Riparian Vegetation Responses to Altered Disturbance Regimes in the Grand Canyon

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Abstract

Since the construction of Glen Canyon Dam was completed and the dam was closed in 1963, the post-dam flow regime has resulted in decreased bare sediment area due to the encroachment of riparian vegetation onto these formerly unstable sediment areas. As a result, there has been increased colonization of invasive vegetation such as Tamarisk, and less sandbar surface area for recreational activities in the Canyon such as river rafting and camping. This paper will discuss the processes of riparian vegetative growth as a result of the post-dam flow regime and the complexities surrounding the relationship between riparian vegetation, Colorado River ecology, and recreational resources using three case studies as reference.

Background: Policy and Infrastructure

The area of focus for this paper will be Glen Canyon Dam, which is located upstream to the Colorado River in the Northwestern portion of Arizona, and the area that it encompasses moving all the way down to Lake Mead, which can be seen in **Figure 1** (Durning, 2016)**.** Construction of the Glen Canyon Dam began in 1956 and was completed in 1963 (USBR, 2023). The Glen Canyon Dam is the second highest concrete-arch dam in the United States, second to the Hoover Dam (USBR, 2023). After its completion, the dam was closed in order to allow Lake Powell to fill, acting as a "savings account" of water to be used primarily in times of drought (USBR, 2023). In 1980, Lake Powell was officially filled (USBR, 2023). Another important feature of the Dam is its hydroelectric power generation. Water released from Lake Powell that runs down through the Colorado River is referred to as "releases" or "flows" which help to generate hydropower for Arizona residents (USBR, 2023). The pattern of these releases, and the amount of water in each release has both direct and indirect effects on ecological, recreational, and even cultural resources along the Colorado River.

In the early years after the closure of the dam and before 1990, dam operations were running at full capacity in an effort to maximize power generation (USBR, 2016). However, after 1990, Reservoir operations were adjusted in an effort to reverse sandbar erosion and address other environmental concerns (USBR, 2016). As a result of the increased attention toward "environmental flows" or flow releases that considered ecological and biological effects rather than solely economic profit, in 1992, the Grand Canyon Protection Act was passed which officially called for a Glen Canyon Adaptive Management Program (AMP). As a part of this program, the Bureau of Reclamation (USBR) committed itself to operating Glen Canyon Dam in accordance with the Law of the River and all applicable environmental Laws (USBR, 2023). Management of the dam flows by the USBR is largely based on the Glen Canyon Dam management plan. Another part of this AMP was that an Environmental Impact Statement (EIS) would be prepared on the operation of Glen Canyon Dam. This EIS had actually already begun in 1989 but was officially completed in March of 1995 (USBR, 2023). The daily releases from the dam typically range from 5,000 to 31,500 cfs (cubic feet per second) but are typically on the lower portion of this range due to the implementation of the 1996 Record of Decision (ROD) by the Bureau of Reclamation which was also proposed in the 1995 EIS (USBR, 2016). Today, the Glen Canyon Power Plant produces around 5-billion kilowatt-hours of hydroelectric power annually (USBR, 2023). In order to maximize electricity generation, the Glen Canyon Dam releases vary hourly, increasing or decreasing over a 24-hour period (Ralston, et al., 2014).

