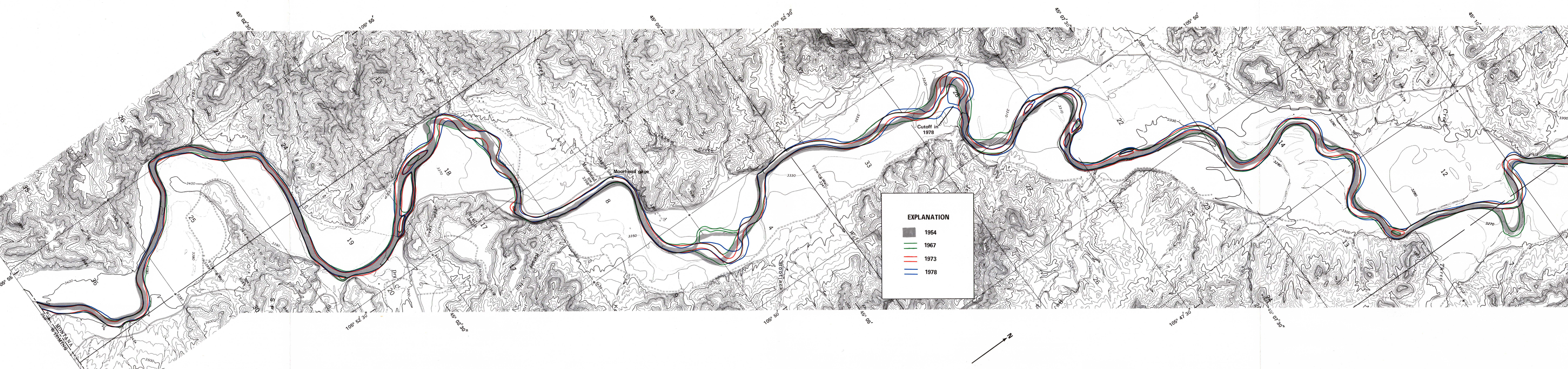
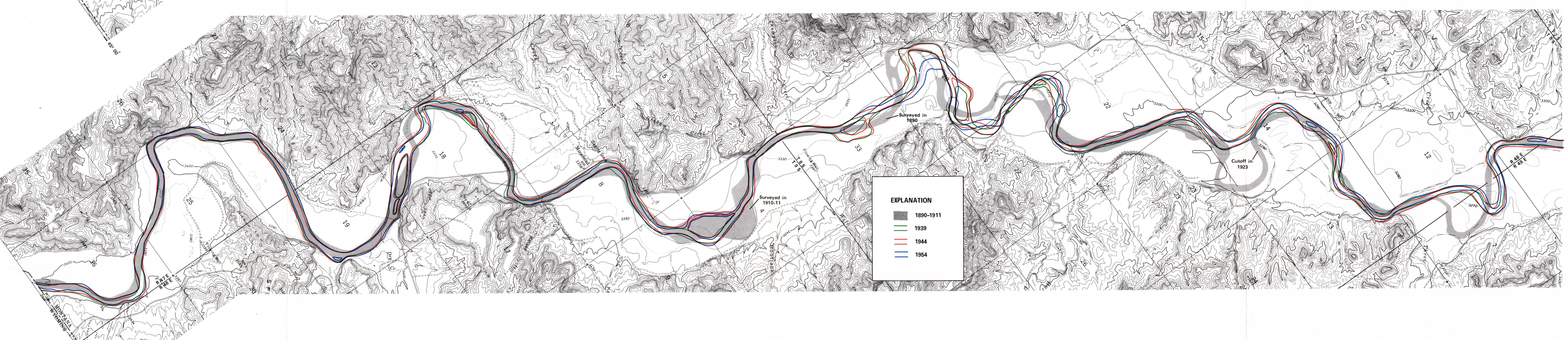




SCALE 1:24 000

1 ½ 0 1 MILE

1 .5 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET
WITH SUPPLEMENTARY CONTOURS AT 10 FOOT INTERVALS
NATIONAL GEODETIC VERTICAL DATUM OF 1929

INTRODUCTION

Powder River Study Area

The Powder River originates on the eastern flanks of the Bighorn Mountains of Wyoming and flows about 500 mi northeast to its confluence with the Yellowstone River in eastern Montana (Hembree and others, 1952). Data from the Powder River are ideally suited to studies of natural channel processes because there are no large diversions or reservoirs, only a fraction of the valley bottom bordering the channel is irrigated, and the land use (primarily grazing and alfalfa production) has changed little during the past 40 years. Therefore flow of water through the channel is virtually unregulated. However, recent coal-resource assessments within the basin suggest that the water resources soon may be used or augmented for energy development. Thus data for the Powder River can be used to assess and monitor the impact of changes induced by energy development on water and sediment loads on the channel.

