APPENDIX G

SEDIMENT CONTAINMENT SYSTEM DESIGN RATIONALE

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FIGURES

TABLES

G.I Sediment Containment System Design Rationale

The following design rationale is considered reasonable to evaluate the effectiveness of containment system (Type I and II) for use at high to medium risk areas.

- An inflow quantity (Q_i) is assessed based on runoff volume (Q) from a 24-hour intensity rainfall, a 1:2 year storm. (Runoff from a 1:10 year storm will be approximately 2.5 times that for a 1:2 year storm. Thus, it is impractical to provide such large storage volume, especially if revegetation of disturbed area is to be achieved in 1-2 years and deactivation of the basin/trap considered for rural highways.)
- A sediment delivery ratio (SDR ranges from 0 to 1) is a subjective parameter
- SDR = 1; when a high risk area is at immediate connectivity downslope of an erosion source

Runoff (Q) and Inflow (Q_i) Estimation ***(1:2 yr. storm, 24hr intensity rainfall, soil type, area of disturbance)***

$$Q_i = SDR \times Q \qquad \text{(Equation G.1)}$$

Where: Q_i = Inflow to sedimentation pond (m^3/s)

SDR = Sediment delivery ratio (dimensionless)

Q = Natural runoff (m^3/sec)

Runoff is estimated using:

- Precipitation of a 24 hour rainfall intensity from a 1:2 year storm;
- Effect of ground absorbency of different soil types affecting runoff. For various soil types, a general relationship between precipitation and runoff per hectare can be assessed. (see Figure G.1);
- Some jurisdictions (such as EPA) assume 25 mm runoff as minimum parameter;
- 150-250 m^3/ha of disturbed land;
- Amount of fine sediment laden runoff close to high risks: SDR=1

The quantity of runoff from precipitation is affected by the absorbance, permeability and texture of the surficial soils (Figure G.1).

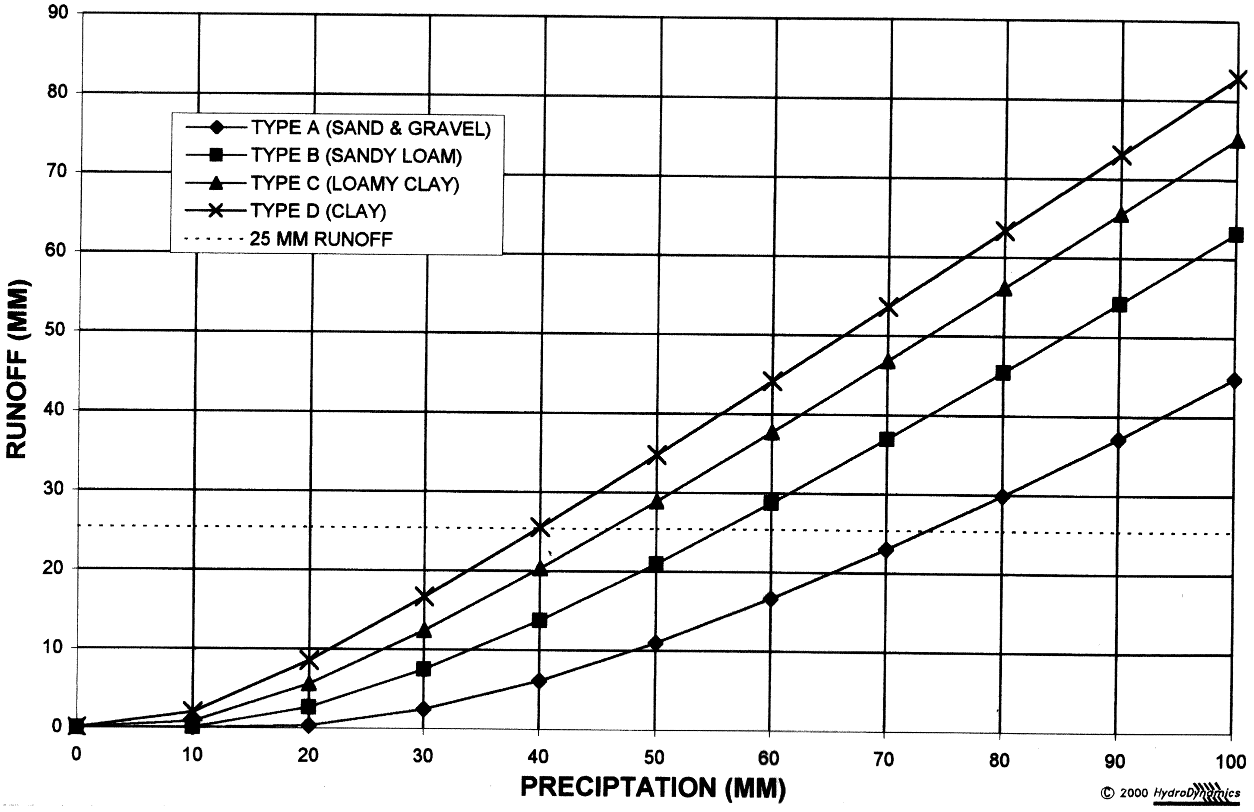


Figure G.1: Estimated Runoff from Precipitation over Different Soils

Source: Fifield, 2001

Settling Velocity (Vs) for Soil Particles

A particular soil particle size (D_S) can be targeted within the sediment laden runoff and its percentage by weight is determined from a hydrometer gradation curve of local soil materials. Different size particles exhibit different settling velocities with smaller particles requiring a longer time to settle. The different settling velocities for sand to silt to clay size particles are presented in Table G.1. The times required for the clay to sand size particles to settle in vertical distances in water are presented in Figure G.2 and it shows that clay size particles require a very long settling time.

