Erosion and Sediment Delivery

Introduction

Soil erosion consists of a series of natural processes that move earth and rock material. The land surface is worn away through the detachment and transport of soil and rock by moving water, wind, and other geologic agents. Although erosion is a natural process, disturbance of the land surface by humans has greatly increased this erosion rate. For years, efforts have been made to reduce this rate and protect the soil resource.

In the past, offsite sediment delivery concerns have been mainly for sediment storage requirements of ponds and reservoirs. Sediment delivery procedures available in the ”Iowa Small Structure Design Manual, Subpart C - Sediment Storage” and the “EFM Chapter 11, Ponds and Reservoirs, Amendment IA27” have been used to determine storage requirements. Recently there has been increasing concern in these offsite effects. Eroded soil is delivered to lakes, rivers, streams, etc. and produces various environmental impacts. Many water quality projects are being directed toward reducing these impacts.

Determining location and sources that are delivering sediment to these resources will help optimize project inputs. Erosion sources need to be identified and amounts (rate) quantified. Common sources of erosion are sheet and rill, ephemeral gullies, gullies, streambanks, roads, construction sites, and feedlots. After source and quantity are identified, a sediment delivery procedure can used to determine delivery to a specific location. For water quality projects it’s important to know the quantity of sediment presently being delivered and the kind of affect that can be expected by applying conservation practices and reducing erosion. Estimating this amount is not easy and requires considerable technical judgment.

Following is a general description of erosion and sediment delivery processes. The primary objectives are to help identify sources of erosion, quantify erosion amounts, and provide information on sediment delivery procedures.

Sediment Sources

Sheet and Rill
Sheet and rill erosion is the detachment and removal of soil from the land surface by raindrop impact, and / or overland runoff. It occurs on slopes with overland flow and where runoff is not concentrated. The Universal Soil Loss Equation (USLE) is used to calculate sheet and rill erosion and estimates average annual erosion in tons/acre/year. Procedures for USLE can be found in the NRCS “Field Office Tech Guide” and will not be discussed any further here.

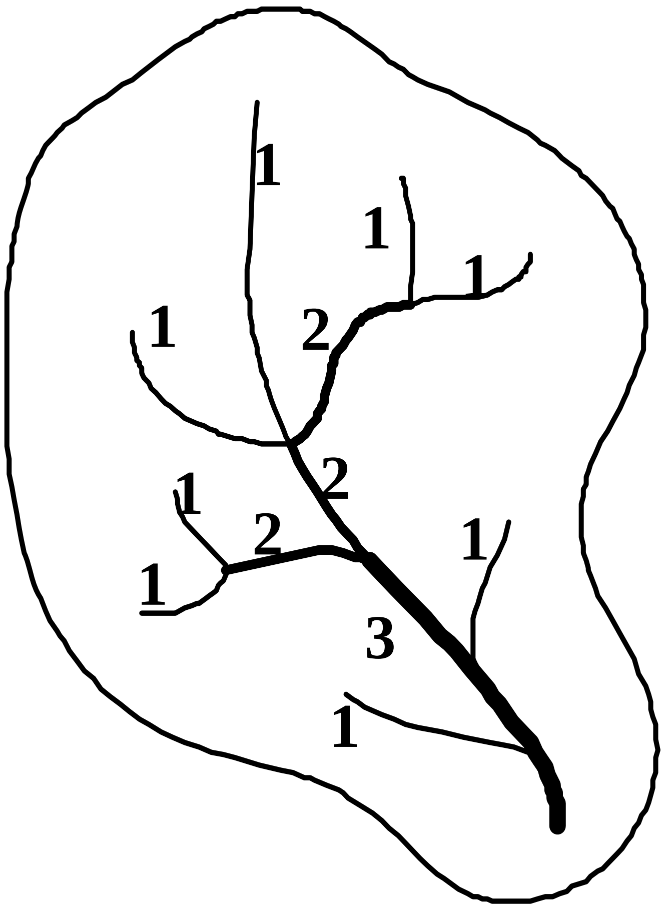
Ephemeral gully
Ephemeral gullies occur where runoff from adjacent slopes forms concentrated flow in drainageways. Ephemerals are voided areas that occur in the same location every year. They are crossable with farm equipment and are often partially filled in by tillage. Because they are filled by tillage, they need to be measured after a significant runoff event. After crops are out in the fall is a good time to measure ephemerals. Determining erosion from ephemerals is basically a volume/density calculation and is known as the direct volume method.

