Managing Pollution from Highway Storm Water Runoff

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Guidelines to reduce the impacts of highway storm water runoff have been developed to address both management practices and mitigation measures. The research is a part of the Federal Highway Administration's ongoing program, "Nonpoint Source Pollution from Highway Storm Water." Provided in this paper is a synopsis of interim guidelines for the design of management measures for the removal of pollutants from highway storm water runoff. Three general types of management measures have been determined through previous FHWA studies to be effective in treating highway runoff: vegetative controls (overland flow and grassed channels), detention basins (wet detention basins and wetlands), and retention measures (retention basins, trenches, and wells). Interim design guidelines have been developed based on the experience of the project team and a thorough review of available literature. Field and laboratory studies are currently under way to verify the design procedures and assumptions presented in this paper.

The Clean Water Act (PL 95-217), as amended, sets forth national policy and national water quality programs to restore and maintain the chemical, physical, and biological integrity of water resources. To realize the objectives of the act, the following were established as national goals: (a) that the discharge of pollutants into the navigable waters be eliminated; (b) that, wherever attainable, an interim goal of water quality that provides for recreation in and on the water be achieved; (c) that a major research and demonstration effort be made to develop the technology necessary to eliminate the discharge of pollutants into the water resources; and (d) that federal agencies cooperate with state and local agencies in minimizing pollution.

The Federal Highway Administration (FHWA) has under its purview protection of the environment from pollution by highway sources under the Clean Water Act and other federal laws. The FHWA, in response to these laws and the potential impact on water resources from highway runoff, initiated a cooperative federal and state research program to identify and quantify the effects of highway runoff and to develop management practices for the protection of water resources. The FHWA approached the problem in a four-phase contract research program, as follows:

1. Identify and quantify the constituents of highway runoff,
2. Identify the sources of these pollutants and migration paths from the highway to the receiving water,
3. Analyze the effects of these pollutants in receiving waters, and
4. Develop the necessary analytical tools and abatement/treatment criteria and guidelines for minimizing objectionable constituents.

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The first three phases are complete.

The fourth phase is currently being addressed by three research projects. The first research project is complete and constitutes a literature review and state-of-the-art synthesis of storm water best management practices (BMP) applicable to highway systems (*1–4*). The second research project is the subject of this paper and will evaluate retention, detention, and overland flow for pollutant removal from highway runoff based on laboratory and field testing. The third research project will improve on the existing procedures for estimating pollutant loadings from highways.

Summarized in the paper are FHWA interim guidelines (*5*) for the design of retention, detention, and overland flow management measures for pollutant removal from highway runoff. The guidelines assume that the need for controlling pollution from a specific highway site has been established, using guidelines such as those presented by Dupuis and Kobriger (*6*). Effective and ineffective management measures are presented, along with ratings for pollutant removal effectiveness and highway applicability. Presented in the paper are general management techniques and a synopsis of design procedures for site-specific management measures.

SOURCES OF HIGHWAY POLLUTION, CHARACTERISTICS, AND IMPACTS

Highway operation and maintenance can contribute an array of pollutants to surface and groundwater resources. Highway runoff may contain solids, heavy metals, nutrients, oil and grease, bacteria, and other pollutants. The impacts of highway runoff pollution on receiving waters' aquatic ecosystems are extremely site- and runoff-event specific. The objective of a highway runoff pollution management program is to reduce the total pollutant loading that enters receiving waters from highway runoff. The emphasis of the management program is on total runoff, not individual events. Although all highway runoff contains pollutants, the pollutant loading does not always necessarily constitute a problem for receiving waters.

Pollutants accumulate on highway surfaces, roadside areas, and rights-of-way from highway use, maintenance, natural sources, and deposition of air pollution. The concentrations of these pollutants are highly variable by site, and are affected by numerous factors such as traffic characteristics, climate, maintenance, adjacent land use, and others.

Highway pollutants, such as solids, heavy metals, and organics (found in fuels and motor oils) have been found to correlate directly with traffic volume. Other pollutants (herbicides and nutrients) are found in highway runoff mainly as a result of highway maintenance activities and adjacent land-use contributions. Management techniques for the control of traffic- or maintenance-related pollutants are, therefore, different. Maintenance-related pollutants are better controlled through the use of general measures, such as herbicide and fertilizer application management (*7*). Traffic-related pollutants are more applicable to site-specific control measures and are the focus of this paper.

