Provisional data, subject to change.

Assessing geomorphic change for 454 river km of the Colorado River in Grand Canyon, AZ via continuous and high-resolution water surface and bed profiles

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Photo: Geoff Gourley

USGS science for a changing world

Introduction

- The Colorado River in the Grand Canyon is a bedrock-confined river with morphology determined by debris fans from tributaries, creating a pool-drop sequence.
- Operation of Glen Canyon Dam (GCD), a large hydropower dam completed in 1963, increases baseflow, eliminates annual floods, and traps all upstream sediment supply.
- The Grand Canyon is difficult to access, and large rapids and steep canyon walls make surveying precise locations difficult.
- Changes in morphology since 1963 are well-documented (Hazel et al., 2006). However, few measurements were made before 1963, making comparisons to pre-GCD conditions difficult.
- **To assess changes of the water surface and riverbed due to Glen Canyon Dam closure and hydropower operations, we collected complete centerline profiles for 282 river miles (RMs) at a steady flow of 227 m³/s (8,000 cfs) from May 29, 2021 to June 5, 2021 and compared them to previous surveys, including pre-GCD measurements.**

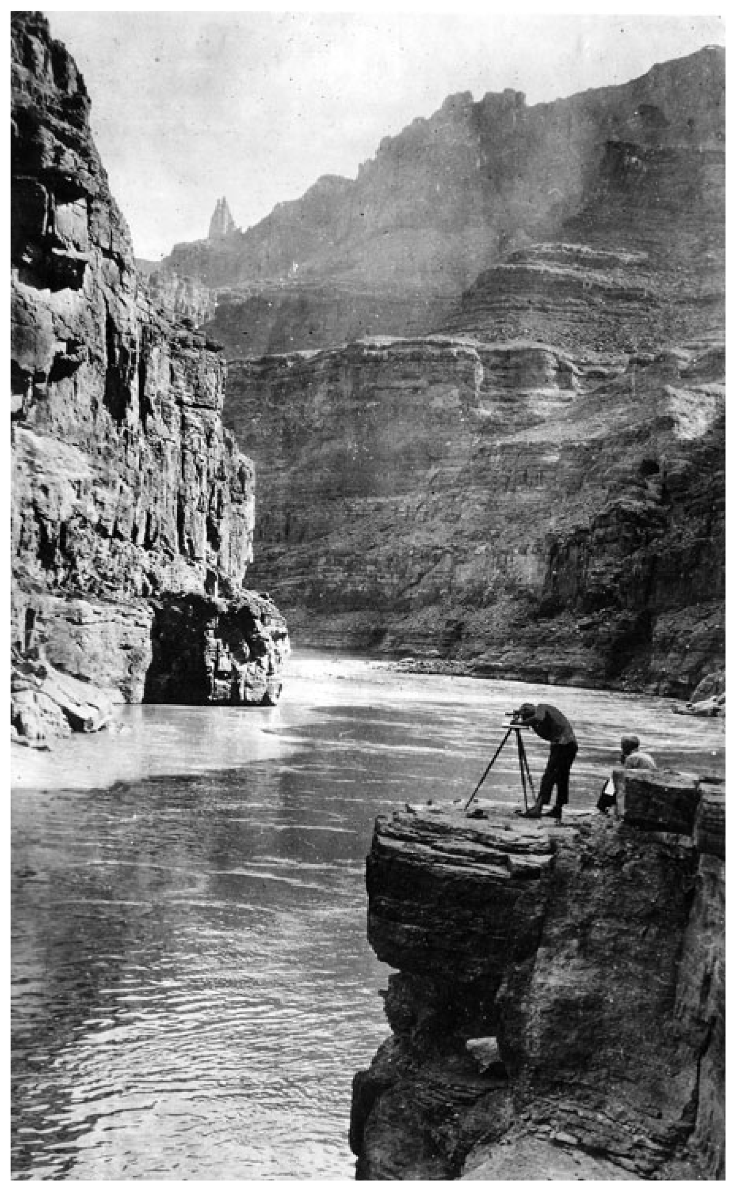
The 2021 Survey and Previous Surveys

Previous Surveys

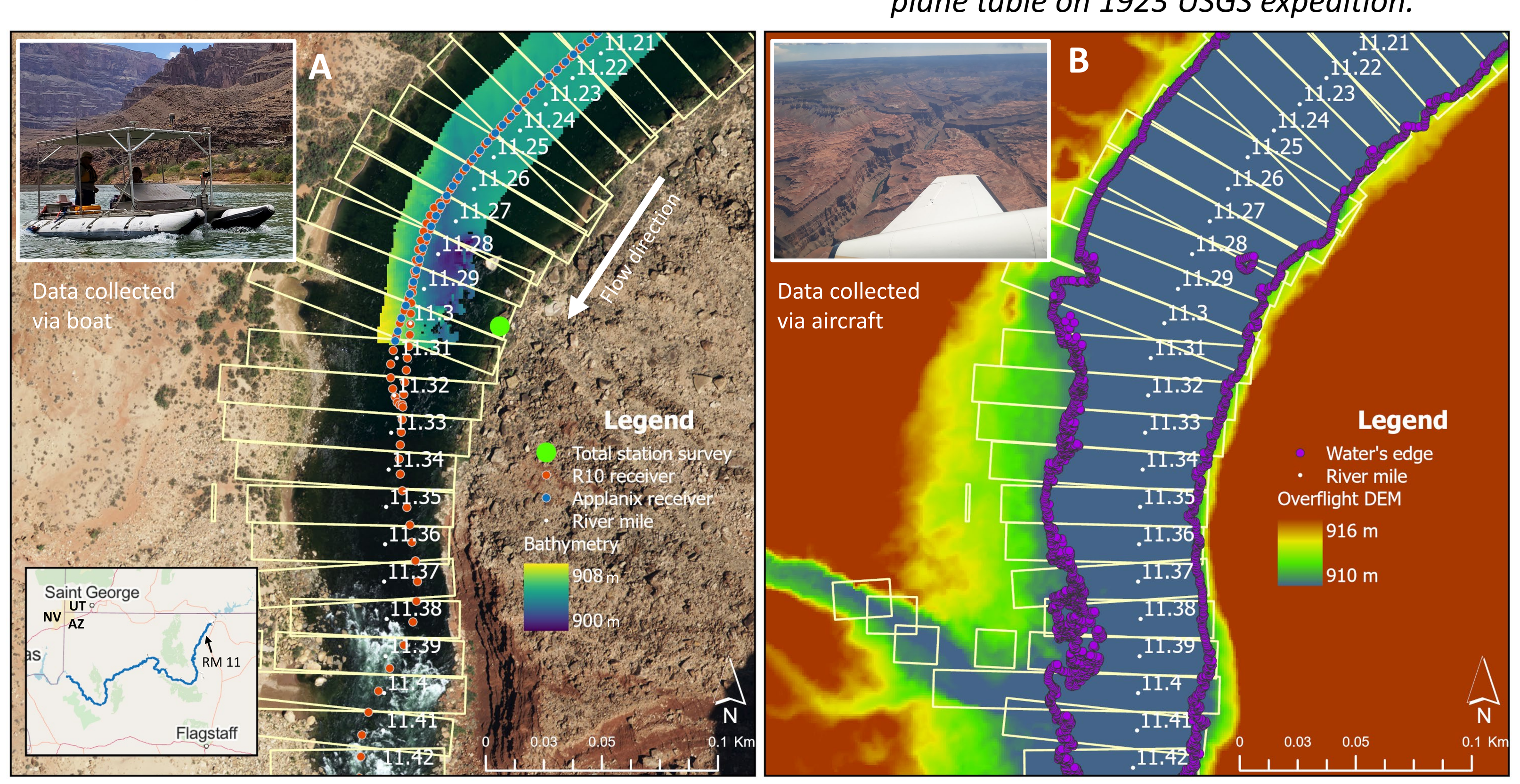
- Previous water surface profiles:
  - 2000: (at 227 m³/s (8,000 cfs), collected with GNSS of aircraft and LiDAR, ± 0.5 m) (Magirl et al. 2005)
  - 1923: (at unregulated discharge, collected with stadia rod and plane table, ± 1.4 m) (Birdseye and Burchard, 1924)
- Previous bed surveys collected using multibeam sonar in pools since 2009 in ~30 to ~70 RM segments at fluctuating flow.
- Bed cross-section profiles collected for planned Marble Canyon dam sites in 1951.

This Survey

- Water surface elevation collected simultaneously using two watercraft GNSS receivers.
  - GNSS elevations validated with total station water surface elevations collected via canyon-wide control network.
- Bed profile collected using multibeam sonar along centerline for the entire river excluding rapids.



