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SCIENTIFIC INVESTIGATIONS MAP 2868
(Sheet 1 of 5)
Parrett and others, 2005, Water-surface elevation data and flood and floodway boundaries for the upper Yellowstone River, Montana

Water-Surface Elevation Data and Flood and Floodway Boundaries for the Upper Yellowstone River, Montana

By Charles Parrett, Stephen R. Holnbeck, and Katherine J. Chase

Introduction

The upper Yellowstone River in south-central Montana is an important source of irrigation water and a blue-ribbon trout stream. In addition, an increasing number of homes are being built in the scenic upper Yellowstone River valley. In 1996, severe flooding caused substantial channel and bank erosion, particularly just upstream from Livingston (fig. 1). Following the flood, numerous projects were completed to stabilize the banks. In 1997, a severe flood again caused channel and bank erosion. Although previously constructed stabilization projects decreased erosion in some locations, they were thought to have contributed to increased erosion in 1997 at upstream or downstream locations, and future bank-stabilization projects, therefore, became controversial. To study the effects of bank stabilization on the dynamic upper Yellowstone River, a task force was appointed by the Governor of Montana. The Upper Yellowstone River Task Force initiated a cumulative-effects study of the upper Yellowstone River. The main objective of the cumulative-effects study was to gather information from a wide range of scientific investigations in the basin and to use the scientific information as a basis for assessing the long-term, cumulative effects of proposed streambank-stabilization projects. The U.S. Geological Survey (USGS), in cooperation with Montana Departments of Transportation (MDT) and Natural Resources and Conservation (MDNRC), Park Conservation District, and the U.S. Army Corps of Engineers (USACE), investigated the hydraulic characteristics of the upper Yellowstone River as part of the cumulative-effects study. The investigation of hydraulic characteristics had two major objectives: (1) determination of flood and floodway boundaries for parts of the upper Yellowstone River and (2) simulation of sediment transport for a part of the upper Yellowstone River.

This report presents water-surface elevation data required to meet objective 1 and shows the mapped flood and floodway boundaries. The mapped flood boundaries show the extent of flooding from flood discharges having recurrence intervals of 500 and 100 years. The mapped floodway boundaries show the area within the boundaries of the 100-year flood discharge that is reserved for the passage of flood flows under Montana Administrative Rule 36.15.502 (1995). The hydrologic analysis is based on recorded annual-peak discharge data from 1890 through 1998 for two USGS streamflow-gaging stations (stations 06191500 and 06192500, fig. 1). The hydraulic analysis is based on channel- and bridge-geometry data collected between 1999-2001. The hydraulic analysis and resulting flood mapping were more detailed for the lower study reach from Carter Bridge upstream to Point of Rocks bridge than for the upper study reach from Point of Rocks bridge upstream to Gardiner.

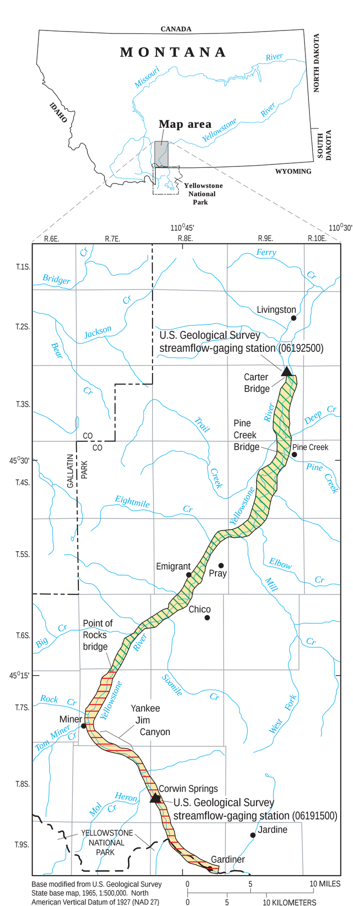


Figure 1. Location of the upper Yellowstone River study area, Montana.

