Grassy Swales To Control Highway Water Quality Runoff

STUART M. FINLEY AND G. KENNETH YOUNG

The authors propose grassy swales for roadsides for new or upgraded highway facilities to provide water quality benefits. The proposal applies to state and local agencies responsible for highway infrastructure development, restoration, and maintenance. The concept is to incorporate grassy swales into land development street design and into highway repair activities. Vegetated side ditches are known to provide significant suspended solids and phosphorus reductions. Within urban to suburban developments, the tendency has been to require relatively expensive curb-and-gutter street cross sections from developers. Curbs and gutters concentrate storm flow and its suspended sediments, including phosphorus, and this contributes to non–point source pollutant loadings from developed areas. Providing grassy swale shoulders with underground storm drains to pick up flows that are on erosion thresholds may be an attractive alternative for new projects or for curb and gutter replacement if right-of-way costs are not a major factor. Concentrated flows would be slowed and subject to sediment deposition in swales. Highway, road, and particularly local street developments could cost less, be more attractive, and provide water quality benefits for nutrient and suspended solids removal with the use of grassy swales.

The objectives are to propose and justify the use of grassy swales as the preferred method of handling pavement drainage. Rural highway and road systems typically have such vegetated side treatments, but other systems—including Interstate, federal aid, and local streets in settled areas—are usually designed with paved ditches or curb-and-gutter systems, both with possible storm sewers, to accept pavement drainage and to cope with erosive velocities.

Consider Fairfax County, Virginia, as a well-organized example of a densely settled, nonincorporated region of 1 million inhabitants. The county's public infrastructure, including streets and drainage, has been installed by land developers who must comply with local regulations (*1*). These regulations are included in a county public facilities manual that provides comprehensive street and drainage design details. The local regulations are in accordance with Virginia Department of Transportation (VDOT) (and hence federal) design standards (*2,3*) and with the county zoning ordinance. Taken together, the federal and state design standards and the local zoning requirements led to developments in Fairfax County that provide curb-and-gutter streets for densities greater than one dwelling unit per acre. Also, most development occurred in the last half of the 20th century and can be expected to need repair and replacement during this generation.

This documented pressure in Fairfax County to give curb-and-gutter sections to local streets in highly populated regions is believed to be typical of urban and suburban developments across the country and to apply to higher-class road facilities as well. The influence is seen to be widespread and has resulted in an existing urban and suburban street system infrastructure that efficiently drains pavement and quickly moves the runoff away from the roads and developments. Pollution prevention was not a past concern. Road infrastructure generally preceded the nation's pollution control system (Pub. L. 92-500). Massive inputs of public money developed both. Now it appears that pollution control and road development policies may interact as we close out the 20th century.

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The initial mid-century focus of pollution control was the collection and purification of sewage and industrial wastes—the so-called point sources. As this effort resulted in more and more success, the focus has now shifted. The present end-of-century focus is the control of the pollutants contained in land washoff—the so-called non–point sources (NPS). The control of NPS has led the federal government to expand the National Pollutant Discharge Elimination System (NPDES) to include the discharge from storm sewers. Jurisdictions are engaged in acquiring federal permits for their stormwater systems. The policy is clear: reduce NPS. Specific methods to implement the policy are in a state of flux and are being defined as part of the process of implementing the policy. State highway departments are engaged in these efforts.

Why highway departments? Because pavement drainage collects pollutants and may be considered to be an NPS. Regulators are looking for ways to control NPS, the term "control" meaning to impose best management practices (BMP) to runoff. BMP is a term that originated in a farming context and applied to the minimization of soil loss and the efficient use of agricultural chemicals, fertilizers, and pesticides to avoid their loss to runoff waters. The BMP concept translates to urban settings with the following practices: zoning modifications, detention ponds with or without permanent pools (wet or dry), intermittent wet ponds (extended detention), infiltration pits, grassy swales, biofiltration swales, buffer areas, and street cleaning.