The introduction and use of approved coagulants, such as polyacrylamide (PAM), causes the coagulation of small clay particles into larger particles thereby increasing their settling velocity and effectively reducing the settling time for small particle-sized soil.

The settling velocity (V_S) is assessed for a target soil particle size

$$V_S \ \alpha \ D_S \quad \text{(Stokes' Law)}$$

Where:

D_S = Diameter of a target particles size (cm)

Stokes' Law

$$V_s = g \times (S - 1) \times d^2 / (18 \times \mu) \qquad \text{(Equation G.2)}$$

Where: V_s = Settling velocity (cm/sec)
g = Acceleration of gravity (981 cm/s^2)
μ = Kinematic viscosity of a fluid (cm^2/s^2)
S = Specific gravity of a particle
d = Diameter of a particle (cm) (assuming a sphere)

Table G.1: Settling Velocities (V_s) for Suspended Particles (Specific Gravity = 2.65) in Water at Different Temperatures, as Calculated by Stokes' Law

Diameter (mm)	**Settling Velocity in Centimetres per Second**					**Particle**
	0°C	**5°C**	**10°C**	**15°C**	**20°C**	
0.01	0.005	0.006	0.007	0.008	0.009	Fine Silt
0.02	0.020	0.023	0.027	0.031	0.035	Medium Silt
0.03	0.044	0.052	0.060	0.069	0.078	
0.04	0.078	0.092	0.107	0.122	0.139	Coarse Silt
0.05	0.122	0.143	0.167	0.191	0.217	
0.06	0.176	0.207	0.240	0.275	0.313	
0.07	0.239	0.281	0.327	0.375	0.426	Very Fine Sand
0.08	0.312	0.367	0.427	0.490	0.556	
0.09	0.395	0.465	0.540	0.620	0.704	
0.11	0.488	0.574	0.667	0.765	0.869	
0.11	0.590	0.694	0.807	0.926	1.051	
0.12	0.703	0.826	0.960	1.101	1.251	
0.13	0.825	0.970	1.127	1.293	1.468	Fine Sand
0.14	0.956	1.125	1.307	1.499	1.703	
0.15	1.098	1.291	1.501	1.721	1.955	
0.16	1.249	1.469	1.707	1.958	2.224	
0.17	1.410	1.658	1.928	2.211	2.511	
0.18	1.581	1.859	2.161	2.478	2.815	
0.19	1.761	2.072	2.408	2.761	3.136	
0.20	1.952	2.295	2.668	3.060	3.475	
	32°F	41°F	50°F	59°F	68°F	

Source: Fifield, 2001

Commonly Used Conversion Factors

- 1.0 cm/sec. = 0.0328 ft/s or 0.3937 in/s
- 1.0 m = 3.281 ft or 39.37 in
- 1.0 in. = 2.54 cm = 254 mm
- 1.0 ha = 2.471 ac = 107,637 ft^2 = 10,000 m^2
- 1.0 m^3 = 35.3 ft^3
- °C = 5/9(°F - 32°)

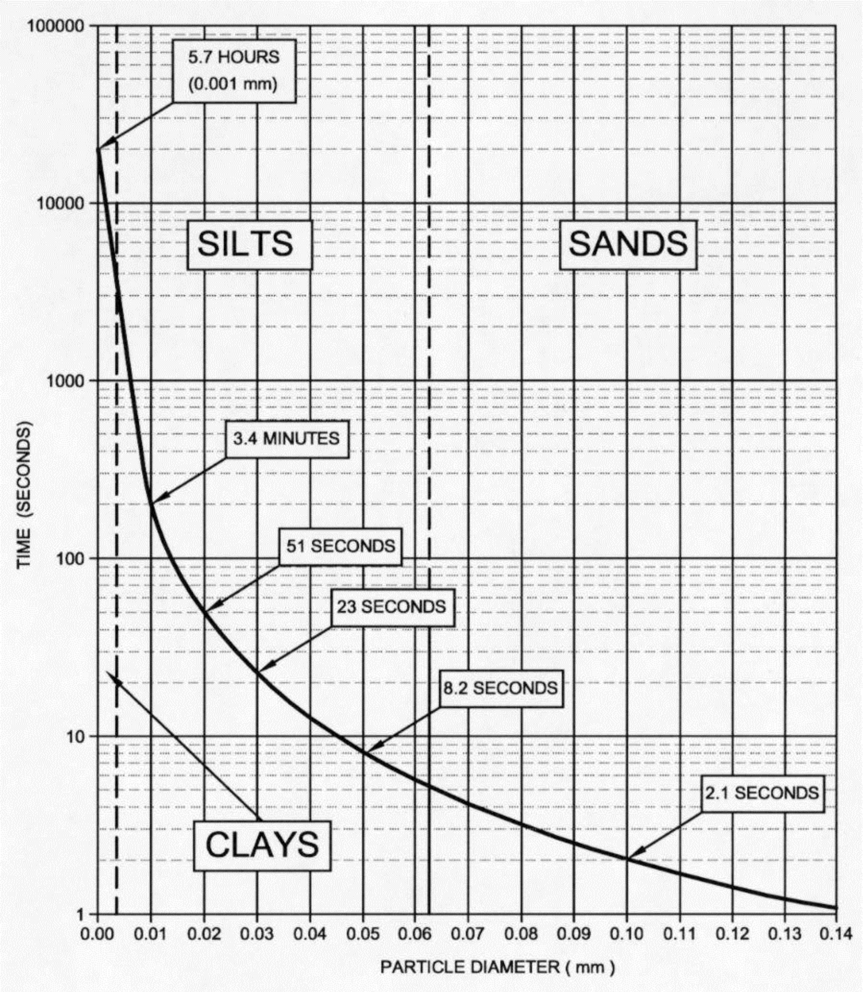


Figure G.2: Time for Suspended Particles to Fall 1 cm in Water at 0°C (Stokes Law)

Source: Fifield, 2001

From Figure G.2, the smaller diameter (D_S) soil particle (such as fine silt and clay) yields a very slow settling velocity (V_S), thus rendering a low efficiency system to settle very fine size clay particles.