Study Area Description

The Yellowstone River originates in Wyoming, in and near the southern part of Yellowstone National Park. The river enters Montana near the town of Gardiner and flows north and east across 500 mi of southern Montana, joining the Missouri River just inside North Dakota. The study area consists of the Yellowstone River flood plain from Gardiner, near the boundary of Yellowstone National Park, to Carter Bridge, about 56 river mi downstream near Livingston (fig. 1). The topography through this reach varies from steep, winding mountain canyons to a broad alluvial valley bordered by high mountains. Estimated elevations in the drainage basin range from 12,160 ft at the headwaters in Yellowstone National Park to 4,480 ft at Livingston.

Land uses in the study area include irrigated hay production, livestock grazing, and residential development. Cottonwood, western snowberry, woods rose, red-osier dogwood, and various native grasses and sedges grow along the stream banks (U.S. Department of Agriculture, Natural Resources Conservation Service, 2001).

The climate is semiarid with cold winters and warm summers. Based on climatic data for the period of record, 1971-2000, average monthly temperatures at Livingston range from 25.6 °F in January to 67.3 °F in July. Average annual precipitation in Livingston is 15.7 in., with about 53 percent of this amount falling in April through July. May typically is the wettest month, with an average of 2.8 in. of precipitation, whereas February typically is the driest month, with an average of 0.5 in. (National Oceanic and Atmospheric Administration, 2001, p. 14, 21).

Major tributaries of the Yellowstone River in the study area include Mol Heron Creek, Tom Miner Creek, Big Creek, Mill Creek, and Trail Creek (fig. 1). These are perennial streams, and most runoff results from snowmelt or snowmelt augmented by rain in May or June.

Methods Of Analysis

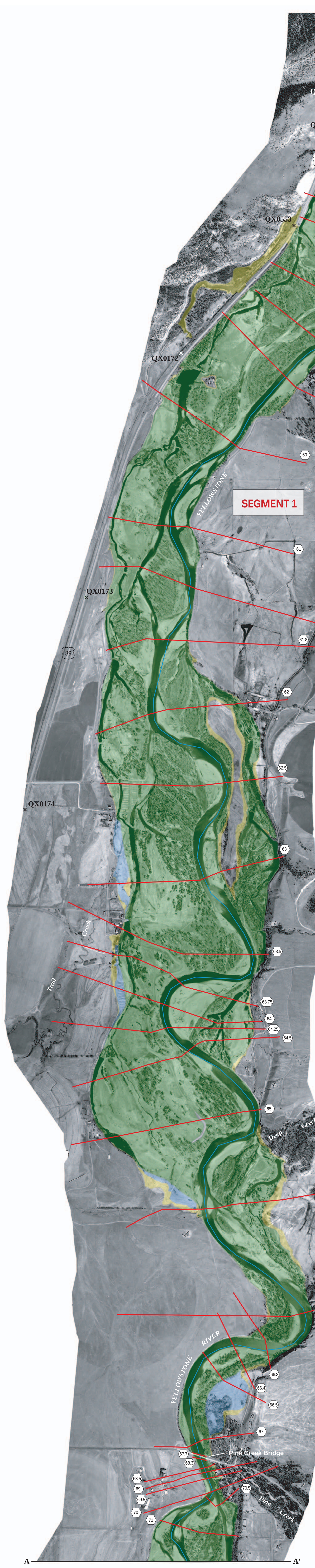
Hydrologic Analysis

Data for the largest recorded annual peak discharges from 1890 through 2001 at two streamflow-gaging stations on the Yellowstone River within the study area are summarized in table 1. The 1997 peak discharge, the largest recorded at both stations, was nearly equivalent to the 100-year flood estimate at both sites. The 1996 peak discharge was identical to the 1997 peak discharge at Corwin Springs and almost as large as the 1997 peak discharge near Livingston. Other notable large floods occurred in 1918 and 1974 (table 1).

Flood-frequency data (annual peak discharges having selected recurrence intervals) were determined by application of the log Pearson Type III probability distribution to the recorded annual peak discharges at the mainstem streamflow-gaging stations at Corwin Springs and near Livingston for their periods of record through 1998 (U.S. Geological Survey, 2002). Flood-frequency data also are commonly referred to as *T*-year floods, where *T* is the recurrence interval for a particular annual peak discharge (flood). Flood-frequency data for the gaging station at Corwin Springs were considered applicable to the reach from Gardiner to the mouth of Mol Heron Creek. Flood-frequency data for the gaging station near Livingston were considered applicable to the reach from the mouth of Trail Creek to Carter Bridge, where the gage near Livingston is located (fig. 1). Flood-frequency data were estimated for four ungaged reaches between Mol Herron Creek and Tom Miner Creek, between Tom Miner Creek and Big Creek, between Big Creek and Mill Creek, and between Mill Creek and Trail Creek. Estimates were based on a linear interpolation between logarithms of flood discharges at the two gaged sites using logarithms of drainage area as the basis for interpolation (Parrett and Johnson, 2004). Drainage-area information and flood-frequency data for the Yellowstone River throughout the study area are summarized in table 2.