Historic channels have been mapped for the 120-mi reach between the Wyoming-Montana state line and Powderville, but measurements of channel change have been restricted to a 65- to 70-mi reach between Moorhead and Broadus (see location map) for the following reasons: (1) No major tributaries enter the Powder River between Moorhead and Broadus. Morphometric and hydrologic measurements are confined to a single population affected by similar water and sediment loads. (2) Historical photographic coverage is more complete for the reach between Moorhead and Broadus. (3) The study reach is bracketed by streamflow-gaging stations at both Moorhead and Broadus. The Moorhead gaging station at the upstream end of the study reach has operated almost continuously since 1928. The record of daily mean discharge and peak flows includes the period of photographic coverage. Suspended-sediment samples have been collected daily at both stations since about 1975. (4) The reach between Moorhead and Broadus contains 20 channel cross sections that we have resurveyed every year or two since 1975 to show short-term changes in the channel resulting from flows between surveys (unpublished data). These field measurements also provide data with which to assess measurements made from aerial photographs.

Map Coverage

Although topographic maps of the Powder River were published in 1944 and 1969-73, they were not used in the present study because the channels portrayed on them were defined using criteria inconsistent with those used for this study. No information was lost by excluding these previously published maps, as photography was available to remap the channel for 1944 and 1969-73 using the criteria of this study.

The earliest maps of the channel were those made during the cadastral surveys between 1885 and 1911. They are included here with the warning that they show the location, pattern, and width of the Powder River only approximately. The course of the river, as mapped in the cadastral surveys, had to be adjusted in a few places (notably in Section 3 of T5S, R51E on sheet 2B, and in Section 10 of T3S, R52E on sheet 3A) so that the channel would appear in the valley bottom rather than at some distance up the side of the valley. Data from the cadastral surveys were not used in the measurements to assess bank erosion and channel change.

Photographic Coverage

Since 1939, eight historic configurations of parts of the Powder River have been recorded through aerial photography. Six of these sets were used to construct maps of the historic channel of the Powder River. Dates, scales, sources, and coverage of the photographs are summarized in table 1. The miscellaneous annotations on the maps, such as "cut off in 1978" or "artificial cutoff" are based on direct observations or on reliable reports by local residents.

Table 1. AERIAL-PHOTOGRAPHY DATA, POWDER RIVER COUNTY, MONTANA

Year	Dates flown	Approximate scale	Source	Coverage
1939	5/27/38-6/28/39	1:20,000	USFS[1]	Moorhead to Broadus
1944	7/28/44-10/8/44	1:40,000	Aero Service[2]	Moorhead to Powderville
1954	8/27/54-9/26/54	1:20,000	ASCS[3]	Moorhead to Powderville
1967	6/21/67-8/15/67	1:20,000	ASCS	Moorhead to Powderville
1972	7/23/72-7/26/72	1:30,000	USGS[4]	Broadus to Powderville
1973	7/04/73-7/05/73	1:24,000	Intrasearch[5]	Moorhead to Broadus
1978	7/26/78	1:40,000	ASCS	Moorhead to Powderville

[1] U.S. Department of Agriculture, Forest Service, Division of Engineering, Fort Missoula, Montana.
[2] Western Geophysical Company of America, Aero Service Division, Houston, Texas.
[3] U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service, Aerial Photography Field Office, Salt Lake City, Utah.
[4] U.S. Geological Survey, Denver, Colorado.
[5] Intrasearch, Inc., Denver, Colorado.

CONSTRUCTING CHANNEL MAPS FROM AERIAL PHOTOGRAPHS

Criteria for Mapping the Channel

Because daily mean discharges on the days on which aerial photographs of the channel were taken ranged from 1.4 to 3,430 ft^3/s (measured at the Moorhead gage), channels were defined from the aerial photographs by the positions of the banklines rather than by the left and right edges of water. To minimize the extent to which measurements from the mapped channels reflected a difference in river stage rather than actual changes in channel dimensions or location, channels were mapped from banktop to banktop on the basis of topographic and vegetational criteria.