The efficiency of a containment system is proportional to the settling velocity (V_S) and the particle size (D_S).

Outflow capacity (Q_o) of the containment system can be designed, based on free-draining properties of an outflow system which normally functions through a seepage or filter drainage outlet of the containment system. The outflow capacity is designed equal to or smaller than the inflow volume. It functions in a pond size configuration to provide sufficient flow path and containment time to effect sedimentation of a target size particle. During the time of containment, the target size particle will have sufficient detention time to settle to the bottom of the pond system. Generally, the outflow design of these systems is a free drainage granular berm, or a combination of perforated pipes, or a riser system functioning as filter/seepage structures and the size/configuration of the system will allow sufficient settling time for sediments to collect within the containment system. An example of the containment systems (Type I and II) is presented in Figures G.3d, G.3e and G.3f , as discussed below.

The general criteria for the selection and functioning of a containment pond system are presented in Section 12.2. The selection is dependent on the size of disturbed land, amount of runoff into the pond (Q_i) and target particle size (D_s) for settlement in order that an assessment of pond size/surface area (SA) can be estimated. The outflow capacity (Q_o) of the pond outlet is a function of structural and permeability design.

Generally, the runoff inflow (Q_i) is determined by a hydraulic or hydrotechnical professional or engineer. For the efficient settling operation of a pond, the inflow (Q_i) is equal to or less than the outflow (Q_o) to allow for sufficient settlement time for a low lateral flow passage within the pond chambers. Therefore, the rationale of settlement pond design assumes inflow (Q_i) equals outflow (Q_o).

$$Q_o=Q_i \qquad \text{(Equation G.3)}$$

Where:

Q_o = Outflow capacity of containment system

Q_i = Inflow

Outflow System

Two options of an outflow system: (1) Riser Outlet Option; (2) Permeable Rock Berm Outlet Option. They are discussed below:

Riser Outlet Option

A riser outlet is a circular overflow spillway that is connected to a culvert that passes through the containment berm. The riser pipe is fabricated from corrugated steel pipe conforming to CSA Standard CAN 5-G401-M81. The outlet pipe passing through the containment berm consists of a horizontal pipe welded to a 45° elbow (mitre joint) connecting to the riser pipe. The riser outlet system is equipped with a trash rack to minimize debris blockage.

100 mm diameter drainage holes are cut in the base of the riser pipe to form a perforated section near the elbow. A steel mesh is tack welded over it to form a screen. The portion of the riser pipe and elbow with the 100 mm diameter drainage holes and

mesh is to be backfilled with gravel. The size of the mesh covering the 100 mm diameter holes should be fine enough to filter granular material but coarse enough not to impede flow. Similar 100 mm diameter drainage holes can be provided along the riser pipe immediately above the elevation of the projected maximum sediment level.

The design of a riser pipe outlet can be completed by a hydrotechnical engineer to ensure the system has adequate capacity to discharge design flows without the risk of overtopping. Furthermore, a geotechnical engineer should design the culvert passing through the containment berm if the risk consequences of berm failure are significant.

Overflow Section System

An overflow section in the sediment containment system is not recommended as the primary means of discharging water due to concern of erosion of the containment berms. However, an overflow section is considered appropriate as an auxiliary outflow system for use in the event that the primary permeable rock outlet system (described in the following paragraph) should become blocked. Erosion protection at the outlet and on the berm slope is to be designed by an engineer. The overflow section is to be dimensioned at a minimum width of 1.5 m per 250 m^2 of pond area.

Permeable Rock Berm Outlet Option

One type of granular berm system is considered appropriate for use to allow seepage flow to exit from a sediment containment system. The following relationship (Jiang et al., 1998) can be used. The seepage outflow through drainage rock (25 mm to 100 mm diameters) in a gabion basket is modeled and can be applied to a granular berm outlet of a sedimentation pond/trap as illustrated in Figure G.3a and G.3b. The parameters and porosity of drainage rocks are shown in Figure G.3c.

$$Q_o = 0.327\, e^{1.5S} (g\, D_{50} / T)^{0.5} \rho W\, H^{1.5} \qquad \text{(Equation G.4)}$$

(Jiang et al, 1998)

Where: Q_o = Outflow capacity of containment system (m^3/s)

g = Acceleration due to gravity = 9.8m/s^2

D_{50} = Mean diameter of the rock (m)

W = Total width of the barrier (m)

ρ = Porosity of the rock barrier

T = Thickness of the barrier (m)

H = Hydraulic head (m)

s = Slope of channel (%) (generally varies from 0% to 7% for highway gradeline profiles)

