Development of Regionalized Curves for Drainage Area Versus Sediment Basin Size

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The Environmental Protection Agency (EPA) has required the South Carolina Department of Transportation (SCDOT) to obtain National Pollutant Discharge Elimination System permits for storm water discharges from construction sites. EPA has assigned regulatory authority for issuing these permits to the South Carolina Department of Health and Environmental Control (DHEC). Additional regulatory requirements have been implemented by DHEC's delegated authorities. These additional requirements further define the EPA regulatory requirements and mainly comprise limits on the effluent from construction-site runoff. The effluent limits for construction-site runoff have been set to achieve an equivalent removal efficiency of 80 percent for suspended solids or a peak settleable solids concentration of 0.5 ml/L. Only one of these effluent limitations must be met to satisfy the permit requirements. DHEC's delegated authorities will issue permits on the basis of standard engineering calculations that show that the proposed sediment basins will meet the required effluent limitations. A computer program named SEDIMOT is recommended by DHEC's delegated authorities to establish the sediment basin sizes. SEDIMOT was used to model standardized sediment basins that will be used by SCDOT throughout South Carolina. The state was divided into two hydrologic regions (Piedmont and Coastal Plain), and two statewide soil categories were determined for the computer simulations. A range of sediment basin sizes was determined with SEDIMOT that meets effluent limitations for each region and soil category in the state. This information was summarized in charts for SCDOT to use in the design of sediment basins. The charts provide the required sediment basin size depending on the drainage area for each region and soil category in the state. SCDOT intends to use the charts to determine the sediment basin sizes that will be included in permit applications to DHEC's delegated authorities.

In 1972 the U.S. Congress enacted the Federal Clean Water Act to restore the quality of the nation's rivers and streams. Amendments to this law in 1987 required the Environmental Protection Agency (EPA) to regulate the release of the sediment-laden runoff that flowed into these bodies of water from construction activities involving 2.02 ha [5 acres (ac)] or more of land disturbance. To implement the Clean Water Act Amendments, EPA began requiring National Pollutant Discharge Elimination System permits for qualifying construction sites.

The authority to regulate these EPA permits in South Carolina was assigned to the South Carolina Department of Health and Environmental Control (DHEC). DHEC's delegated authorities, the South Carolina Land Resources Conservation Commission and the South Carolina Coastal Council, have implemented additional regulatory requirements that have further defined EPA's regulatory requirements. These authorities currently issue permits that require construction projects to meet the standards established in the South Carolina Stormwater Management and Sediment Reduction Act of 1991. These additional requirements are mainly composed of limits on the effluent from construction-site runoff. The effluent limits for such runoff have been set to achieve an equivalent removal efficiency of 80 percent for suspended solids or a peak settleable solids concentration of 0.5 ml/L for the 10-year, 24-h design event. Construction projects need to meet only one of these effluent limitations to satisfy the permit requirements.

The South Carolina Department of Transportation (SCDOT) is required to obtain permits for construction activities involving 2.02 ha (5 ac) or more of land disturbance. Each permit application usually includes the design of sedimentation devices that range in size from small sediment traps to large sediment ponds. The design procedure preferred by the delegated regulatory authorities is primarily based on the results of a computer program named SEDIMOT.

Ralph Whitehead & Associates was hired by SCDOT to perform numerous generalized SEDIMOT II (1983) computer simulations and to develop regionalized curves for drainage area versus sediment basin size. The state was divided into two hydrologic regions, and two statewide soil categories were determined for the computer simulations. SCDOT provided standard details for three different types of sedimentation devices to be used in the computer simulations. Results of the computer simulations were used to develop the regionalized curves. The sediment basin sizes determined with the regionalized curves will be used by SCDOT in permit applications to the delegated regulatory authorities.

SCDOT has funded the study described here to provide a manual for day-to-day use by its design and resident construction engineers. The use of the manual will allow a consistent approach to sedimentation design performed for SCDOT by a variety of users. The overall effect of using the manual will be a rational and economical design approach resulting in effective sediment control.

