SEDIMENT LOADS IN AN UNDISTURBED BASIN AND A BASIN DISTURBED BY GAS-WELL DRILLING, RITCHIE COUNTY, WEST VIRGINIA, 1985-87

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
ton, short	0.9072	megagram
ton per square mile (ton/mi^2)	0.3502	megagram per square kilometer

Water temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by using the following equation:

$$°F = 1.8\ (°C) + 32$$

<u>Sea level</u>: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

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By Stephen M. Ward[1], *Alex R. Topalanchik*[2], *Gary R. Milliman*[2], *and Ronald A. Wigal*[3]

ABSTRACT

Total sediment loads in two small basins in northwestern West Virginia were studied to evaluate the effectiveness of required State reclamation practices in controlling erosion and sedimentation associated with oil- and gas-drilling activities. Streamflow and precipitation data, suspended-sediment concentrations of storm samples, cumulative trapped-sediment data, and pin-transect data related to soil erosion were collected from June 14, 1985, through September 30, 1987, in an undisturbed basin (North Bend Run) and in a basin disturbed by drilling activity and later reclaimed (Robinson Run).

The total sediment yield for the study period from the undisturbed basin (North Bend Run) was 0.30 tons per acre, whereas the yield from the Robinson Run basin was 1.14 tons per acre. Soil-erosion data obtained from the linear-pin erosion study in the Robinson Run basin indicated that the average loss at the well site was two times the loss in the remaining, undisturbed part of the basin. The average soil loss at the well site in Robinson Run was four times the loss in the undisturbed North Bend Run basin.

[1] *U.S. Geological Survey*
[2] *U.S. Soil Conservation Service*
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INTRODUCTION

Extensive oil and gas drilling in the northwestern part of West Virginia in the early 1980's caused severe soil erosion and related problems associated with sedimentation. The lack of reclamation requirements for drilling sites and access roads was a major concern, especially in Ritchie County. Ritchie County, near Parkersburg (fig. 1), contained nearly 20 percent of all oil and gas wells drilled in the State in 1982.

In 1983, the State legislature enacted the Surface Owners Rights Bill, which required that a construction and reclamation plan be prepared as part of the drilling permit and which also provides landowners an opportunity for comment and arbitration. Prior to this legislation, an informal, voluntary process for planning and implementing drilling-related sediment controls had been developed by the West Virginia Department of Mines, Oil and Gas Division; the West Virginia Department of Natural Resources, Division of Water Resources; and the West Virginia Soil Conservation Committee. The latter agency, through its 14 Soil Conservation Districts, served as the review agency for sediment-control plans. With the enactment of Surface Owners Rights Bill, erosion and sediment control became mandatory for drilling and reclamation of the disturbance upon completion. The techniques for control involve a variety of water-management practices to minimize the effects of road construction and site development. The practices are designed to be applicable to the State's mountainous terrain. Some forethought on the part of the drilling company is required with regard to site suitability, soil type, and road and site layout.

A cooperative study by the U.S. Geological Survey, the U.S. Soil Conservation Service, and the West Virginia Department of Natural Resources was begun in 1985 to evaluate the effectiveness of the State mandated reclamation practices in controlling erosion and sedimentation at oil and gas sites. This study was intended to aid water-resource managers in defining the magnitude of sediment yields associated with oil and gas exploration.

Two small watersheds in Ritchie County were selected for the study. The two watersheds are about 6 mi (mile) apart and are similar in topography, soils, slope, and vegetation. The undisturbed watershed, about 90 acres within the boundary of North Bend State Park, had no evidence of oil and gas drilling and, because of its designation as parkland, was not likely to be disturbed during the study. One gas-well drilling site in the 45-acre disturbed watershed was reclaimed 8 months before the study began and was assumed to be typical of the construction and reclamation practices in use at the time. For this report, the undisturbed watershed has been designated North Bend Run basin and the disturbed watershed has been designated Robinson Run basin (fig. 1).

Sediment-retention dams were constructed on the main channel in each watershed. Instrumentation was installed at each dam to record stage data continuously and to collect suspended-sediment samples automatically during storms. Precipitation gages were also located within the basins. Additional suspended-sediment samples were collected periodically to

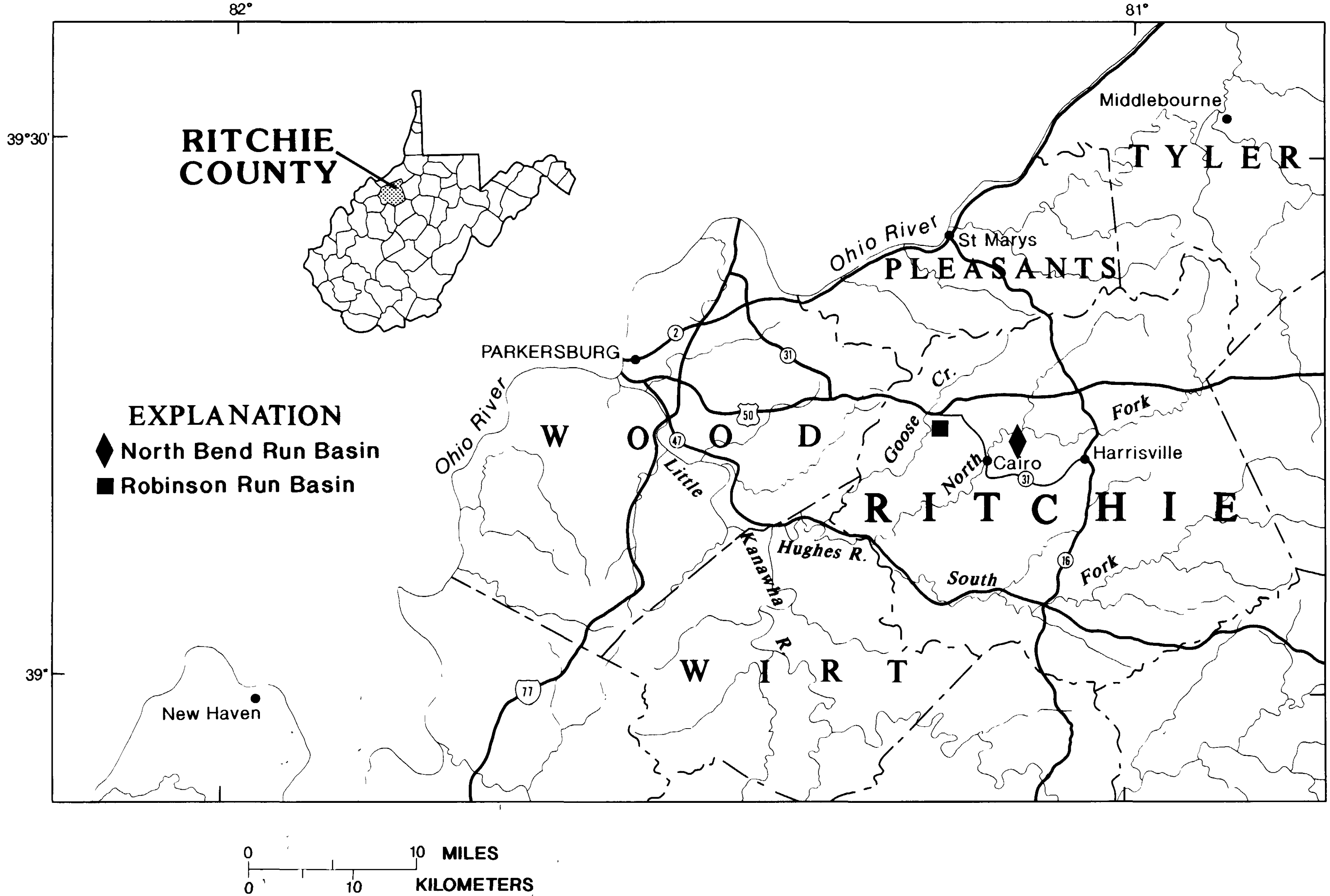


Figure 1.--Locations of North Bend Run and Robinson Run basins.

verify the automatic sampler concentrations. Pin grids were established around the catchment ponds to aid in measuring the sediment deposition. Linear pin grids were established in the basins to measure soil erosion.

The purpose of this report is to summarize and interpret the data collected at the two study sites from June 14, 1985, through September 30, 1987. Differences in soil erosion, suspended sediment, trapped sediment, and total sediment loads between the two basins are discussed.