Table 1. Largest recorded annual peak discharges for the Yellowstone River at Corwin Springs and near Livingston, Montana, 1890-2001.

Date	Discharge of Yellowstone River, in cubic feet per second	
	At Corwin Springs (06191500), fig.1	Near Livingston (06192500), fig.1
06/06/1997	32,200	38,000
06/10/1996	32,200	37,100
06/17/1974	30,900	36,300
06/14/1918	32,000	No record
06/13/1911	25,800	No record
06/11/1902	No record	30,100



Hydraulic Analysis

A one-dimensional, hydraulic-flow model was used to determine water-surface elevations for selected flood discharges where channel cross sections were surveyed. The hydraulic flow model developed by the U.S. Army Corps of Engineers (USACE), HEC-RAS, version 3.0, (2001a,b,c), requires channel, bridge, and flood-plain geometry data and channel and flood-plain roughness characteristics (Manning's *n* values) to calculate flood elevations. Channel and bridge geometries were surveyed at 139 river cross sections from Gardiner to just downstream from Carter Bridge near Livingston. Flood-plain geometry data were obtained from digital topographic maps. Roughness characteristics, which were determined in the field at the time of channel surveys, ranged from 0.025 to 0.065 for the main channel and from 0.030 to 0.150 for the flood plain. High-water marks (such as seed lines and flood debris) from either the 1996 or 1997 floods were surveyed at cross sections wherever they could be found. These high-water marks, though of variable reliability, were used to help calibrate the hydraulic model. At six locations, additional surveyed cross-section data were available from the U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS), and were included in this analysis (Ralph Bergantine, Natural Resources Conservation Service, written commun., 2000). Interpolated cross-section data were used at 12 more locations where the hydraulic-model results indicated that additional channel and flood-plain geometry were required. Thus, a total of 157 cross sections were used for the determination of water-surface elevations in the entire study area. The total number of cross sections also included sections at the upstream and downstream faces of each of the seven bridges in the study area. Those 14 bridge cross sections are not shown on the flood-plain maps (segments 1-8) for clarity.

Field surveys and elevations are referenced to U.S. Geodetic Survey or U.S. Coast and Geodetic Survey bench marks along the upper Yellowstone River which are shown on the flood-plain maps. Information about the bench marks can be obtained from the National Geodetic Survey at *http://www.ngs.noaa.gov* (accessed March 16, 2004).

Data from about 53 surveyed cross sections from various sources were being used for hydraulic analyses by the USACE downstream from Carter Bridge. Calculations by the hydraulic model proceed in an upstream direction; consequently, cross sections used for this study were numbered in an upstream direction starting with cross section 54 just below Carter Bridge (segment 1, sheet 1). Graphs showing sample cross sections (figs. 2-4) are for a channel reach with multiple channels and a wide 100-year flood plain (cross section 71, fig. 2), a channel reach with an incised channel and narrow 100-year flood plain (cross section 90, fig. 3), and a channel reach with a typical bridge and pier (cross section 149, fig. 4). Data for all cross sections used in the study are available in files at the USGS Montana District Office in Helena, Mont.

Two different levels of hydraulic analysis were used for the study, depending upon the accuracy and resolution of the digitized aerial-photographic base used for flood-plain mapping, the availability of digital topographic data, and the number of and spacing between surveyed channel cross sections. The best resolution (1:8,000 scale) digital orthophotographs were available for the lower study reach from just below Carter Bridge (cross section 54) upstream to just above Point of Rocks bridge (cross section 124). Digital topographic maps with 4-ft contour intervals and intermittent elevation data (spot elevations) meeting Federal Emergency Management Agency (FEMA) mapping standards also were available for this reach. Accordingly, a more-detailed hydraulic analysis was performed for this lower study reach. The more-detailed hydraulic analysis included determination of water-surface elevations at cross sections for the 2-, 10-, 50-, 100-, and 500-year flood discharges, determination of a floodway, and determination of the areas that would be inundated by the 100-year and 500-year flood discharges.