The extent to which a pollutant is susceptible to movement from the highway source to the environment will vary based on the chemical nature of the pollutant, its physical-chemical properties such as water solubility and vapor pressure, and its tendency to adsorb to organic matter or sediment (see Table 1). The actual processes that remove or degrade will depend not only on the properties of the pollutant already mentioned, but on the management practices being used to mitigate loading. Certain measures will not provide the time or environment to allow a particular removal process to occur. Of the major transport processes, the combination of sorption and settling will be the key removal mechanisms applicable to highway runoff. Many of the constituents will be in particulate form and will settle. Further, organic chemicals and heavy metals in solution will tend to adsorb to suspended sediments and then settle. Biological action, both degradation and assimilation by microbial and rooted vegetation populations, will be the most applicable transformation process.

Highway runoff pollution may affect water quality of receiving waters through shock or acute loadings and through chronic effects from long-term accumulation within the receiving water. The significance of these impacts is very site specific, and will depend heavily on the highway and receiving water characteristics. Recent research (*6, 8, 9*) indicates few significant impacts for highways with less than 30,000 average daily traffic (ADT). Potential impacts are generally short-term, localized acute loadings from temporary water quality degradation, with few, if any, chronic effects.

Dupuis et al. (*8*) monitored highway runoff pollution impacts on receiving streams at three sites with ADT volumes of 7,400, 25,500, and 15,600. Laboratory bioassays were also conducted with the highway runoff for ADTs up to 135,000. Dupuis et al. concluded that

1. There were no apparent water quality impacts during storm events;
2. Benthic invertebrate faunal population distribution, abundance, and composition were unaffected by the runoff;
3. Periphyton communities showed no discernible impacts; and
4. Bioassays with undiluted highway runoff showed no acute effects on test organisms. Some sublethal chronic effects were observed; however, the use of undiluted runoff makes this a worst-case situation not likely to occur in any receiving water.

In a study of the effects of highway runoff on receiving waters, Dupuis and Kobriger (*6*) summarized the findings of several bioassay studies of highway runoff. Runoff from high traffic highways [one highway at 185,000 ADT (*10*) and one at 50,000 ADT (*11*) did have toxic effects on aquatic biota. Runoff from lower ADT rural highways did not cause discernible toxic stress to aquatic biota].

From these studies and other literature reviewed, the following conclusions can be reached regarding highway runoff pollution potential:

1. Highway runoff does have the potential to adversely affect the water quality and aquatic biota of receiving waters;
2. The significance of these adverse effects is variable by highway, receiving water, and runoff event;
3. Runoff from urban highways with high ADT volumes may have a relatively high potential to cause adverse effects; and
4. Runoff from rural highways with low ADT volumes has a relatively low potential to cause adverse effects.

TABLE 1 PRINCIPAL POLLUTANT FATE PROCESSES BY MAJOR MANAGEMENT MEASURES

	Management Measures			
Pollutant	Vegetative Controls	Detention Basins	Infiltration Systems	Wetlands
Heavy metals	Filtering	Adsorption Settling	Adsorption Filtration	Adsorption Settling
Toxic organics	Adsorption	Adsorption Settling Biodegradation Volatilization	Adsorption Biodegradation	Adsorption Settling Biodegradation Volatilization
Nutrients	Bioassimilation	Bioassimilation	Absorption	Bioassimilation
Solids	Filtering	Settling	Adsorption	Adsorption Settling
Oil and grease	Adsorption	Adsorption Settling	Adsorption	Adsorption Settling
BOD	Biodegradation	Biodegradation	Biodegradation	Biodegradation
Pathogens	Not applicable	Settling	Filtration	Not applicable

DESIGN CONTEXT

Mitigation measures should be designed to take advantage of the following characteristics of highway runoff: (a) nonpoint pollution discharges from frequent minor storms are more critical than discharges during infrequent major storms, (b) first-flush conditions result in relatively high pollutant concentrations during the initial stages of storm runoff, (c) loadings of heavy metals and other toxicants tend to be of greater concern than loadings of nutrients and biological oxygen demand (BOD), and (d) critical pollutants such as heavy metals tend to appear primarily in a suspended form.