DESIGN PARAMETERS

Engineering design parameters were selected to provide generalized design data that would be representative of conditions at typical South Carolina highway construction projects. Four design categories were selected to address the various hydrologic and soil conditions across the state. The generalized designs that were prepared are based on two hydrologic divisions of South Carolina and two soil categories. The state was divided into the Piedmont and Coastal Plain areas to address the different hydrologic conditions of the state (Figure 1). Generally, when compared with the Coastal Plain, the Piedmont has less rainfall from each storm and shorter times of concentration.

In addition to the two hydrologic divisions of the state, two soil categories were considered for each hydrologic region. The two

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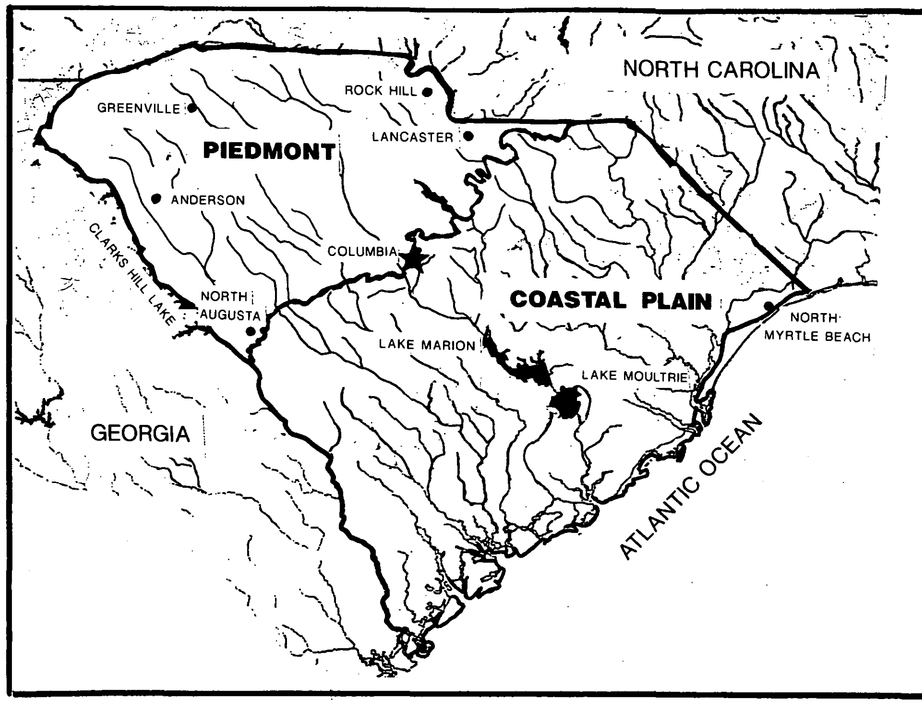

FIGURE 1 Delineation between Piedmont and Coastal Plain regions.

soil categories were selected from DHEC's delegated authority's eroded particle distribution list and are referred to as coarse soil and fine soil. A soil type with a median particle distribution was chosen to represent coarse soils; a soil type with the finest particle distribution was chosen to represent fine soils. The selection of these soil types for inclusion in the SEDIMOT analyses provided calculated results that meet or exceed the required effluent limitations for all soils in the state.

For a soil to be classified as a coarse soil, the following particle size criteria had to be met:

	Eroded Particle Distribution (percent finer)			
Size (mm)	0.044	0.038	0.004	0.003
Coarse soil	0–32	0–31	0–6	0–4

Particle sizes of 1.4, 1.0, and 0.063 mm did not significantly affect the SEDIMOT results, and all of the percent finer values for the 0.001-mm size were zero. Soil that did not meet these particle size criteria was classified as fine soil. The division between coarse soil and fine soil was selected to classify approximately half of the soils in the state into each category.