The aerial-photographic base map available for the upper study reach just upstream from the Point of Rocks bridge (cross section 124) upstream to Gardiner (cross section 160) had less resolution (1:12,000 scale) than the base map for the lower study reach. Also, the only available digital topographic data for this upper study reach were USGS 1:24,000 digital-elevation-model (DEM) data with 20-ft contour intervals. Finally, because of the lower-resolution aerial photography and less-detailed topographic information, fewer cross-sections were surveyed in this upper study reach than in the lower study reach. Consequently, a less-detailed hydraulic analysis was performed from Point of Rocks bridge to Gardiner. The less-detailed analysis included only determination of the 100-year water-surface elevation at cross sections and the areas that would be inundated by the 100-year flood discharge. A floodway was not determined for this less-detailed, upper study reach. Water-surface elevations and mapped limits of the 100-year flood discharge are considered to be less reliable within this upper study reach than in the lower study reach because of the less-detailed base map and topography and few cross-section data.

Yankee Jim Canyon is located within the less-detailed, upper study reach (segment 6). Streamflow is very turbulent in this steep canyon and cross sections could not be safely surveyed. Thus, water-surface elevations were not determined between cross sections 131 and 135. Nevertheless, flood boundaries in the canyon are considered to be no wider than the channel because of the steep canyon walls.

Water-Surface Elevation Data

Table 3 (sheet 2) presents the streambed- and calculated water-surface elevation data for the 2-, 10-, 50-, 100-, and 500-year flood discharges at each cross section in the more-detailed, lower study reach from Carter Bridge upstream to Point of Rocks bridge. Table 4 (sheet 2) presents the calculated water-surface elevations for the 100-year flood discharge at each cross section in the less-detailed, upper study reach from Point of Rocks bridge upstream to Gardiner. Cumulative distances for all cross sections upstream from cross section 54 (most downstream cross section) used in the hydraulic analysis are presented in both tables. The water-surface elevation data can be used with the distance data to construct profiles of flood elevations throughout the study area (except for Yankee Jim Canyon). Flood profiles are useful for estimating flood elevations at selected locations between cross sections. Three representative flood-profile graphs are shown in figure 5. This hydraulic analysis was based on unobstructed flow. Water-surface elevations presented in tables 3 and 4 and in the representative profiles (fig. 5) are valid only if hydraulic structures remain clear of debris and do not fail. The water-surface elevations also are valid only for channel and flood-plain conditions at the time of the surveys.

Flood Boundaries

The flood boundaries along the river define areas that would be inundated by the 100- and 500-year flood discharges. The flood boundaries were delineated using water-surface elevations determined at each cross section. Between cross sections, the flood-elevation profiles were used to determine water-surface elevations, which in turn were used to interpolate flood boundaries based on mapped elevation contours. RiverCAD (Boss International, 2000) was used to interpolate and draw flood boundaries between cross sections.

Flood boundaries for both the 100- and 500-year flood discharges are shown for the lower, more-detailed study reach (map segments 1 through 4), while flood boundaries for just the 100-year flood discharge are shown for the upper, less-detailed study reach (map segments 5 through 8). In both study reaches, small areas within the flood boundaries for the 100-year flood discharges might be above the water-surface elevation, but cannot be shown because of the limitations of the map scale or the lack of sufficiently detailed topographic data. Likewise, small areas within the flood boundaries for the 500-year flood discharge shown in the more-detailed study reach might be above the water-surface elevation.