Channel length X Channel width X Channel depth X density of soil (lbs/ft3) / 2000lbs = tons / year

The dimensions of ephemeral gullies should be measured in the field when possible. Length can be measured by pacing the channel distance. Several width and depth measurements should be taken with a surveying rod and averaged. In many soils, depth of the ephemeral gully may be the same as tillage depth. Remote methods using aerial photos, soil surveys, topographic maps, etc. can be used to measure length if necessary, but don’t allow for accurate measurement of width and depth. Density of the soil can be obtained from the soil survey. Typical densities are 85-95 lbs/ft3.

Drainage systems usually form a branching network as shown in Figure 1. An ordering system allows channels of similar width and depth to be grouped together for easier calculation, especially for larger watersheds. The total length of similar order channels are added together to allow one calculation to be done per channel order. For example, in Figure 1 all 1st order channel lengths would be added together to get a total 1st order length. An average width and depth of 1st order channels would be obtained from several field measurements. A similar method is used for all channel orders.

Channel Order	Total Length		Average Width		Average Depth		soil density lbsft3 / 2000 = Tons
1st	_____	X	_____	X	_____	X	_____ / 2000 = _____
2nd	_____	X	_____	X	_____	X	_____/ 2000 = _____
3rd	_____	X	_____	X	_____	X	_____/ 2000 = _____
							Total = _____



1" = 200'

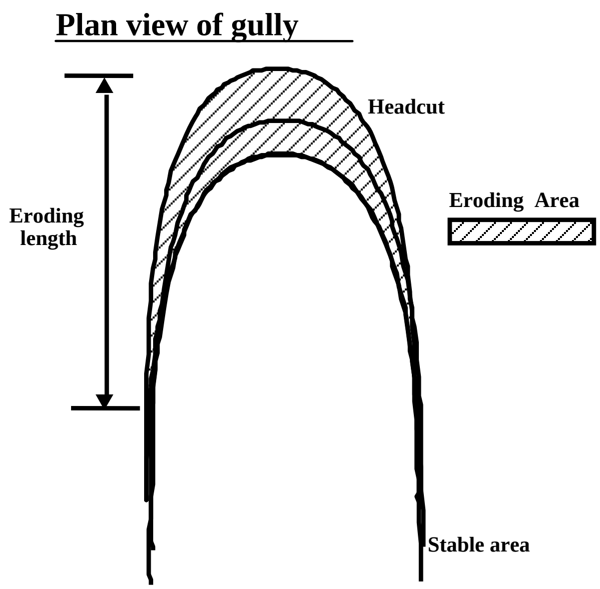
Channel ordering sytem: Channel order increases when two channels of similar order come together. Examples: (1+1=2), (1+2=2), (2+2=3)

Figure 1

Streambank and Gully Erosion
Streambank and gully erosion is also calculated by direct volume method, which is simply a bank height X widening rate X eroding length calculation. Widening rate is the lateral movement in ft/yr of the bank. Rates can be estimated using Table 1. The volume is then multiplied by soil density to determine tons. Streams and gullies are usually not eroding throughout their entire length so eroding length needs to be measured. An average bank height and widening rate can be used.

Eroding Length X bank height X widening rate X soil density (lbs/ft3) / 2000 lbs = tons/yr

(Gully)
Gullies form as a headcut (overfall) develops and moves up the drainageway. Gullies are often actively eroding at the headcut and will stabilize as the headcut moves up the drainageway (Figure 2). The eroding area should be determined by field measurement. Measure eroding length by tape measure or pacing and bank height with a surveying rod. Use Table 1 to estimated widening rate. Account for both the headcut surface and the bank widening surface to determine volume and soil loss.