Because frequent storms tend to cause runoff primarily from paved areas, they tend to produce highly concentrated discharges of highway runoff and reduced dilution by upstream runoff. As a result, most urban runoff pollution management programs rely on controls for minor storms with relatively short recurrence intervals (e.g., less than 1 yr), rather than the relatively infrequent major storms (e.g., 10-, 25-, and 100-yr events) that serve as performance standards for flood management programs. Mitigation measures are typically designed to control most storms that occur each year. For example, in many sections of the United States, mitigation measures designed to control storms producing less than 1.0 in. of rainfall will control nonpoint pollution discharges from about 90 percent of the storms each year. Runoff from the more significant storm events that are not controlled tends to exhibit significant flows from nonurban areas that can dilute discharges from paved areas.

"First flush" effects refer to conditions under which a large percentage of the total storm pollution load is produced by a relatively small percentage of the runoff volume during the initial stages of runoff. As a result, the initial stages of runoff can exhibit relatively high pollutant concentrations that may induce shock-loading conditions and short-term contraventions of water quality criteria in receiving waters. Conversely, mitigation measures that can isolate first flush loadings for "treatment" may take advantage of smaller storage capacities than measures that must treat all runoff flows. Field studies have shown that the significance of first flush conditions is positively related to the amount of pavement in an urban watershed. Consequently, first flush conditions should be prevalent for most highway runoff settings. Further, first flush effects are attributed primarily to the washoff of particulates from paved areas, meaning that first flush runoff tends to exhibit relatively high loadings of suspended pollutants. Finally, heavy metals tend to exhibit a more pronounced first flush effect than other pollutants.

Heavy metals and other toxicants in highway runoff tend to be of greater concern than other nonpoint pollutants such as nutrients. This is because paved areas tend to produce the highest per-acre loadings and concentrations of heavy metals, because of contributions from vehicular traffic. Likewise, paved areas tend to exhibit less significant sources of nutrient loadings than unpaved areas.

Because most heavy metals and other toxicants in highway runoff tend to occur in suspended form, mitigation measures that achieve high removal efficiencies for suspended solids should also achieve significant removal efficiencies for heavy metals and other critical constituents. However, solids-settling design should account for the fact that the majority of suspended loadings in highway runoff is associated with fine silt particles characterized by relatively low settling velocities.

GENERAL MEASURES FOR EFFECTIVE MANAGEMENT

Certain general measures for managing highway storm water runoff pollution are applicable to virtually all highway situations. These measures are not directed toward site-specific problems, although they can be used in conjunction with effective site-specific measures. The practices cited are relatively low cost and can be incorporated into existing highway design procedures and maintenance programs. They are intended to be used wherever practicable without the necessity of identifying a specific highway runoff pollution problem.

Typically, the pollutant load from highways is transported by storm water runoff from the pavement along curbs. Most of the pollutant load in the runoff is carried as suspended solids or adsorbed to suspended solids. Therefore, management measures are usually intended to reduce the volume of particulates available for transport by runoff or to filter and settle out suspended solids. The measures, which fall into these two categories, are presented as follows (*5*):

1. Curb elimination: Future design or reconstruction of highways should omit the use of curbs for delineation and storm water runoff control where practicable. Where curbs are necessary for traffic control or other reasons, consider partial removal (i.e., leave gaps instead of a continuous curb) to allow air transport of pollutants from the highway. However, partial elimination of curbs should be done with caution, as discontinuous curbs may be a traffic hazard.
2. Litter control: Existing litter control programs and regulations were designed primarily for aesthetic and safety objectives. However, they also achieve pollutant-reduction benefits through limitation of potential pollutant sources.
3. Deicing chemical use management: Proper storage and handling of deicing chemicals coupled with sound application practices will provide significant reduction for potential ground and surface water contamination. Covered storage and handling facilities designed to prevent washoff and loss of deicers coupled with good housekeeping will effectively mitigate potential pollution from these facilities. Attention to optimum application rates of chemicals along with maintenance calibration of spreading equipment will eliminate excessive deicer application.
4. Pesticide/herbicide use management: Use of pesticides and herbicides by state highway agencies (SHAs) are typically limited in scope and have strict controls on application, employee training, and so on. The benefits of these controlled-use programs are shown by the low percentage of total pollutant load attributed to pesticides or herbicides. The pesticide/herbicide controls exercised by SHAs should continue.
5. Reduction of direct discharges: Avoid direct discharges of highway runoff to receiving waters (including ground water) wherever practicable. This would include collection and conveyance through closed conduits. Highway runoff should be routed through an effective management measure, or a combination of them, before discharge to receiving waters.

