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Abstract

The Yampa River in northwestern Colorado is the largest, relatively unregulated river system in the upper Colorado River Basin. Water from the Yampa River Basin continues to be sought for a number of municipal, industrial, and energy uses. It is anticipated that future water development within the Yampa River Basin above the amount of water development identified under the Upper Colorado River Endangered Fish Recovery Implementation Program and the Programmatic Biological Opinion may require additional analysis in order to understand the effects on habitat and river function. Water development in the Yampa River Basin could alter the streamflow regime and, consequently, could lead to changes in the transport and storage of sediment in the Yampa River at Deerlodge Park. These changes could affect the physical form of the reach and may impact aquatic and riparian habitat in and downstream from Deerlodge Park.

The U.S. Geological Survey, in cooperation with the Colorado Water Conservation Board, began a study in 2011 to characterize the current hydrodynamic and sediment-transport conditions for a 2-kilometer reach of the Yampa River in Deerlodge Park. Characterization of channel conditions in the Deerlodge Park reach was completed through topographic surveying, grain-size analysis of streambed sediment, and characterization of streamflow properties. This characterization provides (1) a basis for comparisons of current stream functions (channel geometry, sediment transport, and stream hydraulics) to future conditions and (2) a dataset that can be used to assess channel response to streamflow alteration scenarios indicated from computer modeling of streamflow and sediment-transport conditions.

Introduction

The Yampa River in northwestern Colorado is the largest, relatively unregulated river system in the upper Colorado River Basin. Water from the Yampa River Basin continues to be sought for a number of municipal, industrial, and energy uses. It is anticipated that future water development within the Yampa River Basin above the amount of water development identified under the Upper Colorado River Endangered Fish Recovery Implementation Program and the Programmatic Biological Opinion may require additional analysis in order to understand the effects on habitat and river function. Water development in the Yampa River Basin could alter the streamflow regime and, consequently, could lead to changes in the transport and storage of suspended and bedload sediments (Elliott and others, 1984; Elliott and Anders, 2005). These changes could affect the physical form of the reach and may impact aquatic and riparian habitat in and downstream from Deerlodge Park, much like the changes observed in the Green River following construction and operation of Flaming Gorge Reservoir (Andrews, 1986). Knowledge of existing hydrodynamic and sediment-transport conditions in river reaches that support specific life-stages of endangered native fish, such as those that occur downstream from Deerlodge Park in the lower Yampa and Green Rivers, is critical to managing the effects of altered streamflow on endangered fish (Williams and others, 2012).

Purpose and Scope

The U.S. Geological Survey (USGS), in cooperation with the Colorado Water Conservation Board, began a study in 2011 to characterize the current hydrodynamic and sediment-transport conditions for a 2-kilometer (km) reach of the Yampa River in Deerlodge Park. Characterization of channel conditions in the Deerlodge Park reach was completed through topographic surveying, grain-size analysis of streambed sediment, and characterization of stream-flow properties. This characterization provides (1) a basis for comparisons of current stream functions (channel geometry, sediment transport, and stream hydraulics) to future conditions and (2) a dataset that can be used to assess channel response to streamflow alteration scenarios indicated from computer modeling of streamflow and sediment-transport conditions. Channel response assessments can provide resource managers and planners with information to determine how streamflow alterations can be managed to maintain fluvial processes in the Yampa River while minimizing the effect on the sediment budget and fluvial geomorphology in Deerlodge Park.

This report presents the results of topographic surveying of a reach of the Yampa River in Dinosaur National Monument. The report contains a description of the data collection and analytical methods used to survey the reach and to develop datasets for water management. A bathymetric map of the reach is presented with plots of hydro-dynamic conditions such as water-surface elevation to streamflow rating curves, streambed grain-size information, and velocity and stream depth during the time of the survey.

Description of Study Area

Deerlodge Park is located in northwest Colorado along the eastern boundary of Dinosaur National Monument in western Moffat County, and it is an important source of sediment within Dinosaur National Monument as well as endangered razorback sucker spawning habitat downstream from the Yampa River confluence with the Green River (Mark Wondzell, National Park Service hydrologist, oral commun., January 6, 2011) (fig. 1). Deerlodge Park is a broad, alluvial valley. The reach is highly dynamic, and the stream channel is often braided and composed of multiple intertwining channels that change position season-to-season and year-to-year. At the downstream boundary of the study reach is a USGS streamflow-gaging station, 09260050–Yampa River, at Deerlodge Park, Colorado. The drainage area at the station is 20,541 km^2 (U.S. Geological Survey, 2011).