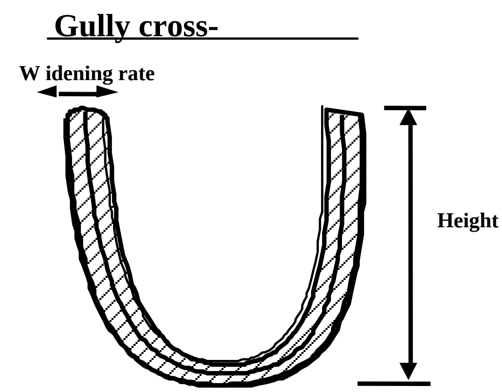


Figure 2

(Streams and Channels)
Natural, unchannelized streams usually have a meandering pattern where erosion occurs mainly on the outside bends (cutbanks) of these meanders. Most of this eroded material is usually deposited on the inside bends (pointbars) of meanders downstream. This natural process may not be a concern unless its rate is excessive or it is impacting human activities. Straightened, modified, or disturbed channels, may be contributing significant sediment to a resource. Erosion may be occurring on both banks at the same time as well as downcutting of the channel bottom. Rate of downcutting is often difficult to determine but can be estimated from exposed culverts, tile lines, bridge piles, etc. Keep in mind that rate of bed degradation usually slows or may stop as the stream approaches a stable grade.
To calculate erosion amounts, volume eroded must be determined. For small watersheds simply measure the length of eroding bank (Figure 3), the bank height, and the widening rate to determine soil loss. For larger watersheds it is sometimes easiest to determine channel soil loss by using a sample reach of the stream. The sample reach's eroding length is divided by the sample reach's total length. Multiple this ratio by the total length of stream/channel in the watershed to get a total eroding length. Measure average bank height and estimate channel widening rate (Table 1). Several sample reaches may be needed to get a good representation of the watershed. Remember to account for both sides of the stream.

Sample reach

Total length of sample reach	(A)	______
Total eroding length of sample reach	(B)	______
% of sample reach eroding	(B/A)	______

Total length of watershed channel	X	% eroding	=	eroding length
________	X	______	=	________

