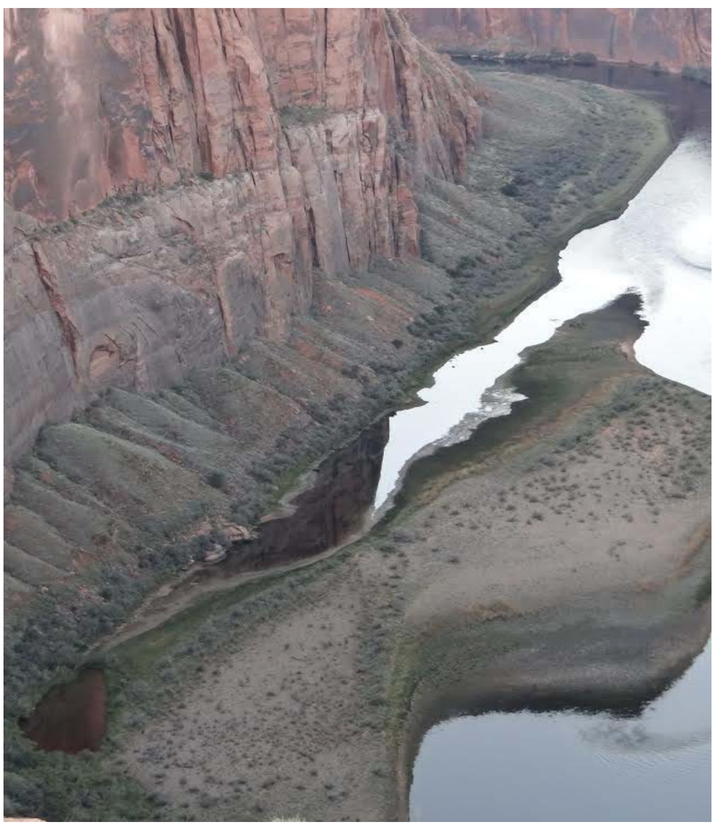
RECLAMATION
Managing Water in the West

Technical Report No. SRH 2018-17

Temperature Reduction Options for Glen Canyon Slough; RM -12

Upper Colorado Regional Office
Colorado River, AZ



U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, CO

May 2018

Mission Statements

The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Temperature Reduction Options for Glen Canyon Slough; RM -12

Upper Colorado Regional Office

Technical Report No. SRH-2018-17

Peer Review Certification: This document has been peer reviewed and is believed to be in accordance with the service agreement and standards of the profession.

PREPARED BY:

____

Blair Greimann, Ph.D., P.E.
Hydraulic Engineer
Sedimentation and River Hydraulics Group (85-824000)

____

Michael Sixta, M.S., P.E.
Hydraulic Engineer
Sedimentation and River Hydraulics Group (85-824000)

PEER REVIEWED BY:

____

Timothy J. Randle, Ph.D., P.E., D.WRE.
Supervisory Hydraulic Engineer
Manager, Sedimentation and River Hydraulics Group (85-824000)

Contents

Figures

Tables

Introduction

At the request of the Bureau of Reclamation's (Reclamation) Upper Colorado (UC) Regional Office, the Sedimentation and River Hydraulics Group developed and analyzed options for reducing the temperature in the upper slough (Upper Slough) that is located on the Colorado River in Glen Canyon at approximately RM -12, roughly 3.5 river miles downstream of Glen Canyon Dam (Figure 1). The goal of this project is to cool water temperatures in the Upper Slough so that invasive Green sunfish (*Lepomis cyanellus*) and other warm water fish do not find warm water conditions that allow them to propagate in this off channel slough area.

All elevations presented in this report are based on surface data from the USGS that are in ellipsoid height utilizing the NAD83 (2011), StatePlane, Arizona Central spatial reference.

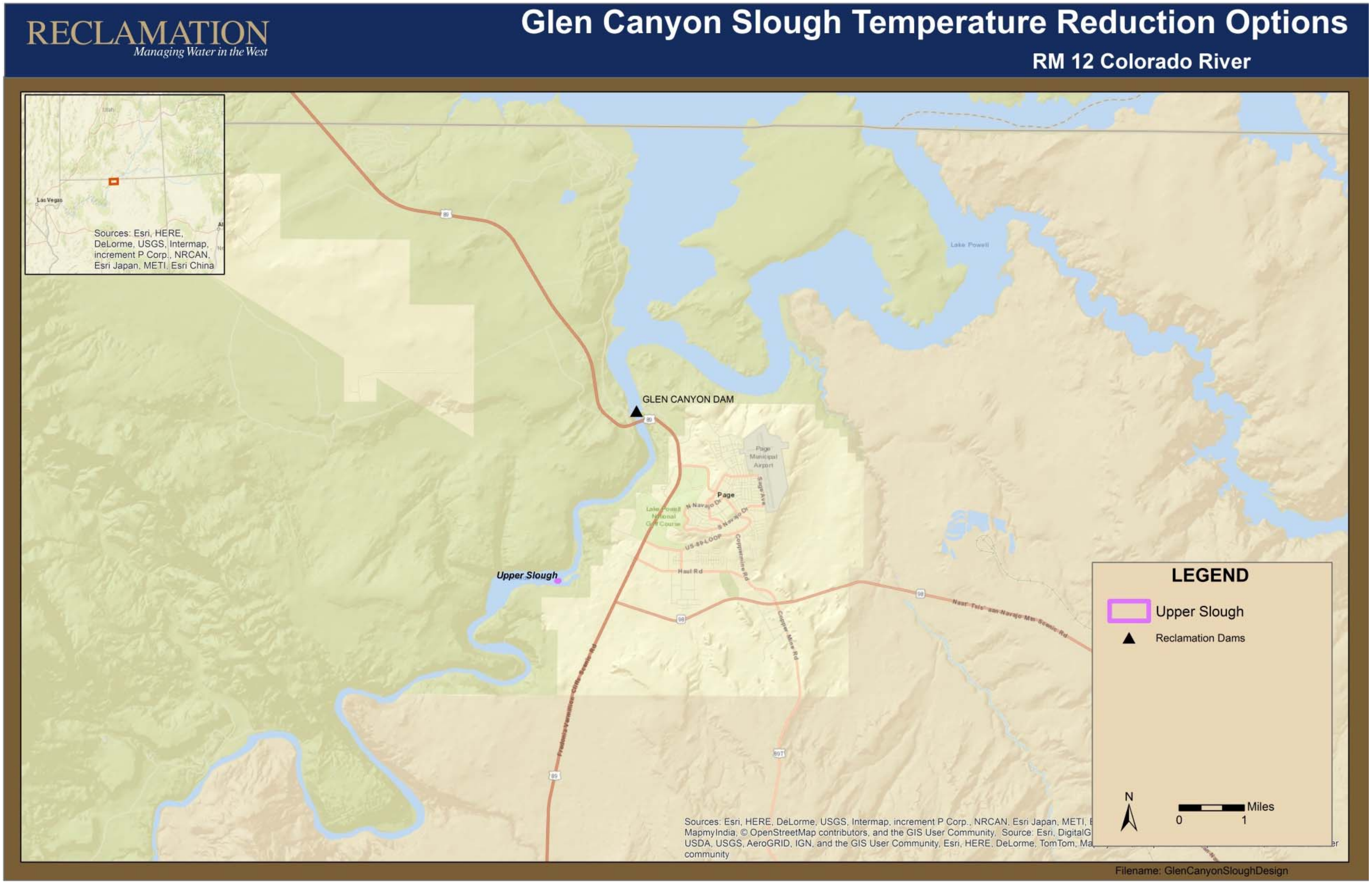


Figure 1. Vicinity map of the Glen Canyon Slough.

Existing Conditions

Hydrology

The flows at the Glen Canyon Slough are almost completely controlled by releases from Glen Canyon Dam. In December of 2016, The U.S. Department of Interior released the Record of Decision for the Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP) Final Environmental Impact Statement (FEIS). The proposed Federal action considered in the LTEMP FEIS is the development and implementation of a structured, long-term experimental and management plan for operations of Glen Canyon Dam. The LTEMP will provide a framework for adaptively managing Glen Canyon Dam operations and other management and experimental actions over the next 20 years, consistent with the Grand Canyon Protection Act (GCPA) and other provisions of applicable federal law.

