ANALYSIS OF SEDIMENT PRODUCTION FROM TWO SMALL SEMIARID BASINS IN WYOMING

By J.G. Rankl

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CONVERSION FACTORS

The following factors may be used to convert the inch-pound units used in this report to metric units:

Multiply	By	To obtain
cubic foot per second	0.02832	cubic meter per second
foot	0.3048	meter
square foot	0.09290	square meter
gallon	3.785	liter
inch	2.540	centimeter
inch per hour	2.540	centimeter per hour
mile	1.609	kilometer
mile per hour	1.609	kilometer per hour
square mile (mi^2)	2.590	square kilometer
ton (short)	0.9072	megagram
ton (short) per year	0.9072	megagram per year

Temperature in degrees Fahrenheit can be converted to degrees Celsius by the following equation:

$$°C = 5/9(°F-32)$$

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ABSTRACT

Data were collected at two small, semiarid basins in Wyoming to determine the relation between rainfall, runoff, and sediment production. The basins were Dugout Creek tributary and Saint Marys Ditch tributary. Sufficient rainfall and runoff data were collected at Dugout Creek tributary to determine the source of sediment and the dominant sediment-production processes. Because runoff from only one storm occurred in Saint Marys Ditch tributary, emphasis of the study was placed on the analysis of data collected at Dugout Creek tributary.

At Dugout Creek tributary, detailed measurements were made to establish the source of sediment. To determine the quantity of material removed from headcuts during the study, two headcuts were surveyed. Aerial photographs were used to define movement of all headcuts. The total quantity of sediment removed from all headcuts between September 26, 1982, and September 26, 1983, was estimated to be 1,220 tons, or 15 to 25 percent of the estimated total sediment load passing the streamflow-gaging station. A soil plot was used to sample upland erosion.

A rainfall and runoff modeling system was used to evaluate the interaction between the physical processes which control sediment production. The greatest change in computed sediment load was caused by changing the parameter values for the sediment-transport equations. Changes in parameter values for equations used to compute the detachment of sediment particles by rainfall and overland flow resulted in very small changes in computed sediment load. The upland areas were the primary source of sediment.

A relationship was developed between the peak of storm runoff and the total sediment load for that storm runoff. The sediment concentration used to compute the total sediment load for the storm runoff was determined from sediment samples collected by two automatic pumping samplers. The coefficient of variation of the relationship is 34 percent with a 0.99 correlation coefficient.

INTRODUCTION

Very little sediment-concentration data and total sediment-production information are available for small ephemeral streams, and even less is known about the source of sediment from small semiarid basins. Years of data collection are required to define sediment-production relations for small ephemeral streams; that is, the relationship of rainfall, runoff, particle detachment by raindrops, channel erosion, headcuts, and deposition to the total sediment production. Researchers have provided an insight into these relationships.

Foster and Meyer (1971) developed an approach by which total sediment load for storm runoff could be computed. Their approach utilizes equations to compute sediment detachment by rainfall, detachment by runoff, transport and deposition, coupled with a continuity equation. A precipitation-runoff modeling system (PRMS) developed by Leavesley and others (1983) uses the conservation of mass equation, developed by Hjelmfelt, Piest, and Saxon (1975), to describe sediment detachment and transport. The modeling system also uses rainfall detachment rates of sediment as described by Smith (1976).

Rainfall and runoff studies have been conducted in Wyoming (Craig and Rankl, 1978) and surrounding States. The rainfall and runoff studies did not include sediment production.

Erosion and sedimentation studies were conducted in the Cheyenne River basin by Hadley and Schumm (1961). The study used accumulated water and sediment in small stockponds to estimate rates of runoff and sediment production for five different types of rock outcrops. The source areas of sediment production were inferred from stockpond measurements, observation of the contributing area, and observation of erosion or nonerosion in the channel.

A study was made to compare the sediment production from two small basins. One basin was undisturbed, and the other basin was an unreclaimed mine area (Ringen and others, 1979). The report shows the unit sediment yield to be 11 times greater in the disturbed basin than in the undisturbed basin. A runoff comparison was not made for the two small basins.

The following terms are used in this report to describe sediment. Sediment production is a general term used to describe processes of erosion and contributions by various processes of erosion. Sediment load is the volume or mass of sediment passing the streamflow-gaging station. It may be measured, computed or simulated by a model. Sediment yield is the volume of sediment per unit area.

Acknowledgment

The author is indebted to many individuals for their assistance through the course of this study. A special acknowledgment is made to William R. Glass, U.S. Geological Survey, for his time and effort spent on new approaches for collecting sediment data and his suggestions which made this project possible.

Purpose and Scope

The purpose of the study described by this report was to establish a relation between sediment production, rainfall, and runoff to determine any significant difference in basin runoff and sediment production that can be attributed to surface mining. A secondary objective was to determine the relative importance of upland erosion and channel erosion as a source of sediment. Emphasis was placed on the systematic collection of sediment data to meet the objectives of the study.

This study entailed the close observation of two small basins over a two-year period. One basin was natural and had a large sediment production; the other basin was constructed entirely from coal mine spoil. Data from the natural basin was sufficient to define total sediment loads for storm runoff and to develop relationships between rainfall, runoff, and sediment production. The reclaimed basin had a very rapid infiltration rate and, therefore, had no runoff or sediment production. Slope transects were established in the reclaimed basin to aid in documenting erosion beyond the time frame of this project.

Basin Descriptions

Location of streamflow-gaging stations and their station numbers are shown in figure 1. Streamflow-gaging stations used in this study have been assigned an 8-digit number. The 8-digit number consists of two parts: The first two digits identify the major river basin in which the stream is located. The remaining six digits identify the relative location of the station, with numbers increasing in a downstream direction.

Dugout Creek tributary (station 06313180) is located in northern Natrona County in central Wyoming (fig. 1). The area of the basin is 0.81 mi^2. The terrain is primarily badlands with some rolling hills in the upland areas. Numerous headcuts are found in the channels. Soils which are derived from the Cody Shale of Late Cretaceous age, have a small permeability and a high shrink-swell potential. They are strongly alkaline and moderately salty. Vegetation consists of western wheatgrass, blue grama grass, and sagebrush. A photograph showing the vegetation and terrain is presented in figure 2.

Saint Marys Ditch tributary (station 06630150) is located near the middle of Carbon County, about 13 miles west of Hanna, Wyo. (fig. 1). Before being mined, the area which is now drained by Saint Marys Ditch tributary was part of an interior drainage system. The present drainage basin was constructed from strip-mine spoils. The tributary drains into Saint Marys Ditch which flows into Seminoe Reservoir. The area of the basin drainage above the streamflow-gaging station is about 0.50 mi^2. Surface soil material is similar to a sandy loam in texture. Vegetation is wheatgrass and halogeton. A photograph of the basin (fig. 3) shows the terrain and the sparse vegetation.

Climate

Continuous weather records are not available for Dugout Creek tributary. However, 59 years of precipitation and temperature data have been collected by the National Weather Service at a site 1 mile south of Midwest (Midwest 1S) and about 8 miles southeast of the basin. The mean annual precipitation is 14.06 inches, and the mean annual temperature is 47.2° Fahrenheit for 1951-80 (National Oceanic and Atmospheric Administration, 1982). Monthly precipitation and temperature values for Midwest 1S are presented in figure 4. During the summer months (May through September), most of the precipitation is from high intensity rainfall. Wind direction and velocity data are not available at Midwest 1S, but data are collected by the National