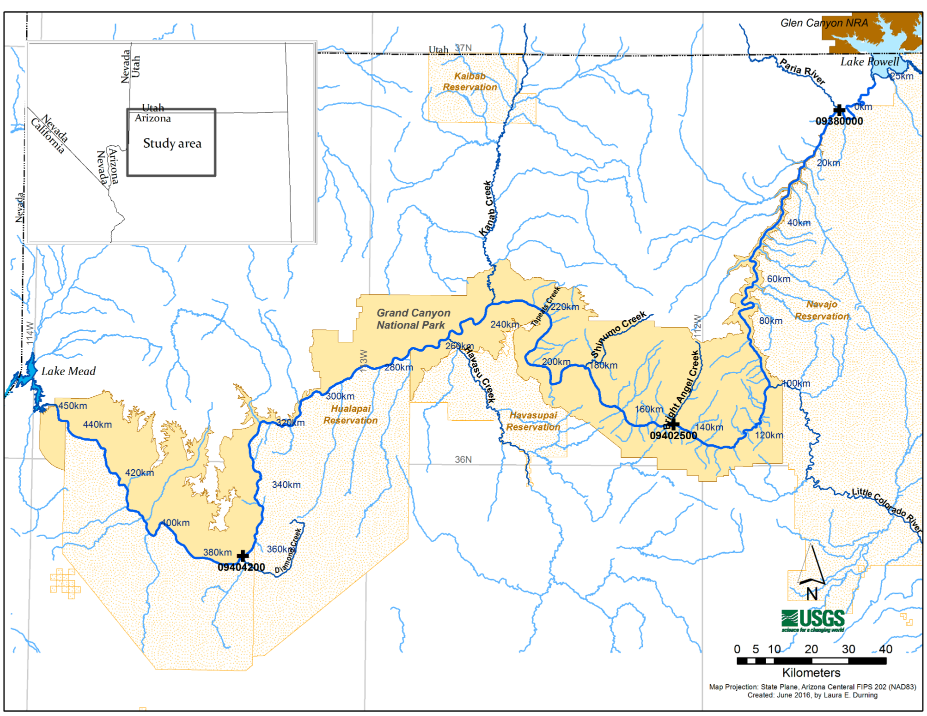


Figure 1. A map of the Grand Canyon boundaries, the Colorado River and its tributaries. This map also displays the location of Glen Canyon Dam (top right corner) above the Colorado River system all the way to the Hoover Dam (left center). (Durning, 2016).

Background: Ecology and Riparian Vegetation

The timing, duration and magnitude of a river's hydrology has an effect on riparian vegetation responses (Ralston, et al., 2014). Before the construction of the dam. The natural flow regime of the Colorado River was constantly changing and highly unstable with wide variations in annual flows (USBR, 2016). This hydrology caused high rates of plant scouring and drowning making it very difficult for riparian vegetation to grow beneath the annual flood zone. This plant scouring made it so that there was limited vegetation on the sandbars and therefore more area for recreational activities that play a role in the economic environment of the Grand Canyon. After the construction of the dam, changes to water levels, sediment transport and stream flow resulted in an encroachment of riparian plant species onto the sandbars and into lower elevations, thus narrowing the channel (USBR, 2016). Drought and the resulting low flows also increased soil salinity and sand coarseness (USBR, 2016). Furthermore, these altered hydrologic patterns have been shown to negatively affect the establishment of native plant species while promoting the spread of invasive species such as Tamarisk. For this paper, "riparian vegetation" includes all plants that are found within the four hydrologic zones of the Colorado River. The riparian vegetation community post-dam is characterized by a growing community of nonnative species (Ralston, et al., 2014). In order to understand how the downstream environment of Glen Canyon Dam can be managed to promote a healthy riparian ecosystem composed of native riparian plant species, the specific effect of flows on the riparian vegetation needs to be studied and understood (Ralston, et al., 2014). Hydrology is a major driving force for the composition of riparian communities (Ralston, et al., 2014).