Hydrodynamic and Sediment Characterization

Data collection began in Deerlodge Park on April 21, 2011, with the deployment of water-surface elevation data loggers (Onset Hobo Water Level Data Logger-U20-001-01) at four rating locations along the riverbanks (rating locations 1–4, fig. 1) and a fifth location that is a U.S. Geological Survey streamflow-gaging station (rating location 5, fig. 1). One additional water-level data logger was deployed June 21, 2011, along the east riverbank at rating location 2a (fig. 1). Data collection continued for these water-level data loggers until base-flow conditions in August. During this period, repositioning of the sensors occurred, as necessary, to maintain positions within the water column. Postprocessing of the elevation data was done to maintain a consistent vertical datum over the entire deployment period. At some locations this involved horizontal as well as vertical shifts in positioning, as shown in figure 1 where data loggers at the rating locations occupy multiple positions.

Standard techniques, as described in Rantz and others (1982), were used to relate water-surface elevations to streamflow at the five rating locations along the longitudinal flow path of the reach (fig. 2). Rating locations 1–4 had the deployed data loggers, and rating location 5 was at the USGS streamflow-gaging station. Seasonal shifts in the relation are apparent within the reach following peak snowmelt-runoff conditions and are likely the result of topographic changes of the channel. These changes are most evident in rating locations 1–3 and show patterns where the water-surface elevations are lower on the rising limb than the recession limb of the snowmelt-runoff period for the same streamflows. The progression of water-surface elevations through time at each location produces a counter-clockwise loop beginning at lower water-surface elevations at lower streamflows climbing toward peak-streamflow conditions and then a positive shift in water-surface elevations along the recession limb returning to lower streamflows and water-surface elevations. These patterns of water-surface elevations are typical of scour and fill cycles in rivers and speak to the dynamic nature of these river systems from season to season.

Velocity data were collected on June 22, 2011, along cross sections A–E (fig. 1) using a boat-mounted Teledyne RD Instruments Rio Grande Acoustic Doppler Current Profiler (ADCP, 1,200 kilohertz (kHz)) and WinRiver II software (Teledyne RD Instruments, 2007). Multiple traverses along each cross section were combined using the USGS Velocity Mapping Toolbox (VMT) software (Jackson, 2013) to produce composite velocity profiles for a streamflow of 484 cubic meters per second (m^3/s) (fig. 3).

Streambed-sediment grain-size sites were sampled during the surveying effort (June 20–23, 2011) using a dredge sampler following standard collection techniques (Edwards and Glysson, 1999). Grain-size analysis was completed using dry-sieving techniques at the USGS Geomorphology and Sediment Transport Laboratory in Golden, Colorado, with cumulative-percent finer by mass presented in figure 4.

Topographical Surveying and Postprocessing

Terrestrial and bathymetric surveying efforts were performed June 20–23, 2011, while streamflow conditions within the study reach were near bankfull corresponding to a range of 420–520 m^3/s (U.S. Geological Survey, 2011). Overbank flooding precluded completion of surveying within some areas on the flood plain but facilitated data acquisition from the boat-mounted equipment in the majority of the channel. Streamflow conditions present the week of June 20 also limited some bathymetric mapping in a shallow subreach along the right bank near the upstream boundary (indicated by hachuring in fig. 1B).

The USGS performed a topographical survey of Deerlodge Park on June 20–23, 2011, using a man-operated boat-mounted multibeam echo sounder integrated with a global positioning system (GPS) and a terrestrial real-time kinematic (RTK) GPS (fig. 1D). The multibeam echo sounder collected data at depths of approximately 1 meter (m) and greater. Topographic surveying was performed on foot with the RTK GPS in shallow areas near the shore not navigable by boat as well as in exposed fluvial surfaces such as alluvial bars and the flood plain.

