U.S. Department of the Interior
U.S. Geological Survey

Geomorphic background for Glen Canyon Slough

Glen Canyon Dam Adaptive Management Program
Technical Working Group Meeting
October 29, 2024

Paul Grams
U.S. Geological Survey
Southwest Biological Science Center
Grand Canyon Monitoring and Research Center

The rate and pattern of bed incision and bank adjustment on the Colorado River in Glen Canyon downstream from Glen Canyon Dam, 1956–2000

Paul E. Grams[†]
John C. Schmidt
Department of Watershed Sciences, Utah State University, Logan, Utah 84322-5210, USA

David J. Topping
Geomorphology and Sediment Transport Laboratory, U.S. Geological Survey, 4620 Technology Drive, Suite 400, Golden, Colorado 80403, USA

ABSTRACT

Closure of Glen Canyon Dam in 1963 transformed the Colorado River by reducing the magnitude and duration of spring floods, increasing the magnitude of base flows, and trapping fine sediment delivered from the upper watershed. These changes caused the channel downstream in Glen Canyon to incise, armor, and narrow. This study synthesizes over 45 yr of channel-change measurements and demonstrates that the rate and style of channel adjustment are directly related to both natural processes associated with sediment deficit and human decisions about dam operations. Although bed lowering in lower Glen Canyon began when the first cofferdam was installed in 1959, most incision occurred in 1965 in conjunction with 14 pulsed high flows that scoured an average of 2.6 m of sediment from the center of the channel. The average grain size of bed material has increased from 0.25 mm in 1956 to over 20 mm in 1999. The magnitude of incision at riffles decreases with distance downstream from the dam, while the magnitude of sediment evacuation from pools is spatially variable and extends farther downstream. Analysis of bed-material mobility indicates that the increase in bed-material grain size and reduction in reach-average gradient are consistent with the transformation of an adjustable-bed alluvial river to a channel with a stable bed that is rarely mobilized.

Decreased magnitude of peak discharges in the post-dam regime coupled with channel incision and the associated downward shifts of stage-discharge relations have caused sandbar and terrace erosion and the transformation of previously active sandbars and gravel bars to abandoned deposits that are no longer inundated. Erosion has been concentrated in a few pre-dam terraces that eroded rapidly for brief periods and have since stabilized. The abundance of abandoned deposits decreases downstream in conjunction with decreasing magnitude of shift in the stage-discharge relations. In the downstream part of the study area where riffles controlling channel elevation have not incised, channel narrowing has resulted from decreased magnitude of peak discharges and minor post-dam deposition. These physical changes to the aquatic and riparian systems have supported the establishment and success of an artifact ecosystem dominated by non-native species.

Models for the channel response downstream from large dams typically consider factors such as the degree of sediment deficit, the pre-dam surface and subsurface grain size, and the magnitude of post-dam average flows. These results suggest that it is also necessary to consider (1) the possibility of variable responses among different channel elements and (2) the potential importance of exceptional flows resulting from management decisions.

Keywords: channel adjustment, erosion, dams, geomorphology, alluvial deposits.

INTRODUCTION

Large dams, which are defined as those that impound more than 10^7 m^3 of water (Graf, 2005), cause changes to downstream flow and sediment supply that lead to changes in downstream channel form (e.g., Lawson, 1925; Stevens, 1938; Stanley, 1951; Borland and Miller, 1960; Petts, 1979; Lagasse, 1981; Galay, 1983; Williams and Wolman, 1984; Brandt, 2000a, 2000b; Simon et al., 2002; Hazel et al., 2006). Because large dams typically trap all sediment delivered from the upstream watershed, supply to the channel segment immediately downstream is virtually eliminated. The sediment mass balance of the downstream channel, which may have been in equilibrium, is, therefore, shifted into deficit. The magnitude of deficit depends on the change in sediment supply relative to the change in transport capacity. Large deficits extending over long river segments exist where transport capacity is little affected by impoundment and tributary sediment supply to the downstream channel is negligible (Schmidt et al., 1995). Small deficits or surplus conditions result where tributary supply is large and post-dam flow regulation reduces the downstream transport capacity (Andrews, 1986; Grams and Schmidt, 2002; Grant et al., 2003).

When the mass balance is shifted into deficit, evacuation of sediment occurs by export of bed and bank material. Here, we use the term *sediment evacuation* to describe the gross channel response to sediment deficit, and we use the term *bed incision* to specifically describe lowering of the bed, which is only one of the channel attributes potentially affected by evacuation. Distinction between these evacuation processes is especially important in systems where water-surface elevations are controlled at discrete locations by particular channel features, such as rapids or riffles. Thus, erosion of material from channel margins or pools between riffles that does not change the large-scale gradient is considered sediment evacuation, not incision. Incision has also been referred to as degradation (Pemberton, 1976) and retrogression (Stevens, 1938). Evacuation processes result in changes to the channel cross section, bed-material grain

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[†] E-mail: grams@cc.usu.edu.

GSA Bulletin; May/June 2007; v. 119; no. 5/6; p. 556–575; doi: 10.1130/B25969.1; 16 figures; 2 tables; Data Repository item 2007089.

Pre-dam Glen Canyon

1952

- Photo at 7,050 cfs shows water, sand, and gravel.
- Shadows limit view of river left bank.
- Here and throughout Glen Canyon, annual snowmelt floods scoured the channel and mobilized sand and gravel bars.

Pre-dam Glen Canyon

July 23, 1956: Looking downstream toward river Section R-15.

July 27, 1956: Looking downstream toward river Section R-15.