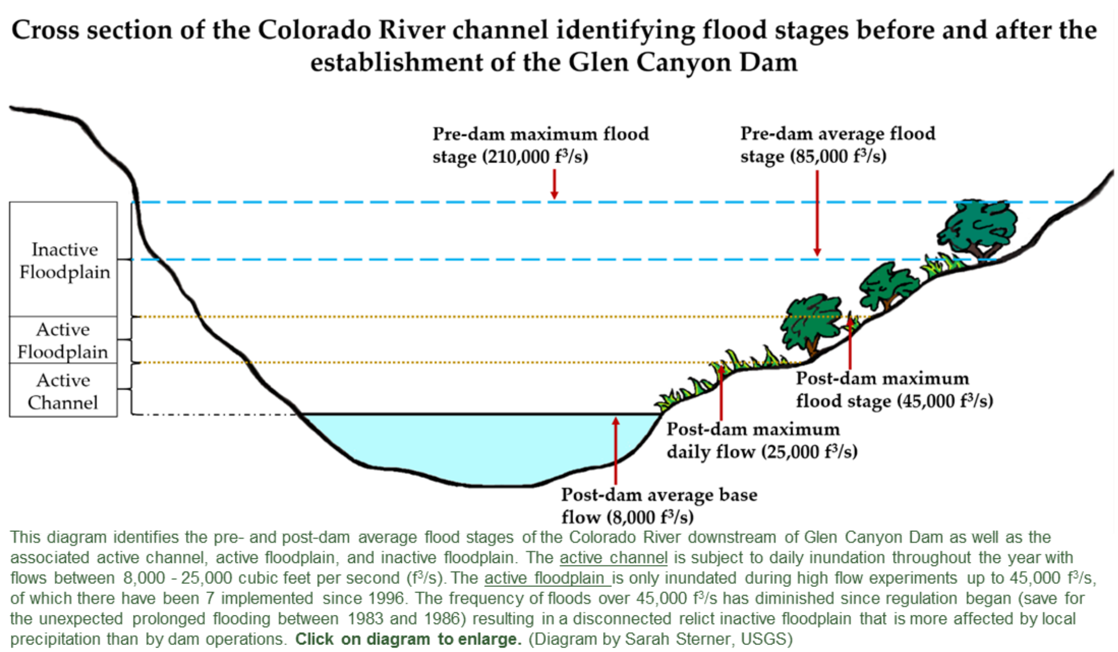


Figure 2. A cross section of the colorado river channel labeled with the different flood stages before and after the establishment of Glen Canyon Dam (Sterner, 2018).

Ralston, et al. describes the three portions of the floodplain that are based on dam releases: the active channel, the active floodplain, and the inactive floodplain, displayed above in **Figure 2** (Stern, 2018 and Ralston, et al., 2014)**.** The active channel is the area of shoreline that experiences the daily operations of the dam flows (Ralston, et al, 2014). The active floodplain is the portion of shoreline that experiences periodic flooding of varied durations and magnitudes outside of the daily dam flows that the active channel experiences (Ralston, et al, 2014). Finally, the historical, or inactive, floodplain is the portion of shoreline that has not received water from Glen Canyon discharges since pre-dam flows (Ralston, et al., 2014). As it was previously described in the *Long-Term Experimental and Management Plan Final Environmental Impact Statement* published by the USBR in 2016, Scott, et al., found that pre-dam water flows were so frequent and high in magnitude that the majority of the active channel, prior to the 1960s, was devoid of vegetation (Scott, et al., 2018). There is documentation as early as the 1980s, that describes the widespread establishment of riparian vegetation post-dam on the formerly active channel downstream of the Glen Canyon Dam (Scott, et al., 2018). There was a period of high flows in the late 1980s, on behalf of hydroelectric power generation, that provided an interesting look into the response of riparian vegetation to managed flows. This high flow period showed that due to specific-species differences in reproduction methods, re-establishment patterns, and flood mortality, post-flood vegetative reestablishment specifically favored tamarisk and cat-claw acacia but not seep-willows or brickell brush (Scott, et al., 2018). After flows were decreased again in 1991, researchers like Sankey et al., in 2015 found that riparian vegetation began expanding into lower elevations of the Old High Water Zone and in some areas increased 90 percent from 1990 to 2012 (Scott, et al., 2018).

