped unit can differ in slope, depth, drainage, and stoniness. Descriptions of wetland soils in the vicinity of Lover's Lane are provided in Table 1.

Figure 2. Soil types in the area of Lover's Lane (from the USDA/NRCS official soils mapping at 1:12,000). Wetland soil types are hatched.



	Map Unit Name
3	Ridgebury*, Leicester, Whitman*, extremely stony
13	Walpole sandy loam
17	Timakwa and Natchaug
34B	Merrimac sandy loam, 3 to 8% slopes
38C	Hinckley gravelly sandy loam, 3 to 15% slopes
47C	Woodbridge* fine sandy loam, 2 to 15% slopes, extremely stony
52C	Sutton fine sandy loam, 2 to 15% slopes, extremely stony
61B	Canton and Charlton soils, 3 to 8% slopes, very stony
62C	Canton and Charlton soils, 3 to 15% slopes, extremely stony
85B	Paxton* and Montauk* fine sandy loams, 3 to 8% slopes, very stony
86C	Paxton* and Montauk* fine sandy loams, 3 to 15% slope, extr. stony

Table 1. Description of the wetland soil types in the area of Lover's Lane.

<u>LEICESTER SERIES</u>
The **Leicester** series consists of very deep, poorly drained loamy soils formed in friable acid glacial till derived mostly from schist, gneiss, and granite. They are nearly level or gently sloping soils found in drainageways and in low-lying areas along hill slopes. Permeability is moderate or moderately rapid in the upper soil profile and moderate to areas of Leicester remain wooded with common trees include red maple, red oak, elm, aspen, gray birch, white pine, balsam fir, red spruce, and ironwood, although some areas have been improved for haying and pasture.

<u>NATCHAUG SERIES</u>
The **Natchaug** series consists of very deep, very poorly drained soils formed in woody and herbaceous organic materials overlying loamy deposits in depressions on lake plains, outwash plains, till plains, moraines, and flood plains. These soils have moderate to very rapid permeability in the organic material and moderately slow to moderately rapid permeability in the loamy material, and surface runoff is negligible or very low. Depth to the seasonal high water table ranges from 1 foot above the surface to 1 foot below the surface from October to June. Some areas are subject to rare, very brief flooding during March and April. Most areas are used for wildlife habitat, or are in woodland or clear-cut woodland, although some areas are used for pasture. Common vegetation is red maple, skunk cabbage and sphagnum moss.

<u>RIDGEBURY SERIES</u>
The **Ridgebury** series consists of very deep, poorly drained (and sometimes the wetter part of somewhat poorly drained) soils formed in loamy till derived mainly from granite, gneiss and schist. These nearly level to gently sloping soils are found in slightly concave areas and shallow drainageways of till covered uplands. Permeability is moderate or moderately rapid in the upper soil profile and slow or very slow in the dense till below. A perched, fluctuating water table above the dense till saturates the upper soil layers at or near the surface for 7 to 9 months of the year. Most areas of Ridgebury are forested, with common trees including gray birch, yellow birch, red maple, hemlock, elm, spruce and balsam fir.

<u>TIMAKWA SERIES</u>
The **Timakwa** series consists of very deep, very poorly drained soils formed in woody and herbaceous organic materials over sandy deposits in depressions on lake plains, outwash plains, till plains, moraines, and flood plains. These soils formed primarily in woody organic materials with some herbaceous material. They have moderate to very rapid permeability in the organic material and rapid to very rapid permeability in the sandy material, and surface runoff is negligible or very low. Depth to the seasonal high water table ranges from 1 foot above the surface to 1 foot below the surface from October to June. Some areas are subject to rare, very brief flooding from November to May. Most areas are used for wildlife, are in woodland or clear-cut woodland, or are used for pasture. Common vegetation is red maple, skunk cabbage, and sphagnum moss.

<u>WALPOLE SERIES</u>
The **Walpole** Series consists of very deep, poorly drained sandy soils formed in outwash and stratified drift. They are nearly level and gently sloping soils in shallow drainageways and low-lying areas on terraces and plains. The soils formed in sandy glaciofluvial and stratified drift materials derived mainly from crystalline rocks. Permeability is moderately rapid in the upper soil profile and rapid or very rapid in the substratum. Walpole soils have a water table at or near the surface much of the year. Most areas of Walpole are wooded, although cleared areas are used for hay and pasture and drained areas are used for silage corn and hay. Common trees are red maple, white oak, white ash, aspen, elm, white pine, and hemlock.

<u>WHITMAN SERIES</u>
The **Whitman** series consists of very deep, very poorly drained soils formed in glacial till derived mainly from granite, gneiss, and schist. . These soils are nearly level or gently sloping soils in depressions and drainageways of glacial uplands. They are shallow to a compact dense till, and permeability is moderate or moderately rapid above the dense till and slow or very slow within it. Runoff potential is negligible with ponding often occurring. Perched water tables or excess seepage water can be found at or near the surface for about 9 months of the year. Nearly all areas are forested (common trees include alder, gray birch, red maple, hemlock, elm, spruce, balsam fir), although there is some clearing and draining for pasture. Sedges, rushes, cattails, and other water-tolerant species are the principal vegetation found in Whitman soils.

Nonpoint Source Pollution

Impervious surfaces have the potential to collect pollutants that can then run off into nearby receiving waters. A concerted effort is being made nationwide to control this type of pollution, generally referred to as nonpoint source pollution, since it is recognized as the leading cause of water quality impairment. Nonpoint source pollutants on roadways range from sands and sediments, to salts, metals, trash and heat. For many roads nonpoint source pollutants are collected in runoff along long stretches of curb and gutter, and then discharged either to a stormwater facility, overland flow, or to a wetland or watercourse.

Lover's Lane is a fairly unique situation. The section of road where nonpoint source pollutants can collect is relatively short; however the pollutants wash directly into the open water portion of the wetland marsh system. One of the most obvious, and direct, sources of nonpoint pollution is sand and salt applied for de-icing. Any de-icing materials applied will eventually wash directly into the wetland or will be side-cast into the wetland during plowing operations. The other major source of pollution is from vehicles that use the roadway. Pollutants can passively be released onto the roadway and washed into the marsh during rainfall or snowmelt, or when the roadway is flooded, pollutants can be washed directly off vehicle under-carriages and tires into the marsh. The most likely vehicle related pollutants include sediments (mud, road sand, etc), oils and fuels, trash and debris, and heavy metals (from exhaust, brakes, and worn tire and engine parts).

Published data on the amount of nonpoint pollution found in road runoff was not easy to find, however two scientific papers on the effect of parking lots on water quantity and water quality were obtained. These studies evaluated water quality characteristics of runoff from different types of permeable pavement as well as standard asphalt. Brattebo and Booth (2003) found that runoff from asphalt parking lots had higher mass concentrations of motor oil, copper and zinc, and that state water quality standards for copper and zinc were exceeded (chronic and acute criteria). Rushton (2002) found that yearly loads of iron, manganese, lead, copper and zinc were higher in asphalt versus permeable pavement systems. In general, the export of pollutants from impervious (i.e., asphalt) parking lots is higher because runoff collects and discharged rather than infiltrating into the subsurface where pollutant capture/treatment occurs. While these studies are not of the exact conditions at Lover's Lane, they do provide some relevant information on the potential concentrations of various pollutants from asphalt runoff. *(Please refer to the Appendix for these articles and others.)*

Alternatives Analysis and Recommendations

By virtue of its location Lover's Lane has had chronic structural and flooding problems. The road is also a source of nonpoint pollution loading to the marsh – not only from every day vehicle use but from the application of de-icing materials.

To deal with the on-going issues four alternative strategies have been put forward. Each one has potential environmental, social, and fiscal costs and benefits. Below is a brief analysis of how each strategy may positively or negatively impact the water quality and environmental function of the marsh. Additionally, a number of recommendations for dealing with both existing and possible future adverse conditions in the marsh caused by the road are provided.

1. Maintain the Status-Quo

This alternative would continue the current practice of closing the road when it is flooded and performing maintenance as needed (i.e., adding pavement to adjust for settling). It is clear that the road is a direct and chronic source of nonpoint pollutants. It would be difficult to quantify how much pollutant (load or concentration) is entering the marsh. It would also be equally difficult to demonstrate that the pollutants are the cause of measurable adverse impact on the quality or physical characteristic of the downstream wetland. Even with this lack of quantitative information there is enough evidence that stormwater runoff is a source of nonpoint pollution to motivate action. The 2004 CT Stormwater Quality Manual and the General Permit for Stormwater Discharges from MS4s (both developed by the CT DEP) justify the need to treat stormwater to minimize nonpoint source polluted runoff whether it is from new development or redevelopment projects.

In addition to the chronic pollutant input from road use, there is a risk that by maintaining the status-quo a catastrophic event, such as a vehicle accident, jack-knife, or rollover, could cause the release of a substantial quantity of a toxic, hazardous, or polluting substance. As long as the road remains open there is the potential for an extreme or catastrophic event. This risk can be minimized, however, if the road is upgraded to addresses the current flooding and seasonally icy conditions, or if restrictions are placed on the use of the road.

Recommendations

1. Discontinue the use of any and all de-icing products. Currently available products (sand, salt, liquid spay, etc) have the potential to adversely impact the water quality of the adjacent marsh.
2. Close the road to truck traffic. All vehicles that could carry a substantial quantity of toxic, hazardous, or polluting substances should be prohibited from using the road.
3. Consider having appropriate pollution clean up kits or containment devices (floating booms, etc) stationed nearby in case there is a serious spill.
4. Good housekeeping measures, e.g., trash pick up as street sweeping, should be conducted on a regular basis.
5. Investigate if the process of laying new asphalt, or the wearing of old asphalt, could be a source of pollution to the marsh. Studies have demonstrated that coal-tar sealcoat is a source of polycyclic aromatic hydrocarbons

(http://water.usgs.gov/nawqa/asphalt_sealers.html). If there are differences in the type or method of applying maintenance asphalt the alternative that minimizes the potential for pollution migration into the marsh should be selected.

2. Close the Road Permanently

Permanently closing the road would eliminate any future inputs of nonpoint pollutants associated with the use and maintenance of the road. Closing the road permanently would also allow the two sides of the divided marsh to re-connect. Both of these outcomes would help to protect, preserve, and enhance the ecology and natural processes of the marsh.

If the road is closed consideration should be given to what will happen to the asphalt pavement. The road is damming the flow from one side of the marsh to the other, and therefore affects the hydrology, vegetation, and natural processes of the marsh. As the roadway deteriorates there may be changes in the upstream and downstream hydrology that will affect marsh conditions. Changes in the composition of the plant community or possibly in marsh processes may occur, however these changes are likely to be slow. The eventual revegetation of the road surface will help to connect the two sides of the marsh, and will eliminate heating of waters on the paved surface during the warm summer months. Consideration should be given to the benefit of removing the asphalt surface course, even if only in select locations. While the roadway will naturally revegetate over time, reclamation of the surface asphalt could accelerate the revegetation process.

Recommendations

1. Revisit the marsh seasonally after the road is closed to document changes in hydrology, the plant community, or other marsh processes. If there appears to be detrimental changes to the natural ecology of the marsh consider taking corrective action.

3. Span the Entire Peat Marsh with a Bridge

Spanning the marsh with a bridge would allow for the passage of vehicles, however, it would not eliminate the other concerns. Stormwater runoff on the road surface would need to be collected and treated prior to discharge. The discharge location is still likely to be into a low point in the marsh system. In addition, the bridge would need to be treated with de-icing materials, which would still have the potential to end up in the marsh unless diligent maintenance was conducted to collect and remove the material during and after the de-icing season. Finally, the chance for a catastrophic event or accident would still remain, however the risk would be reduced since the roadway would not be flooded.

Recommendations

1. Capture and treat the road runoff prior to discharging to the marsh. All stormwater treatment facilities provided should be frequently monitored, and maintenance activities should be conducted on a regular basis.

2. Good housekeeping measures, e.g., trash pick up as street sweeping, should be conducted on a regular basis.

4. Construct a Culvert or Small Bridge in the Vicinity of Most Concentrated Flow

Spanning or culverting a portion of the marsh, where there is currently the most flow, would only solve the problem of flooding and icing. It would be difficult to solve the issues with nonpoint pollutants from road use and seasonal de-icing, and would only minimize the risk of a catastrophic event or accident. In addition, construction of a culvert or small bridge may require altering the hydrology of the marsh by changing the upstream and downstream water surface elevations. This manipulation of the marsh water surface elevations would likely cause a change in the plant community and other natural processes. Once a structural change to the road is made that alters the hydrology it will be difficult to take corrective action.

Recommendations

1. Unless there is a means to capture and treat stormwater runoff from the road, de-icing materials should be prohibited from use.
2. Consider limiting the amount and type of truck traffic allowed on the road.
3. Good housekeeping measures, e.g., trash pick up as street sweeping, should be conducted on a regular basis.
4. Consider having appropriate pollution clean up kits or containment devices (floating booms, etc) stationed nearby in case there is a serious spill.

WETLAND REVIEW

The Team reviewed the site on Lover's Lane on Tuesday, November 28. It was overcast, but not rainy. The road was closed at the time of the visit and will remain so through the winter months. Generally, the road is open to vehicular traffic about six months of the year. There seemed to be a consensus among the local individuals that water over the road has been more of a problem in the last five to six years.

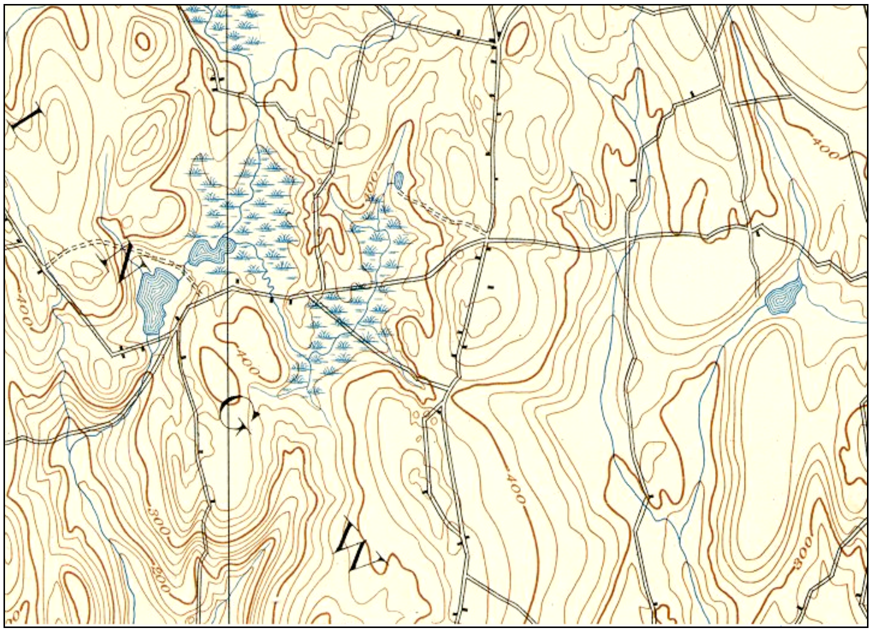
The last rain event greater than one one hundredth of an inch had been five days earlier when on the 23rd - 24th 1.66 inches fell. Before that, three quarters of an inch fell eleven days earlier in a November 16th - 17th rain event. (These numbers are an average of the records kept at the New Haven and Groton airports.)

The road has a history of sinking into the organic materials on which it was constructed. It is readily apparent that over the years several layers of asphalt have been added to maintain the elevation the road surface above the water level. Seemingly, the weight of the new asphalt and the continued compression of the traffic cause it to subside again. Stop gap drainage efforts have been employed to keep the north to south flow of water *under* the road, but those efforts too have sunken with the road bed.

Environmental considerations are of interest here. When the road is open and it floods cars pass through the water and create a kind of car wash effect, leaving questions in their wake about road salt and petroleum product washing into the wetland. Traffic counts of 600 vehicles per day were described to Team members.

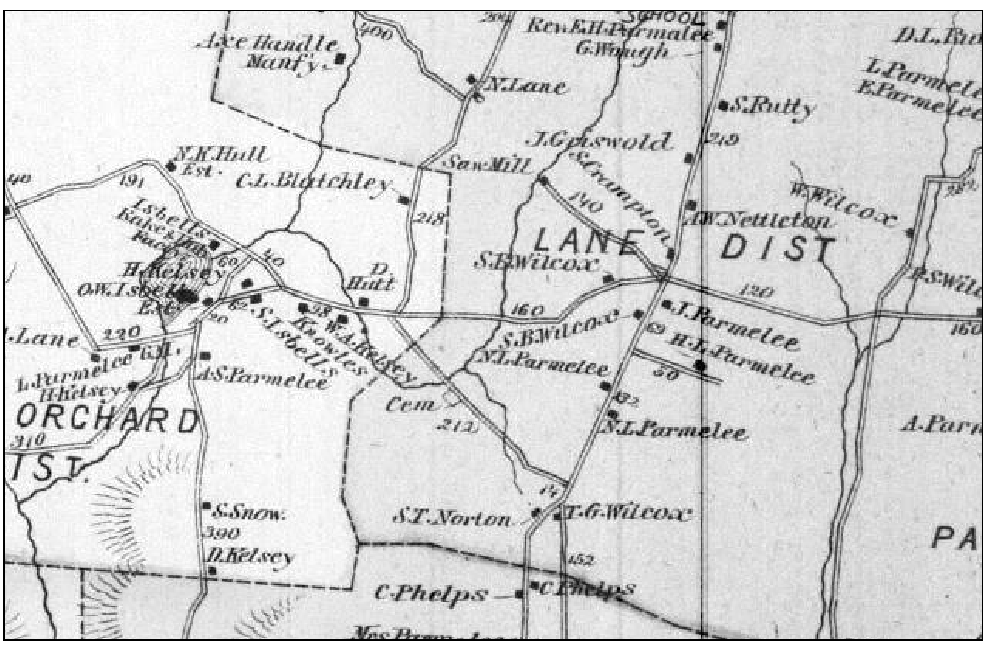
DISCUSSION

Lovers Lane has been in place a very long time. A look back at the United States Geological Survey map which covers Killingworth dated 1893 (field surveyed in 1890) shows the road in place at that time. Indeed, judging by the way it is drawn, the same as all other local roads, it was regarded as just another thoroughfare.



Above is a section of the 1893 USGS topographic map. It shows Lovers Lane as the bottom road of the center triangle. The road was there at the time of the 1890 field survey.

Further investigation revealed that even as of 1890 the road had been around quite awhile. The image below is from a map circa 1855. It too shows the road well established. This map is notable as it depicts the boundaries of the cemetery as well.



The image above is from a Killingworth, Connecticut map, Circa 1855. It shows that the road was in existence even 150 years ago. Source: UCONN Map and Geographic Information Center.

These maps show that the road has been in place a long time. But it is easy to forget that the vehicles at the time were measured in weight by hundred pound increments. Today's vehicles are measured in increments of one thousand pounds. And therein lays a part of the problem.

Lovers Lane was laid down over a heavily organic bottomed wetland area. That is, an area made up of highly saturated, typically acidic, organic material of variable depth. Currently, the surface of the organic layer lies several feet below the open water level. But that surface elevation fluctuates in places. Where it is close to or at the water surface it allows for the growth of scrub shrub, and where the surface of the organics is above the surface of the water red maples can establish a foothold. Thus the elevation differences/ increases in the micro-relief allow for varied vegetative cover. Core samples show the organic material in this location to be as deep as 36 feet. A true bog is fed by precipitation runoff, while this wetland has substantial inflow and outflow. A true bog has it own vegetative classes special, and often unique to the bog environment.