Although the method is somewhat subjective, previous investigators have used the distribution of vegetation to define tops of the banks both on site (Schumm, 1960; Sigafoos, 1964; Emmett, 1975) and from maps or photographs (Hallberg and others, 1979). Surfaces lower than the flood plain usually have little or no vegetation (Emmett, 1975; Williams, 1978). For the point-bar side of an active reach, the bankline was mapped where vegetation began to dominate the ground surface, or at the riverward limit of established vegetation. The primary drawbacks of defining bankfull stage by the distribution of vegetation are: (1) Patchy distribution of vegetation and sediment on point bars; (2) the possibility that the limit of vegetation may fluctuate landward or riverward on point bars; and (3) the difficulty in distinguishing on photographs some perennial riparian species from herbaceous annuals that populate point bars and mid-channel bars during low-flow periods. On the outsides of bends, intersection of the water surface with the vertical or near-vertical cutbank was used to map position of the bankfull channel. In relatively stable reaches, tops of the banks usually were identified by both a recognizable break in slope and a change in the distribution of vegetation.

Similarly, islands were distinguished from bars primarily on the basis of vegetation. Regular inundation and movement of sediment across the surface of mid-channel bars were presumed to prevent the establishment of significant vegetal cover.

Map Construction

A map of the bankfull channel was constructed on mylar, for scale stability, from each set of aerial photographs as an overlay to the corresponding 1:24,000 topographic base. Use of a stereoplotter permitted accurate transfer of data from photographs to maps through direct viewing of the aerial photographs, resolving parallax, and correcting mechanically for scale changes and displacement due to topography. For further details on the use of stereoplotters, see Wolf (1974).

Measurements from the Maps

Channel area, island area, and channel length were measured from each historic channel map with a planimetric digitizer connected to a desk-top calculator. Adjusted channel area was determined by subtracting total area of the islands from the total measured channel area between banks. Mean channel width was computed by dividing the adjusted channel area by the channel-centerline length. Channel sinuosity was determined by dividing channel-centerline length by the valley length measured between topographic contours on the base map. These data are summarized in table 2.

Chronologically consecutive maps of the historic channels were overlain and areas of bank erosion measured with the digitizer. Small areas eroded from discrete sites were summed together to measure total bank erosion from the study reach for each interval of time between maps. Average bank erosion per unit length of channel for each period of time bracketed by aerial photographs was computed by dividing the total area eroded by the channel length from the earlier of the two maps.

Accuracy and Reproducibility of the Measurements

Possible sources of error in the maps and their effect on measurements from the maps were assessed. Inaccuracies introduced due to thickness of the pencil point, unsteadiness of hand, or imprecisely defining the bank in the point-bar environment were assumed to be random and to offset each other throughout the reach of channel. Inadvertent errors, inherent in setting up the stereo-pair models, however, will always result in an overestimation of bank erosion (although measurements of width and length would not be affected). The amount of overestimation possible was determined by constructing duplicate maps for a reach of the Powder River from each set of photographs, overlaying the duplicates, and measuring "apparent erosion or channel shift," where in reality there could have been none. Each pair of duplicate maps examined overestimated bank erosion by an average of 0.0041 mi^2 per mile of channel. Overestimation appeared to be independent of age or scale of the photography. Therefore, measured values for erosion for the entire study reach for each set of chronologically consecutive channels were adjusted by 0.0041 mi^2 per mile of channel. Adjusted values for total erosion are summarized in table 3.

Table 2. CHARACTERISTICS OF HISTORIC CHANNELS MEASURED BETWEEN THE 3390- AND 2290-FOOT TOPOGRAPHIC CONTOURS, POWDER RIVER MONTANA

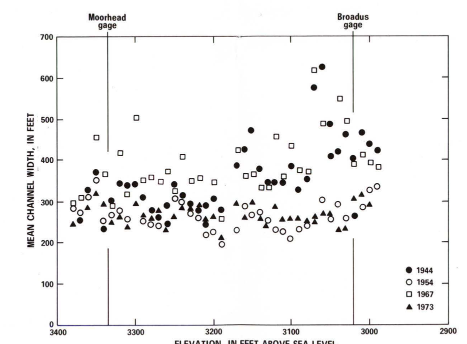
Year of photograph	Channel area (square miles)	Channel length (miles)	Mean channel width (feet)	Island area (square miles)	Adjusted area (square miles)	Adjusted mean width (feet)	Sinuosity[1]
1939	5.065	65.44	408	0.452	4.613	372	1.40
1944	5.045	65.87	404	.575	4.469	358	1.41
1954	3.745	67.27	294	.416	3.329	261	1.44
1967	5.399	68.65	415	.437	4.962	382	1.47
1973	3.494	69.87	264	.139	3.355	253	1.50
1978	4.245	68.43	328	.192	4.053	313	1.47

[1] Sinuosity is the ratio of channel length to valley length. Valley length between the 3,390- and 2,990-foot topographic contours is about 46.7 miles.