Bathymetric data from the multibeam echo sounder were collected June 21–22, 2011, using a Teledyne Odom Hydrographic ES3PT–M integrated multibeam echo sounder and motion sensor (Teledyne Odom Hydrographic, Inc., 2011) equipped with a Trimble SPS461 GPS receiver using procedures described in Wilson and Richards (2006). The vertical and horizontal precision of the multibeam echo sounder GPS, as rated by the manufacturer, are ±0.020 m and ±0.010 m, respectively (Trimble Navigation Limited, 2009a). The multibeam echo sounder has a swath width of 120 degrees capable of collecting data to depths of 60 m. The echo sounder collects 240 data points at a sample frequency of 12 hertz (Hz); however, this varies with depth. The GPS generates position data at a rate of 5 Hz and navigational data at a rate of 1 Hz. A Teledyne Odom Hydrographic Real Time Appliance (RTA) was used for data synchronization of all aforementioned instruments resulting in a data string recorded at 1 Hz. The bathymetry data from the multibeam echo sounder were compiled and stored using the hydrographic survey software, HYPACK 2010 (HYPACK, Inc., 2010).

The multibeam echo sounder emits a pulse at a frequency of 240 kHz, which is reflected off the streambed and detected by the receiver. The velocity of the pulse is affected by the water temperature and salinity. For the Yampa River, the effect of salinity was assumed to be negligible (U.S. Army Corps of Engineers, 2002). Velocity profiles of the river were recorded using a Teledyne Odom Hydrographic Digibar-Pro velocity meter throughout the study and were used to correct the data during postprocessing (Teledyne Odom Hydrographic, Inc., 2001). Calibration points were obtained with the RTK GPS while the multibeam echo sounder was simultaneously recording for confirmation of the results.

The exposed stream channel and flood plain were surveyed using the RTK GPS. This survey was performed June 20–23, 2011, using Trimble R8 GNSS RTK GPS receivers, a Trimble HPB450 radio modem, and a Trimble TSC2 controller. The vertical and horizontal precision of the RTK GPS, as rated by the manufacturer, are ±0.020 m and ±0.010 m, respectively (Trimble Navigation Limited, 2009b). The RTK GPS setup consisted of a base station, which included a receiver and radio, and a rover, which consisted of a receiver and controller. The base station was located at a fixed position on the west end of the reach along a rock outcrop. It receives information from satellites and transmits data to the rover's receiver via the radio. The base station also continuously records its position. The rover communicates with the base station and is used to collect and record individual data points throughout the study area based on the position of the base station. The water-surface elevation was determined from the RTK GPS survey-data points on June 21–22, 2011.

All survey data were collected with a common coordinate system, geoid, ellipsoid, and datum. The coordinate system used was Universal Transverse Mercator (UTM), zone 12 north; the horizontal datum was North American Datum 1983 (NAD 83), and the vertical datum was North American Vertical Datum 1988 (NAVD 88), Geoid 03, ellipsoid World Geodetic System 1984 (WGS 84). Data from the base station, collected throughout the study, were submitted to the National Geodetic Survey's Online Positioning User Service (OPUS) Web site for processing (http://www.ngs.noaa.gov/OPUS/, accessed July 21, 2011). All survey data were recomputed to reflect the OPUS solution correction.

The motion sensor in the multibeam sonar records the instrument's pitch, roll, heave, and yaw. Pitch is the alternating rise and fall of the boat's bow and stern; roll is rotation of the boat about its main horizontal axis; heave is the vertical rise and fall of the entire vessel; and yaw is the rotation of the sonar from the boat's main direction of motion. The ambient offsets of pitch, roll, and yaw were corrected using a calibration test, otherwise known as a patch test, because the instrument was not installed exactly vertical and in-line with the boat's main axis (HYPACK, Inc., 2011). From the patch test, the pitch offset angle was determined to be 10 degrees and the roll 0.40 degree. The yaw offset angle was not corrected, because no consistent value could be determined from the patch test. During data collection, instrument malfunction resulted in horizontal positions and corresponding depths instead of streambed elevations. This error required correction of elevation from corresponding water-surface elevations measured along the channel banks from the terrestrial survey (edge of water, fig. 1).

The postprocessing of the multibeam echo sounder bathymetry data was performed using HYPACK 2011 (HYPACK, Inc., 2011). All the data were filtered using the automated search and filter tool to remove spikes and inconsistencies. Manual filtering was then performed on the multibeam echo sounder bathymetry data to edit any spikes or inconsistencies that the automated filter overlooked. Once all the data were filtered, the data were separated by day of observation. The multibeam echo sounder bathymetry data were interpolated onto a 0.5- by 0.5-m grid by computing the average depth in each cell and positioning the mean at the cell center.