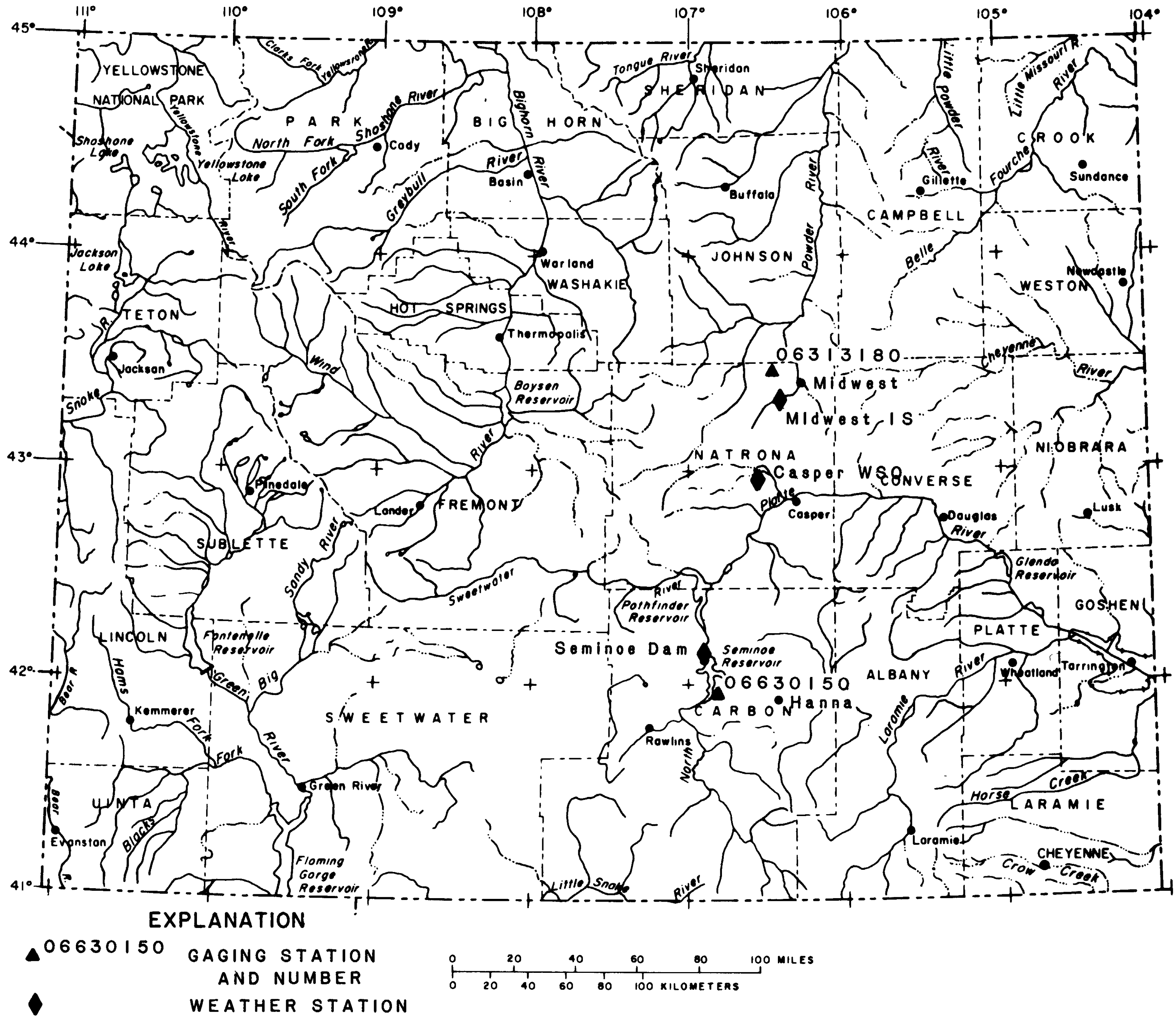


Figure 1.--Location of streamflow-gaging stations used in this report.

Figure 2.--Terrain and vegetation of Dugout Creek tributary near Midwest, Wyoming (station 06313180).

Figure 3.--Saint Marys Ditch tributary near Hanna, Wyoming (station 06630150).

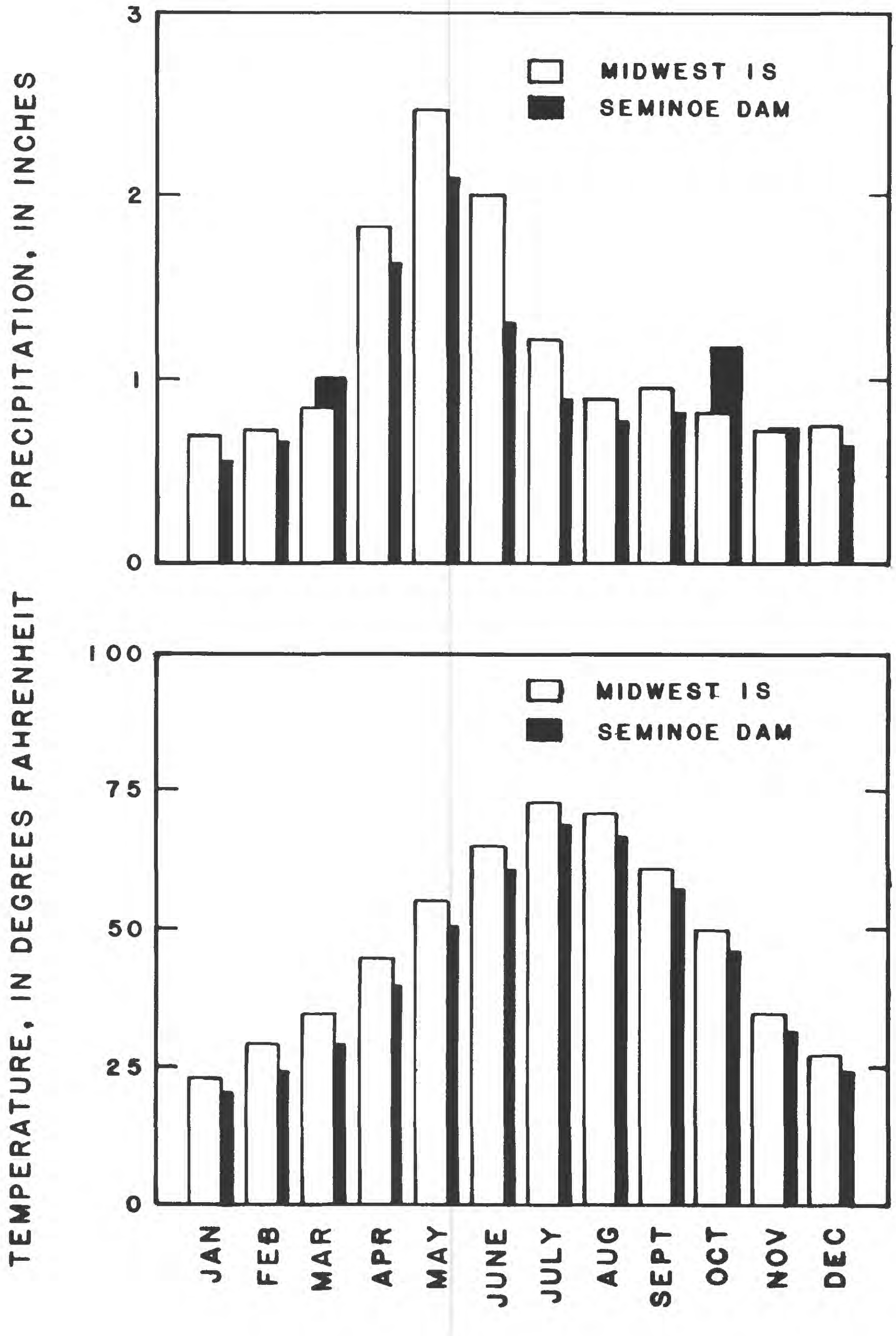


Figure 4.--Average monthly precipitation and temperature data for Midwest 1S and Seminoe Dam, Wyoming, 1951-80.

Weather Service at Casper, Wyo., located about 40 miles to the south of Dugout Creek tributary. The predominate wind direction at Casper is from west-southwest, with an average velocity of 12.9 miles per hour and frequent gusts between 30 and 40 miles per hour (National Oceanic and Atmospheric Administration, 1982).

The climate at Saint Marys Ditch tributary is represented by the climate at the National Weather Service station located 15 miles north at Seminoe Dam. The mean annual precipitation at Seminoe Dam is 12.39 inches for 1951-80, and the mean annual temperature is 43.2° Fahrenheit for 1951-80 (National Oceanic and Atmospheric Administration, 1982). Monthly precipitation and temperature values for Seminoe Dam are shown in figure 4. Winter precipitation values at Seminoe Dam are about the same as those at Midwest 1S, but the summer values are much smaller. Wind data are not available for this area.

DUGOUT CREEK TRIBUTARY

Data Collection

Rainfall data for Dugout Creek tributary were collected during the summer months (May through September) at two sites. One site was at the streamflow-gaging station; the other site was located near the upstream end of the basin. The rain gages have a 5- by 10-inch collector, and the volume of rain collected is recorded by a digital paper-punch recorder. The rain gage located at the streamflow-gaging station was considered the primary rain gage for the study. The rain gage near the upstream end of the basin, which did not record intensity for part of the first year, was used to check rainfall distribution over the basin by comparing the total rainfall at the two gages. Only those storms which had rainfall evenly distributed over the basin were considered in the analysis. A measurement error of 20 percent can be expected because rainfall intensity data from only one rain gage was used.

An artificial control was established at the streamflow-gaging station. The low-water control is a sharp-crested, 152° v-notched, steel-plate weir attached to a concrete structure. The weir plate, the concrete raceway, and the energy dissipation pool are shown in figure 5. The energy dissipation pool is lined with field rock and gravel; the erosion of the sides of the channel are controlled by wire-basket rip rap. The low-water control becomes submerged at a flow depth of about 2.8 feet; at this depth, the channel becomes the control.

Two separate gages were used to obtain the stream-stage record--a well gage with an analog recorder and a servomanometer gas-purge system (known as a bubble gage) with both an analog and a digital recorder. At times the orifice of the bubble gage became covered with silt and would not record the correct gage heights. Subsequently, the well record was used to correct the bubble-gage record when silting occurred. The well, as a rule, filled with silt and was not useful for obtaining data at low stages. Therefore, a combination of data collected from both gages was used to obtain the best records. The flow records are probably within 10 percent of the true value.