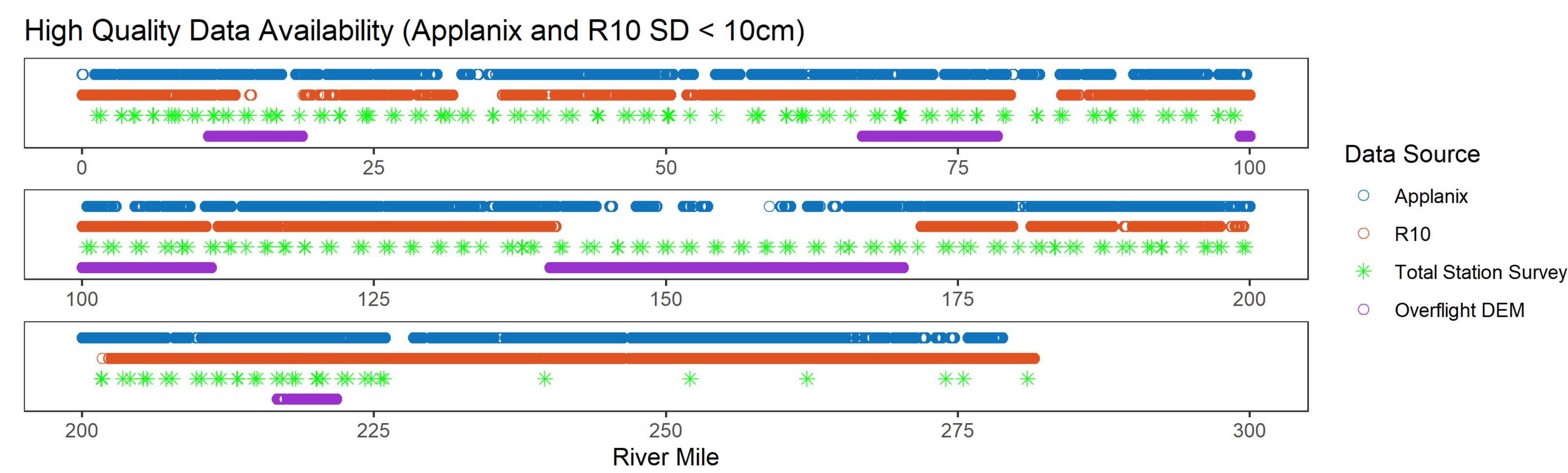
Birdseye and Burchard surveying with plane table on 1923 USGS expedition.



Data collected in this study near Soap Creek Canyon and Rapid via boat (A) and aircraft (B). River miles indicate distance downstream from Lees Ferry. Data collected from boat includes locations and heights from Applanix and R10 GNSS receivers and centerline bathymetry in pools. Data collected from aircraft includes a Digital Elevation Model (DEM) and points along the water's edge from image classification.

Creating the 2021 Water Surface Elevation Profile

Available data

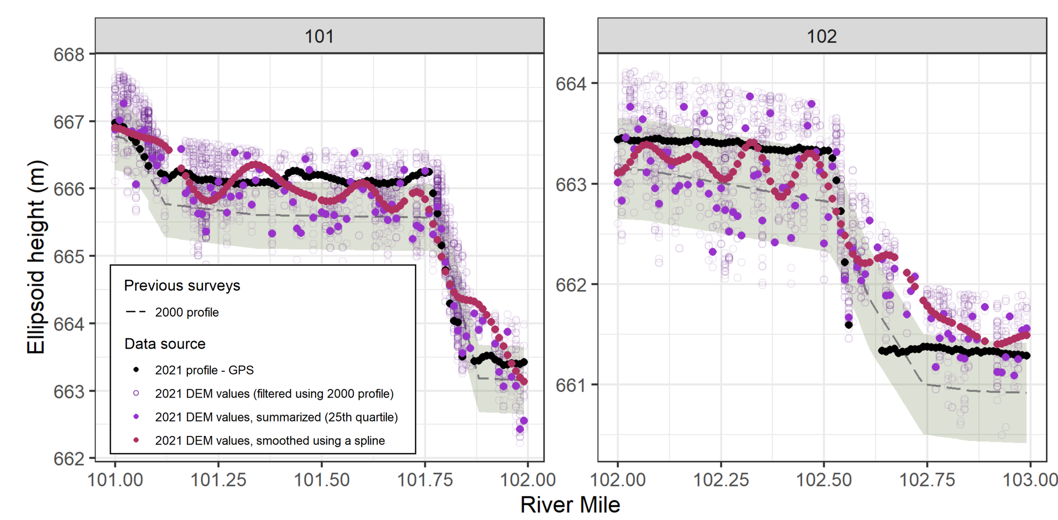


Available, low-error data sources for 282 RMs. Water's edge elevations from overflight DEM are currently being processed and will soon be available for the entire profile.