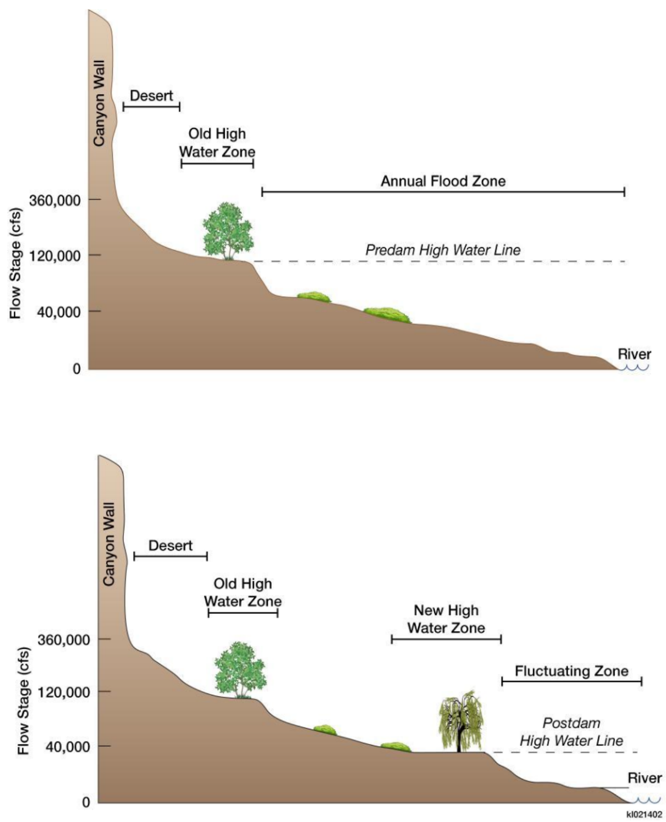


Figure 3. A comparison of the riparian vegetation zones below Glen Canyon Dam before (top) and after (bottom) the construction of Glen Canyon Dam taken from "Chapter 3: Affected Environment" of the *Glen Canyon Dam Long-Term Experimental and Management Plan Final Environmental Impact Statement* by the USBR in 2016 (USBR, 2016).

Historical patterns of dam releases have created a difference in the types of vegetative communities below the 25,000-cfs elevation line and those above this level (USBR, 2016). Across these surfaces, seven plant communities have been identified across four hydrologic zones (USBR, 2016). The four hydrologic zones, shown in **Figure 3,** are important for understanding riparian vegetation growth along the Colorado River. These four zones include (1) the Pre-Dam Flood Terrance or desert, (2) the Old High Water Zone, (3) the New High Water Zone, and (4) the Fluctuating Zone or Annual Flood Zone. The types of plant species that grow within each of these zones have similar responses to moisture gradients, tolerance to water stress and modes of reproduction (USBR, 2016). Beginning with the Pre-Dam Flood Terrace or Desert zone, this is the zone at the highest elevation and flow stage (**Figure 3**). Prior to the construction of the dam, the Flood Terrace was a distinct area above the Old High Water Zone, occupied by drought-tolerant desert species as it is an area that rarely experiences moisture (USBR). Two characteristic species of this zone are Brittlebush (*Encelia frutescens)* and Barrel Cactus *(Echinocactus polycephalus*) both of which are highly adapted to dry environments and can survive in droughts (USBR, 2016). Since the construction of the dam, the amount of species inhabiting the Flood Terrace Zone are decreasing or moving downslope into the Old High Water Zone (USBR, 2016). Pre-Dam, the Old High Water Zone supported drought-tolerant species found in upland habitat such as the netleaf hackberry (*Celtis occidentalis)*, ocotillo (Fouquieria splendens), Apache plume (*Fallugia paradoxa*) and cat claw acacia (*Acacia greggii*) (USBR, 2016). Species such as the Mesquite (*Prosopis glandulosa*) and hackberry (*Celtis occidentalis*) are no longer recruiting in this zone due to the low availability of water and nutrients (USBR, 2016). On average the Old High Water Zone would be inundated with pre-dam flow levels of 120,000 cfs up to 200,000 cfs during flood seasons (USBR, 2016). Post-dam, due to the lower average flows, the upper margins of this zone are moving downslope causing this zone to narrow (USBR, 2016). The lower flow years post-dam resulted in riparian vegetation being permitted to develop below the Old High Water Zone, resulting in the vegetation establishment in the New High Water Zone. The New High Water Zone is inundated by flows up to 45,000 cfs (USBR, 2016). Riparian vegetation supported in this zone is mainly woody riparian species and scrub communities (USBR, 2016). This includes native species such as Arrowweed (*Pluchea Sericea*), Coyote Willow (*Salix exigua*) and seepwillow (*Baccharis salicifolia*), and non-native species such as Tamarisk (*Tamaricaceae Tamarix chinensis*) (USBR, 2016).