Therefore, the simulated proposed flows for the preferred alternative chosen were used as the basis for this design. The flows were provided by Argone National Laboratory on Jan 19, 2018. The flows correspond to the GTMax run 2 values for altT, which represent D4 (the hybrid alternative version chosen for comparison to other alternatives), as referenced in the LTEMP FEIS. The 21 twenty-year hydrologic traces, corresponding to the median sediment trace, were utilized.

An example hydrograph for July and August of the simulated year 2015 is shown in Figure 2, with five of the 21 traces shown. During most days, there can be significant hydropeaking with minimum flows of approximately 8,000 ft^3/s and maximum flows of 22,000 ft^3/s. There can also be extended periods of high flow with flows over 30,000 ft^3/s. The flow duration curve for all 21 traces is shown in Figure 3, broken out by season. The 95% exceedance flow is approximately 7,000 ft^3/s and the 10 % exceedance flow is approximately 20,000 ft^3/s for all seasons combined. The flows during the summer months (June, July, and August) are typically higher than the average flow throughout the year.

The percentage of days in which there is an hourly flow that exceeds a given flow threshold is shown in Figure 4. Three different key flows are noted in the figure whose significance will be discussed later in the report. Also of note is the distinction of the April through September time period. The significance of this refers to the estimated total time period when the Upper Slough is 70 degrees F or warmer, and relates to Option #1.2 as described below.

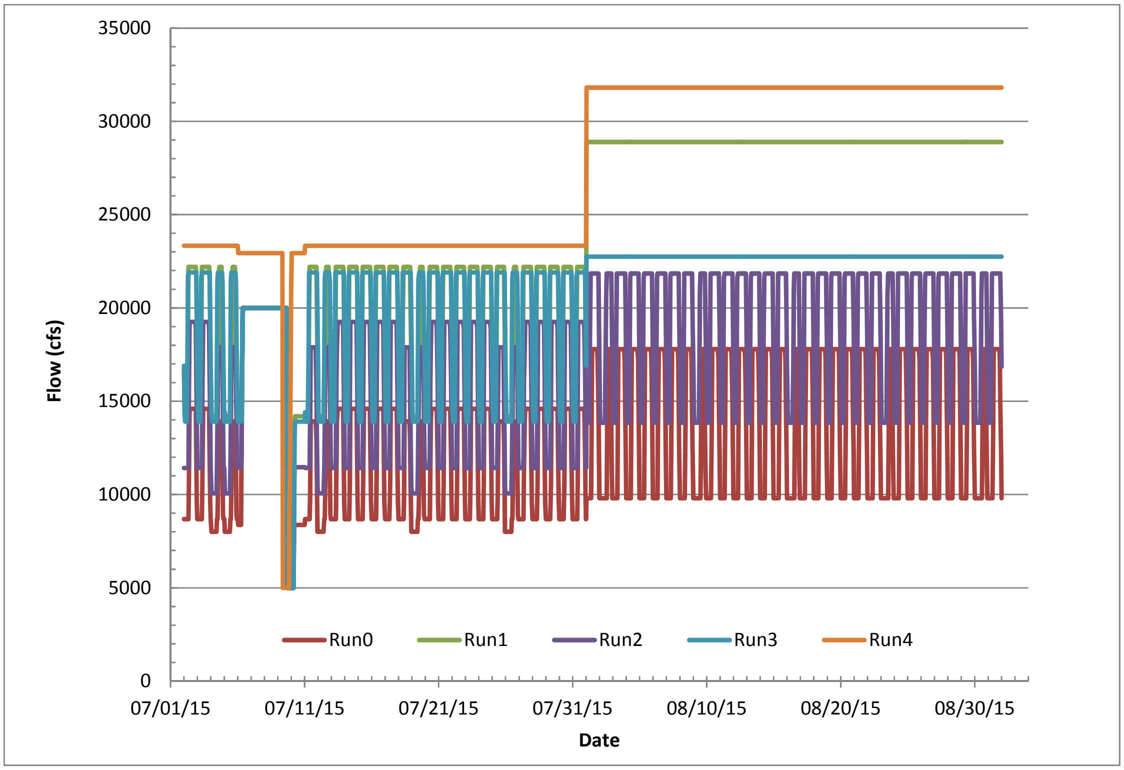


Figure 2. Example simulated hydrograph for 4 hydrologic traces showing typical hourly variation of flow in July and August.

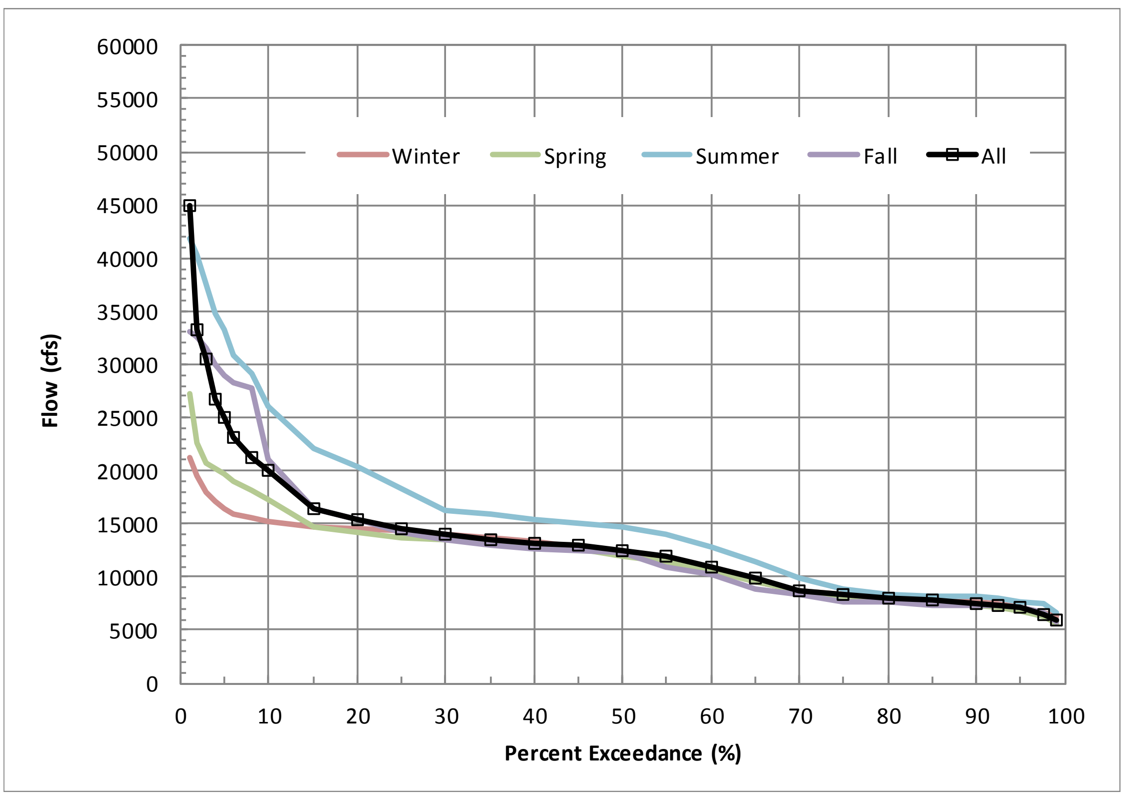


Figure 3. Percent exceedance for all 21 hydrologic traces.