The RTK GPS dataset was filtered manually to remove errant or poor data. The water-surface elevations along the reach were then assembled from the edited dataset and extrapolated along cross sections that were oriented perpendicular to the primary flow direction along the reach. This produced a grid of water-surface elevations along the study reach for each day of the survey corresponding to streamflows between 487 m^3/s on June 21 and 445 m^3/s on June 22. The multibeam echo sounder bathymetry data, which initially used the water-surface elevation as a datum, were converted to elevation (NAVD 88) using these water-surface elevations. The result was one multibeam echo sounder dataset with a common horizontal and vertical datum (NAD 83 and NAVD 88) that could be merged with the RTK GPS survey points.

Available Light Distance and Ranging (LiDAR) data from Utah State University provided detailed elevation and positions information of the flood plain and the vegetated islands. These data were collected September 14, 20, and 21, 2011, throughout the reach for areas above water. The LiDAR data vertical datum was adjusted down by 0.180 m to account for observed differences in elevations between the LiDAR and RTK GPS elevations at stable locations within the reach producing a consistent vertical datum between all datasets. LiDAR data were used in areas from the channel margin to an elevation of 1,720 m (NAVD 88) and in the active channel along exposed channel bars to increase the resolution of these features (fig. 1*D*).

The survey datasets (multibeam echo sounder, RTK GPS, and LiDAR) were imported into Environmental Systems Research Institute (ESRI) ArcMap 9.3.1 (Environmental Systems Research Institute, Inc., 2010) so that a continuous elevations dataset could be generated using a triangulated irregular network (TIN) from all datasets. The TIN was then converted to a horizontal grid using the Spatial Analyst tool in ArcMap to produce the final topographic surface (fig. 1).

Summary

The Yampa River in northwestern Colorado is the largest, relatively unregulated river system in the upper Colorado River Basin. Water from the Yampa River Basin continues to be sought for a number of municipal, industrial, and energy uses. It is anticipated that future water development within the Yampa River Basin above the amount of water development covered under the Upper Colorado River Endangered Fish Recovery Implementation Program and the Programmatic Biological Opinion may require additional analysis in order to understand the effects on habitat and river function. Water development in the Yampa River Basin could alter the streamflow regime and, consequently, could lead to changes in the transport and storage of sediment in the Yampa River at Deerlodge Park. These changes could affect the physical form of the reach and may impact aquatic and riparian habitat in and downstream from Deerlodge Park.

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This report presents the results of topographic surveying of a reach of the Yampa River in Dinosaur National Monument. The report contains a description of the data collection and analytical methods used to survey the reach and to develop datasets for water management. A bathymetric map of the reach is presented with plots of hydrodynamic conditions such as the stage-discharge relations, streambed grain-size information, and velocity and stream depth during the time of the survey. Data collection began in Deerlodge Park on April 21, 2011, with characterization of water-surface elevations at multiple locations within the reach. Additional channel characterization occurred June 20–23, 2011, including (1) an assessment of velocity profiles along five cross sections for a streamflow of 484 cubic meters per second, (2) collection of sediment grain-size samples, and (3) topographic surveying of exposed stream channel and flood plain.

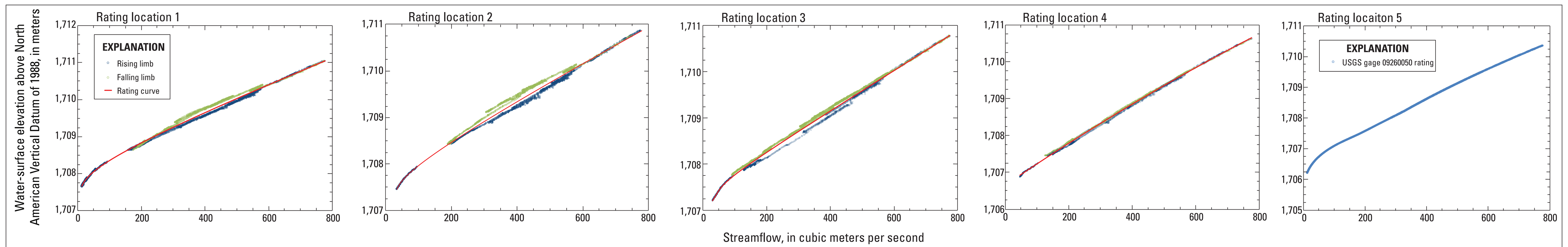


Figure 2. Comparison of water-surface elevations to streamflow at five rating locations (rating locations 1–5 shown on fig. 1*B*) on the Yampa River in Deerlodge Park, April 21 through August 31, 2011.