Pre-dam Glen Canyon

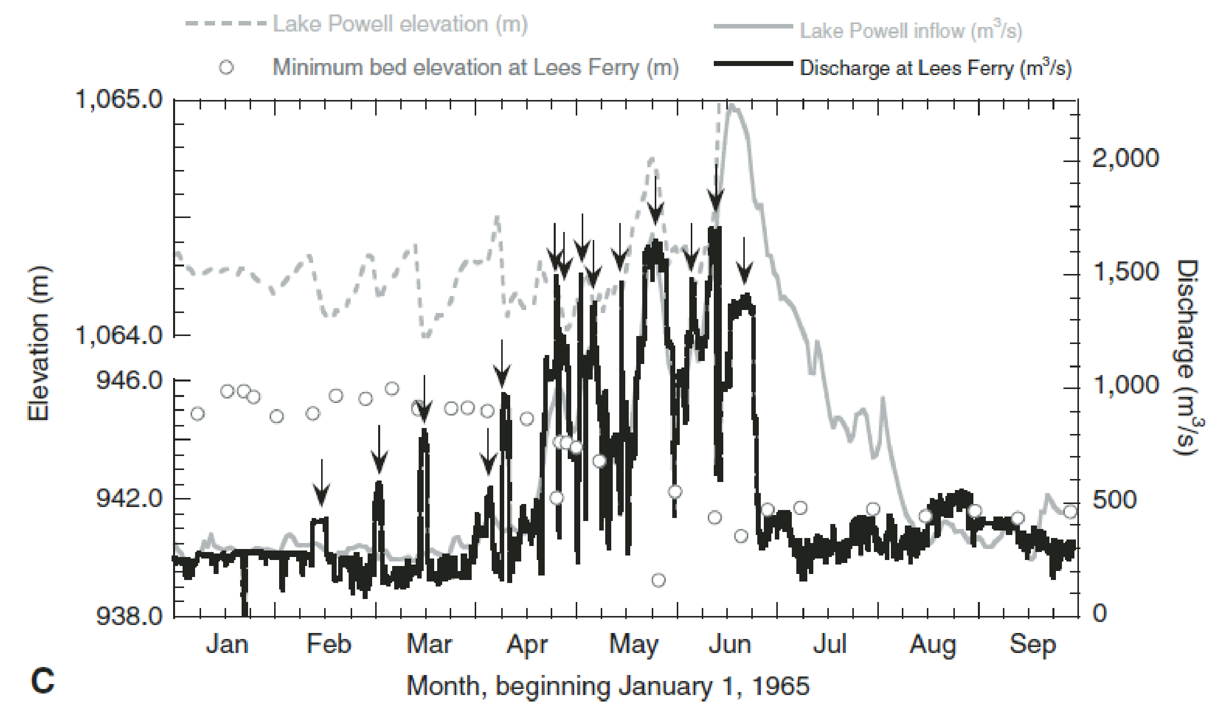
July 27, 1956: Looking at left bank from gravel and cobble bar at river section R-15 (This has not been relocated in the field, but could be looking directly at the present slough).

July 31, 1956: R-15 looking toward left bank from right. Note terrace gravels in foreground and gravel bar in river channel.

1965 “channel cleaning” flows

May 4, 1965: 52,000 cfs

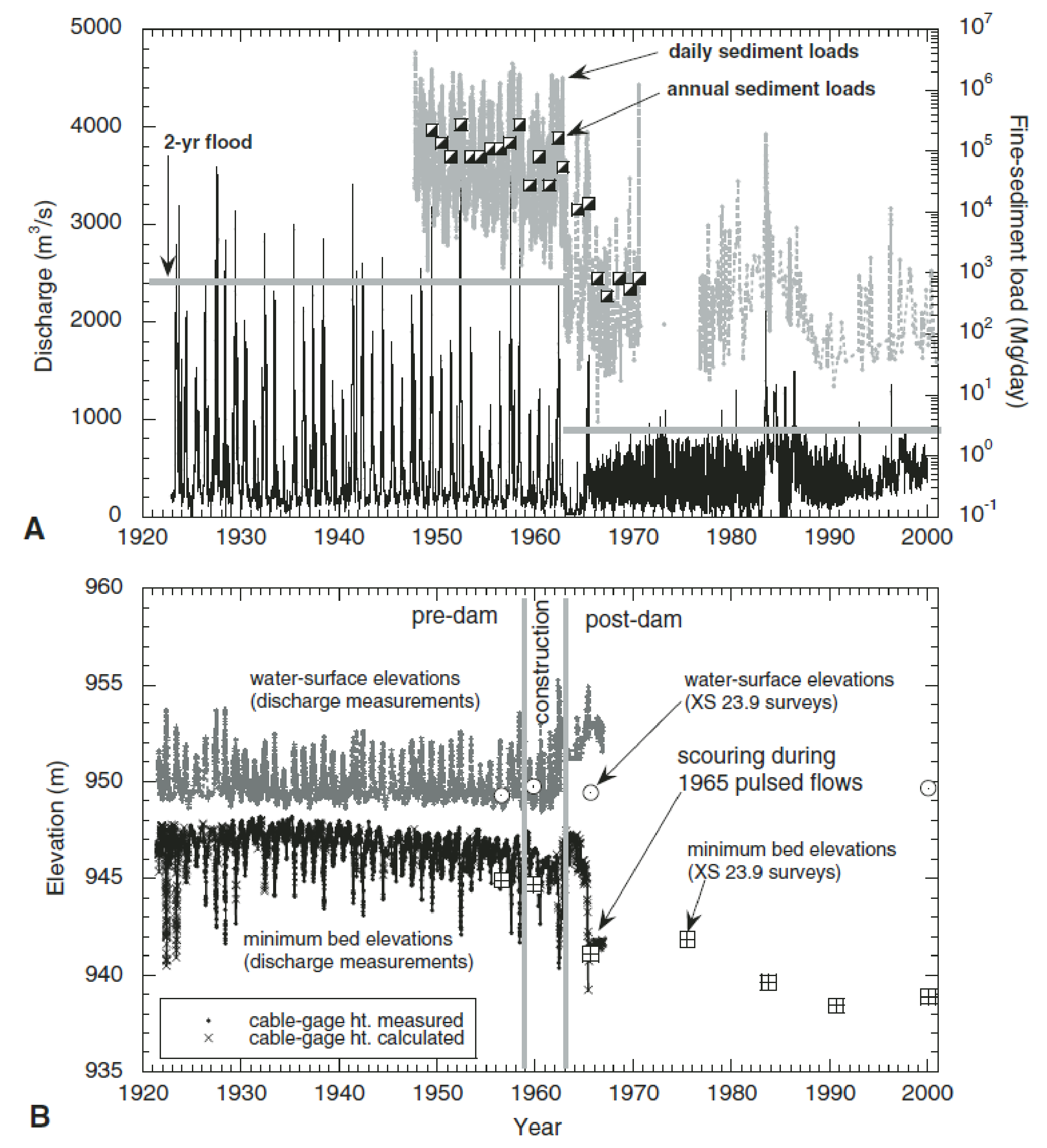
- Beginning in February 1965, a series of progressively larger flow pulses were released from the dam, using the outlet works, river diversion tunnels (before they were closed off), and the partially completed powerplant.
- Largest pulse was 60,000 cfs in June 1965



Grams and others (2007)