Understanding the above statement, an analogy to having Lovers Lane located where it is would be as follows: Using the "bog" as a road bed would be somewhat akin to acquiring a huge sponge, as big as the new school just across Route 81. You would then saturate that massive sponge with water and send a construction crew up to lay a road across the top of it. The soaked sponge would easily hold up a foot path with people walking over it, but once a two ton SUV crosses, it easy to see water come squishing out, and the road easing down into the sponge, little by little. That is what is happening on Lovers Lane. As that imaginary road sinks into the sponge under the weight of the SUV, we could add a little more asphalt to bring the road up to grade, but little by little, it will continue to sink.

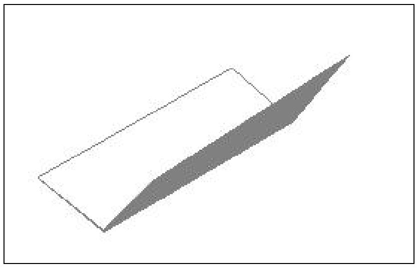
The situation at the time of the visit had water running over Lovers Lane and flooding it in two distinct places. North of the road the water level seems to be about eight to ten inches higher than south of the road. This elevation difference causes water to run steadily over the road as the Team observed in the field. Clearly the road bed is serving as a dam which impounds water north of the road.

The stream that flows through this wetland originates at the northern most reach of the watershed. It is impounded in Fricks Pond and then flows freely south from there. For the purposes of this section of the report it will be referred to as Frick Pond Brook

In this April, 2004 aerial photograph Lovers Lane runs from the mid-left center to bottom right. This photograph shows the wetland very clearly along the well defined, meandering stream channel. It is considered a palustrine wetland with a small area of open water by the road, scrub shrub parallel to the water course, and forests further away from the water course. The image shows the road flooded (dark/black areas on road) in two distinct locations, just as it was when the Team visited. In the right hand inundation the stream passes over the road flowing rapidly. The inundation to the left was still/quiet water but deeper than the flowing water. In the larger inundation, the ponded open water at the road measures ~a quarter of an acre in size.

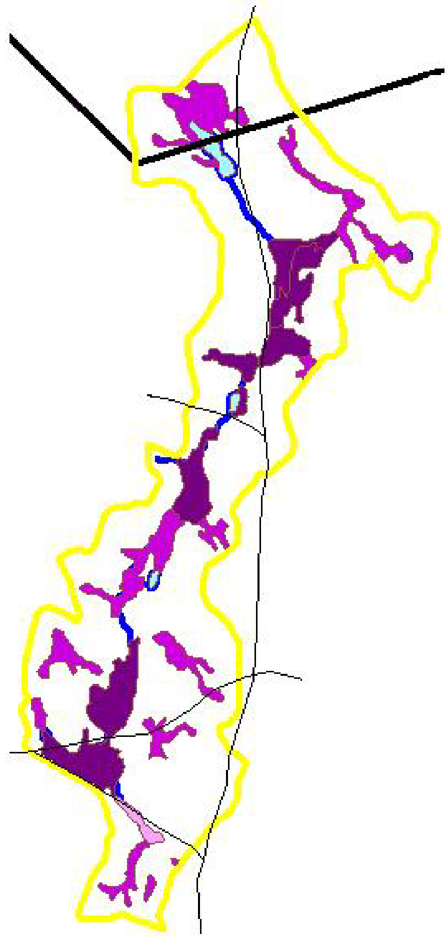
THE WATERSHED

Every watercourse has a finite geographical area that sheds water into its dominant stream. This area is called the watershed. In this case, Fricks Pond Brook watershed above Lovers Lane measures ~873 acres. It runs generally from the northeast to the south-southwest. The watershed is long and narrow. From the very northern reach of the watershed, in the town of Haddam, to Lovers Lane it measures ~2.6 miles in length. But the average distance east to west, measured perpendicularly across the stream, is 2,417 feet. That means it is more than five and a half times longer than it is wide. That would be analogous to holding a sheet of paper with a typical width of 8.5 inches (as this report might be printed on) that has a length of four feet. And to take this analogy one step further, by creasing the four foot length of paper the long way, and then unfolding it, you would have a pretty good example of what the side slopes of this watershed look like in profile.



Above is the simplified profile of the watershed. Note that the side slopes are steep and drain directly to the crease in the fold.

To the right is the actual watershed delineation with a few of the major roads and all the mapped wetland soils in various shades of purple. It is narrow, and the side slopes are in the range of 10 to 14 percent grades. The heavy black line at the top is the Killingworth-Haddam boundary.



WATERSHED DEVELOPMENT AS IT AFFECTS WETLANDS

In the 14 years from 1990 to 2004 roughly 21.6 acres were altered/developed from woodland into houses, lawn and driveways. Of that total 19.6 acres were north of Pond Meadow Road. (That is, the road depicted in the above watershed graphic that splits the area in half north and south). The 19.6 acres represents a little over six per cent of the non-wetland land north of Pond Meadow Road. And while six per cent does not seem significant, it is of note that all development is on slopes in the range of 10 to 14 per cent, and almost all of the development is within 400 feet of the wetlands. All activity on the landscape is local in this watershed thus the results of altered land use directly impacts the headwater streams.

The DEP Watershed Management Program states that "Headwater streams are exceptionally vulnerable to watershed changes." Thus it is that 10 to 14 per cent slope surfaces allow precipitation to run off more rapidly than woodlands and put a spike in the runoff curve. This means that runoff works it way downstream quickly and en masse rather that running off slowly over a longer period of time.

Water is seen flowing freely over the road from north (left) to south. The road bed in general dams the water flow and only where the road has sunk does the water have its downstream outlet.

So, combining the probability of increased speed and quantity of runoff after a precipitation event due to development and steepness of slope, and the continued subsidence of the road bed, flooding problems along Lovers Lane have little chance of stabilizing and all indications point to increased problems in the future. There is little wonder that the water north of the road backs up and is finally forced to flow over the road as it travels downstream.

Observations

- There was no indication of motor oil or gasoline product on the water surface when the Team visited, but the road had been closed for awhile, and the flow at the time would easily have carried away any petroleum residue from 'car washing'. It should be interesting to note that Fricks Pond Brook is classified as a "AA" stream in the DEP Water Quality Classification mapping. This is on a rating scale of "AA" being the best, "A" being next, then "B", "C", and finally "D". The further into the alphabet the letter, the more degraded the water quality. AA is the highest possible classification offered by the department. The full text of the DEP's *Water Quality Standards and Criteria* can be found on the web at: http://www.dep.state.ct.us/wtr/wq/wqs.pdf

- Closer inspection of the above photograph shows the absence of chunks of asphalt from the road surface especially easy to see just to the right of the team members' reflections. It should be noted that broken up chunks of asphalt from a road or parking lot is "considered clean fill" by DEP Waste Unit. It is generally not a problem as fill material so long as it is not placed in wetlands or around a well. Milled asphalt is a different story as it presents a worst case condition from a standpoint of leaching. The missing asphalt in the photo above may have been initially broken up by freezing and thawing and subsequently washed downstream in smaller pieces.

Conclusion

Well over 150 years ago this large wetland was split north and south by the construction of Lovers Lane. This is a road that would never be permitted to be constructed today.

It is a simple act to predict additional <u>and larger</u> water / road conflicts at Lovers Lane in the future for the following reasons:

1) Killingworth zoning allows for residential development in the upper reaches of the watershed;
2) There is a general sensitivity of watercourses to headwaters development;
3) The watershed is narrow and features naturally occurring steep slopes; and
4) There is no compensatory increase in wetland flood storage capacity leaving increased runoff no option as it travels downstream than to pass over the road.

Add to the above four reasons the fact that road will continue to sink into its sponge-like organic base (since it was *never* constructed on a solid base or footing to begin with) and it is easy to envision heightened flooding events on Lovers Lane in the future.

The alternatives necessary to avoid these conflicts would be costly, some of the stated alternatives prohibitively so. And because of the proximity of the road to the wetland, any construction would have significant impacts to the resource.

Lovers Lane is ~3,500 feet in length. It is open six months of the year. “Going around” adds a bit over seven tenths of a mile and about 86 seconds to any given trip. Making Lovers Lane passable and safe and situated so traffic does not impact the immediate wetlands will cost taxpayers hundreds of thousands of dollars.

THE NATURAL DIVERSITY DATA BASE

The Natural Diversity Data Base maps and files regarding the project area have been reviewed. According to our information, there are records of State Special Concern *Lycaena epixanthe* (bog copper) from the vicinity of this project site.

The Bog Copper is a fairly conspicuous butterfly that is associated with sphagnum bogs in Connecticut. Activities that alter the physical or chemical nature of the aquatic habitat, cause siltation or any source of pollution will be detrimental. Any work that will detrimentally impact the associated sphagnum bog will affect this species.

If the habitat described above is going to be impacted by any project then the DEP Wildlife Division recommends that an entomologist conduct surveys for this species. A report summarizing the results of such surveys should include habitat descriptions, invertebrate species list and a statement/resume giving the entomologist' qualifications. The Wildlife Division does not maintain a list of entomologists in the state. A DEP Wildlife Division permit may be required by the entomologist to conduct survey work; you should ask if your entomologist has one. The results of this investigation can be forwarded to the Wildlife Division and, after evaluation, recommendations for additional surveys, if any, will be made. The Wildlife Division has not made an onsite inspection of the project area nor been provided with details or a timetable of the work to be done. Consultation with the Wildlife Division should not be substituted for on site surveys required for environmental assessments. Please be advised that should state permits be required or should state involvement occur in some other fashion, specific restrictions or conditions relating to the species discussed above may apply. In this situation, additional evaluation of the proposal by the Wildlife Division should be requested.

Natural Diversity Data Base information includes all information regarding critical biological resources available to us at the time of the request. This information is a compilation of data collected over the years by the DEP's Natural History Survey and cooperating units of DEP, private conservation groups and the scientific community. This information is not necessarily the result of comprehensive or site-specific field investigations. Consultations with the Data

Base should not be substitutes for on-site surveys required for environmental assessments. Current research projects and new contributors continue to identify additional populations of species and locations of habitats of concern, as well as, enhance existing data. Such new information is incorporated into the Data Base as it becomes available.

Also be advised that this is a preliminary review and not a final determination. A more detailed review may be conducted as part of any subsequent environmental permit applications submitted to DEP for the proposed site.

ECOLOGIST REVIEW

This reviewer visited Lover's Lane on Tuesday August 22, 2006 and looked at the two low areas in the road with culverts that are flooded during high water conditions. He also looked at both areas where the unnamed brook flows in and out of the wetland under Route 148. In all areas the stream showed little indication of flow, reflecting the low gradient of the wetland area. The surface water level also appeared to be higher upstream of Lover's Lane, indicating inadequate water flow from one side of the road to the other, likely caused by the restriction of the road fill.

Lover's Lane is a collection location for bog copper *(Lycaena epixanthe)*, a Special Concern butterfly whose larvae feeds on wild cranberry. Although he did not venture far into the wetland, there is an area that appears on the 2004 aerial photographs to be composed of low shrubs upstream of Lover's Lane, likely a low shrub fen with cranberry plants growing in it. This is the likely breeding site for bog copper. In 1996, several adult bog copper individuals were observed on cranberry along the road, and DEP has no additional information on its extent or its current status since that time.

The Team ecologist reviewed the engineering reports concerning the recommendations to remedy the flooding of the road and has little to add. The construction of the road has already impacted the wetland and since the road has been there for a considerable length of time, the wetland has stabilized to the existing conditions.

This reviewer's recommendations are to either abandon the road and excavate the area with the stream crossing to provide better flow, improving the wetland habitat for wildlife; or leave the road the way it is, closing it to vehicular traffic during high water conditions. In his opinion, any other options would not provide any long term solutions to the flooding and just add to the tax burden of the town.

FISHERIES RESOURCES

UNNAMED TRIBUTARY TO POND MEADOW BROOK

Based upon instream habitat and watershed characteristics, this watercourse may support a warmwater fish population; however the specific composition of the fish community is unknown.

Given the bog-like characteristics of the wetland, its possible that waters are acidic which could limit fish survival and distribution. There are ponded, open water habitats in this system immediately upstream of the Route 148 road crossing. These ponded habitats provide more viable fish habitats and may be a source of fish, which could seasonally utilize the wetland system above and below Lovers Lane. Fish community composition is most likely comprised of sunfish species (bluegill and pumpkinseed), golden shiner and possibly chain pickerel. At present, the multiple and small diameter PVC pipes under Lovers Lane impede fish passage through the area.

RECOMMENDATION/COMMENTS

Lovers Lane bisects the existing wetland bog system and as such impacts the conveyance of water through the area. It is understood that the road is often closed due to flooding. No doubt this wetland's function and form have adapted and evolved over time due to the presence of the road. Past efforts to improve water conveyance have been unsuccessful due to gradual roadway and culvert settlement into the bog. Engineering information provided to the Team involves discussion of various options. Options designed to specifically improve flow conveyance and keep the road open involve costly infrastructure replacement in the form of culverts or a span bridge.

It is the responsibility of the Town of Killingworth to determine the "public safety need" for keeping this road open. If there is no overwhelming need from a public safety perspective to keep the road open, then it would appear that a prudent and feasible option would be to permanently close the road to all vehicular traffic. If this option was chosen, then consideration should be given to removing the road and culverts at the existing crossing and restoring a natural stream channel through the area. This would facilitate passage of fish and wildlife as well as improve flow conveyance in the main watercourse channel.

PLANNING REVIEW

The project under review concerns the question of whether or not there would be an environmental advantage to abandoning Lover's Lane, a local road which "cuts the corner" between State Routes 8 1 and 148. It is the Connecticut River Estuary Regional Planning Agency's (CRERPA) understanding that the purpose of the ERT is to provide guidance to the Town of Killingworth, from an environmental perspective, that will aid in deciding whether the road should be kept open, whether it should be abandoned permanently or whether it should be opened for part of the year and closed for part of the year. Currently the roadway is closed during the winter months due to freezing of surface water that periodically floods it. CRERPA's contribution to the ERT process will primarily be from the perspective of overall planning issues, which in this case, takes the form of traffic circulation patterns and overall access through this part of Killingworth. This review follows a presentation and site walk hosted by First Selectman Martin Klein on Tuesday, November 28, 2006.

BACKGROUND

Lover's Lane runs in a northwest/southeast direction in a location which connects north/south Route 8 1 and east/west Route 148. Physically, topographic elevations are highest where Lover's Lane intersects with the two state roads. The lowest area exists where the roadway transects an area of inland wetlands approximately halfway between Routes 81 and 148. It is this low area that floods during times of high water and, in winter, freezes over creating hazardous traffic conditions.

Legend has it that Lover's Lane, a local road of approximately 0.6 miles in distance, was originally called "Lowell's Lane" after local property owner Lowell Parmalee. Mr. Parmalee reportedly lived on or near the southeastern end of Lover's Lane and used to cut through to the northern part of the road to access another property he is said to have owned. For Mr. Parmalee, it was apparently a road of convenience. At some intervening time, the road was renamed "Lover's Lane", the reason for which can only be speculated upon.

At one time in the past, Lover's Lane was what is called a "corduroy road", a series of logs laid on top of the wetlands that would allow for the crossing of the wet areas. The term "corduroy" refers to the corduroy look of the logs when laid side-by-side. It is known that the southeast end of Lover' s Lane must date back to the early 1800's as the earliest interment in a small cemetery on the southwest side of the road dates back to approximately 1820. Several residences are located along the southerly end of Lover's Lane as well.

Corduroy

Corduroy was originally used to provide access through wetlands to areas being logged or mined. Essentially, the technique involved laying a bridge on the ground where the soil would not support a road. Two log stringers or beams were placed on the ground about 8 feet apart. Small- diameter logs or half logs were placed on the stringers, spanning them. The logs became the tread or surface of the road. They were spiked or pinned to the stringers (figure 12).

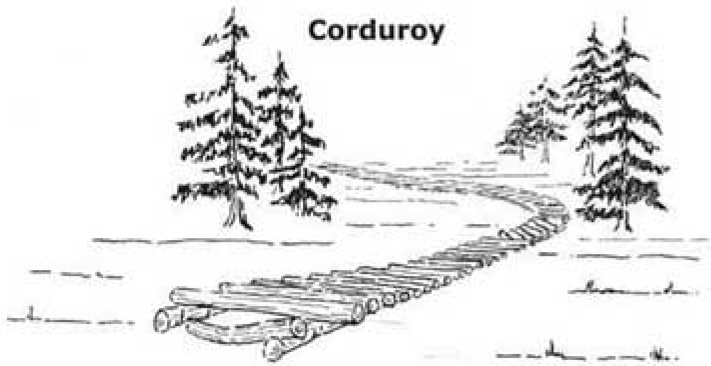


Figure 12-Corduroy requires a lot of native material, rots quickly to an unsafe condition, and is no longer recommended for new construction.

A variation of corduroy construction was to place the tread logs directly on the ground. No stringers were used, and the logs were not pinned or spiked to the ground or each other. Some excavation was required to ensure the tread logs were level. The tread logs eventually heaved up or sank, creating severe cross slopes in the tread.

Corduroy construction was often used in areas with deep shade and considerable rainfall. The combination of sloping, wet tread resulted in a slippery, hazardous surface. The stringers and tread logs soon rotted. With no support, the cross slope on the tread logs became worse and more hazardous.

When corduroy was laid directly on the ground, it interfered with the normal flow of runoff. Runoff was blocked in some areas and concentrated elsewhere. Erosion and relocation of minor streams resulted. No plants grew underneath the corduroy, further damaging the wetland resource. Many trees needed to be cut to provide the logs for the corduroy. In many cases, these impacts would be unacceptable today. The useful life of corduroy today is only 7 to 10 years. Corduroy is rarely replaced because suitable trees are even farther from where they are needed for the reconstruction job.

Corduroy did not represent sustainable design and required considerable maintenance. Corduroy is rarely used today. We do not recommend it.

(Federal Highway Administration – Wetland Trail Design and Construction)

(Additional information on road development through peat wetlands for forest service roads may be found in the Appendix.)

