BEST MANAGEMENT PRACTICES

ENHANCED EROSION AND SEDIMENT CONTROL USING SWALE BLOCKS

University of Central Florida
Department of Civil Engineering and
Environmental Sciences

Martin P. Wanielista
Y. A. Yousef
L. M. Van DeGroaff
S. H. Rehmann - Koo

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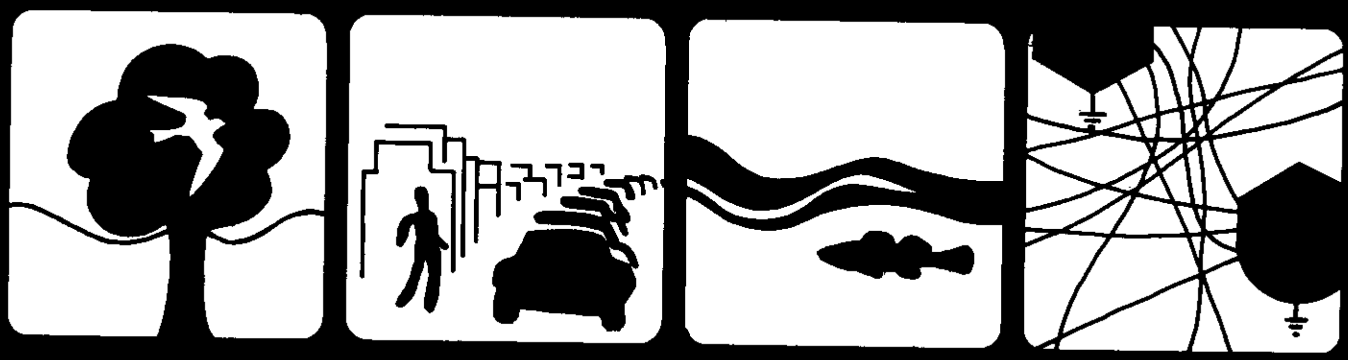

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16. Abstract:

This report has as its focus erosion and sediment control of an existing highway using an innovative control concept, namely swale blocks.

Swales are an important management practice for source control of rainfall excess (runoff volume) from highways. Inherent in the design is the specification that the swale wetted areas will infiltrate the rainfall excess. The swale design investigated in this work is one which will infiltrate the runoff from the first 3 inches (7.6 cm) of every storm event. When this removal is not achieved during flow through, swale blocks are suggested to retain the remaining waters.

Swale blocks or filter berms were designed and constructed to illustrate operational effectiveness. Design aids were developed for various berm heights and highway slopes as a function of berm spacing for an Interstate highway section. Berms were constructed in swales along a four-lane roadway to determine hydraulic and sediment control effectiveness for a particular design.

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BY

M.P. Wanielista, Y.A. Yousef, L.M. Van DeGraaff
and S.H. Rehmann-Koo

Civil Engineering and Environmental Sciences Department
College of Engineering, University of Central Florida
Orlando, FL 32816-0993

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ABBREVIATIONS AND CONVERSION FACTORS

[Factors for converting inch-pound units to International System of units (SI) and abbreviation of units]

Multiply	By	To Obtain
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
acre	0.4047	hectare (ha)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
square foot (ft^2)	0.09290	square meter (m^2)
pound (lb)	0.4536	kilogram (kg)
cubic foot (ft^3)	0.02832	cubic meter (m^3)

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CHAPTER I

INTRODUCTION

The concern for improved water quality control through reduction in erosion and sediment transport is an important aspect of highway operation. Erosion is the process of removing surface materials which when entrained in water become sediment. Sediment is then transported from the erosion site to another location. By reducing water velocity and volume from a site, erosion and sediment reductions can be partly achieved.

The quality of receiving water bodies has possibly deteriorated in part due to uncontrolled discharges of sediment. Methods have been developed to reduce the quantity of stormwater and associated sediments by re-routing runoff waters into stormwater management facilities. This report presents results of work on modifying the design to improve the effectiveness of one of these stormwater facilities, namely swales. By definition, swales are vegetation-covered open channels which transport and infiltrate some of the runoff waters. Swales have been primarily successful in flood control by reducing peak discharges and acting as equalization basins. By reducing the velocity of flow in a swale, infiltration and sedimentation may be increased. Thus, the concept of pooling water in a swale by means of a swale block was initiated.

Currently in Florida, swales used for stormwater water quality control are designed to hold the runoff from the three year frequency, one hour duration rainfall event. Considering many years of rainfall data and one hour duration storms, the maximum volume of rainfall associated with the time duration and the frequency of occurrence can be estimated. However, this volume most likely will be exceeded more than once every three years because other duration storms are present and must be considered. Also for the same storm duration time, it is possible that the volume associated with the three year frequency will be exceeded. Using data from 15 hourly rainfall stations in Florida, there is approximately one 3 inch (7.6 cm) or greater rainfall event for every 100 storms. There are approximately 125 storms per year. The volume used for the example calculations of this report is three (3) inches (7.6 cm). This volume is the approximate maximum for the State of Florida.

Highway runoff transports sediment and various chemical forms such as heavy metals, oils, greases and nutrients. Possibly this water can be conveniently stored in swale areas. Thus it seems logical that this is the place where sediment and other chemical reductions can occur. The use of swale blocks for increased sediment reduction and flood control would add to the value of these facilities.

SCOPE

The scope is limited to erosion control and sediment retention from operating highways and to development of swale blocks as sediment control systems. Since swales are vegetated open channels, the vegetation cover reduces erosion.

This is the second of a series of reports leading to a procedure for the design of Best Management Practices (BMP's) for highway runoff. The first was published in 1985 (Yousef, et al.). Focus for this report is the hydrologic design of swale blocks and an examination of the sediment retention effectiveness of actual operational swale blocks. The purpose of these findings is to aid in the design of swale blocks operating adjacent to highways. Specific results can be used to develop design procedures which will assist in swale block sizing and spacing.

CHAPTER II

EROSION AND SEDIMENT CONTROL

Soil erosion is essentially the detachment and relocation of soil particles through the dynamic action of water or wind. Soil exposure inevitably accelerates the erosion process because of the removal of the protective soil cover. A reduction in the rate of erosion is achieved by controlling the vulnerability of the soil to the erosion process.

Soil particles become sediment when they are detached and moved from their initial resting place. Even with the best erosion control practices, some sediment will be generated. Deposits of sediment in a stormwater conveyance system reduces the hydraulic capacity of the system and can destroy aquatic habitats. Increased turbidity will reduce light penetration and, possibly alter the ecological balance of receiving waters. The colloidal fraction of suspended sediment is capable of adsorbing nutrients, pesticides, heavy metals and organics. Eutrophication in many fresh water systems is caused by discharging runoff carrying nutrients adsorbed to soil particles.

EROSION POTENTIAL

A combination of climate, vegetative cover, land use, soil properties, topography, and erosion control methods determines the erosion potential. The universal soil loss equation (Agricultural Research Service, 1961) was developed to estimate water soil loss potential. Israelsen, et al, in a National Cooperative Highway Research Program Report (1980) modified the universal soil loss equation to serve as a basis for estimating water soil loss potential. They conducted extensive controlled testing using a number of control methods. The modified soil loss equation is:

$$A = (R)(K)(LS)(VM) \tag{1}$$

where
- A = computed amount of soil loss per unit area and time interval of study (generally expressed as tons/ac-yr)
- R = rainfall energy factor
- K = soil erodibility factor (tons/acre-year per unit of R)
- LS = topographic factor, length and steepness of slope (dimensionless)
- VM = erosion control factor (dimensionless)

Each factor in the equation has to be determined from site specific conditions. Rainfall energy and control methods have the greatest effects on the sediment yield. The rainfall energy factor is reported to vary in the United States from a low value of 20 in the Northwestern area to a high of 350 in Florida and some other Gulf State areas.

Vegetative covers were identified by Israelson (1980) and are being specified as one of the more effective erosion and sediment control methods by State Departments of Transportation (Florida, 1985, North Carolina, 1972, Minnesota, 1970, etc.). Vegetative covers protect the soil from rain impact and prevent the removal of soil particles. They also reduce the velocity of the runoff and increase soil storage. Table 1 indicates the relative erosion control potential of vegetative covers and other methods more appropriate to construction activities. From Table 1 it is noted that vegetative covers can be very effective in the control of erosion.

Once established, vegetation requires a minimal amount of maintenance, with a possible need for selective sodding and seeding of small areas. Generally, slopes upon which vegetation can be satisfactorily established and maintained cannot exceed 50 percent. However, optimum vegetative stability requires slopes of 25 percent or less. The maximum slope steepness is a function of the structure and composition of the soil and the moisture content. Vegetative covers have been shown to be the most effective soil stabilizers. The cover shields the ground and its roots bind and secure the soil particles. Permanent vegetative stabilization is accomplished by the proper selection and planting of grasses, legumes, shrubs and trees. The type and mixture of plant species will depend on the seasonal mixture and environmental exposure. Before planting a crop, the topsoil should be treated with fertilizer, and the pH of the soil should be between 5 and 7 (Florida DOT, 1982).