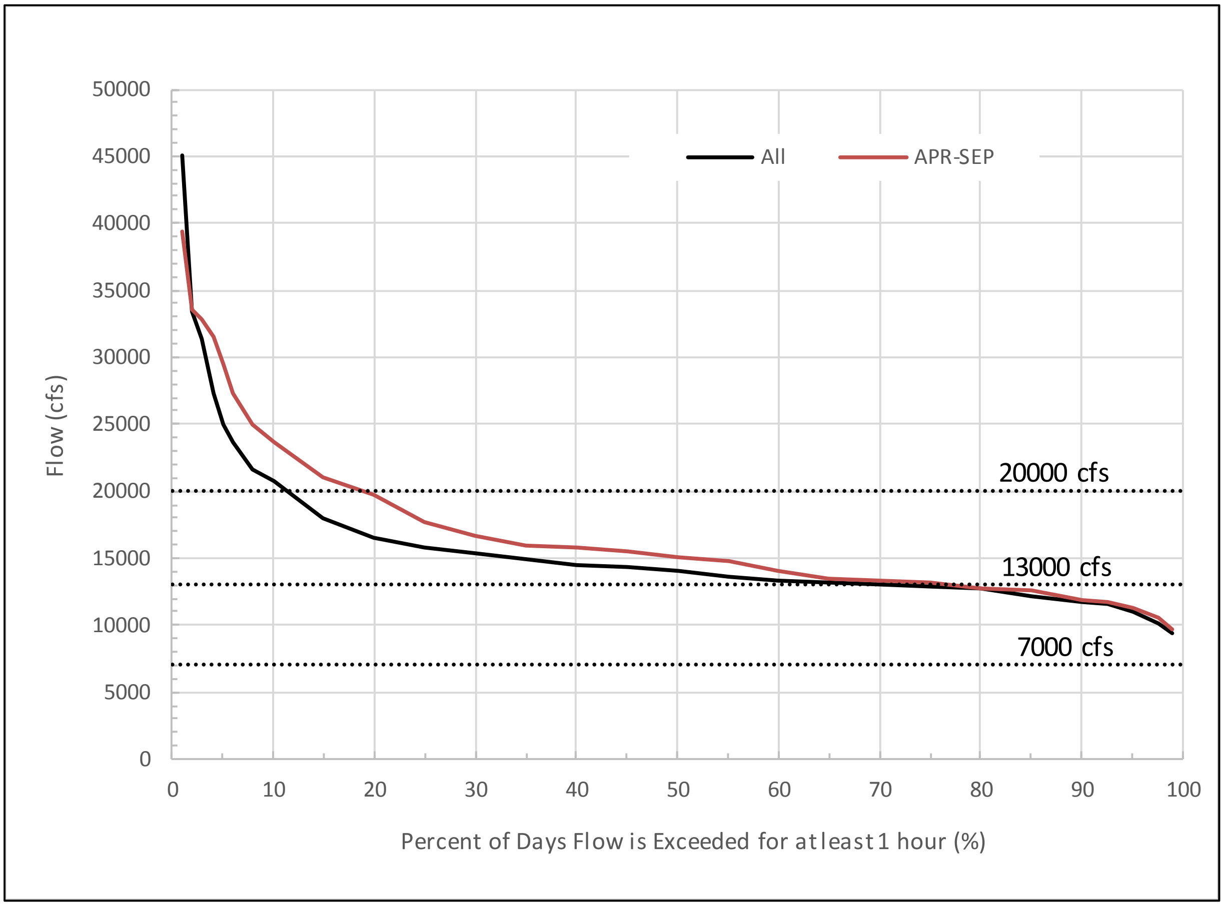


Figure 4. Percent of days at which different flow magnitudes are exceeded for at least 1 hour for all 21 hydrologic traces.

Hydraulics

Existing Conditions Topography

A Digital Elevation Model (DEM) of the Colorado River and surrounding canyon was obtained from the U.S. Geological Survey (USGS). The provided DEM was a raster image mosaic that included both aerial LiDAR topography collected in 2009 and bathymetry (under water) data that was collected during the 2014 high flow event (T. Gushue, USGS, written comm.). The DEM extended from Glen Canyon Dam down to Lee's Ferry (~16 mi downstream from the dam). The spatial reference for the DEM was NAD 1983 (2011), StatePlane, Arizona Central, meters; the vertical datum of the DEM was in ellipsoid height (meters). For data consistency, all hydraulic modeling was performed using metric units that was later converted to English units. Resulting elevations were not converted from ellipsoid heights to orthometric heights (ground elevations) so the proposed alternatives would remain comparable relative to one another. This would need to be done prior to final design by applying a geoid model. Figure 8 shows an existing conditions topographic map of the project area.

Existing Conditions Hydraulics Analysis

The numerical model utilized for this assessment was the fixed bed version of SRH-2D (Lai, 2008), a two-dimensional (2D) depth-averaged hydraulic model specifically focused on the flow hydraulics of river systems. SRH-2D adopts a zonal approach for coupled modeling of channels and floodplains. A river system is broken down into modeling zones (delineated based on natural features such as topography, vegetation, and bed roughness), each with unique parameters such as flow resistance. One of the main features of SRH-2D is the use of an unstructured hybrid mixed element mesh, which is based on the arbitrarily shaped element method of Lai (2000) for geometric representation. This meshing strategy is flexible enough to facilitate the implementation of the zonal modeling concept, allowing for greater modeling detail in areas of interest ultimately leading to increased modeling efficiency through a compromise between solution accuracy and computing demand. Other notable capabilities of SRH-2D include the following (Lai, 2008):

- SRH-2D solves the 2D depth-averaged dynamic wave equations (St. Venant equations) using a finite volume numerical methodology;
- Both steady and unsteady flows may be simulated;
- An implicit scheme is used for time integration to achieve solution robustness and efficiency;
- All flow regimes (i.e. subcritical, transcritical, and supercritical) may be simulated simultaneously without the need for special treatments;
- SRH-2D contains a robust and seamless wetting-drying algorithm; and,
- Solution domain may include a combination of main channels, overland flow, and floodplains.

A pre-existing SRH-2D model was utilized for this effort. The model domain utilized the same downstream boundary condition and channel roughness coefficient, while the mesh was refined in the area of interest (Upper and Lower Sloughs). For more model specifics refer to Foster et al., 2017.

The water surface elevations upstream and downstream of the slough were calculated for a range of flow conditions to provide input on design features. The locations and corresponding resulting rating curves with labeled pertinent design features are shown in Figure 5 and Figure 6, respectively. According to the ground surface profile leading from the Colorado River into the Upper Slough, a water surface elevation of roughly 3057 ft starts to inundate the Upper Slough, which corresponds to an approximate main channel discharge of 20,000 ft^3/s.