Tamarisk is the most prominent invasive riparian species in the Grand Canyon and existed in the park even in the pre-dam period. Tamarisk plants accumulate salt on their leaf surfaces (USBR, 2016).

When the leaves drop, this salt then accumulates on and within the surface layer of the soil (USBR, 2016). This resulting high soil salinity is not ideal for the germination and establishment of native species. This also gives Tamarisk an advantage over native species that require access to groundwater such as the cottonwood or willow in areas where salinities are elevated. In 2001, as a way to control this quickly spreading invasive plant, the Tamarisk leaf beetle was released by the U.S. Department of Agriculture to defoliate and control their spread (USBR, 2016). However, the tamarisk plant also provides habitat for the Southwestern Willow Flycatcher, a small songbird currently listed on the Endangered Species List. The Southwestern Willow Flycatcher breeds in lush, dense vegetation along rivers and streams from May through September (USBR, 2016).

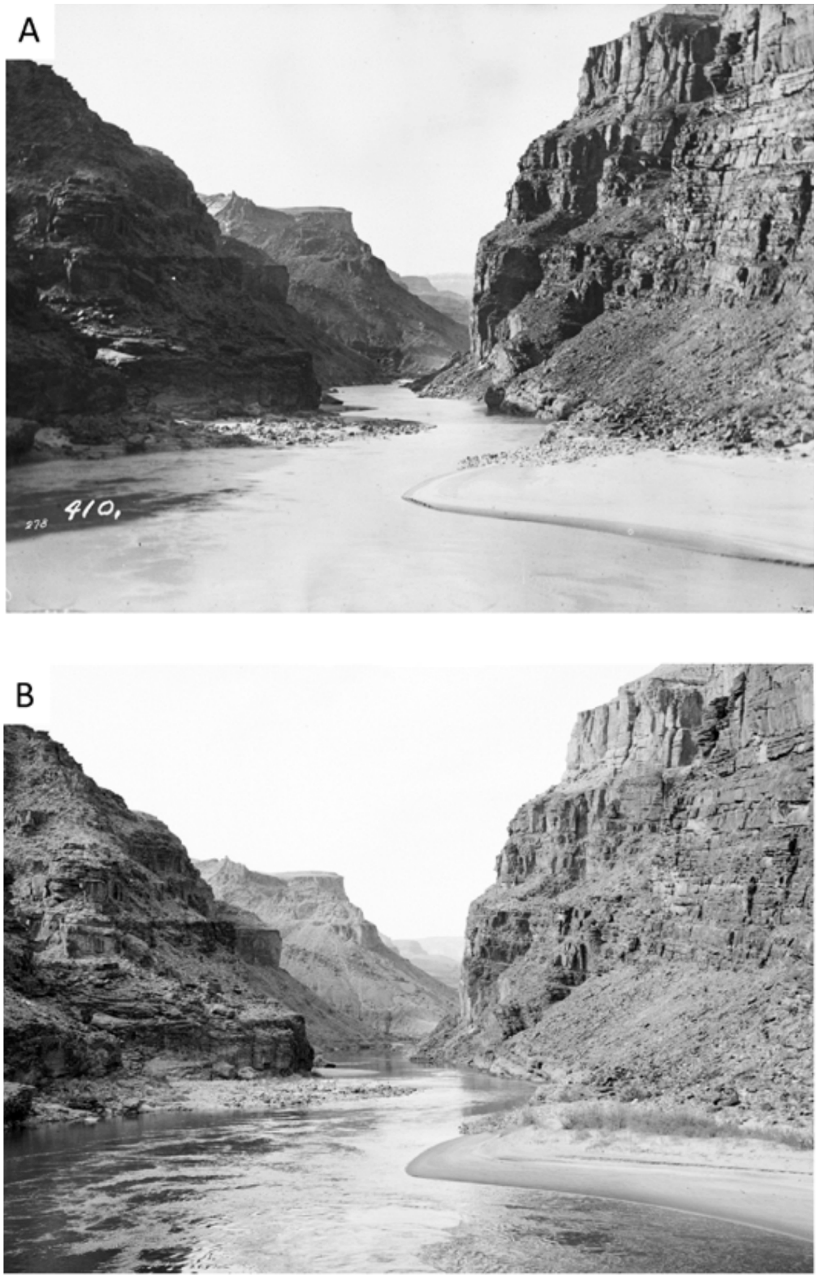
The last hydrologic zone that is important in understanding riparian vegetation along the Colorado River is the Fluctuating Zone. This zone was established post-dam and is the hydrologic zone that is inundated daily with discharges up to 20,000 cfs.The species that occupy this zone are mainly flood-tolerant marsh species such as the Tule Reed (*Schoenoplectus acutus*). This buoyant native reed was used for thousands of years by the First Nations people of the lower Colorado River, including the Mohave and Cocopah peoples (Martin, 2021).