COMMENTS

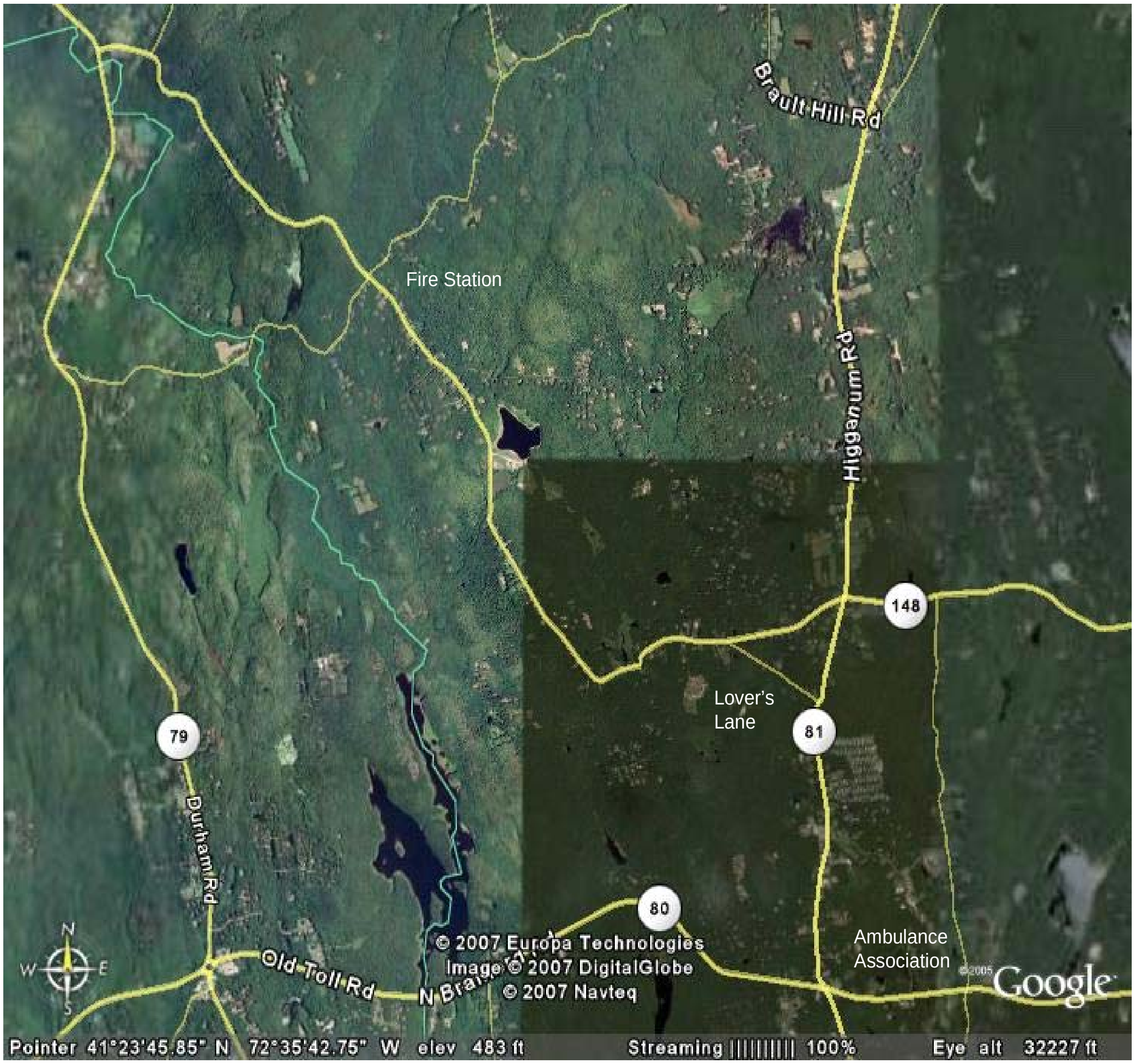
Although there are a number of residences located on Lover's Lane, primarily at the southern end, it seems that a central question is whether or not Lover's Lane as it is presently configured serves more than just the purpose of convenience and whether or not the ongoing costs of continuing the use of such a high maintenance road is justified.

As a shortcut, the road enables travelers the convenience of avoiding the signalized intersection of the two state roads and it offers a time savings of approximately 2 to 3 minutes as measured with a stopwatch. From the perspective of emergency access, it saves what emergency personnel call precious minutes in accessing the northern part of Killingworth to the north and west of Routes 8 1 and 148. The balancing of the costs of maintenance with even several minutes of time savings in emergency situations would seem to be at the heart of the issue, at least from an overall planning perspective. It's hard to ignore liability issues as well, if the road were to be left open, the Town may potentially be open to law suits.

Speaking to emergency management personnel including Don McDougal (Emergency Management Director) and Brian Mahoney (President, Killingworth Ambulance Association), it's no surprise that they find Lover's Lane an important component in their ability to offer emergency services to the residents of Killingworth, particularly the northwestern section of the Town. They indicate that even a savings minutes in an emergency situation can mean the difference between life and death, the loss of life and property.

One particular issue of concern to emergency personnel is one of the impact of an accident located on Route 148 between the intersection of Routes 148 and 81 and the northern entrance to Lover's Lane. Although not frequent, if Lover's Lane were permanently abandoned and an accident occurred in the cited location, the northern part of Killingworth would be inaccessible without a time consuming circuitous trip west to Route 79 in Madison thence north and back east across to northern Killingworth. Although an accident in that location hasn't happened of late, the risk of not being able to access northern Killingworth, from an emergency access perspective, is significant.

One significant fact is that, although the northern end of Town would be accessible to the northern fire substation in the event of a significant auto accident, the ambulance association only has one station — located to the south. So, where there is the second alternative for fire apparatus, there is no such alternative for the Killingworth ambulance. In the event of the referenced accident and without the ability to cross between Routes 81 and 148 using Lover' s Lane, the northern area of Killingworth would be unreachable via ambulance without first going west to Route 79 in Madison, then north on Route 79 and back to the east on Route 148. This detour would take a significant and unnecessary amount of time.



Environmental Comments

From an *environmental* perspective, the question being asked is whether or not the wetlands through which the roadway passes would benefit in an environmental sense should the roadway become abandoned. It would seem that the answer to that question would likely be yes. Of course, the question of how *much* of an environmental benefit could only be answered through detailed investigations. An interesting question to ask would be what would result from the removal of the roadway (versus just its abandonment) and whether or not that would disrupt the ecology and habitat of the area more than just leaving the road there.

Currently, the roadway bisects the northeast/southwest oriented wetland area, creating what some may call a detention basin effect to the north and east of Lover's Lane. Due to the elevation of the roadway, high waters are “metered” out over the northwest/southeast ridge formed by the roadbed, creating a controlled flow of surface waters to the south and west of the road. Were Lover’s Lane to be removed altogether, what, if any, impact would such an action have on the wetland system as a whole and the potential for downstream flooding? Although one could speculate on the results, roadway removal would have to be studied to determine if that was in the best interest of property owners surrounding the wetland system, especially in downstream areas. It may be that removal may only have temporary and localized adverse impacts on wetland habitat and flooding potential. Without studies, that is hard to tell.

SUMMARY

From the perspective of minimizing or eliminating costs associated with the ongoing maintenance of a roadway which subsides through time thereby creating flooding hazards, and from the perspective of improving the environmental quality of the wetlands habitat in the vicinity of Lover’ s Lane, it would seem logical that abandonment of the road would create positive environmental impacts. Although the ongoing road maintenance cost-saving could be significant through time, when one compares that cost savings to the issue of emergency access and the potential for saving even one life, the question becomes more difficult. Even though it would seem that only 2 to 3 minutes of time is saved by cutting through from Route 81 to Route 148 on Lover’s Lane, those 2 to 3 minutes could mean saving the life of a critically ill patient. Further, an accident in *just* the right location could create delays of far more than 2 ½ to 3 minutes.

So, the Town will have to weigh the question of what is more important — the possibility of even saving one life by cutting off 2 to 3 minutes in emergency access time, or eliminating Lover’ *s* Lane as a cut through. One could look at the ongoing costs of road maintenance through time as insurance payments for a policy that would insure that the northern areas of Killingworth are accessible via Lover’*s* Lane in the event of an automobile accident along Route 148 between the signaled intersection and Lover’s Lane. As stated earlier, it’s a difficult philosophical question that only the taxpaying citizens of Killingworth can answer. It would seem that there *is* a point where the costs exceed the benefits, but how that point is identified when emergency access is involved is another question altogether. Although insurance is at times costly and a seemingly unused expense, when it’s needed and available, we sure appreciate having it.

CONNECTICUT DOT TRANSPORTATION PLANNER COMMENTS

The Department would like to review more detailed traffic information before making any final recommendations.

Pertinent issues that should be considered are as follows:

- Traffic data, including am and pm peak hours should be provided.

- An accident analysis for both ingress and egress points should be performed.

- Trucks, while not permitted by signage, should be monitored for compliance. Trucks will degrade the road faster due to their size, weight and operational characteristics.

- To reduce the number through trips, and as a further deterrent to heavy vehicles, speed bumps should be considered an option.

- A recent trip to the site showed two areas of the roadway covered by at least 2 to 3 inches of ice. Frost heaving in numerous locations throughout the area in question was also observed.

- One recommendation was a ten foot +/- bridge at the 4" pvc crossing. While this may remedy one area, the second area of equal or greater size would not be repaired and therefore the road would still have to be closed. Also settling could still occur outside of the repaired area requiring repairs to continue.

- Frost heaving will continue to occur until the roadbed (subbase), usually 10" deep, is allowed to dry and remains dry. Problems with the roadway will continue to occur until this happens.

APPENDIX

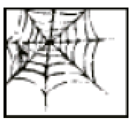
- Controlling Nonpoint Source Runoff Pollution from Roads, Highways and Bridges
- Enhanced Parking Lot Design for Stormwater Treatment
- Long-term Stormwater Quantity and Quality Performance of Permeable Pavement Systems
- Green Roads: Research Into Permeable Pavers

- Riparian Protection and Restoration: Road Design Techniques

Timber Harvesting and Forest Management Guidelines : Forest Roads: Crossing Deep Peat Wetlands

Controlling Nonpoint Source Runoff Pollution from Roads, Highways and Bridges

EPA, Office of Water, August 1995 (EPA-841-F-95-008a)



Note: This information is provided for reference purposes only. Although the information provided here was accurate and current when first created, it is now outdated.

Roads, highways, and bridges are a source of significant contributions of pollutants to our nation's waters. Contaminants from vehicles and activities associated with road and highway construction and maintenance are washed from roads and roadsides when it rains or snow melts. A large amount of this runoff pollution is carried directly to water bodies.

Contaminants in Runoff Pollution
Runoff pollution is that associated with rainwater or melting snow that washes off roads, bridges, parking lots, rooftops, and other impermeable surfaces. As it flows over these surfaces, the water picks up dirt and dust, rubber and metal deposits from tire wear, antifreeze and engine oil that has dripped onto the pavement, pesticides and fertilizers, and discarded cups, plastic bags, cigarette butts, pet waste, and other litter. These contaminants are carried into our lakes, rivers, streams, and oceans.

Contaminants in runoff pollution from roads, highways, and bridges include:
Sediment: Sediment is produced when soil particles are eroded from the land and transported to surface waters. Natural erosion usually occurs gradually because vegetation protects the ground. When land is cleared or disturbed to build a road or bridge, however, the rate of erosion increases. The vegetation is removed and the soil is left exposed, to be quickly washed away in the next rain. Erosion around bridge structures, road pavements, and drainage ditches can damage and weaken these structures.

Soil particles settle out of the water in a lake, stream, or bay onto aquatic plants, rocks, and the bottom. This sediment prevents sunlight from reaching aquatic plants, clogs fish gills, chokes other organisms, and can smother fish spawning and nursery areas.

Other pollutants such as heavy metals and pesticides adhere to sediment and are transported with it by wind and water. These pollutants degrade water quality and can harm aquatic life by interfering with photosynthesis, respiration, growth, and reproduction.

Oils and Grease: Oils and grease are leaked onto road surfaces from car and truck engines, spilled at fueling stations, and discarded directly onto pavement or into storm sewers instead of being taken to recycling stations. Rain and snowmelt transport these pollutants directly to surface waters.

Heavy Metals: Heavy metals come from some "natural" sources such as minerals in rocks, vegetation, sand, and salt. But they also come from car and truck exhaust, worn tires and engine parts, brake linings, weathered paint, and rust. Heavy metals are toxic to aquatic life and can potentially contaminate ground water.

Debris: Grass and shrub clippings, pet waste, food containers, and other household wastes and litter can lead to unsightly and polluted waters. Pet waste from urban areas can add enough nutrients to estuaries to cause premature aging, or "eutrophication."

Road Salts: In the snowbelt, road salts can be a major pollutant in both urban and rural areas. Snow runoff containing salt can produce high sodium and chloride concentrations in ponds, lakes, and bays. This can cause unnecessary fish kills and changes to water chemistry.

Fertilizers, Pesticides, and Herbicides: If these are applied excessively or improperly, fertilizers, pesticides, and herbicides can be carried by rain waters from the green parts of public rights-of-way. In rivers, streams, lakes, and bays, fertilizers contribute to algal blooms and excessive plant growth, and can lead to eutrophication. Pesticides and herbicides can be harmful to human and aquatic life.

Recognizing and Controlling Runoff Pollution
Erosion gullies on land cleared of vegetation at a road construction site are a sign of sediment runoff. Iridescence (rainbow colors) in runoff water is a sign of spilled petroleum products washing off roads. Other signs of runoff pollution during road construction include obvious changes in streams or rivers downstream from the construction, such as bank erosion and sloughing, muddy or oily water, and sandbar relocation. Clumps of mud on roads leaving a construction site can lead to sediment flows heading for drainage ditches and storm inlets that empty into nearby streams.

Rad projects should incorporate pollution prevention , preferably by reducing the amount of pollutants released, into an effective runoff pollution control plan.

Best management practices such as permanent storm water retention/detention ponds, slope protection, or grass strips, and temporary sediment traps, silt fences, diversion trenches, and provisions for washing vehicles before they leave the construction site are all means to reduce runoff pollution.

Pollution Prevention and Control Programs and Regulations
The need to protect our environment has resulted in a number of pollution control laws, regulations, and programs. The implementation of these programs takes place at all levels - federal, state, and local.

Clean Water Act
In 1987, Congress established the Nonpoint Source Management Program under section

319 of the Clean Water Act (CWA), to help states address nonpoint source, or runoff pollution by identifying waters affected by such pollution and adopting and implementing management programs to control it. These programs recommend where and how to use best management practices (BMPs) to prevent runoff from becoming polluted, and where it is polluted, to reduce the amount that reaches surface waters.

Coastal Zone Management Act and Reauthorization
The Coastal Zone Management Act of 1972 established a program for states and territories to voluntarily develop comprehensive programs to protect and manage coastal water resource.

There are now 29 states and territories with federally approved coastal zone management programs.

The Coastal Zone Act Reauthorization Amendments (CZARA) of 1990 specifically charged the coastal states and territories with developing upgraded programs to protect coastal waters from runoff pollution. This program is administered nationally by the Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA). CZARA applies to construction sites in 29 states and territories where less than 5 acres is disturbed. CZARA also applies to storm water runoff from roads that is carried by municipal separate storm sewer systems that serve populations of less than 100,000.

National Pollution Discharge Elimination System
Construction sites where 5 or more acres are disturbed are considered point sources of pollution and require a National Pollutant Discharge Elimination System (NPDES) storm water permit under section 402 of the CWA. In addition. the following types of storm water discharges are regulated under the NPDES permit program: discharges from municipal separate sewer systems serving populations of 100,000 or more; discharges associated with industrial activities, including construction sites of 5 acres or more; and other discharges identified by EPA or a state as needing an NPDES permit because they contribute to a water quality violation.

EPA is developing regulations for other storm water discharges, which may include discharges from municipal separate storm sewer systems serving populations of less than 100,000 and discharges associated with commercial operations, light industries, and construction sites of less than 5 acres. If and when construction sites of less than 5 acres are regulated under the NPDES program, they will no longer be subject to the requirements of CZARA.

Intermodal Surface Transportation Efficiency Act
A major piece of legislation designed to expand and improve the quality and condition of our national highway and transportation systems is the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, better known as "ice tea." This act contains provision for the planning and developing of highway systems and a host of transportation enhancements activities including the mitigation of water pollution due to highway runoff.

Through ISTEA, states are able to use a portion of their federal funding allotment for runoff pollution control devices and other BMPs to prevent polluted runoff from reaching their lakes, rivers, and bays.

Other EPA Programs
Other EPA programs that help control roadway pollution include the National Estuary

Program (NEP) established by the CWA and the pesticides program under the Federal Insecticide, Fungicide and Rodenticide Act. The NEP focuses on point sources and runoff pollution in targeted, high-priority estuaries. The pesticides program regulates pesticides that might threaten ground and surface waters.

Management Measures and Best Management Practices
CZARA established goals to be achieved in controlling the addition of pollutants to out coastal waters. EPA developed a Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters. States with approved coastal zone management programs are required to incorporate the Guidance management measures, or more stringent management measures, into their Coastal Zone Nonpoint Source Control Programs. CWA section 319 programs assist states in the development of nonpoint source controls.

Key management measures for roads, highways, and bridges include the following:

- Protect areas that provide important water quality benefits or are particularly susceptible to erosion or sediment loss.
- Limit land disturbance such as clearing and grading and cut fill to reduce erosion and sediment loss.
- Limit disturbance of natural drainage features and vegetation.
- Place bridge structures so that sensitive and valuable aquatic ecosystems are protected.
- Prepare and implement an approved erosion control plan.
- Ensure proper storage and disposal of toxic material.
- Incorporate pollution prevention into operation and maintenance procedures to reduce pollutant loadings to surface runoff.
- Develop and implement runoff pollution controls for existing road systems to reduce pollutant concentrations and volumes.

Consult the Guidance for detailed information on the management measures.

Management measures, as a practical matter, can often be achieved by applying best management practices appropriate to the source of runoff, runoff location, and climate. The Guidance suggests a number of best management practices that are options for states to use in successfully achieving management measures for bridges, road construction, road maintenance, and operation.

Examples of best management practices for roads, highways, and bridges include:

- Avoid highway locations that require numerous river or wetland crossings (to achieve the Management Measure for Bridges).
- Coordinate erosion and sediment controls with the Federal Highway Administration (FHWA), the American Association of State Transportation Officials (AASHTO), and state guidelines (to achieve the Management Measure for Construction Projects).
- Collect and remove road debris and repair potholes (to achieve the Management Measure for Operation and Maintenance).

For More Information
To obtain more information on the Clean Water Act, runoff (nonpoint source) pollution

control programs, CZARA, storm water regulations and control, ISTEA, or management measures and BMPs for roads, highways, and bridges, contact the appropriate offices listed below.

United States Environmental Protection Agency Nonpoint Source and NPDES Storm Water Coordinators:

- U.S. EPA Region I (Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont) NPS (617) 565-3513 NPDES Storm Water (617) 565-3580
- U.S. EPA Region II (New Jersey, New York, Puerto Rico, Virgin Islands) NPS (212) 637-3701 NPDES Storm Water (212) 637-3724
- U.S. EPA Region III (Delaware, Maryland, Pennsylvania, Virginia, West Virginia) NPS (215) 597-3429 NPDES Storm Water (215) 597-0547
- U.S. EPA Region IV (Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee) NPS (404) 346-2126 NPDES Storm Water (404) 347-3012
- U.S. EPA Region V (Illinois, Indiana, Michigan, Minnesota, Ohio, Wisconsin) NPS (312) 886-0209 NPDES Storm Water (312) 886-6100
- U.S. EPA Region VI (Arkansas, Louisiana, New Mexico, Oklahoma, Texas) NPS (214) 665-7140 NPDES Storm Water (214) 665-7175
- U.S. EPA Region VII (Iowa, Kansas, Missouri, Nebraska) NPS (913) 551-7475 NPDES Storm Water (913) 551-7418
- U.S. EPA Region VIII (Colorado, Montana, North Dakota, South Dakota, Utah, Wyoming) NPS (303) 293-173 NPDES Storm Water (303) 293-1630
- U.S. EPA Region IX (Arizona, California, Hawaii, Nevada) NPS (415) 744-2011 NPDES Storm Water (415) 744-1906
- U.S. EPA Region X (Alaska, Idaho, Oregon, Washington) NPS (206) 553-4181 NPDES Storm Water (206) 553-8399
- U.S. EPA Headquarters NPS (202) 260-7100 NPDES Storm Water (202) 260-9541
- Chesapeake Bay Program (800) 968-7229
- Gulf of Mexico Program (601) 688-7940

Federal Highway Administration Local Transportation Assistance Program (LTAP) Technology Transfer (T2) Centers:

The LTAP program provides training and technical assistance to local/tribal government transportation agencies on roads and bridges. For the location of the LTAP T2 center in your state, contact the T2 Clearinghouse at (202) 347-7267.