DESCRIPTION OF THE UNDISTURBED AND DISTURBED BASINS

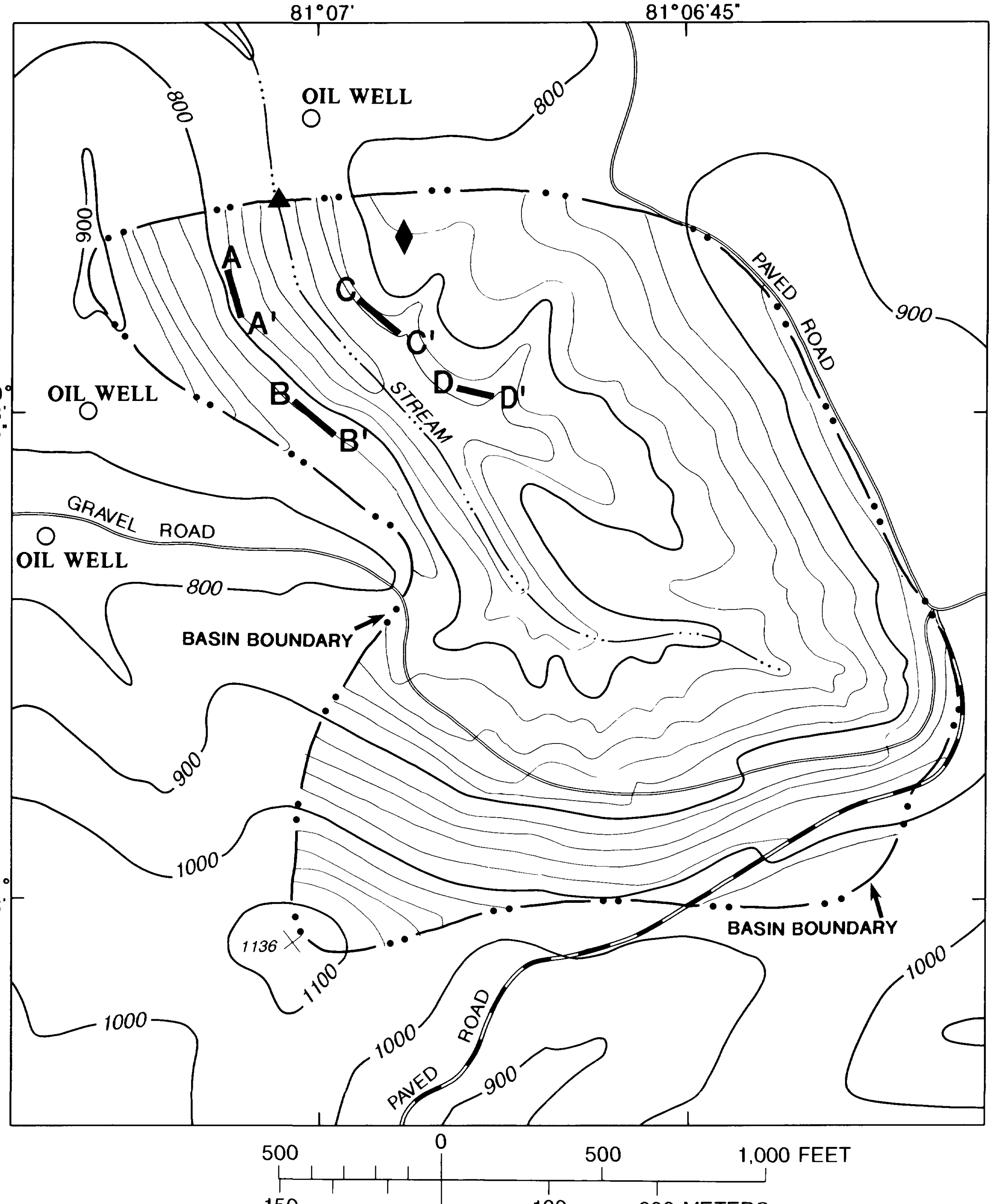
The North Bend Run basin and the Robinson Run basin, both in Ritchie County, encompass 90 acres and 45 acres, respectively. Ritchie County is located on a highly dissected plateau in the Appalachian Plateau physiographic province in west-central West Virginia (Fenneman and Johnson, 1946). The north and south forks of the Hughes River and their tributaries drain all of Ritchie County (fig. 1). Most of the basins in Ritchie County have narrow ridgetops and deep, V-shaped, narrow valleys with steep or very steep side slopes. The hillsides are marked with long, narrow benches (Wright and others, 1986). The steep slopes, rough topography, and the narrow flood plains of the small streams in the county create high soil-erosion potential.

The North Bend Run basin (fig. 2) has an average land slope of about 30 percent. The maximum elevation is 1,136 ft (feet) above sea level at the basin divide, and the minimum elevation is 720 ft at the basin outflow. Relief is 416 ft along 0.6 mi of stream drainage to the streamflow and sediment data-collection site. The Robinson Run basin (fig. 3) has an average land slope of about 35 percent. The maximum elevation is 1,080 ft at the basin divide, and the minimum elevation is 760 ft at the basin outflow. The relief is 320 ft along 0.4 mi of stream drainage to the streamflow and sediment data-collection site. Both streams are intermittent upstream from the data-collection sites.

Geology and Soils

The surficial rocks in the study area are from the Dunkard Group of Pennsylvanian and Permian age. They are the youngest rocks in the Ohio River Valley and are underlain by rocks of the Monongahela Formation of Pennsylvanian age. The Dunkard Group is characterized by nonmarine cyclic sequences of sandstone, siltstone, red and gray shale, limestone, and coal. It extends upward from the top of the Waynesburg coal through the Washington coals and limestones and contains the Greene, Washington, and Waynesburg Formations (Cardwell and others, 1968).

The soils in the Robinson Run and North Bend Run basins in Ritchie County are formed from weathered rock of the Dunkard Group. Four soil series--the Gilpin, Monongahela, Tilsit, and Upshur (figs. 4 and 5)--are identified in the North Bend Run basin and the Robinson Run basin (Wright and others, 1986).



EXPLANATION

B——B' LOCATION OF LINEAR-PIN TRANSECT

——1000—— TOPOGRAPHIC CONTOUR--Interval variable. Datum is sea level

▲ STREAMFLOW AND SEDIMENT DATA-COLLECTION SITE

♦ PRECIPITATION GAGE (Recording)

Figure 2.--Data-collection sites in North Bend Run basin.