TABLE 1 Typical Erosion Control Potential Values (VM)
(adopted from Israelsen, 1980)

Condition	Range	VM (Fraction)
1. Bare Soil Conditions		
freshly disked to 6-8 inches		1.00
after one rain		0.89
loose to 12 inches smooth		0.90
loose to 12 inches rough		0.80
compacted bulldozer scraped up and down		1.30
same except root raked		1.20
compacted bulldozer scraped across slope		1.20
same except root raked across		0.90
rough irregular tracked all directions		0.90
seed and fertilize, fresh		0.64
same after six months		0.54
2. Asphalt Emulsion on Bare Soil		
1250 gallons/acre		
1210 gallons/acre	0.01-0.019	.015
605 gallons/acre	0.14-0.57	.35
302 gallons/acre	0.28-0.60	.44
151 gallons/acre	0.65-0.70	.68
3. Dust Binder		
605 gallons/acre		1.05
1210 gallons/acre	0.29-0.78	.54
4. Other Chemicals		
1000 lb. fiber Glass Roving with 60-150 gallons asphalt emulsion/acre	0.01-0.05	.03
Aquatain		0.68
Aerospray 70, 10 percent cover		0.94
Curasol AE	0.30-0.48	.39
Petroset SB	0.40-0.66	.53
Portland cement + Latex		
1000 lbs/ac + 8 gals/ac		0.13
1500 lbs/ac + 12 gals/ac		0.006
5. Vegetative Cover		
temporary, 0 to 60 days		0.40
temporary, after 60 days		0.05
permanent, 0 to 60 days		0.40
permanent, 2 to 12 months		0.05
permanent, after 12 months		0.01

For best results after seeding, the surface should be mulched. Mulch treatments serve to absorb the impact of rainfall, help isolate the soil surface, and retain the soil moisture, which encourages faster germination of seedlings. Many materials may be used as mulch, including straw and sawdust. Chemical stabilizers may be used instead of mulch or in conjunction with mulch material. The composition of chemical stabilizers varies from asphalt emulsion to a latex. Areas treated with such soil binders show increased soil cohesion, but reduced permeability. Thus, runoff volume control may not be achieved.

Blanket products or nettings serve the same purpose as mulch, and are more difficult to disturb. Most blanket products consist of a type of netting that is interwoven with a mulch material incorporated in the webbing. Blankets are supplied in rolls and are applied in overlapping strips down the slope and attached to the ground with pegs or staples.

The erosion potential of soil particles also depends on the structure and texture, organic and moisture content, and permeability of the soil. Sandy soils are more permeable and allow water to infiltrate. Silts and clays are often quite cohesive and resist erosion, but when in suspension, are most difficult to settle out.

The topographic considerations include the slope steepness and length. Steeper slopes increase the runoff velocity and erosion potential. Long slopes show higher erosion than shorter slopes with the same steepness. Diseker et al. (1967) investigated bank slopes consisting of clay soils and found that flatter slopes show substantially less erosion than steeper slopes.

EFFICIENCY OF EROSION CONTROL

Enhanced erosion control methods for retaining sediment are necessary in some areas. If erosion (removal of surface materials) can be reduced by a fractional amount, then efficiencies of erosion control can be estimated. Average annual reduction of potential sediment loss due to erosion can be estimated using the modified universal soil loss equation.

Reed (1978) reported some sediment reduction in terms of percent effectiveness. Rock dams were reported to obtain a trapping efficiency for both suspended and bed loads of approximately 5 percent, while seeding and mulching reduced erosion by 20 percent and straw bales placed around drainage inlets reduced sediment loads by 10 percent. The erosion control (seeding and mulching) was more effective than the sediment controls (rock dams and straw bales). Using the efficiencies reported by Reed and those efficiencies calculated from the "VM" factors of Israelsen, a comparison of erosion control effectiveness is developed. Calculations of sediment yield from an unprotected shoulder area adjacent to a highway depend on the slope and width (slope-length factor) of the shoulder, rainfall intensity factors and soil texture. Using a range of values as given in Table 2, unprotected shoulder areas are estimated to have a potential to erode between 26.6 and 322 tons of sediment per acre per year. These losses assume conditions which are more common to the Florida and Gulf-coast environment, such as a high rainfall energy factor and soil conditions. For soils from 78 roadside areas in the State of Florida Busey (1977) determined that silt was present in 76 of the samples and the average percentage of silt in a sample was 5.2. Also, clay was present in all but one sample and the average percentage in a sample was 5.4. The maximum percentages for silt and clay were 23.4 and 47.6 respectively. The range of K values used for

Table 2 reflects the Florida extremes to be expected as reported previously (Busey, 1977). For any site specific condition, more accurate estimates can be made. In Table 2 the relative effectiveness of the erosion control methods is shown. Sodding is shown to be the most effective method.

TABLE 2 Control Methods/Removal Effectiveness
Operating Highways

Control Methods	Effectiveness Relative to Bare Ground (1.0-VM)	Reference	Mass Retained/Year Range dependent on K and LS* Ton/Ac	1000 Kg/Ha
Rock Dams	0.05	Reed, 1978	1.33-16.1	2.98-36.1
Straw Bales	0.10	Reed, 1978	2.66-32.2	5.96-72.1
Seeding & Mulching	0.20	Reed, 1978	5.32-64.4	11.9-144.3
Vegetative Covers Temp after 60 days	0.95	Israelsen 1980	25.3-306	56.7-685
Sodding	0.99	Israelsen 1980	26.3-319	58.9-715
Maximum Potential Control	1.00		26.6-322	59.7-721

*Assumed highway shoulder conditions are:

R = 350, for Florida (Wanielista, 1979)

K = .10 to .42, 2% organic loamy sand to 2% organic silty loam

LS = 0.76 to 2.19, 8% slope to 16% slope on a 60 foot slope length (Wanielista, 1979)

Example calculation for sodding:

Estimated Minimum: Mass retained = (R)(K)(LS)(1 - VM)
= 350(.10)(.76)(.99)
= 26.3 tons/ac-yr (58.9 x 10^3 kg/ha)

and Estimated Maximum: Mass retained = 350(.42)(2.19)(.99)
= 319 tons/ac-yr (715 x 10^3 kg/ha)

SEDIMENT

The problem of sediment transport starts when eroded material is removed from the point of origin and is carried away to a different location. Surface runoff is the prime mover of detached soil particles. The sediment load transported by the runoff consists of wash load, suspended sediment load and bed load. The wash load consists of very fine, or colloidal (silt and clay) particles, which settle very slowly. The suspended sediment is composed of soil particles carried and supported by the water itself. Bed load sediment refers to coarser particles, which move by rolling, sliding or bouncing along the stream bed. Sediment transportation and deposition is influenced by the flow characteristics of the water and the nature of the particles transported. As the velocity and turbulence increase, the water is able to transport more sediment; and as the velocity decreases, deposition of sediment occurs.

Sediment can be categorized as organic and inorganic material, where organic material may exist in various states of decompositon. Both the organic and inorganic fraction of natural sediment have been shown to adsorb chemical constituents on the solid surfaces, where the colloidal fraction has been found to be the most reactive (Stumm and Morgan, 1981). Clay particles often are negatively charged. Therefore, they adsorb positively charged ions on their surfaces, such as metals, nutrients and organic constituents. These complexes can exist in suspension or settle to the stream and lake bottoms. Some changes in environmental conditions can cause pollutants in the sediments to be released back to the water column. Organic compounds in stormwater can include oxygen consuming material.

The concentration of suspended sediment in streams can relate to the concentration of several water pollution constituents. Increases in constituent concentrations during periods of stormwater runoff have been shown to be directly associated with increases in suspended sediment concentration (Burton, 1975).

Kobriger, et al. (1981) analyzed highway runoff, performing more than one thousand chemical analyses to develop regression curves for various constituents. The carrier pollutant used was total solids. Good correlation was shown to exist between total solids and sixteen commonly used water quality parameters. Because of these interactions of solids with other pollutants, sediment is an important parameter to consider when assessing surface water quality.

Gupta (1981) completed a constituent study which identified chemical and sediment levels in highway runoff during operating conditions. A summary of concentrations and loadings for sediment per storm event is shown in Table 3.

TABLE 3 Concentration and Loadings of Highway Runoff*

	Suspended Solids		
	Concentrations	Event Loadings	
Location	(mg/L)	(lb/ac)	(kg/ha)
Hwy 794-Milw	268	19.6	22.0
Hwy 45-Milw	445	18.6	20.8
Grassy Site-Milw	303	7.8	8.7
Harrisburg	53	4.7	5.3
Nashville	209	14.0	15.7
Denver	259	13.7	15.3
Average	256	13.1	14.7

*from Gupta (1981)

The amount and composition of contaminants on street surfaces is influenced by many factors some of which are the type and condition of street surface, land use, traffic volume, type of maintenance, etc. The accumulation rate of pollutants on the street surface is affected by deposition and removal rate. Sartor and Boyd (1972) stated that the quantity of contaminant material found at a given test site was dependent on the length and time between cleaning activities either by mechanical means or by rainfall; and streets considered in poor to fair pavement condition have loadings about 2.5 times greater than streets in good-to-excellent conditions. Gupta et al. (1981) found asphalt streets to have loadings up to 80 percent heavier than concrete streets. Most of these loadings are then removed in a rainfall event rather than by mechanical sweeping. The removal rate depends on antecedent dry conditions, rainfall intensity, traffic conditions and other source contributions.

Reinertsen (1981) analyzed sidewalks, roadways, and parking lots for mean surface concentrations of solids, COD, and lead, finding the highest pollutant deposits on sidewalks, followed by busy roadways and parking lots. Sources of these pollutants are illustrated in Figure 1. Note that the design of highway stormwater systems has little or no control of the sources. However, stormwater management of the runoff waters is under the control of the designers.