Floodway Boundaries

The area within the boundaries of the 100-year flood discharge is divided into two portions for flood-plain management purposes. The floodway, which is reserved for the passage of flood flows, includes the channel and some adjoining flood plain. The flood fringe, which is allowed to be developed with structures elevated on suitable fill material, includes the outer parts of the area inundated by a 100-year flood discharge. The width of the floodway under Montana Administrative Rule 36.15.502 (1995) is determined by hydraulic calculation such that the water-surface elevation of the 100-year flood discharge is increased by no more than 0.5 ft by complete filling (encroachment) of the flood fringe. Montana Administrative Rule 36.15.502 (1995) further requires that flood-plain areas where flow depths or flow velocities for the 100-year flood discharge exceed 3 ft or 3 ft/s, respectively, need to be included in the floodway. Figure 6 (sheet 2) shows a hypothetical cross section with a floodway and water-surface elevations for the 100-year flood discharge with and without encroachment in the flood fringe.

The HEC-RAS hydraulic model was used to calculate floodway boundaries by incrementally encroaching on the 100-year flooded area from each side of each cross section and re-running the hydraulic model until calculated water-surface elevations for the 100-year flood discharge increased by a maximum of 0.5 ft at all sections (U.S. Army Corps of Engineers, 2001c). The water-surface elevation for the 100-year flood discharge at many cross sections was not increased by the floodway-boundary calculations because the floodway width was expanded to include areas of high depths and velocities. At a few cross sections near bridges, the calculated water-surface elevation for the 100-year flood discharge with a floodway was less than that without a delineated floodway. The calculated lower water-surface elevation probably is the result of more efficient hydraulic transitions between adjacent cross sections with a delineated floodway than without. For those few sections with lower calculated water-surface elevations with a floodway, the lower elevations were raised to match those without a floodway.

Data for floodway widths and changes in water-surface elevations for the 100-year flood discharge as a result of floodway delineation at all sections in the lower, more-detailed study reach are shown in table 5 (sheet 3). Floodway boundaries are shown together with 100- and 500-year flood boundaries (segments 1 through 4).

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0 0.25 0.50 0.75 1 MILE
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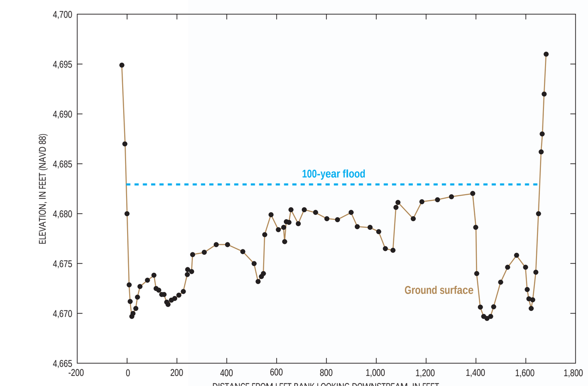


Figure 2. Cross section 71, which is typical of a location in the lower study reach with multiple channels and a wide flood plain.

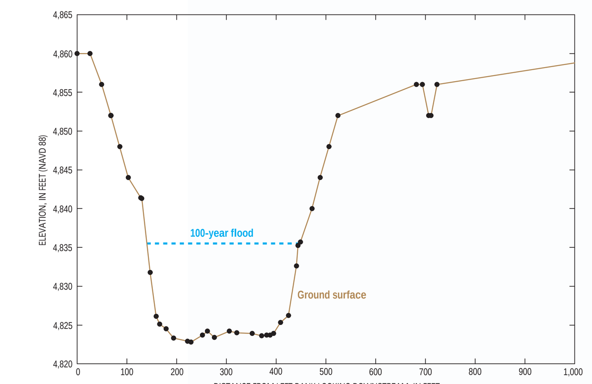


Figure 3. Cross section 90, which is typical of a location in the lower study reach where the channel is incised and the flood plain is narrow.

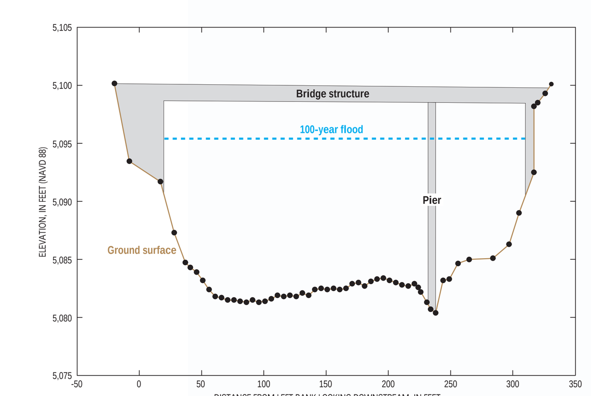


Figure 4. Cross section 149, which is typical of a location in the upper study reach with a bridge and pier.