Figure 3

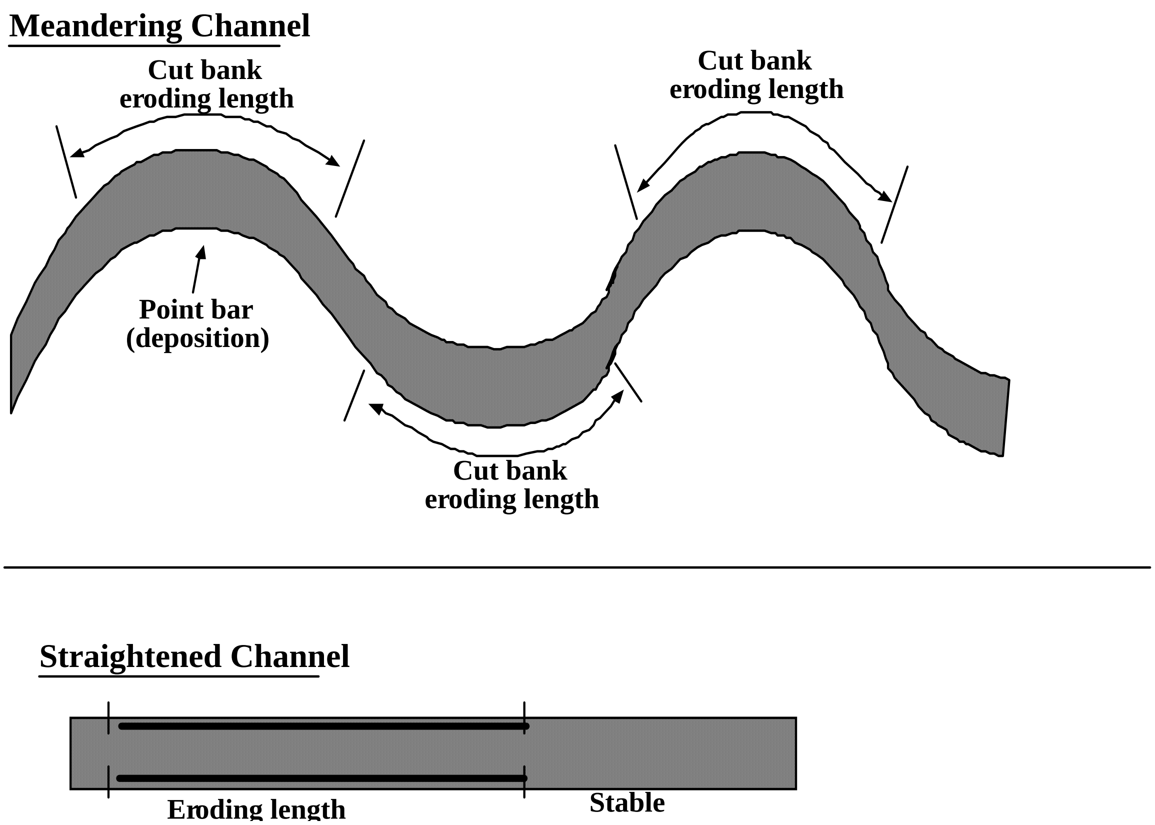


Table 1

(Recession Rate) Widening (ft/yr)	Category	Description
0.01 - 0.05	Slight	Some bare bank, but active erosion not readily apparent. Some rills but no vegetative overhang. Maybe some exposed tree roots.
0.06 - 0.2	Moderate	Bank is predominantly bare with some rills and vegetative overhang. Some exposed tree roots, but no slumps or slips.
0.3 - 0.5	Severe	Bank is bare with rills and severe vegetative overhang. Many exposed tree roots and some fallen trees and slumps or slips. Some changes in cultural features such as fence corners missing and realignment of roads and trails. Channel cross-section becomes more U-shaped as opposed to V-shaped
> 0.5	Very severe	Bank is bare with gullies and severe vegetative overhang. Many fallen trees, drains and culverts eroding out and changes in cultural features as above. Massive slips or washouts common. Channel cross-section is U-shaped and stream course or gully may be meandering.

The previous discussion has provided information on how to identify and quantify several major sources of erosion. There are many other sediment sources most of whose quantities are figured using either the USLE or direct volume method. Several other methods are sometimes used to estimate erosion rate. Comparing airphotos from different time periods may show a difference in channel location. Setting a survey point and measuring the movement over a period of years is sometimes possible. Rate is simply calculated by dividing distance moved by length of time

SEDIMENT DELIVERY RATIO

Gross erosion means all erosion in the watershed, (i.e., sheet and rill, gully, streambank, landslides, roads, roadbanks, construction sites, etc). **Sediment yield** is the quantity of gross erosion that is delivered to a specific location. **Sediment delivery ratio (SDR)** is defined as the sediment yield from an area divided by the gross erosion of that same area. SDR is expressed as a percent and represents the efficiency of the watershed in moving soil particles from areas of erosion to the point where sediment yield is measured. Different sources of erosion have different SDR's. Each erosion source is multiplied by its SDR to get the sediment yield from that source. Other methods used to estimate sediment delivery include sediment surveys, stream sediment gages, and predictive equations. NEH Section 3 Sedimentation (Chapter 6 & 7) and T. R. 32 & 55 contain further information on sediment delivery.

Sediment delivery ratios (SDR's) are probably the simpliest and most likely method to be used in the field. SDR's have been derived from numerous sediment surveys. A graph developed from watershed characteristics and drainage area is used to obtain percent delivered (Chart I). Drainage area shows one of the best relationships with sediment delivery.

Sediment surveys are the measurement of reservoir volume lost to deposited sediment. The original reservoir volume, along with landuse (gross erosion) records for the time period measured must be known. The sediment that is delivered to the reservoir and passes through the reservoir must also be accounted for. The total amount of sediment delivered to the reservoir is divided by the gross erosion in the watershed to determine sediment delivery ratio. This method may correlate well if used in a watershed with similar characteristics in the same geographic region.

Stream sediment gages are used to measure suspended sediment transported by a stream. Gages are usually located on larger streams which may limit their correlation with smaller drainage areas. They also don't measure bedload which could be a significant portion of the total sediment delivered in some areas. Sediment gage data is usually available from the USGS Water Resources Division.

Predictive equations are sometimes used to estimate sediment delivery. They are usually calibrated from sediment surveys or stream gages. The formulas can be complicated which may make them difficult to use.

Factors to Consider for SDR's

SDR's vary between watersheds due to differing physical attributes.