SEDIMENT CONTROL

Sediment control involves the retaining of transported sediment from highway impervious surfaces and contributing adjacent lands. Wanielista (1977) completed a field sampling program which included measures of

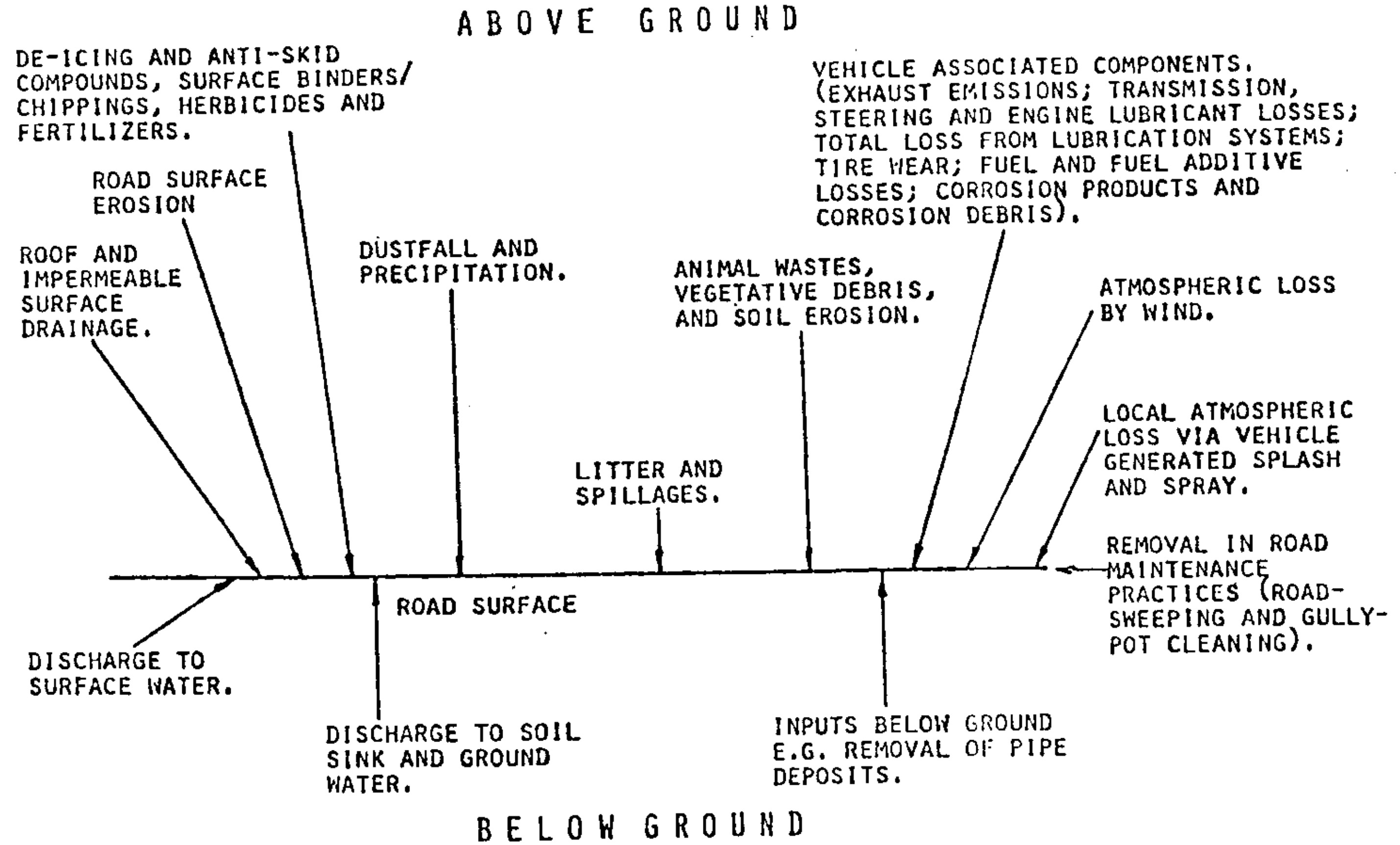


Figure 1 SYSTEM DIAGRAM OF POLLUTIONAL INPUTS/OUTPUTS TO AND FROM THE ROAD SURFACE

suspended solids for 14 off-line (diversion) retention sites in the Orlando, Florida area. Ten of these sites had runoff from highway or parking lot areas. Using field collected data on suspended solids for a 4 acre parking lot; the retention efficiencies per storm event for these off-line structures were found to vary from 64 percent to 100 percent if 1/4 inch (0.64 cm) of every runoff volume were diverted for treatment. When 1/2 inch (1.3 cm) capacity was provided, the efficiency range was from 92 percent to 100 percent per storm event. The retention efficiency was estimated by determining the pollutant mass at the inflow and at the outflow. This small watershed exhibited a first flush effect and this diversion produced very high retention effectiveness. On an average annual basis, using all the field collected data from all watersheds, the percent effectiveness on an average annual basis was calculated as about 80 percent for 1/4 inch (0.64 cm) treatment and 90 percent for 1/2 inch (1.3 cm) treatment volumes.

For a land use that was a mixture of highway pavement, residential and commercial areas, Oliver et al. (1981) examined the operation of a detention system. The average residence time was 28 days and the reported suspended solids removal efficiency was 88 percent. The East Central Florida Regional Planning Council (1983) reported an 85 percent efficiency for similar designed systems.

Shallow-water roadside ditches were examined to determine the fate of solids, bacteria, oils, metals, and nutrients from highway runoff (Wanielista, 1978). This study indicated that most of the sediment could be retained in the ditches with a very small fraction in the water column.

Field studies by Yousef et al. (1985) on swales showed that infiltration of runoff waters in swales was directly related to efficiency.

Thus if the runoff waters can be retained for infiltration in the swale efficiency would increase proportional to the amount of water infiltrated Kent et al. (1983) presented a methodology for incorporating soil storage into the design of on-site drainage (swale) systems. They projected decrease in the size of detention ponds when vegetation and soil storage were considered in design. However, no suggestions were made for the hydrologic design of swales. No data were reported on sediment retention effectiveness. A possible modification of a swale for sediment control to add a check dam to either contain or filter the runoff water before discharge. The check dam is called a swale block.

EFFICIENCY OF SEDIMENT CONTROL

Sediment can be retained in detention ponds, off-line retention ponds filters, swales, and can be controlled by other less commonly used stormwater management methods. However, most data collected relates non-highway conditions. The efficiencies of swales and swale blocks have seldom been reported in literature (Yousef, 1985).

Other preliminary work in a laboratory on efficiencies of swale blocks that both store and infiltrate runoff waters has been completed (Wanielista et al. 1982). It was noted that removal efficiencies were dependent flow rates, such that the lower flows gave a greater reduction for some the water quality parameters. Solids reduction as high as 90-99 percent were observed using a filter composed of building sand and alum sludge Harper et al. (1982) extrapolated these results and designed filters for the Lake Eola Watersheds in Orlando, Florida. He observed a phosphorus removal efficiency of about 75% for a filter composed of alum sludge and sand that was 15 inches (38 cm) deep. Sediment removal was about percent. The filter material replacement was estimated to be once every two years. Thus, maintenance time and costs will be significant. Because of this maintenance activity, these filters are rarely used. Hickok (1980) showed that an organic rich soil was capable of removing mainly phosphorus and nitrogen forms from stormwater. Another study with intermittent sand filters by Otis (1982) found ortho- and total phosphorus removals of 50 percent. Also, it was found that mixing the sand with calcium, aluminum, or iron species could improve removals up to 70 to 90 percent. This particular study was with filters which were 2 to 3 feet deep (0.6-0.92 m), and of "granular materials" underlain with collection drains. The disadvantage of using the sand was that the sorption sites were quickly covered with biological film, and thus, had to be replaced more often. The filter concept can be applied to swale blocks. Each block can be designed to retain and filter stormwater to achieve sediment removals. However, from a maintenance viewpoint, it is advisable to design the swale block to store water for infiltration through the swale bottom rather than through the block.

The efficiencies reported in Table 4 are believed to be a reasonable assessment for practices excluding swales since they relate to watersheds with highways. The development of the numbers of pounds per acre per event retained assumes the average discharge data from Table 3. Data for swales are non-existent, and at this time, a comparison is not available. However, if the swale block can achieve similar efficiencies at lower cost or need less maintenance, then the swale block would be a candidate for control of sediment.

TABLE 4 Sediment Control/Removal Effectiveness
Operating Highways

Sediment Control Methods	Effectiveness (Relative to no control)	Event Retained Suspended Solids* (lbs/ac)	(kg/ha)	Reference
Detention Pond (28 days average detention)	88	11.5	12.9	Oliver, 1981
Off-line Retention 1/4" diversion	80	10.5	11.8	Wanielista, 1977
1/2" diversion	90	11.8	13.2	Wanielista, 1977
Filters	95	12.5	14.0	Harper, 1982
On-line Retention (no discharge for rainfall less than 3 inches)	99	13.0	14.6	Wanielista, 1979
Maximum Possible Retained	100	13.1	14.7	Table 3

*use of average values

MAINTENANCE AND OPERATION

All sediment and erosion control practices need routine inspection and maintenance. Whether the practice is vegetative or structural, minimum maintenance schedules must be implemented to ensure proper functioning. For retention ponds and other sediment accumulating devices, a most important activity is the timely cleanout and disposal of the accumulated deposits. Experiences in this research indicates that semi-annual inspection is necessary. The inspection frequency can be modified after a few years.