The concepts espoused herein are

1. Pavement systems transport NPS pollution deposited on them by the NPS contributions of adjacent property.
2. Sooner or later, policies will develop to use highway BMPs to mitigate NPS.
3. Infrastructure maintenance and repair affords an opportunity to supply BMPs.
4. Future development can be reregulated so that new construction includes appropriate BMPs.
5. A very promising BMP is the grassy swale.

6. The grassy swale has technical and policy barriers to implementation in urban settings where it would be beneficial as a BMP.

The benefits of grassy swales are that they remove silts and fines from the stormwater; they do so by slowing the flow and allowing deposition to occur. Not only is a portion of the suspended solids removed, but the phosphorus that is sorbed to soil fines or is in a precipitate state is removed. The removal of phosphorus is beneficial ecologically and is the subject of additional regulation in regional settings.

For example, the states that drain into the Chesapeake Bay have agreed to a policy to remove 40 percent of the nutrients to the bay using BMPs. This is accomplished with buffers, swales, detention ponds, and the like being applied to development and redevelopment. Legislation has been enacted to achieve this policy in Virginia (*4*).

Another example is the provision of "ecology ditches" by Washington State Department of Transportation to respond to the Puget Sound regional planning manual (*5*). Puget Sound, like the Chesapeake Bay, is being managed to control phosphorus inputs. The ecology ditch is a biofiltration swale that, in the context of this paper, is a grassy swale with an underdrain, bedded in porous backfill, that provides biotic action on the storm waters. In the Puget Sound manual, the term "biofiltration" describes the more-or-less simultaneous processes of filtration, infiltration, adsorption, and biological uptake of pollutants in storm water that takes place when runoff flows over and through vegetated treatment facilities.

This paper discusses adapting the geometrics of 50-ft rights of way, typically found in urban and suburban settings, to the incorporation of swales. The principal reason for considering grassy swales is to acquire water quality benefits for street projects. A major hurdle is that with any topographic relief, streets achieve grades that cause road-side drainage to flow with erosive velocities; thus the erosion issue requires more detailed roadside design considerations.

GRASSY SWALE CROSS SECTIONS

The typical curb-and-gutter cross section for areas with high population densities is shown in Figure 1 for a 50-ft right of way. There is a minimum of 30 ft from curb to curb for two traffic lanes. The gutters are extended from the curbs with a 1 to 2 percent cross slope. Curb, grate, or combination inlets admit the pavement drainage to storm sewers. The water is quickly removed, and velocities in the gutters and storm sewers are sufficient to transport suspended materials. A design criterion of typical storm sewers is to ensure sufficient velocity, typically greater than 1 ft/sec, to transport any suspended particles and to avoid deposition.

Alternatively, Figure 2 presents a ditch section cross section with a 50-ft right of way. The site treatments for this design are paved ditch, grassy swale, or earthen ditches, depending on erosive stability. This ditch section can also have underground storm sewers to pick up surface water before it floods the traveled way or achieves erosive velocities.

Within the present regulations in Fairfax County, Virginia, the ditch section would be acceptable only if zoning was a density of one dwelling unit per acre or less. This is a local requirement—VDOT enables ditch sections across the board but the county opted for a more stringent standard. Ditch cross sections require load-bearing shoulders for parking. Paved ditches would be provided when flow velocities in the side channels become erosive. Unless the street is nearly flat, paved ditches tend to prevail over grassy swales or earthen ditches.

Curb, gutter, paved ditch, and storm drain calculations can be accomplished using the HYDRAIN computer system (*6,7*). Key design elements are inlet spacings to avoid gutter spread, types of inlet, and sizing of storm drains.

For streets with mild grades, the ditch section shown in Figure 2 reduces to the alternative grassy swale section shown in Figure 3. Because erosive velocities are avoided with flat or nearly flat grades, the side drainageways can be vegetated ditches. Such ditches move water slowly, so particles have opportunity to settle out. Keeping suspended solids in the side ditches provides benefits to water quality.

Technical difficulties that arise with the grassy swale section are those of keeping velocities low and removing water when the ditch fills up. A secondary issue is the integration of a shoulder into the swale that will support parked vehicles. However, if the technical difficulties can be overcome, the more widespread use of grassy swales in new and retrofit situations will provide a BMP to address the NPS concerns associated with pavement drainage.