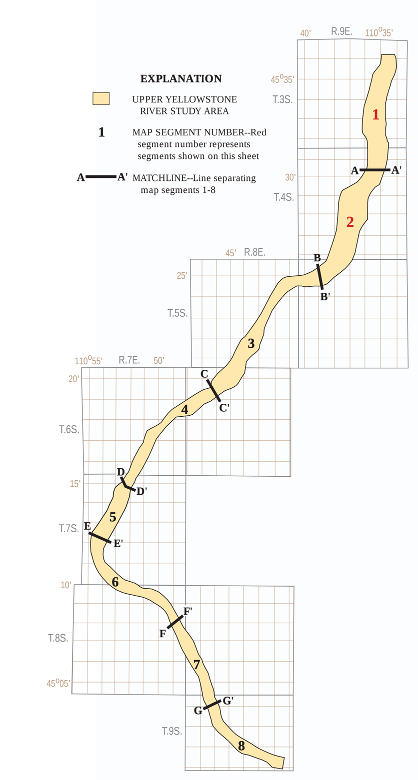


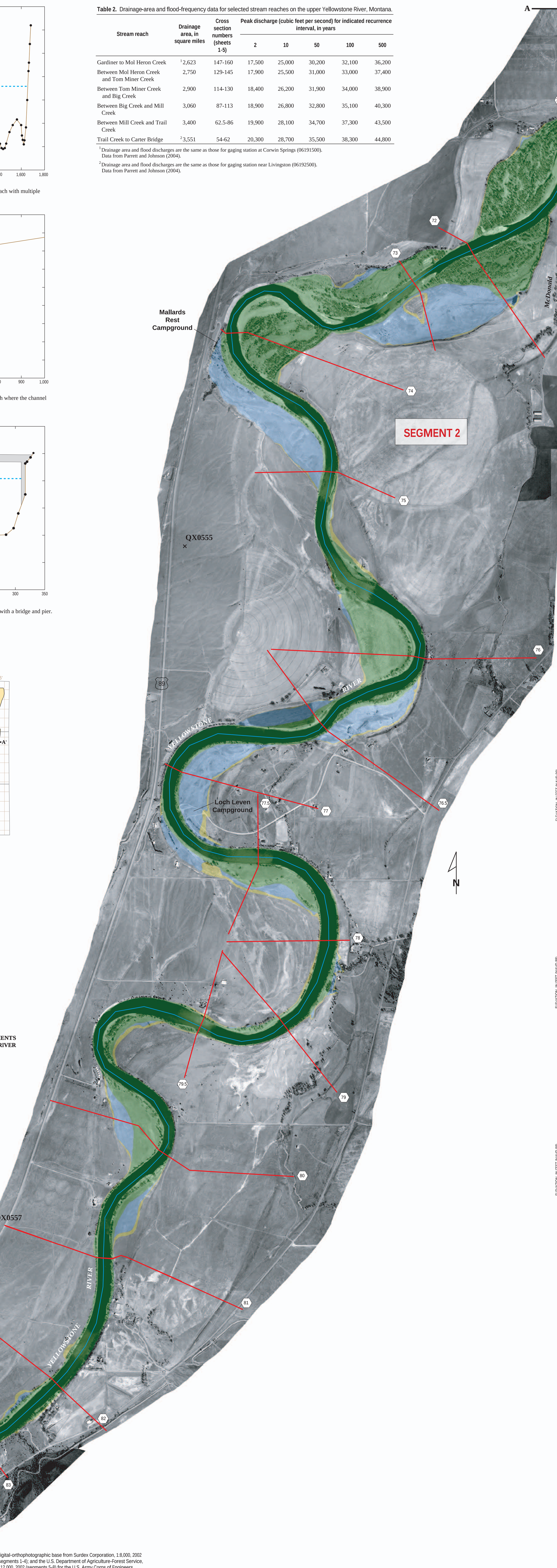
DIAGRAM SHOWING RELATIVE POSITION OF MAP SEGMENTS AND MATCHLINES ALONG THE UPPER YELLOWSTONE RIVER

Table 2. Drainage-area and flood-frequency data for selected stream reaches on the upper Yellowstone River, Montana.