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Enhanced Parking Lot Design for Stormwater Treatment

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ABSTRACT

A low impact (dispersed) design demonstrates how small alterations to parking lots can reduce runoff and pollutant loads. Storm runoff was treated as soon as rain hit the ground by encorporating a network of swales, strands and a small wet detention pond into the overall design (Figure 1). When the volume of water discharged from all the different elements to the treatment train (the swales, the strand, and the pond) are compared, calculations showed that almost all the runoff was retained on site. The most effective method for reducing pollutant loads is to keep runoff on site and allow time for infiltration as well as for chemical, biological and hydrological processes to take place. Basins paved with porous pavement had the best percent removal of pollution loads with many removal rates for metals greater than 75 percent in the basin with a smaller garden area and greater than 90 percent with larger gardens. More phosphorus loads were discharged from basins with vegetated swales than from basins with no swales. It should be emphasized here that even with some poor removal rates by swales in the parking lot for phosphorus, when the entire system is evaluated, efficiencies are good since the site retained over 99 percent of the storm runoff during the year that it was evaluated. Sediment sampling identified polycyclic aromatic hydrocarbons, chlordane and DDT products as problems. Phosphorus and nitrogen in the sediments increased from year one to year two. Metal and nutrient pollutants in the sediments were not found to be migrating to the deeper strata.

INTRODUCTION

An innovative parking lot at the Florida Aquarium in Tampa was used as a research site and demonstration project to determine whether small alterations to parking lot designs can decrease runoff and pollutant loads. Over two years of data were collected which included most storm events that produced enough flow to collect water samples. A total of 59 rain events were included in the data set and represented storms that produced as little as 0.38 cm (0.15 in) of rain to a maximum amount of 7.39 cm (2.91 in). Three paving surfaces were compared as well as basins with and without swales to measure pollutant concentrations and estimate infiltration. To determine how these modifications and paving types might change runoff amounts and pollutant concentrations, both water quality and quantity were measured in eight small basins in the parking lot. To evaluate long term consequences and estimate maintenance requirements, sediment samples were collected. To understand conditions that influence pollutant concentrations, rainfall characteristics, vegetated areas and paving types were analyzed. Once the berm between the strand and Ybor channel was repaired, water quality, sediment samples, and flow measurements were collected in the strand and the wet detention pond to estimate the additional stormwater treatment they provide. Finally the data were evaluated statistically to determine differences between years, differences between basins and relationships between variables. In this report, swales were defined as vegetated open channels that infiltrate and transport runoff water while strands were larger vegetated channels collecting runoff after treatment by swales.

METHODS

Site Description - The parking lot design for the Florida Aquarium uses the entire drainage basin for low-impact (dispersed) stormwater treatment. The study site is a 4.65 hectare (11.25 acre) parking lot serving 700,000 visitors annually. The research is designed to determine pollutant load reductions measured from three elements in the treatment train: different treatment types in the parking lot, a planted strand with native wetland trees, and a small pond used for final treatment (Figure 1). The final treatment pond discharges directly to Tampa Bay (HUC 03100206), an Estuary of National Significance included in the National Estuary Program and identified as a water body in need of attention (Section 19, Township 29, Range 19, Hillsborough County).

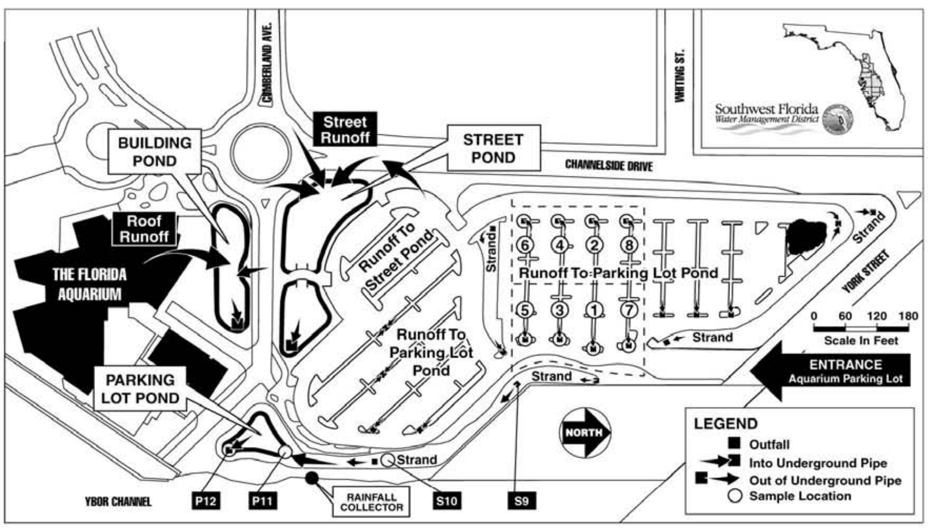

Figure 1a. Site Plan of the Parking Lot Demonstration Project showing sampling locations. The eight drainage basins evaluated in the parking lot are outlined by the dotted lines and shown in more detail in the next diagram. Numbered black boxes indicate sampling locations in the strand and the pond.

Experimental Design - The experimental design in the parking lot allowed for the testing of three paving surfaces as well as basins with and without swales, creating four treatment types with two replicates of each type. The eight basins were instrumented to measure discharge volumes and take flow-weighted water quality samples during storm events. The four treatment types included: 1) asphalt paving with no swale (typical of most parking lots), 2) asphalt paving with a swale, 3) concrete (cement) paving with a swale, and 4) porous (permeable) paving with a swale. The

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swales are planted with native vegetation. The basins without swales still had depressions similar to the rest of the parking lot, but the depressions were covered over with asphalt. All basins had some landscaped garden areas providing opportunities for runoff to infiltrate. The comparative size of the garden areas can be seen in Figure 1b. Three different breaches through the berm that was located between the strand and Ybor Channel interfered with collecting data in the strand and pond as planned, but even so, over one year of data were collected and analyzed once the problem was corrected in July 1999.

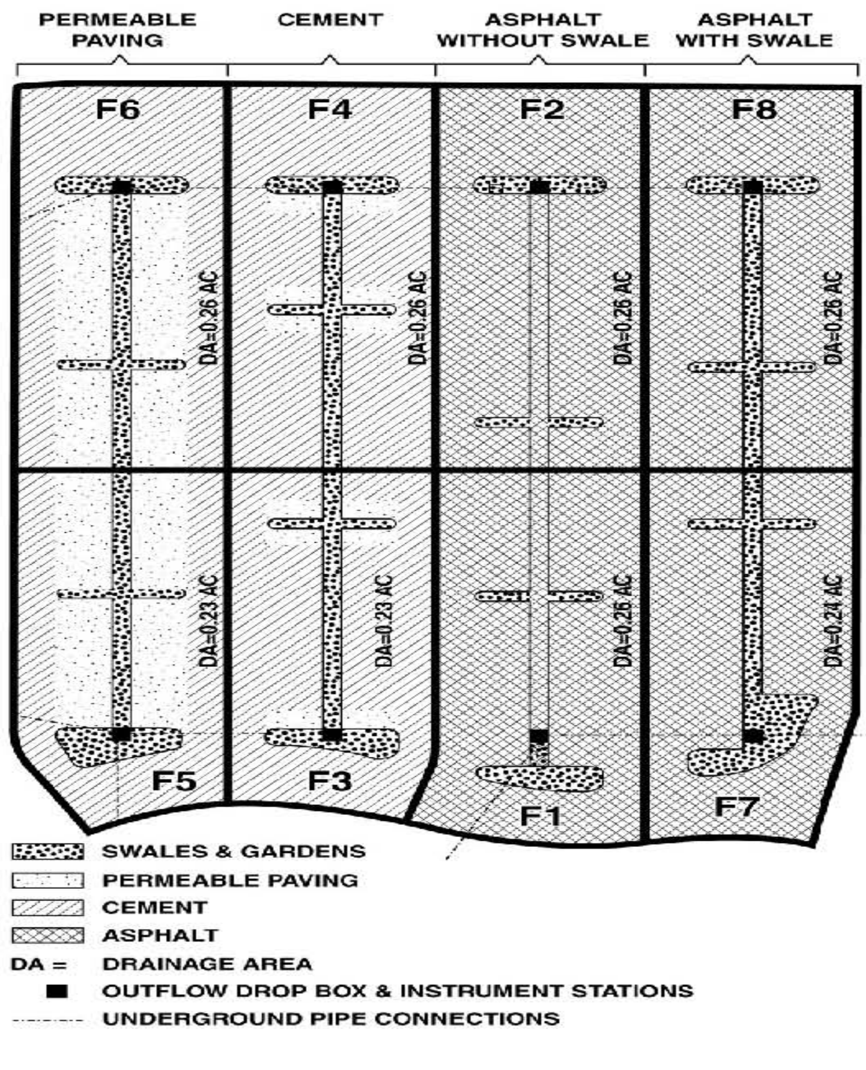

Figure 1b. Site plan of the parking lot swales delineated by the dotted lines in Fig 1a.

Flow out of each of the eight small parking lot drainage basins (0.09 to 0.105 ha) was measured using identical H-type flumes and shaft encoders (float and pulleys) connected to four Campbell Scientific CR10™ data loggers. The major differences at the pond site compared to the parking lot were the primary measuring devices that were weirs instead of flumes.

Rainfall characteristics were calculated using measurements from a tipping bucket rain gauge, summed over 15 minute intervals and stored in Campbell Scientific CR10™ data loggers. Rainfall was characterized by calculating total rainfall, duration, inter-event dry period, and rainfall intensity. Runoff coefficients (RC), LOADS, and LOAD EFFICIENCY were calculated using the following formulas:

RC = (volume discharged) / ((basin size)*(rainfall amount))
LOADS (kg/ha-yr) = ((concentrations)*(volume discharged))/(basin size)
LOAD EFFICIENCY (%) = ((Sum of Loads (SOL) in - SOL out)/SOL in)*100

Water quality samples were collected on a flow-weighted basis and stored in iced ISCO samplers until picked up, fixed with preservatives and transported to the Southwest Florida Water Management District (SWFWMD) laboratory. Samples were analyzed according to the guidelines published in their Quality Assurance Plan. Rainfall was collected using an Aerochem Metrics™ model 301 wet/dry precipitation collector. A small refrigerator was mounted under the collector to immediately store the sample until it could be fixed with the appropriate preservatives and transported to the laboratory.

Sediment samples were collected in front of the outfall (drop box) in each of the swales, and also at one location in the strand and two locations in the pond during the fall of 1998 and again in the fall of 2000 (see Figure 1). Samples were extracted intact from the sediments using a two-inch diameter hand driven stainless steel corer. Cores were collected at two depths, representing sediments in the top 2.54 cm (1 in) layer and sediments 10 to 13 cm (5 to 6 in) below the surface. Residue in the drop boxes used to transport stormwater to the strand were also collected in 1998. Sediment samples were analyzed by the Department of Environmental Protection laboratory in Tallahassee by the methods outlined in their approved Comprehensive Quality Assurance plan .

Statistical computations were performed using the SAS system (v 8.1) to determine significant differences and to analyze relationships among variables. Most statistical tests assume the variables are from an independent and normally distributed population and that the variances are homogeneous. This condition rarely prevails for water quality data, and most test were run using non-parametic statistics such as Spearman correlations, Wilcoxon rank sum test and the Kruskal-Wallis chi-square test.

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RESULTS AND DISCUSSION

Data for the two-year study are reported here with emphasis on rainfall characteristics, hydrology, water quality, sediment analyses and statistical verification.

Hydrology

Rainfall Characteristics - The type of storms and the amount of rainfall are relevant to water quantity issues such as flooding, volume of runoff and peak discharge, and also to water quality, particularly constituent concentrations and removal efficiency. Antecedent conditions (inter-event dry period) and rainfall intensity increase pollutant concentrations by providing time for pollutant accumulation on land surfaces as well as the rain energy to flush pollutants through the system. Also whether it is a wet or dry years affect input and output concentrations by changing subsurface flow and evapotranspiration. Rainfall during both years of the study can be described as drought conditions (Table 1), but the rainfall deficit was much more severe during the second year..

Table 1. Comparison of rainfall characteristics calculated between years (August through July of each year). The long-term average for the region is 127.0 to 137.7 cm per year. The data include all storm events greater than 0.40 cm.

STATISTICS	RAIN (cm)	INTER-EVENT (hrs)	DURA-TION (hrs)	MAX. INT, (cm/hr)	AVG. INT, (cm/hr)
Year One Summary Data	**Total rain 105.83 cm Number of storms 60**				
Average	1.79	143.78	2.58	1.23	1.02
Median	1.30	70.25	1.50	0.94	0.93
Maximum	6.45	921.25	20.50	3.73	4.11
Minimum	0.38	3.75	0.25	0.28	0.15
Standard Dev.	1.35	194.36	3.05	0.85	0.75
C.V.	0.75	1.35	1.18	0.69	0.73
Year Two Summary Data	**Total rain 86.30 cm Number of storms 48**				
Average	1.76	155.13	3.07	1.16	0.95
Median	1.09	50.50	2.25	0.71	0.79
Maximum	7.39	1723.00	12.75	5.05	5.05
Minimum	0.41	6.00	0.25	0.23	0.09
Std.Dev.	1.51	284.70	2.89	1.13	0.88
C.V.	0.89	1.84	0.95	0.97	0.92

Runoff - Drought conditions also reduced the amount of runoff and the runoff coefficients for the parking lot. But even with drought conditions, the calculation of runoff coefficients for each basin demonstrated the reductions that can result from even small swales and garden areas. The runoff coefficient (Table 2) accounts for the integrated effect of rainfall interception, infiltration, depression storage, evaporation and temporary storage in transit. If all the rain falling on a drainage basin ran off, the coefficient would be 1.0 or 100 percent. Except for basin F1, the odd numbered basins were slightly smaller and had larger recessed garden areas than the even numbered basins. The larger garden areas (less than the size of one parking space) in the odd numbered basins accounted for their 40 to 50 percent lower runoff coefficients. Another factor that may account for the good infiltration rate is the soil structure. The site is constructed on filled land and from soil analysis, the Florida Aquarium parking lot had a high gravel content (average 9.9% for soil particles > 2 mm) and it usually took a rain event of at least 0.84 cm (0.33 in) to produce enough flow to collect samples, especially in the basins with swales. Also the data suggest that for large rain events, basin F2 overflows its boundaries and some of its runoff is actually discharged from basin F1. This accounts for the smaller runoff coefficient for both years in basin 2 despite the similarity between the two basins.

Table 2. Summary of runoff coefficients for the eight basins calculated separately for two years. Total rainfall amount (cm) for the storms sampled.

	RAIN AM'T cm	ASPHALT WO/SWALE F1	F2	ASPHALT W/SWALE F7	F8	CONCRETE W/SWALE F3	F4	POROUS W/SWALE F5	F6
YEAR ONE		**total rain**	**87.71**						
Average	2.66	0.58	0.50	0.15	0.31	0.19	0.29	0.09	0.17
Median	2.08	0.57	0.48	0.12	0.30	0.13	0.25	0.02	0.14
max	6.60	0.97	0.86	0.43	0.78	0.67	0.75	0.51	0.59
Stddev	1.57	0.18	0.17	0.12	0.19	0.19	0.22	0.12	0.17
c.v.	0.59	0.31	0.33	0.83	0.60	1.01	0.76	1.44	0.98
YEAR TWO		**total rain**	**77.22**						
Average	3.09	0.50	0.43	0.15	0.29	0.17	0.27	0.10	0.15
Median	2.72	0.53	0.46	0.08	0.29	0.06	0.26	0.04	0.13
max	7.49	0.78	0.67	0.53	0.74	0.65	0.72	0.56	0.72
Stddev	1.55	0.18	0.15	0.15	0.18	0.20	0.18	0.15	0.17
c.v.	0.50	0.36	0.34	1.00	0.63	1.18	0.66	1.49	1.09

Comparison of Flow One of the major advantages of low impact designs for parking lots is the reduction in the volume of water discharged from the site. When the volume of water discharged from the different elements of the treatment train at the Florida Aquarium site were compared, the results showed almost all runoff was retained on site (Table 3). Although the year sampled was during an extreme drought, it is still remarkable that stormwater was discharged for only one storm event and would probably have only discharged four or five times in a normal year. The data represented almost all major storms that produced significant flow for a one year period.

Table 3. Discharge volumes measured for four basins with paving similar to most of the 4.65 hectare parking lot compared to the measured flow from the strand, under drain and out of the pond. Since the four basins included in the analysis represent about 8.8% of the parking lot that ratio was used to estimate the total discharge from all basins.

SAMPLE DATE	RAIN AMOUNT	ASPHALT W/SWALE		CONCRETE W/SWALE		SUM 4 BASINS	ESTIMATE ALL PARKING	STRAND OVER WEIR	UNDER DRAIN	POND
		F7	F8	F3	F4	8.8%	100%			
	cm	m^3	m^3	m^3	m^3	m^3	m^3	m^3	m^3	m^3
11/01/99	4.14	7.22	16.25	6.09	12.94	42.50	374.04	0.00	248.68	0.00
12/17/99	1.91	0.00	0.42	0.00	0.14	0.57	4.98	0.00	0.00	0.00
01/06/00	2.01	1.76	6.48	0.88	4.36	13.48	118.62	0.00	0.00	0.00
01/24/00	1.73	0.00	1.81	0.00	1.70	3.51	30.90	0.00	0.00	0.00
01/31/00	1.78	0.31	3.45	0.00	2.52	6.29	55.32	0.00	0.00	0.00
06/13/00	3.28	1.61	5.41	1.56	9.74	18.32	161.23	0.00	0.00	0.00
06/22/00	0.99	0.06	0.57	0.00	0.17	0.79	6.98	0.00	0.00	0.00
06/24/00	3.53	0.28	3.43	0.06	2.89	6.65	58.56	0.00	0.00	0.00
06/29/00	1.80	1.16	5.01	1.05	4.47	11.70	102.92	0.00	0.00	0.00
07/01/00	2.06	0.82	4.53	0.48	4.81	10.65	93.70	0.00	34.04	0.00
07/04/00	4.95	16.99	30.78	25.26	30.95	103.98	915.04	0.00	381.89	0.00
07/08/00	2.72	8.50	12.74	3.26	11.44	35.93	316.23	0.00	0.00	0.00
07/15/00	5.03	17.67	28.09	21.32	24.64	91.72	807.14	0.00	211.67	0.00
07/26/00	3.15	2.15	4.87	0.65	5.01	12.69	111.64	0.00	0.00	0.00
07/31/00	6.83	35.43	36.50	35.93	31.86	139.72	1229.52	0.00	413.94	19.65
08/29/00	3.05	7.82	13.79	11.04	13.90	46.55	409.67	0.00	5.18	0.00
09/07/00	4.98	13.76	23.08	18.04	22.14	77.02	677.80	0.00	182.82	0.00
09/17/00	5.21	12.03	19.88	12.12	23.73	67.76	596.32	0.00	173.47	0.00
09/24/00	2.95	7.08	11.30	7.31	10.59	49.81	438.33	0.00	60.23	0.00
11/26/00	3.48	5.04	10.00	6.26	6.20	27.50	242.00	0.00	79.35	0.00
total	65.58	139.7	238.4	151.3	224.2	767.14	6750.94	0	1791.3	19.65

Water Quality

The concentration of pollutants is useful for investigating processes taking place in stormwater systems, while pollutant loads are more appropriate for assessing impacts to downstream habitats. Both types are discussed below.