1965 “channel cleaning” flows

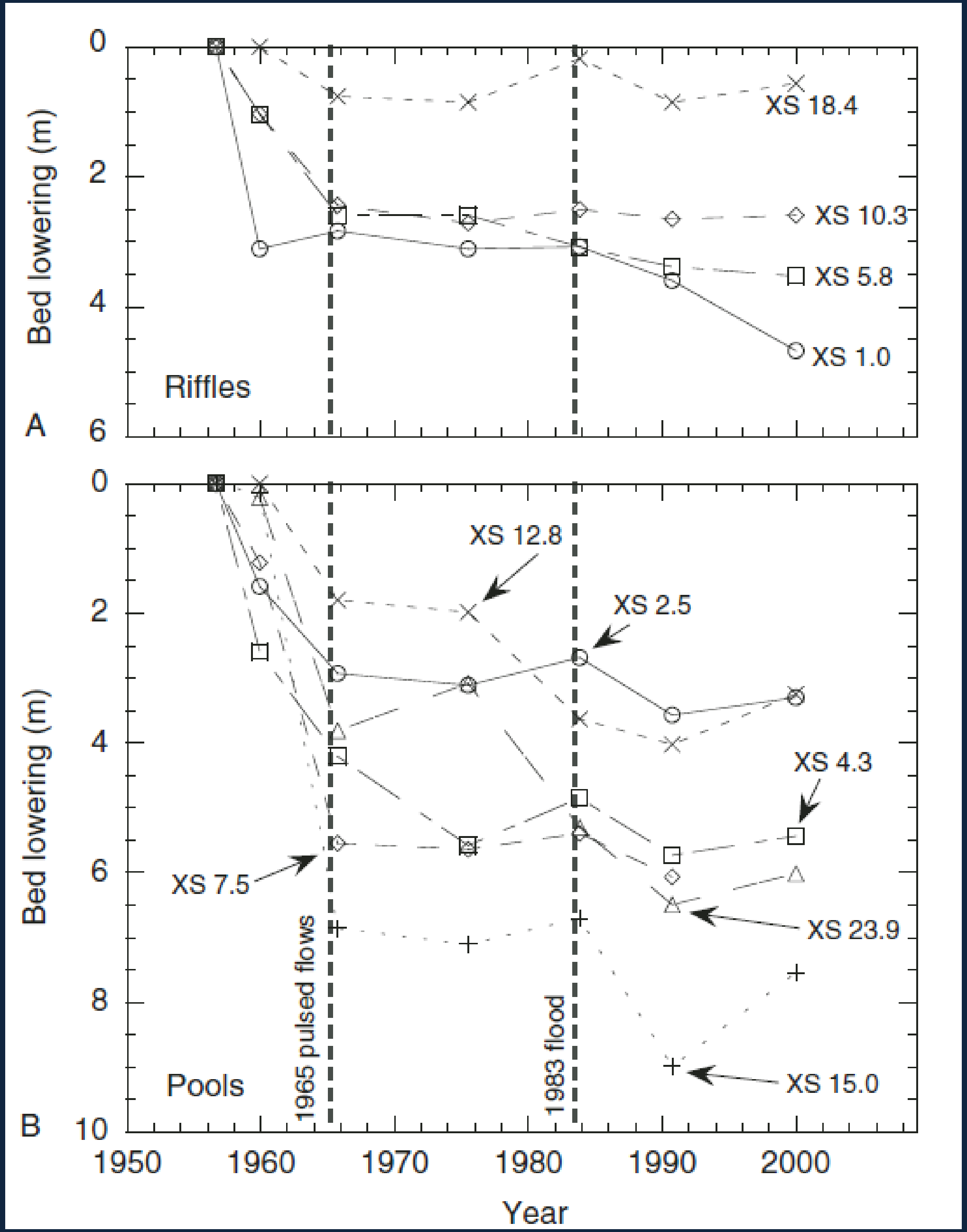
- Pre-dam snowmelt floods caused 15 to 20 feet of scour and fill of the river channel at Lees Ferry annually
- The “low” flows during initial reservoir filling left the channel in a “filled” (aggraded) condition.
- The 1965 flow pulses scoured the bed, leaving it in the “scoured” condition that has persisted for the past 60 years



Grams and others (2007)

1965 “channel cleaning” flows

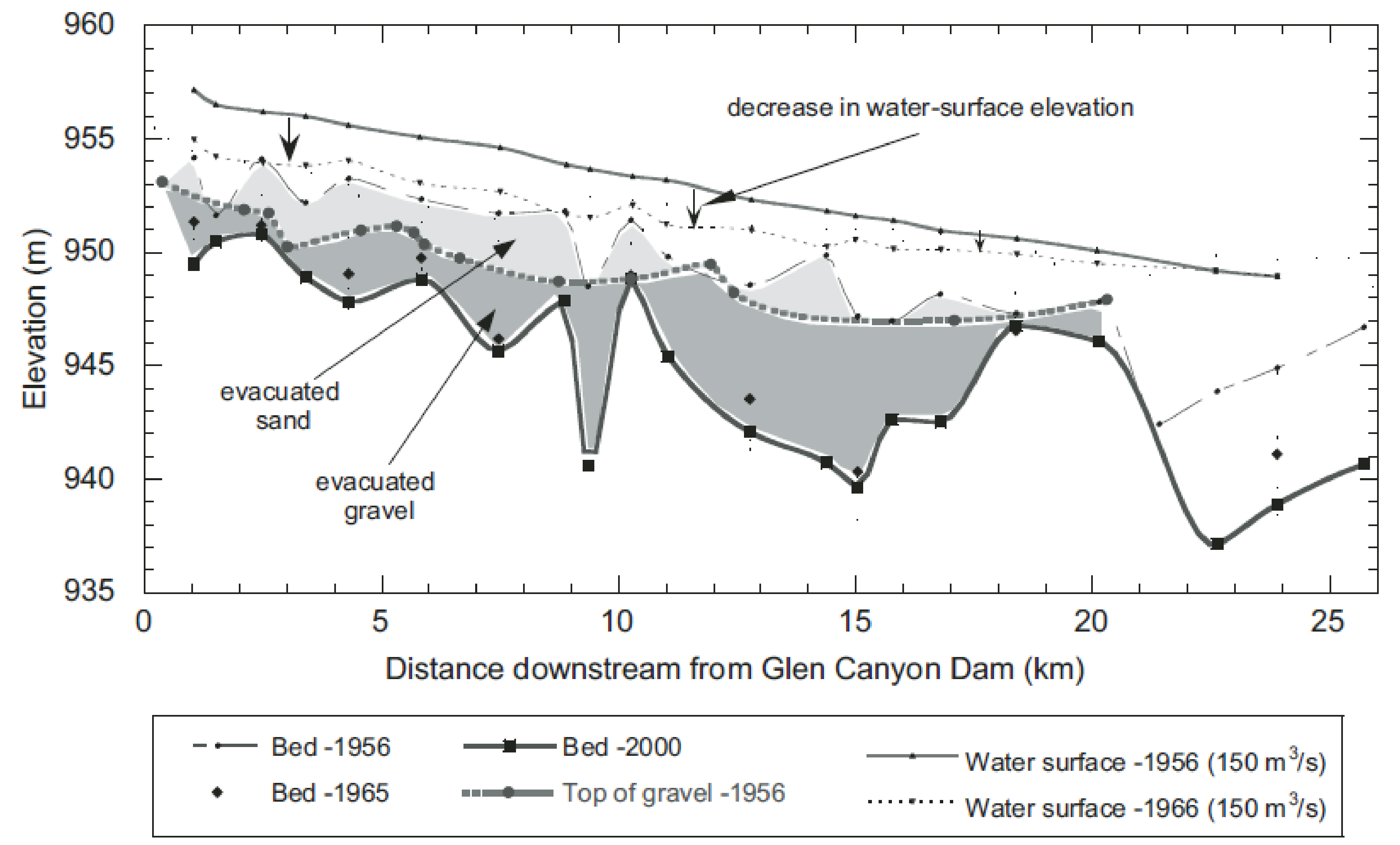
- Scour occurred throughout the entire reach between the dam and Lees Ferry
- Scour occurred in both pools and riffles
- The slough is adjacent to the gravel bar riffle at 5.8 km downstream from dam (RM -12)