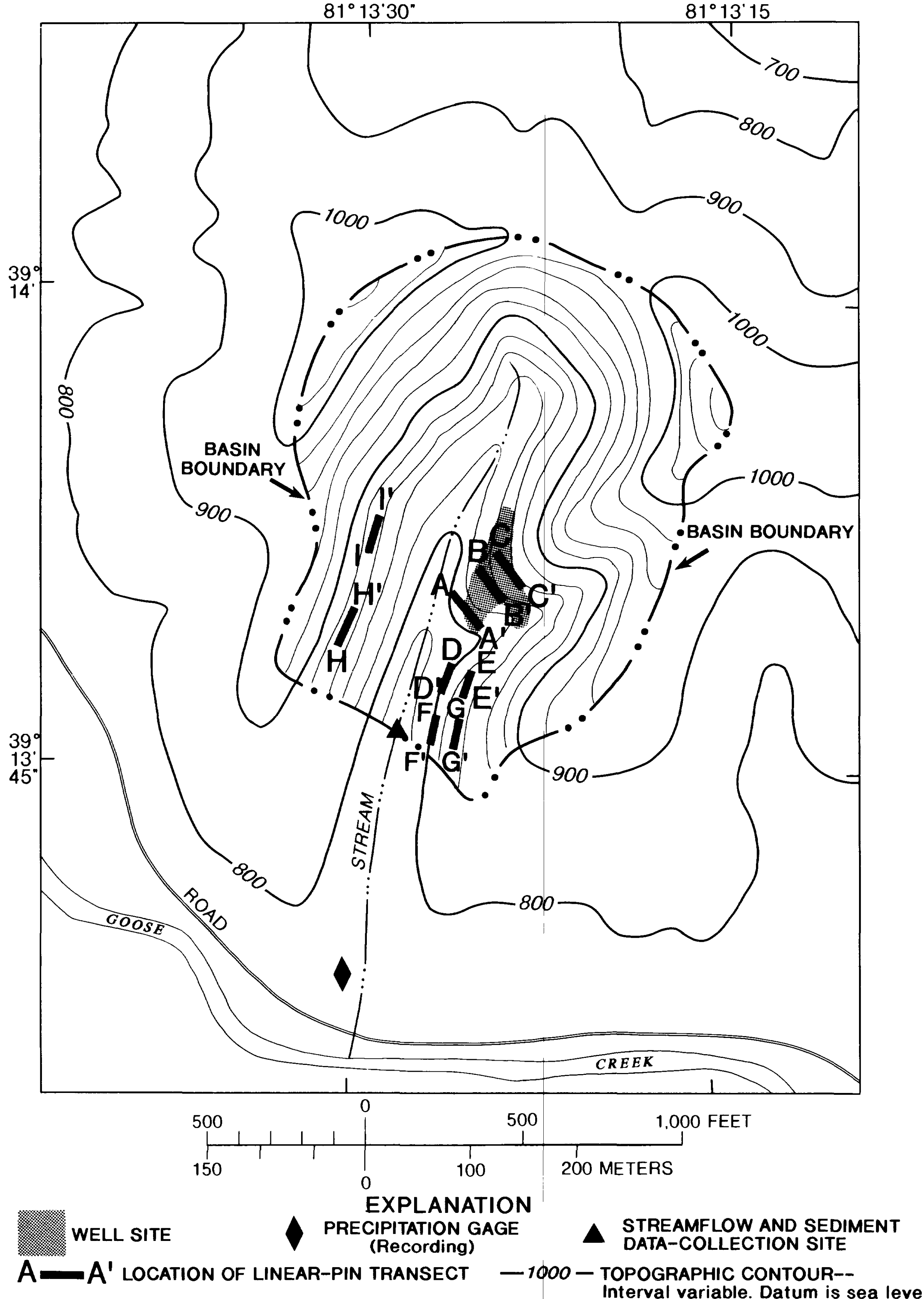
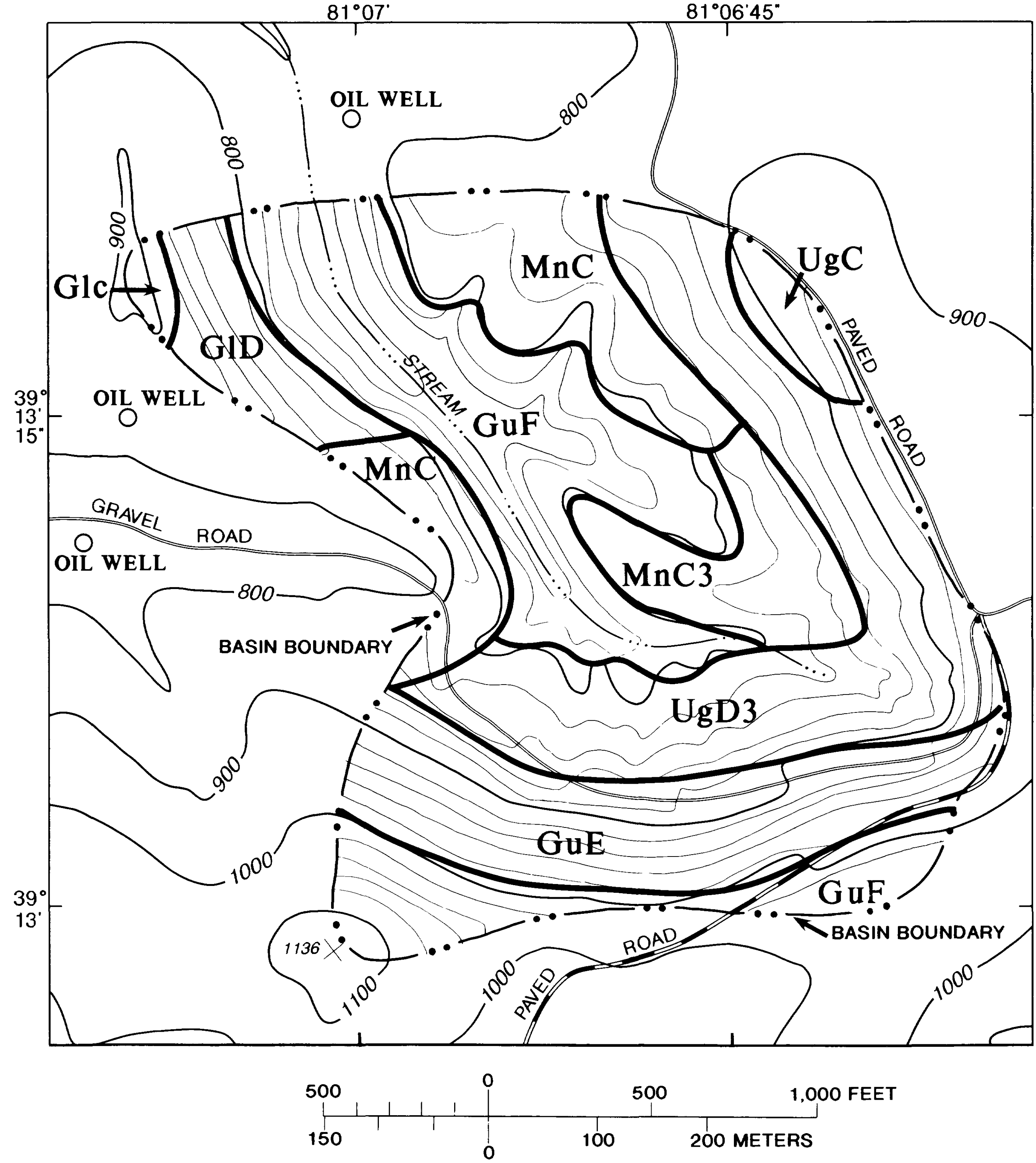


Figure 3.--Data-collection sites in Robinson Run basin.

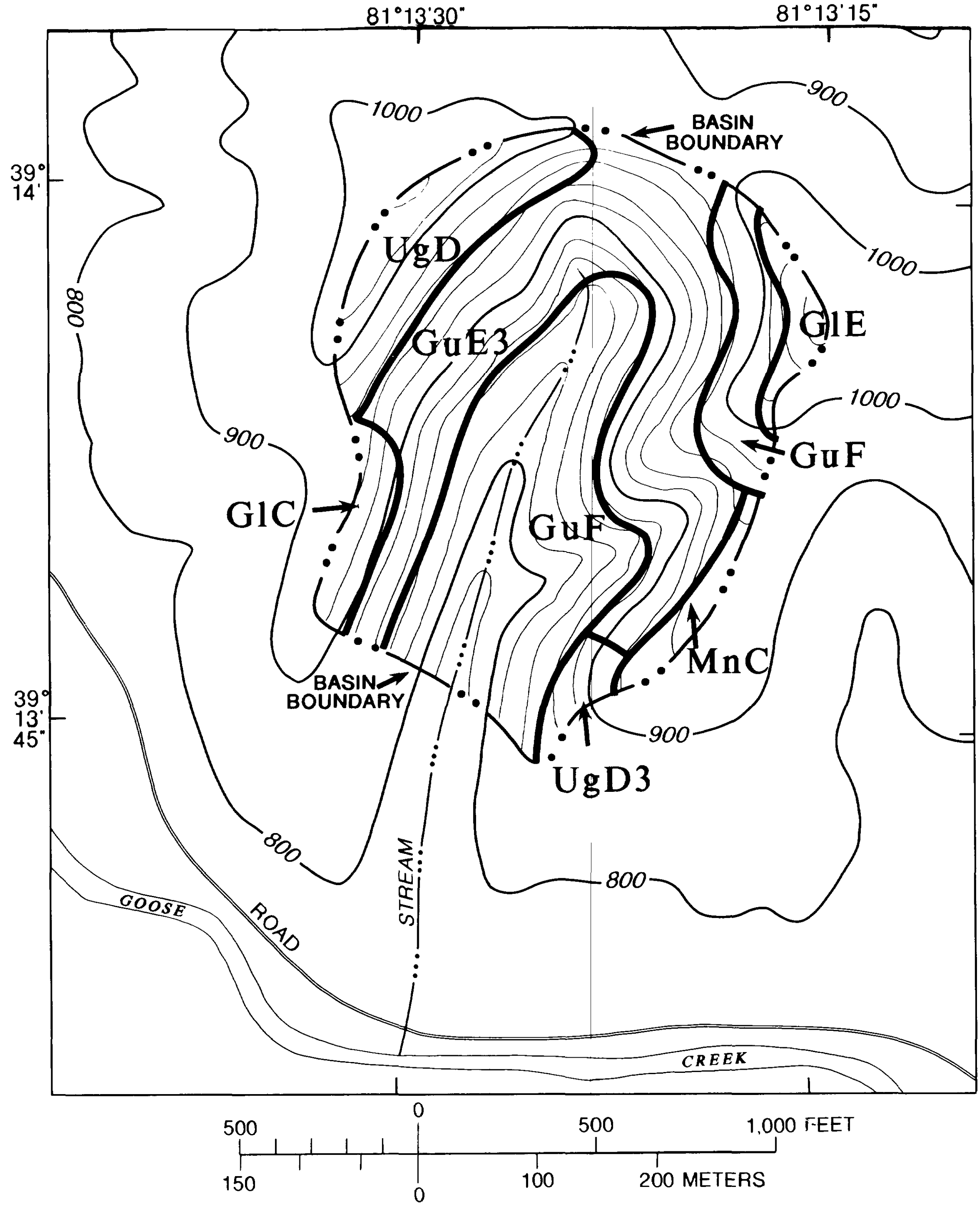


EXPLANATION

GlC	Gilpin silt loam, 10- to 20-percent slopes	MnC	Monongahela and Tilsit silt loams, 10- to 20-percent slopes
GlD	Gilpin silt loam, 20- to 30-percent slopes	MnC3	Monongahela and Tilsit silt loams, 10- to 20-percent slopes, severely eroded
GuE	Gilpin-Upshur complex, 30- to 40-percent slopes	UgC	Upshur-Gilpin complex, 10- to 20-percent slopes
GuF	Gilpin-Upshur complex, 40- to 55-percent slopes	UgD3	Upshur-Gilpin complex, 20- to 30-percent slopes, severely eroded

——1000—— TOPOGRAPHIC CONTOUR--Interval variable. Datum is sea level

Figure 4.--Distribution of soils in North Bend Run basin (modified from Wright and others, 1986).