Case Studies

Since the construction of Glen Canyon Dam and even more so since the release of the first Glen Canyon Dam Environmental Impact Report in 1995, extensive research has been conducted to investigate how riparian vegetation has responded to the lower average daily flows. Beginning with a research study by Palmquist, et al., in 2018, researchers studied the landscape-scale processes that influence riparian plant composition in regulated rivers such as the Colorado River (Palmquist, et al., 2017). They utilized hierarchical frameworks as a method of analyzing landscape-scale factors that play a role in riparian vegetation changes over time (Palmquist, et al., 2017). Specifically, using R-programming software (version 3.2.1), Palmquist, et al., identified floristic groups using both a Hierarchical Cluster Analysis (HCA) and an Indicator Species Analysis (ISA) (Palmquist, et al., 2017). The results of this analysis provided insight into which species are characteristic of each floristic group. One of the important findings from this study was that riparian community compositions can change drastically over relatively short longitudinal gradients and that of their three study areas, Marble Canyon, Eastern Grand Canyon, and Western Grand Canyon, the two later had the highest rates of shrubs and perennial grasses. Researchers in this study note that riparian vegetative management needs to account for different environments and ecological conditions (Palmquist, et al., 2017).

In another study, Ralston, et al., utilizes another unique method for evaluating riparian vegetation responses to the dynamic flows of the Glen Canyon Dam. In this study, researchers conduct frame-based, state-and-transition prototype modeling for riparian vegetation downstream of the Dam (Ralston, et al., 2014). Frame-based modeling methods include both Microsoft Excel spreadsheets and C sharp programming to look at the transition between states of seven plant communities across five dam operations (Ralston, et al., 2014). This type of research method is ultimately used to help identify the ecological drivers and flow patterns that result in riparian vegetative state changes over a desired period of time (Ralston, et al., 2014). The resulting prototype model can be used to test alternative flow options and ideally find the most efficient flow for both ecological and economic sustainability (Ralston, et al., 2014). The downside of this method is the assumption that the predicted riparian responses are correct, especially with the high level of uncertainty associated with drought, climate change, and stakeholder decisions.

Scott, et al., approaches the study of riparian vegetation changes in a completely different way than Palmquist et al. and Ralston, et al. Scott, et al., conducts a study that evaluates the changes in riparian vegetation along the Colorado River with a research method that recognizes the extent of pre-dam photographic documentation and thus utilizes this visual record to compare pre-development conditions to post-development conditions (Scott, et al., 2018). Using a total of 445 photographs, some of which date back to 1889, provide an actual visual record of changes to riparian vegetation over time relative to the changing Glen Canyon Dam flow regime (Scott, et al., 2018).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Figure(s) 4. A set of three photographs taken in the Upper Grand Canyon in (A)1890, (B)1991, and (C) 2011, portraying vegetation encroachment (Scott, et al., 2018). Tamarisk is shown in photos B and C to increase in size and number (Scott, et al., 2018). Native vegetation present in this photograph includes sand-bar willow, arrow-weed and seep-willow (Scott, et al., 2018).