The fast-rising stage of a small ephemeral stream requires closely spaced sediment samples. This is necessary in order to determine the sediment load carried by storm runoff. Two automatic, pumping samplers were used; one set at a 7-1/2-minute interval, to collect sediment data for the fast changing part of the runoff and the other set at a 15-minute interval to collect samples for the longer recession limb of the hydrograph. These samples were pumped from the energy-dissipation pool in order to obtain representative samples (fig. 5).

A series of depth-integrated suspended-sediment samples were collected, along with the automatic pump samples, during snowmelt runoff on September 16, 1982, the only time that a hydrologist was at the gaging station for a major storm runoff. A comparison was made of the sediment concentrations contained in the two sets of samples. The concentration in the samples collected by the automatic pumping samplers were 20 to 25 percent greater than sediment concentrations in the samples collected by the depth-integrating suspended-sediment sampler (fig. 6).

Two sediment samples were collected and analyzed to determine the particle-size distribution. One sample was collected by the automatic pumping sampler, the other by the depth-integrating suspended-sediment sampler. These samples were collected on the same day for the same storm runoff but at different times. Size of the particles in the sample collected by the pumping sampler was larger than the size of the particles in the sample collected by the depth-integrating suspended-sediment sampler; thus indi-

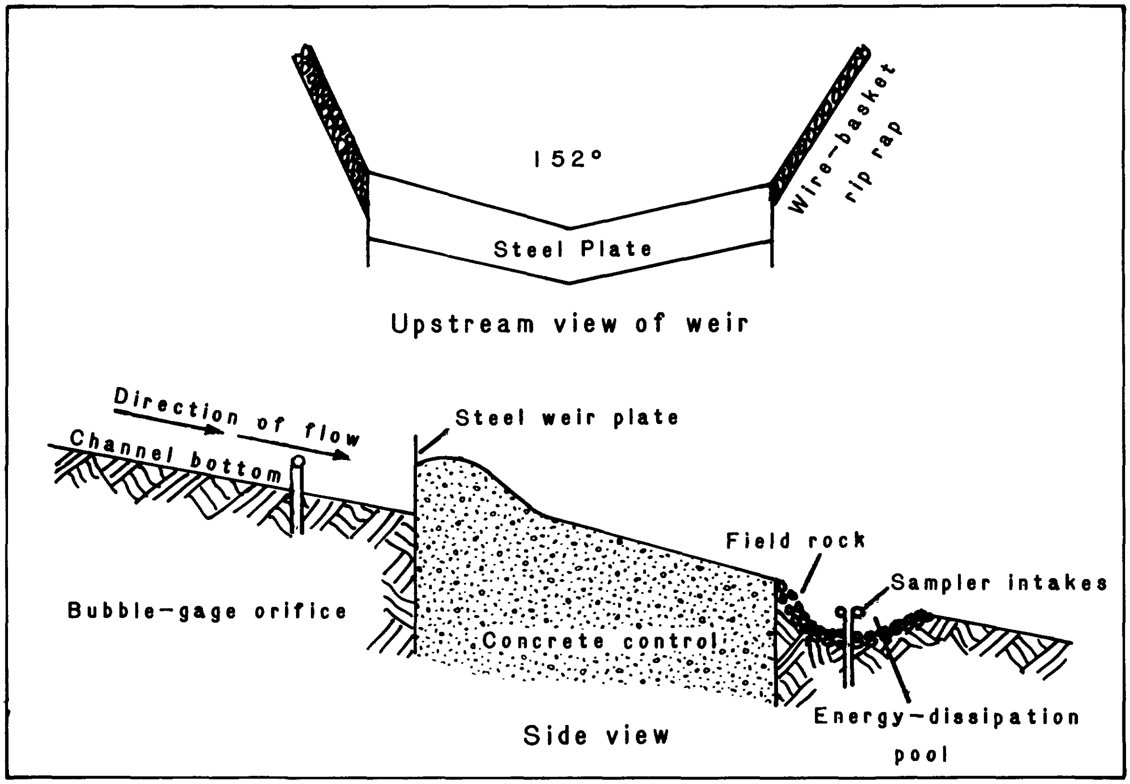


Figure 5.--Low-water control for streamflow-gaging station at Dugout Creek tributary near Midwest, Wyoming (station 06313180).

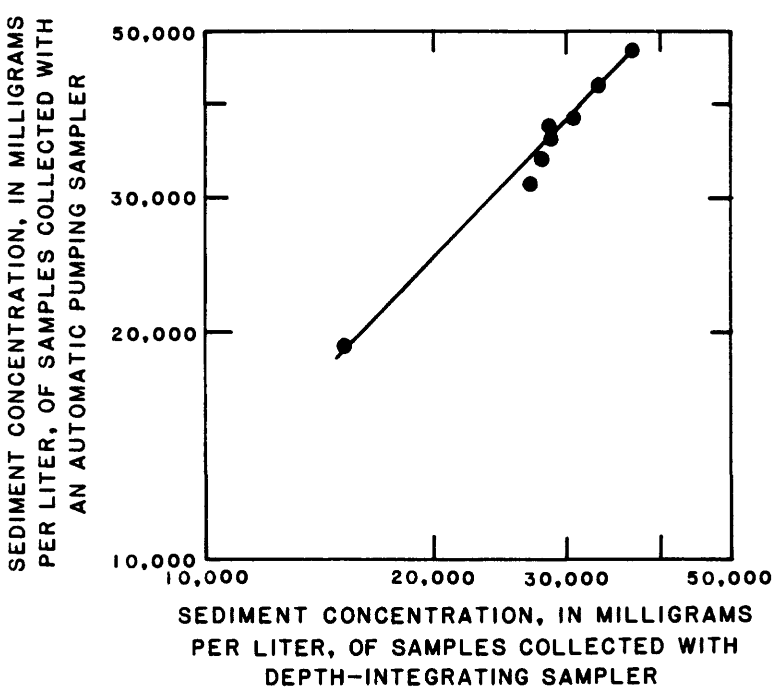


Figure 6.--Relationship of sediment concentration from samples collected by automatic pumping sampler and depth-integrating suspended-sediment sampler.

cating that bed material is included in the sample collected by the automatic pumping sampler. Distribution of selected particle sizes for the two samples is listed in table 1.

The method developed by Colby (1957), was used to compute the unmeasured sediment load. A computer program developed by J. E. Kircher (U.S. Geological Survey, written commun., 1983) was used to perform the Colby computation. The program requires an input of discharge, channel width, channel area, mean velocity, and suspended-sediment concentration. The output from the program is the unmeasured sediment load and total sediment load.

A cross-section of the channel, located about 100 feet upstream from the streamflow-gaging station, was used to define the hydraulic characteristics for the computations of unmeasured loads of eight suspended-sediment samples collected with the depth-integrating suspended-sediment sampler. The results of the analysis were converted to values of concentrations in milligrams per liter in order to compare with the concentrations in samples pumped from the energy-dissipation pool by the automatic pumping sampler. Results of the analysis and the differences between the sediment concentrations in samples collected by the automatic pumping sampler and computed by Colby's method of determining total sediment load are listed in table 2.

It was concluded that the samples collected by the automatic pumping samplers represented total sediment load consisting of suspended sediment and bed material. This conclusion was reached when an analysis was made of the following three factors: 1) particle size of the samples, 2) location of the intake of the pumping sampler, and 3) the resulting computations of

Table 1.--Distribution of particle size for samples collected with two types of samplers.

Particle size diameter (micrometers)	Particle-size distribution (Percent finer than indicated diameter) Automatic pumping sampler	Depth-integrating suspended-sediment sample
1,000	97.6	----
500	95.7	99.9
250	94.0	99.6
125	92.8	99.2
62	88.8	98.8
16	----	95.8
8	----	80.2
4	25.4	66.7

Table 2.--Results of the analysis of total load concentrations.

		Sediment concentration, in milligrams per liter			Difference in concentration between automatic pumping sampler and Colby's method (percent)
		Measured		Computed	
Sample number	Discharge (cubic feet per second)	Depth-integrating suspended-sediment sampler	Automatic pumping sampler	Colby's[1] method	
1	12.2	26,981	31,200	32,940	+ 5.6
2	12.9	27,830	33,600	33,990	+ 1.2
3	14.0	28,420	37,100	34,960	- 5.8
4	14.8	28,586	35,900	35,033	- 2.4
5	18.8	30,561	37,950	37,549	- 1.1
6	21.0	33,122	42,000	39,867	- 5.1
7	27.8	36,488	46,950	34,492	- 7.4
8	33.8	37,083	47,050	44,623	- 5.2
9	39.1	36,248	([2])	43,629	----
10	22.1	15,224	19,000	------	----

[1]From Colby (1957)
[2]No sample

unmeasured sediment load. All samples, except those with a small draw or an obvious error, were used to compute sediment load for storm runoff.

