Emerging Perspectives

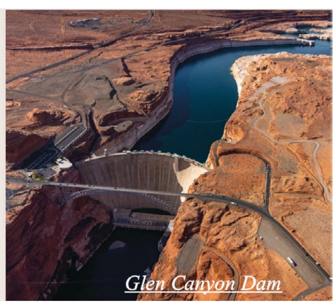
Sediment Delivery to Lake Powell and Lake Mead

By Emma Krolczyk and John C. Schmidt

Hoover Dam & Glen Canyon Dam

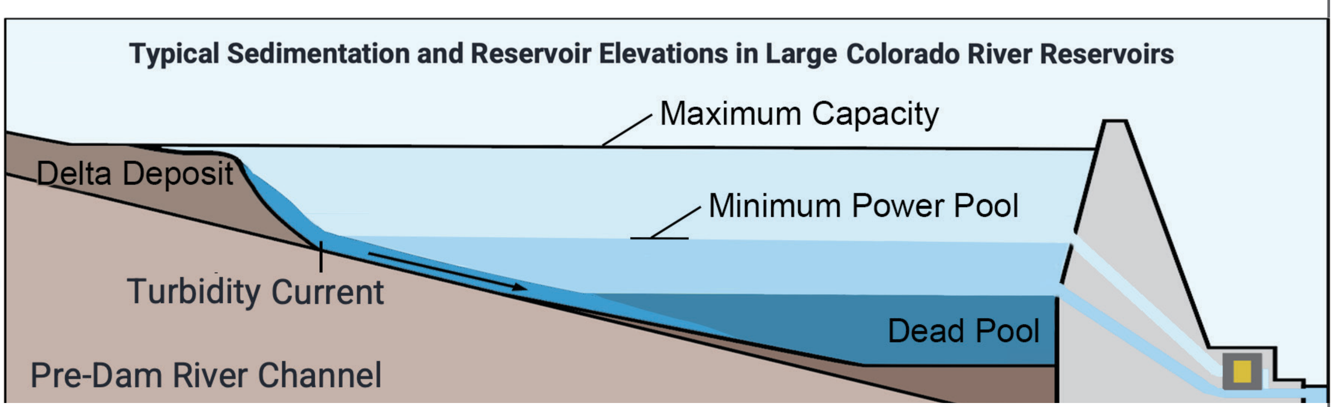
The Colorado River has one of the largest natural sediment loads of any large river in the United States. In 1936, Hoover Dam was completed, thereby beginning the filling of Lake Mead and the trapping of the upstream sediment load. In 1963, Glen Canyon Dam was completed and filling of Lake Powell began, thereby trapping of a significant part of the sediment load that had been delivered to Lake Mead. These two reservoirs are the largest in the United States, and the useful lifespan of these reservoirs is controlled by sedimentation in the reservoirs. Decisions about where to store Colorado River water in the future will inevitably necessitate consideration of the on-going effects of sedimentation in each reservoir.


Hoover Dam


Glen Canyon Dam

General Principles of Reservoir Sedimentation

Large dams dramatically alter the natural sediment mass balance of a river. When a dam is closed, the sediment load, that would otherwise be transported downstream, is deposited in the reservoir. Incoming bedload and suspended sediment is primarily deposited in deltas where the influent rivers enter the reservoir. Turbidity currents in some reservoirs redistribute the delta sediment further into the reservoir, sometimes all the way to the base of the dam. Sediment deposition in reservoirs reduces storage capacity and potentially impacts water withdrawal structures at the dam. Sedimentation may also affect reservoir recreation in the upstream parts of the reservoir.. Prior to the closure of Hoover Dam and Glen Canyon Dam, approximately 91 million tons per year of fine sediment were transported by the Colorado River through the Grand Canyon [7].