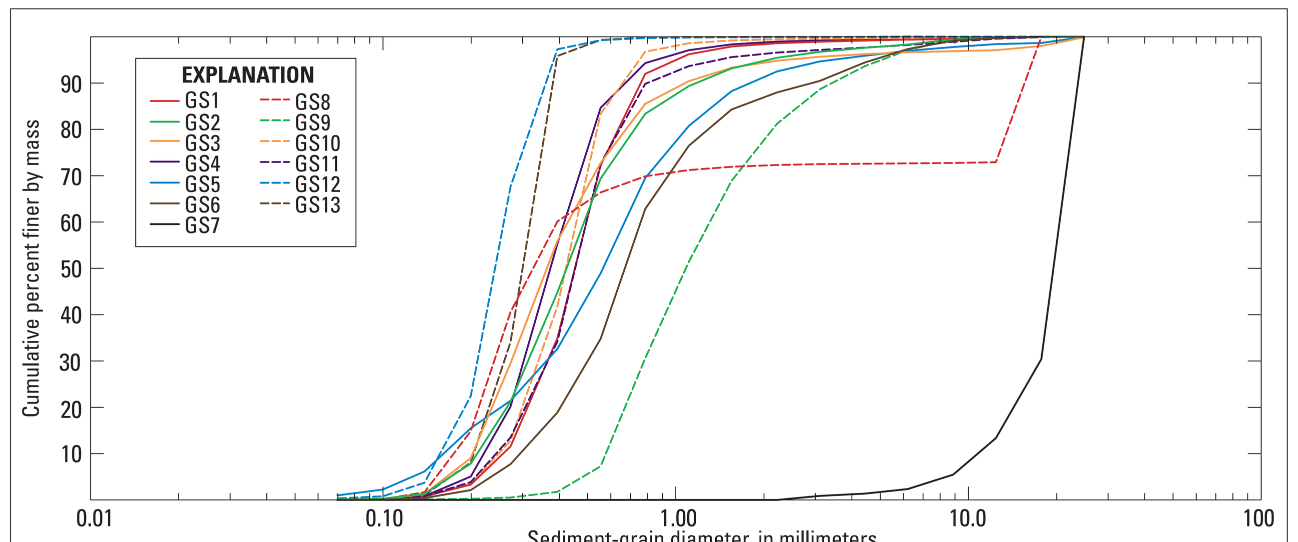
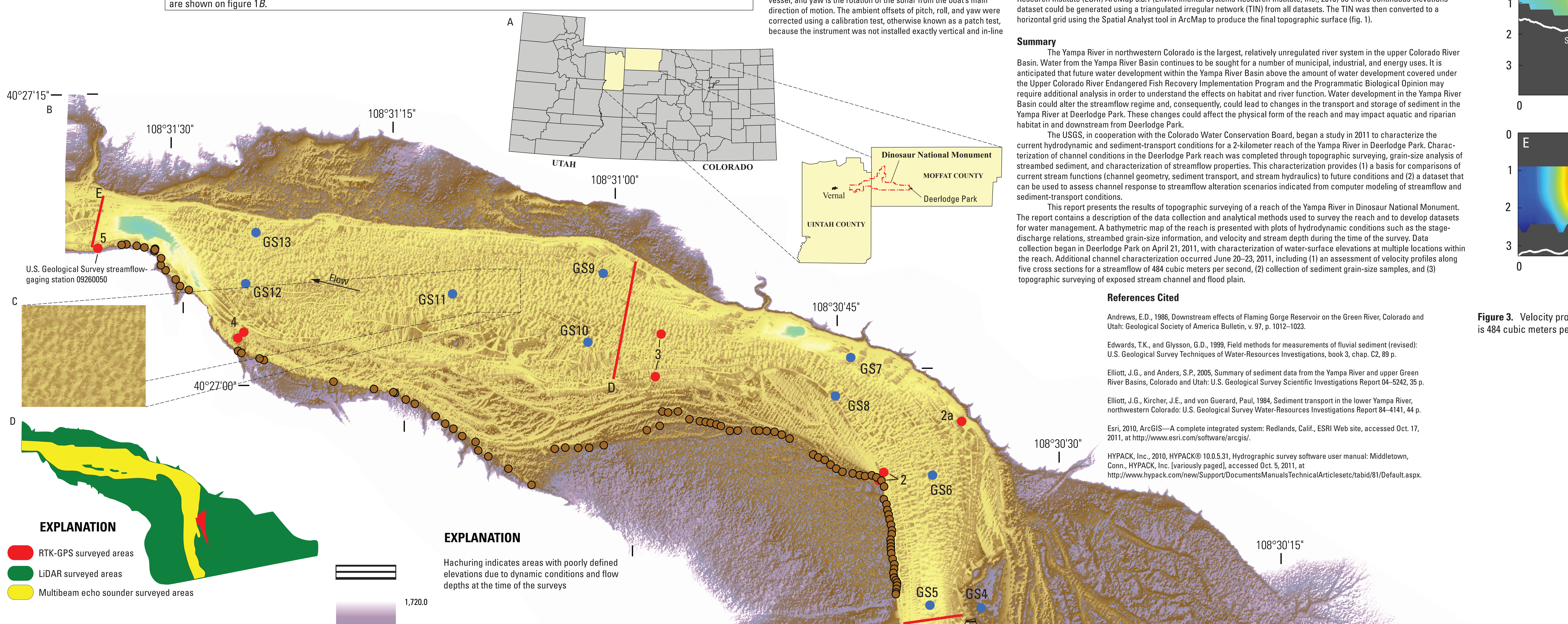