CHANNEL CHANGES BETWEEN 1939 AND1978

Changes in Channel Width

Mean channel width (henceforth referred to as width or channel width) measured 15 percent less in 1978 than in 1939. This cannot be interpreted to signify channel narrowing through time, however, as width measured from the photographs increased and decreased several times during the 40 years of photographic coverage (see figure below and table 3). The narrowest channel (1954) was 40 percent of the widest channel (1967). This is on the same order of upstream and downstream variability in width for a single period of time. The apparent variability in channel width must be interpreted cautiously because of the uncertainty in defining the bankfull channel using vegetational criteria.



Nonetheless, changes in channel width could be related to the antecedent hydrologic conditions. Following periods characterized by relatively higher peak flows, channel width appeared to have increased (1944, 1967, 1978). Conversely, following periods characterized by lower peak flows, channel width appeared to have decreased (1954, 1973). This variability would be expected, in that channel dimensions reflect the amount of water passing through the channel. The channel might be widened, if only temporarily, by large flows.

However, the widest measured channel (1967) did not coincide with the highest peak flow (1978). Neither did measured mean width correlate closely with the peak flow during the last or next-to-last runoff season preceding the photography. Since 1944, the narrowest to widest channels have corresponded respectively to the periods of least to greatest bank erosion. Perhaps then, the distribution of vegetation near the channel represents some cumulative response to the discharge events preceding width measurement and not only to flows during the year or two immediately preceding the photography.

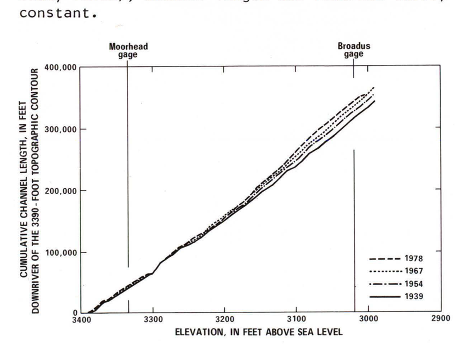
Changes in Island Area

Islands occupied between 4 percent (1973) and 12 percent (1939) of the bank-to-bank area of the channel. Although net island area decreased by 50 percent between 1939 and 1978, it increased during periods of higher peak flows and greater bank erosion. Conversely, island areas decreased during periods of lower flows. This variability in island area may reflect temporary changes in the amount of material being stored in the channel.

Changes in Channel Length

Between 1939 and 1973, channel length increased by 7 percent between the 3,390- and 2,990-ft topographic contours (approximately the reach between Moorhead and Broadus portrayed on sheets 1 and 2). Although meander-bend cutoffs eliminated more than a mile of channel, growth of existing meander bends and the initiation of new bends resulted in net elongation of the channel. Although this process of meander growth continued between 1973 and 1978, the breaching of several large meander bends in 1975 and 1978 resulted in net shortening of the channel by more than a mile.

Changes in channel length were not distributed equally along the reach. For each set of maps, the length of channel between contours was measured. A plot of the cumulative downstream distance corresponding to valley-floor elevation for each of four sets of maps (below) shows that the river upstream of about 3,190-ft valley-floor elevation (sheets 1 and 2A) has remained relatively constant in length; decrease in length due to meander bend cutoffs is compensated by channel elongation due to growth of meanders in other locations. Practically all net elongation has occurred between 3,190 and 3,070 ft (sheet 2). Between 3,070 ft and Broadus (approximately the downstream 9 miles of the study reach), channel length has remained fairly constant.



The variable rates of lengthening correspond to the pattern of channel deformation or lack thereof within the valley. Upstream of about 3,330 ft (sheet 1) there has been no lengthening. The valley bottom is narrow (on the order of 10 channel widths) and deformation of the channel within this reach has been negligible, probably because of bedrock constraints imposed by the valley. Between 3,330 and 3,190 ft (sheets 1 and 2A), the channel also has maintained a constant length. Meander cutoffs or chute cutoffs have balanced the slight increases in length that were due to lateral migration of the meander bends in this segment of channel. Meander bends are linked by straight, stable reaches of channel, indicating the probability of bedrock control in this reach. Between 3,190 and 3,070 ft (sheet 2), the channel has consistently lengthened, primarily through lateral migration of meander bends with negligible downstream translation of the meanders. The channel impinges the valley wall periodically along the reach. Between 3,070 ft and Broadus (sheet 2), the channel has migrated through the valley primarily by downstream translation, with negligible lateral migration of the meander bends. That the meanders can translate so freely downstream suggests a lack of bedrock constraints and control on the channel. Thus, between Moorhead and Broadus, rate of meander growth and mode of meander deformation probably reflect the transition from bedrock to alluvial channel, and the degree of bedrock control probably is responsible for at least some of the variability in channel pattern and channel behavior.