Key Definitions

- Delta – landform composed of sediment deposited where the river flows into the reservoir
- Dead Pool – occurs when reservoir water drops below the lowest elevation to withdraw water
- Knickpoint – sharp change in river channel due to erosion

Lake Mead Sedimentation

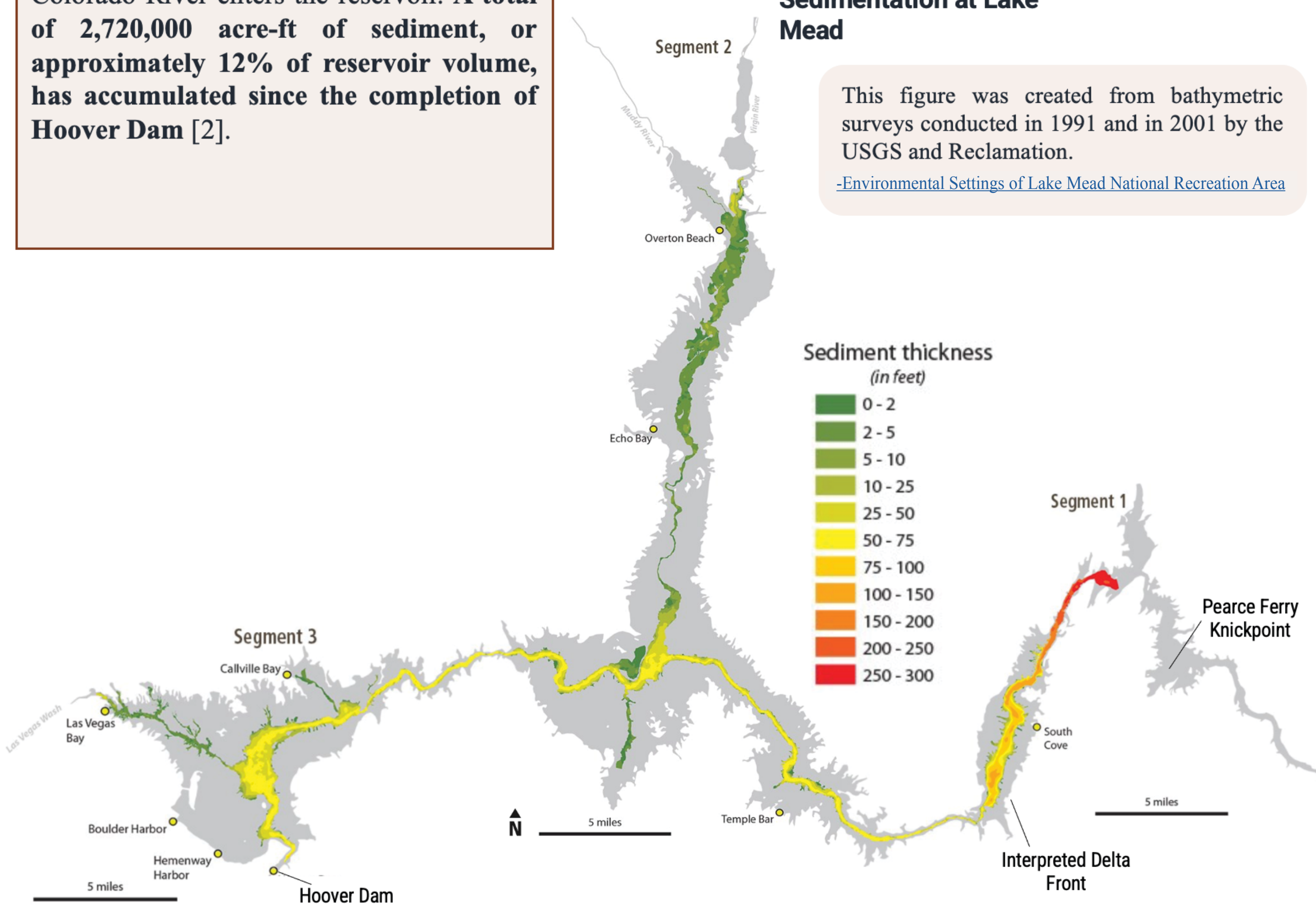
Sediment accumulation in Lake Mead was significant for 27 years until completion of Glen Canyon Dam. Thereafter, Lake Powell trapped most of the sediment delivered from the Upper Basin, but fine sediment delivered from the Paria, Little Colorado, and Virgin Rivers still accumulates in Lake Mead today. Thus, sediment delivery to Lake Mead decreased from ~91 million tons per year to ~5 million tons per year [7, 12]. Sediment deposited in Lake Mead extends the entire length of the reservoir, and the thickest deposits (~279 ft thick) occur where the Colorado River enters the reservoir. **A total of 2,720,000 acre-ft of sediment, or approximately 12% of reservoir volume, has accumulated since the completion of Hoover Dam** [2].