Stream reach	Drainage area, in square miles	Cross section numbers (sheets 1-5)	Peak discharge (cubic feet per second) for indicated recurrence interval, in years				
			2	10	50	100	500
Gardiner to Mol Heron Creek	[1]2,623	147-160	17,500	25,000	30,200	32,100	36,200
Between Mol Heron Creek and Tom Miner Creek	2,750	129-145	17,900	25,500	31,000	33,000	37,400
Between Tom Miner Creek and Big Creek	2,900	114-130	18,400	26,200	31,900	34,000	38,900
Between Big Creek and Mill Creek	3,060	87-113	18,900	26,800	32,800	35,100	40,300
Between Mill Creek and Trail Creek	3,400	62.5-86	19,900	28,100	34,700	37,300	43,500
Trail Creek to Carter Bridge	[2]3,551	54-62	20,300	28,700	35,500	38,300	44,800

[1]Drainage area and flood discharges are the same as those for gaging station at Corwin Springs (06191500). Data from Parrett and Johnson (2004).

[2]Drainage area and flood discharges are the same as those for gaging station near Livingston (06192500). Data from Parrett and Johnson (2004).



Digital orthophotographic base from Surdex Corporation, 1:8,000, 2002 (segments 1-4), and the U.S. Department of Agriculture-Forest Service, 1:12,000, 2002 (segments 5-8) for the U.S. Army Corps of Engineers. Digitized aerial-photographic base by MAP, Inc., April 1999.

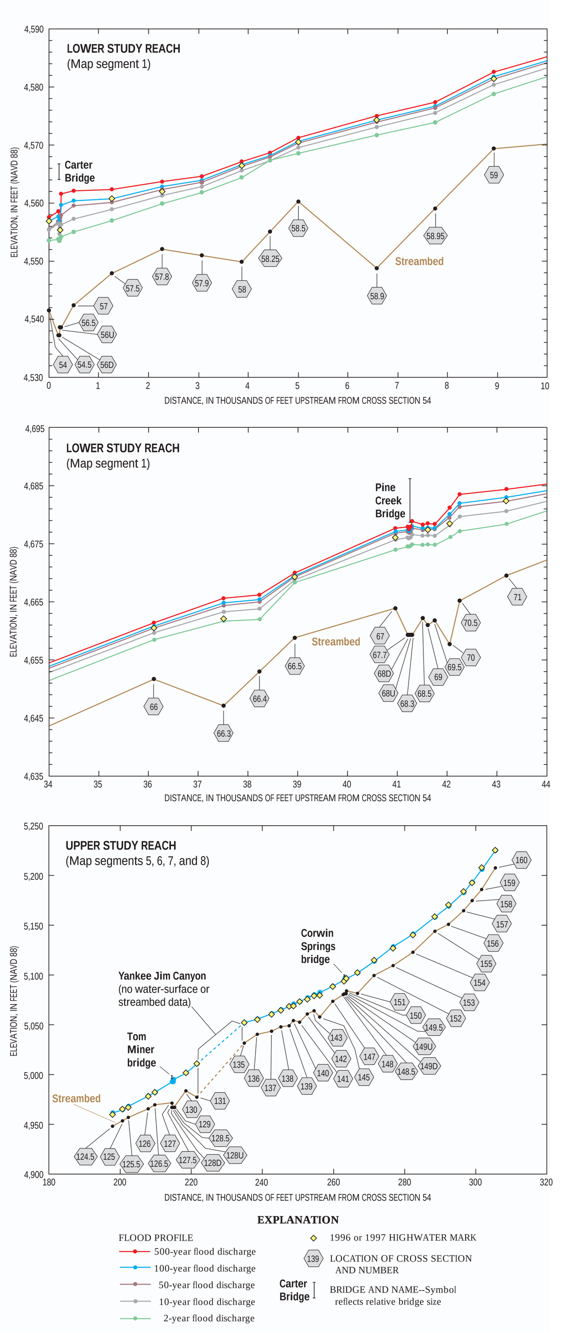


Figure 5. Streambed and flood profiles for selected reaches of the upper Yellowstone River, Montana.

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