Drainage Area
Large watersheds will generally have a lower SDR than small watersheds due to the increased number of areas within a watershed that can trap soil particles. Chart I shows this general relationship between watershed size and SDR. There may be considerable variation and actual SDR value could be considerably higher or lower than the value on the chart depending on other physical characteristics of the watershed. Using a drainage area relationship is a good way to get a first approximation of a SDR but other watershed factors should be examined to adjust this initial estimate.

Land Use
Land use can change both the cover condition and the permeability of a watershed. A watershed with poor cover will have a high SDR because nothing impedes runoff. If the runoff is not slowed by growing vegetation or litter, the chance for eroded soil particles to deposit is low. Increased runoff also occurs in watersheds with impermeable soils.

Particle Size
Clay and silt sized soil particles are much more readily moved through a watershed than sand or gravel particles.

Channel Density
Channels are very efficient at transporting sediment. A high channel density (total length of channel/drainage area) means that the distance from eroding areas to a channel is short. There is less chance for soil particles to deposit when moving a short distance so a high channel density indicates a high SDR. Shape of the watershed also affects SDR by changing distance from erosion source to a channel.

Topography
Eroded soil cannot get to a channel unless runoff carries it. Short, steep slopes will deliver more sediment to a channel than a watershed with long, complex slopes. A complex slope is a combination of convex, concave, and flat surfaces. Whenever changes in slope occur, deposition may also occur. Also a watershed with a large flood plain area will usually have a lower SDR since flood plains are natural deposition areas.

Sediment Source
Sediment from streambank and gully erosion has a much higher chance of being delivered than does sediment from sheet and rill erosion due to the high transport capacity of gullies and streams. Watersheds with a high percentage of channel erosion will have a higher SDR than a watershed with predominantly sheet and rill erosion.

By reviewing the above factors it can be seen that SDR's are affected by many highly variable physical features. It is difficult to imagine developing an equation that would tie all the variables together and estimate their cumulative impacts on SDRs. "**Considerable technical judgment is required to select and use SDR's".**

SEDIMENT ROUTING THROUGH WATERSHEDS

Much conservation work today is aimed at offsite environmental benefits. Sediment yield to environmentally sensitive areas must be determined to evaluate conservation practice impacts on such areas. Sediment data collected should be in a flexible format so sediment delivery can be estimated at any point in the watershed. Large watersheds can be broken down into subwatersheds to allow much of this flexibilty. A SDR is applied to the subwatershed gross erosion to estimated sediment yield from each subwatershed. This yield is then routed through the next subwatershed. If debris basins, terraces, reservoirs, floodplain, etc. are located in a subwatershed you may have to subtract sediment from the total load during sediment routing to account for deposited sediment.

Sheet and Rill Delivery

Chart I was produced using soil association areas and has been converted to the major landform regions of Iowa (Figure 4). ***An alternate version of Chart I, showing area in acres, is attached at the end of this document.*** SDR is determined by measuring drainage area in square miles and reading the plot for the specific landform region. Table 5 should be used to adjust the SDR for other variables in the watershed. The modifiers can simply be added to the SDR from Chart I. This SDR is then applied to gross sheet and rill erosion to determine the amount sediment delivered. Remember that SDR is a percentage when multiplying.