This research by Scott, et al., contributed heavily to riparian vegetation research (Scott, et al., 2018). Based on their photographic analysis, they found that Tamarisk was found in 79.5 percent of the views that they examined from 1989 to 1992 (Scott, et al., 2018). Furthermore, between 2010 and 2012, there was little apparent change to vegetative composition (Scott, et al., 2018). Their research can be used as a reference for future research to predict changes in riparian vegetation changes in times of drought, resulting in low flows.

Conclusion

Research methods such as frame-based modeling techniques, and historical data such as photographic records have contributed greatly to the knowledge and understanding of how riparian vegetation has responded to dramatic changes in river flows since the closure of Glen Canyon Dam. Policies specific to environmental flows will be not only beneficial but key for riparian vegetative management as the Colorado River experiences more drought and lower water levels. Adaptive management will be essential to protect Grand Canyon native riparian plant species and manage the spread of invasive species such as the Tamarisk. Specifically, policy and management that understand how the timing and duration of flows needs to coincide with the reproductive periods and methods of native plants and avoid high flows during months where the Tamarisk is seeding and can germinate and be transported via flooding. The more research that is conducted on riparian vegetative growth patterns as these plants respond to dam flows, climate change and tourism, the better adapted policy makers, and environmental managers will be to the overall uncertainty of the future.

References

Durning, L.E. (2016). Map of Colorado River in Grand Canyon. USGS. https://www.usgs.gov/media/images/map-colorado-river-grand-canyon

Martin, T. (2021, January 29). A tule reed boat runs the Grand Canyon. The U.S. Department of the Interior Bureau of Land Management. https://www.blm.gov/blog/2021-02-24/tule-reed-boat-runs-grand-canyon

McCoy-Sulentic, M.E., Kolb, T.E., Merritt, D.M., Palmquist, E., Ralston, B.E., Sarr, D.A., Shafroth, P.B. (2017). Changes in Community-Level Riparian Plant Traits over Inundation Gradients, Colorado River, Grand Canyon. Wetlands, 37, (635-646). https://doi.org/10.1007/s13157-017-0895-3.

Palmquist, E.C., Ralston, B.E., Sarr, D., Merritt, D.M., Shafroth, P.B., Scott, J.A. (2017). Functional traits and ecological affinities of riparian plants along the Colorado River in the Grand Canyon. Western North American Naturalist, 77(1), 22-30. https://scholarsarchive.byu.edu/cgi/viewcontent.cgi?article=1801&context=wnan.

Palmquist, E.C., Ralston, B.E., Sarr, D., Merritt, D.M., Shafroth, P.B. (2018). Landscape-scale processes influence riparian plant composition along a regulated river. Journal of Arid Environments, 148, 52-64. https://doi.org/10.1016/j.jaridenv.2017.10.001.

Ralston, B.E., Starfield, A.M., Black, R.S., Van Lonkhuyzen, R.A. (2014). State-and-transition prototype model of riparian vegetation downstream of Glen Canyon Dam, Arizona. U.S. Geological Survey. U.S. Geological Survey Open-File Report 2014-1095, 26 p., http://dx.doi.org/10.3133/ofr20141095.

Scott, M.L., Webb, R.H., Johnson, R.R., Turner, R.M., Friedman, J.M., Fairley, H.C. (2018). Chapter 9: Evaluating Riparian Vegetation Change in Canyon-Bound Reaches of the Colorado River Using Spatially Extensive Matched Photo Sets. USDA Forest Service. https://www.fs.usda.gov/rm/pubs_series/rmrs/gtr/rmrs_gtr377/rmrs_gtr377_148_173.pdf.

USBR. (2023). Glen Canyon Unit. Bureau of Reclamation. https://www.usbr.gov/uc/rm/crsp/gc/.

USBR. (2016). Section 3.6: Vegetation, Chapter 3: Affected Environment, Glen Canyon Dam Long-Term Experimental and Management Plan FEIS. Bureau of Reclamation. National Parks Service. https://ltempeis.anl.gov/documents/final-eis/.