- GNSS data are available for 246.78 of 282 RMs with vertical errors ≤ 10 cm and for an additional 12.20 RM ≤ 30 cm. GNSS data are validated by total station elevations referenced to a canyon-wide control network, with a median height difference of 3.3 cm (Applanix, n = 272 comparisons) and 1.1 cm (R10, n = 299 comparisons).
- Outages are due to obstruction of the sky by canyon walls, especially in the Muav Limestone Gorge (RMs 140 to 160), which is approximately east-west oriented.

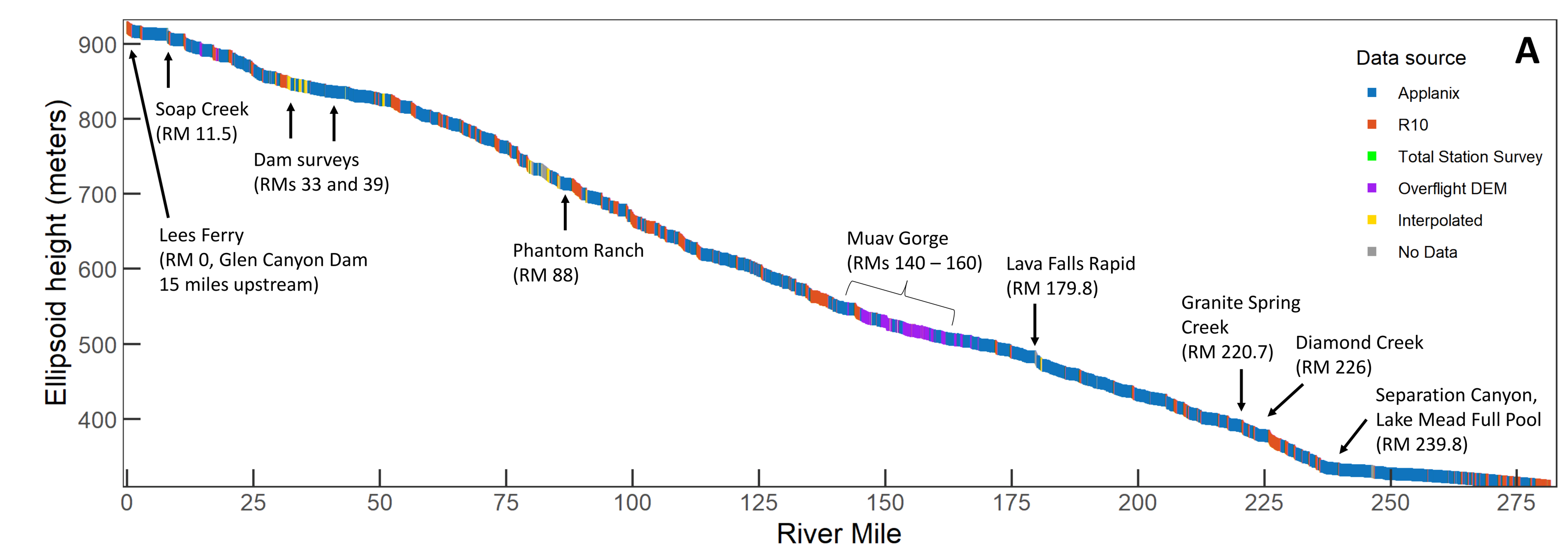
In progress: filling in gaps in profile with overflight raster data