6. Reduction of runoff velocity: Lowering the runoff velocity to a nonerosive level reduces the ability of the flow to transport particulates, especially bed load, and encourages sedimentation. This can be accomplished by reducing gradients, installing velocity-reduction devices such as drop structures and baffles, and using grassed waterways. There will be some situations, however, where higher velocities may be required to provide for timely drainage of the highway surface and roadside areas, and where devices used to reduce gradients could be a roadside hazard.

7. Establishment and maintenance of vegetation: Vegetation along highway rights-of-way is generally established and maintained for aesthetic purposes and erosion control. Vegetation, particularly dense grass cover, also provides pollutant-reduction mechanisms (filtration, sedimentation, and infiltration) for highway runoff.

These mechanisms can be enhanced by

- Establishing dense grass cover wherever practicable.
- Minimizing the number of grass cuttings per growing season to increase the grass height and resistance to flow. Note that there is a limit to the effectiveness of this; at some height (variable by species) and flow depth, the grass will lie flat and become a less effective pollutant-removal measure. The determination of the optimal number of cuttings should be based on local experience.
- Leaving grass cuttings on the ground to act as additional filter material to encourage velocity reduction and to provide mulch.

INEFFECTIVE MANAGEMENT MEASURES

Several storm water runoff pollution management measures occasionally recommended as BMPs were found to be ineffective in reducing pollutant loads in highway runoff. These ineffective measures are (5)

- Street cleaning: Street cleaning is accomplished either by sweeping or street flushing. Although the practice has aesthetic benefits, it is not effective for highway runoff pollutant management.
- Catch basins: A catch basin combines a storage chamber for particulates with a drainage inlet for intercepting storm water runoff. However, the finer solids associated with most of the pollutant load are not effectively removed.
- Dry detention basins: Dry detention basins are used for flood abatement and drainage structure cost economy. Storm water runoff peak flow rates are reduced by storing floods and releasing the water from storage at a lesser rate over a longer period of time. Detention time is generally only a few hours and inadequate to permit settling out of the smaller fractions of suspended materials associated with pollutants.
- Porous pavements: Porous pavements consist of a relatively thin coat of open-graded asphalt over a base of crushed stone. The stone temporarily stores water until it percolates into the subbase material or moves laterally into a drainage channel. Potential pollutant removal occurs as the water infiltrates through the subbase. Because a key aspect of highway design is to maintain a dry subbase for structural stability, use of porous pavements is limited to parking areas and low traffic volume highways.
- Filtration systems: Filtration systems are used extensively as temporary sediment control measures during construction and vegetative cover establishment periods. Commonly used filtration systems include straw bales, sand bags, filter cloth fences, gravel, and sand filters. Filtration systems are generally used to filter out larger fractions of suspended sediments and to cause some deposition upstream of the installation. Finer solids are not effectively trapped and, therefore, highway runoff pollutant removal potentials are low.

MANAGEMENT MEASURES, EFFECTIVENESS AND APPLICABILITY

Management measures were rated (*1, 5*) on the basis of their pollutant removal effectiveness for specific pollutants, relative capital costs, land requirements, and operation and maintenance costs. Ratings are based on information gathered from the review of literature. Efficiencies inferred from other than specific data in the literature are identified. Qualitative ratings are used because effectiveness is dependent on the design of the management measure and site-specific factors that determine runoff characteristics and pollutant loads. The ratings are shown in Table 2.

All measures found effective require space for construction and maintenance. Because the need for mitigation is usually associated with high traffic volumes, and high traffic volumes occur in or near urban areas, the costs of management measures can be high. In many locations, the most practical and cost-effective approach to storm water runoff management may be cooperation with local government in installations that serve the purposes of both levels of government. Shown in Table 3 is the applicability of the specific management measures for use in different highway configurations.