Grams and others (2007)

1965 “channel cleaning” flows

- More than 10 million cubic meters of sand and gravel evacuated from reach
- This bed scour lowered the water surface for a given discharge by up to 7 feet
- At the slough, the water surface lowered by ~6 feet for discharges from 5000 to 30,000 cfs
- That resulted in the “abandonment” of the gravel bar and formerly active side channel next to the gravel bar



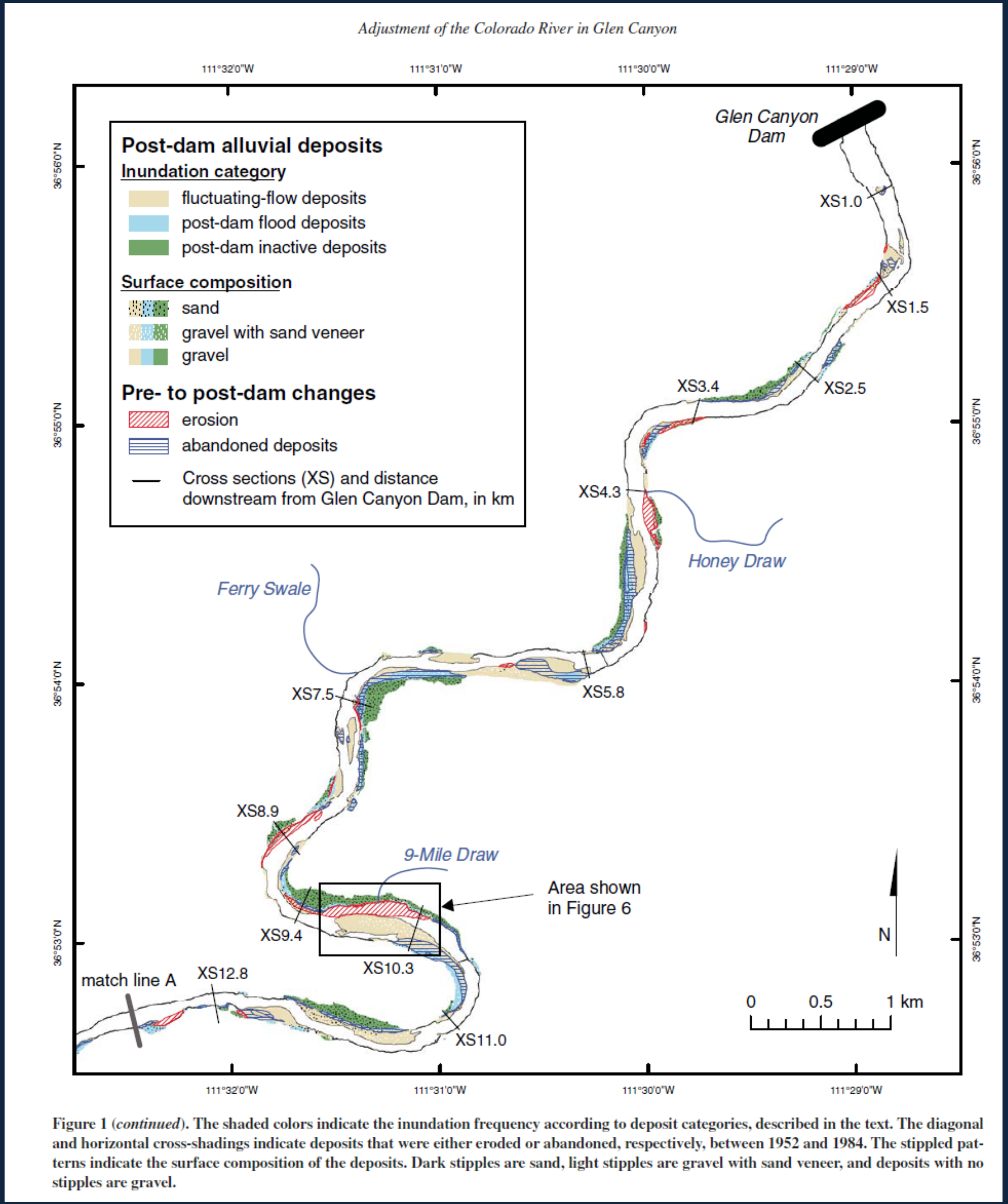
Grams and others (2007)