A sediment concentration and discharge relationship could not be developed for Dugout Creek tributary. The scatter of data points for the sediment samples collected by the automatic pumping sampler are shown in figure 7. The peak sediment concentration may occur before, at, or after the peak discharge; therefore, the sediment load for a specific storm runoff had to be computed from samples collected for that storm runoff. Discharge hydrographs were plotted in 5-minute intervals. Sediment concentrations curves were sketched from the samples, and an estimated value was assigned for each 5-minute interval. An example of one storm runoff hydrograph and its associated sediment-concentration trace are shown in figure 8. Sufficient data were collected to compute the total sediment load for 11 storm runoffs--1 of which was snowmelt.

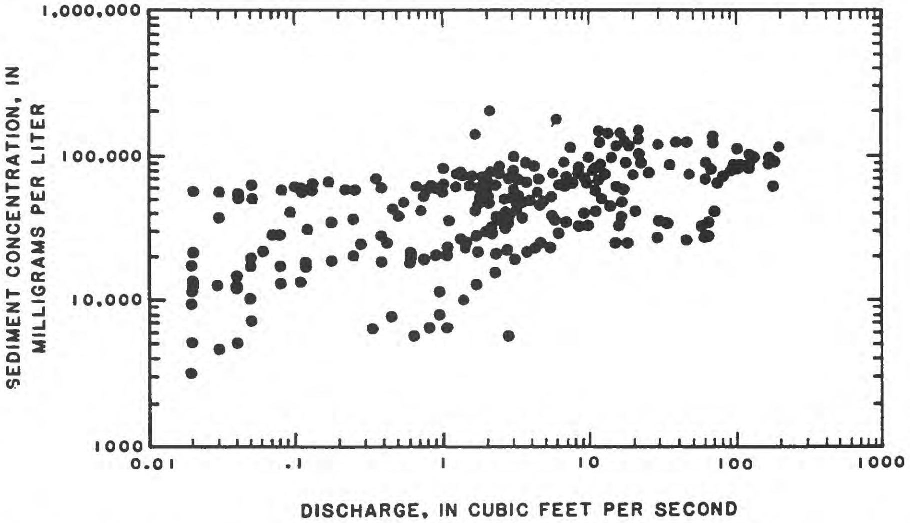


Figure 7.--Sediment concentration versus discharge, Dugout Creek tributary near Midwest, Wyoming (station 06313180).

Upland Erosion

Two major source areas for sediment were considered in this study: upland erosion and channel erosion. To evaluate upland erosion, a soil plot of approximately 71 square feet was constructed on a west-facing slope near the rain gage at the upstream end of the drainage basin. The plot is about 12 feet long and 6 feet wide with a 30-percent slope. The average basin slope is about 14 percent. The plot was constructed by using plastic lawn edging to confine the flow to the area. All flow is collected at the lower end of the plot and transported to a 55-gallon barrel by a 3-inch pipe. The water-sediment mixture was sampled for sediment concentration and the volume of the mixture was measured. A photograph of the soil plot is shown in figure 9.

Data were collected for the 1982 runoff season. The time period of each sample, total rainfall and its maximum intensity, plot runoff, basin

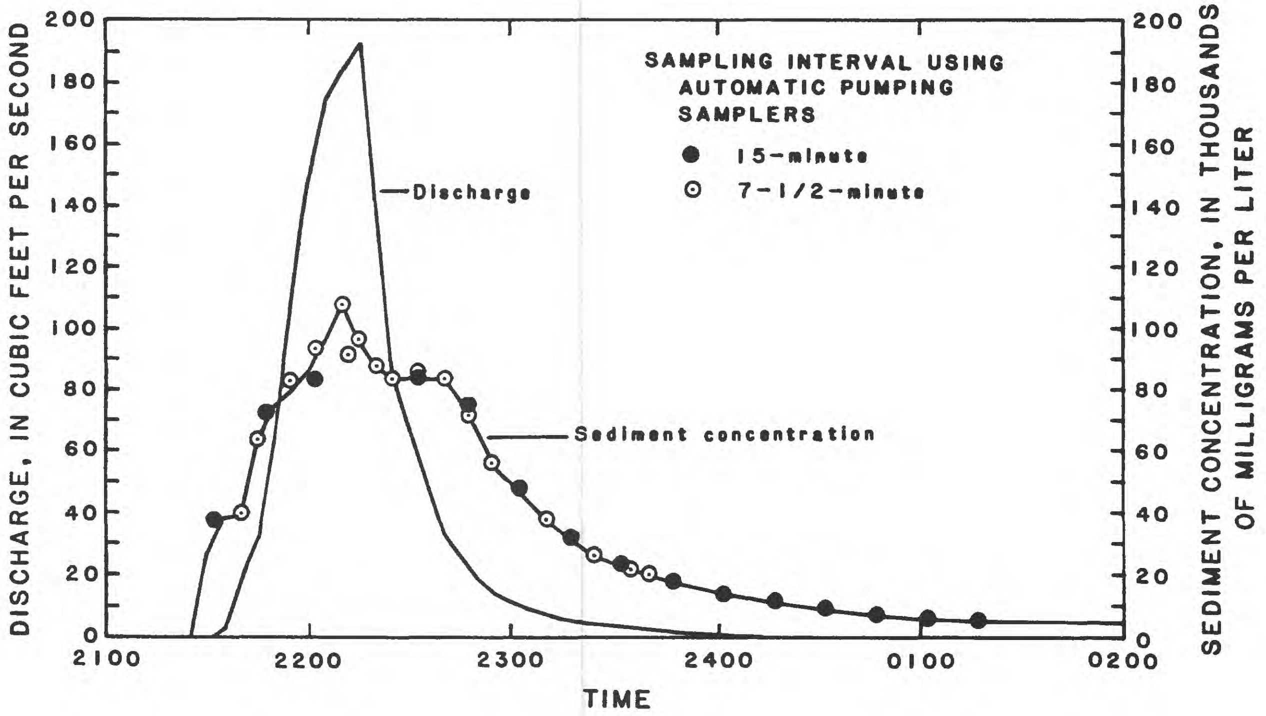


Figure 8.--Discharge and sediment concentration for Dugout Creek tributary near Midwest, Wyoming (station 06313180) (storm of August 4-5, 1983).

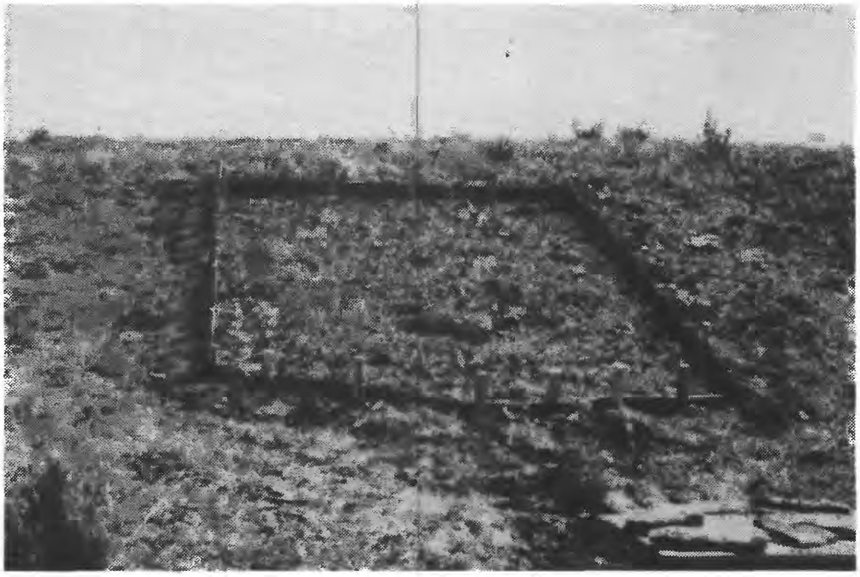


Figure 9.--Soil plot used to sample upland erosion in Dugout Creek tributary near Midwest, Wyoming (station 06313180).

runoff, and concentration of the water-sediment mixture are listed in table 3. The sediment concentration appears to be related to maximum rainfall intensity. Total runoff (in inches) from the soil plot was 11 percent less than total runoff from the basin; therefore, the soil plot data appears to be representative of the basin. Sediment concentration data was not available for all runoff events from the basin, therefore a comparison between sediment production from the soil plot could not be made to sediment production from the basin.

Table 3.--Soil plot data.