Concentrations - The average concentrations of constituents measured in each of the basins for all storms sampled showed some differences between paving types as well as other variables. A comparison of constituents for all storms (Figure 2) indicated some of the processes taking place in the parking lot, the strand, the under drain and the pond. For inorganic nitrogen, nitrate levels were highest in the parking lot and much lower once water collected in the strand and pond. High concentrations were also measured in rainfall. Ammonia reflects almost the same pattern as nitrates except it exhibits about the same concentration as nitrate in the strand and pond and measures higher concentrations in the basins paved with asphalt. At least some of the higher than expected ammonia concentrations in the strand and pond can be attributed to stagnant conditions since they seldom discharged. The lowest concentrations of organic nitrogen were measured in rainfall and the basins without a planted swale and concentrations are highest in the strand and pond.

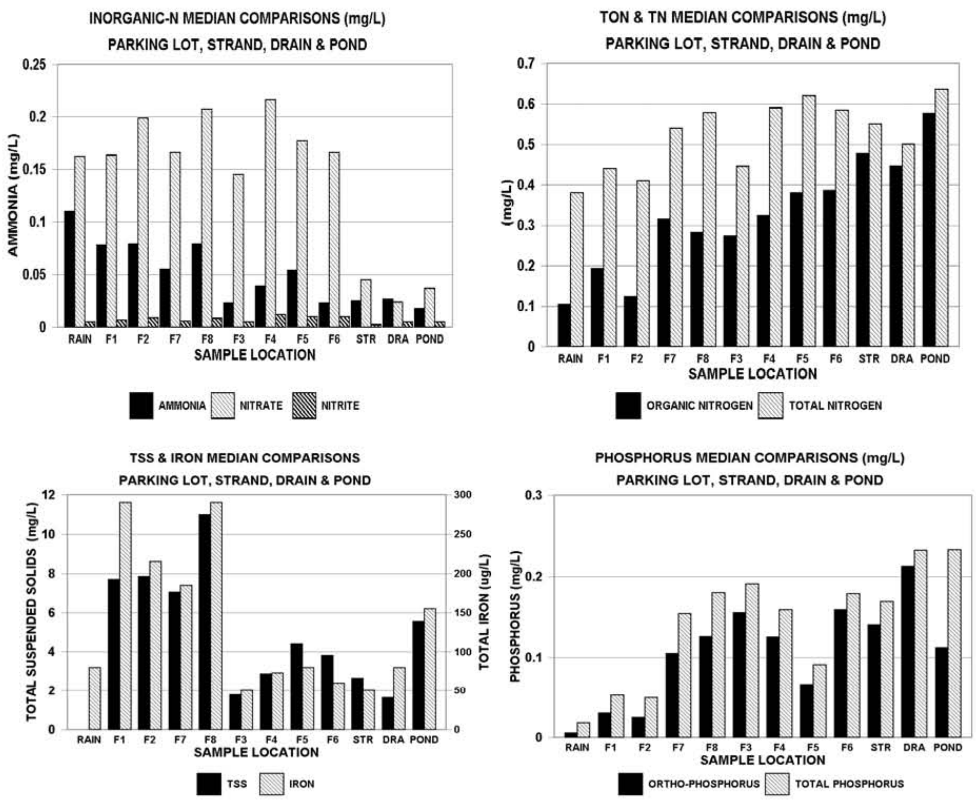

Figure 2. Comparison of median water quality concentrations at the outflows of the various elements of the stormwater system. See Figure 1 for sample locations. Abbreviations: STR=strand, DRA=under drain, POND=pond.

Phosphorus concentrations (Figure 2) were much lower in rainfall and only somewhat higher than rainfall in the basins without planted swales (F1, F2). The highest concentrations of phosphorus were measured in basins where runoff had traveled through grassed areas (F3, F4, F5, F6, F7, F8) and in the vegetated strand. Even higher concentrations were measured in the under drain and in the pond. These may have been caused by mulch that was applied when the pond and strand were constructed and by the filter material used in the under drain when it was installed. Some metals in runoff reflected the type of paving material over which it traveled as illustrated in Figure 2 with iron. Iron, manganese, lead, copper and zinc were measured at concentrations over twice as high in the basins paved with asphalt (F1, F2, F7, F8) compared to the basins paved with concrete products. Total suspended solids were also higher in basins paved in asphalt, although TSS was measured at low concentrations at the site.

Water Quality Loads - A more reliable measurement than pollutant concentrations for understanding the impact of stormwater on receiving waters is to evaluate pollutant loads. Pollutant loads include in the calculations both the volume of water discharged and the concentration of pollution measured. The most effective method for reducing pollutant loads is to retain runoff on site and allow time for infiltration and evaporation as well as for chemical, biological and hydrological processes to take place. The positive effect of the low impact design features is demonstrated with summary data in Table 4. Higher runoff volumes were discharged from the basins without swales (F1, F2), consequently they usually had much higher loads for all the constituents except phosphorus. In contrast the basins with larger garden areas (F7, F3, and F5) had much lower runoff volumes (Table 4) demonstrating the value of recessed areas for infiltration to occur in much the same manner as it did before development. Although it is important to reduce pollutant concentrations, it is an even better strategy to reduce runoff volume using low impact concepts.

Load efficiencies were calculated to quantify how much pollutant loads can be reduced by infiltration with vegetated depressions (Tables 5a and 5b). The low impact design produced significantly reductions for most constituents, especially in the basins with larger garden areas (Table 5b). The basins paved with porous pavement had the best per cent removal, with most removal rates greater than 75%. Phosphorus was a notable exception to this pattern of increased efficiency in basins with swales. Higher phosphorus loads were discharged from basins with vegetated swales than from the basins with no swales. This might be expected since there is not much phosphorus in rainfall, asphalt or automobile residues, but there is phosphorus in vegetation and especially in soils. Also total nitrogen was not removed as well as other pollutants. As almost all runoff was retained on site, these were not serious problems.

In general, removal efficiency was much better for the first year than for the second year. This is probably the result of more rainfall and runoff during the first year (see Table 1), or perhaps, the storage capacity in the swales had been decreased by the second year as a result of increased vegetative mass when the grass in the swales was replaced with shrubs. Reduced efficiency was most noticeable in the asphalt basin with a swale (F8). In contrast, efficiency of total nitrogen was usually improved during the second year especially in basins with larger garden areas. Some of the poor reduction in phosphorus loads may be attributed to landscaping practices since high concentrations, some greater than 1 mg/L, were sometimes measured in the basins with swales during the spring.

Additional infiltration capacity such as porous paving or larger garden areas (F5, F3, F7) improved efficiency, indicating both infiltration and more mature vegetation can improve total nitrogen efficiency (Table 7b). Better efficiency was most evident in the basin with porous pavement and

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both a swale and larger garden area (F5). This basin (F5) reduced by over 80 percent almost all constituents except phosphorus. Eighty percent removal of pollutant loads, especially for TSS, is a state water quality goal.

Table 4. Yearly constituent loads for the basin as calculated for each pavement type *.

Constituents	units	Asphalt no swale		Asphalt with swale		Concrete with swale		Porous with swale	
		YR 1	YR 2	YR 1	YR 2	YR 1	YR 2	YR 1	YR 2
		F2		**F8**		**F4**		**F6**	
Ammonia	kg/ha-yr	0.43	0.38	0.23	0.22	0.12	0.19	0.08	0.06
Nitrate	kg/ha-yr	0.61	0.74	0.34	0.58	0.36	0.58	0.21	0.29
Tot. Nitrogen	kg/ha-yr	1.58	1.77	0.73	1.56	1.33	1.64	0.92	0.80
Ortho Phos.	kg/ha-yr	0.19	0.11	0.54	0.36	0.54	0.48	0.34	0.28
Total. Phos	kg/ha-yr	0.34	0.20	0.66	0.51	0.55	0.63	0.33	0.35
TSS	kg/ha-yr	58.61	29.12	32.79	7.31	12.76	15.43	5.11	20.83
Copper	kg/ha-yr	0.033	0.031	0.025	0.027	0.009	0.013	0.006	0.006
Iron	kg/ha-yr	1.396	0.994	0.667	1.150	0.228	0.165	0.107	0.132
Lead	kg/ha-yr	0.017	0.009	0.007	0.007	0.004	0.002	0.003	0.009
Manganese	kg/ha-yr	0.041	0.029	0.024	0.025	0.013	0.007	0.003	0.029
Zinc	kg/ha-yr	0.147	0.098	0.079	0.083	0.056	0.049	0.036	0.057
		F1		**F7**		**F3**		**F5**	
Ammonia	kg/ha-yr	0.57	0.47	0.11	0.10	0.08	0.08	0.11	0.09
Nitrate	kg/ha-yr	0.72	0.81	0.19	0.27	0.26	0.37	0.15	0.16
Tot. Nitrogen	kg/ha-yr	1.86	2.04	1.07	0.69	1.15	0.93	0.53	0.39
Ortho-Phos.	kg/ha-yr	0.15	0.14	0.15	0.15	0.31	0.35	0.06	0.06
Tot. Phosphor	kg/ha-yr	0.28	0.25	0.21	0.21	0.37	0.42	0.07	0.08
TSS	kg/ha-yr	52.28	37.06	8.68	16.33	4.47	3.41	4.26	3.99
Copper	kg/ha-yr	0.042	0.039	0.008	0.010	0.008	0.008	0.003	0.003
Iron	kg/ha-yr	1.805	1.361	0.227	0.287	0.156	0.086	0.114	0.076
Lead	kg/ha-yr	0.018	0.010	0.002	0.003	0.003	0.002	0.001	0.001
Manganese	kg/ha-yr	0.042	0.031	0.007	0.008	0.004	0.003	0.003	0.002
Zinc	kg/ha-yr	0.174	0.115	0.037	0.032	0.042	0.032	0.020	0.016

* For missing data, which occurred in the basins with swales, a median water quality value for the measured rain event was used in the calculations.

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Table 5a. Load efficiency (%reduction) of pollutants for the even numbered basins as compared to Basin F2 (no swale).

Constituents	Asphalt with swale F8		Concrete with Swale F4		Porous w/swale F6	
	YEAR 1	YEAR 2	YEAR 1	YEAR 2	YEAR 1	YEAR 2
Ammonia	46%	42%	73%	49%	85%	75%
Nitrate	44%	21%	41%	22%	66%	60%
Total Nitrogen	4%	12%	16%	8%	42%	55%
*Ortho Phosphorus	-180%	-230%	-180%	-337%	-74%	-153%
*Total Phosphorus	-94%	-157%	-62%	-216%	3%	-77%
Suspended Solids	46%	-11%	78%	78%	91%	71%
Copper	23%	14%	72%	60%	81%	82%
Iron	52%	-16%	84%	83%	92%	87%
Lead	59%	28%	78%	75%	85%	83%
MangGanese	40%	15%	68%	76%	92%	91%
Zinc	46%	15%	62%	50%	75%	41%

Table 5b. Load efficiency (%reduction) of pollutants for the odd numbered basins with larger garden areas (F7, F3, F5) as compared to Basin F1 (no swale).

Constituents	Asphalt with swale F7		Concrete w/ Swale F3		Porous w/swale F5	
	YEAR 1	YEAR 2	YEAR 1	YEAR 2	YEAR 1	YEAR 2
Ammonia	80%	79%	86%	83%	80%	90%
Nitrate	73%	67%	64%	55%	79%	80%
Total Nitrogen	58%	66%	58%	54%	71%	81%
Ortho Phosphorus	-1%	-4%	-105%	-149%	-61%	55%
Total Phosphorus	-26%	16%	-32%	-69%	76%	66%
Suspended Solids	83%	56%	91%	91%	92%	89%
Copper	81%	75%	81%	79%	94%	94%
Iron	87%	79%	91%	94%	94%	94%
Lead	87%	73%	83%	85%	93%	94%
Manganese	83%	75%	90%	90%	93%	95%
Zinc	79%	72%	76%	72%	89%	86%

* Notice that some efficiencies are negative, indicating an increase in loads in the basins with a swale.

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Sediment Samples

Soil samples were collected in the swales, the strand and the pond in 1998 and again in 2000 (see Figure 1 for sampling locations). For 1998, samples were also collected in the drop boxes that received runoff from the swales. For the basins without swales, the sediments that had accumulated in the asphalt depressions were analyzed and there were no deeper soils to sample.

Metals - Consistent results were seen for 1998, with metals usually measured at higher concentrations in basins paved in asphalt (F1, F2, F7, F8) compared to basins paved with concrete (F3, F4) or porous paving (F7, F8). Aluminum, iron and copper concentrations measured in the strand and pond only occasionally showed concentrations as high or higher than the asphalt basins in the parking lot even though most of the 10-acre parking lot is paved in asphalt. Results indicate that the swales, strand and pond are effective for sequestering metals near the source. An example with zinc is shown in Figure 3.

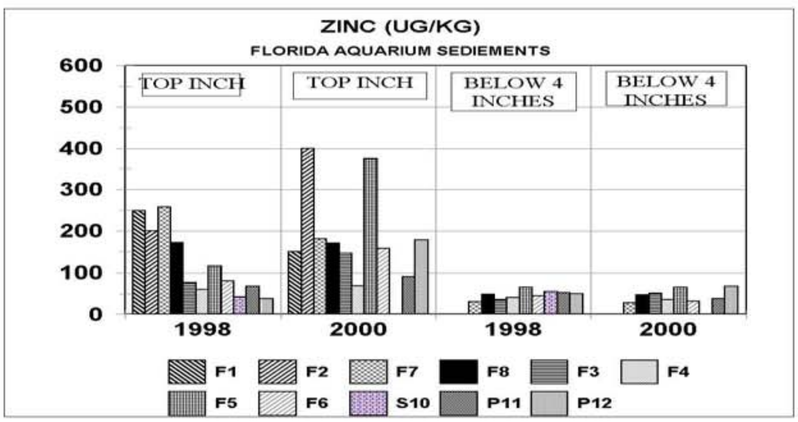

Figure 3. Sediment samples for zinc collected in 1998 and again in 2000 at the outfall of each drainage basin as well as in the swale and pond.

When the metal concentrations in 1998 in the swales are compared to 2000, values are about the same or only marginally higher in 2000 when considering the inherent variability that is characteristic of soils. The possible exception of comparable concentrations is porous pavement (F5, F6) that almost always had higher concentrations in 2000. When the site in the strand in 1998 (S10) is compared to values in 2000, the year 2000 concentrations are usually significantly lower and these results can be explained by the berm repair. All of the soils in the strand were excavated during berm construction, so these data are the result of deeper, cleaner soils. When the Pond data are compared between years, the concentrations are much higher in 2000, probably the result of Ybor channel water pumped into the pond during the repair and the subsequent inflow of stormwater from the channel into the pond through the under drain.

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Nutrients - Total phosphorus and Kjeldahl nitrogen measured in the soils showed an increase in most basins from 1998 to 2000, especially for nitrogen (Figure 4). Usually nutrients are quite low for the basin without a swale that has no vegetation or deeper soils to cycle nutrients. Nitrogen, and to a certain extent phosphorus, increased in the swales from 1998 to 2000. The pond showed a considerable increase in phosphorus and nitrogen from 1998 to 2000. Total phosphorus in the deeper sediments also increased by 2000, but a corresponding increase in nitrogen in the deeper sediments was not usually seen.

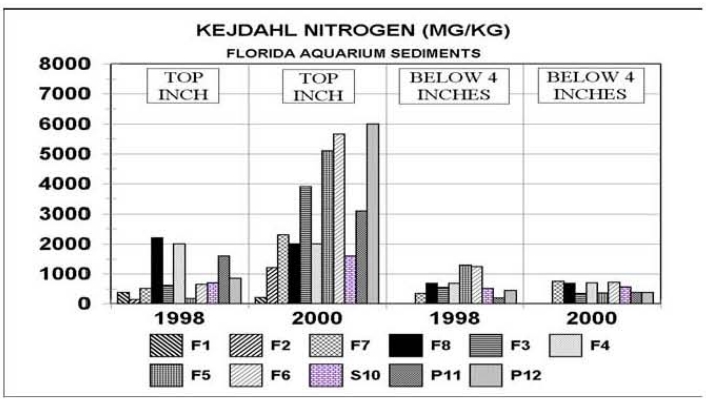

Figure 4. Sediment samples for total Kjeldahl nitrogen collected in 1998 and again in 2000 at the outfall of each drainage basin, the swale, and the pond.

Polycyclic Aromatic hydrocarbons (PAHs) - PAHs are compared by percentages in Table 6. The highest percentage of detection was found at the deeper depths (12.7 cm) suggesting previous hydrocarbon contamination. The lowest number of samples with hydrocarbon detection occurred in the surface soils in 2000. In 1998 more PAHs were detected in the soils of more sites than in 2000 indicating that hydrocarbon pollution may be decreasing at the site. The most frequently measured hydrocarbon was fluoranthene, which was detected in at least 50 percent of the samples collected in each category. Chrysene and pyrene were also frequently detected, followed by the benzo-series (Table 6).

Pesticides & PCB's - At most sites pesticides and polychlorinated biphenyls (PCBs) were not detected but there were some exceptions (Table 6). Chlordane was the pesticide most often detected in measurable quantities and it was found at all locations but three. Unlike the PAH data where concentrations in the boxes were low, the sediments in the drop boxes had the highest percent detection of pesticides. Dichlorodiphenyltrichloroethane (DDT) and its daughter products were measured at almost all locations, and DDE was found in measurable quantities. But the quantities were not considered toxic. At the Florida Aquarium, DDT and DDD were more often measured in the deeper soil profile and DDE in the surface soils. Polychlorinated biphenyl (PCB-

1260) was frequently detected in the soils and it was more often detected in the deeper sediments than in the surface soils.

Table 7. Percentage of samples that detected pollutants in each of the soil strata for each of the eleven sampling sites.

PAH SEMI-VOLATILE ORGANIC		1998 TOP	1998 DEEP	1998 BOX	2000 TOP	2000 DEEP
Acenaphthene	ug/kg	0	20	25	0	17
Acenaphthylene	ug/kg	0	0	0	0	17
Anthracene	ug/kg	0	17	25	0	17
Benzo(a)anthracene	ug/kg	67	70	38	40	70
Benzo(a)pyrene	ug/kg	75	70	38	33	60
Benzo(b)fluoranthene	ug/kg	42	70	25	17	70
Benzo(k)fluoranthene	ug/kg	50	50	25	17	20
Benzo(g,h,i)perylene	ug/kg	17	30	13	17	20
Bis(2-ethylhexyl)phthalate	ug/kg	8	0	0	0	10
Butyl benzyl phthalate	ug/kg	0	0	50	0	10
Chrysene	ug/kg	67	70	38	50	70
Di-n-octyl phthalate	ug/kg	8	0	0	0	10
Dibenzo(a,h)anthracene	ug/kg	0	0	0	0	10
Diethyl phthalate	ug/kg	0	0	0	0	10
Fluoranthene	ug/kg	75	100	63	50	80
Fluorene	ug/kg	17	0	13	0	10
Indeno(1,2,3-cd)pyrene	ug/kg	17	30	25	17	30
Phenanthrene	ug/kg	75	70	25	25	40
Pyrene	ug/kg	83	90	50	58	80
PESTICIDES						
Chlorpyrifos Ethyl	ug/kg	0	0	25	0	0
Diazanon	ug/kg	10	0	50	0	0
Parathion Methyl	ug/kg	0	10	0	0	10
Aldrin	ug/kg	8	0	0	0	10
Chlordane	ug/kg	75	40	63	25	10
DDD-p,p'	ug/kg	17	30	13	8	20
DDE-p,p'	ug/kg	83	60	50	66	30
DDT-p,p'	ug/kg	33	50	12	42	50
Dieldrin	ug/kg	0	20	63	0	8
Endosulfan Sulfate	ug/kg	0	0	8	42	10
Endrin Aldehyde	ug/kg	0	0	0	8	0
Methoxychlor	ug/kg	0	0	0	17	8
PCB-1248	ug/kg	8	0	13	0	0
PCB-1260	ug/kg	33	70	38	17	20

Particle Size Analysis and percent organic matter - The size of sediment particles affects the removal of pollutants in stormwater runoff by sedimentation. Most sites exhibited a similar pattern for particle size (medium fine sand) and there were no obvious differences between paving types or the pond and the strand. Organic matter improves soil structure and provides conditions conducive to healthy soil microbes. These microbes are important for transformation and degradation processes that remove pollutants. Organic matter content ranged from 1.6 to 8.4%.