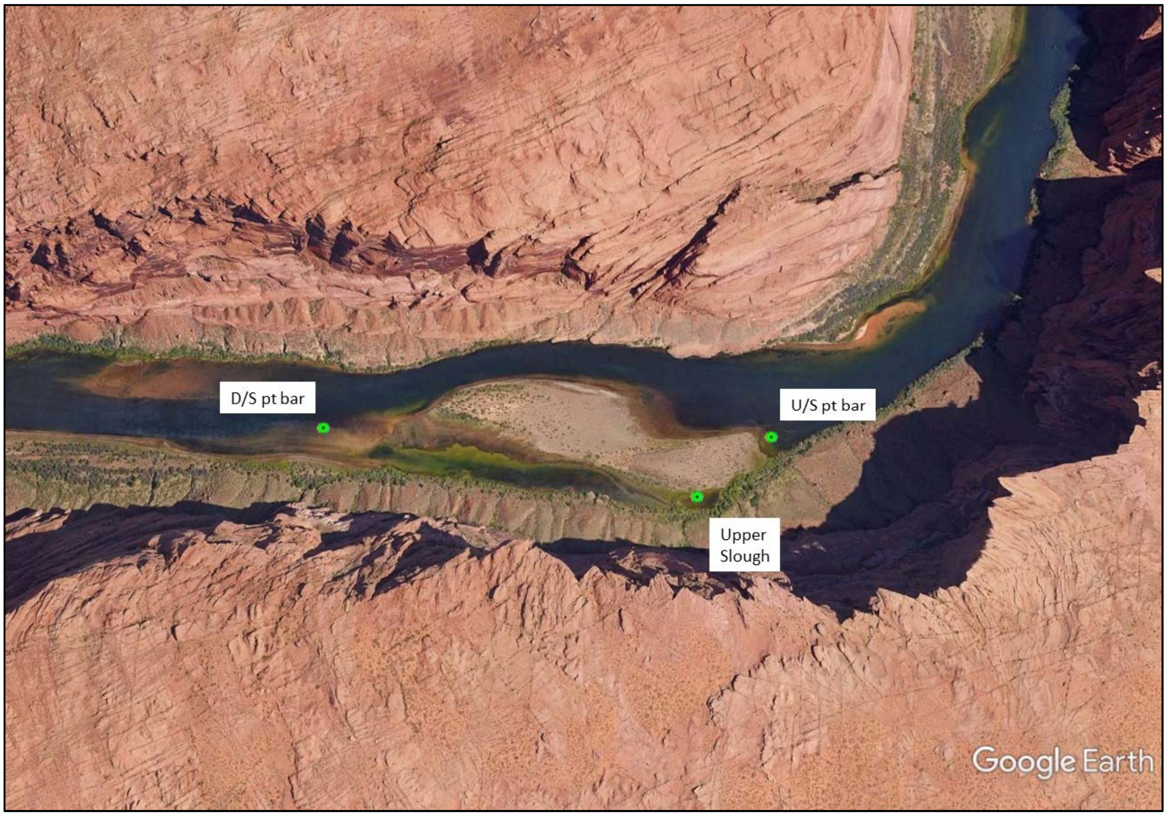


Figure 5. General locations of Upper Slough and rating curves.

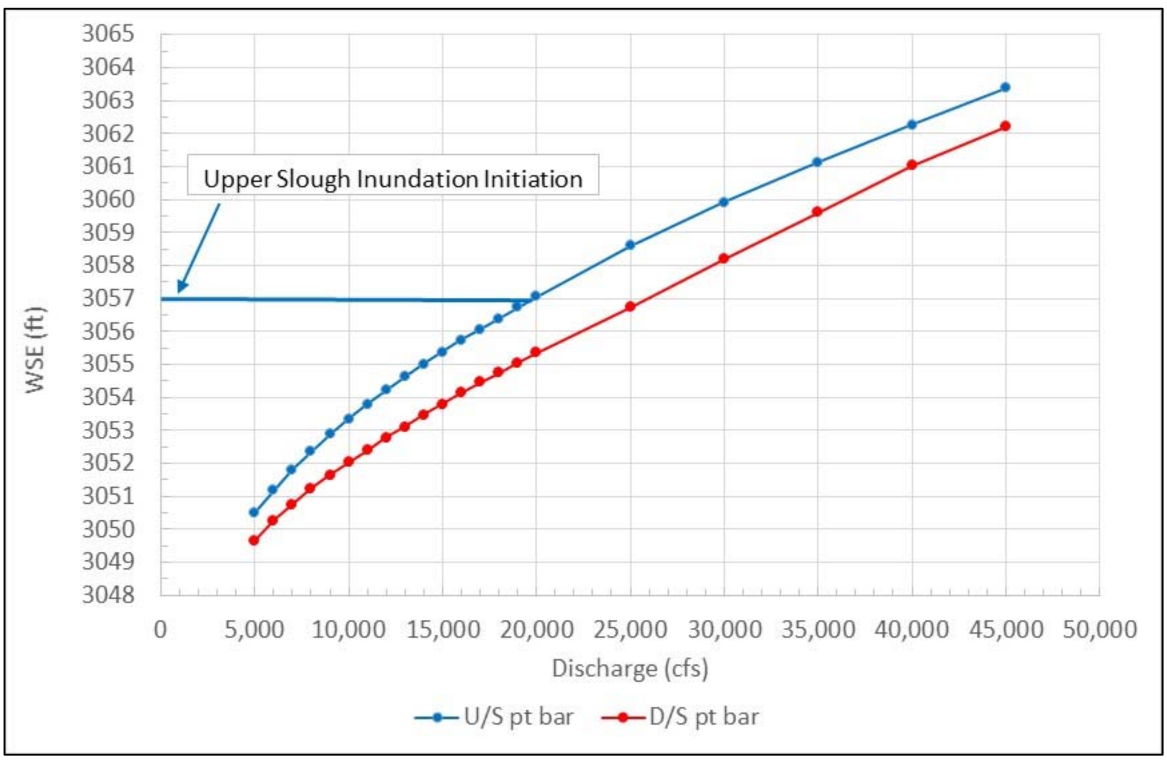
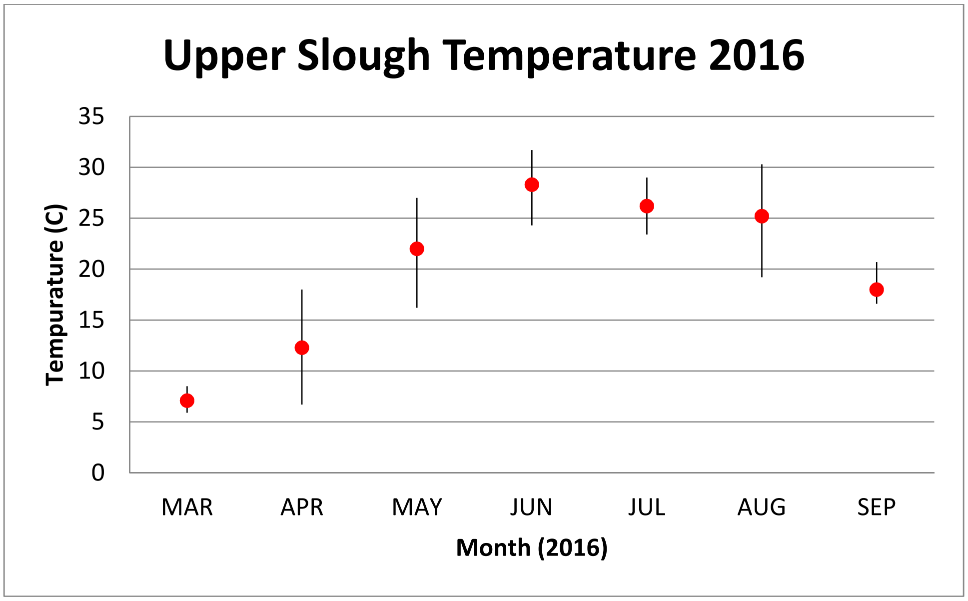


Figure 6. Hydraulic rating curves upstream and downstream of the Slough and point bar.

Existing Temperatures

The existing temperatures were provided from the National Park Service (NPS) and given in Figure 7 (Arizona Game and Fish Department (AGFD) temperature data). Data show the median Upper Slough temperature is 17.8 degrees Celsius warmer than the main channel temperature during the month of June in 2016.



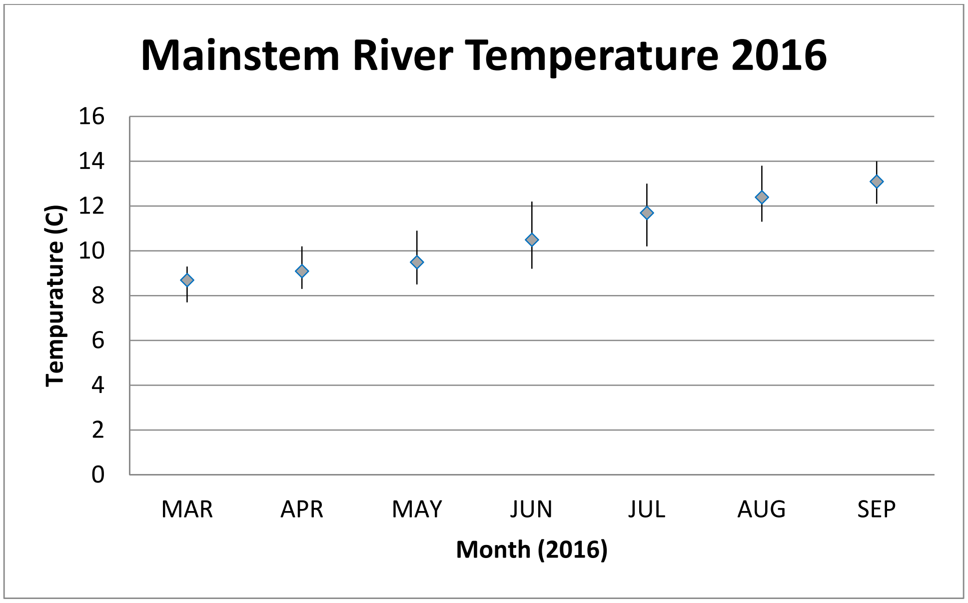


Figure 7. Monthly temperatures in Celsius (maximum, minimum, and average) from the Upper Slough, and the main channel river at Lees Ferry gage from 2016.