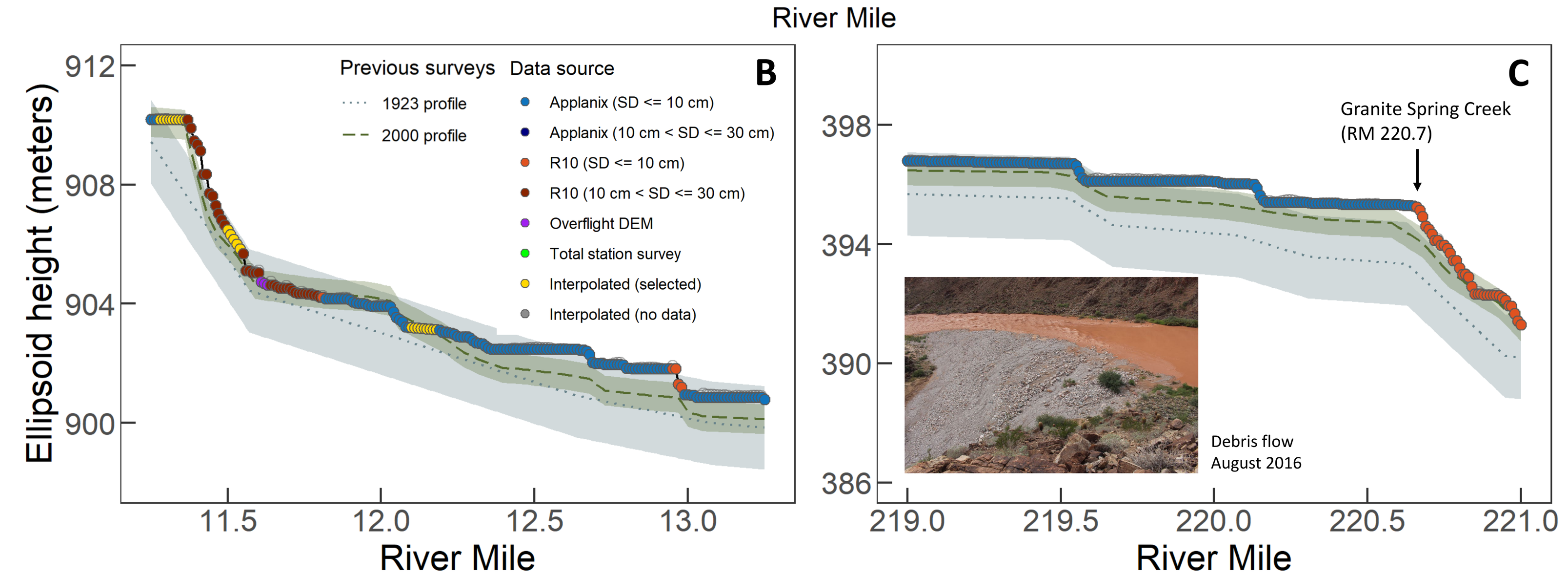
- The remaining 23.13 RM with poor or no data will be filled in with water's edge elevations from a DEM collected via aircraft, which contains noise.
- How can we smooth the water's edge elevation profile while preserving pool-drop morphology?



Filtering, summarizing, and smoothing DEM water's edge elevations. On average, there are 81 water's edge points per hundredth mile.

Assembling the profile and comparing to previous profiles





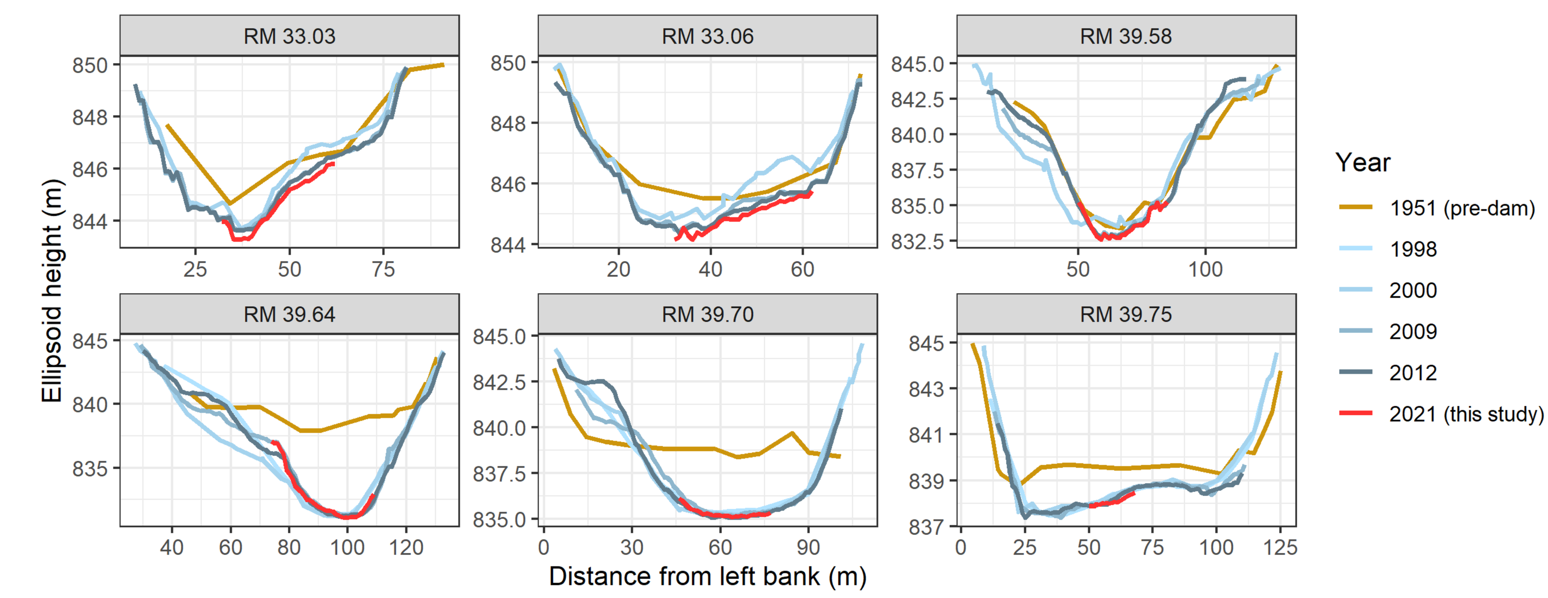
Completed water surface profile (A), including segments RMs 11.25 to 13.25 (B) and 219.0 to 221.0 (C). Previous profiles and corresponding margins of error shown in green (2000) and grey (1923). Elevations are held constant in cases where the river goes "uphill", original elevations shown as grey circles. 2021 profile shows an increase in elevation at RM 220.7 from a debris flow at Granite Springs in August 2016.