The generalized designs also addressed the range of slopes normally found on and adjacent to highway construction projects across the state. The slopes in the Piedmont area generally tend to be steeper than those in the Coastal Plain. In both areas the average slopes tend to be steeper for small drainage areas. The variation in slope, depending on the drainage area, is mainly due to the isolated, steep slopes resulting from human activities (i.e., cuts and fills) related to highway construction.

The main design components of the sedimentation devices consisted of the storage volume and the discharge structure. The storage volume, as used in the SEDIMOT analyses, was defined with a pool-area ground surface that had a low point and uniform slopes on all sides. The sediment storage volume was assumed to be full and was not included in the SEDIMOT simulations. This assumption was necessary, since the sediment storage volume will not be cleaned out after each storm and the entire volume identified in the SEDIMOT analysis must be available for runoff storage. For the sake of convenience the runoff storage volume was defined as the volume below the crest of the discharge structure. Actually, the true runoff storage volume is below the maximum pool elevation, but this is a difficult point to define for design purposes. The discharge structures were either broad-crested weirs or riser-pipe combinations. Standard engineering calculations were performed to determine the discharge characteristics of the outlet structures.

The primary focus of the present study was identification of the necessary runoff storage volume for the sediment basins. The sediment storage volume will not adversely affect the performance of the sediment basins, provided the sediment storage volume is cleaned at the proper intervals. SCDOT has decided to use a sediment yield of 127 m^3/disturbed ha [67 yd^3/disturbed ac] to size the sediment storage volume. This value may be changed by SCDOT in the future on the basis of the history of clean-out requirements. The sediment yield value was chosen after consultation with SCDOT and review of the sediment yield requirements for the mining industry (*1*). The sediment yield that was chosen is based on 13 mm (½ in.) of uniform erosion from the disturbed area.

TABLE 1 Design Parameters

10-year, 24-hour rainfall (Piedmont): 140 mm
10-year, 24-hour rainfall (Coastal Plain): 165 mm
100-year, 24-hour rainfall (Piedmont): 203 mm
100-year, 24-hour rainfall (Coastal Plain): 254 mm
Drainage area for sediment traps with Type C filters:
0.13 ha for normal crown roadway and
0.28 ha for superelevated roadway
Drainage areas for sediment traps with Types A & B filters, and sediment dams: 0 to 0.4, 0.4 to 2.0, 2.0 to 4.1 ha
Drainage areas for sediment basins: 0 to 2.0, 2.0 to 4.1, 4.1 to 8.1, 8.1 to 20.2 and 20.2 to 40.5 ha
Hydrologic soil group: B (Piedmont and Coastal Plain)
Construction CN: 0 to 2.0 ha
4.1 to 40.5 ha
Eroded particle distributions:

		Percent Finer							
		Size (mm)							
	K	1.4	1.0	0.063	0.044	0.038	0.004	0.003	0.001
Finest soil (Nemours)	0.28	100.0	80.6	36.2	35.0	34.9	15.5	11.2	0.0
Median soil (Chenneby)	0.24	100.0	99.0	98.0	30.9	30.9	5.7	3.7	0.0
			(84.8)	(49.9)					

Specific gravity: 2.65
Submerged bulk specific gravity: 1.35
SEDIMOT slope length: 31 m for 0.4 to 40.5 ha, 21 m for superelevation and 9 m for normal crown

SEDIMOT percent slope:	Piedmont	Coastal Plain
for 0.13 ha (Normal crown)	2.1%	2.1%
for 0.28 ha (Superelevation)	6.3%	6.3%
for 0.4 ha	20.0%	15.0%
for 2.0 ha	15.0%	10.0%
for 4.1 to 40.5 ha	10.0%	5.0%

Sediment yield: 127 m^3/disturbed ha (67 cy/disturbed ac)
Sediment removal efficiency: 80% suspended solids or 0.5 ml/l peak settleable solids

UNIT CONVERSIONS:

1 in = 25.4 mm
1 ha = 2.47 ac

The design parameters used in the study were selected to represent general conditions throughout South Carolina and to address the varying hydrologic, soil, and physical conditions across the state. Table 1 gives these parameters.