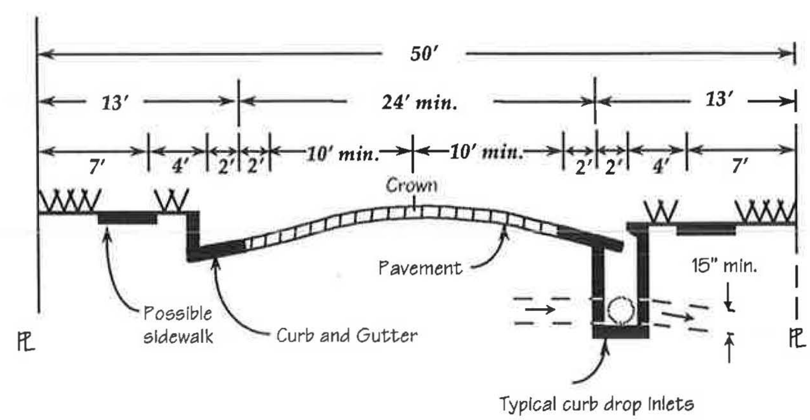


FIGURE 1 Cross section of typical urban local street, curb-and-gutter section (not to scale).

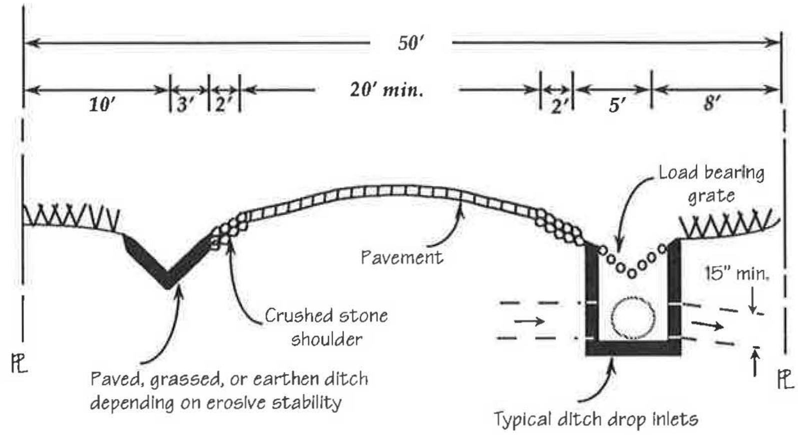


FIGURE 2 Cross section of typical urban local street, ditch section (not to scale).

The design of roadside channels having dirt, grass of various types, and riprap is also facilitated by HYDRAIN (*8,9*). Tractive force theory is used to size swales and grades to avoid erosion and to promote deposition. This latter design objective—the encouragement of siltation in roadside channels, in other words—is new. However, reflection indicates that a design to avoid erosion is also a design to encourage deposition. Furthermore, a new set of design concepts is needed to extend the grassy swale cross section from mild street grades to steeper grades in order to achieve more widespread benefits for water quality.

Consider the journey of NPS silt and pollutants in surface washoff. The NPS materials are added to the drainage from the pavement, roadsides, and adjacent property. They proceed in roadside conveyance channels (gutters and paved or unpaved ditches) to storm inlets and then to the storm sewer itself. The sewer outfall moves the NPS materials to downstream receiving waters and may damage them or their riparian property owners.

The objective is to reduce the NPS materials, which is what a BMP does. Grassy swales can retain NPS material near to the location where it starts its journey. It seems reasonable to let it settle out there before it accumulates and becomes a progressively larger amount within a converging storm water pipe system. The chore of maintaining swales becomes one of cleaning, regrading, and reseeding ditches and not one of maintaining detention ponds or other downslope facilities, which may require costly space that the right-of-way engineer must acquire.