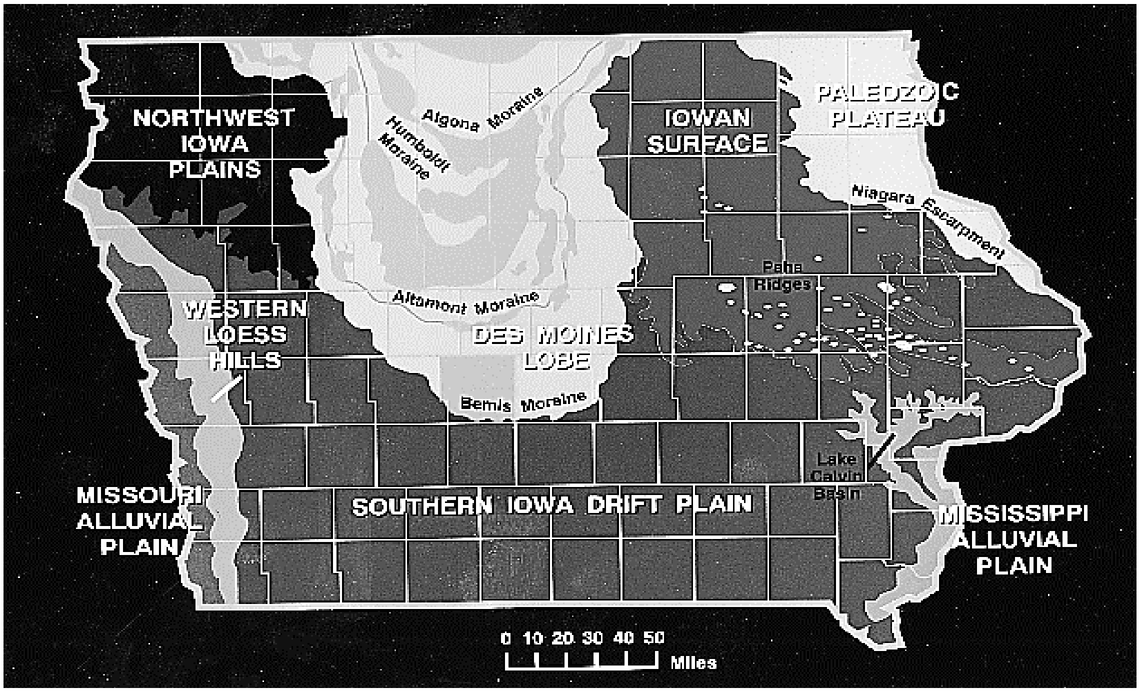
Example: 500 acre watershed in Paleozoic Plateau Region. The watershed averages 5 t/ac/yr from sheet and rill erosion. Gross sheet and rill erosion is 2500 t/yr

Drainage area .78 sq/mi
Graph Plot # 2

	Description	Modifier
Watershed shape	2-1	(2)
Predominant topography	rolling C slope	(0)
Channel density	100-200 ft/ac	(2)
Channel	nonincised	(0)
Drainage	integrated	(2)
	Total	+6