Figure 4. Sediment-grain-diameter plots for 13 locations on the Yampa River in Deerlodge Park, June 20–23, 2011. Sample sites GS1–GS13 are shown on figure 1*B*.



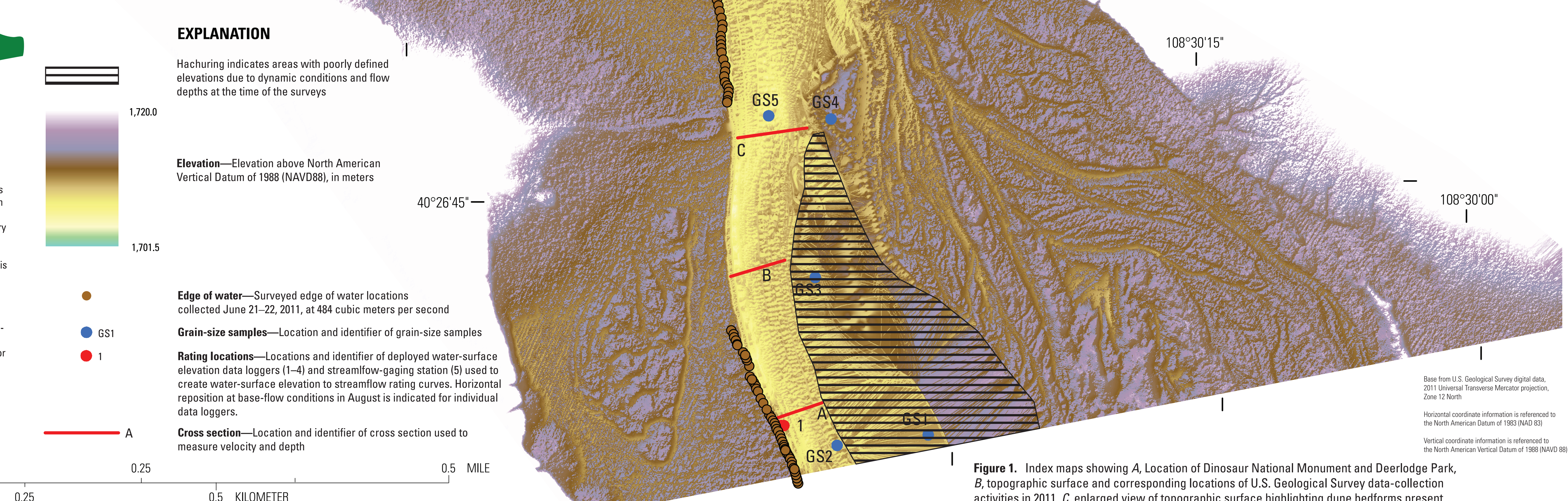


Figure 1. Index maps showing *A*, Location of Dinosaur National Monument and Deerlodge Park, *B*, topographic surface and corresponding locations of U.S. Geological Survey data-collection activities in 2011, *C*, enlarged view of topographic surface highlighting dune bedforms present along the streambed June 20–23, 2011, and *D*, graphic showing data-collection techniques by area.