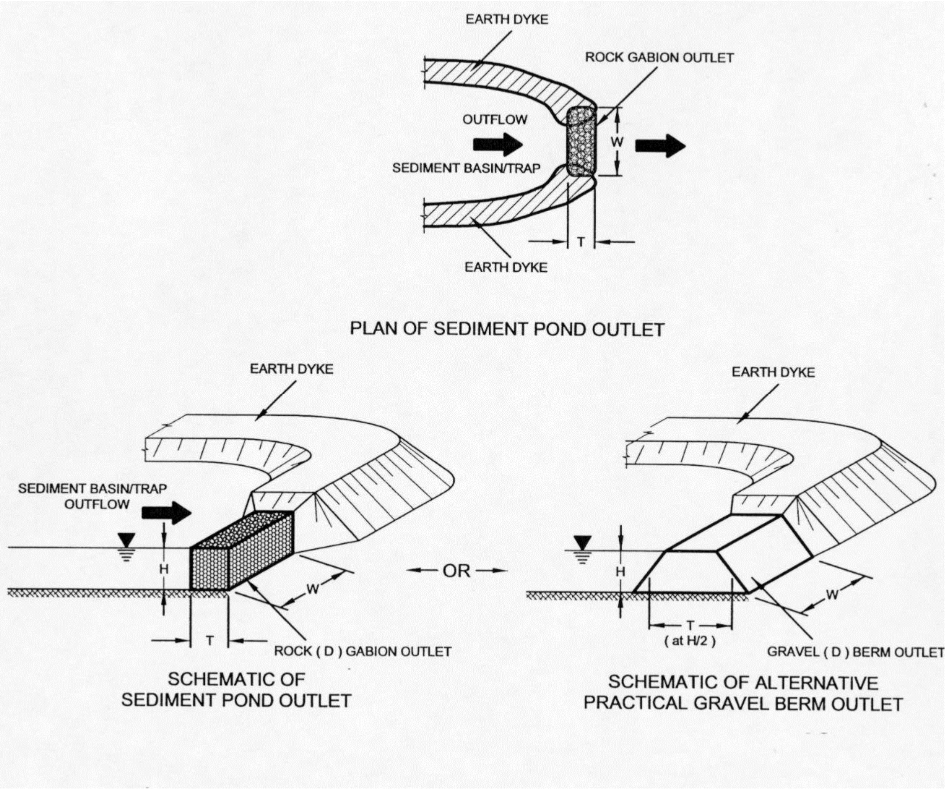


Figure G.3a: Model of Drainage Outlet of Sediment Pond

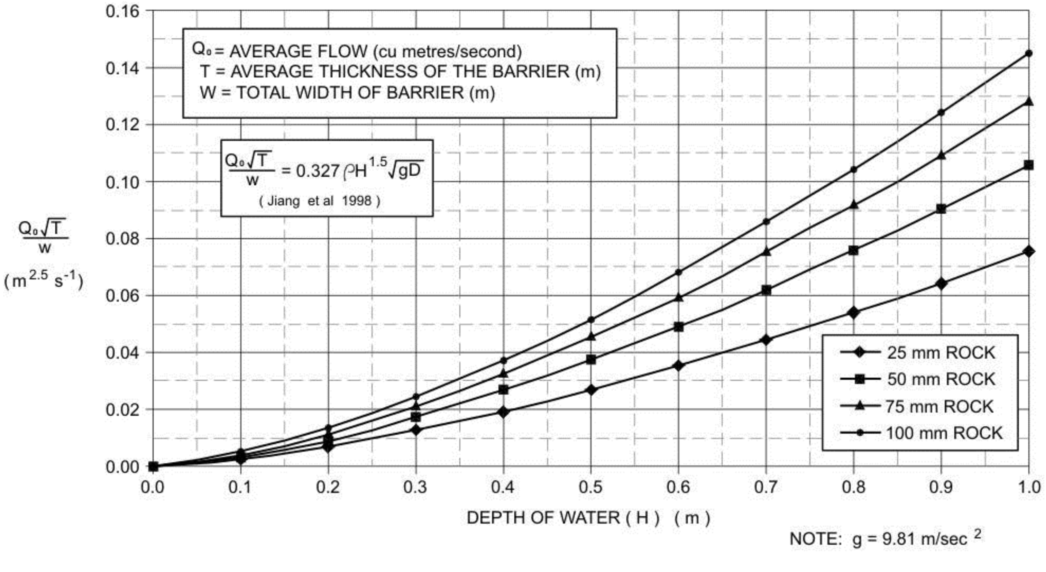
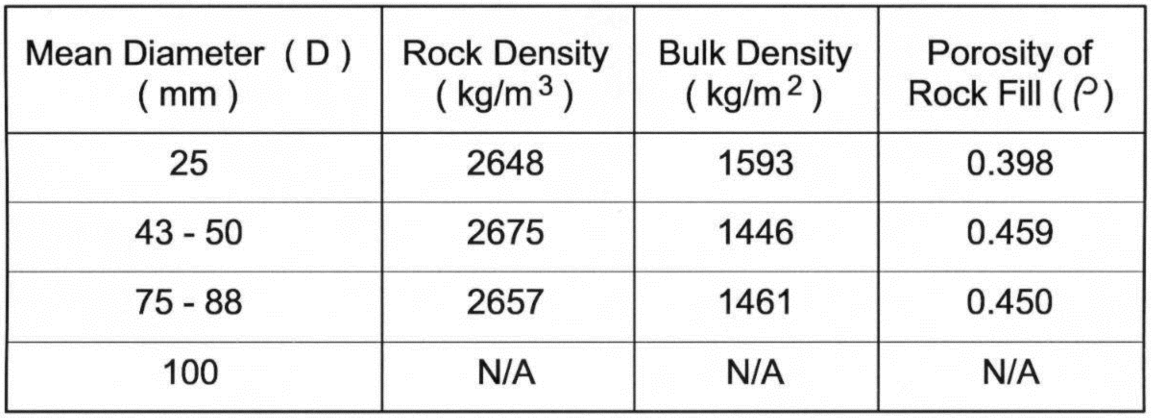