Reservoir sedimentation in deltas can cause changes in the river landscape. During the most recent lowstand of Lake Mead, the Colorado River near Pearce Ferry has downcut into its delta, but not in the same location where the channel formerly occurred. Today, the river flows over a bedrock outcrop and forms Pearce Ferry Rapids, unnavigable at most reservoir levels and a blockage to upstream fish migration from the reservoir.

Sedimentation at Lake Mead

This figure was created from bathymetric surveys conducted in 1991 and in 2001 by the USGS and Reclamation.

-Environmental Settings of Lake Mead National Recreation Area



This figure shows the thickness of sedimentation in the Colorado River channel through most of Lake Mead. The interpreted front edge of the delta is near South Cove where the sediment thickness decreases from >150 ft to <75 ft. Not included in the figure is the thickness of sediment (>250 ft) upstream from Pearce Ferry that extends ~40 miles to Separation Rapid. See figure on next page for conditions upstream from Pearce Ferry.

Rate of Sediment Accumulation in Lake Mead

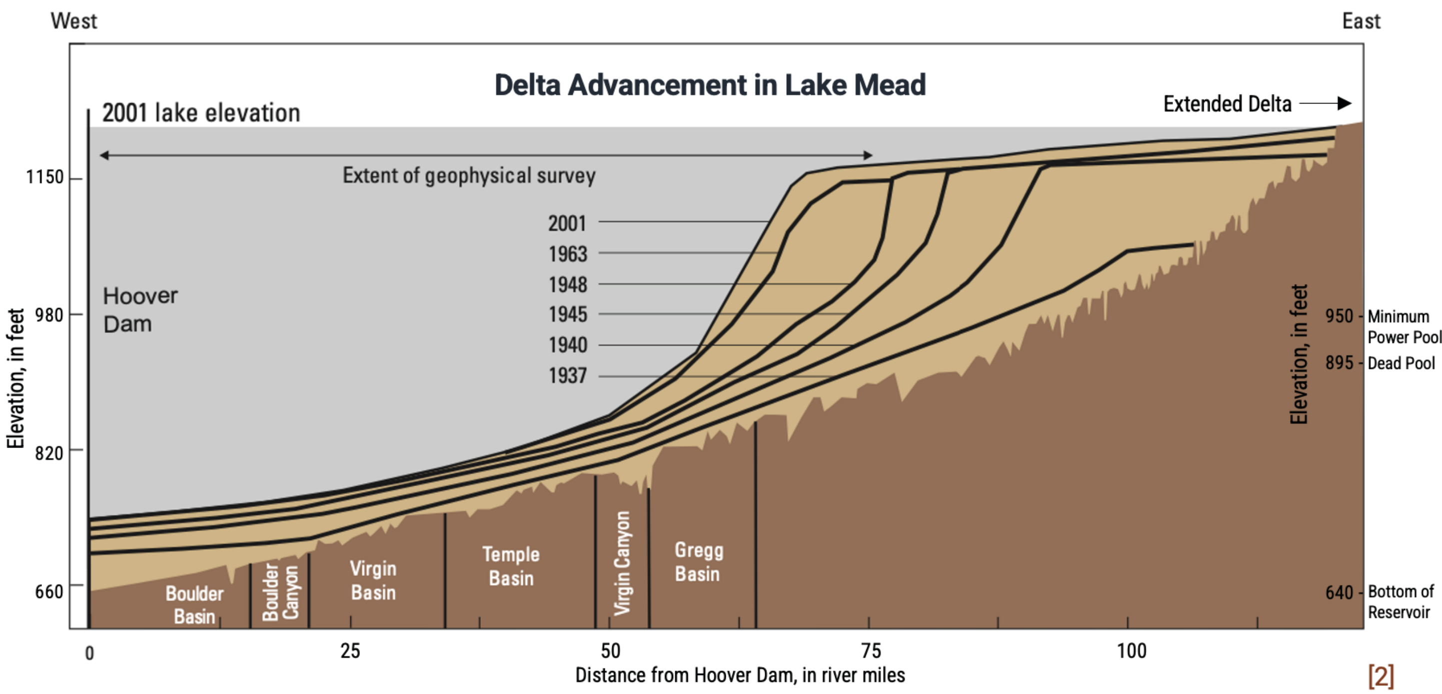
Fine sediment is distributed throughout Lake Mead at various depths through the entire length of the reservoir. The bulk of the reservoir's delta formed prior to 1963. Reservoir capacity decreased and sediment volume increased substantially between 1935-1963. The rate of sedimentation decreased drastically after the closure of Glen Canyon Dam in 1963. Sediment compaction in the reservoir began to occur at a faster rate than sediment delivery which has resulted in a small increase in reservoir capacity. Water levels have been declining since 2000 yet the actual capacity for storage has increased.