LIMITATIONS

The representative designs and details in the present study have been developed for temporary structures used during the construction of SCDOT roadway projects under normal site conditions.

The representative spillway designs and details in the study are based on drainage areas that are entirely disturbed with an average hydrologic soil group (B) and average topographic slopes. Modifications may be needed for sites that differ from these conditions; for example, when the majority of the drainage area is highly urbanized or when the pool area has steep slopes, the spillway sizes may need to be increased.

The representative erosion control and sedimentation designs and details used in the study are based on drainage areas that are entirely disturbed. Modifications may be needed for sites that differ from these conditions; for example, when the majority of the drainage area is vegetated and undisturbed, the procedures in this manual may result in structures that are larger than needed.

SCDOT STANDARD SEDIMENTATION DEVICES

SCDOT has prepared three standard construction details for sedimentation devices: sediment trap, sediment dam, and sediment basin. These standard details are the same sedimentation devices discussed in the EPA publication *Storm Water Management for Construction Activities* (*2*). The publication uses the terms *storm drain inlet protection, sediment trap*, and *temporary sediment basin*, respectively, to identify the sedimentation devices covered by SCDOT's standards.

The hydraulic performance of each SCDOT standard sedimentation device was established for inclusion in the SEDIMOT computer model. The input data included elevation versus pond area and discharge rate.

The sediment removal performance of the SCDOT standard sedimentation devices is based on the performance of similar devices documented by Barfield (3). The computer program SEDIMOT II, also by Barfield (4), incorporates the research results and calculation methods presented in that publication. Because SEDIMOT II is recommended for design use by the regulatory authorities in South Carolina, it is understood that the validity of the calculations is acceptable.

The following describes the design of the individual SCDOT standard sedimentation devices that were developed on the basis of the SEDIMOT computer results.

SEDIMENT TRAPS

Sediment traps are used to remove sediment from the runoff leaving small construction areas before the runoff enters a storm drain system. Once the construction areas are paved or fully vegetated, the sediment traps are removed. The components of sediment traps are an inlet structure filter, the sediment storage volume, and the runoff storage volume.

Sediment traps have three different types of inlet structure filters, Types A, B, and C. The Type A filter is used around existing catch basins, the Type B filter is used around new catch basins, and the Type C filter is used in front of curb inlets. The Type A filter is constructed above the grate elevation by using concrete blocks. The Type B filter is constructed below the grate elevation through excavation or by limiting fill placement in the area of the catch basin. The Type C filter is constructed by placing a small aggregate dam at the downstream end of the curb inlet. Type C filters are not required for sediment traps in curb inlet sag locations, since the sag and concrete gutter form the necessary runoff storage volume.

The design sediment storage volume for sediment traps with Type A and B filters is calculated on the basis of the area of exposed soil within the drainage area of the trap. Cleaning will be performed for sediment traps with Type A and B filters when the sediment storage volume is reduced by half. The sediment traps with Type C filters do not require a sediment storage volume, since they will be in service only for a short time. Cleaning the sediment from the front of each Type C filter is required after each storm.

The runoff storage volume for sediment traps with Type A filters will be provided between the top of the total sediment volume and the top of the concrete blocks. The runoff storage volume for sediment traps with Type B filters will be provided between the top of the total sediment volume and the top of the grate. The runoff storage volume for sediment traps with Type C filters will be provided between the subgrade and the edge of the concrete gutter.

Sediment trap designs have been developed for projects in the Piedmont and Coastal Plain areas (Figure 1) with fine and coarse soils. The design criteria are shown in Figures 2 to 6. The design details are shown in Figure 7.