Glen Canyon, September 14, 1952

Mean-daily discharge was 7,050 ft^3/s

Glen Canyon, August 2, 2015

Discharge at 7:30 AM was 9,160 ft^3/s

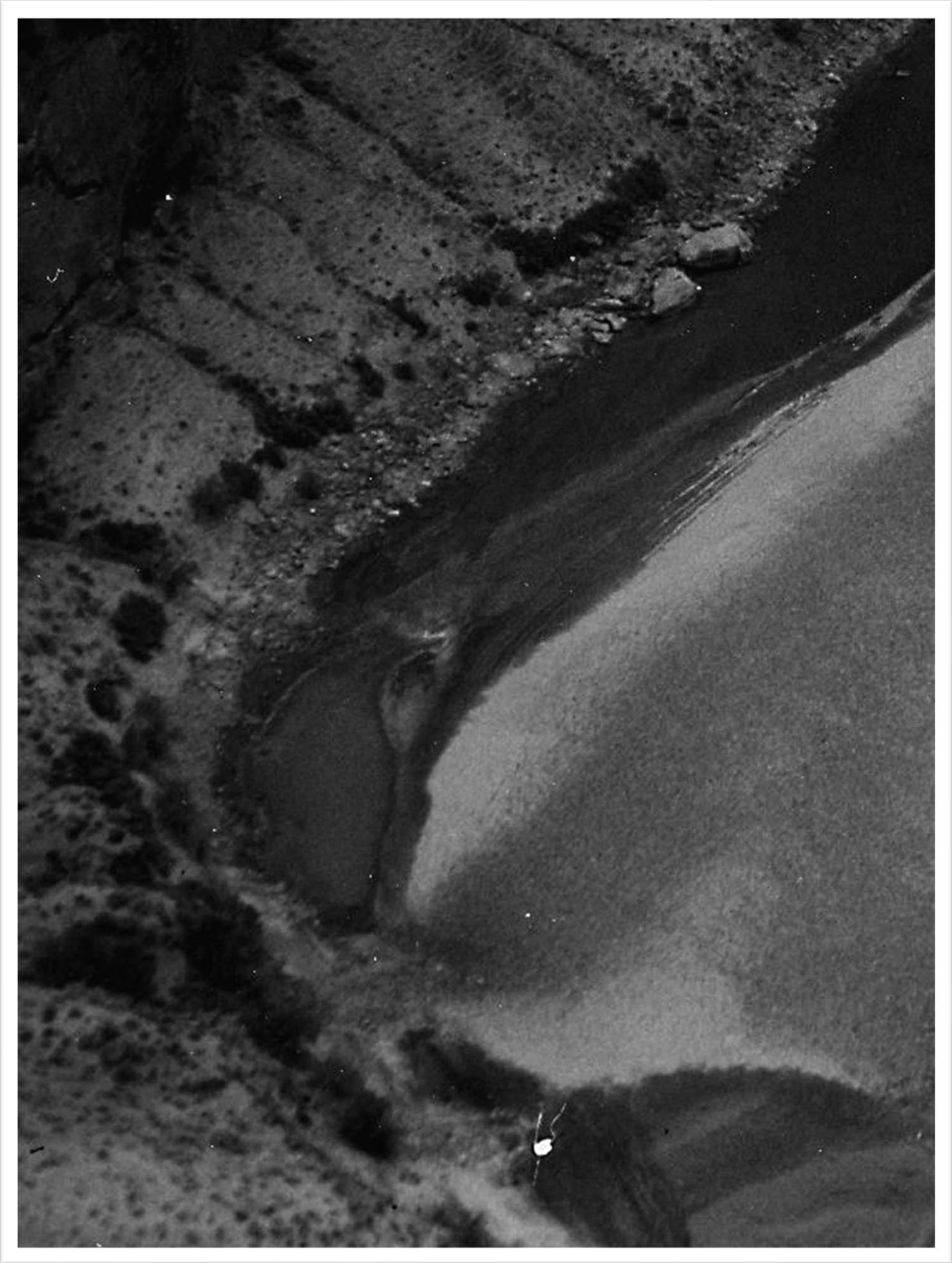


Adjustment of the Colorado River in Glen Canyon

Figure 1 (*continued*). The shaded colors indicate the inundation frequency according to deposit categories, described in the text. The diagonal and horizontal cross-shadings indicate deposits that were either eroded or abandoned, respectively, between 1952 and 1984. The stippled patterns indicate the surface composition of the deposits. Dark stipples are sand, light stipples are gravel with sand veneer, and deposits with no stipples are gravel.

Grams and others (2007)

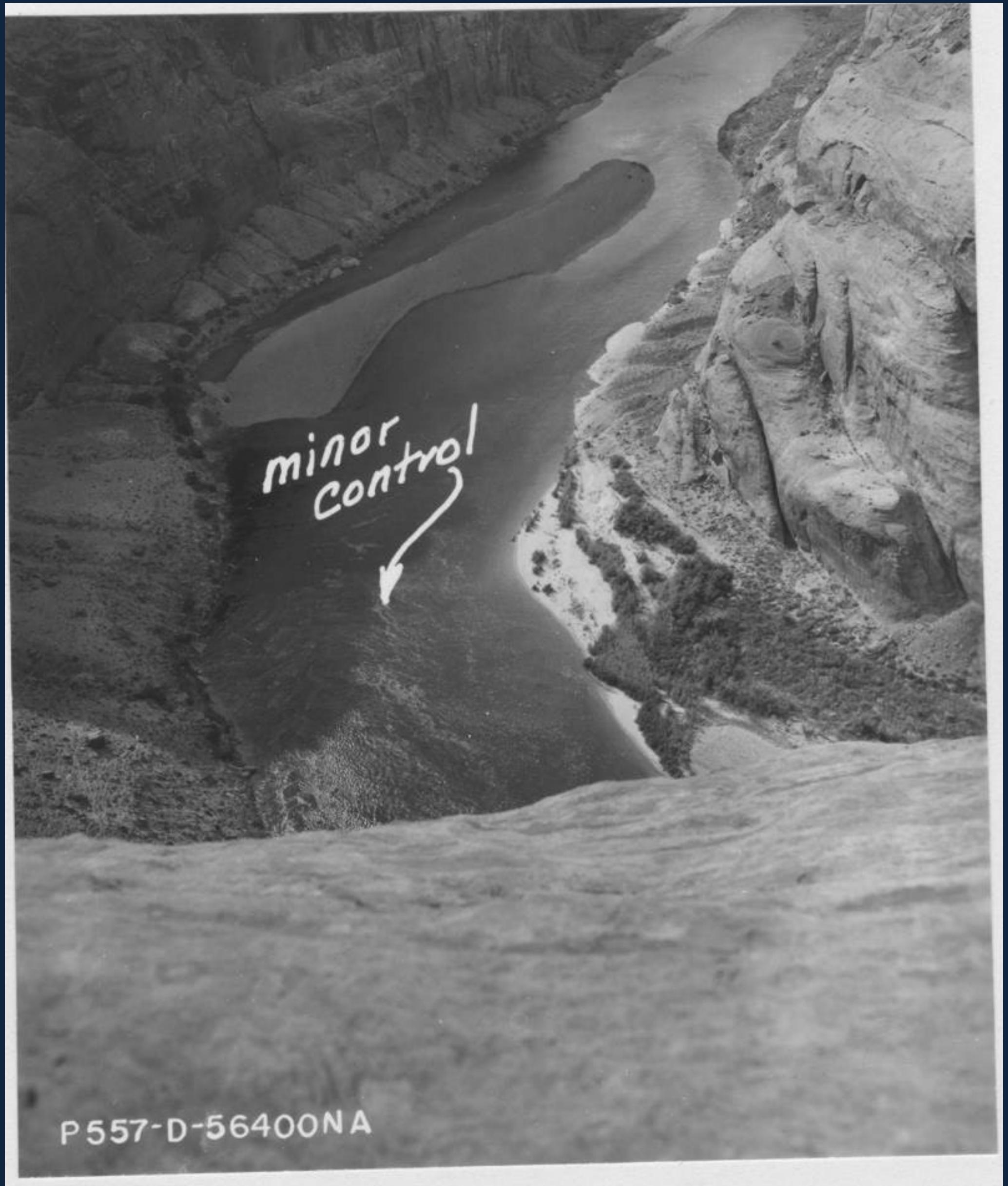
Early post-dam



December 2, 1960: Looking downstream at -12 mile gravel bar and Ferry Swale. Discharge was approximately 1500 cfs.