Design Criteria

The central design criteria used in this report is the elimination of the Green sunfish habitat. To meet this design criteria, either the water needs to be drained from the Upper Slough, the Upper Slough needs to be filled in, or a water temperature goal needs to be met. The temperature goal was deemed to be met when the Upper Slough temperature is lowered to where it is within 1 degree C of the main river temperature, or 13 degrees Celsius, whichever is highest. The other design criterion is a requirement that no fill material can be brought to the site or taken from the site due to difficult site access issues.

Options Considered

Option #1: Cut channel from the main river to the Upper Slough

Option #1.1: Lower elevation cut channel without filling the Upper Slough

The main feature of this option is a channel cut from the main river to the upper slough to lower the water temperature. The channel was sized so that it would provide enough water to meet the temperature criteria stated previously, meaning that the temperature rise in the Slough would be less than 1 degree C warmer than the main river channel. A simple energy calculation was performed to determine the required flow rate into the upper slough to maintain lower temperatures, and then the channel was sized to initiate flow into the Upper Slough when the flow in the main channel is at least 6,000 ft^3/s. According to the flow-duration curve (Figure 4), this flow is exceeded daily. As the main channel flow increases, the flow though the Slough would also increase and decrease the temperature differential between the main channel and the Slough.

The design invert of the channel was chosen to be 3051.2 ft with a bottom width of 10 ft and 3H:1V side slopes. The average depth of cut is expected to be 5 ft. The length of the cut would be approximately 430 ft and have a volume of 1400 yd^3. Using the rating curve information (Figure 6), at a main channel flow of 7,000 ft^3/s (95% exceedance flow) the approximate depth in the channel will be 0.6 ft. Assuming the average water surface slope through the Slough would be equal to the water surface slope in the main channel, the approximate flow rate through the Slough would be 6 ft^3/s.

The approximate volume of water in the slough at a flow rate of 7,000 cfs in the main steam is 600 yd^3. Assuming that the warming in the Slough is primarily due to the solar energy supplied to it, it is possible to calculate the rise in temperature in the Slough. The amount of solar energy supplied to the water is assumed to be 50 % of the average solar irradiance at the edge of the atmosphere, which is assumed to be 1361 W/m^2 (Coddington et al., 2016). The equation used to predict the warming of water in the Upper Slough due to solar heating is:

$$\Delta T = \frac{IA}{C_p \rho Q}$$

Where: ΔT = rise in water temperature in Upper Slough (C),
I = solar irradiance at the Upper Slough (J/s/m^2),
A = area of the Upper Slough (m^2),
C_p = specific heat of Water (4814 J/kg/C),
ρ = density of Water (1000 kg/m^3), and
Q = flow rate of water (m^3/s)

If 6 ft^3/s is supplied to the Slough, the approximate residence time of water in the Slough is slightly less than 1 hr and the amount of warming possible in that 1 hr is less than 1 degree C (see Table 1).

Eventually, this channel is expected to fill with sediment entering the main channel from canyon wall side-cast material and localized upstream drainages or get modified during high flow events. However, the rate of filling would likely be rather slow because of the low sediment supply being only 3.5 miles downstream of the Glen Canyon Dam. Removal of large rockfall into the channel from the nearby cliffs may also require periodic maintenance with heavy equipment.

Table 1. Value of parameters sued to predict temperature rise in Upper Slough.

Variable	Description	Value
I	solar irradiance	684 J/s/m^2
C_p	specific heat	4186 J/kg/C
ρ	water density	1000 kg/m^3
A	surface area	1000 m^2
Q	Q	0.17 m^3/s
ΔT	rise in temperature	0.96 C

Option #1.2: Higher elevation cut channel with filling the Upper Slough

This option is similar to Option #1.1, but the channel is cut to a higher elevation and the resulting material is placed within the Upper Slough to essentially fill the Upper Slough to the elevation of the cut channel. For preliminary design purposes, the elevation of the cut channel and Upper Slough was set to 3054.5 ft. The cut channel would have a bottom width of 20 ft with 3H:1V side slopes. The resulting volume of cut and fill is approximately 600 yd^3. The comparison of existing and proposed topographic surfaces for this option is shown in Figure 8 and Figure 9, respectively, highlighting the vision of this design.

With this option, the channel starts to activate at a main channel flow of roughly 13,000 ft^3/s. The Upper Slough becomes essentially an extension of the cut channel as it too would only have water at a flow of 13,000 ft^3/s and higher. Should warmer water temperatures develop in the Lower Slough, this option would provide cooler river water to the Lower Slough in order to limit spawning by non-native species such as small-mouth bass. The channel may need to be deeper (i.e. Option #1.1) if continuous flow of cold water was needed to remove the favorable spawning conditions in the Lower Slough.

This option was modeled using SRH-2D. Depth results for flow conditions at the start of channel activation (13,000 ft^3/s) and the highest modeled flow (45,000 ft^3/s) are shown in Figure 10 and Figure 11, respectively. According to the flow-duration curve (Figure 4), a flow of 13,000 ft^3/s will be exceeded for at least 1 hour 75% of the days between April 1 through September 30. Therefore, there will be water flowing from the main channel of the river into the filled-in Upper Slough, lowering the water temperature, on 75% of the days.