LAKE MEAD SEDIMENT STATISTICS

Year	Reservoir Capacity* (acre-feet at 1,220 feet)	Rate of Sedimentation (acre-feet per year)	Sediment Volume (acre-feet)
1935	30,994,400	137,000	0
1948	29,878,000	97,429	1,066,400
1963	28,321,300	88,200	2,623,100
2001	28,543,420	<10,000	2,400,980

-Environmental Settings of Lake Mead National Recreation Area

*Includes water in dead pool



[2]

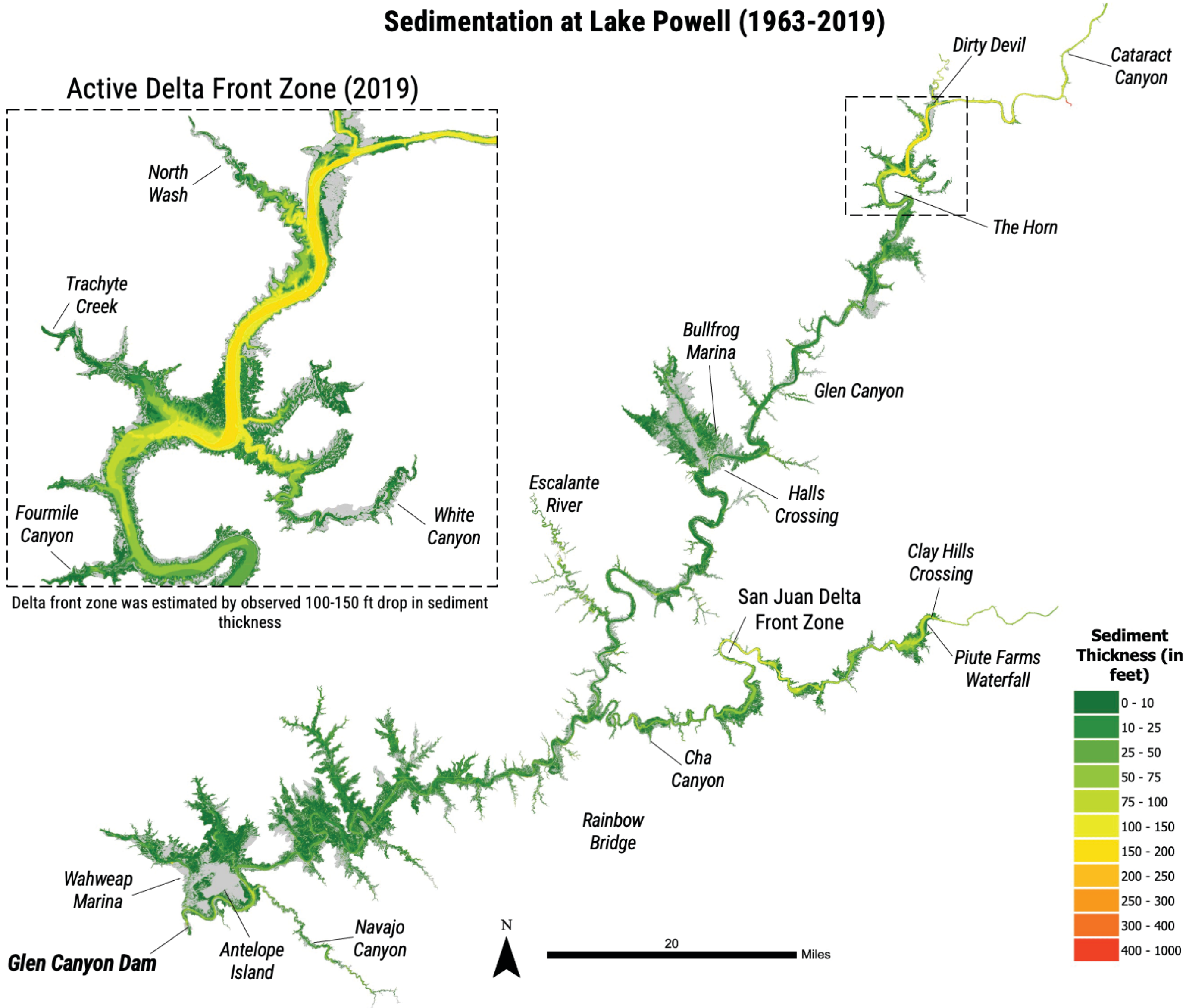
Figure is modified from Turner, et al. (2012) which combined four bathymetric surveys along the Colorado River channel through Lake Mead to show changes in sedimentation from 1937 to 2001. It demonstrates that sedimentation covers the entire channel, all the way to the dam. Note that most sedimentation occurred prior to 1963.