Figure G.3b: Flow (Q) Through an Outlet Barrier of Various Diameter (D) Rocks in Gabion Basket

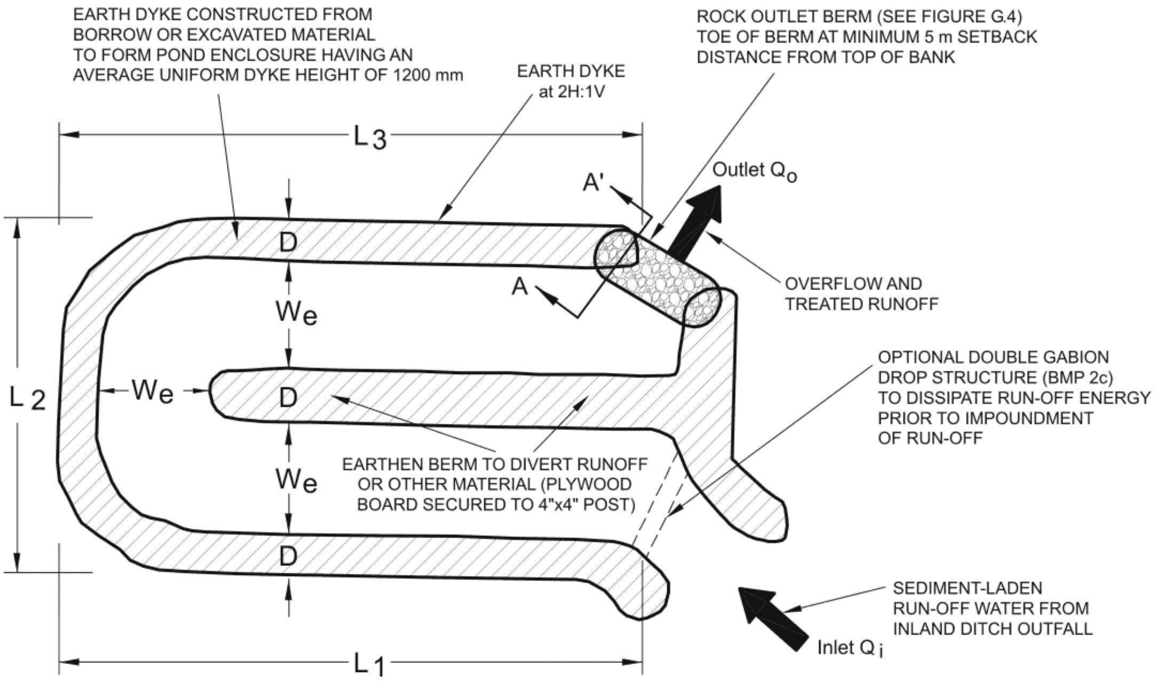
Source: Fifield, 2001



Mean Diameter (D) (mm)	Rock Density (kg/m^3)	Bulk Density (kg/m^2)	Porosity of Rock Fill (ρ)
25	2648	1593	0.398
43 - 50	2675	1446	0.459
75 - 88	2657	1461	0.450
100	N/A	N/A	N/A

(Source: Jiang et al 1998)

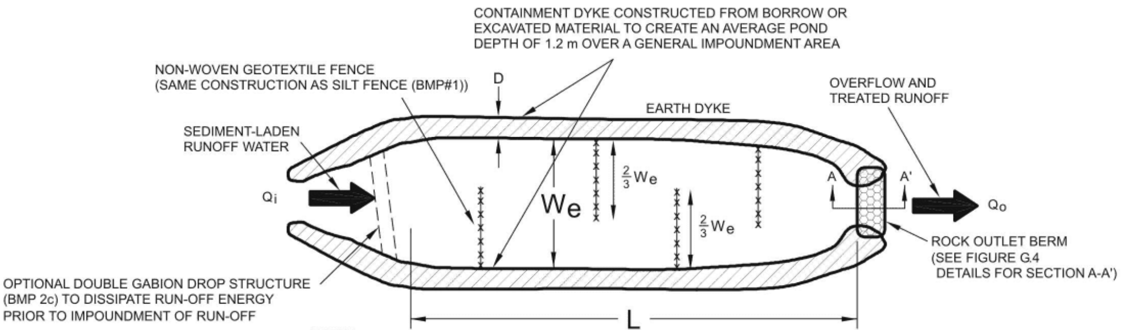
Figure G.3c: Parameters and Porosity (ρ) of Rocks



NOTES:

1. CONTRIBUTING RUNOFF AREA CAN BE LARGER THAN 2.0 ha BUT LESS THAN 40.0 ha.
2. EFFECTIVENESS APPROPRIATE FOR REMOVING MEDIUM TO COARSE SILT PARTICLES SUSPENDED IN RUNOFF.
3. FLOW PATH L = L1+ L2+ L3; FLOW WIDTH We = 6 m MINIMUM
4. PROVIDE 1 TO 2 m (1 TO 2% GRADE) ELEVATION DROP BETWEEN INLET AND OUTLET GRADES.
5. SHAPE OF POND TO CONFORM TO LAND WITH OUTLET AT MINIMUM 5 m SETBACK FROM TOP OF BANK.
6. CONSTRUCTION TO ENSURE SWALES AND BAFFLES ARE TO CHANNEL WATER INTO THE PROPOSED SEDIMENT PONDS.