EXPLANATION

GlC	Gilpin silt loam, 10- to 20-percent slopes
GlE	Gilpin silt loam, 30- to 40-percent slopes
GuE3	Gilpin-Upshur complex, 30- to 40-percent slopes, severely eroded
GuF	Gilpin-Upshur complex 40- to 55-percent slopes
MnC	Monongahela and Tilsit silt loams, 10- to 20-percent slopes
UgD	Upshur-Gilpin complex, 20- to 30- percent slopes
UgD3	Upshur-Gilpin complex, 20- to 30-percent slopes, severely eroded
—1000—	TOPOGRAPHIC CONTOUR-- Interval variable. Datum is sea level

Figure 5.--Distribution of soils in Robinson Run basin (modified from Wright and others, 1986).

Gilpin soils are moderately deep, well-drained, yellowish-brown soils on hilly uplands. They have a medium-textured surface layer and a medium- to moderately fine-textured subsoil. They are underlain by interbedded acidic shale, siltstone, and sandstone at depths of about 2 to 3 ft below the surface (Wright and others, 1986).

Monongahela soils are deep, moderately well-drained, yellowish-brown soils on old stream terraces. They have a seasonally high water table within 1.5 to 2 ft of the surface. Monongahela soils have a medium-textured surface layer, a medium- to moderately fine-textured subsoil, and a firm (fragipan) layer at à depth of about 2 ft. Bedrock generally is at depths greater than 5 ft (Wright and others, 1986).

Tilsit soils are deep, moderately well-drained soils on ridgetops. They have a seasonal high water table within 1.5 to 2 ft of the surface. Tilsit soils have a medium-textured surface layer, a medium- to moderately fine-textured subsoil, and a firm (fragipan) layer at a depth of about 2 ft. Bedrock generally is at depths of 4 to 5 ft (Wright and others, 1986).

Upshur soils are deep, well-drained soils on hilly uplands. They have a moderately fine-textured surface layer and a fine-textured subsoil that is sticky and plastic when wet. Upshur soils have a slip hazard, especially on slopes greater than 20 percent and in cove areas. Their subsoils are highly susceptible to shrinking upon drying and to swelling upon wetting. Upshur soils are underlain by red and olive shales at depths of about 3 to 6 ft below the surface (Wright and others, 1986).

Some soils are mapped together as a soil complex or as an undifferentiated unit. The Gilpin and Upshur soils are mapped as a soil complex. A soil complex is a mapping unit of two or more soils occurring in such an intricate pattern that they cannot be shown separately on a soil map at the scale selected for mapping. A soil-complex mapping unit contains all of the soil series named. The Monongahela and Tilsit soils are mapped as an undifferentiated unit. An undifferentiated unit is a mapping unit of two or more soil series that occur together without regularity of pattern and are large enough to be mapped separately; however, they are mapped together because they have similar use and management problems. This mapping unit may contain one or all of the soils named.

Vegetative Cover and Land Use

The vegetative cover of the two study basins was delineated from aerial photographs and onsite verification. Because of the difference in basin acreages, categories of vegetative cover were expressed as percentages of total acreage for comparison. Forest was the largest vegetation category in both basins. The North Bend Run basin contained 87.2 percent mature forest (table 1 and fig. 6). This forest consisted of 56.29 acres of mixed hardwoods and 22.20 acres of pine and pine and mixed hardwoods. By comparison, the Robinson Run basin contained 86 percent mature forest consisting of mixed hardwood species (table 2 and fig. 7).

Table 1.--Data for vegetative cover and land use in the North Bend Run basin

Vegetative cover or land use	Area (acres)	Percentage of total watershed
	FORESTED AREAS	
Mixed hardwoods	56.29	62.5
Pines/pine hardwood mixed	22.20	24.7
Total	78.49	87.2
	EARLY-SUCCESSION AREAS	
Powerline	2.42	2.7
Old field	2.17	2.4
Lawn	3.30	3.7
Total	7.89	8.8
	DISTURBED AREAS	
Paved road	1.95	2.2
Gravel road	1.67	1.8
Total	3.62	4.0
Grand total	90.0	100.0

Table 2.--Data for vegetative cover and land use in the Robinson Run basin

Vegetative cover or land use	Area (acres)	Percentage of total watershed
	FORESTED AREAS	
Mixed hardwoods	38.70	86.0
	EARLY-SUCCESSION AREAS	
Hayfield	0.36	0.8
Old well and access road	.68	1.5
Pasture	3.64	8.1
Total	4.68	10.4
	DISTURBED AREAS	
Well site	1.18	2.6
Access road	.44	1.0
Total	1.62	3.6
Grand total	45.0	100.0

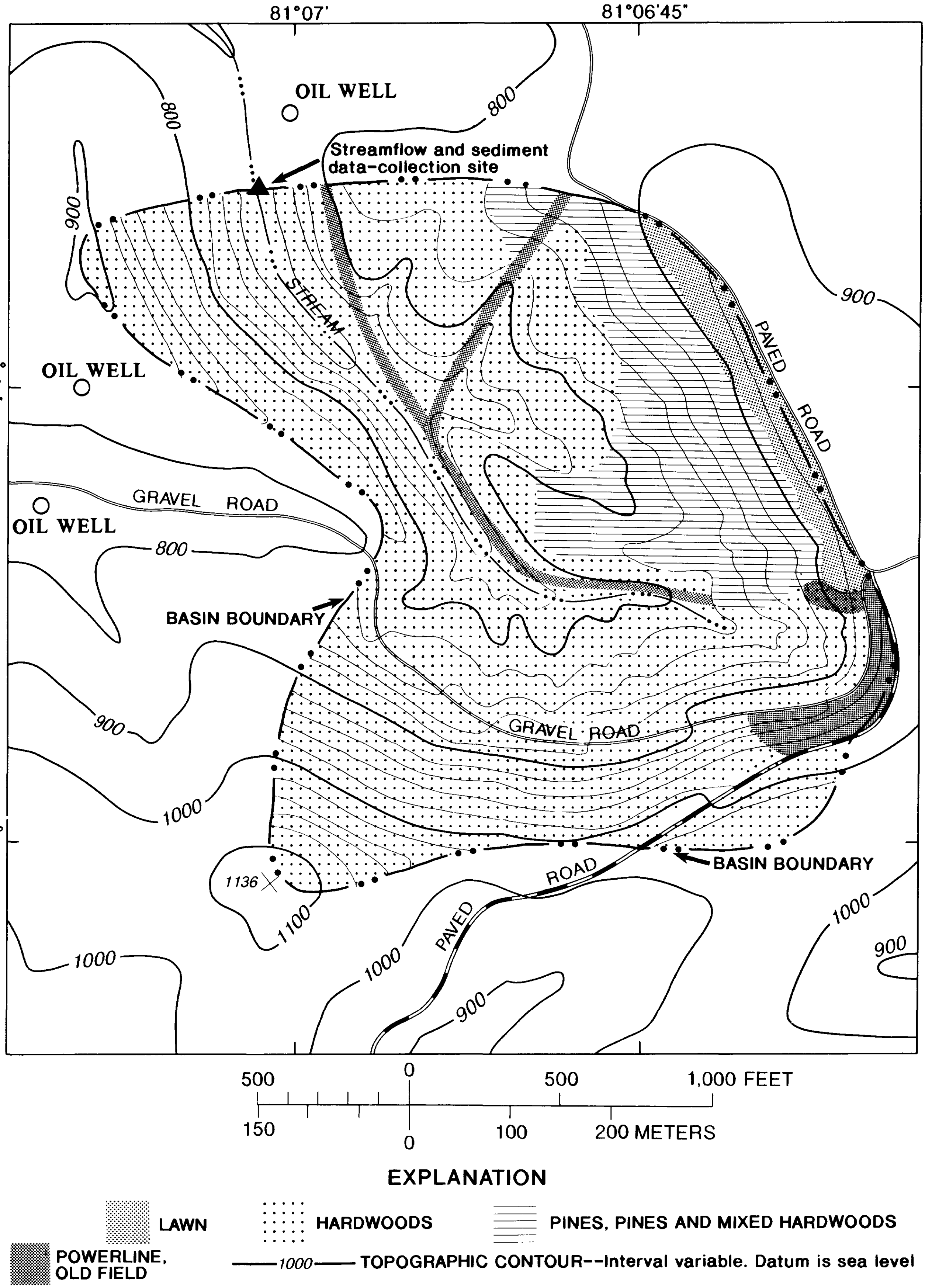


Figure 6.--Vegetative cover and land use in the North Bend Run basin.