Period		Rainfall (inches)	Intensity[1] (inches per hour)	Plot runoff (inches)	Basin runoff (inches)	Sediment concentration (milligrams per liter)
Start	End					
5-10-82	6-02-82	2.35	1.20	0.214	0.115	17,500
6-02-82	6-17-82	.71	.96	.109	.086	8,220
6-17-82	7-22-82	1.03	2.09	.159	.137	27,900
7-22-82	8-19-82	1.24	.96	.360	.319	13,000
8-19-82	9-21-82	2.75	.72	1.124	1.583	2,630
9-21-82	10-14-82	1.55	.72	.319	.314	2,480
5-10-82	10-14-82	9.63		2.285	2.554	

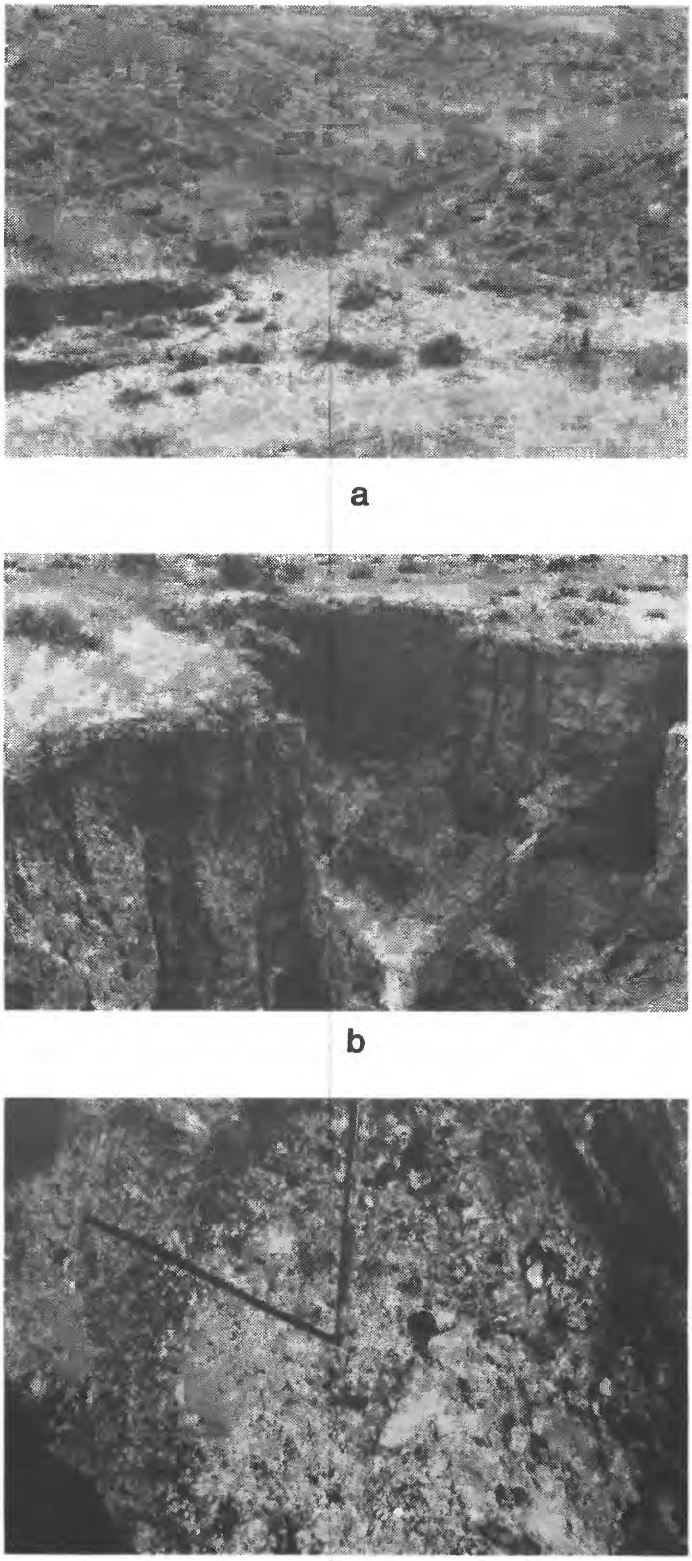
[1]Maximum 5-minute intensity during each period

Channel Erosion

Three types of channel erosion and deposition have been identified in Dugout Creek tributary: (1) An upstream reach in a deposition cycle, (2) an active headcut section, and, (3) a stable, armored main channel downstream from the headcut to the gage. The three channel types are shown in figure 10.

The upstream depositional reaches are wide, flat, and grassy. The moderate slope of the channel and large roughness coefficient reduces the sediment transport capacity of the stream; thus deposition is increased. The extent of these reaches is minor when compared to the length of the stable, armored channel. Generally, the headcuts extend into the depositional reaches.

Ten major headcuts are in the drainage basin. Two of these were used for determining volume of sediment removed during the study. The remaining eight headcuts were used to determine movement up gradient in order to estimate the total volume of material removed from all headcuts. Aerial photographs taken on July 19, 1967, and on July 23, 1976, were used to measure movement up gradient of these 10 headcuts. The aerial photographs showed no change in several of the headcuts. These headcuts were field-



a

b

c

Figure 10.--Channel types in Dugout Creek tributary near Midwest, Wyoming (station 06313180). (a) Wide depositional channel, (b) channel with active headcut, and (c) a stable, armored channel.

checked, and it was determined that the reason for lack of movement was bedrock control.

The volume of channel material removed by the headcuts was estimated from surveys. A large headcut in the main channel was surveyed on September 26, 1982, and again on September 26, 1983. Cross-sections were used to define the quantity of material removed from the channel for the interim period. At the time of the two surveys, the lip of the headcut was defined to determine the movement up gradient of the headcut and to aid in computing the volume of material. A second headcut, in the channel of the largest tributary, was surveyed on July 20, 1982, and again on September 22, 1983. Channel cross-sections were not used to define the volume of material removed because the headcut was almost 20 feet deep and had an angle of repose of 85°. The upper lip of the headcut and the channel bottom was surveyed to determine the size of the headcut. From the two surveys, the volume of material removed from the tributary channel was estimated. Figure 11 shows the change in area for the two headcuts.

The total quantity of sediment removed by all headcuts was estimated. Distance of movement for the 2 surveyed headcuts was measured on aerial photographs and equalled a combined total of 219 feet. The 8 smaller headcuts had moved a total distance of 168 feet. The total quantity of material removed from the 2 surveyed headcuts was estimated to be 692 tons for a 1-year period. A ratio of the distance of movement for the 2 surveyed headcuts to the distance of movement for all 10 headcuts, and the volume of material from the 2 surveyed headcuts was used to compute the quantity of material removed from all 10 headcuts. The total quantity of material removed for a 1-year period was estimated to be 1,220 tons.

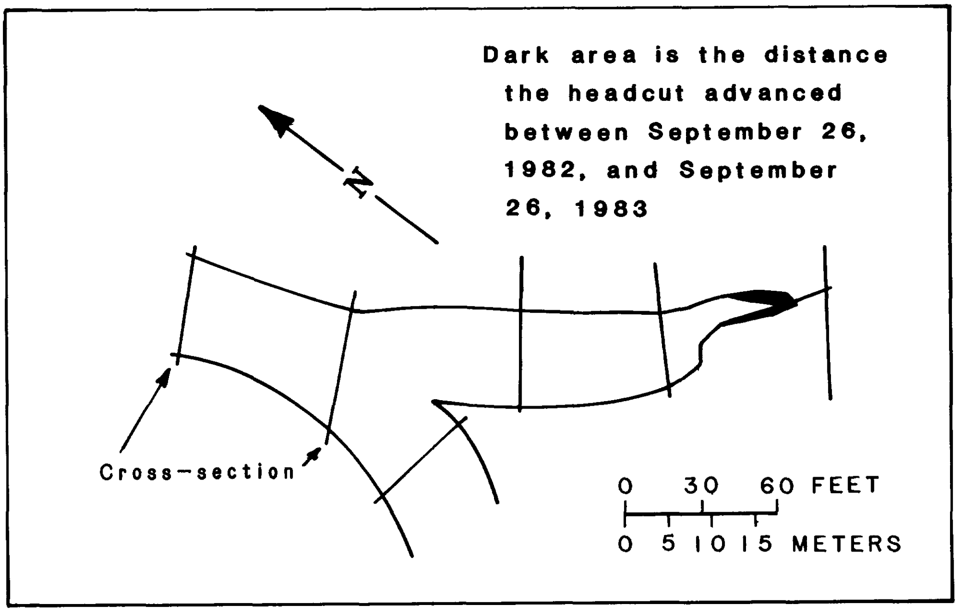
An average sediment concentration of the September 16, 1982, snowmelt runoff was used to make a conservative estimate of sediment production from the basin for the time period between headcut surveys. The average sediment concentration for the runoff during September 16, 1982, was 24,000 mg/L (milligrams per liter). Total sediment production between September 26, 1982, and September 26, 1983, was computed and compared to the quantity of sediment removed from all headcuts. Assuming an average sediment concentration of 24,000 mg/L, the headcuts yielded a maximum of 25 percent of the total sediment production from the basin for the period investigated. If an average sediment concentration of 40,000 mg/L (an average concentration of all samples collected) were used to compute the total sediment production, then the headcut sediment production would be reduced to 15 percent of the total sediment production.

The remainder of the channels, about 80 percent of the total length, have steep slopes, are narrow, and are armored. Erosion appears negligible in these channel reaches. A few depositional bars can be found but do not appear to be increasing in numbers or size.