RELATION OF BANK EROSION TO DISCHARGE

Values of bankfull discharge and effective discharge were computed for the Powder River from water and sediment records for Moorhead and Broadus. Flow-frequency analysis indicates that bankfull discharge (estimated as the 1.5-year flood) is about 5,600 ft^3/s. The effective discharge (that increment of discharge which transports the largest fraction of the total sediment load throughout a number of years) computed by the procedure described by Andrews (1980) is about 2,200 ft^3/s.

Relations between bank erosion measured from historic channel maps and water discharge for the 40 years of concurrent photographic coverage and daily discharge data were tested for statistical significance for the range of discharge values, using an F-test. Bank erosion was found to correlate significantly at the 95-percent confidence level with the number of days that mean discharge equaled or exceeded bankfull discharge.

Threshold discharges of bank erosion were identified by comparing measured bank erosion at nine cross sections that we established in 1975 and resurveyed in 1977, 1978, 1979, and 1980 (unpublished data) to the record of daily mean and peak flows for that period. When daily mean discharge was less than about 2,200 ft^3/s (effective discharge), there was no measurable bank erosion. When daily mean discharges were between 2,200 and 5,600 ft^3/s, there were small, unsystematic, but measurable amounts of bank erosion. Significant bank erosion occurred at sustained flows greater than bankfull discharge (Martinson, 1983).

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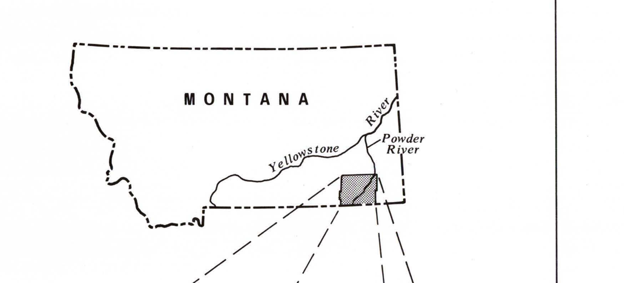
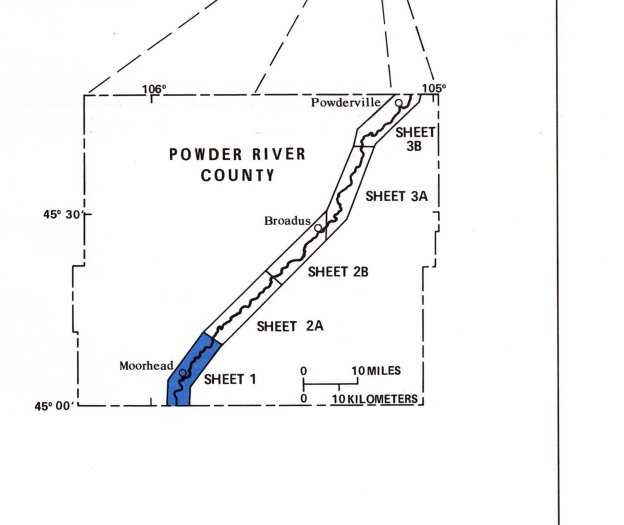
Table 3. CHANNEL CHANGES, POWDER RIVER BETWEEN MOORHEAD AND BROADUS, 1939-78

	Time intervals				
	1939-44	1944-54	1954-67	1967-73	1973-78
Change in area (square miles)---------	-0.020	-1.300	+1.654	-1.904	+0.751
Change in length (miles)-------------	+.428	+1.399	+1.376	+1.219	-1.439
Change in mean width (feet)----------	-4	-110	+121	-151	+64
Change in adjusted mean width (feet)--	-14	-97	+121	-129	+60
Change in island area (square miles)--	+.123	-.159	+.021	-.298	+.053
Bank erosion (square miles)----------	.520	.146	1.804	.007	.592
Point bar deposition (square miles)---	.539	1.446	.150	1.915	-.163
Number of cutoffs--------------------	1	6	4	1	3





CONVERSION FACTORS

Multiply inch-pound unit	*By*	*To obtain metric unit*
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

CHANNEL CHANGES OF POWDER RIVER, 1938-78, POWDER RIVER COUNTY, MONTANA

By
Holly A. Martinson and Robert H. Meade
1983

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