The removal of accumulated sediment from swales and detention/retention facilities should be carefully evaluated as to the method or combination of methods to accomplish sediment removal in an efficient and economical way, while minimizing surrounding disturbances which could cause erosion. Some conventional sediment removal devices include a dragline, dredge, front-end loader, crane, dozer, shovel, or a vacuum device. Sediment disposal is an integral part of the sediment removal program. Retained material dumped and piled near the drainage structure can likely re-enter the surface drainage system during storm events and thus become a pollutant again. Sediments can be disposed of properly behind protective berms, buried or stockpiled, de-watered and properly vegetated. Vegetative practices require periodic inspection, cutting of the grass cover and shrubs, replacement of dead plants and re-seeding or other methods to re-establish a vegetative cover for bare areas. Roadway maintenance is important and routine work should include sediment removal, litter and refuse collection, drainage structure and culvert cleaning and erosion protection.

SUMMARY

Past research indicates that vegetation cover is effective for erosion control and there are three primary methods to control sediment in stormwater systems. One method is to design retention/detention systems with adequate holding time to allow settling of sediments. However, they may require a large area, which could be costly. The second method uses overland flow with infiltration. Areas adjacent to highways are sometimes used. The third alternative proposed here is to use swale blocks to infiltrate waters. This technique has been examined and its efficiences have been shown to relate to infiltration (Yousef et al. 1985). The type of soil that works best for infiltration is one which has a variety of natural characteristics, such as silt, clay, organic matter, aluminum, iron, and calcium, and a high permeability rate through the soil. Infiltration volume can be increased if the stormwaters can be stored between swale blocks to be constructed along the entire length of the swale.

CHAPTER III

SWALE HYDROLOGY AND HYDRAULICS

Swales and swale blocks can be used for erosion and sediment control. But, how effective are they for the reduction of runoff volume and flow rates? A swale is a vegetated open channel primarily designed to transport and infiltrate stormwaters. Since it is vegetated, it will have minimum erosion potential. The volume of runoff water that will infiltrate increases when the retention time increases. Thus, swale blocks constructed perpendicular to the swale flow line are useful to pond stormwaters. Use of swales and swale blocks decrease end-of-swale discharge volume and flow rates. In some cases these blocks eliminate or reduce the need for land aquisition outside of highway right-of-ways to store highway runoff. In this chapter, swale hydrology and hydraulics are examined using two sites adjacent to an interstate highway and a procedure for evaluation of a design is suggested.

DESIGN CRITERIA AND PROCEDURES

A swale must be designed to infiltrate. The infiltration volume is a function of soil-water contact time which in turn is a function of slope, distance traveled, flow rate, depth of flow and the soil water holding capacity. In addition, the wetted area affects the volume of infiltrate given a known infiltration rate. If the first 3 inches of the runoff can be stored in the swale and allowed to infiltrate over a period of time during and immediately following a storm event, then stormwaters from 99 percent of the storm events in Florida will be infiltrated. This statement assumes the stored water will infiltrate before the next storm. The desig criteria specified here is to store the runoff from a 3 inch (7.6 cm) stor event. Using rainfall volume data for the State of Florida, Anderso (1982) determined that approximately one percent of the rainfall volume were greater than three inches. Since there are about 125 stor events/year, there are on the average one or two storms per year wit three inches or more of rainfall. Using daily rainfall volumes for th Orlando, Florida area, Walsh (1985) predicted 1.19 events per year with a inch (7.6 cm) volume or more. He used twenty years of data.

THEORY

Knowing watershed characteristics and a design storm for a particula area, an estimate can be made of rainfall excess (runoff) for tha watershed. If it must be infiltrated, two simplified design conditions ca be specified, namely provide an area large enough to infiltrate th rainfall excess, or provide a transport area to infiltrate some of th rainfall excess and another area to store and infiltrate that portion whic has not been infiltrated during transport. Figure 2 illustrates thes concepts. The watershed cumulative volume would be rainfall excess. Swal volume would be that remaining after swale transport. The major problem i to estimate the infiltration in the swale so as to reduce required storag at the end of the swale or to provide swale blocks to store the water i the swale. In equation form, a mathematical translation of rainfall t runoff can be done, such as illustrated in equation 2.

$$R = cP \qquad (2)$$

where R = rainfall excess volume (depth)
c = watershed runoff coefficient (dimensionless)
P = rainfall volume (depth)

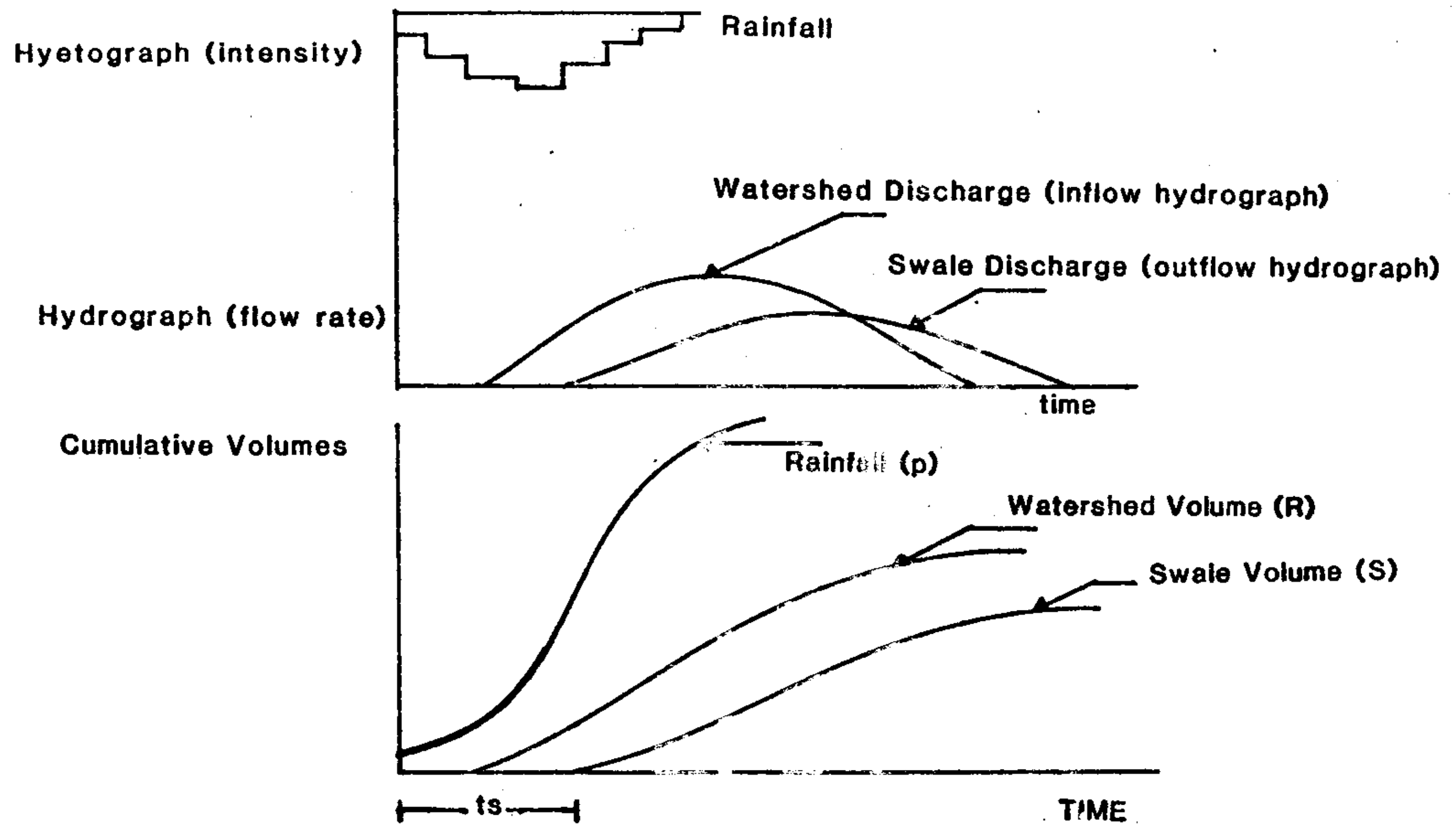


FIGURE 2 SCHEMATIC DIAGRAMS FOR HYDRAULIC DESIGN OF SWALES

The runoff coefficient can be estimated from past studies, hydraulically connected area, or from published data. It should be recognized that it is variable and prudent conservative estimates are usually done. Since swale can infiltrate, a runoff coefficient exists for a swale but is sit specific. It can be used to translate watershed runoff volumes (rainfal excess) into swale volume shown in equation 3.

$$S = C_v R = C_v c P \quad ($$

where S = swale volume (depth)
C_v = swale volume runoff coefficient (dimensionless)

If the flow time in a swale area can be increased, then infiltrat volume can be increased. However, it is not always possible to constr longer swales, provide greater infiltration areas, and milder slop Thus, swale blocks to provide storage within the swales should considered.

Experiments can be designed to measure actual flow conditions in field environment which will aid in demonstrating infiltration by mean estimating the swale runoff coefficient and Manning's roughness coeffi "n".

FIELD EXPERIMENTATION

Water flow over two swale areas in Central Florida was moni Double ring infiltrometers were used to estimate static infiltration Water flow in the swales was monitored to describe the hydrograp volume relationships shown in Figure 2. The field sites and the hydrograph shapes were described in Yousef et al. 1985.

During the experiments, the water depths across the area for s every ten to twenty feet from the beginning of the swale were recor surveys of cross sections were made. This procedure was neces estimate the average cross sectional area of the water flowing through the swale. Measurements of the inflow and outflow from the swale area and the water cross sectional areas assisted in the determination of hydraulic parameters for the study area during these experiments.