SAINT MARYS DITCH TRIBUTARY

Data Collection

Saint Marys Ditch tributary was instrumented to collect four types of hydrologic data; rainfall, stream stage, sediment concentration and ground-



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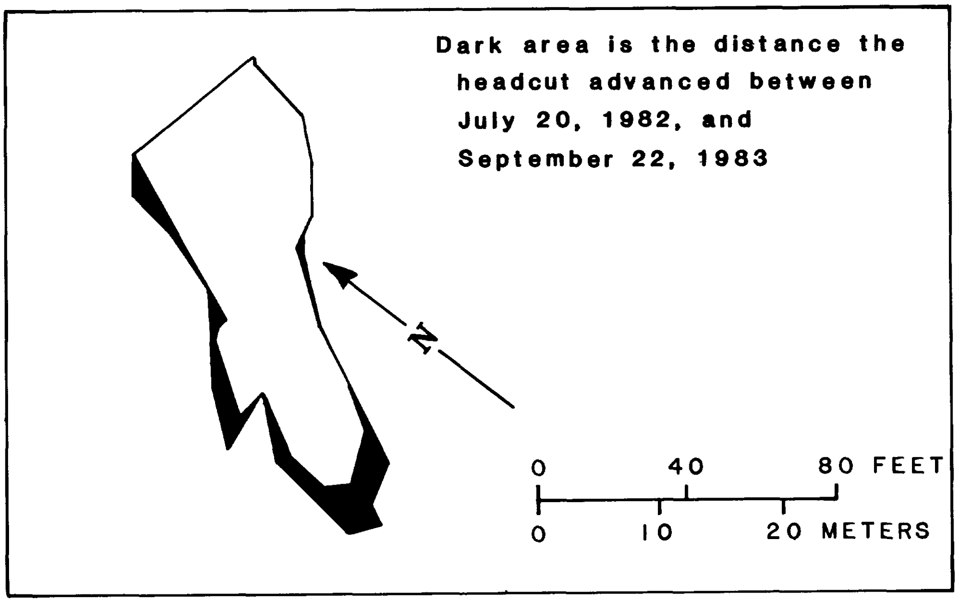

b

Figure 11.--Headcut advance in (a) the main channel and (b) a tributary channel of Dugout Creek tributary near Midwest, Wyoming (station 06313180).

water level. Stage data and water-level data were collected for the entire year; rainfall and sediment concentration data were collected during May through September, the months when most of the precipitation is from high intensity rainfall. The recorders and samplers were installed in May 1982 and discontinued in September 1984. The water level recorder was installed in November 1984.

Rainfall intensity and volume data were collected using a 5- by 10-inch collector. The quantity and rate of rainfall were recorded using a digital paper-punch recorder. The rain gage was located at the downstream end of the drainage basin, near the streamflow-gaging station.

Because the reconstructed channel is unstable, a temporary, artificial low-water control was constructed. The control was a 146° v-notched weir plate constructed from 3/4-inch plywood. The weir plate was cemented into the channel. A small raceway and energy-dissipation pool were constructed on the downstream side of the weir plate. The orifice for a bubble-gage was located about 3 feet upstream from the weir plate. The water stage was recorded by a digital paper-punch recorder. Sediment concentration data was collected using an automatic pumping sampler. The samples were pumped from the energy-dissipation pool. The low-water control was similar to the control on Dugout Creek tributary.

As a result of small precipitation volumes and rapid infiltration rates, erosion in the reconstructed basin was minor. The collection of rainfall, runoff, and sediment concentration data was limited to two summer seasons; therefore, it was necessary to document the channel and two hillslopes from which erosion can be measured. Channel cross-sections and hillslope transects were surveyed to provide the necessary data base.

Data Analysis

The largest rainstorm in the 1983 runoff season was 0.68 inch during 2.17 hours. This rainstorm produced local areas of overland flow, but there was not sufficient rain to produce runoff that flowed past the streamflow-gaging station. On August 16, 1984, an intense rainstorm, 0.64 inch during 10 minutes, exceeded the infiltration rate of water into the soil causing runoff to flow past the gaging station. The storm runoff eroded the channel, and a slump caused by the differential packing of the mine-fill material destroyed the control. At a point 50 feet below the control, the maximum discharge was estimated to be 5 cubic feet per second. Twenty-four sediment samples were collected by the automatic pumping sampler. The sediment concentrations for these samples ranged from 1,490 to 3,290 mg/L with an average concentration of 2,330 mg/L.

On October 4, 1983, 9 steel pins, spaced 50 feet apart, were installed in a line on the right hillslope near the streamflow-gaging station, and 7 pins were installed on the left hillslope. The elevation of the top of the pins was determined with a level. A brass washer was placed over the top of each pin, and the distance between the ground (top of the washer) and the top of the pin was determined. The washer was removed from each of the pins. The procedure was repeated on July 2, 1984, to determine erosion and/or deposition on the hillslopes. The measurements indicated 0.02 foot of deposition on the right hillslope and no change on the left hillslope.

SIMULATION OF RUNOFF AND SEDIMENT PRODUCTION WITH A HYDROLOGIC MODEL

The interaction between physical processes controlling sediment production needs to be evaluated. The interaction between runoff, particle detachment by raindrops, sheet erosion, transport capacity, and deposition can be evaluated using a hydrologic simulation model. The approach used was collection of rainfall, runoff, and sediment concentration data, calibration of the hydrologic simulation model, and then placement of a stress on the model parameters to obtain an estimate of changes in runoff and sediment load. The U.S. Geological Survey's precipitation-runoff modeling system (PRMS) developed by Leavesley and others (1983) was used to determine the interaction of physical processes.

Dugout Creek tributary was considered a basin where rainfall, evaporation, soils, infiltration, and runoff was similar throughout the basin. However, the basin was divided into 13 flow planes and 8 channel segments for the purpose of routing excess precipitation and sediment to the mouth of the basin. Parameter values for soil-moisture accounting, infiltration, evaporation, sediment detachment, sediment transport, and runoff were the same for all flow planes. The initial parameter values for computing rainfall runoff were obtained from previous rainfall and runoff model results (Craig and Rankl, 1978). Parameter values for the overland flow equations were estimated from land slope and roughness. Parameter values for routing flow down the channel were estimated from cross-section properties. The initial parameter values for sediment detachment and transport were suggested by R. W. Lichty (U.S. Geological Survey, oral commun., 1984).

Rainfall, runoff, and sediment concentration data collected at Dugout Creek tributary were used to calibrate the parameters of the model. Data from 12 storms were used in the calibration process. Eight of these storms had sufficient sediment data to determine the total sediment load for storm runoff. Daily precipitation values for the winter period were obtained from the National Weather Service station, Midwest 1S, 8 miles southeast of the study site. Pan-evaporation data were obtained from the weather station near Gillette, 76 miles northeast of the study site.

Saint Marys Ditch tributary had insufficient data for modeling the hydrology of the basin. There was only one storm with runoff and one set of sediment samples.

Calibration

Runoff

Optimization runs were made in the daily mode to estimate soil-moisture conditions prior to optimizing parameters for the unit storms. An attempt was made to fit computed daily runoff to measured daily runoff in order to estimate the initial soil-moisture parameters; however, the variability of rainfall during a 24-hour period made it impossible to accurately compute values of daily runoff. To obtain appropriate values for soil-moisture accounting parameters, all daily mode parameter values were optimized so that computed annual runoff closely approximated measured annual runoff.

Next, parameter values for computing unit storm runoff volumes were optimized. The application of the parameters used to fit the measured and computed runoff volumes, as well as the optimized parameter values, are described in table 4. Four infiltration parameters, KSAT, PSP, RGF, and DRN

Table 4.--Parameter descriptions and optimized values.

Parameter	Parameter description[1]	Unit	Optimized value
	Runoff		
KSAT	Hydraulic conductivity of the transmission zone.	Inches per hour.	0.0214
PSP	Suction at the wetted front for soil moisture at field capacity.	Inches.	1.14
RGF	Ratio of the suction at the wetted front for soil moisture at wilting point to that at field capacity.	------	8.97
DRN	A constant drainage rate for redistribution of soil moisture.	Inches per hour.	.010
REMX	Maximum moisture storage in the recharge zone of the soil profile.	Inches.	.180
	Overland flow routing		
ALPHA	Coefficient for overland flow plane characteristics for kinematic wave routing.	------	23.2
RM	Exponent for overland flow-plane characteristics for kinematic wave routing.	------	1.59
	Channel flow routing		
ALPHA	Coefficient for channel characteristics for kinematic wave routing.	------	2.31
RM	Exponent for channel characteristics for kinematic wave routing.	------	1.18
	Sediment		
KR	Coefficient used to compute raindrop detachment of sediment.	------	1200
HC	Exponent used to compute raindrop detachment of sediment.	------	100
MM	Coefficient used to compute the sediment transport of flow.	------	21.6
EN	Exponent used to compute the sediment capacity of flow.	------	1.50
KF	Coefficient used to compute the detachment of sediment by flow.	Feet.	29.4

[1]Leavesley and others (1983)

(see table 4 for definitions), were optimized in the unit mode to obtain the best fit between measured and computed storm runoff values. The parameter REMX (maximum moisture storage in the recharge zone of the soil profile), optimized in the daily mode, was reoptimized in the unit mode to obtain a better fit between measured and computed runoff. No significant change was made in the parameter value for the two fitting procedures. A least-squares analysis was made to determine the fit between computed and measured runoff. The coefficient of variation was 14 percent; the coefficient of variation of log-transformed data was 48 percent. A graphical approach (fig. 12) was used to check for skewness and the distribution of data.