Statistical Analysis

Differences Between Basins - Since there were few significant differences between years, all 59 of the storms sampled were combined for hypothesis testing. The basins exhibited at least one significant difference for all parameters except nitrate (Table 8). Some of the patterns can be explained by basin characteristics. For example, the basins paved in asphalt had significantly higher concentrations of metals and total suspended solids, which may be increased by the paving material itself. Higher phosphorus concentrations were measured in basins with planted swales, probably a result of the vegetation and soil particles. Inorganic nitrogen is usually measured at relatively high levels in rainfall and nitrogen transformations may explain the differences measured in runoff between the various basins especially after runoff travels through vegetation. To test this theory further, correlations were run.

Table 8. Significant differences between even numbered basins. Data from Duncan Multiple Range Test and significant differences calculated by the Kruskal-Wallis test.

Parameter	Pr>Chi-Square	Asphalt wo/ swale	Asphalt with swale	Concrete with swale	Porous with swale
		F2	F8	F4	F6
Ammonia	0.0004	0.111 a	0.112 a	0.069 b	0.049 b
Nitrate	0.76 ns	0.264 a	0.263 a	0.242 a	0.221 a
Total Nitrogen	0.05	0.511 b	0.737 a	0.684 ab	0.639 ab
Ortho-Phosphorus	< 0.0001	0.047 b	0.192 a	0.203 a	0.195 a
Total Phosphorus	< 0.0001	0.082 b	0.267 a	0.253 a	0.237 a
Total Copper	< 0.0001	12.70 a	9.929 a	4.892 b	4.08 b
Total Iron	< 0.0001	431.67 a	328.93 a	85.40 b	87.73 b
Total Lead	< 0.0001	3.43 a	3.42 a	1.14 b	1.30 b
Total Zinc	< 0.0001	40.62 a	35.01 a	20.80 b	22.12 b
Total Susp. Solids	< 0.0001	16.02 a	11.48 a	4.70 b	5.53 b

Correlations - The small basin size and the short time of concentration contributed to close correlations between the nitrate measured in rainfall and the nitrate measured in runoff from each of the basins. The results of the correlations show the closest relationship among the asphalt basins without a swale, the next highest correlations were among the basins with smaller garden areas (F4 is an exception) and the weakest relationship was observed in the basins with larger garden areas. The data demonstrated an effect of vegetation in transforming the nitrogen found in rainfall.

Table 8. Correlations between nitrate measured in rainfall and nitrate measured in runoff. Results listed in order of decreasing correlation coefficient. SM=small garden LG=large garden

	Site Description	N	Prob > r	Coefficient
F1	Asphalt without a swale (SM)	51	< 0.001	0.924
F2	Asphalt without a swale (SM)	52	< 0.001	0.908
F6	Porous with swale (SM)	35	< 0.001	0.855
F8	Asphalt with swale (SM)	43	< 0.001	0.821
F3	Concrete with swale (LG)	32	< 0.001	0.799
F7	Asphalt with swale (LG)	30	< 0.001	0.789
F4	Concrete with swale (SM)	47	< 0.001	0.700
F5	Porous with swale (LG)	27	0.004	0.632

MAJOR FINDINGS

- Basins with swales and paved in asphalt or concrete reduced runoff to 30 percent and porous paving to about 16 percent compared to basins without planted swales, 55 percent. The basins with larger garden areas reduced runoff by an additional 50 percent (Table 2)
- Basins paved with porous pavement had the best percent removal of pollutant loads with greater than 90 percent removal in basins with larger garden areas. More phosphorus loads were discharged from basins with vegetated swales than from basins with no swales (Table 5). When the entire system is evaluated percent pollution reduction is greater than 99 percent since almost all runoff was retained on site (Table 3).
- Sediment samples implicated asphalt paving material as a source for metals (Figure 3). TKN and phosphorus in the sediments showed a considerable increase from 1998 to 2000 (Figure 4). Polycyclic aromatic hydrocarbons (PAHs) were detected in the soils at the site and some approached the significantly toxic levels (Table 6).

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Florida Water Management District laboratory staff was indispensable in carefully analyzing samples that could never be collected on a pre-determined schedule. Innumerable interns kept samplers iced, entered data into tables and collected samples. Allen Yarbrough designed the cover of the report, the site plan and parking lot swale diagrams. The Finance Department and especially Donna Farrell tracked our budgets, submitted invoices and kept us posted about our expenditures. Chuck Tornabene, our librarian, and his staff edited the report and also Dr. Tricia Dooris, Manager of the Environmental Section. A special thanks to the very careful review provided by Dr Woo-Jun Kang, one of our laboratory scientist, who gave special scrutiny and advice about the sediment and water quality data, an area of expertise where he is especially well-qualified. Everyone receives our grateful appreciation.

Copies of the complete report are available from the author upon request

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Long-term stormwater quantity and quality performance of permeable pavement systems

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Abstract

This study examined the long-term effectiveness of permeable pavement as an alternative to traditional impervious asphalt pavement in a parking area. Four commercially available permeable pavement systems were evaluated after 6 years of daily parking usage for structural durability, ability to infiltrate precipitation, and impacts on infiltrate water quality. All four permeable pavement systems showed no major signs of wear. Virtually all rainwater infiltrated through the permeable pavements, with almost no surface runoff. The infiltrated water had significantly lower levels of copper and zinc than the direct surface runoff from the asphalt area. Motor oil was detected in 89% of samples from the asphalt runoff but not in any water sample infiltrated through the permeable pavement. Neither lead nor diesel fuel were detected in any sample. Infiltrate measured 5 years earlier displayed significantly higher concentrations of zinc and significantly lower concentrations of copper and lead.

Keywords: Impervious surfaces; Permeable pavement; Stormwater; Urban runoff; Water quality

1. Introduction

Impervious surfaces have long been implicated in the decline of watershed integrity in urban and urbanizing areas [1–3]. Most of these surfaces serve automobile travel, but a significant portion of these impervious areas, particularly parking lots, driveways, and road shoulders, experience only minimal traffic loading [4,5]. Parking lots are typically sized to accommodate peak traffic usage, which occurs only occasionally, leaving most of the area unused during a majority of the time [6,7]. Other large parking areas, such as those for businesses and schools, may be used to full capacity nearly every day but with only once-in and once-out traffic that imposes little long-term wear.

The creation of any large impervious surface commonly leads to multiple impacts on stream systems. These impacts include higher peak stream flows which cause channel incision, bank erosion, and increased sediment transport [8–11]. Another impact is a reduction of infiltration which lessens groundwater recharge and potentially lowers stream base flows [1,12,13]. Runoff from impervious areas may also increase pollutant loads to streams [14–17].

Permeable pavements offer one solution to the problem of increased stormwater runoff and decreased stream water quality associated with automobile usage. Permeable pavement systems are commonly made up of a matrix of concrete blocks or a plastic web-type structure with voids filled with sand, gravel, or soil. These voids allow stormwater to infiltrate through the pavement into the underlying soil, which in turn can play a significant role in mitigating the impacts of stormwater runoff caused by urban development [18–21].

The purpose of this study was to evaluate the long-term effectiveness of permeable pavements as a

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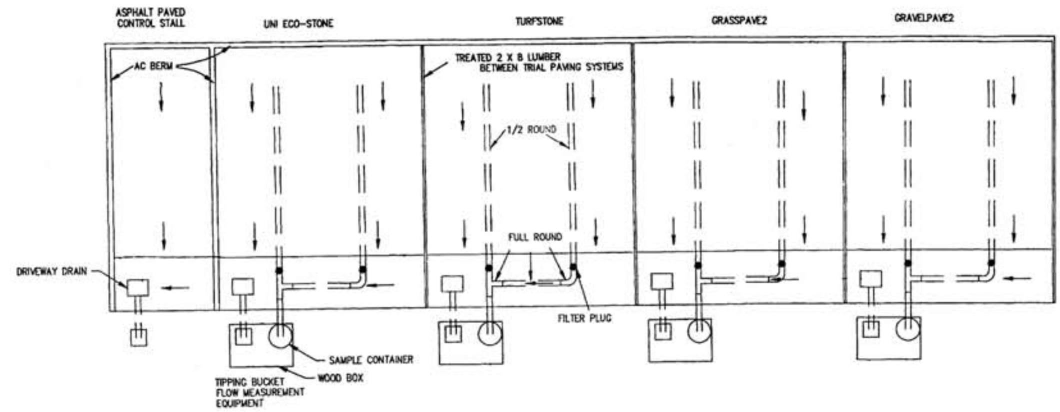

Fig. 1. Plan view of the nine test parking stalls. Each permeable pavement type had two parking stalls paired into one instrument station.

stormwater management strategy, expecting that if they can infiltrate stormwater reliably without creating a new set of water-quality problems then they present an attractive adjunct or replacement for the current structural requirements for stormwater management. This investigation was made by evaluating the water-quality and water-quantity performance of four permeable pavement systems in an intensively monitored parking lot after 6 years of constant use. Our intention was to address commonly raised questions about permeable pavement systems:

- Is permeable pavement structurally durable, and can it withstand long-term use as well as asphalt?
- Do permeable pavements remain permeable or does particulate matter and grease reduce infiltration over time?
- What is the water quality of the infiltrate through permeable pavement, and how does it compare to runoff from asphalt?

2. Project history

This work follows the study of Booth and Leavitt [22], which presented the results of a preliminary test of a field installation of permeable pavement systems as a means of improving stormwater management. That study was conducted in the first year following construction of the site, using the same facility as the present evaluation.

The field site used for both studies was constructed in 1996. It is located in Renton, Washington, 20 km south of Seattle, and includes nine parking stalls, eight of which are constructed of four pairs of different permeable pavement systems. The ninth stall is covered with asphalt and used as the control (Fig. 1).

The study site was chosen for several reasons. It has very deep permeable soil that is well suited for infiltration, good security for monitoring equipment, and frequent use. A site with intrinsically good infiltration properties was selected to ensure that the permeable pavements systems were not hindered by poor infiltration in the underlying soil. The site is used for employee parking at the King County Public Works facility, with once-in, once-out daily usage. Stalls were presumed clear of cars at night and on weekends, although this was directly verified only sporadically during the study. Occupancy of the nine stalls during working hours was typically 90–100%.

The initial study by Booth and Leavitt [22] examined both hydrologic and water-quality characteristics of the site. Their results showed no measurable surface runoff from the permeable pavement areas. In samples of infiltrate collected during three storms, concentrations of several priority pollutants (copper, lead, and zinc) were generally low and not significantly different from runoff from the asphalt surface; hardness and conductivity were significantly higher in all subsurface infiltration samples.

3. Methods

The experimental methods used for the present work followed those established in the earlier study [22]. Eight stalls were constructed with four types of commercially available permeable paving systems, with two neighboring stalls covered with each of the four permeable paving systems. The permeable pavement systems used in this study were:

- Grasspave2®, a flexible plastic grid system with virtually no impervious area, filled with sand and planted with grass.
- Gravelpave2®, an equivalent plastic grid, filled with gravel.
- Turfstone®, a concrete block lattice with about 60% impervious coverage, filled with soil and planted with grass.
- UNI Eco-Stone®, small concrete blocks with about 90% impervious coverage, with the spaces between blocks filled with gravel.

Each test parking stall was 3 m wide by 6 m long. A series of gutters and pipes, discussed in detail by Booth and Leavitt [22], were used to collect both surface runoff and subsurface infiltrate. Surface runoff and subsurface infiltration from each pair of stalls were measured with tipping-bucket gauges for each of the four types of permeable pavements and the impervious asphalt stall. Precipitation and runoff rates were recorded in a data logger at 15-min intervals. Durability of the permeable pavement systems was assessed by qualitative visual comparison with the asphalt control stall.

During rainfall events, composite samples were collected from surface runoff from the asphalt and from infiltrated water at each of the four pairs of instrumented stalls. Following the guidelines outlined in Washington State Department of Ecology [23], a "rainfall event" was considered to be at least 13 mm of precipitation in 24 h, preceded by at least 24 h of no rain. Flow splitters at each tipping bucket were adjusted to yield about 2 l of sample for 10–15 mm of rain for both the permeable (subsurface) and asphalt (surface) runoff collectors. Samples were collected from the field and held for less than 24 h on ice before being taken to the laboratory, where they were analyzed for hardness, conductivity, dissolved metals (lead, copper, and zinc), diesel fuel, and motor oil. Analysis of the samples was done by Aquatic Research, Inc., Seattle, WA, USA, a state-certified laboratory.

4. Results

4.1. Durability

Visual inspection of the permeable pavement systems showed varying, but generally minor, signs of wear and tear after 6 years. In two small areas, the interlocking sheets of the Grasspave2® and the Gravelpave2® plastic matrix had shifted slightly and partly lifted out of the soil in the area where the rear wheels of the parked cars typically rest. The Turfstone® and UNI Eco-Stone® showed no areas of rutting, settling, or shifting. Grass was growing uniformly across the Turfstone® surface, but more spotty (and locally quite sparse) in the Grasspave2® stalls.

4.2. Runoff and infiltration

Surface runoff and infiltration rates were measured at the site throughout November 2001 and from the beginning of January until early March 2002. During the period of measurement, rainfall at the site totaled 570 mm. A total of 15 distinct precipitation events were measured during the study period.

Runoff from the asphalt stall closely followed precipitation rates during all rain events (Fig. 2). Any delay between the onset of rainfall and the runoff of water was less than the 15-min time step of the data logger, and there was no measurable continuation in runoff after precipitation stopped. This response was dramatically different from any measured "runoff" (see below) from the permeable stalls.

For the permeable stalls, virtually all water infiltrated for every observed storm. Measurable surface runoff did occur during several of the precipitation events, but this resulted primarily from observed leaks through the cover of the troughs used to capture surface runoff. These leaks typically resulted in one to three tips (200–600 ml) of the gauge per hour; during the same interval, rainfall events delivered up to several hundred times this volume onto each pair of stalls. These results were therefore deemed insignificant.

During six of the 15 distinct precipitation events, however, surface runoff from a single pair of stalls was

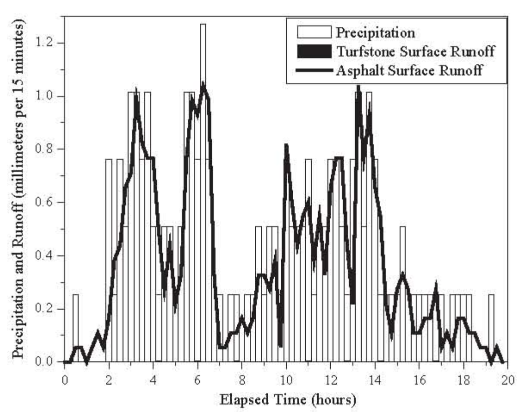

Fig. 2. A comparison of precipitation rates and surface runoff from a permeable pavement stall and the asphalt stall during a storm beginning at 16:00 on 6 January 2002. Minor surface runoff from the permeable Turfstone® stall occurring around 4, 6, 8, 11, 13, 14, and 17 h is attributed to leaks in the piping used to capture water.

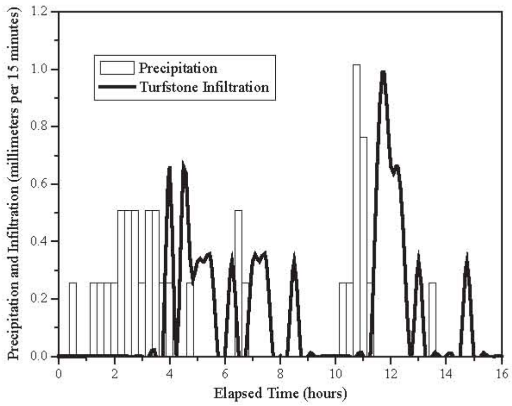

Fig. 3. A comparison of precipitation and subsurface infiltration during a storm beginning at 2 pm on 20 November 2001.

greater than could be attributed to leakage into the trough. Five of these six cases occurred from the Grasspave$^{2®}$ surface and the 6th event was from the Gravelpave$^{2®}$ surface. In four of the six cases, surface runoff occurred during working hours and so cars almost certainly covered the pavement area. Presumably, water sheeting off the roofs and hoods of the cars temporarily saturated the exposed permeable areas, resulting in local surface runoff.

In two cases, substantial surface runoff occurred from the Grasspave$^{2®}$ surface during non-business hours when parked cars were unlikely. One of these runoff events occurred during the most prolonged period of high-intensity rainfall seen during the study. In that storm, 42 mm of rain fell in 14 non-business hours and yielded 1 mm of surface runoff from the Grasspave$^{2®}$ surface during that period. The entire storm lasted 72 h, produced 121 mm of rainfall, and yielded 4 mm of surface runoff in total, the most voluminous example of surface runoff (3% of total precipitation) during the entire study.

Measured infiltration in the permeable pavement stalls followed the trends of precipitation but with a significant lag-to-peak due to subsurface flow rates (Fig. 3). Though the flow path was quite short (<10 cm through soil, plus a few meters along the gravel-filled buried gutter) it imposed delays of up to about an hour.

4.3. Water quality

Composite water samples for entire storms were collected from the asphalt runoff and the infiltrated water passing through each of the pervious pavement systems. Because surface water runoff from the permeable pavement was extremely limited and overwhelmingly due to leakage, water quality was not tested for this fraction.

Nine storms were sampled for water quality (Table 1 and Fig. 4). Of the nine, seven fully met the Washington State Department of Ecology definition of a "rainfall event" (13 mm of rain within the first 24 h proceeding at least 24 h of no precipitation). Though two sets of samples did not meet these storm criteria, they were included in the water quality analysis because they "failed" only minimally: in the first case, more than 30 mm of rain fell in 36 h; in the second case, 12.4 mm fell in 48 h. Water quality data were log-transformed for statistical tests and for determining mean concentrations, following the well-established observations that constituent event mean concentrations in urban stormwater follow a log-normal distribution [24]. Paired *t*-tests on the log-transformed data were used to compare the quality of the infiltrated water from the pervious surfaces with the asphalt runoff. In samples where concentrations were below the minimum detection limit, a concentration of one-half the detection limit was assumed [25,26]. The minimum detection limits for sample constituents were as follows: motor oil, 0.10 mg/l; diesel fuel, 0.05 mg/l; copper, 1.0 μg/l; zinc, 5 μg/l; lead, 1 μg/l.

Overall, surface runoff from the asphalt showed significantly higher concentrations than the infiltrated water of most measured constituents, namely motor oil, copper, and zinc. No samples from any surface had detectable diesel fuel or lead. Both hardness and conductivity had significantly higher concentrations in the subsurface infiltrate than in the asphalt runoff samples ($P<0.01$) (Table 1 and Fig. 4). Among the permeable systems, these parameters were also significantly higher from the concrete-based systems (Turfstone® and UNI Eco-Stone®) than from the plastic systems (Grasspave$^{2®}$ and Gravelpave$^{2®}$).