Early post-dam

October 1966: Looking downstream at -12 mile gravel bar and Ferry Swale.



October 1966: Looking downstream at -12 mile gravel bar and Ferry Swale.

16 years post-dam

1979

- Daily fluctuations between 12,000-26,000 cfs
- Little vegetation visible due to frequent scouring.   both cobble and sand visible.
- Flow through back channel and across center.

August 8, 1979: 21,900 cfs

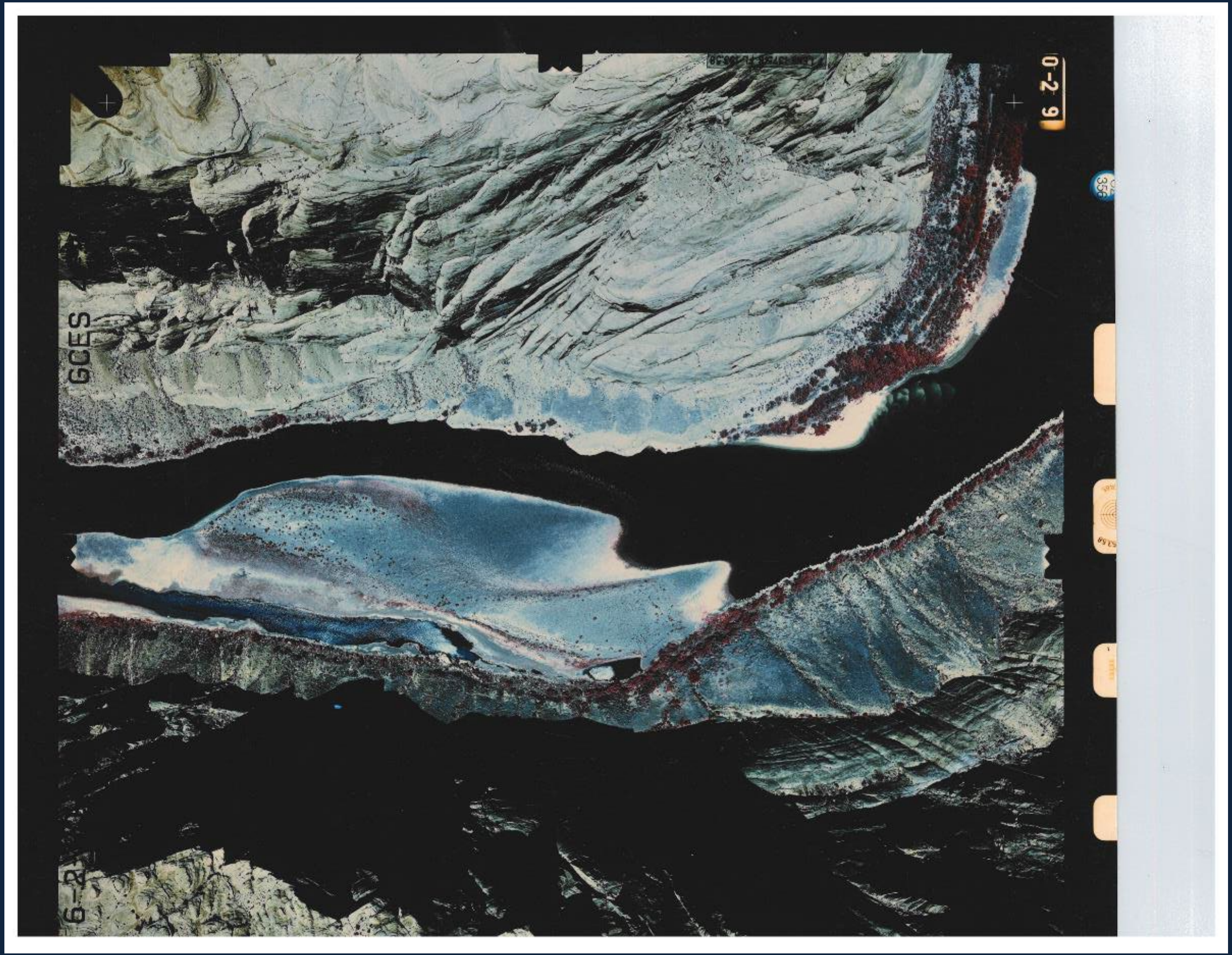
1980s floods

1984

- This photo is after the 1983 and 1984 spillway floods.
- Daily fluctuations were still very high so daily overtopped
- The 1983 and 1984 high flows scoured vegetation and deposited fresh sand and gravel