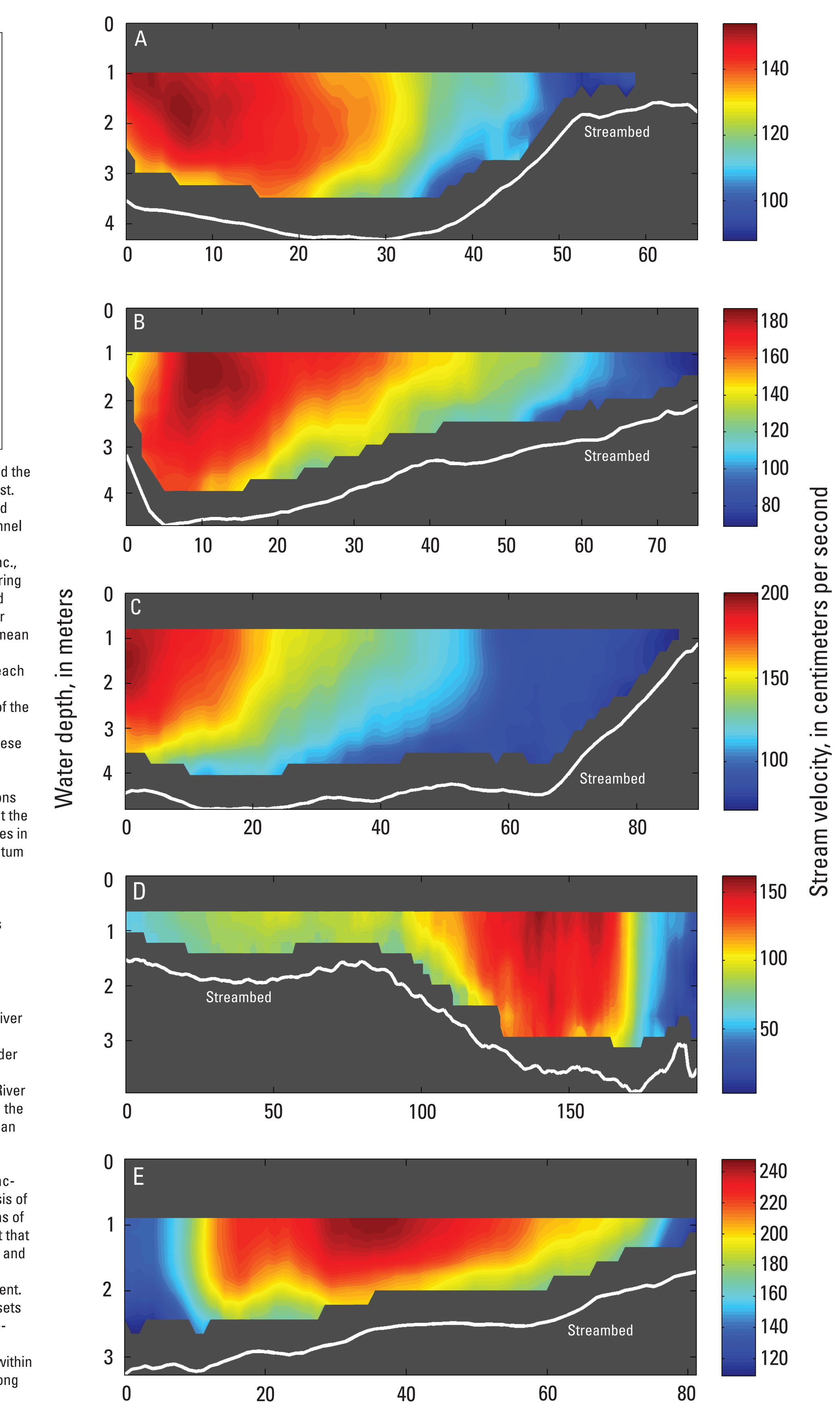


Figure 3. Velocity profiles for five cross-section locations on the Yampa River in Deerlodge Park. Streamflow is 484 cubic meters per second, June 22, 2011. Locations A–E shown on figure 1*B*.

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Characterization of Hydrodynamic and Sediment Conditions in the Lower Yampa River at Deerlodge Park, East Entrance to Dinosaur National Monument, Northwest Colorado, 2011

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2013

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