The primary management measure for highway runoff pollution is vegetative controls because of their relatively low costs (compared to the other measures) and their widespread applicability. However, considering that storm water runoff management for pollution abatement is principally needed in high-traffic corridors, vegetative controls may be impractical in many locations. The second choice for a management measure is wet detention. Detention typically costs more than vegetative controls and less than infiltration systems or wetlands. Infiltration systems and wetlands are variations on detention, and are considered as special subsets of detention.

Combinations of measures may be used to compensate for certain site limitations and to increase pollutant-removal effectiveness. An example would be use of infiltration wells in a detention basin to increase pollutant removal while decreasing long-term runoff storage requirements. Another example is the use of overland flow to filter suspended sediments from runoff upstream from an infiltration basin or trench.

IMPLEMENTATION OF SITE-SPECIFIC MEASURES

Site-specific management measures can be used singly or in combination to address highway runoff pollution problems. They are presented based on their relative effectiveness, adaptability to highway design and right-of-way, ease of operation, and minimum maintenance (*12*).

TABLE 2 EFFECTIVENESS RATINGS OF MANAGEMENT MEASURES

Management Measure	Type	Pollutant Removal Effectiveness: Particulates	Heavy Metals	Pesticides	Organics	Relative Capital Costs/ Acre[a]	Additional Land Requirements	O & M Costs: Routine	Nonroutine
Curb elimination	Post deposition	H	H	N/A	H	L	M to H	0	0
Litter control	Source	L to H	L to H	L to H	L to H	L	0	0	0
Controlled use of deicing chemicals	Source	N/A	H	H	H	L	0	0	0
Controlled use of pesticides/herbicides	Source	N/A	H	H	H	L	0	0	0
Grassed channels	Post runoff	H	H	M	H	L	L	L	L
Overland flow	Post runoff	H	H	M	H	L	M to HL	L	L
Dry detention basins	Post runoff	L to H	L to H	L to M	L to M	M	M	L	L
Wet detention basins	Post runoff	H	H	H	H	H	H	L	L
Infiltration systems	Post runoff	H	H	H	H	M to H	L to M	H	H
Wetlands	Post runoff	H	H	M to H	M to H	M to H	M to H	L	L
Street cleaning	Post deposition	L to H	L	L	L	L	0	H	0
Catchbasins	Post runoff	L	L	L	L	M to H	L to M	H	H
Porous pavements	Post runoff	H	H	N/A	H	L to H	0	M	M
Filtration systems	Post runoff	L to M	L	L	L	L	0	M	M

NOTE: Ratings: H = high, M = medium, L = low, 0 = none, N/A = not applicable.
[a]Based on additional capital costs required for nonpoint pollution management per acre.

TABLE 3 APPLICABILITY OF POLLUTION MANAGEMENT MEASURES TO HIGHWAY CONFIGURATIONS

Management Measure	Planned Highway Construction: Interchange	Elevated Highway	At-grade Highway	Depressed Highway	Existing Highway Retrofit: Interchange	Elevated Highway	At-Grade Highway	Depressed Highway
Vegetative controls								
Grassed channel	High	Low	High	Low	Medium	Low	High	Low
Overland flow	Medium	Low	High	Low	High	Low	High	Low
Detention basins	High	Medium	Medium	Low	Medium-High	Medium	Medium	Low
Infiltration measures								
Basin	High	Medium	Low	Low	Medium-High	Medium	Medium	Low-Medium
Trench	Low	Medium	Medium	Medium	Medium	Low-Medium	Medium	Low-Medium
Well	Medium	Low	Low	Low	Low-Medium	Low-Medium	Low	Low
Wetlands	Medium	Low	Low	Low	Low-Medium	Medium	Medium	Low

Vegetative Controls

Vegetative controls involve the use of vegetated surfaces to manage storm water runoff pollution from highways. Vegetative controls are also common management practices for erosion and sediment control. The natural capability of vegetated surfaces to reduce velocity of runoff, enhance sedimentation, filter suspended solids, and increase infiltration can be used to remove runoff pollutants.

Vegetative controls include

1. Grassed channels, or waterways, which are ditches, channels, or swales with a cover of grass designed to inhibit erosion and enhance settling of suspended solids; and
2. Overland flow, which is an application of the filter strip concept, in which strips of grass are designed for sheet flow to filter pollutants from the runoff and increasing infiltration.