Figure G.3d: Type I Sedimentation Pond Containment Structure (Sediment Basin Plan)



NOTES:

1. CONTRIBUTING RUNOFF AREA SHOULD BE OR SMALLER THAN 2.0 ha.
2. EFFECTIVENESS APPROPRIATE FOR REMOVING MEDIUM TO COARSE SILT PARTICLES SUSPENDED IN RUNOFF.
3. L/W_e RATIO 3:1 CAN BE APPROPRIATE.
4. W_e = 8 m MINIMUM BOTTOM WIDTH.
5. NON-WOVEN GEOTEXTILE FABRIC WITH A0S ≤ 0.15 mm.

Figure G3.e: Type II Containment Structure (Sediment Trap Plan)

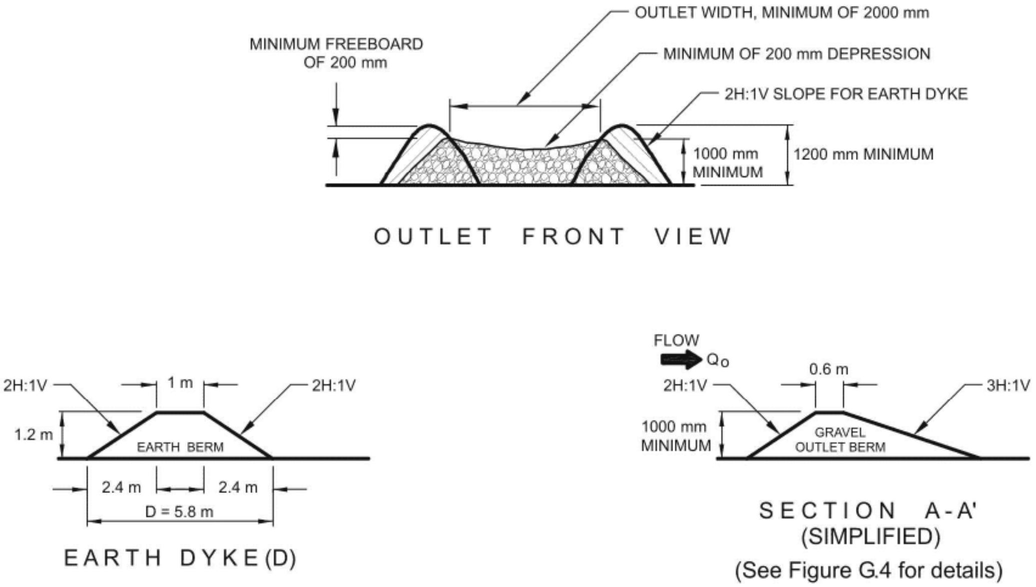


Figure G.3f: Simplified Sections of Dyke/Outlet

Source: Fifield, 2001

The outflow filter capacity of a rock barrier appears not sensitive to channel slopes varying from 0 to 6% (Jiang et al., 1998). The equation (Jiang et al., 1998) can be used for rock checks along channel with properly sized rocks for appropriate flow velocity (a nominal gradation can be: top size 250 mm, average size 150 mm, and bottom size 25 mm diameter) to provide stability to flow impact. A typical permeable outlet structure (with rock filter and perforated pipe) for sediment basin/trap is presented in Figure G.4 for practical highway constructions.

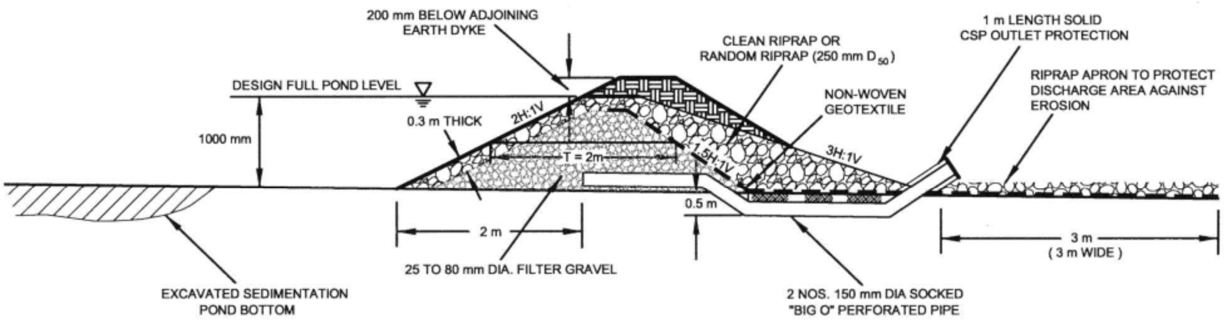


Figure G.4: Typical Sedimentation Basin/Trap Outlet Permeable Structure with Rock Filter Barrier and Perforated Pipe

Pond Area

The pond area (SA) size is based on the outflow capacity (Q_o) of the outlet structure (Figure G.3d and G.3e) and the settling velocity (V_s) of a target size particle. The outflow capacity (Q_o) is designed based on the runoff inflow quantity (Q_i) (Equation G.3).

$$SA = 1.2\ Q_o / V_s \qquad \text{(Equation G.5)}$$

Where:

SA = Pond area (m^2)

Q_o = Outflow capacity for an outflow structure (m^3/s)

V_s = Settling velocity of a target particle size (m/s)

1.2 = 20% extra capacity allowed for pond size

Pond Configuration

The size and configuration of a containment system is designed to provide sufficient volume and flow path to allow the target soil particles within the sediment laden runoff to settle during the time of impoundment.