SDR	+	Modifier	=	Total SDR
38	+	(+6)	=	44

Gross erosion	x	SDR	=	Tons delivered /yr
2500	x	.44	=	1100

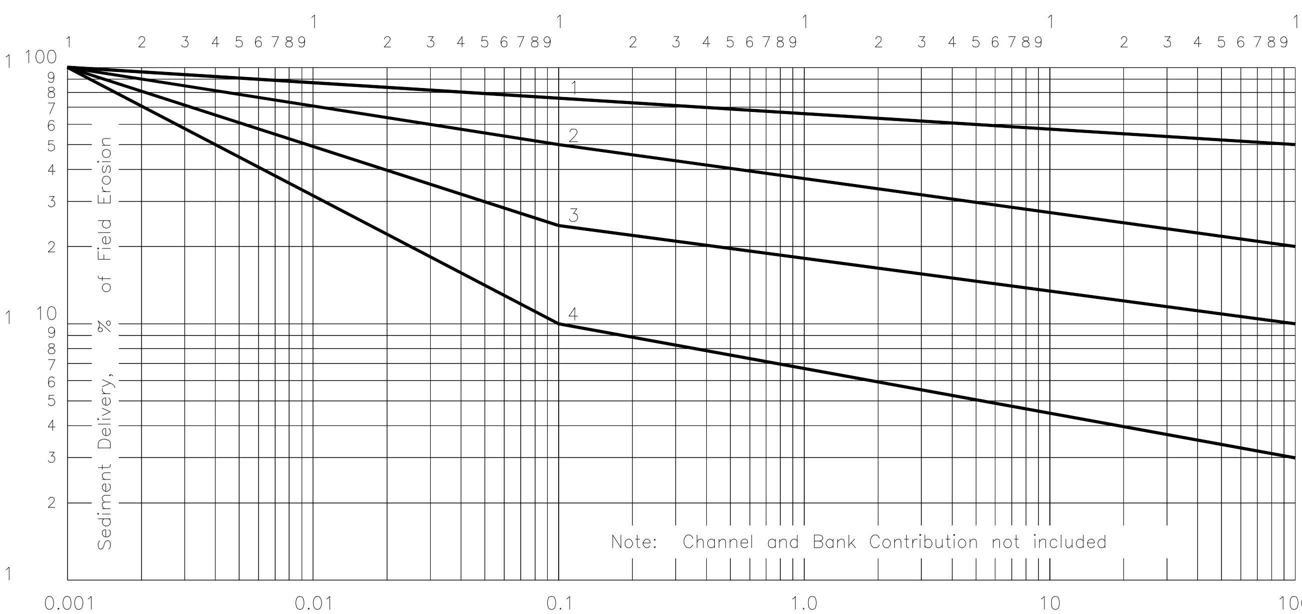


Landform Regions of Iowa

Figure 4

	Plot to use
Loess Hills	1
Southern Iowa Drift Plain, Northwest Iowa Plains, Paleozoic Plateau	2
Iowan Surface	3
Des Moines Lobe, Missouri Alluvial Plain, Mississippi Alluvial Plain	4

Chart I. Estimated sediment delivery for Landform Regions



Drainage Area, Square Miles

Table 1

These modifiers can be used to adjust the landform regions sediment delivery ratios. The modifiers are added to the sediment delivery ratio. Refer to section "Factors to Consider" for guidance.

Watershed shape				**Modifier**
	Ratio			
Length	to	Width		
2	to	1	or >	2
1	to	1		0
1	to	2	or <	-2

Predominant topography
(slope)

Steep (E and steeper)	4
Steeply rolling (D)	2
Rolling (C)	0
Gently Rolling (B)	-2
Flat (A)	-4

Channel Density *

Ft/ac	
> 200	4
100-200	2
50-100	0
0-50	-2

* Length of all channels (ephemeral, gully, stream, etc) added together and divided by acres

Channel

Deeply incised..(severely downcut)	4
Incised (downcut)	2
Non-incised	0

Drainage

Integrated (connected)	2
Non-integrated	-2

Concentrated Flow Erosion Delivery

As stated earlier different sources of erosion have different delivery ratios. Concentrated flow erosion such as ephemeral gully, gully, and streambank erosion usually have a higher delivery ratio then sheet and rill erosion. If the drainage system is integrated (continuously connected) and the channel incised (downcut) delivery rates may be high. If the drainage system is nonintegrated and nonincised, delivery may be low. Typical streambank and gully delivery rates for an incised channel are 80% -100% . Delivery rates for a nonincised channel or gully may be 60% - 80%. Ephemeral gully delivery rates for an integrated system are typically 50% - 90% and for a nonintegrated system, 20% -50%. Gross erosion amounts are multiplied by these rates to determine amount delivered.

Table 2

Typical delivery rates for concentrated flow erosion
(watersheds < 20,000 acres)

	Integrated drainage Incised channel	Nonintegrated drainage Nonincised channel
Ephemeral gully	50-90	20-50
Classic gully	80-100	60-80
Streambank	80-100	60-80

Sediment reduction and trapping efficiency
As sediment is transported through the watershed, there are many places for it to be deposited. Common locations are the base of slopes, fence rows, waterways, ditches, terraces, and ponds. The trapping efficiency of these may range from 0-100%. Technical judgment will be necessary to estimate the trapping efficiency. Below are a few typical trapping efficiencies that are used for structures and terraces. Flood control structures will normally have a trap efficiency toward the higher range of ponds and reservoirs. These rates assume that structures are in good working condition. Structures are also designed for a given size storm so sediment may pass through on larger storms. Terraces, for example are designed for a 10 year storm, so if a 25 year storm occurs the trap efficiency will be considerably less.

Table 3

Structure	**Trap efficiency**
Ponds and reservoirs	80-95
Terraces	
Graded	80
Tile intake	95
Level	100

"Sediment routing is basically a series of additions and subtractions as sediment moves through a watershed."