DISCUSSION OF DESIGN DIFFICULTIES

Consider a parabolic grassy swale with a ½-ft depth at a full width of 15 ft. Such a swale could be provided on both sides of a ditch section street with 50-ft right of way. Figure 4 shows slopes calculated by HYDRAIN that are possible for this swale at various nonerosive velocities. At a 3 percent grade, the swale can convey 3.5 ft^3/sec at a nonerosive velocity of 0.7 ft/sec. Once the swale fills up or achieves erosive velocities, a stormwater pickup to a storm sewer is needed.

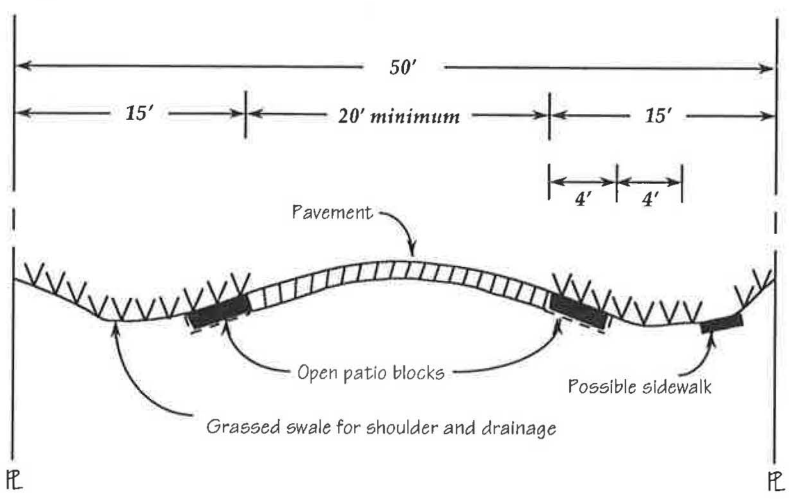
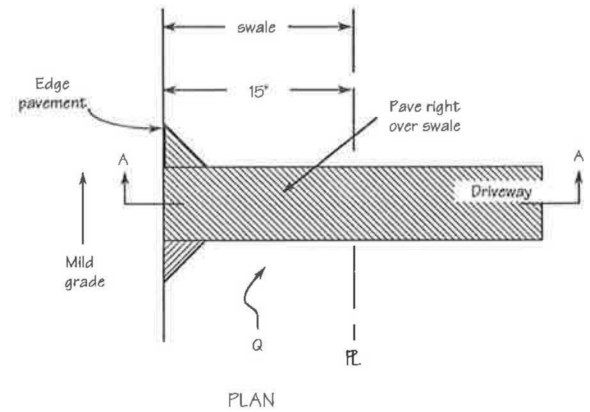
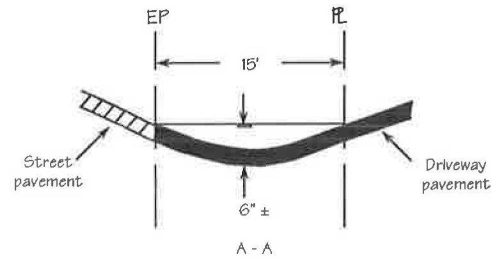


FIGURE 3 Cross section of grassy swale roadside improvement (not to scale).





S Swale Slope	Q (cfs)	V (f/s)	Non-errosive
.5%	.35	.07	yes
1%	.5	.1	yes
2%	.9	.23	yes
3%	3.5	.71	yes
>3%	--	--	no

(Mowed established grass)
Parabolic Full Swale Capacity (15′ by 6″)

FIGURE 4 Design concepts for mild grades (under 3 percent) (not to scale).

The individual properties along the street can provide driveways right across the swale. This is shown in Figure 4, as well. The swale would be vegetated and mowed; it probably would integrate into the landscaping of residential property.

A problem with grassy shoulders is a need to maintain vehicle loads. When wet, grassy areas with clayey soil soften and become rutted. To provide adequate bearing and avoid rutting, patio blocks, such as shown in Figure 5, can be placed next to the pavement at the roadside edge of the swale. Their open structure can be filled with sandy soil and grass planted on top. Such open concrete blocks would have to be placed on select material to avoid differential settlement. Whoever performs the ditch-side maintenance to remove accumulated silt must take care to not dislodge the blocks.