Effects on Reservoir Capacity

Lake Mead is the largest and most important storage reservoir in the Colorado River watershed, and its releases immediately meet downstream demands. The reservoir provides 90% of southern Nevada's water supply. Southern Nevada Water Authority has pumping stations at 1,050 ft, 1,000 ft, and 875 ft elevation. Water levels at the reservoir have already dropped below the highest pumping station. If the water level at Lake Mead continues to drop, the low reservoir level pumping station at 875 ft may have to battle between lack of water and increased sediment depth [8]. With a low modern rate of sedimentation, the estimated lifespan of Lake Mead has been extended to more than a thousand years. The reservoir reaches dead pool when the water level falls below 895 feet elevation. **For Lake Mead sedimentation to fill to dead pool elevation, another ~340 feet of sediment would have to be delivered to the dam.** Thanks to Lake Powell, Lake Mead will continue to be able to store water for the Lower Basin for the foreseeable future. The limiting factor for the reservoir's lifespan is now diminishing water inflow rather than sediment accumulation.

Lake Powell Sedimentation

Sedimentation in Lake Powell reduces its useful life span at the same times as the sedimentation extends the lifespan of Lake Mead. The filling of Lake Powell during more than 50 years has resulted in deltas at the mouths of Colorado and San Juan Rivers. Between 2004-2005, the water level dropped below the upper delta plain and the river began to incise a new channel through its own delta. Estimates of the pre-dam fine sediment transport through Glen Canyon were 63 million tons per year [7]. Today, fine sediment delivery is probably somewhat less, but remains significant. **Additionally, the deltas have been exposed during reservoir lows and are being reworked and redeposited further into the reservoir** [3].