The sediment storage volume for sediment traps with Type A and B filters is variable and depends on the area of exposed soil in the highway project. The sediment storage volume is obtained by multiplying the disturbed area of the highway project within the drainage area of the filter by 127 m^3 disturbed ha (67 yd^3/ac). The runoff storage volume for sediment traps with Type A and B filters is obtained from Figure 2 or 3.

The sediment storage volume is not included in the sediment traps with a Type C filter design. These traps are only in service for a short time, and the sediment is required to be cleaned out after each storm. Sediment dams or sediment basins will be designed to control the sediment from the roadway earthwork until the sediment traps with Type C filters are in place. The allowable effluent limits for the sediment traps at curb inlets in areas with fine soils will be exceeded for some roadway geometries. When the limits for the sediment traps are exceeded, additional traps will be placed between the curb inlets. In areas with coarse soils the allowable effluent limits will be met by using a sediment trap at each curb

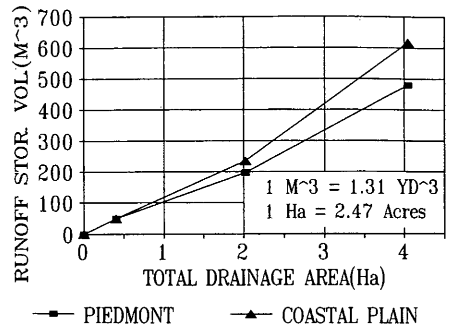

FIGURE 2 Design criteria for sediment trap Type A and B inlets and sediment dams: fine soil.

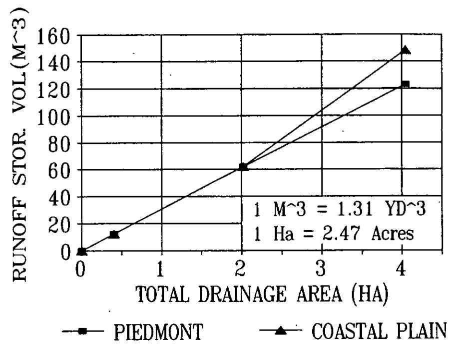

FIGURE 3 Design criteria for sediment trap Type A and B inlets and sediment dams: coarse soil.

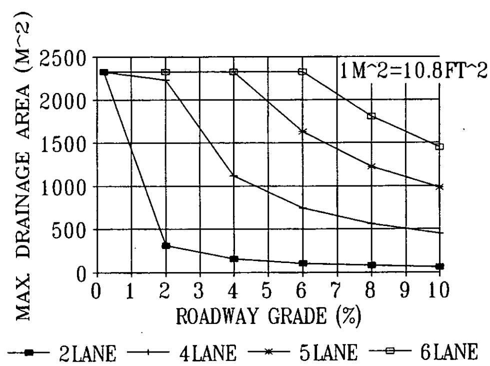

FIGURE 4 Design criteria for sediment trap Type C: normal crown fine soil.

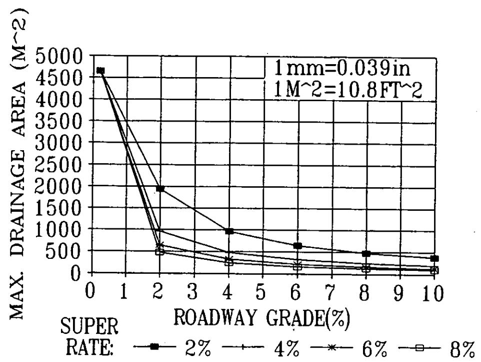

FIGURE 5 Design criteria for sediment trap Type C: fine soil, 203-mm subgrade superelevation.