Pond configuration entails length (L) and width (We) can be evaluated from pond area (SA).

$$L = SA / We \qquad \text{(Equation G.6)}$$

Multiply both sides by L, $L^2 = (SA \times (L / We))$

$$L = (SA \times (L / We))^{0.5} \qquad \text{(Equation G.7)}$$

Where:

We = Width of Pond Chamber (m)

L = Length of Pond Chamber (m)

SA = Surface Area of Settling Pond (m^2)

L/We = 10 is recommended for 100% apparent efficiency (A_{eff}) to minimize short-circuiting and maximize settling area (Goldman 1986). However, the exact behaviour of L/We in determining 100% A_{eff} can be subjective. The limitation of space does not normally allow a large size pond to be constructed to an L/We ratio of 10. The following pragmatic L/We ratios can be considered appropriate for the following structures:

Containment Structure	**L/We**
Sediment Basin (Type I)	8
Sediment Trap (Type II)	3

Pond Efficiency

The net efficiency (N_{eff}) of the containment system can be assessed based on model suggested by Fifield (Fifield 2001) utilizing the following concepts.

A_{eff} (%):	Apparent Efficiency
PEG (%):	Particle Size Equal to and Greater than a target size soil particle of a substrate soil (Reverse presentation of hydrometer gradation curve)

A_{eff} is modeled on pond dimensions (Fifield 2001) and the L/We ratios are postulated (Goldman, 1986). The dimensions of a pond to be designed are compared to dimensions of a model pond where 100% A_{eff} can be achieved for a target soil particle size.

PEG is a form of presentation of the gradation curve (hydrometer results of the fines portion) of an erodible substrate soil showing the percentage of coarser particles (Figure G.5) in the runoff that can be settled out in comparison to a target size soil particle (e.g., medium silt of 0.04 mm diameter). The soil tested for sedimentation PEG is usually taken from erodible soil sources of cutslope or borrow material used as fills on highway projects.

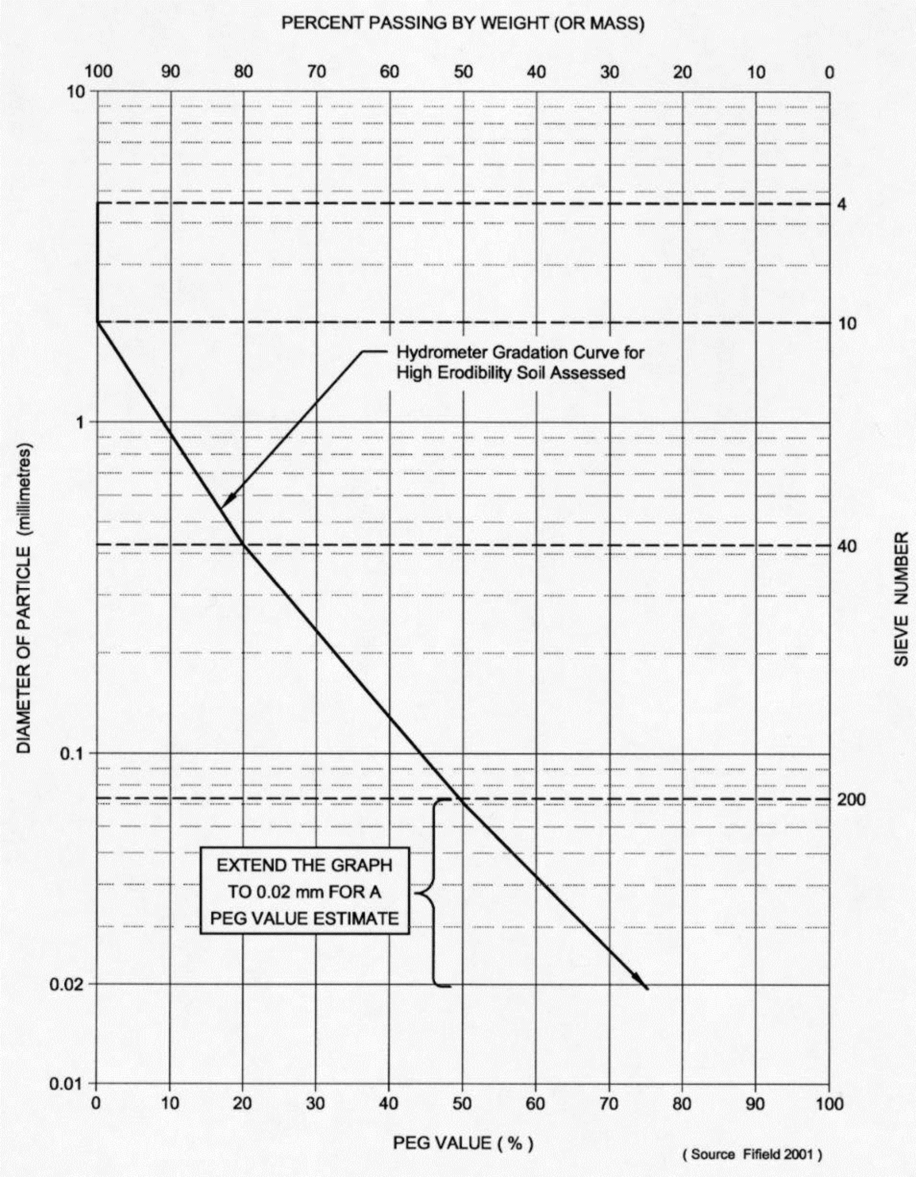


Figure G.5: Hydrometer (Particle Size) Gradation Curve to Determine PEG

Source: Fifield, 2001

Apparent Efficiency (A_{eff}) is modeled from the ratio of a 2-dimensional (length and height of flow area) design pond (A_c) to a model pond (A_{tc}) with an idealized design outfall capacity. A proportionality factor (K) of 0 to 1 is proposed for the ratio of realistic pond area of sediment capture to the model pond area (A_{tc}) of sediment capture. Within the containment pond, the flow path (L) is sized utilizing a lateral flow velocity (V_a) and a vertical settling velocity (V_s) of a target size soil particle allowing sufficient time for the particle to settle within the containment system (Fifield 2001). An illustration of the Apparent Efficiency (A_{eff}) model is presented in Figure G.6. The vertical distance of settlement is suggested by some investigators at 0.67 m for minimum height for a pond dyke. However, for design purposes with a factor of safety of 1.8, it is prudent to use 1.2 m for pond dyke to provide an extra freeboard of 0.2 m above the outlet permeable berm.