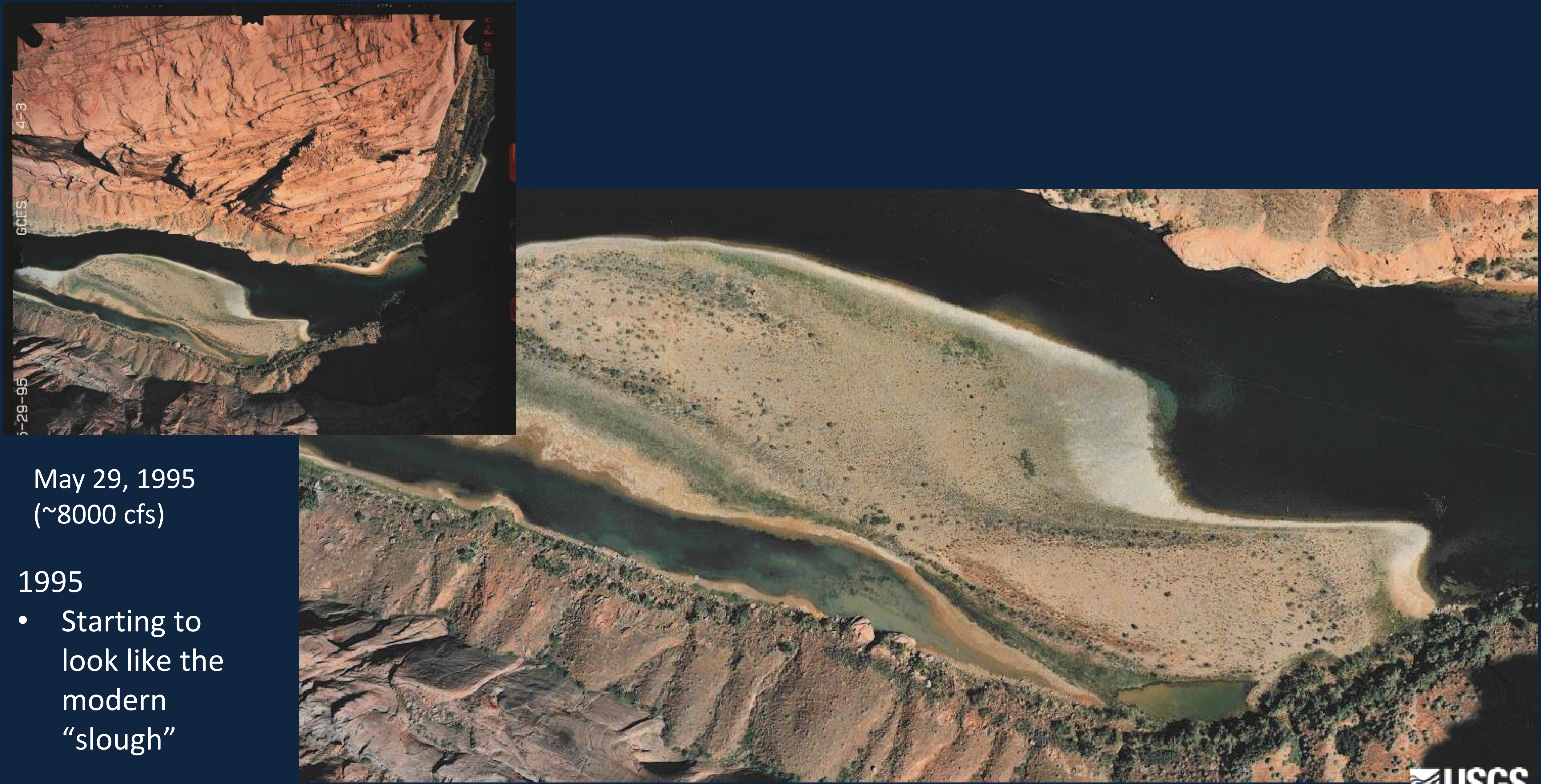
October 21, 1984: 5220 cfs

May 28, 1988 (6550 cfs)



June 2, 1990 (~5000 cfs)

June 2, 1990 (~5000 cfs)



May 29, 1995
(~8000 cfs)

1995

- Starting to look like the modern “slough”

Pre-dam / Post-dam

1952 – Pre-Dam
- No cobble above water at 7,050 cfs
- No vegetated wetland present
- Sand and gravel bar, reworked by annual snowmelt flood

2015 – Post-Dam
- “abandoned” gravel/cobble bar with vegetation
- Ponded, vegetated area present because bar is not overtopped by annual floods