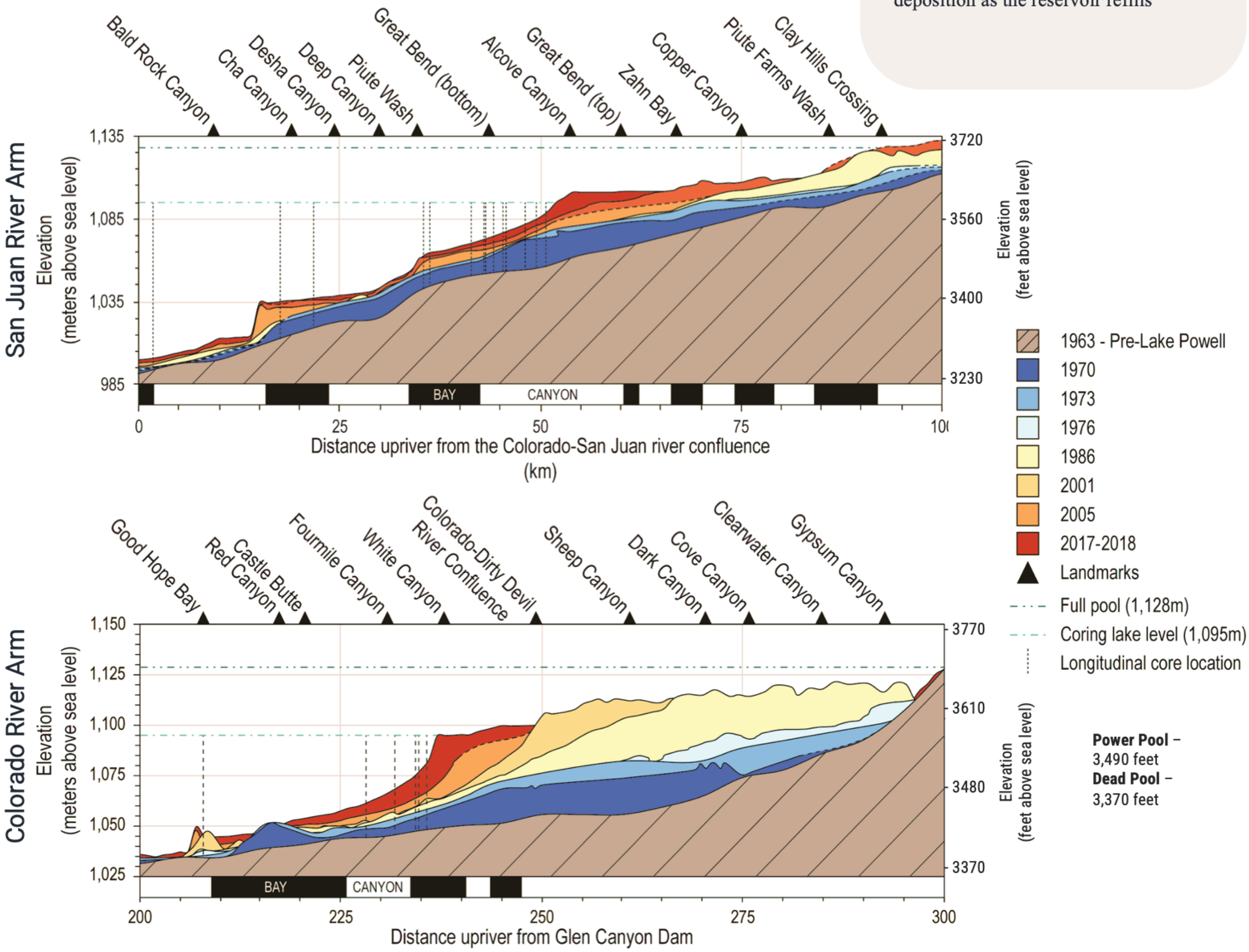
This sedimentation map was created by subtracting the pre-Lake Powell topography from 1963 [10] from Lake Powell topography surveyed in 2019 [9]. The pre-Powell data were published as USGS Data Release "Digital Elevation Model of Glen Canyon Prior to the Flooding of Lake Powell from Historic Topographic Surveys, Utah and Arizona" from Root et al. (2019). The 2019 data were published as USGS Data Release "Modified topobathymetric elevation data for Lake Powell" by Jones & Root (2021). Grey areas demonstrate areas of no sediment accumulation. Most of the reservoir has received between 1-25 feet of sediment accumulation since closure of Glen Canyon Dam and advancing deltas now extern beyond Cataract Canyon well beyond Hite as well as well downstream from Paiute Farms in the San Juan arm.

Effects on Reservoir Capacity

- The most recent bathymetric surveys report that sedimentation in Lake Powell has decreased its storage capacity by 6.8% or 1.83 million acre-feet from 1963 to 2018 [4].
- Deadpool at Lake Powell is 3,370 feet elevation. The reservoir floor is now at ~3132 feet elevation at the dam. **Another ~238 feet of sediment delivered to the dam would aggrade the bed to dead pool elevation.** Estimates of the future life of the reservoir range from 80 to 500 years.
- Some groups have advocated prioritization of water storage in Lake Mead and bypassing of Glen Canyon Dam. Any sediment that bypasses Lake Powell would be delivered to Mead, thereby initiating a new episode of accelerated sedimentation in Lake Mead.

These plots were modified from an investigation by the USGS Utah Water Science Center in cooperation with Utah Department of Environmental Quality, Reclamation, Bureau of Land Management, National Park Service, University of Utah, and Utah State University. These graphs were created from several bathymetric surveys and demonstrate the advance of deltas in the Colorado and the San Juan arms between 1963 and 2018. Large runoff in 2023 is anticipated to cause additional incision during the beginning of the flood, followed by upstream deposition as the reservoir refills

Delta Advancement to Lake Powell



Sedimentation in Lake Powell

Sediment Management

Methods for removing some of the sediment from large reservoirs consist of flushing, excavation, dredging, and sluicing. thereby increasing the Lake Powell's lifespan. No economic analysis has been conducted on implementing these management strategies at Lake Powell or Lake Mead.