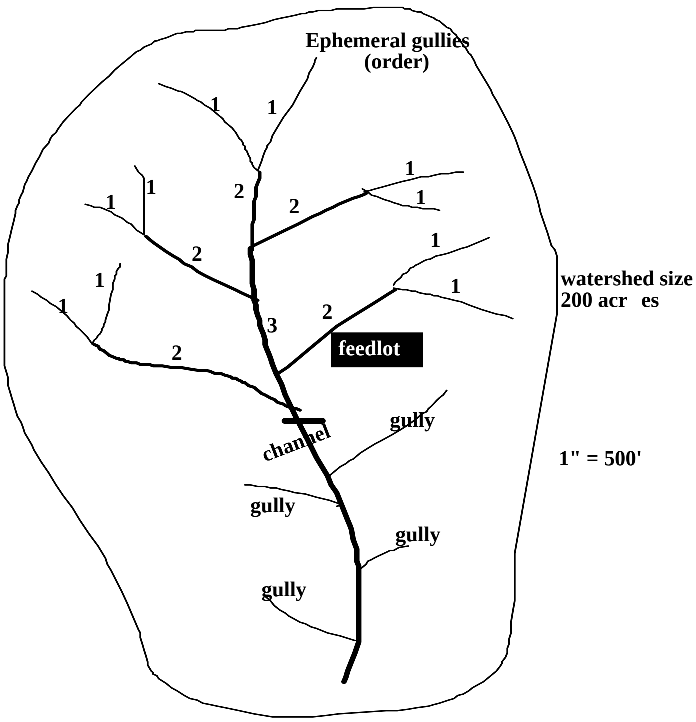
Sample Watershed Exercise

Prepared by J. Smith

Watershed name Sample

Date 0/0/96

Present or Future



Watershed is located in the Paleozoic Plateau Region. Drainage area 200 acres (.31 sq/mi). Sheet and rill erosion averages 6/t/ac/yr

Ephemeral gully Order		Total Channel Length	Eroding lengths
1		3100’	
2		2350’	
3		400’	
Gully	1250’ x 2 sides =	2500’	100’ x 2 sides = 200’
Channel	1000’ x 2 sides =	2000’	300’ x 2 sides = 600’
Feedlot		80 tons (calculated based on # animals present)	

Concentrated Flow Erosion Worksheet

Prepared by J. Smith
Watershed name Sample
Date 0/0/96
Present or Future

This worksheet is designed to help calculate concentrated flow erosion (ephemeral, gully, streambank). The direct volume method is used and is basically a volume x density calculation. Similar channels and gullies can be grouped together. Watersheds may need to be subdivided to help prioritize areas. Sample areas may want to be used for large watersheds. Further explanation on how to figure amounts is contained in the previous text.

Ephemeral Gullies

Channel Order	Length		Width		Depth		lbs/ft3	/ 2000	=	Tons
1	3100	X	1	X	.3	X	85	/ 2000	=	40
2	2350	X	1.2	X	.3	X	85	/ 2000	=	36
3	400	X	1.4	X	.3	X	85	/ 2000	=	7
								Total		83

Gullies

Number Gullies	Eroding Length		Rate		Depth		lbs/ft3	/ 2000	=	Tons
5	200	X	0.2	X	5	X	90	/ 2000	=	9
______	_______	X	______	X	______	X	______	/ 2000	=	______
								Total		9

Streambank (Channel)

Reach #	Eroding Length		Rate		Height		lbs/ft3	/ 2000	=	Tons
1	600	X	0.3	X	7	X	90	/ 2000	=	57
____	______	X	______	X	______	X	______	/ 2000	=	______
								Total		57

"If sample reach used"

Total length of sample reach	(A)	_______
Total eroding length of sample reach	(B)	_______
% of sample reach eroding	(B/A)	_______

Total length of watershed channel	X	% Eroding	=	Eroding length
_________	X	________	=	_______

Sediment Delivery Worksheet

Prepared by J. Smith

Watershed name Sample

Date 0/0/96

Present or Future

Multiply gross erosion by sediment delivery ratio (SDR) to determine sediment delivered. For explanation of terms and formulas refer to the text. Chart 1 & Figure 4 should be used to help determine SDR for sheet and rill. Use Table 2 for with concentrated flow SDR. Tables 1 & 3 should be used to adjust SDR's.

	Gross Erosion		SDR		Total Delivered
Sheet & Rill	1200	X	.42	=	504
Ephemeral	83	X	.5	=	42
Gully	9	X	.7	=	6
Streambank	57	X	.8	=	46
Feedlot	80	X	.6	=	48
Other ________	______	X	______	=	______
				Total	**645**

"Measurements are best taken in the field"