Changes in the Water Surface Profile

- We compared changes in the elevations of the water surface that exceed margins of error for each survey. The margin of error is greatest for the 1923 survey.
  - From 2000 to 2021, we compared water surface elevations for 218.7 RMs. Elevations increased at 15.51 RMs (7.1%) and decreased at 9.57 RMs (4.4%).
  - From 1923 to 2021, we compared water surface elevations for 221.9 RMs. Elevations increased at 15.78 RMs (7.1%) and decreased at 3.18 RMs (1.4%).
- From 1923 to 2000, "comparison of the two water surface profiles showed enhanced pool-and-rapid morphology." (Magirl et al. 2005)
  - In 1923, 50% of drop occurred over 9% of distance (RMs 0 to 150, Leopold, 1969)
  - In 2000, 66% of drop occurred over 9% of distance (RMs 0 to 226, Magirl et al., 2005)
  - In 2021, this is currently 70.6% (RMs 0 to 226). This value will increase with more data and fewer areas completed with linear interpolation.

Changes in the Bed Profile

- Previous, complete bathymetry surveys are conducted over 18 to 25 days and cover the full extent of all pools in a shorter segment of the river. This survey was conducted over 8 days and only the centerline of the river was surveyed.
- More analyses specific to this study are needed to quantify recent bed changes and the use of the centerline swath versus full pool surveys.
- Comparing pre- and post-GCD bed surveys supports previous findings and shows evacuation of fine sediment from pools in the Grand Canyon post-GCD.



Historical cross-sections at RMs 33 and 39. Cross-sections from 1951 showed in gold surveyed for potential dam locations. Cross-sections from previous bed surveys of the entire channel shown in blue. Cross-sections from this survey shown in red show the extent of the centerline swath in this study.

Conclusions

- We find that the elevation of the water surface increased in more areas than it decreased, often at rapids or riffles, indicating an **addition of coarse sediment** on debris fans from side canyons.
- We also find that, bed elevations in pools between rapids have decreased in some locations relative to pre-GCD conditions, indicating an **evacuation of fine sediment**.
- **Under Glen Canyon Dam operations, the frequency of high flows capable of transporting the coarse sediment added to the mainstem by tributaries has decreased (Pizzuto et al., 1999), while the frequency of moderate flows capable of transporting fine sediment has increased (Topping et al., 2021).**
- The final profiles and accompanying analyses will be used for sediment and flow modeling to inform Glen Canyon Dam management.

References and Acknowledgments

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This study was conducted in the Grand Canyon, a place of origin and/or importance to many tribes in the Southwest, including the Havasupai, Hualapai, Hopi, Navajo, Zuni, Kaibab Band of Paiutes, Las Vegas Paiutes, Moapa Band of Paiutes, Paiute Indian Tribe of Utah, the San Juan Southern Paiutes, and the Yavapai-Apache.

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