Six flow experiments were conducted using different watershed flow rates (inflow to the swale). The results are shown in Table 5. During watershed runoff to the swale, the flow from the swale was monitored to produce the shape of the swale discharge hydrograph. The rainfall excess inflow (watershed runoff) and swale outflow was calculated in depth of flow by dividing the volume measurements by the average swale wetted area. Estimates could then be made for the swale runoff coefficient.

RUNOFF COEFFICIENTS

Flow hydrographs were analyzed by hydrologic and hydraulic properties and the hydrograph characteristics of the swale experiments are shown in Table 5. This represents the flow data reduced to volume measurements and the swale runoff coefficients. There are two runoff coefficients noted in Table 5; one is used to calculate the runoff volume from the swale, and the other is used to calculate peak discharge (outflow) from the swale. The volume runoff coefficient is the one noted in equation 3. It is a function of the flow, moisture conditions, and detention time in the swale. Thus, variable numbers can be expected. It is however noted that the longer the duration of flow, the closer the volume runoff coefficient is to the coefficient used to estimate peak discharge. Using these runoff coefficients, swale outflow volume is estimated using equation 3 and peak discharge can be estimated using:

TABLE 5 Hydrograph Characteristics Of Swale Experiments

Experiment No.	Location	Flow Characteristics Length (feet)	(m)	Duration (hr)	Rainfall Excess Inflow (inches)	(cm)	Swale Outflow (inches)	(cm)	Infiltration (inches)	(cm)	Swale Runoff Coefficients Volume (C_v)	Peak (C_p)
1	Maitland	174	53	3.0	18.18	46.18	7.80	19.81	10.38	26.37	0.43	0.48
2	Maitland	174	53	4.0	11.32	28.75	4.56	11.58	6.76	17.17	0.40	0.46
3	Maitland	160	49	5.5	7.81	19.84	0	0	7.81	19.84	0	*
4	Maitland	174	53	4.0	14.48	36.78	3.76	9.55	10.72	27.23	0.74	0.78
5	EPCOT	295	90	4.2	17.34	44.04	11.76	29.87	5.58	14.17	0.68	0.76
6	EPCOT	295	90	4.0	14.76	37.49	9.72	24.69	5.04	12.80	0.66	0.77

* not defined

TABLE 6 Hydraulic Characteristics Of Swale Experiments

Experiment No.	Location	Length (feet)	(m)	Slope	Rainfall Excess (m/hr)	(in/hr)	Time to Peak (min)	Manning's "n"
1	Maitland	174	53	.0075	0.154	6.06	18	.058
2	Maitland	174	53	.0075	0.072	2.83	30	.086
3	Maitland	174	53	.0075	0.092	3.62	20	.049
4	EPCOT	295	90	.0034	0.105	4.13	25	.031
[illegible]	[illegible]	[illegible]	[illegible]	.0034	0.094	3.69	30	.038

$$Q_o = C_p Q_I \tag{3}$$

where Q_o = outflow hydrograph peak (L^3/T)
C_p = peak runoff coefficient for swale (dimensionless)
Q_I = inflow hydrograph peak (L^3/T)

The peak discharge equation can be used when steady state conditions are achieved.

ROUGHNESS COEFFICIENT

If the Manning equation is used to estimate steady state flow discharge, the choice of the roughness coefficient is needed. Published data gives some indication of a value and the field data collected and reported here also can be used to estimate a value for the roughness coefficient (n). Using the Manning equation:

$$V = K/n \; r^{2/3} \; S^{1/2} \tag{4}$$

where		English	Metric
	K = constant,	1.486	1.0
	V = flow velocity (L/T),	ft/sec	m/sec
	r = hydraulic radius (L),	ft	m
	S = slope along the flow line (L/L),	ft/ft	m/m
	n = roughness coefficient,	(dimensionless)	

and assuming the width of flow to be much greater than the depth of flow (overland flow) and rainfall excess is equivalent to depth of flow per unit time, then the Manning coefficient can be estimated using the equation developed by Wanielista et al. (1983):

$$n = (t_e^{5/3} \; S^{1/2} \; (R/t)^{2/3})/L \tag{5}$$

where R/t = Rainfall excess rate (m/hr)
t_e = time to equilibrum, (min)
L = length of swale (m)

Table 6 illustrates the results with other hydraulic characteristic data. The Manning roughness coefficient is lowest for the EPCOT site most likely because there was new vegetation on the site and thus relatively lower resistance. The vegetation at the Maitland site was more dense and well established. The cover grass is bahia with height varying between inches during the entire experimentation period. The average Mann coefficient (n) was about 0.050.

SWALE BLOCKS

The rainfall excess volume from the 3" storm at the Maitl Interchange would be approximately 100 cubic feet (2.8 cubic meters) about 2500 cubic feet (70.8 cubic meters) at the EPCOT Interchan Infiltration of this volume of water by the swale would at best be ab 60% (1 - 0.40) except for that storm similar to the third experiment. course, low rainfall intensities would allow greater runoff water volu to infiltrate such as in experiment three as shown in Table 5. Thus, f the field experimentation, it is not probable that these swales infiltrate the inflow waters from a 3 inch (7.6 cm) rainfall event. V long swales with long detention times and high infiltration rates would required. Swale blocks to provide storage of that rainfall excess removed by infiltration through the swale must be designed for t situation.

Rehmann-Koo (1984) developed swale block spacing for the runoff f an interstate highway system. The runoff volumes were from one and th inch storms and the calculated required swale block storage for two ty of soil are shown in Table 7. For this swale block spacing analysis, infiltration rates were considered. The high infiltration rate waters had a rate (limiting of 1 in/hr, 2.54 cm/hr) similar to "A" type hydrologic classified soils while the low infiltration rate watershed ha much lower rate (about 0.1 in/hr, 0.254 cm/hr).

TABLE 7 Required Storage Volume for Two Watershed Infiltration Rates Using a 1" and 3" Volume of Rainfall

Watershed	Volume of excess/foot of highway (ft^3 volume/ ft highway)* 1" of rainfall	3" of rainfall
Impervious (no infiltration)	8.33	25.0
Infiltration Rate (0.1 "/hr)	7.60	22.8
Infiltration Rate (1"/hr)	3.80	11.4

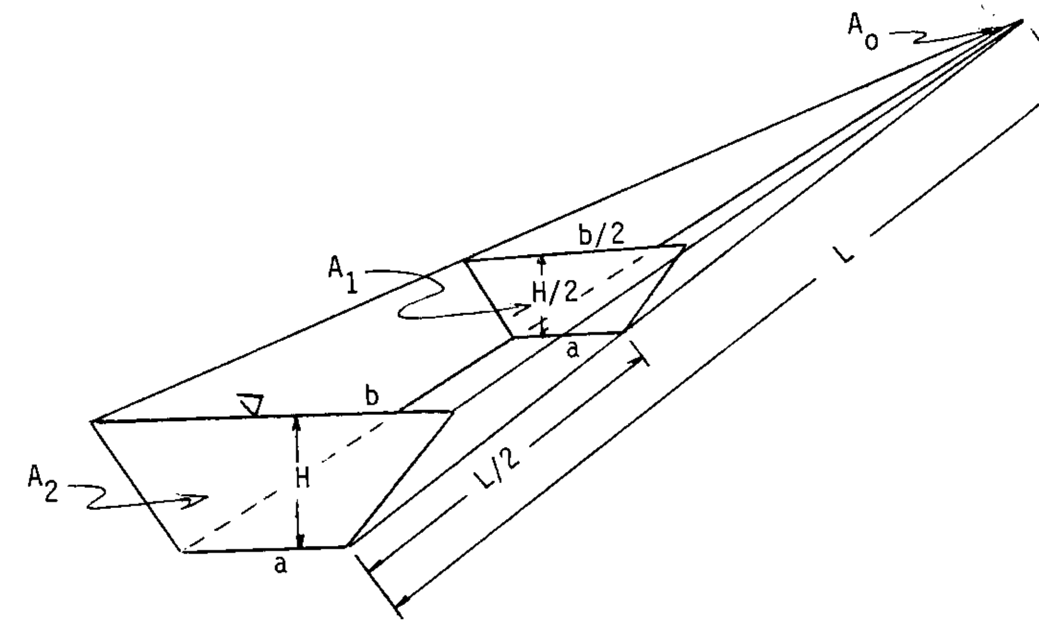
*Adopted from Rehmann-Koo (1984)

Since a swale block will produce a pool of water similar in shape to a frustum, the required storage area and geometry can be calculated for various cross sections and slopes of swales. All the as-built swale and ditch cross sections that were measured at the Maitland and EPCOT Interchanges can be approximated more easily by a triangular section. However, they were most likely designed as a trapezoidal section. For the analysis of an operational highway, it is expected that grass cutting equipment and normal slope deterioration will reduce the trapezoidal section to one approximating a bowl or triangular shape. For analysis of swale blocks, the triangular shape is assumed. Typically the Florida Department of Transportation (FDOT) uses a trapezoidal ditch rather than a triangle as shown. The trapezoidal shape provides more soil contact area for infiltration. Thus, the trapezoidal shape is preferred for infiltration. For a trapezoidal shaped swale, the swale block geometry can be estimated using Equation 6.

$$V = 1/6\ L\ (A_o + 4A_1 + A_2)$$

$$V = 1/6\ L\ \{0 + 4[1/2(a + b/2)H/2] + [1/2(a + b)H]\}$$

where
- L = total length, (ft) (m)
- A_o = Volume at end of swale, (ft^3) (m^3)
- A_2 = Cross-sectional area at berm, (ft^2) (m^2)
- A_1 = Cross-sectional area at half the length, (ft^2) (m^2)
- a = Width of the bottom of the swale, (ft) (m)
- b = Width of swale water line at berm, (ft) (m)
- H = Maximum depth at center line of swale at berm, (ft)



Swale Isometric

For a 6:1 side slope and various longitudinal slopes, Rehmann-Koo developed a berm spacing chart as shown in Figure 3. Similar charts developed for other sets of assumptions on rainfall storms and wa characteristics. Since there is a variety of watershed condition area of highway must be examined separately.