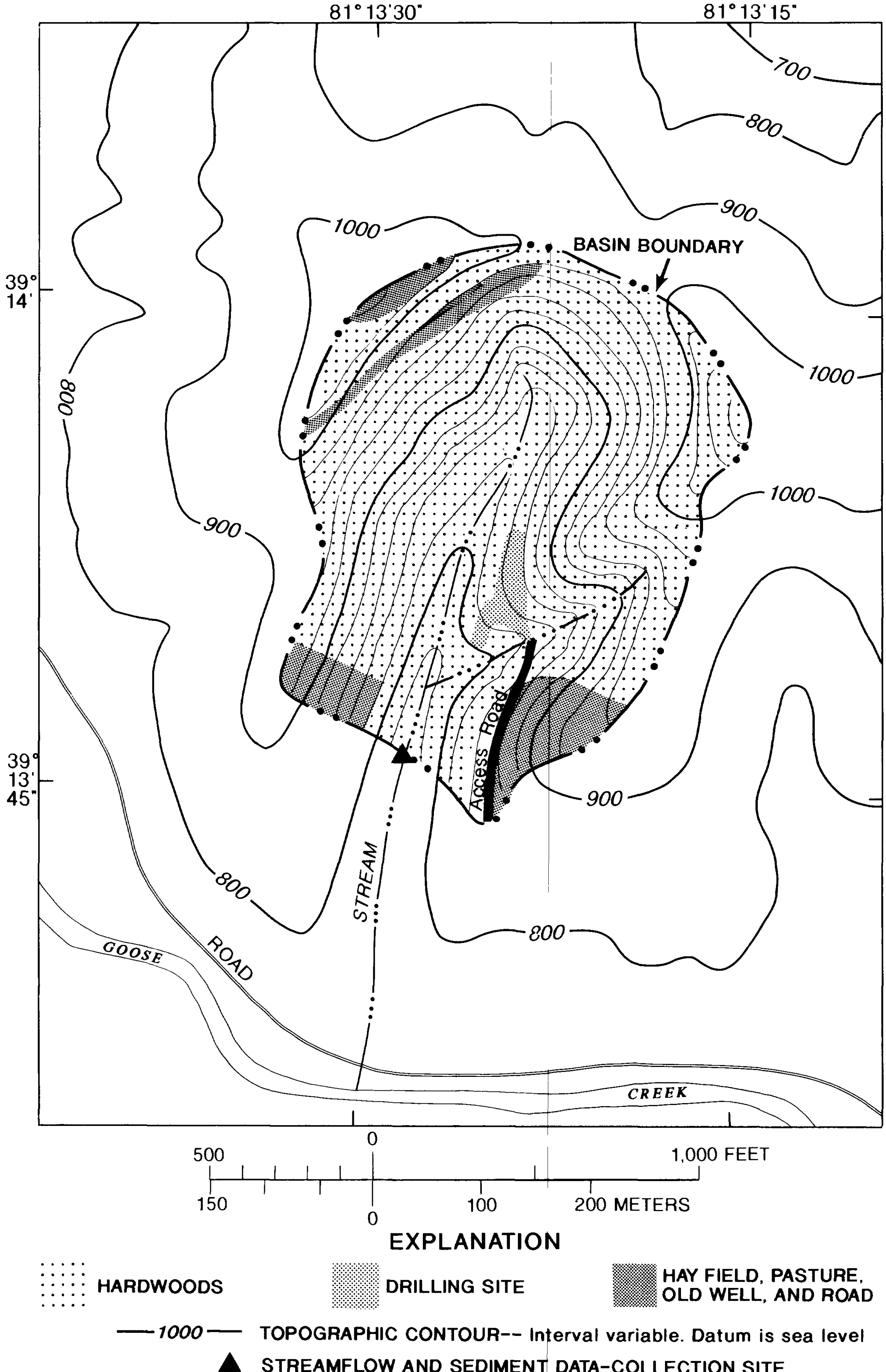


Figure 7.--Vegetative cover and land use in the Robinson Run basin.

The early-succession vegetative cover was the second largest category in both basins. The component parts of this category were influenced by land-use activities on the two basins; although the activities were different, the resultant vegetation was similar. Early-succession areas in the North Bend Run basin included powerline right-of-way (2.42 acres), an old field area (2.17 acres), and lawns (3.30 acres), and composed 8.8 percent of the basin (table 1). Early-succession areas in the Robinson Run basin included hayfield (0.36 acres), an old gas well and access road (0.68 acres), and pasture (3.64 acres), and composed 10.4 percent of the basin (table 2).

The final major category, disturbed areas, includes sparsely vegetated or nonvegetated areas. At North Bend Run, 1.95 acres consisted of paved roads and 1.67 acres consisted of graveled county roads. These unvegetated areas composed 4.0 percent of that basin (table 1). At Robinson Run, the gas-well site (1.18 acres) and the access road (0.44 acres) composed 3.6 percent of that basin (table 2).

Soil-Disturbing Activities

Soil-disturbing activities associated with the development and reclamation of oil and natural gas resources are the primary focus of this study. Other land uses in the study basins, however, have the potential to affect the sediment load and are summarized here to document background erosion potential.

Mature forest generally is the most stable vegetative cover with regard to erosion potential. A comparison of the two basins indicates that the percentage of forest cover is nearly equal. The primary difference between the basins is the presence of pines in the North Bend Run basin forests and the somewhat younger age of the Robinson Run forests; however, because both forest stands are well established with stable root masses and thick leaf litter, background soil loss for the forested areas in both basins is similar.

Soil-disturbing activity in the North Bend Run basin was minimal during the study period. The county road shown in figure 6 passes through about 2,200 ft of the upper end of the basin. The gravel road is probably the major area of erosion in the basin. Runoff from a lawn on the eastern basin boundary also entered the drainage area. The lawn area may have had a higher rate of erosion than adjacent woodlands; however, most sediment was filtered from the runoff by the forests between the lawn and the streambed. The powerline right-of-way and an old field area are probably not substantial contributors of sediment to the basin. They are densely vegetated and have stable soils.

Much more soil-disturbing activity took place in the Robinson Run basin than in the North Bend Run basin. The primary land disturbance (erosion-producing activity) was well drilling on 1.62 acres near the center of the drainage basin, as shown in figure 7. This 1.62-acre area included the well site and a part of the well access road.

Other land-use activities in the Robinson Run basin include a small area of pasture, an old well site, and a small area of hayfield. The pasture area was lightly grazed and probably did not contribute much sediment. The old well site was adequately vegetated and considered stable. Any sediment transported from the old well site and the small hayfield would be filtered through forest litter before reaching the stream.

The new gas-well site was constructed at an elevation of 816 feet. Drilling began in early February 1984, and reclamation was completed in October 1984. Reclamation consisted of grading to original contour and the planting of perennial ryegrass as a cover crop. Other types of vegetative cover were not apparent at the well site. Ground cover at the beginning of the study was about 30 percent over most of the disturbed area and during the study was sparse or absent on the level area surrounding the wellhead, the upper cut-slope above the well, and on the road surface.

Climate

The climate is characterized as continental inland with warm, humid summers and relatively long winters. The prevailing wind is from the southwest (U.S. Department of Commerce, 1977). Temperature and precipitation data were obtained from National Oceanic and Atmospheric Administration (NOAA) records from Cairo, West Virginia (site 46-1328, elevation 680 ft), which lies between both study basins in Ritchie County, about 4.0 mi from Robinson Run (fig. 1). Average monthly mean temperatures for January and July are 30.9 °F (-0.6 °C) and 73.7 °F (23.2 °C), respectively (U.S. Department of Commerce, 1982). The mean annual temperature for 1951-80[4] is 53.4 °F (11.9 °C). The frost-free season averages 140 days in duration and occurs from mid-May to late-September.

Precipitation averages 43.27 in. (inches) per year and is generally greatest during the spring and summer. The average monthly and annual precipitation measured at Cairo during 1951-80 is summarized in table 3. Precipitation from June 1985 through September 1987 was below normal in both study basins. Only 9 of the 28 months had above-normal precipitation in both basins. The North Bend Run basin had a deficit of 9.4 in. for the study period, and the Robinson Run basin had a deficit of 12.5 in. Monthly and annual precipitation totals for both study basins are also shown in table 3. Comparison of these totals with the monthly normals yields departures from normal for each month of the study period.

Convection thunderstorms are common during June and July, but can occur during other months. These storms may produce intense local rainfall that may cause flooding in the narrow valley bottoms (U.S. Department of Commerce, 1977) and considerable erosion on slopes.

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[4] At the date of writing, the period 1951-80 is the most recent period on which climatological normals have been based.