These vegetative controls are highly effective management measures for highway runoff pollution and are the primary management measures for most highway runoff situations. Vegetative controls are adaptable to a variety of site conditions, are flexible in design and layout, and are the least costly management measure. Their use is recommended wherever practical. Vegetative controls can be used as sole management measures or in combination with secondary measures (e.g., detention basins, infiltration systems, and wetlands). Grass is the most common vegetation used and is more effective at pollutant removal than shrubs, trees, or other vegetation.

The development of vegetative controls, whether grassed channels or overland flow over grass cover, involves design for pollutant removal and stability and the establishment and maintenance of grass cover. Use of vegetative controls is influenced by the following factors: topography, soils, space, climate, and erosion. The design process is summarized as follows:

1. Estimate runoff flow rates for design runoff event;
2. Estimate grade of proposed channel or overland flow;
3. Select a grass cover suitable for the site;
4. Determine maximum permissible flow depth for the grass cover and slope to be used;
5. Estimate channel or overland flow dimensions;
6. Determine flow velocity;
7. Determine whether design flow is less than maximum permissible flow (stable) or greater than maximum permissible flow (unstable);

8. Reduce flow depth by increasing bottom width or using flatter side slopes, or both, if channel or overland flow is unstable. Maximum noneroding depth can be increased by decreasing the slope;

9. Determine whether provisions for erosion protection are necessary during establishment of grass cover; and

10. Establish and maintain continuous grass cover.

Detention Basins

Where it is impractical to use vegetated roadside ditches, wet detention basins are the most practical and effective storm water runoff management measure for pollution abatement. Detention is a highly effective management measure for controlling storm water runoff quality, if sufficient detention time is provided. Performance of wet detention basins, or those that maintain a permanent pool of water, has been found to range from poor to excellent, depending on the size of the basin relative to the size of the drainage area served and on storm characteristics of the area. The principal mechanism for the removal of particulate forms of pollutants in wet basins is sedimentation, but some basins exhibit substantial reductions in soluble nutrients such as soluble phosphorus, and nitrate and nitrate nitrogen. This may be attributable to biological processes in the permanent pool.

Any particular detention basin will exhibit variable performance characteristics depending on the size and characteristics of the storm and the storm water runoff being processed by the basin. Therefore, a procedure for estimating the long-term average performance of a basin is a more practical tool than a procedure for analyzing individual storm events. Driscoll (*13*) reported a procedure based on a probabilistic analysis methodology used to compute long-term average performance from the statistical properties of detention basin inflows. The analysis assumes that overall performance is due to the combined effect of removals under dynamic conditions as flows move through a basin and under quiescent conditions between storms. The methodology was tested against observed performance and monitored storm events from the Environmental Protection Agency's Nationwide Urban Runoff Program (NURP) data base of 5 to 30 or more separate storm events at each of 13 detention basins.

The following adaptation of the methodology reported by Driscoll can be used to estimate long-term efficiency of wet detention basins or to estimate the dimensions or proposed basins to achieve desired removal rates. This presentation assumes a permanent pool in the detention basin. It is not applicable to dry basins, and cannot be used to size basins for peak flow attenuation. Infiltration of water from the retained pool would increase performance under both dynamic and quiescent conditions.

The design procedures for wet detention basins are outlined as follows:

1. Determine rainfall characteristics;
2. Determine runoff coefficient;
3. Determine settling velocities of particulates;
4. Determine distribution of pollutants in runoff;
5. Estimate the dimensions of proposed basins to achieve desired removal rates;
   - Estimate dynamic removal efficiency and estimate quiescent performance;
   - Develop a chart to estimate percentage of total suspended solids removal versus basin surface area;
6. Design basin configuration to minimize potential for short-circuiting; and
7. Design all basin bank slopes at 3:1 or flatter, maintain grass cover where practicable.

Rainfall and runoff characteristics, settling velocities for suspended solids in runoff, and the distribution of particulates and pollutants in each size range are needed to design wet detention basins to achieve pollutant-removal objectives.