EXAMPLE PROBLEM

Using the data generated from the research reported in the p sections, an evaluation procedure is illustrated using similar s water table conditions. This is done to determine if it is feas

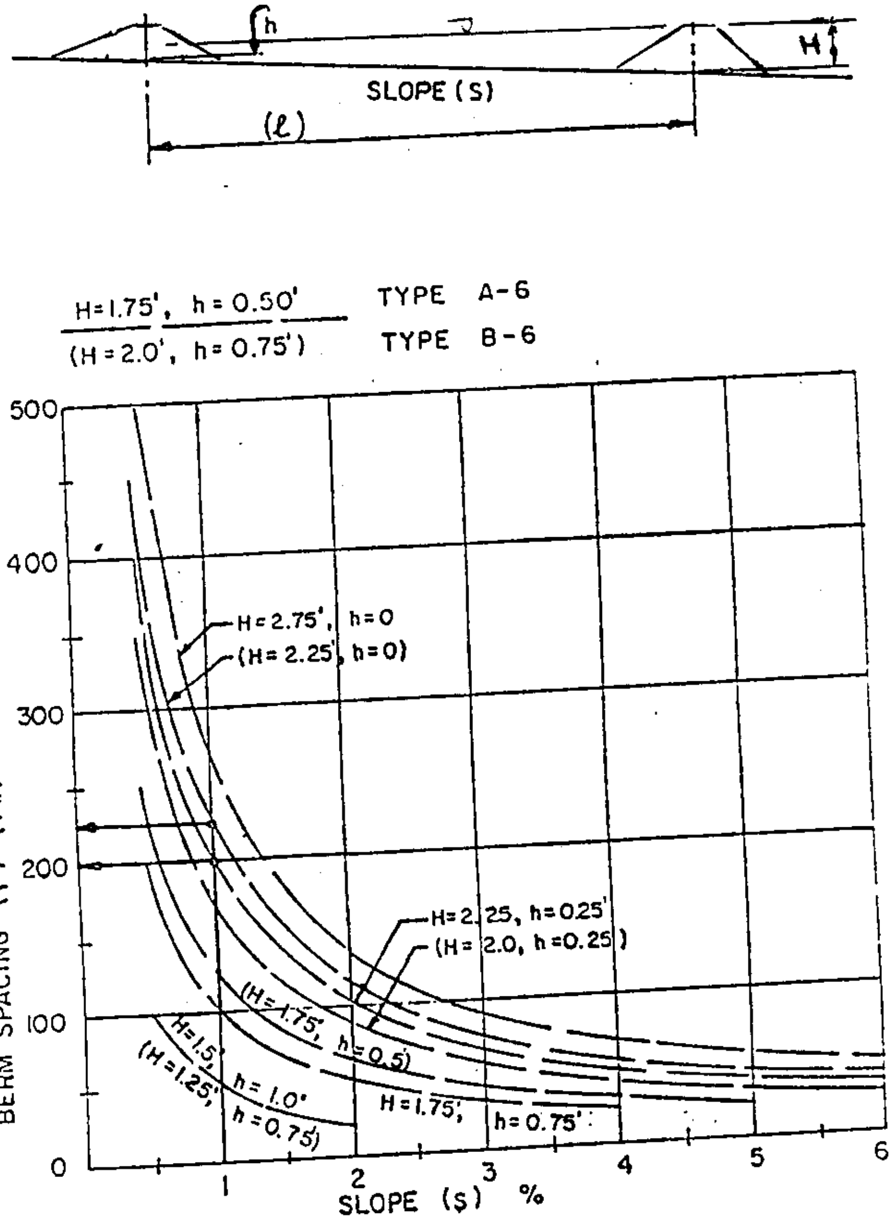


Figure 3 Berm Spacing (ℓ) as a Function of Berm Heights (H, h) and Slope (s) for Swale of Side Slope of 6 on 1

(from Rehmann-Koo, 1984)

construct a swale block for an operational highway. Three inches (7.6 cm of rainfall is used. The watershed area is one acre with a typica watershed runoff coefficient of 0.4. The designer must determine th runoff coefficient value based on actual conditions (Florida Department c Transportation, 1986). These values will vary with the interstate or othe highway under investigation. The runoff volume is:

$$R = (0.4)(3")(43,560\ ft^2/ac)(1\ ac)(1'/12")$$

$$R = 4356 \text{ cubic feet (123 cubic meters)}$$

Using a swale volumetric runoff coefficient, (C_v) of 0.70, a length c swale equal to 500 feet (152 meters), and a cross sectional side slope of on 6, the following calculations for a swale block design results. Th runoff coefficient most likely would be lesser for a 500 foot (152 m length at the Maitland and EPCOT sites. The width of highway at th Maitland site (watershed width) including the swale area is about 90 fee (37 meters). The hydraulic slope of the swale bottom over the 500 fee (152 m) averages .002.

Swale Volume:

$$S = C_v R$$

$$= 0.7(4,356) = 3049\ ft^3\ (86.4\ m^3)$$

Swale Block Design Height:

To store 3049 cubic feet (in a triangular section)

$$S = (L/3)(A + a + \ Aa) \qquad (7$$

$$= 500/3\ (WH/2 + wh/2 + \ (WH/2)(wh/2))$$

$$\text{and } W = 12H,\ w = 12h,\ h = H - .002(500)$$

substituting and solving

$$H = 1.5 \text{ feet (45 cm)}$$

$$\text{and } h = 0.5 \text{ feet (15 cm) (approximately)}$$

A swale block height of 1.5 feet (45 cm) using a (10 to 1) flow line swal block slope is considered reasonable from a safety and maintenanc viewpoint.

If a trapezoidal section with a six foot base were used, the height of the swale block would be 0.8 feet (0.25 m). If the section after construction would remain more trapezoidal, then a lesser height of swale block would be necessary.

Similarly constructed swale blocks on the campus of the University of Central Florida and in Orange County, Florida have had no maintenance problems over a 2 year period of time. Grass cutting has not been a problem.

SUMMARY

Swales are grassy waterways in soils that will infiltrate rainfall excess. With significant infiltration, peak discharges and rainfall excess volume will be reduced. Two field sites were carefully instrumented to document runoff and infiltration. With these data, estimates were made of runoff coefficients that illustrate the effectiveness of the swale to reduce runoff volumes and peak flow rates. Also estimates were obtained for the roughness coefficient of the swales studied. Average runoff coefficients will vary from site to site. An average roughness coefficient of 0.05 is suggested for use in similar systems.

Swale blocks can be used to further retain water for infiltration. Essentially, the geometery of the swale and rainfall excess determine the size of swale blocks and their spacing.

This research should be demonstrated using other field sites to document infiltration rates and to generate site-specific efficiences and design criteria based on infiltration rates, geometry, hydraulic, and hydrologic data.

CHAPTER IV

SWALE BLOCK PERFORMANCE

INTRODUCTION

A site adjacent to a four lane highway located on the campus of th University of Central Florida was selected to determine the efficiency of swale block system. The site was chosen because of its well documente soil and watershed sizes, and because of its proximity for constar investigations. Details for the swale block design are outlined in th Chapter. During rainfall events, runoff volume and solids concentratio were obtained from field instrument and laboratory analysis. The time sp for sediment data collection was from July through October 1983, t typical wet season in the area. Continued observation of the volu retained has proceeded for an additional 2 years.

DESCRIPTION OF SWALE SYSTEM

The swale system studied collects runoff from a watershed area approximately fourteen acres. The watershed is divided into two ma subwatersheds with approximately 5 acres located to the south approximately 9 acres situated to the north of University Boulevard shown in Figure 4. The swale blocks and sampling site locations are sh in Figure 4 and details for the swale block construction in Figure Swale block (A) was constructed in July 1983 and washed out after th consecutive storms. Swale block (A) was not designed to store runoff f a 3 inch (7.6 cm) storm nor was overflow considered. It was not cove with sod and its flow-line slopes were one-to-one. It was built to exam structural design integrity. Swale blocks (B), (C), and (D) were built