Table 3.--Monthly and annual precipitation at Cairo during 1951-80 (normal period) and in the North Bend Run and Robinson Run basins during water years 1985-87

[All precipitation in inches]

CAIRO

January	3.28
February	2.78
March	3.73
April	3.93
May	4.14
June	4.04
July	4.93
August	4.42
September	3.02
October	2.89
November	2.97
December	3.14
Average long-term annual precipitation	43.27

Water year	October	November	December	January	February	March	April	May	June	July	August	September	Annual
NORTH BEND RUN BASIN													
1985	---	---	---	---	---	---	---	---	[a]1.43	5.02	4.09	0.36	[b]10.90
1986	5.68	8.51	1.90	1.62	3.97	2.95	2.70	2.73	5.08	3.38	3.64	3.31	45.47
1987	2.16	6.89	4.18	1.97	1.73	1.64	4.04	1.01	2.24	1.35	3.47	6.50	37.18
ROBINSON RUN BASIN													
1985	---	---	---	---	---	---	---	---	[a]1.10	5.43	2.85	0.65	[b]10.03
1986	4.80	8.81	1.90	1.57	3.59	2.68	3.30	2.79	4.82	3.54	3.75	3.92	45.47
1987	2.37	5.71	3.40	1.90	1.92	1.55	3.75	1.25	2.42	3.27	2.77	4.67	34.98

[a] Denotes part of month.

[b] Denotes part of year.

DATA-COLLECTION TECHNIQUES

Hydrologic data in the North Bend Run and Robinson Run basins were collected from June 14, 1985, through September 30, 1987. Locations of data-collection sites are shown in figures 2 and 3, and the types of data collected are listed in table 4. All suspended-sediment, streamflow, and precipitation data for the study are published in "Water Resources Data--West Virginia, Water Year 1987" (Ward and others, 1989)[5].

Table 4.--Streamflow and suspended-sediment data-collection sites in the study area

Station number	Station name	Drainage area (acres)	Streamflow: Period of record	Streamflow: Type of data	Suspended sediment: Period of record	Suspended sediment: Type of data
03155410	North Bend Run near Cairo	90	June 1985 through September 1987	Daily	August 1985 through September 1987	Intermittent storm samples[1]
03155520	Robinson Run near Petroleum	45	June 1985 through September 1987	Daily	July 1985 through September 1987	Intermittent storm samples[1]

[1] *Storm-runoff samples collected at 15-minute intervals by automatic pumping samplers.*

Precipitation-Runoff Measurement

Precipitation was measured in both basins by use of automated recording collectors developed by the U.S. Geological Survey. Precipitation was recorded to hundredths of an inch and totaled every 15 minutes. Local observers read cylindrical precipitation gages daily. These daily totals were obtained to verify the automated-collector data and were used to estimate any missing data. On the basis of the recorded precipitation totals, precipitation at Robinson Run was 3.07 in. (3.3 percent) less than that at North Bend Run for the study period.

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[5] *All "annual or yearly" references hereafter in this report are for water years. A water year is defined as the 12-month period beginning October 1 and ending September 30; it is designated by the calendar year in which it ends.*

Basin-runoff (streamflow) data were obtained by use of the sediment-catchment ponds constructed in both basins. These ponds served two purposes: (1) they trapped the coarse sediments, and (2) they formed pools behind their dams, which allowed stream elevations (stage) to be recorded. Concrete blocks forming an 8-ft weir were constructed across the stream channel to create the sediment ponds. One 2-in. by 16-in. block was removed from the top of each weir to increase the sensitivity of stage to discharge at low flows. The weirs were embedded into the banks to prevent leakage. Fabric was anchored on the side slopes of each basin to prevent sloughing of soil material into the ponds. Both ponds had bedrock bottoms.

Discharge measurements were made with a current meter immediately downstream of the weir or by volumetric calculations at the weir openings to develop a stage-discharge relation. Runoff was computed by methods described by Rantz and others (1982). Streamflow data for both sites are published in Ward and others (1989).

Suspended-Sediment Sampling

An automatic pumping sampler at each site collected suspended-sediment samples at 15-minute intervals during storms. These samplers were activated by the stage recorders at predetermined elevations. Periodic suspended-sediment samples were manually collected in both basins with standard U.S. Geological Survey depth-integrating samplers (US-DH49) to verify suspended-sediment concentrations in the automatically collected point samples.

Suspended-sediment concentrations, expressed in milligrams per liter (mg/L), were determined by the dry-weight methods outlined by Guy (1969), and suspended-sediment loads and yields for storms were computed by techniques described by Porterfield (1972). The turbidity and specific conductance of all suspended-sediment samples were measured in the laboratory. All laboratory analyses were done by the Water Resources Division, West Virginia Department of Natural Resources.

The computed daily suspended-sediment loads for storms and corresponding mean daily sediment concentration for both sites are published in Ward and others (1989). Instantaneous data for all suspended-sediment samples collected during the study are also published in that report.

Measurement of Sediment Deposition in Ponds

In each of the sediment-catchment ponds, a centerline was established perpendicular to the weir and extending to the upper end of the pond. Irregularities in the pond bottom along the centerline were marked by steel pins driven into the ground on each side of the pond. The pins were set so that a line connecting them would be perpendicular to the centerline. Cross sections were established from the uppermost reach of the pond to the weir. On the basis of measurements made with a tagline and stadia rod at these cross sections, the volume of sediment deposited at each station was determined from the difference in elevation of the top of the sediment and the bedrock bottom.

Initially, a survey was made of each pond. After sediment accumulated to a significant level, the ponded water was slowly released through a drain at the bottom of the weir, and the accumulation of deposited sediment was measured and plotted. At each cross section, initial plots of the pond bottoms were compared to subsequent plots made after sediment accumulation. The basins were then cleaned and new cross-sections were surveyed after each pond cleaning. This cycle was continued throughout the project to determine the total sediment deposited from each basin. Random core samples were taken of the trapped sediments to determine the percentage of organic material. During laboratory analysis, the organic material was burned off, leaving only the mineral content, and adjustments were made to the excavated totals. Results of these analyses are stored in District files of the Soil Conservation Service, Parkersburg, W. Va.

Measurement of Soil Erosion

A linear pin erosion study was done in each basin to determine rates of soil erosion and to identify areas that were eroding more than others. Four linear-pin transects were established in the North Bend Run basin (fig. 2), and nine linear-pin transects were established in the Robinson Run basin (fig. 3). Three of these transects were located on the gas-well site in the Robinson Run basin. All pin locations for each basin were randomly selected.

Each linear-pin transect consisted of eleven 7-in.-aluminum gutter spikes. These pins were driven into the ground, and approximately 0.2 ft of each pin was left exposed above the ground surface to permit measurement of erosion or deposition. The elevations of the pins were measured and the pins were placed in rows with 5-ft spacing on the contour and perpendicular to the slope (adaptation of a method used by Hadley and Lusby, 1967). The elevations of the pins were measured after major storms and monthly during periods without major storms.

SEDIMENT LOADS

The main source of sediment in the disturbed Robinson Run basin is the reclaimed gas-well site and access road, which comprise 1.62 acres of the total basin area (45 acres). During storms, manual suspended-sediment samples were taken on Robinson Run upstream and downstream from the confluence of the small intermittent channel that cuts across the well site and access road (fig. 7). Analysis of these samples showed that suspended-sediment concentrations from the disturbed part of the basin were about three times the concentrations from the undisturbed part of the basin.

The frequency and intensity of storms in the study basins can affect the amount of sediment load. Precipitation totals during the study were 93.55 in. for North Bend Run and 90.48 in. for Robinson Run. During the study period, four storms produced rainfall that exceeded 2 in. in 24 hours in both basins. These storms resulted in runoff that carried 38 and 41 percent of the total suspended-sediment load for the study period at North Bend Run and Robinson Run, respectively. Runoff for the study period for the basins was 35.5 in. and 31.2 in., or about 38 and 34 percent of the precipitation recorded within these basins. The remainder of precipitation was lost to evapotranspiration, interbasin transfer of water, and (or) recharge to deep aquifers. Runoff determinations for both basins for June through August 1985 were not accurate because of intermittent leakage around the base of the dams. Repairs were made at both structures in early September, and runoff determinations for the remainder of the study were valid. Table 5 shows the annual runoff and annual precipitation for both basins for the study period.

Table 5.--Annual runoff and precipitation in North Bend Run and Robinson Run basins, water years 1985-87

[Data in inches]

	Runoff		Precipitation	
Water years	North Bend Run	Robinson Run	North Bend Run	Robinson Run
[a]1985	1.27	0.36	10.90	10.03
1986	19.55	16.73	45.47	45.47
1987	14.67	14.10	37.18	34.98
Total	35.49	31.19	93.55	90.48

[a] *Partial water year (June 14 through September 30, 1985).*

During the study period, maximum daily mean streamflow of 5.4 and 2.2 ft^3/s (cubic feet per second) at North Bend Run and Robinson Run, respectively, were recorded on November 4, 1985. The instantaneous peak flow at North Bend Run was 17 ft^3/s on both November 4, 1985, and September 7, 1987. The instantaneous peak flow at Robinson Run was 12 ft^3/s on April 6, 1986. During the study period, daily streamflow averaged 0.16 ft^3/s for the North Bend Run basin and 0.07 ft^3/s for the Robinson Run basin.