Steeper grades than the 3 percent shown in Figure 4 will cause roadside channels to have erosive velocities if the channels have the same slope as the street grade. Therefore, the channel slopes must be maintained at a 3 percent or lower slope even if the road grade is higher. How? One approach is to break the swale grade at driveways. The driveway can serve as a "check dam" that lets the water drop using a drop inlet and a culvert. Figure 6 shows a schematic of the concept. The swale runs at a slope of 3 percent or less to a drop inlet to a culvert under the driveway. Water exits the culvert on a new invert elevation adjusted to enable the carrying of the swale slope along at less than 3 percent.

The exit end wall could be an obstacle in the traveled way—that is, it might be a safety hazard to errant vehicles. If needed, safety bars can be provided that will protect vehicles and not cause significant hydraulic consequences.

Water in a swale could accumulate to sufficient quantities to overtop the edge of pavement and spread into the traveled way. This situation can be handled by switching from a series of drop inlet and culvert systems to a storm drain beneath and parallel to the swale. Inlets would be provided above driveway entrances as with the culvert scheme and would drop water in excess of what the swale can hold into the storm sewer.

The grassy swale design alternative would provide water quality benefits for highway and street systems: street and adjacent property wash-off would go through grassed swales. Cost savings would accrue because of the deduction of curb-and-gutter costs from projects. Cost increases would be attributed to specialized driveway entrance designs, careful grading, and provision of bearing blocks for shoulder parking. Added costs would be sensitive to topography: steeper grades would necessitate more extensive measures to keep swale grades under 3 percent.

To sum up, the balance of costs is unknown; there would be some savings and there would be some costs. Design of roadside treatments would be more tedious; design costs would increase to accommodate the tedious roadside ditch details and grading plans.

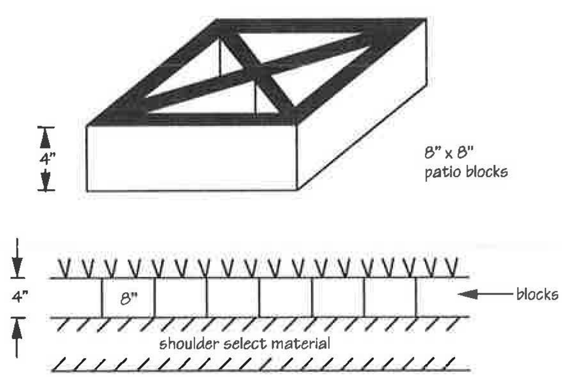


FIGURE 5 Parking support using open concrete blocks: *top*, system to allow turf to grow in swale and to bear load of parked vehicles using open concrete patio blocks; *bottom*, open concrete blocks filled with sandy soil.

PRELIMINARY REACTIONS

The Lake Barcroft Watershed Improvement District (WID), an agency of Virginia's Soil and Water Conservation De-

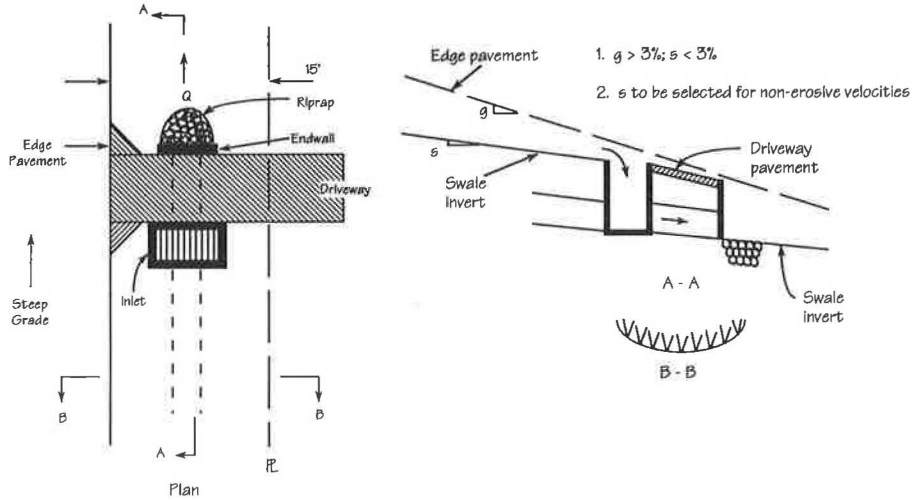


FIGURE 6 Design concepts for steep grades (over 3 percent) (not to scale).