Concentrations for zinc and copper were significantly lower in the infiltration samples then in the asphalt runoff ($P<0.01$) (Table 1 and Fig. 4). In all cases, the asphalt samples had measurable concentrations of copper and zinc, with the highest measured concentrations being 12.1 and 34 μg/l, respectively. Moreover, all samples from asphalt runoff exceeded Washington State surface water-quality standards for copper at both acute and chronic toxicity levels [27]. For zinc, asphalt runoff exceeded the surface water-quality standard in all but one case at both the acute and chronic levels.

In contrast, 72% (copper) and 22% (zinc) of the infiltrated water samples from the permeable systems were below the minimum detection limit (Table 1 and Fig. 4). Only one sample (from UNI Eco-Stone®) exceeded state levels for chronic toxicity for copper. Zinc concentrations were exceeded once for acute level and three times at the chronic level. Note that metal toxicity

Table 1
Mean concentrations of detected constituents from storm samples in 2001–2002 (1996 results from Booth and Leavitt [22] in square brackets). Nine storms sampled in 2001–2002; three in 1996

	Hardness (mg $CaCO_3$/l)	Conductivity (μmhos/cm)	Copper (μg/l)	Zinc (μg/l)	Motor oil (mg/l)
Infiltration samples					
Gravelpave2®	22.6	47	0.89 (66% <MDL)	8.23 (22% <MDL)	<MDL
	[20.3]	[63]	[1.9 (67% <MDL)]	[2.0 (67% <MDL)]	
Grasspave2®	14.6	38	<MDL	13.2	<MDL
	[22.8]	[94]	[21.4 (33% <MDL)]	[2.5 (67% <MDL)]	
Turfstone®	47.6	114	1.33 (44% <MDL)	7.7 (33% <MDL)	<MDL
	[49.4]	[111]	[1.4 (67% <MDL)]	[<MDL]	
Uni Eco-Stone®	49.5	114	0.86 (77% <MDL)	6.8 (33% <MDL)	<MDL
	[23.0]	[44]	[14.3 (33% <MDL)]	[7.9 (33% <MDL)]	
Surface runoff samples					
Asphalt	7.2	13.4	7.98	21.6	0.164 (11% <MDL)
	[6.1]	[17.0]	[9.0 (33% <MDL)]	[12]	

In parenthesis is the percent of samples that fell below detectable levels. Lead was not detected in 2001–2002 but was present in 5 of 15 samples in 1996; motor oil was not tested in 1996. <MDL = all samples below minimum detection limit. Minimum detection limits listed in text.

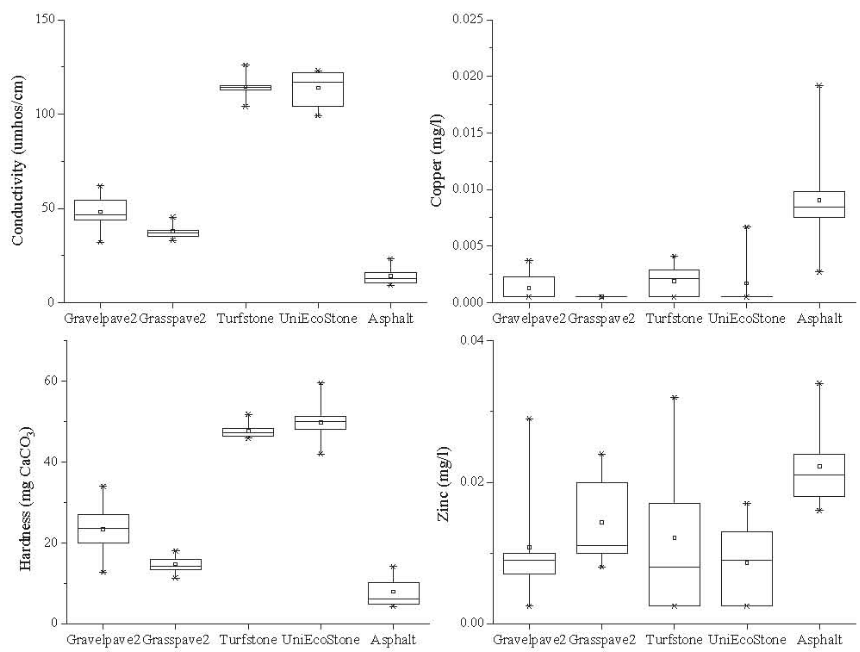

Fig. 4. A comparison of concentrations in composite samples from different paving surfaces collected from nine storms 2001–2002. Samples from permeable pavements were infiltrated water; samples from asphalt were surface runoff. The large box represents the 25th percentile, median, and 75th percentile; the whiskers represent the 5th and 95th percentiles; the small box represents the mean.

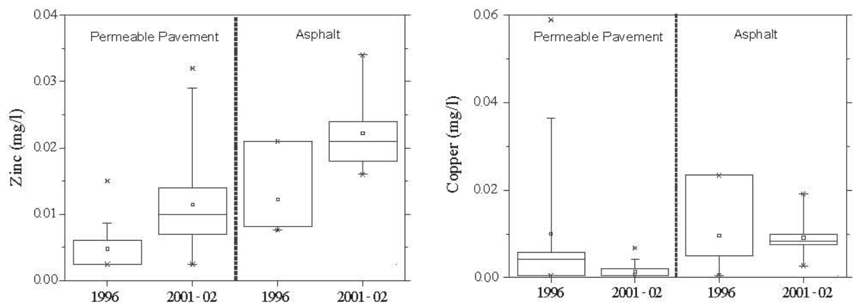

Fig. 5. A comparison of zinc and copper concentrations in samples collected in 1996 and 2001–2002. Concentrations for permeable pavement are averages of infiltrated samples from all four paving systems. For 1996, $n = 12$ from the permeable pavements and $n = 3$ from the asphalt runoff. For 2001–2002, $n = 27$ from permeable pavements and $n = 9$ from asphalt runoff. The large box represents the 25th percentile, median, and 75th percentile; the whiskers represent the 5th and 95th percentiles; the small box represents the mean.

criteria are determined not only by the concentration of the constituent but also by hardness—as hardness increases allowable concentrations for copper and zinc also increase [27].

5. Discussion

Surface durability, infiltration capacity, and water-quality performance of the tested permeable pavement systems all compared well, and in several regards extremely well, with the classic asphalt surface. Structurally, all permeable pavement systems in this study have held up to 6 years of daily usage. Two (Turfstone® and UNI Eco-Stone®) systems are apparently as durable as the asphalt surface under at least this magnitude and frequency of loading; the flexible plastic systems (Grasspave2® and Gravelpave2®) may have required additional maintenance under heavier or more frequent loads. Under the conditions here, however, the wear was minor and presented no impediment to use.

All four permeable pavement systems infiltrated virtually all precipitation, even during the most intense storms experienced during the study period. A larger parking area covered entirely by permeable pavement would almost certainly have sufficient uncovered areas to make up for any local saturation that may have occurred around individual cars.

While this study demonstrated long-term success for infiltration, it does not assure uniformly good performance everywhere. Pacific Northwest has generally low rainfall intensities. The highest rainfall intensity observed during the study was 7.4 mm/h. Our extremely positive infiltration results may not apply as well in other locales that receive higher rainfall intensities. The site itself was specifically chosen because of good underlying drainage characteristics, and so infiltration during extended storms would probably not be as effective in areas underlain with less permeable soils. Windblown dust or particulate matter washed off cars could also reduce permeability over time; we observed such deposits, but the infiltration capacity here has not fallen in consequence to levels approaching the rainfall intensities experienced (typically <5 mm/h).

The water quality results from this study demonstrate clear differences between the subsurface infiltrate and surface runoff from asphalt. For nearly all storms and constituents, water quality of the infiltrated water was significantly different than the surface runoff from the asphalt parking area. For both copper and zinc, infiltration of the stormwater had a dramatic effect on water quality (Table 1): toxic concentrations were reached in 97% of the asphalt runoff samples; but in 31 of 36 infiltrate samples, concentrations fell below toxic levels and in a majority of samples below even detectable levels.

The long-term degradation of water-quality performance may be a modest, but probably not problematic, phenomenon of permeable pavement systems (Fig. 5). Zinc concentrations in both permeable pavement infiltrate (Student *t*-test, $P = 0.002$) and asphalt runoff (Student *t*-test, $P = 0.01$) exhibited significant increases during the 6-year study period. Yet two of the systems, Grasspave2® (Student *t*-test, $P = 0.007$) and UNI Eco-Stone® (Student *t*-test, $P = 0.08$), showed simultaneous decreases in copper concentrations. Lead, present in a third of the 1996 samples, was not detected during the current survey. Conductivity and hardness remained relatively constant between the two studies.

These results suggest both positive and negative changes in runoff water quality after 6 years. Subsurface flow paths for this experimental system, however, were less than 10 cm, a far shorter path to groundwater tables than would occur in most field installations. Longer flow paths would presumably lead to greater attenuation of pollutant loads and a corresponding decrease in the potential for long-term groundwater impacts.

6. Conclusions

This study evaluated the performance of four permeable pavement systems from the perspectives of mechanical durability, infiltration, and water quality after 6 years of daily use. We found generally positive, and in several aspects very positive, performance in comparison to a traditional asphalt surface.

Runoff performance was very good. All four permeable pavement systems infiltrated virtually all precipitation, even during the most intense storms experienced during the study period. The water quality of the resulting infiltrate was significantly different from, and generally much better than, the surface runoff from the asphalt parking area. For both copper and zinc, the infiltrated stormwater usually had concentrations below detectable levels and, in all but four samples, below toxic levels; in contrast, these constituents had near-uniform toxic concentrations in the asphalt runoff. Motor oil was also consistently much lower in the infiltrate than in the surface runoff; hardness and conductivity were generally higher, and neither lead nor diesel fuel were detected in any sample.

Over a 5-year period, concentrations of some infiltrated constituents have increased while others have stayed the same or decreased. Zinc concentrations in both infiltrated and surface runoff exhibited marked increases; copper concentrations decreased substantially in two of the infiltrating systems. Lead was detected in one-third of the samples in 1996 but not in the present study; conductivity and hardness were relatively constant.

Despite these generally quite favorable results, uniformly good performance cannot be guaranteed everywhere. The experimental site has particularly favorable soil conditions, and rainfall intensities in the Pacific Northwest United States are typically quite low, masking any potential consequences of reduced infiltration of the surfaces over time. The study site had no weather conditions requiring snow removal or extended periods of sub-freezing weather, so this study is not a comprehensive evaluation of the suitability of such systems for all climate zones. Financial considerations, either the cost of installing permeable pavement systems or the cost savings from reduced stormwater management facilities, will play a major role in determining the feasibility of any given project. Despite these acknowledged limitations, we believe that these results provide clear indication of the value of permeable pavement systems and their long-term suitability for broad expanses of the built environment.

Acknowledgements

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Stormwater
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FEATURES

Green Roads: Research Into Permeable Pavers

Investigations of infiltration capacity, pavement leachate, and runoff temperature.

By William James

Polluted runoff from impervious road surfaces is a major source of environmental and aquatic degradation. Construction, roads, parking lots, and roofs play a role in reducing the natural ground cover and increasing the impervious area, leading to an accompanying rise in the volume of surface runoff. As a result of urbanization and the accompanying increase in impervious areas, the temperature of surface runoff during storm events increases. The mean summer monthly temperature of receiving water downstream also increases. Urban development often leads to wider channels and more surface ponds and, hence, greater exposure of stormwater to solar radiation, further increasing the runoff temperature. The increased impervious pavement and roofs also cause a decrease in infiltration and baseflow, which reduces the dilution of the heated stormwater runoff.

Methods to control the thermal enrichment of stormwater are becoming available, one of which is the use of permeable pavement, which for several reasons can help reduce the impacts of urbanization on receiving waters. Permeable pavers consist of interlocking concrete paving blocks separated by holes (pores) that are filled with soil and gravel. These pore spaces between the pavers allow infiltration of stormwater into a properly designed storage facility below the surface, reducing runoff volume.

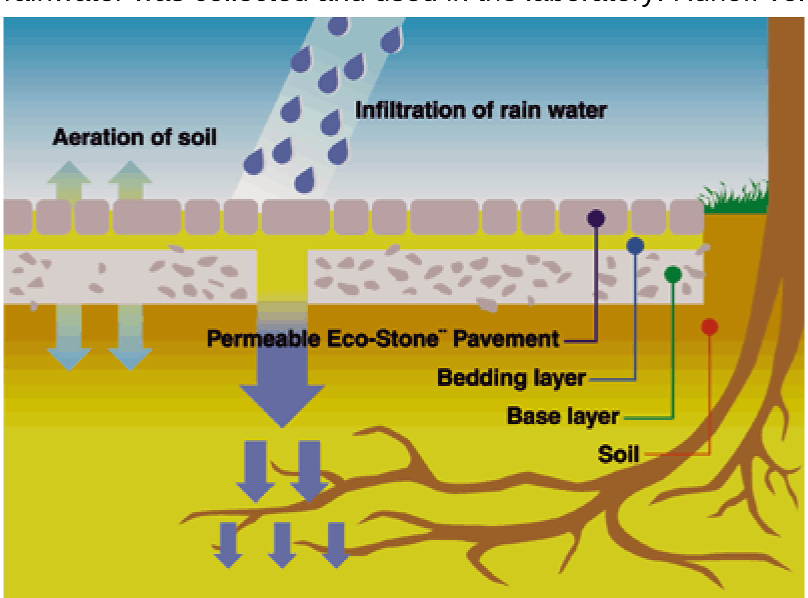
Permeable pavement helps reproduce the predevelopment hydrologic regime at urbanized sites. In reducing the runoff volume, the negative impacts of thermally enhanced stormwater on receiving waterways is also reduced. In achieving this benefit, the key is to provide and maintain a surface infiltration capacity, which allows an adequate volume of stormwater runoff to be captured by the facility and slowly drained away. Designing and constructing a system to provide appropriately high infiltration capacities that can be maintained over several years has proven to be challenging.

Previous Research

Since 1993, my research team at the University of Guelph–consisting of former and present graduate students Michael Thompson, Reem Shahin, Brian Verspagen, Chris Kresin, and Chris Gerrits–and I have been examining the performance of porous pavements versus impermeable pavements in connection with runoff volume, thermal characteristics, and pollutant levels. Experiments were conducted both on outside parking-lot test sites at the university and in a laboratory under controlled settings. In the case of the outdoor experiments, the permeable pavement was found to provide a 90% reduction in runoff volume and significantly cleaner water.

Permeable pavement can reduce the quantity of pollutants reaching receiving waterways because of increased infiltration as the porous pavement filters the stormwater through the pore spaces. This was confirmed with regard to pollution control in a parking lot and laboratory study I conducted with Michael K. Thompson in 1995. The purpose of the study was to compare the performance of four different pavement surfaces: asphalt, concrete brick, and 3- and 4-in.-thick concrete paver stones with infiltration cells. Sampling of runoff from both sets of four pavements was carried out, and the results were used to estimate the flux of 23 contaminants, including heat. For permeable pavers, UNI Eco-Stone was used and was found to significantly reduce surface runoff contaminant loads. Surface runoff was reduced, and pollutants were trapped in the permeable pavement.

In 1995 I conducted a laboratory investigation with Reem Shahin regarding pavement leachate. The purpose of the investigation was to determine the effect of free-draining porous pavement as an alternative to conventional impervious surfaces, independent of traffic and land use. The same four types of pavements were installed in the engineering laboratory at the University of Guelph. Real (acid) rainwater was collected and used in the laboratory. Runoff volume, pollutant load, and the quantity and quality of pollutants in water percolating through these pavements under different simulated rainfall durations and intensities were studied. We compared the results to data collected from four similar test pavements in the university's parking lot. In the study, most contaminants originated in the rainwater. As far as the pavement was concerned, the only contaminants of interest were phenols, pH, zinc, iron, and oils and grease. It was found that the pH of rain is a significant factor,



with asphalt providing the least buffering; that infiltrating pavers reduced both runoff and contaminants the most; and that asphalt reduced them the least.

Clogging of the pore space between the pavers has often been thought to reduce the infiltration capacity of permeable paving. In our tests, Verspagen, Thompson, Shahin, and I observed low surface runoff volumes from permeable concrete pavers; however, the laboratory samples were not influenced by wear or the deposition of particles in the pore spaces that will occur over time in an outside environment. Kresin tested the hypothesis that the infiltration capacity of permeable pavers decreases with age but that the infiltration can be regenerated. The tests were performed to determine whether infiltration capacities decrease with age and certain land uses and with increased compaction. It was found that infiltration capacities can be regenerated to some degree by street sweeping and/or vacuuming the surface. The research used data collected at several UNI Eco-Stone permeable concrete paver installations.

Verspagen conducted a study in 1995 to examine the thermal enrichment of surface runoff from impervious asphalt and porous concrete block pavement. Part of the research was conducted in a laboratory setting on pavement samples measuring about 1 x 1 x 0.5 m. Energy for heating the laboratory pavements was provided by either the sun or a 28,000-Btu radiant propane heater, and a rainfall simulator was used to generate thermally enriched surface runoff. Temperature studies comparing the asphalt surface and paving stones indicated that the asphalt surface reaches greater temperatures than the paving stone. However, the asphalt surface also cools faster. According to study results, the temperature of surface runoff from the permeable pavers was between 2ºC and 4ºC cooler than the surface runoff from the asphalt paving. In addition, the infiltration capacity of the permeable pavers significantly reduced the runoff volume, thus substantially diminishing the total heat content of the surface runoff.

Current Research

Currently, research is being conducted by Chris Gerrits on ways to regenerate the infiltration capacity of the permeable pavement. The main objectives of this study are to (1) determine the infiltration capacity throughout both high- and low-intensity traffic areas, (2) determine a relationship between the amount of cell material removed and the resultant increase in the infiltration capacity of the pavers, and (3) determine how the amount of volatile organic carbon in the cell material varies with depth in the high- and low-traffic areas and how it affects loss of infiltration capacity. Indications are that infiltration capacities can be readily regenerated. However, an engineering challenge ahead is to develop a system that can easily regenerate the infiltration as well as capture and treat the pollutants that were trapped in the open cells.

Design software (PCSWMM for Permeable Pavers) has been developed and is available for pavement and urban drainage designers. It is hoped that findings from this research will encourage designers, engineers, and planners of small urban areas, such as parking lots for shopping centers, to use alternative stormwater management practices, in particular pavement surfaces with environmentally sensitive thermal characteristics. Use of permeable paving surfaces in such locations would allow for a significant decrease in surface runoff volumes and decrease pollutant and temperature loading on receiving waterways. Methods of regeneration would allow regeneration of infiltration capacities, lengthening the life of the porous paving stones.

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Riparian Protection and Restoration: Road Design Techniques

*United States
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Corduroy Road Project

Background—Within the Chippewa National Forest boundary, the USDA Forest Service manages about half of the 1.6 million acres located at the headwaters of the Mississippi River. Water is abundant with over 1,300 lakes, 923 mi of river and streams, and 400,000 acres of wetlands.

The water table in this area is almost at ground level. The drop in elevation of the forest is about 250 ft from the highest to the lowest point. Approximately 75 percent of the land within the forest boundary is aquatic. Water movements throughout the forest are very slow and move through streams, lakes, and wetlands in a random order.

Problem— According to Forest Hydrologist Brenda Halter-Glenn, the Chippewa National Forest does not have the same water- and road-related issues as most forests where the road is falling or sliding into anadromous fish-filled streams. Researchers recognized the Chippewa's need for construction of a low-volume, low-standard road with a dry roadway, which maintained the hydrologic flow of ground and surface water.

Solution— The Minnesota Forest Resources Council (MFRC) developed Timber Harvesting and Forest Management Guidelines. One of the chapters, "Construction of Wetland Forest Roads," explains different techniques on how to construct roads over various materials. These guidelines can be downloaded from the MFRC website at www.frc.state.mn.us.