The linear-pin erosion study within the Robinson Run basin indicated that more soil was lost from the reclaimed gas-well site than from the undisturbed part of the basin during the study period. The soil-erosion data for the three transects at the well site were averaged for each year over the 24-month period October 1985 through September 1987. The remaining six transects were averaged for the remainder of the basin. The study indicated soil loss throughout the basin; the well site lost an average 0.026 ft/yr (foot per year) and the undisturbed part of the basin lost an average of 0.013 ft/yr (table 6). This shows that the average soil loss at the reclaimed well site was two times the loss in the remaining undisturbed part of the basin. The average soil loss in the North Bend Run basin was 0.006 ft/yr. This shows that the average soil loss at the well site in Robinson Run was four times the loss in the undisturbed North Bend Run control basin.

Table 6.--Soil loss in the Robinson Run basin during water years 1986 and 1987

Water year	Soil loss, in feet	
	Well site	Remainder of watershed
1986	0.026	0.010
1987	.025	.016
Average	.026	.013

Suspended Sediment

The maximum daily suspended-sediment load in the North Bend Run basin, 5.9 tons, occurred on September 7, 1987. The suspended-sediment load from this storm was 26 percent of the total suspended-sediment load for the study. Precipitation in the basin totaled 3.60 in. on September 7, 1987. The mean discharge-weighted suspended-sediment concentration associated with this storm was 593 mg/L. Maximum suspended-sediment concentrations sampled in the North Bend Run basin were in excess of 5,000 mg/L and were associated with the instantaneous peak flow on September 7, 1987.

The maximum daily suspended-sediment load in the Robinson Run basin, 9.8 tons, occurred on July 15, 1985. The suspended-sediment load from this storm also was 26 percent of the total suspended-sediment load for the study. Precipitation in the basin totaled 2.88 in. on July 15, 1985, and the maximum hourly precipitation was 1.38 in. The mean discharge-weighted suspended-sediment concentration associated with this storm was 923 mg/L. Maximum suspended-sediment concentrations sampled in the Robinson Run basin exceeded 20,000 mg/L and were associated with the instantaneous peak flow on April 6, 1986.

Table 7 lists the suspended-sediment load, streamflow, and precipitation during selected storms for the study period. The suspended-sediment yields varied greatly depending on the season of the year, the amount and (or) intensity of precipitation, and the amount of soil disturbance in the basin. Generally, the high sediment yields in the spring months are associated with heavy rains. These heavy rains and soil saturation from previous rains contributed to the high yields in the North Bend Run basin on March 14, 1986, and in the Robinson Run basin on April 6, 1986. Soils in the spring had been loosened by repeated freezing and thawing during winter months. The high yields at both sites from the storm of November 4, 1985, were probably caused by heavy rains in the fall when soils were saturated and there was no forest canopy to protect the soils. Suspended-sediment yields from the storm on October 20, 1985, were low at both sites, probably because of the capability of dry soils to absorb most of the precipitation, resulting in little runoff. The instantaneous and mean daily water discharge in the Robinson Run basin was low even though the daily precipitation was in excess of 2 in. Large amounts of precipitation can cause considerable erosion even with full forest canopy. For example, on September 7, 1987, precipitation in excess of 3 in. caused the highest suspended-sediment yield in the North Bend Run basin for the study.

Table 7.--Selected storm data for the North Bend Run and Robinson Run basins, water years 1985-87

[ft^3/s, cubic foot per second]

Date	Daily suspended-sediment load (tons)	Instantaneous peak discharge (ft^3/s)	Mean daily discharge (ft^3/s)	Daily precipitation (inches)	Maximum hourly precipitation (inches)
NORTH BEND RUN (UNDISTURBED)					
July 15, 1985	1.3	12	1.5	2.04	0.92
October 20, 1985	.03	6.0	1.2	2.73	.64
November 4, 1985	1.3	17	5.4	2.69	.51
February 19, 1986	1.2	5.1	1.6	.73	.43
March 14, 1986	5.2	8.0	2.7	1.06	.35
July 9, 1986	.48	3.3	.29	1.12	.98
September 26, 1986	.19	3.0	.06	1.19	.82
December 24, 1986	.26	3.6	1.1	1.00	.23
April 23, 1987	.20	2.0	.63	.92	.56
September 7, 1987	5.9	17	1.1	[a]3.60	[b]--
ROBINSON RUN (DISTURBED)					
July 15, 1985	9.8	10	0.40	2.88	1.38
October 20, 1985	.20	.75	.20	2.15	.36
November 4, 1985	4.7	10	2.2	2.67	.63
February 19, 1986	.10	.45	.27	.26	.11
April 6, 1986	8.7	12	1.0	1.42	.63
July 9, 1986	.28	1.0	.06	.93	.80
September 26, 1986	.82	2.8	.07	1.65	1.09
December 24, 1986	.28	1.7	.58	.86	.14
September 7, 1987	.43	1.3	.15	[a]2.40	[b]--

[a] *From daily totals collected by local observers.*
[b] *No hourly data available.*

High-intensity summer storms can cause high suspended-sediment yields, as indicated by the storm of July 15, 1985. The high yield in the Robinson Run basin may be attributed to the drilling activities at the well site in February 1984. High-intensity storms on July 9, 1986, produced low sediment yields in both basins, possibly indicating a general soil-stabilization trend in the Robinson Run basin. Comparison of sediment yields from the storms on September 26, 1986, and September 7, 1987, in the Robinson Run basin also indicates a reduction of erosion with time. The yield was less for the latter storm, which had a greater daily precipitation. Five storms throughout the study period--July 15, 1985, November 4, 1985, March 14, 1986, April 6, 1986, and September 7, 1987--contributed 61 and 66 percent of the total suspended-sediment load for the North Bend Run and Robinson Run basins, respectively, for the study period.

A number of basin characteristics and conditions can contribute to high or low suspended-sediment yields. Basin characteristics such as topography, soil type, climate, and vegetative cover contribute to the natural soil erosion of a basin. Other conditions such as precipitation duration and intensity, antecedent soil-moisture conditions, amount of runoff, percentage of disturbed areas, and the land-use practice or soil-disturbing activity are all factors that contribute to the volume of sediments eroded from a basin. Total suspended-sediment loads and yields by water year for each basin are shown in table 8.

Table 8.--Annual suspended-sediment loads and yields in North Bend Run and Robinson Run basins, water years 1985-87

	NORTH BEND RUN		ROBINSON RUN	
Water years	Load (tons)	Yield (tons per acre)	Load (tons)	Yield (tons per acre)
[a]1985	2.08	0.02	10.74	0.24
1986	11.67	.13	22.98	.51
1987	8.82	.10	3.56	.08
Total	22.57	0.25	37.28	0.83

[a] *Partial water year (June 14 through September 30, 1985).*

Curves representing the suspended-sediment load and streamflow relation for both basins from June 14, 1985, through March 18, 1986, and from March 19, 1986, through September 30, 1987, are shown in figure 8. These linear-regression curves for each basin characterize the relation between the variables and should not be used for predicting suspended-sediment load from streamflow. Comparison of the curves show that the Robinson Run basin (disturbed) discharged more suspended sediment than did the North Bend Run basin (undisturbed) throughout the study.

The suspended-sediment load for the period June 14, 1985, through March 18, 1986, in the North Bend Run basin was 11.68 tons. This 9-month total represents 52 percent of the total suspended-sediment load for the North Bend Run basin during the study period.