partment, embraces the concept. The WID manages a large real estate lake and receives suburban drainage conveyed through public streets and state highway department and county storm sewers. Its view is that public agencies and state highway departments are expected to carry an inordinate portion of the costs of controlling storm water compared with the revenue from those who yield storm water flows.

The WID sees storm water as the vehicle that carries all the pollution and debris from upstream areas to the lake over which it has oversight. Individual property owners have roofs and pavements that deny infiltration and water retention and instead concentrate the storm waters and rapidly pass them on. The local resident is not required to do anything: retard flow, remove debris, control erosion, or husband lawn chemicals.

With grassy swales, the WID sees many benefits:

1. Debris would be retained in the grassy swales and not make it to the lake.
2. The grassy swales would become integral portions of property owners' front yards; owners would mow and maintain the swales to keep up appearances.
3. The frontage throughout the WID property owners' area would transform from a mixture of ditches, gutters, and swales to a uniform, grassed shoulder appearance if a retrofit program were implemented.

The WID sees the proposed solution as a reversal of the usual practice of shunting everything downstream. Instead of curbs and gutters, the WID desires a more attractive system of grassed swales along the edges of residential streets. Instead of rushing downstream, storm water would linger momentarily near where the raindrops fell. Some would seep into the underground water table. Another portion would temporarily pond and then flow off gradually after the storm. In both cases, at least a portion of the pollution would stay put. To shift costs to their source, the homeowner would have to rake the leaves and other debris and put it in the solid waste disposal system. But this is fair since not only would the owner acquire a large, neat, attractive frontage, but the owner is the one who contributed the debris originally.

The authors presented the grassy swale concept to the Virginia Lake Management Association in April 1992, and the lake manager for Lake Monticello, near Charlottesville, Virginia, composed a poem that expresses local reaction. John Aker, of Palmyra, Virginia, entitled the poem "Swales of Grass"; it is provided in Appendix A.

The authors have met with local government officials and state highway personnel. Preliminary discussions indicate considerable resistance to new standards—bureaucratic inertia being what it is, this reaction is hardly noteworthy. However, there is a clear need for code revisions with respect to zoning. A broad interpretation of state highway department standards indicates that grassy swales are acceptable within a cross section. The institutional difficulty will be in revising the local ordinances to allow such cross sections in ½-acre and higher densities and to develop detailed engineering standards to go with code revisions. This discussion, of course, pertains to Northern Virginia, but it is probably representative of other urban and suburban institutional settings as well.

Another indication of the impacts of BMPs is the localities' concern about maintenance. This parallels the concerns of state highway departments. Once facilities are provided, there will be a long-term need to maintain them. An example of the maintenance concern is a manual prepared by the Rappahannock Area Regional Planning District, Fredericksburg, Virginia, that offers guidance to municipalities on standards for construction of BMPs to minimize maintenance and estimates of what to expect in terms of maintenance needs (*10*). With grassy swales being an integral and prevalent aspect of highway and road cross sections, maintenance would be directed at removing silt and managing vegetation as needed. For large highway facilities, state highway workers or "adopt-a-highway" organizations would perform routine maintenance. For local streets, homeowners could play a role.

