Design Criteria

A. Introduction

Erosion and sediment control should be an integral part of every construction project. Preventing sediment from leaving construction sites is a major advancement toward improving water quality. The first step in erosion and sediment control for a construction project should begin with proper design. In order to effectively design erosion and sediment control measures, a distinction must be made between erosion control and sediment control; and the role of each defined.

The primary method of protecting a site should be preventing erosion. Erosion control measures protect the ground surface and prevent soil particles from being detached by the force of raindrop impact and concentrated flows. Sediment control practices focus on the removal of suspended particles from runoff after erosion has occurred. No sediment control structure is 100% effective, and removal of fine soil particles, which are very common in Iowa, is difficult. The best way to improve the efficiency of sediment control structures is to prevent erosion in the first place.

Sediment control practices are generally more expensive and less effective than providing proper erosion control. While sediment control structures can remove significant amounts of sediment from stormwater runoff, and should be implemented as part of the overall erosion and sediment control plan, they should be considered secondary to erosion control for the reasons described above.

Figure 7D-1.01: Sediment in Street Due to Inadequate Erosion and Sediment Control During Construction

Source: USDA NRCS Photo Gallery

B. Erosion Control

The key to successful erosion and sediment control on construction sites is the prevention of erosion. The simplest way to keep sediment from leaving a site is to keep it in place. The following site management methods should be implemented on all sites to help prevent erosion from occurring:

1. **Limit Exposed Area:** Existing well-vegetated areas are usually stable and nearly erosion-proof. The simplest and cheapest way to prevent erosion on a site is to prevent the existing vegetation from being disturbed. Obviously, this cannot be done for areas that must be graded and some ground must be exposed. However, by carefully planning the construction, controlling staging and equipment storage areas, and marking construction limits, the exposed area can be minimized.

2. **Limit Exposure Time:** Leave existing vegetation in place as long as construction operations allow to reduce the amount of time that a disturbed surface is exposed. If possible, stage construction so that one area is stabilized before grading activities begin on another area. After areas are disturbed, they should be stabilized as soon as possible. The NPDES permit contains specific requirements for initiating stabilization procedures once construction activities are completed or temporarily suspended. Stabilization activities may include temporary or permanent seeding, sodding, rolled erosion control products, turf reinforcement mats, compost blankets, or mulching.

3. **Divert Runoff:** Sheet or concentrated flow over a disturbed area can cause severe erosion. For sites that receive upland runoff, diversion should be constructed to protect bare slopes until vegetation or stabilization is established. Methods of diverting runoff away from or over disturbed areas include diversion structures (berms and swales), slope drains, rock chutes, and flumes. Diverted runoff must be discharged to a stable outlet. A level spreader can be used to convert concentrated diverted flows to sheet flow before they are released onto stable ground.

4. **Limit Velocity:** As runoff travels down a bare slope, its velocity increases. Limiting slope lengths will help prevent high-velocity flows. Where it is not practical to reduce the height of a slope by grading, the slope length can effectively be broken up into several smaller slopes by installing silt fence, filter berms, filter socks, and wattles. In ditches and channels, check dams should be used.

5. **Protect Concentrated Flow Areas:** Concentrated flows will occur on most sites. As sheet flows converge and the volume increases, the flow eventually becomes concentrated and provisions must be made to prevent erosion. Grass channels can carry some concentrated flow. Rolled erosion control products and turf reinforcement mats can provide additional reinforcement when required. At discharge points, rock outlet protection or flow transition mats can be provided to dissipate energy and prevent scour at the outlet.

C. Calculating Soil Loss

Regardless of the stabilizing and vegetative practices employed, inevitably some soil erosion will occur. Over the years, a variety of different models have been developed to estimate the amount of erosion that occurs on a given site. The current model utilized by the National Resource Conservation Service (NRCS) is the second revision of the Uniform Soil Loss Equation (USLE) which is called RUSLE2 (Revised Universal Soil Loss Equation). RUSLE2 is a semi-empirical model that considers the erodibility factors discussed in the previous section. The RUSLE2 model utilizes the following equation to determine sediment delivery rate:

$$A = R \times K \times L \times S \times C \times P$$ **Equation 7D-1.01**

Where:

A = Estimated average annual soil loss in tons/acre/year
R = Rainfall-runoff erosivity factor
K = Soil erodibility factor
L = Slope length factor
S = Slope steepness factor
C = Cover management factor
P = Support practice factor

Manually calculating soil loss with the RUSLE2 model is a time-consuming process that requires extensive weather, soils, and other support information. In order to simplify the use of RUSLE2, NRCS has developed a RUSLE2 software program. The RUSLE2 program utilizes the concept described above to estimate soil loss, sediment yield, and sediment characteristics from sheet and rill erosion. This program is available for download from NRCS at: http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Index.htm.

While the RUSLE2 model was originally developed to analyze conservation practices on agricultural land, it can also be used to estimate sediment delivery rates from construction sites. This is an especially useful tool for designing erosion and sediment control systems for large sites. It is also useful for estimating sediment delivery rates to both temporary and permanent sediment basins. This information can be used to estimate the required cleanout frequency for sediment control structures, and for identifying sites that are highly susceptible to erosion, so potential problems can be addressed prior to construction.

D. Sediment Removal

1. **Sediment Control Devices:** Eroded soil particles that are suspended in flowing runoff waters will be transported offsite unless they are removed. The simplest and most efficient way to remove suspended particles from runoff is by detaining the runoff to slow the flow velocity; thereby allowing the suspended soil particles to settle out. This is most commonly accomplished with a sediment control device.

   The most important factor in designing a sediment control device is selecting the appropriate size. The ideal situation would be to collect and retain all runoff in a large retention structure, preventing any contaminated water from leaving the site. However, this is not practical in most situations. First, to retain all water onsite would require large storage areas and volumes. In addition, the retained runoff would be required to infiltrate into the ground or evaporate. These processes may not be sufficient to remove all of the runoff before the next storm occurs.

A more practical approach is to size a device to detain the runoff for a sufficient time to remove a significant portion of the suspended material, yet allow the structure to outlet excess runoff, rather than retaining it. Since the device is allowed to drain both during and after the storm event, the size can be reduced, and the danger of being flooded out by a subsequent storm event is also reduced.

2. **Designing Major Sediment Control Devices:** For a major sediment control device such as sediment basin or sediment trap to perform efficiently, it must be large enough to detain the contaminated runoff for a sufficient time to allow suspended particles to settle out, allow a sufficient flow of water through the system to prevent flooding, and be small enough that it is cost-effective to construct. In order to size an efficient basin, an understanding of the physics involved in removing suspended soil particles is required.

   a. **Settling Velocity of Suspended Particles:** Particles suspended within a fluid will settle due to the force of gravity according to Stoke's Law. In summary, Stoke's Law states that a particle suspended within a fluid will fall at a constant vertical velocity, or settling velocity. The settling velocity is reached when the force of gravity acting on the particle equals the fluid resistance acting on the particle. The settling velocity of a suspended particle (assumed to be spherical) falling through water can be expressed as:

$$V_s = \frac{\left[g \times (G_s - 1) \times d^2\right]}{(18 \times \mu)}$$

Equation 7D-1.02

Where:

V_s = Settling velocity (ft/sec)
g = Acceleration of gravity (32.2 ft/sec^2)
μ = Kinematic viscosity (ft^2/sec^2)
G_s = Specific gravity of a particle
d = Diameter of a particle (ft)

   b. **Soil Types and Properties:** The size required for a sediment control structure to be effective depends greatly on the properties of the suspended soil particles that must be removed. Soil particles settle at different rates based upon their diameter and specific gravity. Larger particles will settle out according to Stoke's Law, as described above. However, very small particles, such as colloidal clay particles and fine silts have extremely slow settling velocities.

Capturing these small particles with a sediment control device may be impractical due to the extremely large structure size required to provide the long detention time required. Clay particles in particular, may never settle and remain suspended indefinitely due to Brownian Movement, which is a result of negatively charged particles repelling each other.

A sediment control device is designed around a design-size particle. The device is designed to remove 100% of soil particles that are design-size or larger. The design-size particle selected should be based upon the smallest soil particles that are present on the site to be disturbed.