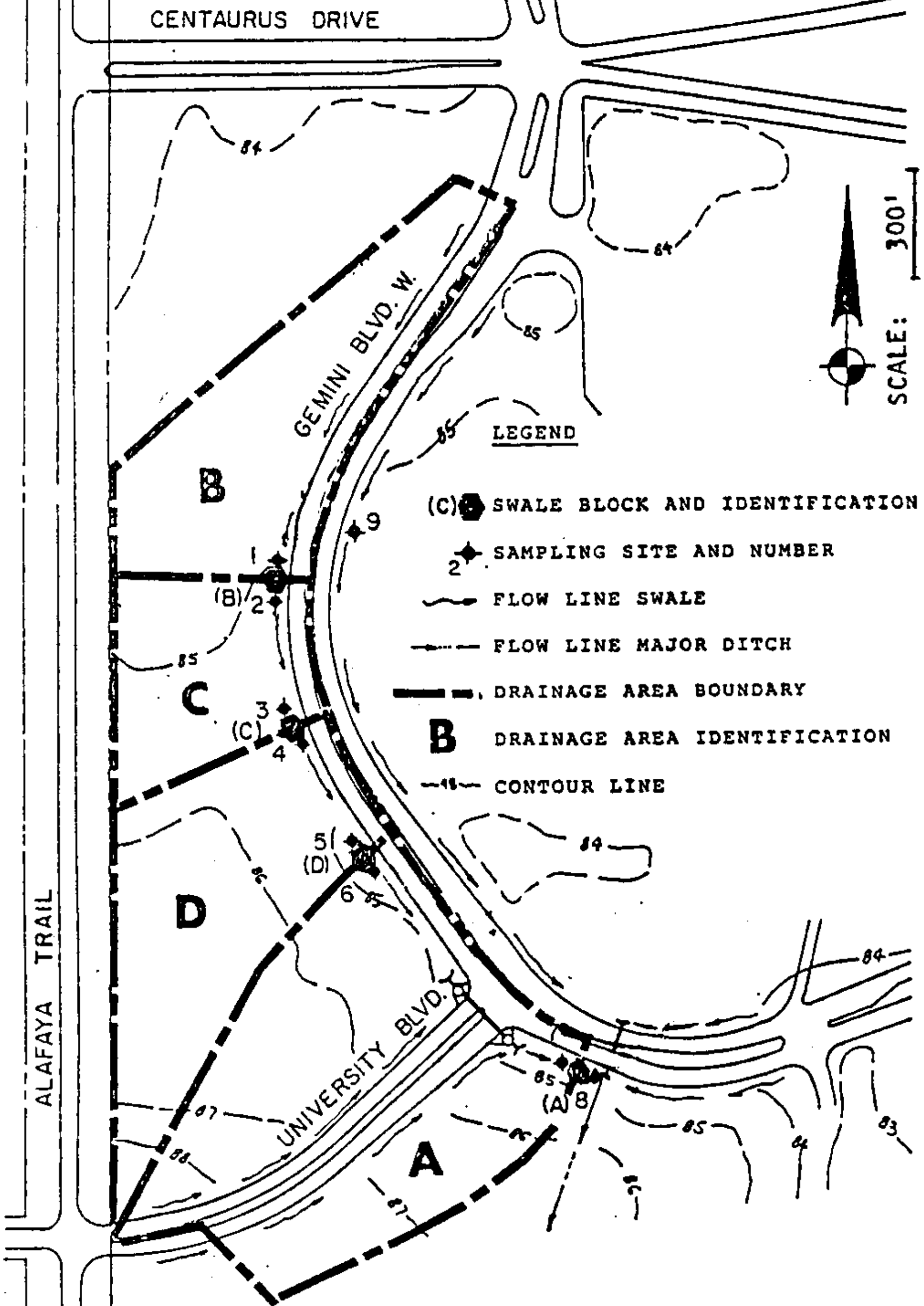
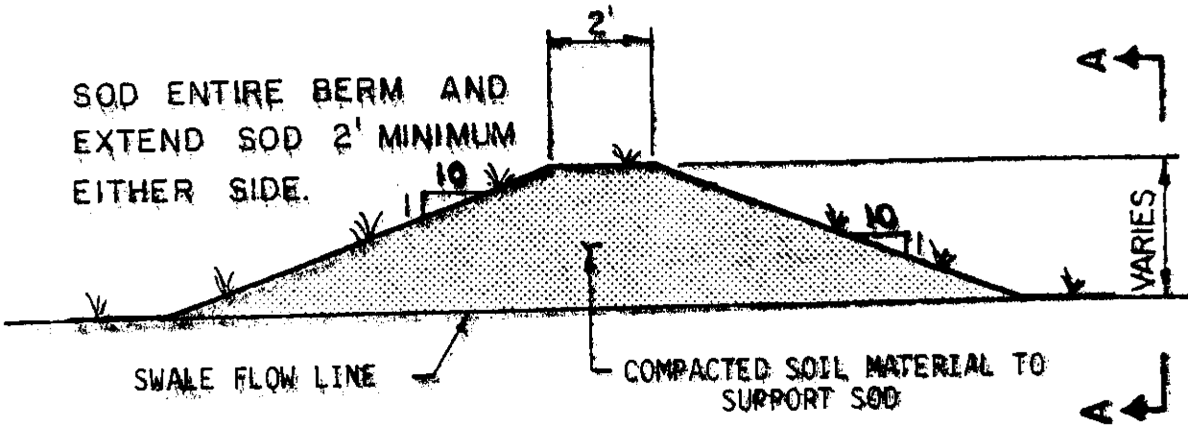
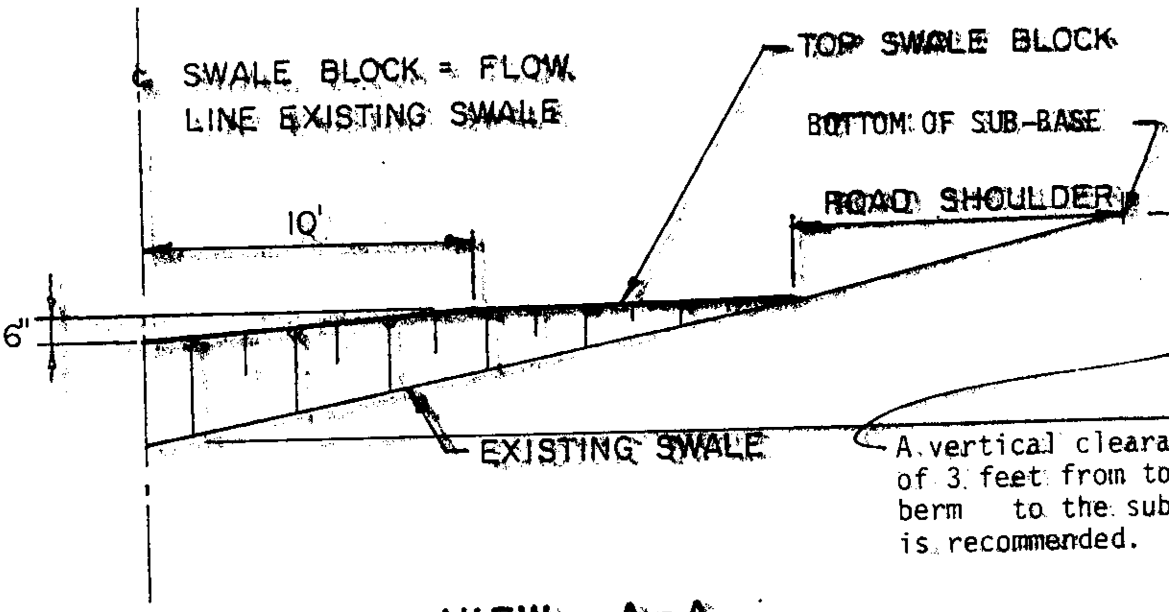


Figure 4 SITE PLAN



TYPICAL SWALE BLOCK CROSS SECTION

Not to Scale



VIEW A-A

Not to Scale

Figure 5 SWALE BLOCK DETAILS

demonstrate proper design and operation. Berms (B), (C), and (D) were constructed with a clayey sand and mechanically compacted having flow-line slopes of six-to-one. The blocks were covered with sod extending two feet either side along the berm toe. The swale blocks still exist 2 years after their construction. Wash-out has not occurred. It is important to keep the height of the swale block above the swale bottom to a minimum to insure that any ponded water does not interact to degrade pavement sub-base materials or produce unsafe conditions. The elevation difference between the bottom of the sub-base materials and the top of the berm is suggested to be at least 3 feet (91 centimeters).

DESIGN OF THE EXAMPLE SWALE SYSTEMS

Parameters of interest to design a swale block are: watershed area, ground cover, type of soil, water table conditions and design rainfall volume. The same design procedures as outlined in Chapter III were employed for design.

The total watershed area as well as the subwatersheds are delineated in Figure 4. The subwatershed areas were delineated from approximate location for the swale blocks. The average slope of the drainage area is about 0.3 percent and runs in an easterly to southeasterly direction. Table 8 lists the individual areas for each subwatershed.

TABLE 8 Subwatershed Areas

Drainage Area	Size (acres)	Size (hectares)
A	5.4	2.2
B	3.1	1.3
C	1.9	0.8
D	3.3	1.3
Total	13.7	5.6

The site was inspected physically and compared with an ae photograph flown in 1981. The three major land uses are (1) roadways, grassed land with some sandy areas and (3) pine trees in sandy soils breakdown of the various land uses for each subwatershed is shown in 9.

TABLE 9 Land Use For Each Subwatershed

Subwatershed	A			B			C			D	
Land Cover	ac	ha	%	ac	ha	%	ac	ha	%	ac	ha
Impervious	0.95	0.38	18	0.33	0.13	11	0.11	0.04	6	0.11	0.0
Grass (70% Cover)	1.05	0.43	19	0.87	0.35	28	0.49	0.20	26	0.59	0.2
Pine Trees	3.40	1.38	63	1.90	0.77	61	1.30	0.53	68	2.60	1.0
Total	5.40	2.19	100	3.10	1.26	100	1.90	0.77	100	3.30	1.3

For the study area the Orange County Soil Survey indicate combination of Blanton, Leon, St. Lucie and Pomello fine sand. Tabl lists the approximate percentage of each soil type.

TABLE 10 SCS Soil Classification And Percentage Of Each Soil Type

Type of Sand	%	SCS Hydraulic Soil Classification
Blanton Fine	20	A
Leon Fine	10	A/D
St. Lucie Fine	60	A
Pomello Fine	10	C

From Table 10 the composite SCS soil classification indicates a drained soil. From field observation to detect the water table and moisture, it was noted that the water table was deeper than one

(30.5 cm) during the wet season. The soils are well drained with high percolation rates. A double-ring infiltrometer estimates a minimum rate of 10-12 inches/hour (25-30.5 cm/hr).