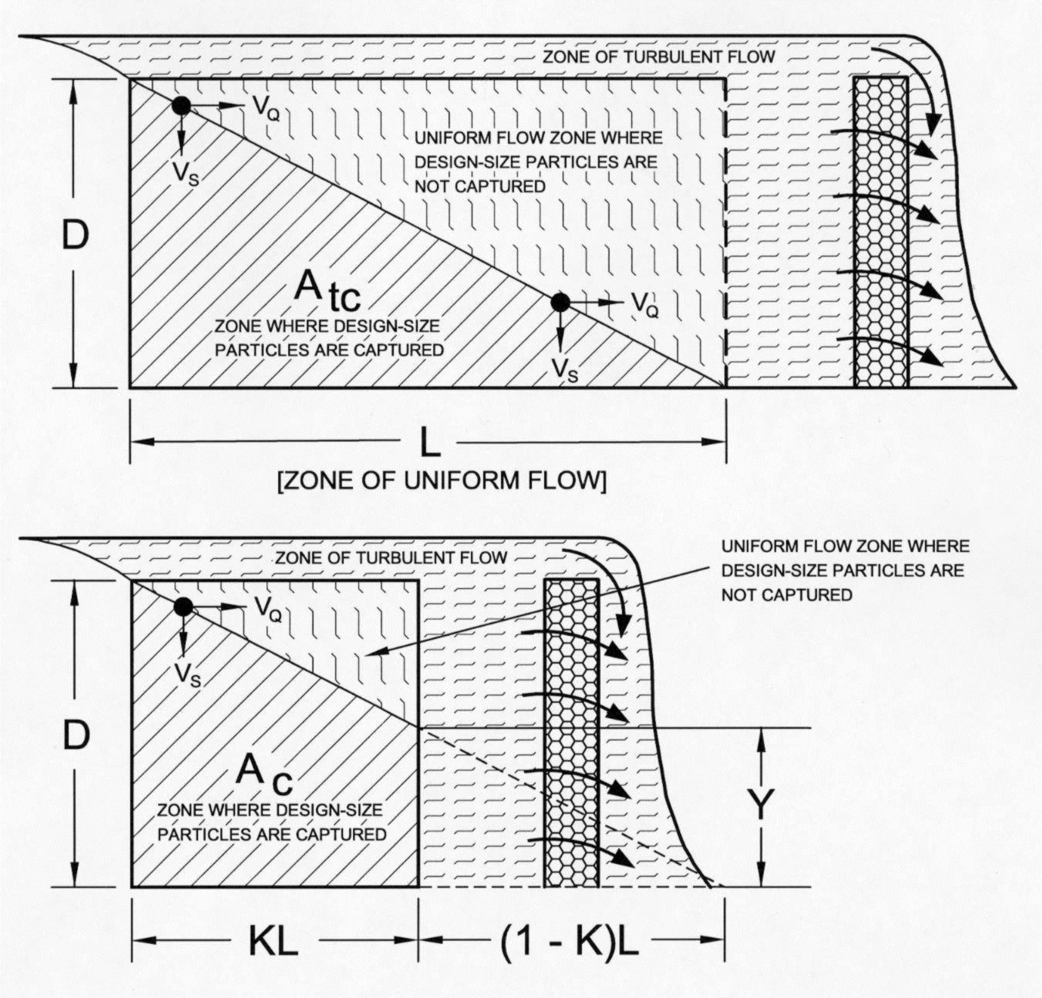


Figure G.6: Concept of Sedimentation Apparent Efficiency (A_{eff}) for Suspended Particles in Zones of Uniform and Turbulent Flows at Permeable Berm of a Containment System Outlet

Source: Fifield, 2001

$$A_{eff} = (A_c / A_{tc}) \times 100 \qquad \text{(Equation G.8)}$$

$$A_{eff} = (2K - K^2) \qquad \text{(Equation G.9)}$$

$$K = 0.1\ (L / We) \qquad \text{(Equation G.10)}$$

$$N_{eff} = A_{eff} \times PEG \qquad \text{(Equation G.11)}$$

Where: D = particle fall distance

A_{eff} = Apparent Efficiency (%)

K = A factor of 0.1 to 1, based on L/We ratio of 0 to 10 (10 is 100% A_{eff})

N_{eff} = Net Efficiency (%)

PEG = % of Particles Equal to and Greater than a target size particle determined from hydrometer gradation curve (see Figure G.5)

L = Length of a containment (chamber) system

We = Width of a containment (chamber) system

= 8 m bottom width is considered appropriate for highway construction application

Incorporating the above relationship, the $\mathbf{A_{eff}}$ can be estimated from the following curve (Figure G.7).

Figure G.7: Apparent Effectiveness (A_{eff}) of a Sediment Containment System

Source: Fifield, 2001

Design Example

A simple design example is presented in Appendix H as H.16.

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