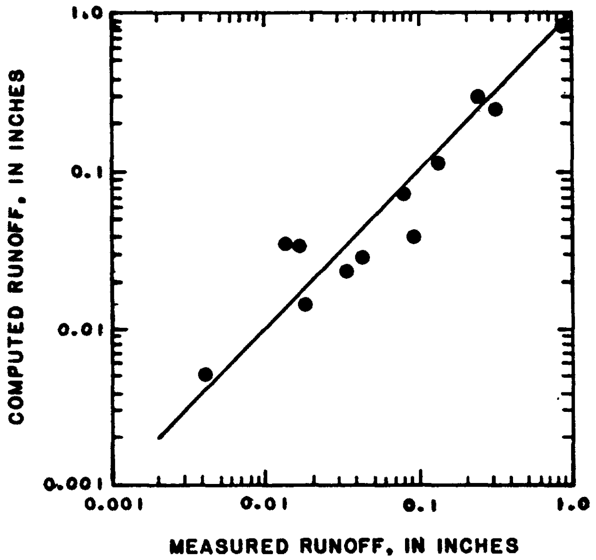

Figure 12.--Comparison of computed runoff to measured runoff for individual storms for Dugout Creek tributary near Midwest, Wyoming (station 06313180).

Parameter values were optimized for routing excess precipitation from the flow planes down through the channel segments. Overland flow of excess precipitation is computed using a kinematic wave approximation described by Dawdy, Schaake, and Alley (1978) and Leavesley and others (1983). Initial values for the parameters for depth-of-flow and rate-of-flow were estimated using equations developed by Dawdy, Schaake, and Alley (1978). Channel-flow routing uses the same approach as that used in overland-flow routing. Eight channel cross-sections were surveyed, and the data were used to estimate the initial kinematic wave parameters. The initial values for parameters ALPHA and RM for both overland flow and channel flow were optimized to obtain the best fit between computed peak discharge and measured peak discharge. Parameter descriptions and optimized values are listed in table 4. The coefficient of variation was 45 percent; the coefficient of variation of log-transformed values was 69 percent. The graphical analysis of the relationship between computed and measured peak values are presented in figure 13. A small reduction in the error of fitting the peak values can be obtained by optimizing the runoff parameters listed in table 4; however, this results in a large increase in error when fitting the sediment data.

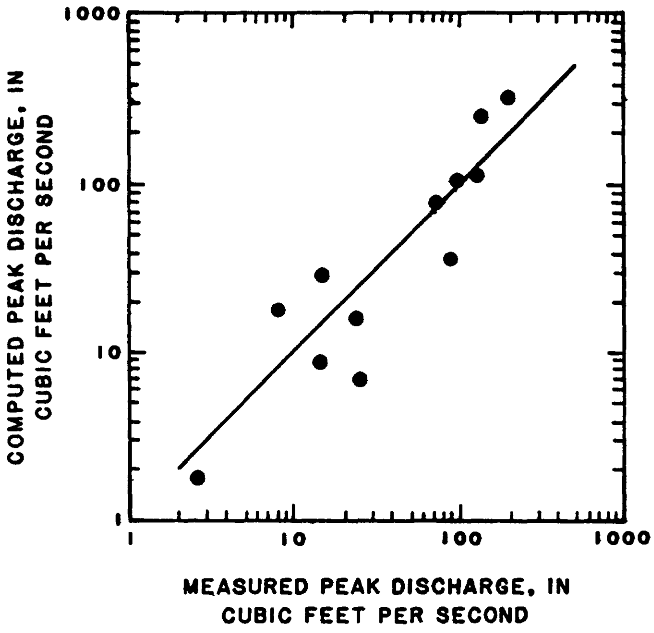

Figure 13.--Comparison of computed peak discharge to measured peak discharge for individual storms for Dugout Creek tributary near Midwest, Wyoming (station 06313180).

Sediment

Sediment load was computed using equations and relationships developed by Hjelmfelt, Piest, and Saxon (1975) and Smith (1976). In the PRMS model the sediment load equations and relationships are solved simultaneously with the equations of overland flow. Leavesley and others (1983, p. 38), describe the sediment routine in the model as, "For a given time step, the rainfall detachment rate (ER) is added to the current transport rate (TR) and the sum is compared to the transport capacity (TC). If the sum is greater than the transport capacity, the current transport rate is set equal to the transport capacity. If the sum is less than the transport capacity, then the flow detachment (EF) computations are made and added to the current transport rate." The sediment from the overland-flow planes is routed down the stream channels as a conservative substance. A continuity of mass equation is used to compute the transport of sediment down the channel. Although the PRMS model computes the total sediment load for storm runoff, it has not been programmed to optimize the parameter values using a least-squares procedure.

Several assumptions had to be made in order to use the sediment component of the PRMS model for Dugout Creek tributary:

1. The sediment erosion from the headcuts in the upper channels will be accounted for by the rill erosion equations.
2. The main channel is armored and is not eroding.
3. Deposition in the main channel is minor.

Five parameters are used to fit the computed-sediment load to the measured-sediment load. Two of the parameters, KR and HC, are used to compute the detachment rate of sediment by rainfall. Two of the remaining three parameters, MM and EN, are used to compute the transport capacity of flow. The remaining parameter, KF, was used to compute the flow-detachment rate of sediment. The equations for these parameters can be found in Leavesley and others (1983). Eight rainfall and runoff storms with sediment-load data were available for determining the best set of parameter values. The initial values for sediment-production parameters were obtained from R. W. Lichty (U.S. Geological Survey, oral commun., 1984). The optimization of parameter values was accomplished by using a least-squares analysis of the computed and measured sediment load for each set of parameters. The statistical equations used to compute the least-squares analysis are the same as those used in the PRMS model. The description and results of sediment parameter optimization are listed in table 4. The coefficient of variation for sediment-load data for the 8 storms was 19 percent. The distribution and the bias of the data are presented in figure 14.

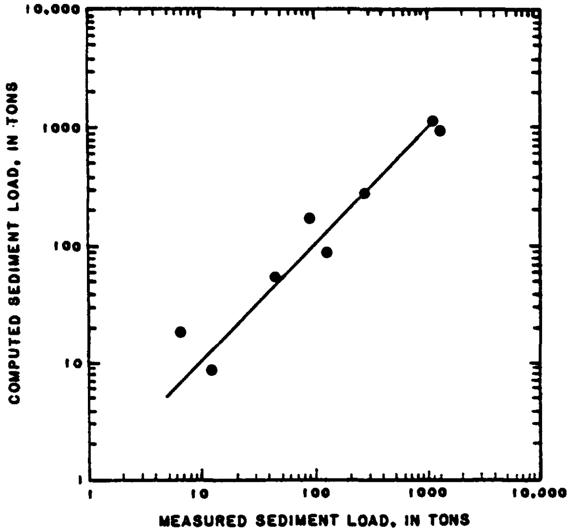

Figure 14.--Comparison of computed sediment load to measured sediment load for individual storms for Dugout Creek tributary near Midwest, Wyoming (station 06313180).

Accounting for sediment removed from the channels by head cutting with the rill erosion equations did not cause a problem in fitting the computed load to the measured load. However, by including the headcut material in the computation of computed load, a problem may exist in obtaining correct values for the sediment parameters; specifically the two parameters for raindrop detachment of sediment which are insensitve when computing sediment load.

Sensitivity Analysis

Sensitivity analysis provides the information that determines the extent to which uncertainty in the optimized parameter values results in uncertainty in predicted runoff. It also determines the magnitude of parameter errors and defines intercorrelation between parameters. A sensitivity analysis was made on runoff parameters and on routing parameters. Sediment parameters cannot be optimized by the PRMS model; therefore, the subroutines used to compute sensitivity analysis of sediment parameters could not be run. A sensitivity analysis of the sediment production parameters was made by varying the parameter values from the best-fit values.

The first sensitivity run was made on log-transformed values of runoff volumes. KSAT was found to be the most sensitive parameter. For example, a 10-percent error in KSAT resulted in an 8.3-percent error in runoff. A 10-percent error in PSP resulted in an 8.0-percent error in runoff and a 10-percent error in RGF resulted in a 7.8-percent error in runoff. The remaining two parameters (DRN and REMX) are not sensitive for the soil type found at Dugout Creek tributary. The parameter coefficient of variation is a measure of the uncertainty of the optimized parameter value. Parameters KSAT, PSP, and RGF had a coefficient of variation of about 22 percent. The coefficient of variation for DRN and REMX were in excess of 300 percent. The large coefficient of variation of DRN and REMX shows the insensitivity of these parameters to the soil type found at Dugout Creek tributary. The correlation between KSAT and PSP, and among RGF, DRN, and REMX is less than 0.5 and the correlations among PSP, RGF, and REMX are greater than 0.99.