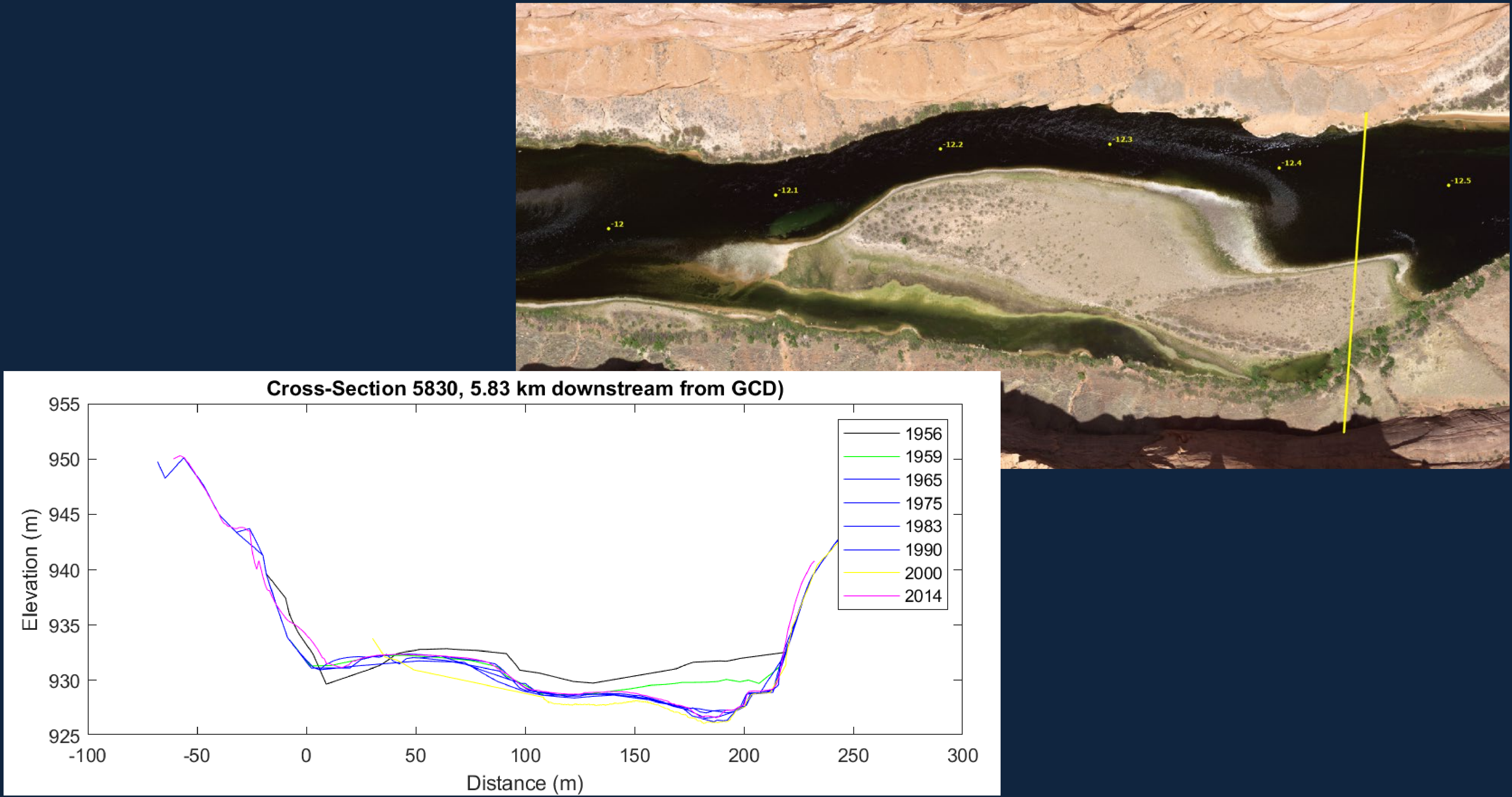

Glen Canyon, September 14, 1952

Mean-daily discharge was 7,050 ft^3/s


Glen Canyon, August 2, 2015

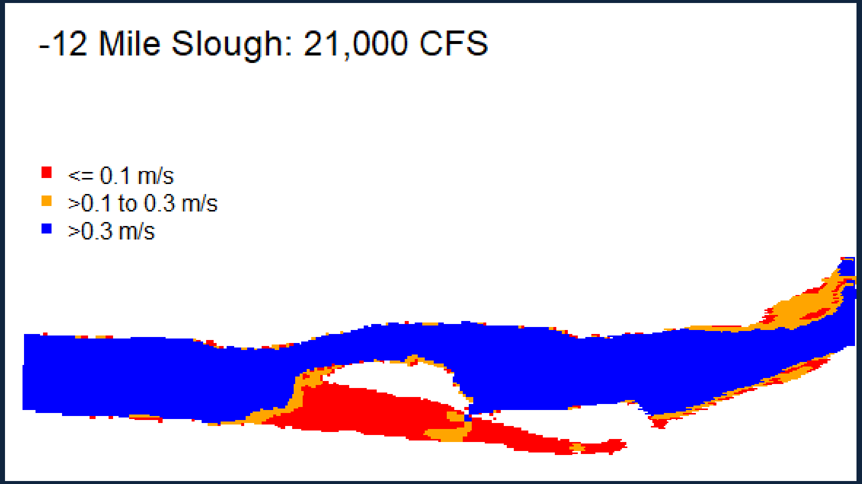
Discharge at 7:30 AM was 9,160 ft^3/s

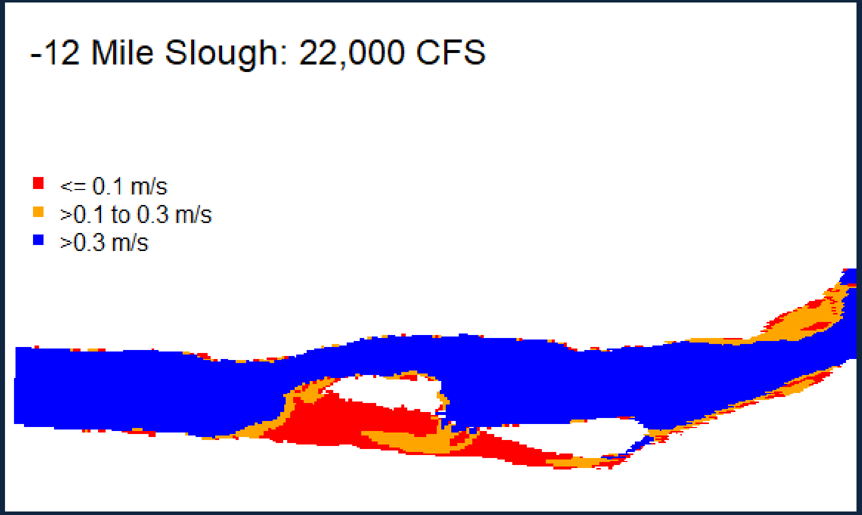
≋USGS

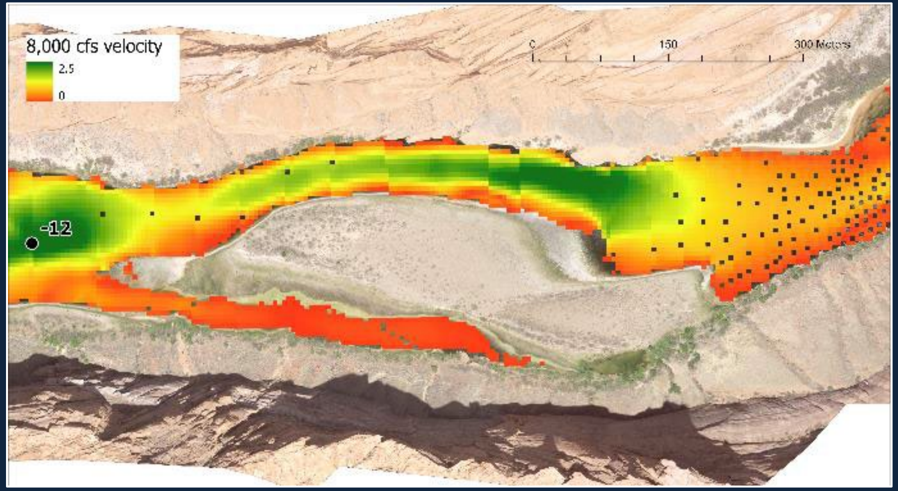


Data from Grams and others (2007) and Kaplinski and others (2022)

Two-dimensional hydrodynamic model for Glen Canyon







Modeled current velocity at 8,000 ft^3/s, near mile -12.

Wright and others (2024)

References

- Grams, P. E., Schmidt, J. C., & Topping, D. J. (2007). The rate and pattern of bed incision and bank adjustment on the Colorado River in Glen Canyon downstream from Glen Canyon Dam, 1956-2000. Geological Society of America Bulletin, 119(5/6), 556–575. https://doi.org/10.1130/B25969.1
- Kaplinski, M., Hazel, J. E. J., Grams, P. E., Gushue, T., Buscombe, D. D., & Kohl, K. (2022). Channel mapping of the Colorado River from Glen Canyon Dam to Lees Ferry in Glen Canyon National Recreation Area, Arizona. U.S. Geological Survey Open-File Report 2022-1057. https://doi.org/10.3133/ofr20221057.
- Kaplinski, M., Hazel, J.E. Jr, Grams, P.E., Gushue, T., Buscombe, D.D., and Kohl, K., 2022, Channel mapping Glen Canyon Dam to Lees Ferry in Glen Canyon National Recreation Area, Arizona - Data: U.S. Geological Survey data release, https://doi.org/10.5066/P98GFP93.
- Wright, S.A., Kaplinski, M., and Grams, P.E., 2024, Hydrodynamic model of the Colorado River, Glen Canyon Dam to Lees Ferry in Glen Canyon National Recreation Area, Arizona: tables of model results and accuracy assessment: U.S. Geological Survey data release, https://doi.org/10.5066/P1QTRNEB.