Based upon the practical limitations discussed above, design-size particle selected to size the structure may normally be limited to medium silts or larger. For sites with fine silts and clay, which are smaller than the size used to design the structure, only a partial removal of these suspended fines can be expected. Because of this, additional efforts to prevent erosion should be utilized. The following table lists common settling velocities for various soil types.

Table 7D-1.01: Typical Soil Particle Settling Velocities

Particle	Diameter (ft)	Settling Velocity @ 60˚ F (ft/sec)
Fine Silt	$3.3\text{x}10^{-5}$	$2.62\text{x}10^{-4}$
Medium Silt	$6.6\text{ x}10^{-5}$	$1.02\text{ x}10^{-3}$
	$9.8\text{ x}10^{-5}$	$2.26\text{ x}10^{-3}$
Coarse Silt	$1.3\text{ x}10^{-4}$	$4.00\text{ x}10^{-3}$
	$1.6\text{ x}10^{-4}$	$6.27\text{ x}10^{-3}$
	$2.0\text{ x}10^{-4}$	$9.02\text{ x}10^{-3}$
Very Fine Sand	$2.3\text{ x}10^{-4}$	0.012
	$2.6\text{ x}10^{-4}$	0.016
	$3.0\text{ x}10^{-4}$	0.020
	$3.3\text{ x}10^{-4}$	0.025
	$3.6\text{ x}10^{-4}$	0.030
	$3.9\text{ x}10^{-4}$	0.036
Fine Sand	$4.3\text{ x}10^{-4}$	0.042
	$4.6\text{ x}10^{-4}$	0.049
	$4.9\text{ x}10^{-4}$	0.056
	$5.2\text{ x}10^{-4}$	0.064
	$5.6\text{ x}10^{-4}$	0.073
	$5.9\text{ x}10^{-4}$	0.081
	$6.2\text{ x}10^{-4}$	0.091
	$6.6\text{ x}10^{-4}$	0.100

Source: Adapted from Fifield, 2001

c. Major Sediment Control Device Sizing: Soil particles are held in suspension by the turbulence associated with high flow velocities. In order to force suspended particles to settle out at a desired location, it is necessary to reduce the velocity of the runoff. Sediment control devices achieve this by increasing the cross-sectional area of the flow.

Based upon the settling velocity of the design-size soil particle and the outflow rate from the structure, the required surface area of the device can be calculated with the following equation:

$$SA = (1.2) \times \frac{(100 \times Q_{out})}{V_s}$$ **Equation 7D-1.03**

Where:

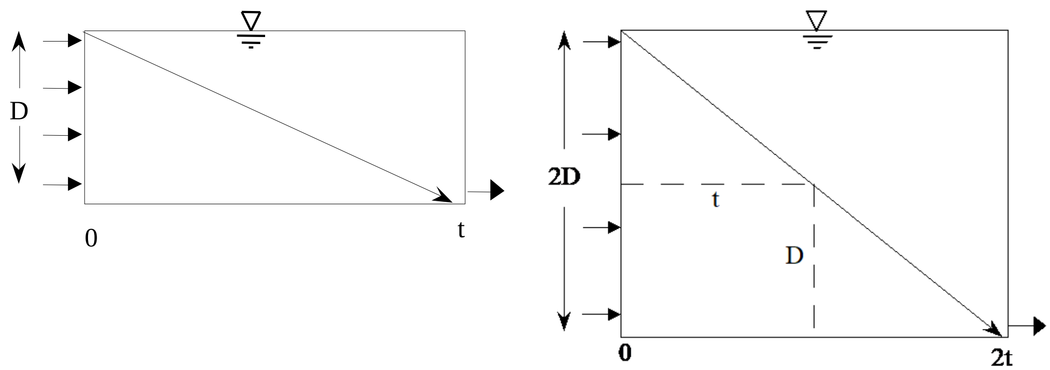
SA = Surface area of sediment control device (ft^2)
Q_{out} = Discharge (ft^3/s)
V_s = Settling velocity of design particle (ft/sec)

The discharge rate from the device is the peak release rate for a 2 year, 24 hour storm. This rate is dependent on the drawdown time and outlet configuration. Refer to the information in Sections 7E-12 and 7E-13 on sediment basins and sediment traps for determining the configuration of the release structure and the drawdown time.