The second sensitivity run was made on log-transformed values of peak discharges. The most sensitive overland flow parameter was ALPHA. A 10-percent error in the parameter resulted in a 30-percent change in peak discharge. A 10-percent error in the overland flow parameter, RM, resulted in only a 2.6-percent error in the peak discharge. ALPHA also is the most sensitive channel-flow routing parameter, a 10-percent error resulted in an 11-percent error in peak discharge. Channel-flow routing parameter RM caused a 5.4-percent change in peak discharge for a 10-percent error in the parameter value. The coefficient of variation for overland flow-routing parameters was 62 percent for parameter RM and 5.4 percent for parameter ALPHA. The coefficient of variation for channel-routing parameters was 30 percent for RM and 14.4 percent for ALPHA.

The sensitivity of sediment production parameters was determined by changing the parameter values by 10-percent increments and by computing the error using the least-squares fit between measured and computed sediment load. Parameters considered in the analysis were KR, HC, MM, EN, and KF. The two most sensitive parameters were EN and MM which were used to compute the sediment transport capacity. A 10-percent change in parameter value EN resulted in a 100-percent change in the computed sediment load. A 10-percent change in MM resulted in an 11-percent change in sediment load. The parameter (KF) used to compute detachment of sediment by overland flow changed the sediment load about 2 percent when the parameter value was changed by 10 percent. Computed sediment production is insensitive to changes in parameter values (KR and HC) used to compute detachment of sediment particles by raindrops for the soil type found in Dugout Creek tributary.

The length of the time step used to route the flow with the sediment from the overland flow planes was critical. Initially, a 5-minute time step was used to compute the flow from the overland-flow plane, but the computation of sediment load was not stable at that time interval. The computation of sediment load was stable at both 1- and 2-minute intervals; a 1-minute interval was used for all computations.

COMPARISON OF BASIN HYDROLOGIC CHARACTERISTICS

The basin characteristics for Dugout Creek tributary and Saint Marys Ditch tributary were used to evaluate the results of the data collected at the two basins. Basin parameters considered for this evaluation are area, basin slope, channel slope, vegetation and soil particle size. The basin characteristics are listed in table 5.

Table 5.--Basin characteristics.

Station name	Area (square miles)	Basin slope (feet per mile)	Channel slope (feet per mile)	Vegetation	Soil median grain size (millimeters)
Dugout Creek tributary near Midwest, Wyoming (06313180)	0.81	728	97.2	sagebrush and sparse grass	0.025
Saint Marys Ditch tributary near Hanna, Wyoming (06630150)	.50	791	71.0	sparse grass and halogeton	.120

The two most significant physical differences between Dugout Creek tributary and Saint Marys Ditch tributary are size of the drainage area and soil type. The drainage area difference between the tributaries does not account for the degree of difference in the volume of runoff from the two basins, but the soil material and its texture caused the difference in runoff. The sandy loam of Saint Marys Ditch tributary has a very rapid infiltration rate which results in small runoff. In addition more stream energy is required to transport the coarser soil material down the channel; therefore, most of the sediment drops out of suspension before reaching the sampling station. In contrast, the soil of Dugout Creek tributary is a clay silt loam which has a high potential for runoff and erosion. The fine material is carried in suspension downstream past the sampling station.

APPLICATION OF RESULTS

The data and information in this study can be used to aid in evaluating sediment production from small basins where strip mining is proposed. The most important factors to consider when evaluating sediment production from small basins in a semiarid climate are infiltration of water into the soil, soil particle size, vegetation, and land and channel slope. Because only Dugout Creek tributary had sufficient data to draw conclusions and evaluate methods of computing sediment load, transfer of results are by inference. From an infiltration study (Rankl, 1982), the soil type found at Dugout Creek tributary has one of the slowest infiltration rates of 29 soil complexes studied. Therefore, data and the results of the sediment production study at Dugout Creek tributary can be used as an upper limit when estimating sediment load for small basins.

Upland erosion is the source of most of the sediment leaving the basin and, from the model studies, erosion by overland flow appears to be the mechanism for the detachment of sediment particles. Headcut erosion is significant but not a major source of sediment in Dugout Creek tributary. The simulated detachment of particles by raindrop is minimal as shown by the insensitivity of the parameters for raindrop detachment.

A relationship between peak discharge and total sediment load for storm runoff was developed for Dugout Creek tributary (fig. 15).

$$S_l = 1.76Q_p^{1.29} \tag{1}$$

where

S_l is the sediment load for the runoff event, in tons and
Q_p is the peak discharge for the runoff event, in cubic feet per second.

Equation 1 can be used to predict total sediment load from the peak discharge for this site. The sediment concentrations used to compute the

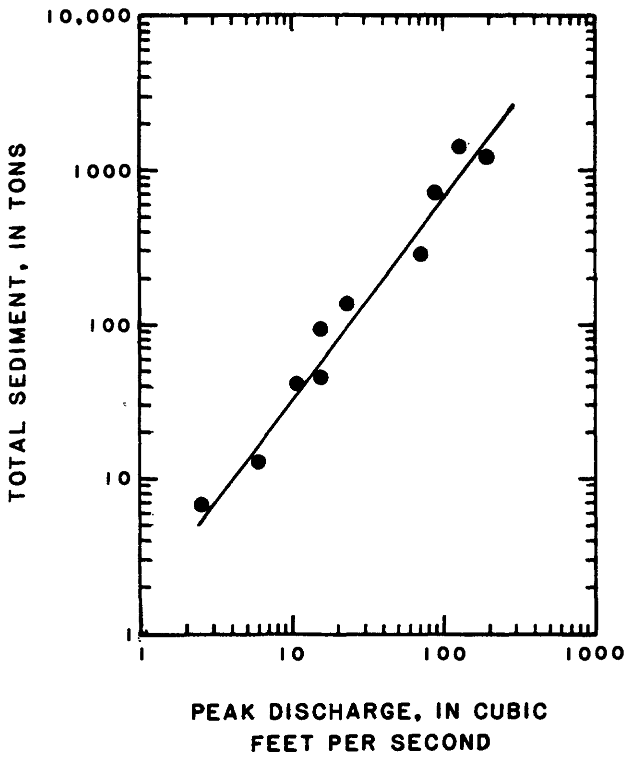

Figure 15.--Relationship of total sediment load to peak discharge for storm runoff, Dugout Creek tributary near Midwest, Wyoming (station 06313180).

total sediment load were obtained from samples collected by the automatic pumping sampler and not from a discharge-concentration curve. The coefficient of variation of sediment load computed by equation 1 is 34 percent and the relationship has a 0.99 correlation coefficient. The sediment load computed by equation 1 is probably an upper limit.

Reclaimed basins and basins constructed from mine spoils are engineered for infiltration rates, runoff volumes, and sediment yield as required by Wyoming reclamation laws. Therefore, data collected from these sites represent the results of the required design. Studies need to be conducted to obtain additional information for natural basins to define the relationship between peak discharge and total sediment load for a variety of soil types, especially those soils found near the major coal deposits in Wyoming. A rigorous data collection program with a design similar to the one used at Dugout Creek tributary is needed to assure quality information. With 10 or more small basins, it may be possible to define relations between peak discharge, soil type, vegetation, and land and channel slope. If these relations can be developed, the information needed for improved planning can be obtained.

SUMMARY AND CONCLUSIONS

Sediment, rainfall, and runoff data were collected using a systematic approach in order to define erosion and depositional processes. Sediment concentration data from an upland soil plot, channel characteristics data, and total sediment load data at the mouth of the study basin were collected at Dugout Creek tributary. A special emphasis was placed on computing the contribution of sediment from headcuts to the total sediment load. The total quantity of sediment removed from all headcuts between September 26, 1982, and September 26, 1983, was estimated to be 1,220 tons, or 15 to 25 percent of the estimated total sediment load passing the streamflow-gaging station on Dugout Creek tributary. The primary source of sediment was from upland erosion.

During the study, Saint Marys Ditch tributary (a basin constructed from mine spoils) had one storm which caused runoff to flow past the streamflow-gaging station. A data set with more than one storm runoff is needed to evaluate changes in hydrology as a result of strip mining. Channel cross-sections and hillslope transects were surveyed to establish a base from which future measurements of erosion and deposition can be made.

A deterministic precipitation and runoff model (PRMS) with a sediment-production routine was used to evaluate the contribution of each of the sediment processes. Transport equations in the sediment subroutine were the most sensitive to parameter change. Particle detachment by overland flow was significant, but particle detachment by raindrop impact was not significant in simulating sediment load. Accounting for sediment removed from the channels by head cutting with rill erosion equations may have caused insensitivity in the equation used to compute sediment detachment by raindrop impact. The length of the time step used to compute transport of sediment from the overland-flow planes was critical. The sediment subroutine of the model was unstable with a time step longer than 2 minutes, while a time step of 5 minutes was suitable for computing runoff.

A relationship was developed between the peak of storm runoff and the total sediment load for storm runoff. The sediment concentration used to compute the total sediment load for the storm runoff was determined from sediment samples collected by two automatic pumping samplers. The coefficient of variation of the relationship is 34 percent with a 0.99 correlation coefficient.

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