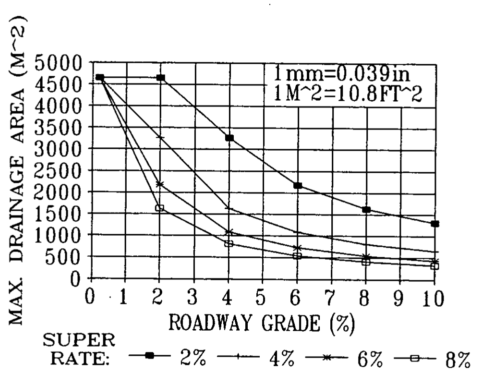

FIGURE 6 Design criteria for sediment trap Type C: fine soil, 305-mm subgrade superelevation.

inlet. The design requirements for Type C filters are summarized in Figures 4 to 6.

SEDIMENT DAMS

Sediment dams are used to remove sediment from the runoff leaving relatively small construction areas. Once the construction areas are fully vegetated, the sediment dams are removed.

The main components of a sediment dam are the rock dam, the rock spillway, the aggregate filter, the sediment storage volume, and the runoff storage volume.

The maximum total area draining to a sediment dam is 4 ha (10 ac) or less. The sediment dams will usually be located inside the right-of-way in a cut ditch or along the toe-of-fill.

The design sediment storage volume is calculated on the basis of the area of exposed soil within the drainage area of the sediment dam. The design sediment storage volume will generally be obtained by incisement. Cleaning is performed when the sediment storage volume is reduced by half. The runoff storage volume is provided between the top of the total sediment volume and the rock spillway crest elevation.

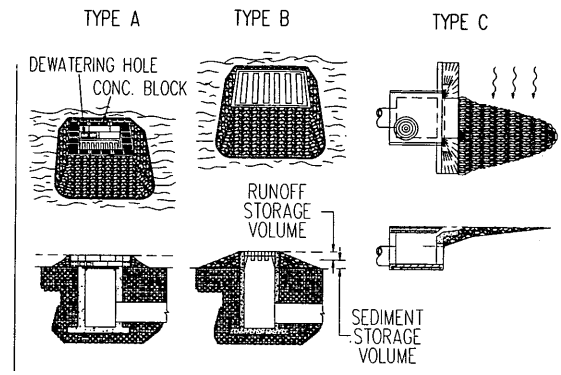

FIGURE 7 Inlet structure filter (SCDOT Drawing 815-4).

Sediment dam designs have been developed for projects in the Piedmont and Coastal Plain areas (Figure 1) with fine and coarse soils. The design criteria are shown in Figures 2 and 3. The design details are shown in Figure 8.

The sediment storage volume for each design is variable and depends on the area of exposed soil in the highway project. The sediment storage volume is obtained by multiplying the disturbed area of the highway project within the drainage area of the sediment dam by 127 m^3/ha (67 yd^3/ac). The runoff storage volume is obtained from Figure 2 or 3.

SEDIMENT BASINS

Sediment basins are used to remove sediment from the runoff leaving relatively large construction areas. After the construction areas are fully vegetated the basins may be removed or released to the landowner.

The sediment basin mainly consists of the earth dam, the principal spillway, the emergency spillway, the sediment storage volume, and the runoff storage volume.

Sediment basins are often located outside the roadway right-of-way on a small creek or drainage pattern. The sediment storage volume may be obtained through excavation or may be established

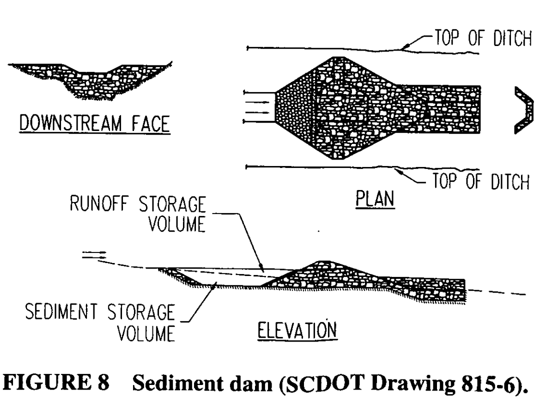

FIGURE 8 Sediment dam (SCDOT Drawing 815-6).

on the basis of the existing topography. In either case the top of the total sediment volume will not exceed the elevation 152 mm (6 in.) above the top of the outlet pipe. Cleaning is performed when the sediment volume is reduced by half. The runoff storage volume is provided between the elevation 152 mm (6 in.) above the top of the outlet pipe and the top of the riser.