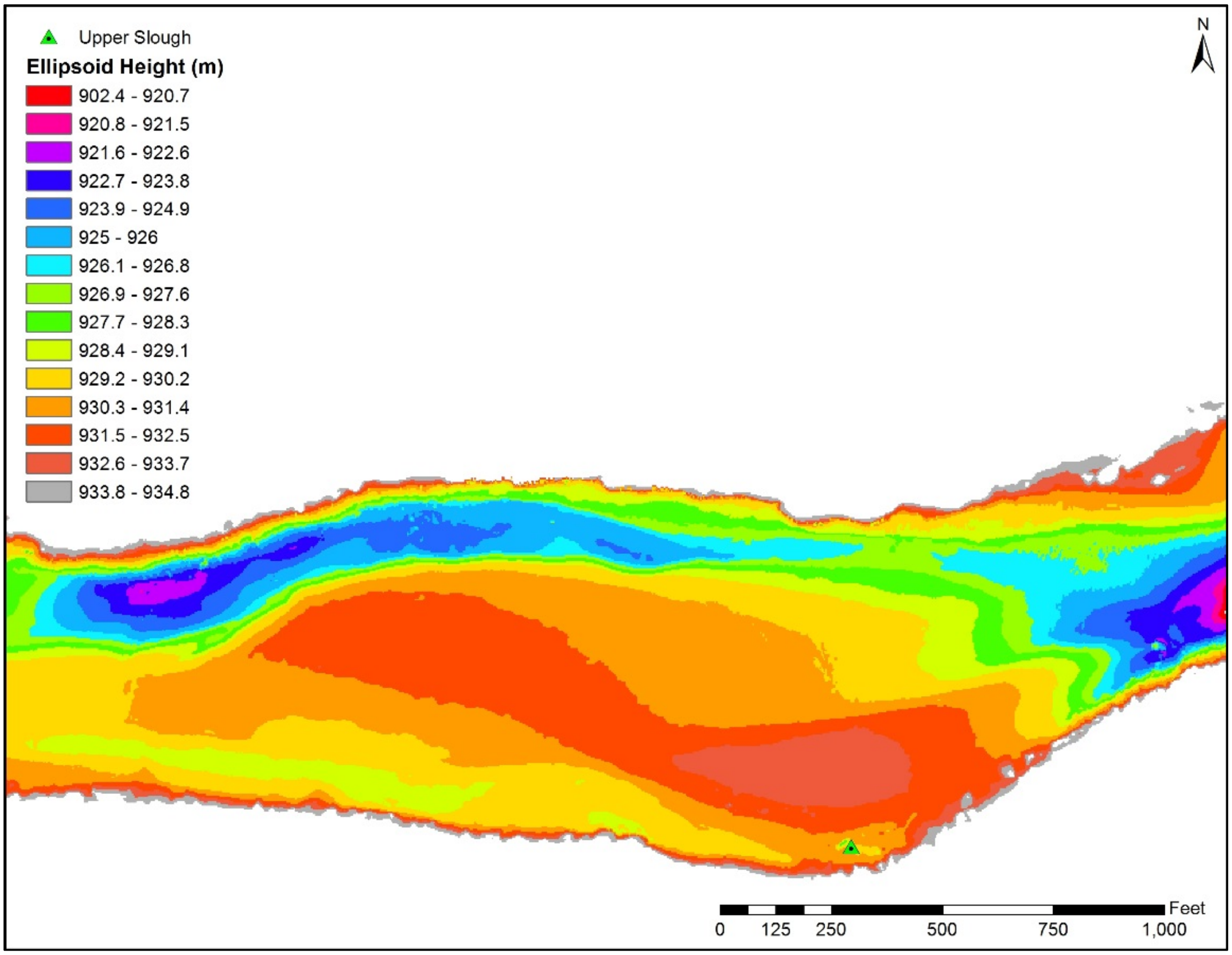


Figure 8. Existing conditions topography in vicinity of Upper Slough.

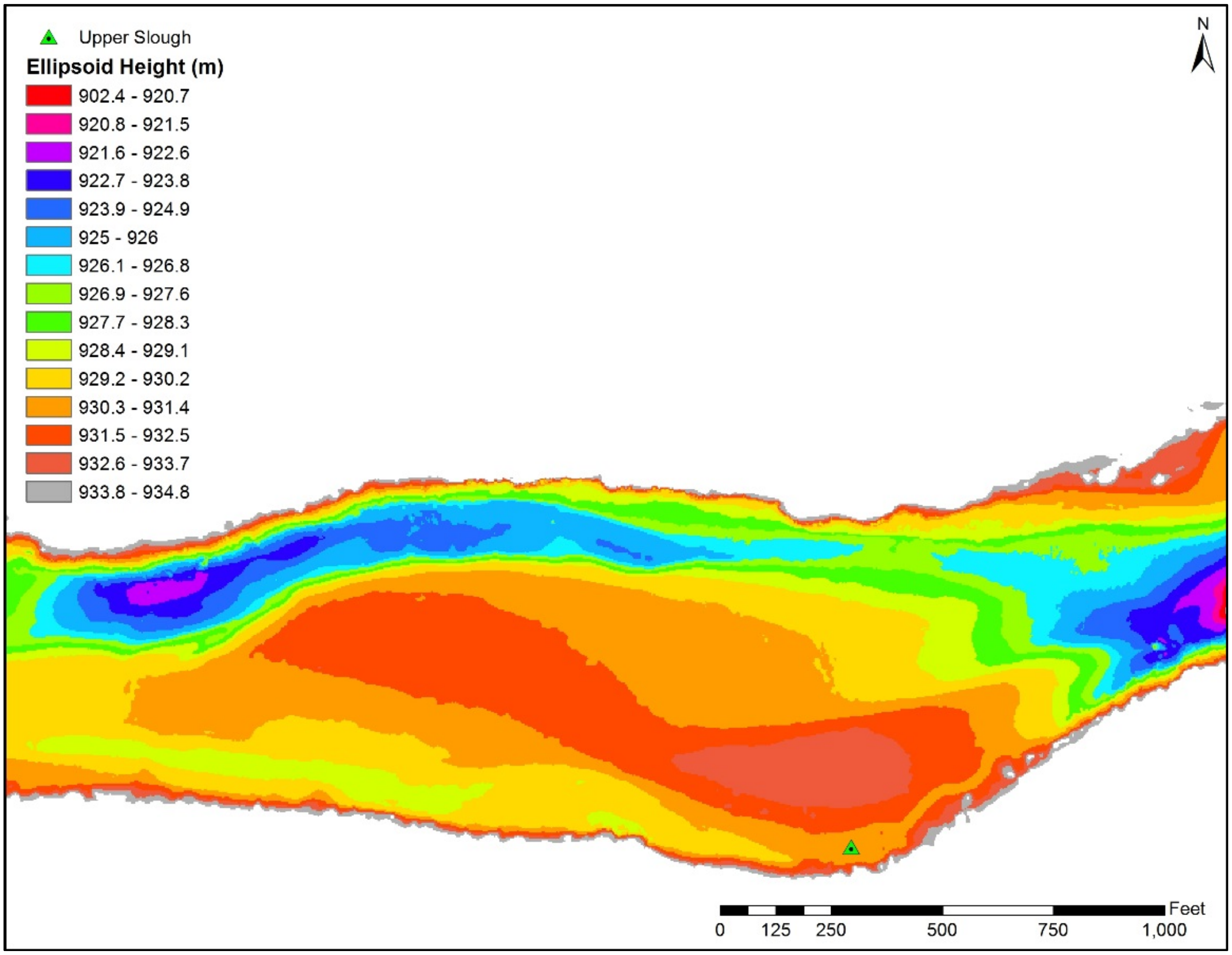


Figure 9. Option #1.2 topography in vicinity of Upper Slough after construction.

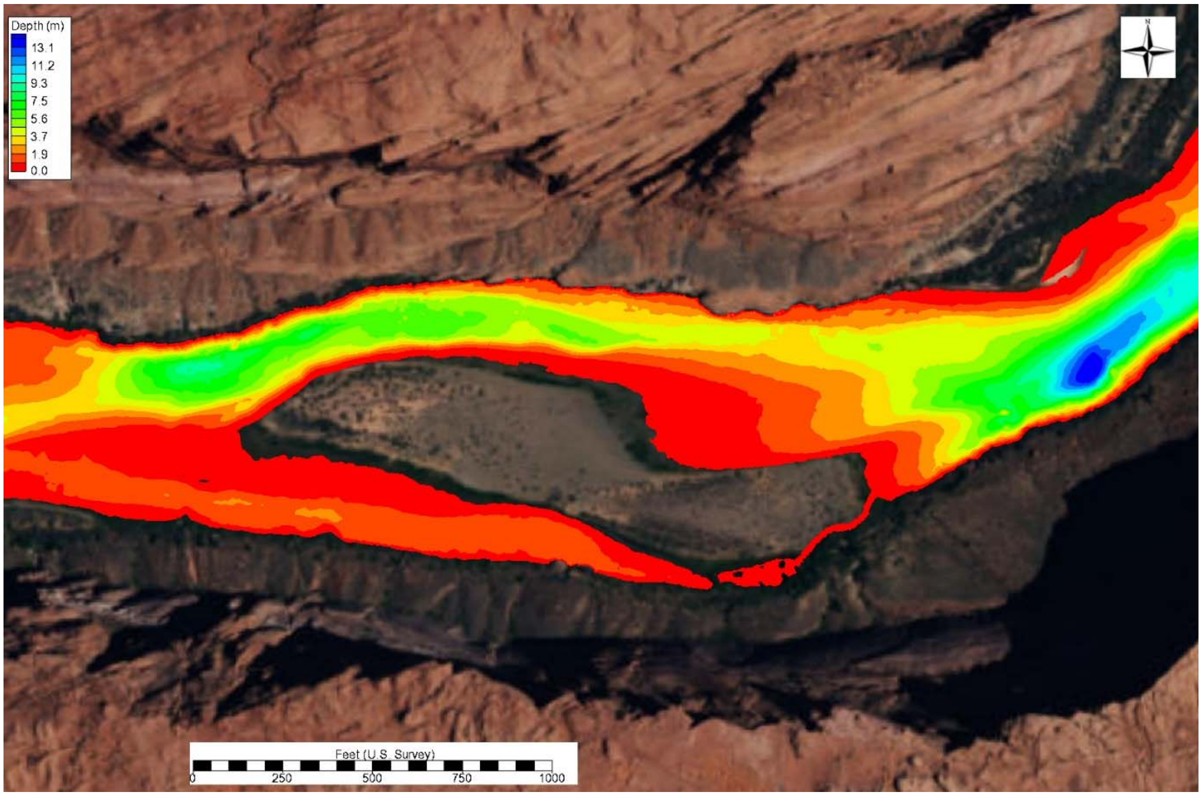


Figure 10. Option #1.2 depth results at initiation of flow (13,000 ft^3/s).