Swale Block (A)

The design parameters for Swale Block (A) are listed as:

Watershed Area:	A = 5.4 ac (2.19 ha)
Impervious Fraction:	I = 0.18
Precipitation:	P = 3 inches (7.6 cm)
Infiltration:	Expected
Swale Cross Section:	6 horizontal to 1 vertical
Swale Slope:	S = 0.3%
Pervious Area Runoff:	PR = 0.15 inches (0.38 cm)

The runoff volume from this drainage area is calculated following standard procedures for estimation. A swale discharge coefficient of 0.7 is used.

$$\text{Total Runoff} = \text{Impervious Area Runoff} + \text{Pervious Area Runoff}$$
$$= I(A)(P)(12''/ft) + (1 - I)(A)(PR)(12''/ft)$$
$$= .18(5.4)(3)(12)^{-1} + .82(5.4)(.15)(12)^{-1}$$
$$= .30 \text{ ac-ft or } 13068 \text{ ft}^3 \ (370 \text{ m}^3)$$

The berm height of swale block (A) is 2 feet (0.61 meters). For a 0.3 percent swale slope, the detained volume upstream of swale block (A) was calculated using equation 7 as 5333 ft^3 (151 m^3). The available volume is much less than the required volume. However, the swale block was built and as expected it failed after three storms in a six day period of time with volume equal to about 1.20, 0.46, and 2.21 inches (30.5, 11.7, and 56.2 mm) respectively.

Swale Block (B), (C) and (D)

The design parameters are the same as stated for swale block (A) except the swale slope is 0.1%. The results for the available and required storage volumes for one foot high swale blocks are listed in Table 11. From this table it can be noted that the available storage volume is less than the required runoff volume for the pervious and impervious portion the watershed area. Because of the mild slopes to the west of the sw and soils with high percolation capability, one foot high swale blocks w chosen for swale blocks (B), (C) and (D). It was assumed that only t runoff from the impervious areas would reach the swale and the runoff fr the pervious areas would percolate into the ground. Some of the watersh area does not contribute runoff because depressions exist in the watershe

TABLE 11 Storage Volumes For Swale Blocks (B), (C) AND (D)

Swale Block	Watershed Area (ac)	(ha)	Impervious Portion (ac)	(ha)	Runoff Volume (ft^3)	(m^3)	Availabl Storage* (ft^3)	(m
(B)	3.10	1.26	0.33	0.13	3594	102	2920	8
(C)	1.90	0.77	0.11	0.05	1198	34	976	2
(D)	3.30	1.34	0.11	0.05	1198	34	975	2

*Storage volume for 1' high swale blocks

FIELD DATA

The data collected at the study site during storm events were rai fall, volume runoff and suspended solids. Runoff water samples we collected at each sampling site as indicated in Figure 4. Two 500 mill liter samples were collected at each site and analyzed for suspended soli in the laboratory immediately after collection. The methods employed collection of the field data are described in the following section.

Rainfall Volume

Because of the localized storms, which are characteristic of t Central Florida area, two rain gages were placed within the watershed; o was located near swale block (B) and the other in the vicinity of swa block (D). Rainfall is recorded daily at the University's Wastewater Treatment Plant, located approximately one half mile southwest of the study site.

It has been observed that storms of about 1.5 inches (3.8 cm) correlate very well with rainfall data from the gage located one-half mile from the berms, but smaller storms were more localized and would sometimes not register at one or the other gaging station.

Runoff Volume and Suspended Solids

To measure the collected volume between the swale blocks (B), (C) and (D) stakes were placed along the swale flow line at twenty foot intervals. The stakes were permanently marked at 0.5 inch (1.3 cm) intervals and the cross- sectional areas were determined for the corresponding heights. To calculate the volume of runoff, the depths were measured at each marker and the corresponding areas calculated for each reading. The volume between the markers was then calculated with an equation for a triangular section.

The topography of the area suggests that nearly all the runoff in the swales originates from the roadways, partly because the slopes of the impervious surfaces are several times steeper than the gentle slopes of the pervious areas. Runoff volumes were recorded in the swales and suspended solids levels recorded for the waters in the swales. Sampling was done to record the solids levels in the water only and not in the bed load. The sampling site locations 1 through 9 are shown in the Site Plan, Figure 4, which corresponds to the sampling location numbers and swale block identifications in Table 12 and 13. Table 12 reports on the runoff volumes after the storm events and Table 13 reports the suspended solids levels.

During the storm events of summer and fall 1983, no runoff over the swale blocks (B), (C) or (D) was observed. Water depths of zero to nine

inches maximum were recorded. If rainfall events occurred with only a c
to two day recurrence interval, the stormwater in the swales was unable
percolate completely before the next storm event. For storms with a long
recurrence interval (several days or weeks) the swales would dry out with
a one to two day period. The greatest rainfall observed was 2.35 inches

TABLE 12 Runoff Volume Between Swale Blocks*

1983 Dates	Rainfall in	Rainfall cm	Up Stream of (B) ft^3	Up Stream of (B) m^3	Up Stream of (C) ft^3	Up Stream of (C) m^3	Up Stream of (D) ft^3	Up Stream of (D) m^3	Down Stream of (D) ft^3	Down Stream of (D) m^3	Remarks
9/03	0.70	1.78	330	9.4	230	6.5	200	5.7	200	5.7	Erosion eviden swale block D
9/19	1.55	3.94	200	5.7	370	10.5	420	11.9	630	17.9	
9/20	0.30	0.76	0	0	0	0	230	6.5	300	8.5	
9/21	0.50	1.27	130	3.7	220	6.7	420	11.9	500	14.2	On 9/22 standi water of sever inches was obs between swale (B), (C) and (
10/11	1.30	3.30	0	0	0	0	0	0	0	0	
10/17	2.35	5.97	200	5.7	270	7.7	330	9.4	240	6.8	

*approximately one hour after every storm event

TABLE 13 Rainfall (Inches) And Average Total Suspended Solids Concentrations (mg/L) For Various Storm Events

Date	Rainfall (inches)	Rainfall (cm)	Suspended Solids at sample site (mg/L) (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
7/27/83	0.41	1.04	*	*	*	*	*	*	34	21
9/03/83	0.70	1.78	21	26	41	45	443	204	71	41
9/19/83	1.55	3.94	4	18	6	17	230	220	136	34
9/20/83	0.30	0.76	3	2	6	*	*	*	54	*
9/21/83	0.50	1.27	3	9	10	47	187	539	23	6
10/11/83	1.30	3.30	*	*	*	*	*	*	248	48
10/17/83	2.35	5.97	40	33	31	38	108	372	114	36

*Missing data because water depth insufficient to sample

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Erosion and sediment transport are possible problems in the operation of highways. Erosion of shoulder areas can alter the structural integrity of the pavement, cause localized flooding and provide sediment which in turn can reduce hydraulic capacity of drainage structures. In addition, sediment can be a primary cause of off-site pollution problems. It would be very helpful to highway designers and maintenance crews to identify the effectiveness of erosion control practices and methods for sediment retention.

Erosion control can be most effectively accomplished using sod or other permanent vegetative cover. Effectiveness is measured by the quantity of sediment retained. Experiences at a field test site showed that those areas that were not sodded experienced erosion and those that had a permanent cover had less erosion with lower sediment loads. Other methods of erosion control were identified from the literature and compared to sodding. Sodding was found to be the most effective method.

Sediment control of stormwater discharges is primarily done using off-line retention (diversion) and detention ponds. Their solids retention effectiveness has been defined and related to design criteria. Swales have not been quantified as to their retention efficiencies. Swales are grassy waterways that transport and infiltrate runoff waters. With significant infiltration, peak discharges and runoff volume will be reduced. Runoff coefficients for two swale areas adjacent to an interstate highway were estimated. A maximum value of 0.74 was noted in six experiments. Also, the roughness coefficient in the Manning equation was estimated as 0.05.

This runoff coefficient and roughness coefficient are appropriate for the length, slope, and vegetative covers in the experimental area. Thus, the values are site specific.

It is highly unlikely that a swale can be designed to retain most runoff waters. Longitudinal and side slopes would have to be, in general, very minimal and the swale very long. However, earthen cross barriers or swale blocks can be used to increase retention. A procedure for swale block design was developed. Three swale blocks were constructed to illustrate operational effectiveness. The blocks were designed to retain the runoff from a 3 inch (7.6 cm) storm event. After more than two years of operation and three storms of over 3 inches (7.6 cm), the retained water has not been known to overflow the block. Thus it is possible that swales and swale blocks within highway right-of-ways can be designed and operated to be as effective in the retention of solids as retention and detention systems.

To retain solids within an operating highway system, the following recommendations are made.

1. Permanent vegetative covers are used to reduce erosion. Other erosion control methods should be considered if their effectiveness is equal to or greater than permanent vegetative covers. However, the use of non pervious erosion control will defeat the infiltration concept in the swale.
2. Sediment can be retained using off-line retention, on-line retention, detention systems, and swale blocks.
3. Swale blocks should be designed using the methodologies of this report. The volume of runoff for each design should incorporate an estimate of infiltration volume.

4. Swale block design must consider at least a 3 feet (91 cm) clearance between the top of a swale block and the bottom of sub-base materials and not present a safety hazard. The beam flow line slopes should be about 1 vertical to 10 horizontal. The maximum height is about 1 1/2 feet.

5. Additional data on infiltration rates, runoff coefficients and roughness coefficients should be obtained for other swales and swale blocks adjacent to highways. This will aid in determining a general design procedure.

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