Sediment basin designs have been developed for projects in the Piedmont and Coastal Plain areas (Figure 1) with fine and coarse soils. The design criteria are shown in Figures 9 and 10. The design details are given in Figure 11 and Table 2.

The sediment storage volume for each design is variable and depends on the area of exposed soil in the highway project. The sediment storage volume is obtained by multiplying the disturbed area of the highway project within the drainage area of the sediment basin by 127 m^3/ha (67 yd^3/ac). The runoff storage volume is obtained from Figure 9 or 10.

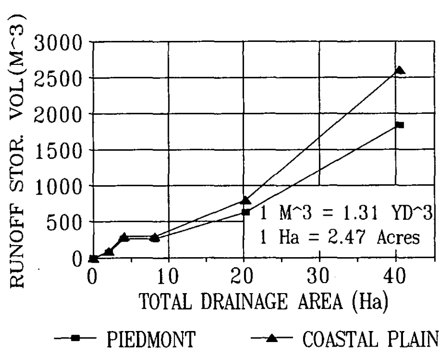

FIGURE 9 Storage volumes in sediment basins: fine soil.

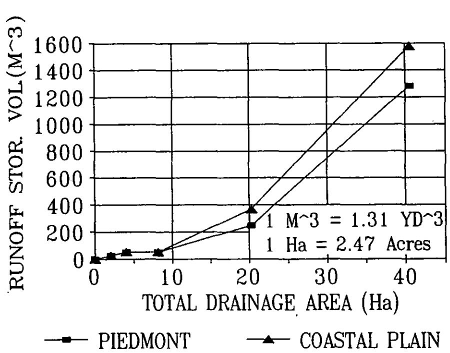

FIGURE 10 Storage volumes in sediment basins: coarse soil.

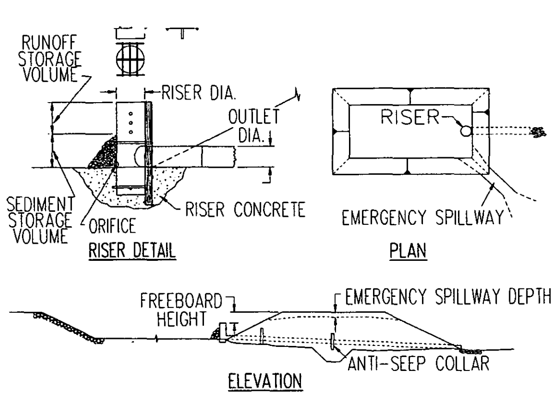

FIGURE 11 Sediment basin (SCDOT Drawing 815-2).

SUGGESTIONS FOR FURTHER STUDY

During the numerous SEDIMOT simulations it became apparent that certain combinations of design data produced unexpected results. To illustrate this phenomenon two relatively simple problems have been prepared by eliminating as many irrelevant variables as possible. The two SEDIMOT analyses outlined in Table 3 are identical except for the depth of each sediment basin. In both simulations the basin volume is defined using a vertically sided storage volume. The vertically sided storage volume allows a constant sediment basin area to be used in both simulations. The change in sediment basins is achieved by increasing the depth in one of the simulations.

Basic knowledge of sedimentation principles would lead a person to expect that a larger sediment basin rather than a smaller one would be more effective in removing sediment. As Table 3 illustrates the results of the SEDIMOT analyses contradict the expected results. Further study of the SEDIMOT program and possible modifications to the program or documentation may help to resolve this issue.