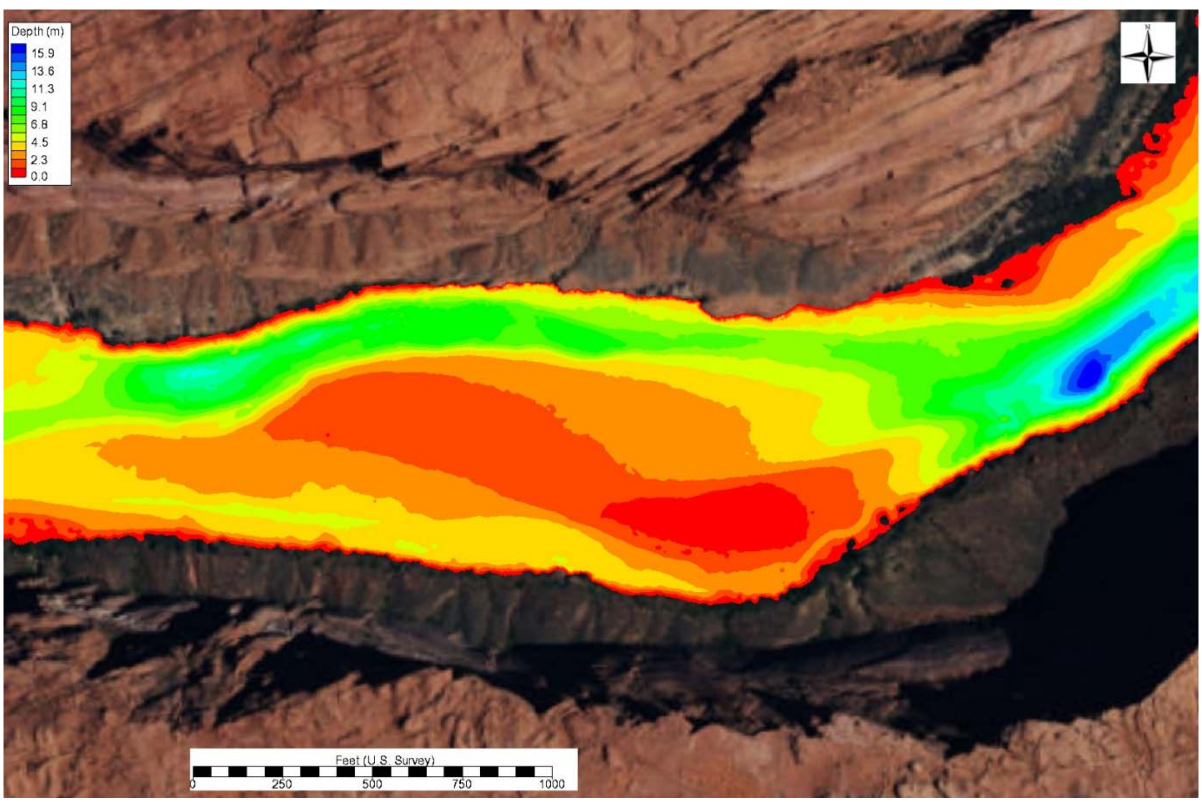


Figure 11. Option #1.2 depth results at highest modeled flow (45,000 ft^3/s).

Option #2: Pipe or culvert from river to Upper Slough

For this option, a pipe or culvert would be placed to provide a hydraulic connection from the main river channel to the Upper Slough. The pipe would be of sufficient size so that there is enough cool water from the main channel flows into the Upper Slough to cool it sufficiently to reach the target temperatures. Cut material from the trench would be put back over culvert.

This option was not considered further because the pipe or culvert would have to be continuously maintained to provide a hydraulic connection. The pipe could become plugged with sediment or debris and the Upper Slough would return to existing conditions temperatures, although a screen on the pipe inlet could certainly aid in the prevention of plugging.

Option #3: Pump cold water into Upper Slough

This option would involve a permanent pump installation that would be used to move water in a pipe connected to the main river channel to the Upper Slough. The pump(s) would be of sufficient size so that there is enough cool water from the main channel flows entering into the Upper Slough to cool it sufficiently to reach the target temperatures. The pump(s) size would be directly related to the temperature criteria assumed; if a 1 degree C temperature increase is used, the pump would need to supply approximately 5 ft^3/s (2,245 gpm).

This option was not considered further because, similar to Option #2, the pipe feeding the Upper Slough would have to be continuously maintained to provide a hydraulic connection. Furthermore, the pump(s) would have to be continuously maintained and powered to maintain low temperatures in the Upper Slough.

Option #4: Pump warm water out of Upper Slough

For this option, one to two high-volume portable pumps with 4-inch piping would be rented and used to pump out all of the water from the Upper Slough following a High Flow Experiment (HFE) or equalization flow that allowed a new infestation of non-natives to enter the Slough. The pumps would be used as a non-permanent water-control structure. Each pump would remove approximately 500 gpm. With the estimated volume of water in the Upper Slough of 120,000 gallons, a pumping time of roughly 4 hours would be required to drain the Slough. Following the removal of most of the water and all of the fish, the Upper Slough would be allowed to refill naturally from the small spring at the upper end (east) of the slough. This dry period would kill most invasive plants, and any fish or crayfish eggs. This option is believed to be credible because the slough is perched above the river level and water conductivity readings indicate that the slough is solely spring-fed except during HFE’s. This option is, however, subject to having to transport the equipment to-and-from the site potentially multiple times per year.

Option #5: Permanent fish barrier between the Upper and Lower Slough

The Upper and Lower Sloughs are currently separated by a naturally occurring berm that is thought to have developed via rock fall from the surrounding canyon walls (Figure 16). This option would include the installation of a permanent barrier between the Upper and Lower Slough with the intent of preventing movement of fish into the Upper Slough (from the Lower Slough) during typical flows. The structure should have the ability to withstand the largest HFE’s/equalization flows with the expectation that it would be overtopped at these flows. This option would require removal of fish that become trapped into the Upper Slough so that they do not become transported downstream.

It is proposed that the barrier be constructed to an elevation of 3057 ft, which means the Upper Slough would not become connected to the lower slough until a main-channel flow of approximately 20,000 ft^3/s (Figure 6). This would prevent movement of fish between the Sloughs for all flows lower than this. However, fish would be free to be transported into and out of the Upper Slough at flows above 20,000 ft^3/s.

The structure would be approximately 3 ft tall and tie into the ground at an elevation of 3057 ft. The structure would have to be approximately 110 ft long. Figure 12 shows the anticipated location and extent of the proposed barrier.

Figure 12. Site map for proposed Option #5.

There would be two options for the structure:

1. A concrete wall built to an elevation of 3057 ft. Cobbles from on site could be placed on either side of the wall to somewhat camouflage the wall. Approximately 55 cubic yards of rock placed a slope of 1.5H:1V against the wall on each side would be necessary for this purpose. An opening in the wall could be built into which stop logs or some other removable and semi-permeable structure could be placed in order to pass water after a HFE.
2. The wall could be composed of cobbles found on site. Based on field photos, there is a substantial amount of 4-to-6 inch cobble that could be used to form the barrier between the Upper and Lower Slough. The barrier could be porous and allow movement of some water between the Sloughs. The upstream slope could be 2H:1V, while the downstream slope would need to be milder than 3H:1V to resist movement of the rock material. Approximately 100 cubic yards of cobbles would be required to build this barrier. It is anticipated that a rock structure may have to be repaired after high flow events.

This option was not considered further because a wall that could exclude all flows up to a full HFE (45,000) was not considered feasible or practical given the existing topography. Concrete is also not a very practical material given the project access limitations.