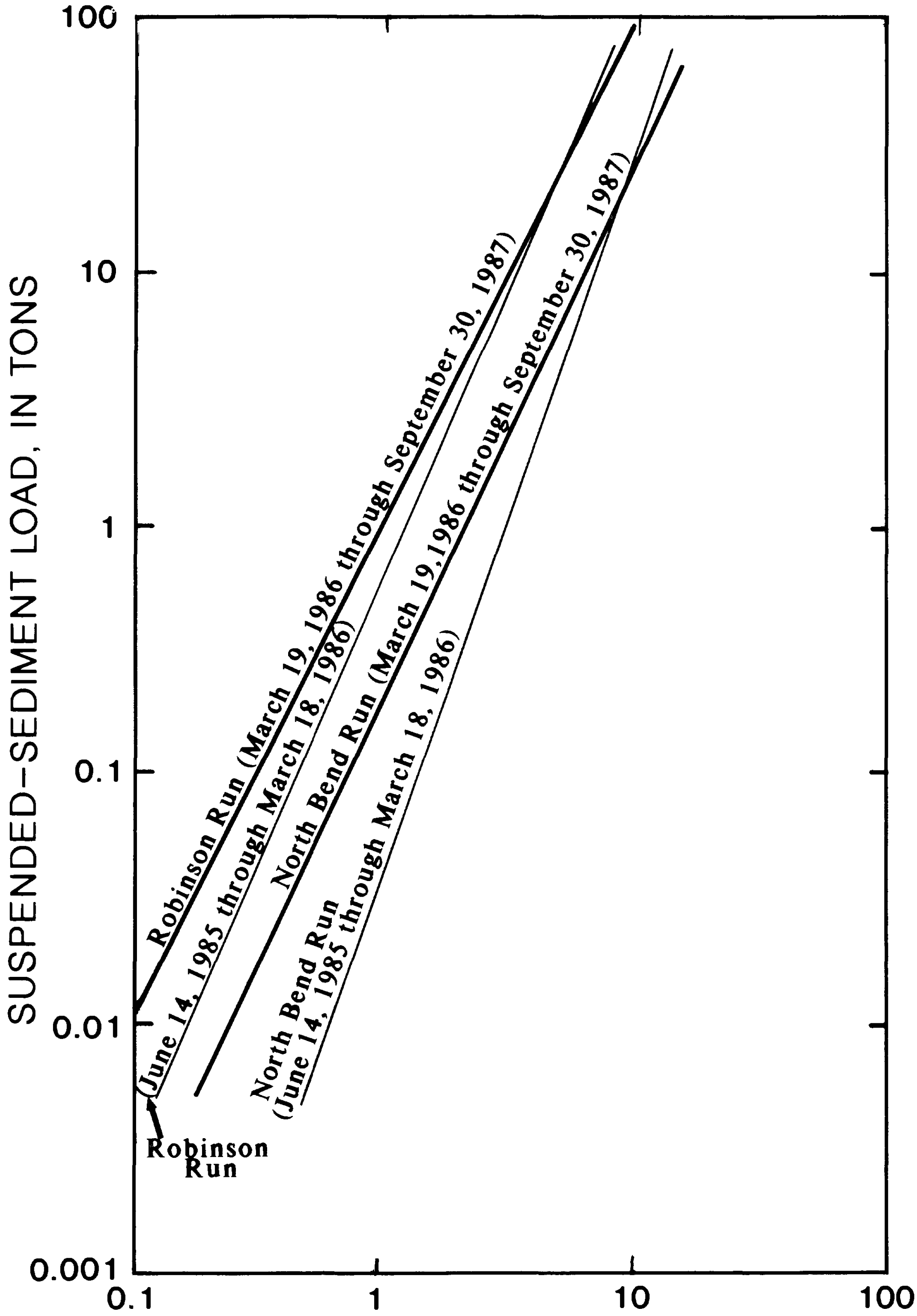

Figure 8.--Relation between suspended-sediment load and streamflow in the North Bend Run basin and Robinson Run basin, June 14, 1985, through March 18, 1986, and March 19, 1986, through September 30, 1987.

The suspended-sediment load for the period June 14, 1985, to March 18, 1986, in the Robinson Run basin was 19.88 tons. This 9-month total represents 53 percent of the total suspended-sediment load for the Robinson Run basin during the study period.

Trapped Sediment

Table 9 lists the total trapped sediment and precipitation from June 14, 1985, through September 30, 1987. The trapped sediments include the bed-material load and any suspended sediments that may have settled and not been flushed out of the ponds. These suspended sediments were assumed to be negligible in calculation of total sediment load. Throughout the study, the Robinson Run basin consistently yielded more sediment than North Bend Run basin. The data indicate that the amount of trapped sediment in the Robinson Run basin was 3.3 times that of the North Bend Run basin for the study period. Table 10 shows the amount of trapped sediment and cleanout dates for both basins during the study period.

Table 9.--Loads of trapped sediment and precipitation in the North Bend Run and Robinson Run basins, June 14, 1985 through September 30, 1987

[Load in tons; precipitation in inches]

Load of trapped sediment		Precipitation	
North Bend Run	Robinson Run	North Bend Run	Robinson Run
4.18	13.98	93.55	90.48

The amount of sediment trapped for the period June 14, 1985, through March 18, 1986, in the North Bend Run basin was 1.94 tons. This 9-month total represents 46 percent of the total trapped sediment for the North Bend Run basin during the study period.

The amount of sediment trapped for the period June 14, 1985, through March 18, 1986, in the Robinson Run basin was 9.72 tons. This 9-month total represents 70 percent of the total trapped sediment for the Robinson Run basin during the study period.

Table 10.--Sediment-deposition data for the Robinson Run and North Bend Run basins, *June 14, 1985 through September 30, 1987*

Cleanout date	Trapped sediment, in tons
ROBINSON RUN BASIN	
July 16, 1985	3.56
November 7, 1985	4.16
March 18, 1986	2.00
March 9, 1987	3.38
October 6, 1987	.88
Total	13.98
NORTH BEND RUN BASIN	
September 4, 1985	0.69
March 18, 1986	1.25
October 5, 1987	2.24
Total	4.18

Total Load

The total sediment loads for both basins during the study are listed in table 11. The totals were calculated by the addition of the suspended-sediment load (table 8) and the measured trapped sediment (table 9) for the study. Yields for each site also are listed in table 11. Because the ponds were cleaned and trapped sediment was measured in each basin only when needed and not necessarily at the same time, it is difficult to compare the total sediment loads on a time (cumulative) basis. Both ponds were cleaned on March 18, 1986, about 9 months after the start of data collection. The total measured at this time indicated that 13.62 tons (51 percent) had been discharged from the North Bend Run basin and 29.60 tons (58 percent) had been discharged from the Robinson Run basin before this date. The percentages of total load are similar despite the fact the North Bend Run basin is virtually undisturbed, whereas the gas-well site in the Robinson Run basin was reclaimed in October 1984. No data were collected before June 1985. Nearly 58 percent of the total sediment load was discharged in Robinson Run during the first 9 months of the study (before March 18, 1986); during the following 18 months (April 1986 through September 1987), the remaining 42 percent was discharged. This reduction in sediment discharge with time indicates that a soil-stabilization trend--associated with the well-site reclamation in the Robinson Run basin--was observed 25 months after the initial well-drilling activities. The suspended-sediment loads from each basin as of March 18, 1986, were similar: 52 percent of the suspended sediment had been discharged from the North Bend Run basin and 53 percent had been discharged from the Robinson Run basin. Analysis of the trapped sediment from each basin as of March 18, 1986, revealed that

46 percent of these sediments had been trapped in the North Bend Run basin, whereas 70 percent of these sediments had been trapped in the Robinson Run basin. This high proportion of trapped sediments from the disturbed Robinson Run basin indicates that most of the heavier sediments were discharged early in the study and that lighter material was available to be eroded to the stream as the study progressed. This reduction in heavy material transported over time in the Robinson Run basin indicates that the use of soil-stabilization practices and reclamation procedures 8 months after the well-site construction was somewhat effective in minimizing soil erosion. The fine materials at the well site were still available to be eroded and transported to the stream, whereas the heavier materials were held in place because they were supporting the grass cover. The below-normal precipitation in the Robinson Run basin also could have contributed to the reduced sediment loads.

Table 11.--Total sediment loads and yields for North Bend Run and Robinson Run basins for the study period

North Bend Run		Robinson Run	
Load (tons)	Yield (tons per acre)	Load (tons)	Yield (tons per acre)
26.75	0.30	51.26	1.14

SUMMARY AND CONCLUSIONS

Hydrologic data were collected from June 1985 through September 1987 to determine total sediment loads in the North Bend Run and Robinson Run basins. The types of data collected included precipitation, continuous stream stage, suspended-sediment concentrations for storm samples, cumulative trapped-sediment data, and pin-transect data related to soil erosion. The data were used to help evaluate the effectiveness of the established management practices in controlling erosion and sedimentation on oil- and gas-drilling sites.

Precipitation in both basins was below normal during the study, and precipitation totals among the basins differed by no more than 3.3 percent. Five storms contributed 61 and 66 percent of the total suspended-sediment load for the North Bend Run and Robinson Run basins, respectively. Runoff during the study period for the respective basins was 35.5 in. and 31.2 in., or about 38 and 34 percent of the precipitation recorded within these basins.

Soil-loss data from the linear-pin erosion study in Robinson Run indicated that the average soil loss at the well site (1.62 acres) was two times that of the remaining 43.38 acres (undisturbed part of the basin). The average soil loss at the well site in Robinson Run was four times that of the loss in the undisturbed North Bend Run basin.

Conclusions from this study are:

1. The total sediment yield at Robinson Run was 1.14 tons per acre compared to 0.30 tons per acre at North Bend Run.

2. Nearly 58 percent of the total sediment load was discharged in Robinson Run during the first 9 months of the study period (before March 18, 1986); during the following 18 months (April 1986 through September 1987), the remaining 42 percent was discharged. This reduction in sediment discharge with time may indicate that a soil-stabilization trend--associated with the well-site reclamation in the Robinson Run basin--was observed 25 months after the initial well-drilling activities. The below-normal precipitation in the Robinson Run basin also could have contributed to the reduced sediment loads.

3. Of the sediments measured in the sediment ponds during the study period, 70 percent had been trapped in the Robinson Run basin and 46 percent had been trapped in the North Bend Run basin before March 18, 1986. The large proportion of sediments trapped at this time indicates that most of the heavier sediments were discharged early in the study and that lighter material was available to be eroded to the stream as the study progressed. This reduction in heavy material transported over time indicates that the use of soil-stabilization practices and reclamation procedures 8 months after the well-site construction was somewhat effective in minimizing soil erosion.

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