The equation above includes a safety factor of 1.2 as recommended by the EPA. This factor increases the minimum surface area by 20% to compensate for disturbances in uniform flow caused by wind, rain, wave action, and turbulence at the outlet structure.

The above equation for determining the size of a sediment control device is independent of depth. The reason the size is independent of depth can best be explained by the figures below. Particles that reach the bottom of the device prior to the overflow point are considered captured and should remain within the device. In the figures below, as the depth of the device is doubled (assuming the surface area remains constant), the suspended particles must travel twice as far to reach the bottom of the device. However, since the volume of storage is twice that of the first figure, the flow velocity through the device is only half that of the first and the particles have twice as much time to settle.

Figure 7D-1.02: Example of the Relationship Between Settling Time and Structure Volume



While theory may suggest that any depth is sufficient, field experience has shown that a minimum depth of 2 feet is required to account for actual conditions. This depth helps eliminate dead zones and short-circuiting, where inflows simply pass straight through the device without spreading out, reducing their velocity, and dropping the suspended sediment. This minimum depth also provides sufficient volume for a deposition zone, reducing cleanout frequency. Additional depth should be provided near the upstream end of the device. This provides an area for heavier particles to be trapped while maintaining the deposition area for smaller sized particles. Permanent sediment control devices should have a minimum depth greater than 2 feet in order to reduce the cleanout frequency.

Based upon field experience and practical limitations, a minimum depth of 2 feet can be applied to Equation 7D-1.04 to determine the minimum storage volume required.

$$SV = (2.4) \times \left(\frac{Q_{out}}{V_s} \right)$$ **Equation 7D-1.04**

Where:

SV = Storage volume (ft^3) (volume of dry storage)
Q_{out} = Discharge (ft^3/s) (peak discharge for a 2-yr, 24-hr storm)
V_s = Settling velocity of design particle (ft/sec)

d. **Device Shape:** The shape of the sediment control device is also important. The longer the flow path is for a particle through a device, the better the chances are that it will be captured. In addition, longer devices provide more area for deposition away from the turbulence of the inlet and outlet. A length to width ratio of 10:1 is recommended. The minimum length to width ratio should be 2:1.

3. **Major Sediment Control Device Requirements:** While the discussion above provides a background on the concept and theory behind designing a sediment control device, the EPA has established its own minimum standards that must be met. The following summary of recommended design standards meet or exceed the EPA's regulations and should be followed for sediment basin and sediment trap design.

   Sediment basins are required for disturbed areas greater than 10 acres, which drain to a common location. Sediment basins must be sized to provide a minimum storage volume of 3,600 cf of storage per acre drained. The storage requirement does not apply to flows from undisturbed areas or stabilized areas that have been diverted around the sediment basin.

   For disturbed areas greater than 10 acres where a sediment basin designed according to the guidelines above is not feasible, smaller sediment basins or sediment traps should be used in conjunction with other erosion and sediment control practices as required to provide equivalent protection.

   The storage volume provided for a sediment basin or sediment trap should be split equally between wet and dry storage. Wet storage is that volume which is below the embankment area and has a permanent pool. Dry storage is the volume that is detained by the release structure, but eventually released.

   The following additional criteria should be provided for sediment control structures:

   a. A minimum length to width ratio of 2:1 (10:1 desirable) should be provided.

   b. A minimum depth of 2 feet from bottom of basin to overflow elevation (deeper structure recommended to reduce cleanout frequency).

   c. Side slopes 2:1 or flatter.

4. **Minor Sediment Control Devices:** For areas where a major sediment control device such as a sediment basin or sediment trap, are not required or cannot be utilized, minor sediment control devices and measures should be provided. These measures provide the last line of defense against releasing sediment-laden stormwater runoff from a construction site. Minor sediment control devices that remove sediment from flow include vegetative filter strips, filter berms, filter socks, silt fence, and inlet protection.

   Other measures that control sediment include stabilized construction entrances, which help prevent track out into streets; flocculents, which help remove suspended particles from standing water; and flotation silt curtains, which are used for construction within or near a water body.