Wetlands

Wetland is a general term for land where the water table is at or near the surface, or the land is inundated by relatively shallow water, or supports aquatic vegetation. Saturation is the dominant factor in soil development and species composition. Wetlands are complex ecosystems often occurring at the interface between terrestrial and aquatic systems. They are generally characterized by high floral productivity and nutrient needs, high decomposition rates, low oxygen content in the sediments and substrates, and large adsorptive surfaces in the substrate.

Wetlands can provide a highly effective management measure for highway runoff pollution, assimilating large quantities of suspended and dissolved materials from inflow. However, development of wetland treatment systems is a complex process that is not well defined. Differences in geographic location, climate, hydrologic parameters, and wetland type significantly affect pollutant removal effectiveness. In many areas, wetlands are not a practical alternative.

Wetland treatment systems are a variation on detention, removing runoff pollutants primarily through sediment retention and vegetative uptake. Wetland designs differ from conventional detention systems by being shallower, using vegetation as a pollutant-removal mechanism, and emphasizing slow-moving, well-spread sheet flow within the wetland. Wetland treatment systems are applicable in place of standard detention basins where the water table is at or near the surface and there is sufficient space for a shallow basin, or where there is an existing natural wetland.

Infiltration Systems

An infiltration system is a runoff management method whereby surface runoff is temporarily stored, allowing it to infiltrate the ground. Infiltration systems are used in several areas of the United States as an alternative method for the disposal of storm water runoff. An infiltration drainage system can consist of one or several types of installations, and can be used alone or in combination with conventional systems of disposal. Infiltration techniques include open basins, infiltration trenches, and infiltration wells.

Infiltration systems can provide effective management of highway runoff pollution, provided that certain requirements are met. An effective infiltration system requires (a) soils or subsoils that are moderately to highly permeable, (b) a groundwater table a minimum of 10 ft (3 m) below the bottom of the infiltration point, (c) a runoff inflow relatively free of suspended solids; and (d) sufficient storage for the design runoff event during the infiltration period.

Infiltration systems are typically designed as management measures to control storm water runoff or recharge groundwater resources, and reduction of pollutant loads in runoff is a byproduct. A general design procedure has been developed that can be adapted to specific site characteristics.

HIGHWAY APPLICATIONS

In applying management measures to specific highway runoff situations, it may be desirable to combine two or more measures. Combinations of measures may increase pollutant-removal effectiveness, allow for filtration of suspended solids, or be used to overcome site factors that limit the effectiveness of a single measure. Although each of the four cost-effective measures previously discussed can be used alone, combinations of measures are recommended where practicable.

Vegetative controls are the only management measure providing pollutant abatement while the runoff is conveyed from point to point. Therefore, vegetative controls should be used to convey highway runoff wherever possible. Such controls should serve as the runoff collection and conveyance system, both as a single management measure and as a link between different measures.

Vegetative controls can be used in combination with other effective management measures to increase pollutant removal, provide filtering of suspended solids for infiltration systems, and reduce erosion and scour at inflow discharges to infiltration basins, detention basins, and wetlands. Combinations are particularly advantageous where the desired length of grassed channel or width of overland flow is unobtainable.

Detention basins may be used in combination with vegetative controls to provide storage of runoff or sediment removal before infiltration basins or wetlands. The primary consideration in the use of infiltration systems for pollutant removal from highway runoff is the vulnerability of the system to sediment. Except for basins receiving relatively sediment-free runoff, infiltration systems require additional highway runoff management measures (vegetative controls or detention basins) to provide adequate runoff storage and sediment removal before infiltration. Thus, infiltration systems are usually an add-on feature to other management measures.

Wetlands can be used in combination only with vegetative controls or detention, not with infiltration. Typically, wetlands would receive inflow from vegetative controls or a detention basin and discharge (if there is an outlet) to vegetative controls. Wetlands should not be used before infiltration basins, as accumulated sediment or decaying plant matter are often flushed from wetlands in the spring. The sediments and particulate matter could clog the infiltration basin. In addition, conditions favorable to wetlands, such as a high water table and impervious soils, are unfavorable to infiltration measures.

CONCLUSIONS

The primary mitigation measures identified as effective for control of pollution from highway runoff are vegetative controls, wet detention basins, infiltration systems, and wetlands. These measures, used singly or in combination, along with application of the general guidelines, can provide major reductions in pollutant loadings resulting from highway runoff.

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