- **Flushing** – This process is conducted by scouring reservoir sediment through low level outlets such as redrilling the sealed river diversion tunnels.
- **Excavation** – This process involves moving sediment with excavators. It requires the sediment to be relatively dry.
- **Dredging** – This process combines digging into the sediment and removing it by using suction or creating a vacuum. This is the most common method for sediment removal in reservoirs.
- **Sluicing** – This process involves rinsing out the reservoir with a pipeline via moveable raft or permanent pipeline. This process has been used on small reservoirs.

In 2008, Reclamation investigated augmenting sediment supply in Grand Canyon by dredging and sluicing sediment from Navajo Canyon delta in Lake Powell to contribute to beach building processes.

Conclusions

- There is a large flux of sediment through the Southern Colorado Plateau. Before 1963, the sediment was trapped in Lake Mead. Today, the sediment flux is primarily trapped in Lake Powell.
- Due to low water levels, the river has incised through previously deposited reservoir sediment, but the new location of the incising channel has created knickpoints and bedrock lips where the river is less navigable. These knickpoints limit upstream migration of reservoir fish into influent channels.
- Diversion of the Colorado River around Lake Powell would deliver large amounts of fine sediment to Lake Mead.
- Although Lake Powell sedimentation may temporarily extend the lifespan of Lake Mead, the large-scale problem of reservoir sedimentation on the Colorado River must eventually be confronted.

LAKE POWELL SEDIMENT STATISTICS

Year	Reservoir Capacity* (acre-feet at 1,220 feet)	Average Rate of Sedimentation (acre-feet per year)	Sediment Volume (acre-feet)
1963	26,993,000	-	0
1986	25,945,000	45,570	1,048,000
2018	25,160,000	24,530	1,833,000

* includes water below dead pool elevation

These statistics were published as a National News Release by the U.S. Geological Survey in cooperation with the Bureau of Reclamation [11].

Source

References

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2 - Turner, K., Rose, M.R., Holdren, G.C., Goodbred, S.L., Twichell, D.C., 2012. Environmental Setting of Lake Mead National Recreation Area. A Synthesis of Aquatic Science for Management of Lakes Mead and Mohave. U.S. Geological Survey. link

3 - Sedimentation in Lake Powell. Recent USGS Utah Water Science Center activities in cooperation with: Utah Department of Environmental Quality, Bureau of Reclamation, Bureau of Land Management, National Park Service, University of Utah and Utah State University. 2021. link

4 - Wegner, D., Gavan, M., 2018. The Story of Sediment in Lake Powell: A Historical Perspective. Glen Canyon Institute link

5 - Elgamal, M., Fouli, H. , 2020. Sediment removal from dam reservoirs using syphon suction action. Arabian Journal of Geosciences. v. 13(943). link

6 - Randle, T.J., Lyons, J.K., Christensen, R.J., 2007. Colorado River Ecosystem Sediment Augmentation Appraisal Engineering Report. Managing Water in the West. Bureau of Reclamation. link

7 – Topping, D. J. Rubin, D. M., and Vierra, L. E., Jr. 2000, Colorado River sediment transport 1. Natural sediment supply limitation and the influence of Glen Canyon Dam. Water Resources Research 36(2): 515-542.

8 - https://www.snwa.com/our-regional-water-system/low-lake-level-pumping-station/index.html

9 - Root, J.C., Hynek, S.A., DiViesti, D.N., and Gushue, T.M., 2019, Digital Elevation Model of Glen Canyon Prior to the Flooding of Lake Powell from Historic Topographic Surveys, Utah and Arizona: U.S. Geological Survey data release, https://doi.org/10.5066/P9368XHU.

10 - Jones, D.K., and Root, J.C., 2021, Modified topobathymetric elevation data for Lake Powell: U.S. Geological Survey data release, https://doi.org/10.5066/P9H60YCF.

11- Lake Powell's storage capacity updated for the first time since 1986. USGS. Communications and Publishing. National News Release. Link

12 – USGS Grand Canyon Monitoring and Research Center Discharge Sediment, and Water Quality Monitoring website, https://www.gcmrc.gov/discharge_qw_sediment/.