CONCLUSIONS

The development of regionalized curves for the design of sedimentation devices will reduce the time and level of expertise required to complete each project. Given the same drainage area, this design method results in a range of sedimentation device sizes that depend on the location and soil types in the project area. In areas where hydrologic and soil conditions allow smaller sedimentation devices, cost savings will result from reduced design time and construction cost. The use of such regionalized curves in the design of SCDOT sedimentation devices will provide an environmentally effective control of sediment-laden runoff from highway construction projects.

TABLE 2 Values for Figure 11 (SCDOT Drawing 815-2)

TEMP SEDIMENT CONTROL STRUCT SIZE (RISER DIA.X OUT DIA.)	FREEBOARD HEIGHT	EMERGENCY SPILLWAY DEPTH	ALLOWABLE PIPE MATERIAL	DIAMETER OF ORIFICE (mm)	NUMBER OF ANTI-SEEP COLLARS	RISER CONCRETE (M^3) •
610 mm X 457 mm	610 mm	305 mm	PE	102	1	0.765
762 mm X 610 mm	610 mm	305 mm	PE	102	1	1.53
914 mm X 762 mm	1219 mm	610 mm	PE	102	1	2.29
1219 mm X 914 mm	1219 mm	610 mm	CSP	152	2	4.59
1372 mm X 1067 mm	1219 mm	610 mm	CSP	152	2	6.88
1524 mm X 1219 mm	1219 mm	610 mm	CSP	152	2	9.18

•FOR DEPTH OF BASIN GREATER THAN 3 OUTLET PIPE DIAMETERS, CONCRETE VOLUMES NEED TO BE CALCULATED

TABLE 3 Comparison of Sediment Basin Depths and SEDIMOT Results

	0.15 m Depth Basin	0.61 m Depth Basin
Storm type	SCS's Type 2	SCS's Type 2
Rainfall depth (mm)	140	140
Storm duration (hr)	24	24
Time increment (hr)	0.10	0.10
Specific gravity	2.65	2.65
Coefficient for distributing sediment load	1.5	1.5
Submerged bulk specific gravity	1.35	1.35
Type of sediment control structure	pond	pond
Subwatershed area (ha)	4.1	4.1
Curve number	81	81
Time of concentration (hr)	0.13	0.13
Unit hydrograph and surface condition	disturbed	disturbed
Soil factor (k)	0.28	0.28
Length of slope (m)	30.5	30.5
Average slope (%)	10	10
Control practice factor	1.0	1.0
Particle size distribution	fine soil	fine soil
Time increment of the routed hydrograph (hr)	0.1	0.1
Non-ideal settling correction factor	1.0	1.0
Percent of permanent pool that is dead space	50	50
Outflow withdrawal option	surface	surface
Inflow vertical concentration	completely mixed	completely mixed
Number of routed hydrograph points	500	500

Pond stage data:

152 mm Depth Basin				**610 mm Depth Basin**			
Elev. (m)	Area (ha)	Volume (ha-m)	Discharge (m^3/sec)	Elev. (m)	Area (ha)	Volume (ha-m)	Discharge (m^3/sec)
0.0	0.14	0.0	0.0	0.0	0.14	0.0	0.0
0.076	0.14	0.011	0.0	0.305	0.14	0.042	0.0
0.15	0.14	0.021	0.0	0.610	0.14	0.085	0.0
0.305	0.14	0.042	0.331	0.762	0.14	0.106	0.331
0.458	0.14	0.064	0.935	0.914	0.14	0.127	0.935
0.762	0.14	0.106	2.64	1.22	0.14	0.170	2.64
1.067	0.14	0.148	4.86	1.52	0.14	0.212	4.86

	0.15 m Depth Basin	0.61 m Depth Basin
Peak effluent settleable concentration (ml/l)	6.1424	8.3405
Basin trap efficiency (%)	77.41	74.79

UNIT CONVERSIONS:
1 ha = 2.47 ac
1 cubic meter per second (m^3/sec) = 35.31 cubic ft per second (cfs)
1 ha-m = 8.10 ac-ft
1 m = 3.28 ft = 39.37 in

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