ENVIRONMENTAL BENEFITS

On the basis of literature research and measurements compiled by the Washington Metropolitan Council of Governments (*11*), the Chesapeake Bay regulations within the state of Virginia tabulate (*12*) phosphorus removal efficiencies. The Chesapeake Bay Preservation Act considers phosphorus to be the target nutrient for control of the ecologic response of bay coastal waters. This attitude is typical across the country for drainage to all lakes and coastal waters, and NPS local controls and regulations are likely to be oriented toward phosphorus. The average efficiencies of phosphorus removal are 10 to 20 percent for grassy swales and 40 percent for vegetated buffers (100 ft wide). Phosphorus carried in storm waters is about 50 percent soluble and 50 percent affixed to sediment. Thus, if the sediment can be settled out and removed, up to about 50 percent of the phosphorus in storm flows can be eliminated physically by settling. This physical removal of sediment and affixed phosphorus by deposition in swales and natural buffers is the benefit of using vegetated swales to collect pavement drainage. Field measurements in local settings would quantify water quality benefits and refine values in the literature.

Thus, the conventional wisdom of the benefit of swales and natural buffers is 10 to 40 percent phosphorus removal with 50 percent as an upper limit. This level of BMP effectiveness is clearly desirable to protect downstream receiving waters from being overfertilized with plant nutrients that cause eutrophication. Downstream streams, lakes, and coastal waters would all benefit from phosphorus reduction. And although the primary focus is phosphorus reduction, downstream silt loads would also be reduced. Siltation in downstream rivers, lakes, and estuaries would be decreased, reducing maintenance and possible dredging and preserving riparian property values.

CONCLUSIONS

1. Grassy swales as highway and street side channels convey pavement drainage and function as a best management practice to reduce NPS pollution.
2. Benefits of grassy swales are reduced phosphorus and silt loadings to receiving waters—stream, lakes, coastal zones—and reduced costs associated with the elimination of curb and gutter and paved ditches.
3. Costs of grassy swales include more detailed design of roadside drainage and driveway features to keep swale invert slopes under erosion thresholds.
4. Maintenance of grassy swales includes removing silt and managing vegetation. Silt and debris reductions in swales should save costs associated with reduced maintenance for storm drains, which clog when transporting debris loads. Adjacent property owners can also be expected to provide maintenance to maintain appearances.
5. Technical difficulties of grassy swales are as follows:
   - Maintaining mild side ditch drainage slopes when street grades are high;
   - Providing drop structures at driveways to break and restart mild ditch slopes;
   - Making structures, inlets, and end walls safe for traffic, if warranted; and
   - Providing sufficient room without excessive right-of-way costs.
6. Technical aids for designing swales, as well as hard drainage features, exist in the HYDRAIN software system and supporting FHWA guidance documents.
7. Leadership at the national level is needed to accelerate the acceptance and implementation of grassy swales. On the basis of the authors' experience, a top-down approach will overcome inertia resistance to change and is preferable to a bottom-up, or grass roots, approach. Model specifications and local ordinances are needed to assist state highway departments and local jurisdictions.
8. The issue cuts across several TRB committees as it pertains to hydrology, hydraulics, water quality, environmental impacts, and highway geometrics. The TRB committees should coordinate needed information gathering and research to provide leadership and provide the needed top-down approach.

ACKNOWLEDGMENTS

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APPENDIX A

Swales of Grass

John Aker

In fair Fairfax's upscale 'burbs,
I find no gutters and no curbs;
Its sculpted hills and classy dales
Are drained by keen, green grassy swales.

There facing upstream stands Stu Finley,
And with glee (disguised quite thinly),

"Send me not your trash," he rails;
"Trap it in your grassy swales."

"Too long my lovely lake has been
Your unwilling, huge trash bin.
But now it's o'er at last," he wails,
"Thanks to our neat grassy swales."

And for the record, notes Ken Young,
"Too long, too long, had mankind clung
To a plan that crassly fails;
Now gaze upon my grassy swales."

"For high- and byway sanitation,
There's but one choice for this nation,
Besides which others vastly pale:
Our silt-consuming grassy swale."

And just to prove that they approve
This revolutionary move,
Flashy girls and dashing males
Now play croquet on grassy swales.

Just a dream? Perhaps a vision?
The Board of Supes must reach decision;
While they bide I brashly hail
That gleaning, greening grassy swale.

To handle future highway runoff,
These two a great idea have spun off;
So folks, don't turn a ghastly pale
When one suggests a grassy swale!