One technique, "Road Design for Peat Wetlands with Continuous Cross-Drainage," is practiced for crossing wetlands with peat soils greater than 4-ft deep. When no excavation or backfill is required, a corduroy technique is used.

To protect the woody rot mat on roadbeds that use geotextile fabrics, trees, and brush should be flush cut leaving unsaleable material in place. The first geotextile fabric should be laid loosely over the cut material with trees placed parallel to each other and perpendicular to the roadbed direction. The trees are then covered as needed with clean roadfill or gravel (figure 8).

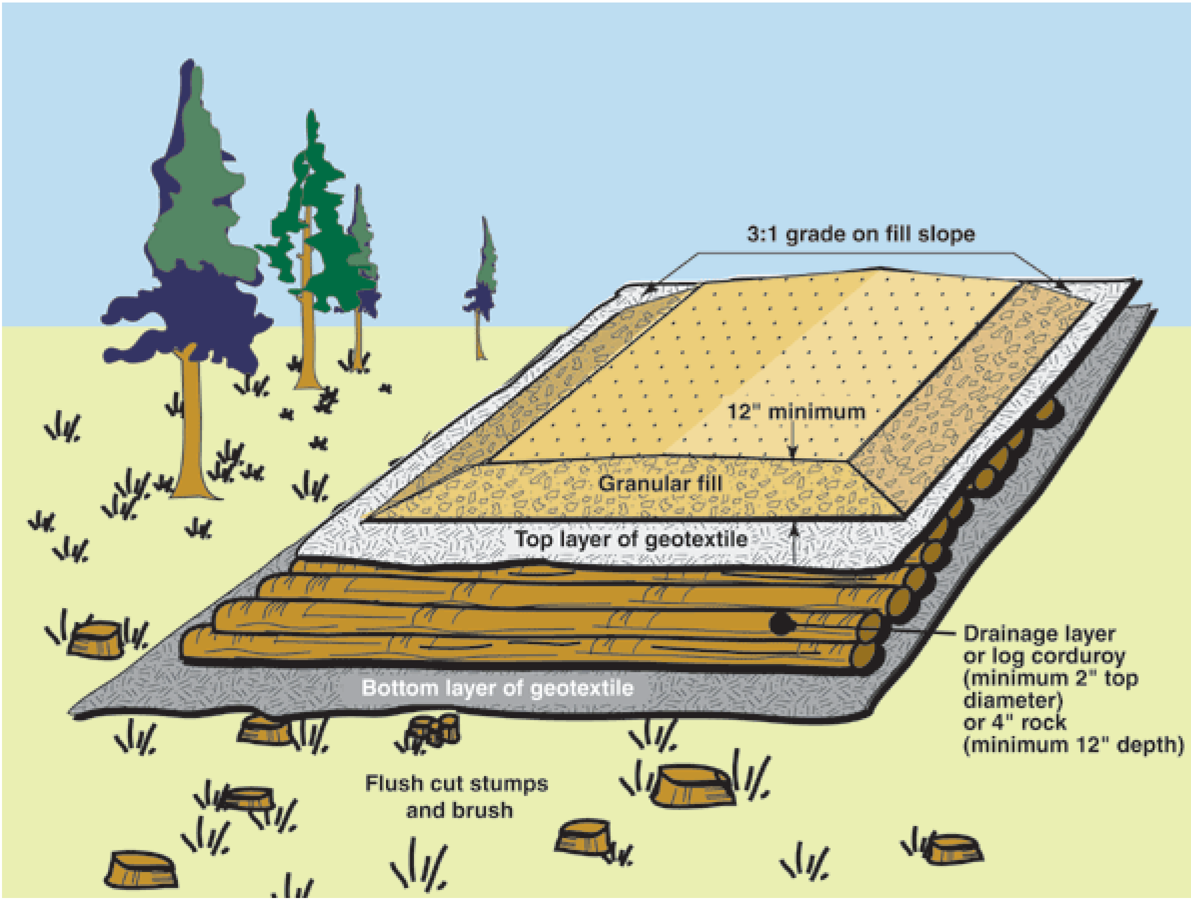


Figure 8—Road design for peat wetands with continuous cross drainage. drainage layers may be used as an alternative to culverts, or in combination with culverts, to provide adequate cross drainage.

If log corduroy is used for cross drainage, geotextile material should be applied above and below the corduroy (figure 9). If log corduroy is not used, other cross-drainage structures should be considered.

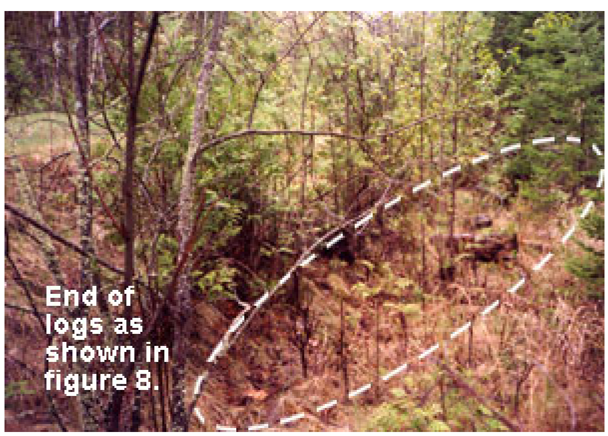


Figure 9—Log corduroy (selected area) was used for cross drainage on this road.

If improperly constructed, road failures can range from gradual sinking to a sudden loss of the road into the wetland. When such failures occur, the peat water flowing through the wetland is greatly disturbed, and large areas of flooding can result.

Cross drainage through the roadbed in a deep peat wetland is normally slowed or halted as a result of the compression of the peat layers from the road embankment, equipment rutting of the peat surface, or road failure. This can cause flooding on the upslope side of the wetland and drying on the downslope side.

Effective cross drainage, the main goal for all of these techniques, can be maintained by proper installation of a culvert and drainage layer. In all cases, the construction objective is to provide a stable road surface while maintaining free flow of water though the roadbed.

Results— In most cases this technique works well. The site shown is 20 years old and is still maintaining the free flow of water through the roadbed while providing a stable road surface (figure 10).

Figure 10—This road still maintains a free flow of water through the roadbed while providing a stable road surface.

Minnesota Forest Resource Council
Excerpt from:
Timber Harvesting and Forest Management Guidelines
http://www.frc.state.mn.us/FMgdline/2005guidelinesbook/FOREST%20ROADS.pdf

Crossing Deep Peat Wetlands

Crossing wetlands with peat soils greater than 4 feet deep can be done using special road construction methods that do not require excavation and backfill. These methods make use of geotextile fabrics, special embankment structures (such as lightweight road fills, extra-wide road bases or log corduroy layers), and the inherent strength of the underlying peat layers to resist slip failure and resultant road failure. (See Figure ROAD-14, page 36.)

Such failures can range from the gradual sinking to the sudden loss of the road into the wetland. When such failures occur, the peat water flow through the wetland is greatly disturbed, which can result in large areas of flooding.

These methods generally specify that a layer of geotextile be placed on the peat surface. Road fill is then placed over the geotextile. To provide additional strength and adequate cross-drainage, special materials such as log corduroy, wood chips or drainage rock may be added in the lower portion of the fill. (See Figure ROAD-14, page 36.)

The specific road structure needed depends on the strength of the peat layers below the road. The determination of shear strength is critical in designing a sound, safe and economical road crossing. The landowner or resource manager is strongly advised to consult a registered civil engineer to accurately determine shear strengths, conduct field testing and provide design specifications.

Some deep peat wetlands with peat layers that are too weak to support a roadbed will require traditional excavation and backfill methods. Because of the high cost of traditional construction methods, as well as environmental effects, it is best to avoid building on these weak peat wetlands.

Cross-drainage through the roadbed in a deep peat wetland is normally slowed or halted as a result of the compression of the peat layers by the road embankment, equipment rutting of the peat surface, or road failure. This can cause flooding on the upslope side of the wetland and drying on the downslope side.

Cross-drainage can be maintained by the proper installation of culvert and drainage layers. In all cases, the construction objective is to **provide a stable road surface while maintaining free flow of water though the roadbed.**

The following techniques can prevent or minimize impacts to deep peat wetlands:

✔ **Construct road embankments across wetlands** with deep peat subsoils when the peat is frozen. Construction on frozen peat avoids rutting and other damage of the topmost root mat layer, which normally contains considerable shear strength. Such damage can greatly reduce the strength of the upper peat layers and reduce the ability of the wetland subsoils to hold up the weight of the roadbed and vehicle loads.

✔ **Install culverts that are a minimum of 24 inches in diameter** buried halfway below the soil surface. The upper half will handle surface storm flows, and the lower half will handle everyday subsurface flows. Failure to bury the lower half of the culvert will cause subsurface water to pond on the upstream side of the road and kill trees. See Figure ROAD-16, page 39.

✔ **Maintain a separation** between the toe of the embankment fill slope and the ditch when constructing ditches parallel to the roadway. The separation distance should be at least three times the depth of the peat, which will prevent or minimize disturbance of the inherent strength of the top layer of peat containing the root mat. See Figure ROAD-15, page 37.

✔ **Provide ditches to facilitate flow** into and out of culverts.

✔ **Construct ditches using flotation devices** (such as timber mats) or schedule construction to occur during frozen conditions, to prevent or minimize impacts on wetlands and minimize damage to construction equipment.

✔ **Obtain professional engineering advice** on design of cross-drainage ditches for permanent roads across deep peat wetlands.

Specific design techniques for crossing deep peat wetlands

Roadbeds that use geotextile fabrics should be prepared to protect the woody root mat by flush-cutting trees and brush and leaving non-merchantable material in place. The first geotextile fabric should be laid loosely over the cut material. Then proceed with one of the following three wetland road construction techniques:

Technique #1: Corduroy

• Place trees parallel to each other, side by side and perpendicular to the roadbed direction

• Cover as needed with clean road fill or gravel.

• If log corduroy is to be used for cross-drainage, apply geotextile both above and below the corduroy. If log corduroy is not to be used for cross-drainage, other cross-drainage structures should be considered. See Figure ROAD-14, page 36.

Technique #2: Rock drainage layer

• Place 12 inches of rock (4 inches or less in diameter) over the geotextile, followed by another layer of geotextile. The rock layer will settle into the top 12 inches of the wetland, providing the pore space for water passage through the roadbed.

• Place clean road fill or gravel on top (typically 18 inches deep).

Technique #3: Lightweight road fills

Lightweight materials may be incorporated into the core of the road embankment fill to lessen the total weight of the road embankment when constructing on weak peat wetlands.

Lightweight materials include wood chips and sawmill residues, among other materials. Materials with known potential to leach toxic substances (such as construction debris, treated wood, tires, asphalt or other petroleum-laden materials) are not suitable for use.

• Place the lightweight materials over the fabric to form the core of the road embankment fill, followed by another layer of geotextile fabric over the lightweight materials.

• Cover the core with at least 18 inches of granular sand or gravel road fill.

• Install culverts and ditches, if necessary, to pass surface and subsurface waters through the road embankment. See Figure ROAD-15, page 37.

Crossing Wetlands in Winter

Roads across wetlands or seasonal ponds are often designed to take advantage of frozen ground conditions. The following guidelines apply to design of roads across all wetland types.

✔ **Plan the layout to maximize operating efficiency** and minimize site disturbance.

✔ **Select the shortest routes practical** that minimize potential problems with drifting snow and the crossing of open water.

✔ **Tramp and pack the wetland area wider than needed** for the driving and working area if sufficient frost is not present. This additional space will allow for turnouts, snow removal and parking.

✔ **Avoid crossing open water or active springs.** If unavoidable, temporary crossings are preferred. These can be ice bridges, temporarily installed bridges or culverts, or timber mats.

✔ **Avoid using soil fill.**

✔ **Install all structures that block water flow** so that they can be easily removed prior to breakup. If the streams are navigable or require a DNR permit to cross, removal may be necessary at the end of each winter of operation, not just at the end of the timber contract.

✔ **Use planking, timber mats or other support alternatives** to improve the ability to support heavy traffic where conditions are inadequate to stay within the stated guidelines. If removal would cause more damage than leaving them in place, these areas may be left as permanent sections on frozen roads.

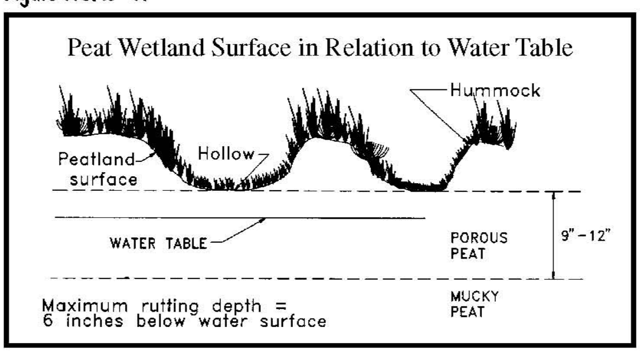
✔ **Anchor temporary structures at one end** to allow the structure to move aside during high water flows.

✔ **Avoid clearing practices that result in berms of soil** or organic debris building up on either side of the road clearing. Such berms can disrupt normal water flow.

✔ **Provide adequate filter strips** near open water. See *General Guidelines: Maintaining Filter Strips* and *General Guidelines: Managing Riparian Areas.*

✔ **When rutting exceeds 6 inches in depth** for continuous distances greater than 300 feet on any portion of the road, cease equipment operations on that portion of road. Resume operations only when conditions are adequate to support equipment. This practice will minimize blockage of cross-drainage and prevent or minimize down-road channelization. See Figure ROAD-17.

Figure ROAD-17



The water table (solid line) is near the bottom of the hollows (upper dotted line). Operations should stop when ruts reach 6 inches below the water table or 6 inches below the bottom of the hollows, whichever is lower. Peat is usually still porous 9 inches below the hollows, and ruts will heal in 2 to 3 years. Deep ruts (more than 12 inches below the hollows) will bring up well-decomposed, mucky peat and may take more than 20 years to heal.

MAINTAINING AND CLOSING ALL FOREST ROADS

➤ **IMPORTANT! Review General Guidelines:**

➔ Post-Operational Activities and Followup Visits

Maintenance Measures for All Roads

✔ **Clean debris from culverts,** ditches, dips and other structures as needed to diminish the danger of clogging and the possibility of washouts. Any debris should be placed away from the watercourse and stabilized, if necessary.

✔ **Restrict use of roads** during times when the road is especially susceptible to damage, including wet periods and spring breakup.

Maintaining Active Roads

✔ **Fill in ruts and holes that develop** during road use. Use a suitable material (such as gravel or compacted fill), and fill as soon as possible to reduce the potential for erosion.

✔ **Grade road surface periodically** to maintain proper surface drainage and eliminate small wheel ruts.

✔ **Minimize berms along the edge of the road** that will trap water on the road surface. Feather material out on the road surface.

✔ **Minimize entry of dust control agents into water.** For example, do not apply an excess of chemicals to the road that could potentially be transported to surface water through erosion and surface runoff.

✔ **Do not treat roads with calcium chloride** as this chemical causes physiological distress for amphibians crossing them.

✔ **Implement stabilization methods** so that the shape, slope, elevation and contours of archaeological sites and other cultural features are preserved. Stabilization should not alter the historic character of the cultural resource.

✔ **Avoid impacting cultural resources** within existing road corridors when reconstructing or maintaining forest roads. Management options include the following:

- Limit or eliminate maintenance (including regrading or widening) in or near cultural resource areas.
- Use "fill only" techniques to improve roads that cross subsurface cultural resources.
- Reroute roads that cross cultural resource areas.

Closing Inactive Roads

✔ **Remove flagging, signs or other markings in cultural resource areas** after road closure, except in those cases where signs are appropriate long-term protection or interpretation tools. These items are indicators that cultural resources are present and may lead to looting.

✔ **Remove temporary fill and structures** to the extent practical when use is completed.

✔ **Close or obliterate temporary forest access roads** after management activities are complete if continued access might result in damage to endangered, threatened and special concern species (ETS species), sensitive communities, cultural resources or water features. If temporary roads will be obliterated, earthwork should be confined to the road corridor.

✔ **Provide appropriate access control** to minimize unauthorized traffic during use and especially after completion of activity.

✔ **Ensure that the road surface is in stable condition** when the road is closed. When closing the road, there are two particularly important aspects to closure and stabilization for inactive roads.

Seeding forest access roads after completion of use provides multiple benefits, including stabilizing the road and protecting it from erosion, and providing food and cover for wildlife. Seeding also eliminates negative visual impacts. *Photo courtesy of Minnesota DNR*

These are: 1) stabilizing surfaces to minimize erosion and sedimentation to water, and 2) stabilizing and maintaining road surfaces to provide for future access.

Seed and fertilize disturbed surfaces as necessary. To facilitate regeneration, back blade or otherwise scarify roadbeds where appropriate. Use native grass or forb mixes if available. For sources of recommendations for seeding and fertilization, see *Resource Directory*.

For temporary closure:

✔ **Control access** to minimize maintenance requirements.

✔ **Install appropriate drainage structures** as necessary and maintain in working order.

✔ **Place a barrier to traffic,** and post "Road Closed" signs at the beginning of the road when closing roads.

✔ **Provide periodic inspection and maintenance** of road surfaces as necessary.

Figure ROAD-18

Barriers to Traffic

For permanent closure:

✔ **Place a barrier to traffic**, such as a berm, and post "Road Closed" signs at the beginning of the road when closing roads. See Figure ROAD-18.

✔ **Place water bars** where necessary. See Figure ROAD-11, page 30.

✔ **Remove structures** that would require continuing maintenance (such as culverts and bridges) even after a road is abandoned.

✔ **Reshape stream crossings** to approximate original channel contour when removing water crossing structures, and stabilize the structure site.

✔ **Provide breaks in extended fills** in flood-prone areas at intervals no greater than 300 feet to accommodate high flows and debris.

Providing appropriate access control eliminates motorized vehicle use (which can lead to erosion) while also encouraging hunters and hikers. *Photo courtesy of Itasca County Land Department*

ABOUT THE TEAM

The Eastern Connecticut Environmental Review Team (ERT) is a group of professionals in environmental fields drawn together from a variety of federal, state and regional agencies. Specialists on the Team include geologists, biologists, foresters, soil specialists, engineers and planners. The ERT operates with state funding under the supervision of the Eastern Connecticut Resource Conservation and Development (RC&D) Area — an 86 town region.

The services of the Team are available as a public service at no cost to Connecticut towns.

PURPOSE OF THE TEAM

The Environmental Review Team is available to help towns and developers in the review of sites proposed for major land use activities. To date, the ERT has been involved in reviewing a wide range of projects including subdivisions, landfills, commercial and industrial developments, sand and gravel excavations, active adult, recreation/open space projects, watershed studies and resource inventories.

Reviews are conducted in the interest of providing information and analysis that will assist towns and developers in environmentally sound decision-making. This is done through identifying the natural resource base of the project site and highlighting opportunities and limitations for the proposed land use.

REQUESTING A REVIEW

Environmental reviews may be requested by the chief elected official of a municipality and/or the chairman of town commissions such as planning and zoning, conservation, inland wetlands, parks and recreation or economic development. Requests should be directed to the chairman of your local Conservation District and the ERT Coordinator. A request form should be completely filled out and should include the required materials. When this request is reviewed by the local Conservation District and approved by the ERT Subcommittee, the Team will undertake the review on a priority basis.

For additional information and request forms regarding the Environmental Review Team please contact the ERT Coordinator: 860-345-3977, Eastern Connecticut RC&D Area, P.O. Box 70, Haddam, Connecticut 06438, e-mail: ctert@comcast.net