Option #6: Create a channel between Upper and Lower Slough

Option #6.1: Channel cut only

In this option, a channel is created that connects the Upper and Lower Slough at all flows and lowers the bottom of the Upper Slough so that daily river fluctuations provide colder water. It is suggested that the fill from the cut channel be used to fill the deeper pools of the Upper Slough. The elevation of the cut channel would be set at 3052.8 ft and have a bottom width of 10 ft with 3H:1V side slopes. The excavation volume is estimated at 150 yd^3. The excavation volume would be sufficient to fill the deeper pools within the Upper Slough to an elevation of 3052.8 ft. Some of this material would likely scour out during flows above 25,000 ft^3/s and re-create a smaller pool of water. If the channel was cut to an elevation equal to the bottom of the Upper Slough (3049.5 ft), the length of the cut would be over 900 ft and progress well into the Lower Slough.

The resulting temperatures in the Upper Slough are expected to be similar to the temperatures in the upstream portion of the Lower Slough, which are shown in Figure 13. The diurnal fluctuation is substantial, where the minimum temperature is similar to the main channel temperature, but the peak temperature can reach over 30 degrees C. There is, however, a spring that comes in at the upper end of the Upper Slough that could create some warm pockets that would allow for spawning as it relates to monthly flow changes.

This channel is expected to be self-maintaining as long as material from the canyon wall does not re-create an obstruction between the Upper and Lower Slough.

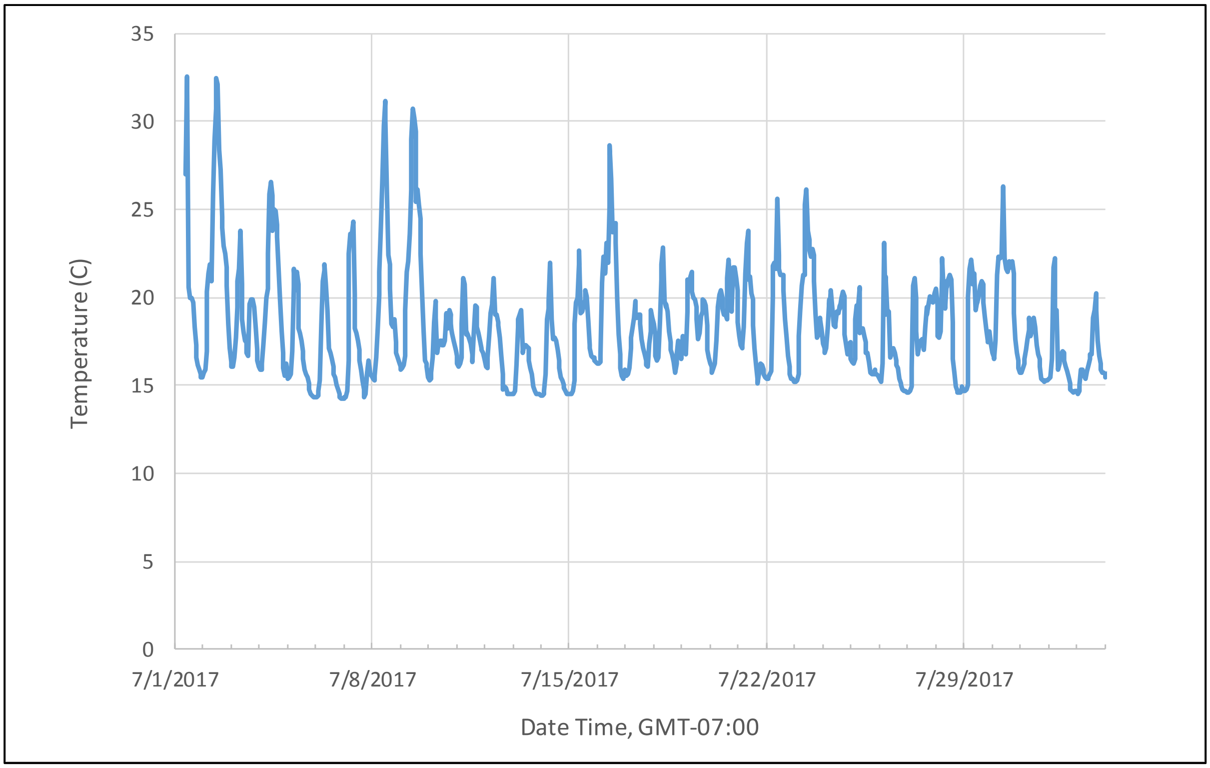


Figure 13. Temperature in Lower Slough for month of July 2017.

Option #6.2: Channel cut with water control weir

In this option, a similar length and dimensioned channel as Option #6.1 is created connecting the Lower Slough to the Upper Slough that would facilitate draining the Upper Slough should non-native species invade. A pre-fab water control weir structure with flash boards would be placed between the two sloughs that would allow for water control, act as a fish passage barrier, and allow the existing aquatic habitat in the Upper Slough to still function. An example of such a structure is shown in Figure 14. This option would likely still require some pumping in order to fully drain the Upper Slough.

Long-term maintenance concerns with this option include:

- Anchoring the weir in place so that it is not impacted by HFE's.
- Maintaining the channel between the two sloughs with scouring and redistributing of gravel by HFE's being a concern.
- Debris and sediment from the main channel and canyon wall side-cast material plugging the weir opening or burying the structure.

Figure 14. Example of a water control weir with flash boards.

Option #7: Fill-in Upper Slough

This option would fill the Upper Slough to an elevation of 3054.5 ft, which is approximately the elevation of the connection between the Upper and Lower Slough. This would mean that there is effectively no Upper Slough that is disconnected from the main river at low flow. Approximately 610 cubic yards of material would be necessary to fill the Upper Slough. Material from on site could be used. The upper 1.5-to-2 foot should be composed of cobble sized material so that it does not remobilize significantly at high flow. Loss of portions of the 'historic' cobble bar due to removal and use of the cobble armoring to fill the Upper Slough would be a concern and might create other backwater concerns. Another risk for this option would be that the continued delivery of water from the small spring and scouring during HFE's could create a much smaller, but warm water pond/wetland that may again be discovered and invaded by warm water non-native fish species resulting in the need for ongoing monitoring and maintenance.

Summary and Conclusions

A graphical depiction of select options is shown in Figure 15 while a corresponding ground surface profile labeled with pertinent features and elevations is shown in Figure 16. The cut/fill volumes, operations and maintenance (O&M), if the habitat control is met, and the area of disturbance for each option is summarized in Table 2. With all options, it would be important to re-survey the project area prior to finalizing a design in order to verify the slough elevations and volumes that are referenced in this report.

Table 2. Summary of option comparison.

Option	Description	O&M Level	Habitat Control Goal Met?	Cut/Fill Volume (cyd)	Area of Disturbance
1.1	Low elevation cut channel from the main channel to the Upper Slough, without filling Upper Slough	Med	Y – Both Sloughs	1,400	12,000 ft^2 channel cut area
1.2	High elevation cut channel from the main channel to the Upper Slough, with filling the Upper Slough	Med	Y – Both Sloughs, but not for entire summer period	600	12,000 ft^2 channel cut area + portion of Upper Slough filled in
2	Pipe or culvert from river to Upper Slough	High	Y – Considered, but many limitations	-	Minimal – pipe trench
3	Pump (permanent) cold water into Upper Slough	High	Y – Considered, but many limitations	-	Zero with removable pipe on surface
4	Pump (temporary) warm water out of Upper Slough	High	Y – Removes all water for short time period for Upper Slough only	-	Zero
5	Permanent Fish Barrier between Upper and Lower Slough	High	N – Considered, but many limitations	100	1,300 ft^2
6.1	Cut channel only between Upper and Lower Slough	Med	Maybe – Upper Slough only. Warm pockets from spring and monthly flow changes could allow spawning	150	3,400 ft^2

Option	Description	O&M Level	Habitat Control Goal Met?	Cut/Fill Volume (cyd)	Area of Disturbance
6.2	Cut channel between Upper and Lower Slough with water control weir	Med	Y – Allows for fish removal and water control in Upper Slough only	<50	3,400 ft^2
7	Fill-in Upper Slough	Low	Y – Upper Slough only. Warm pockets could occur from spring and HFE erosion	600	12,800 ft^2

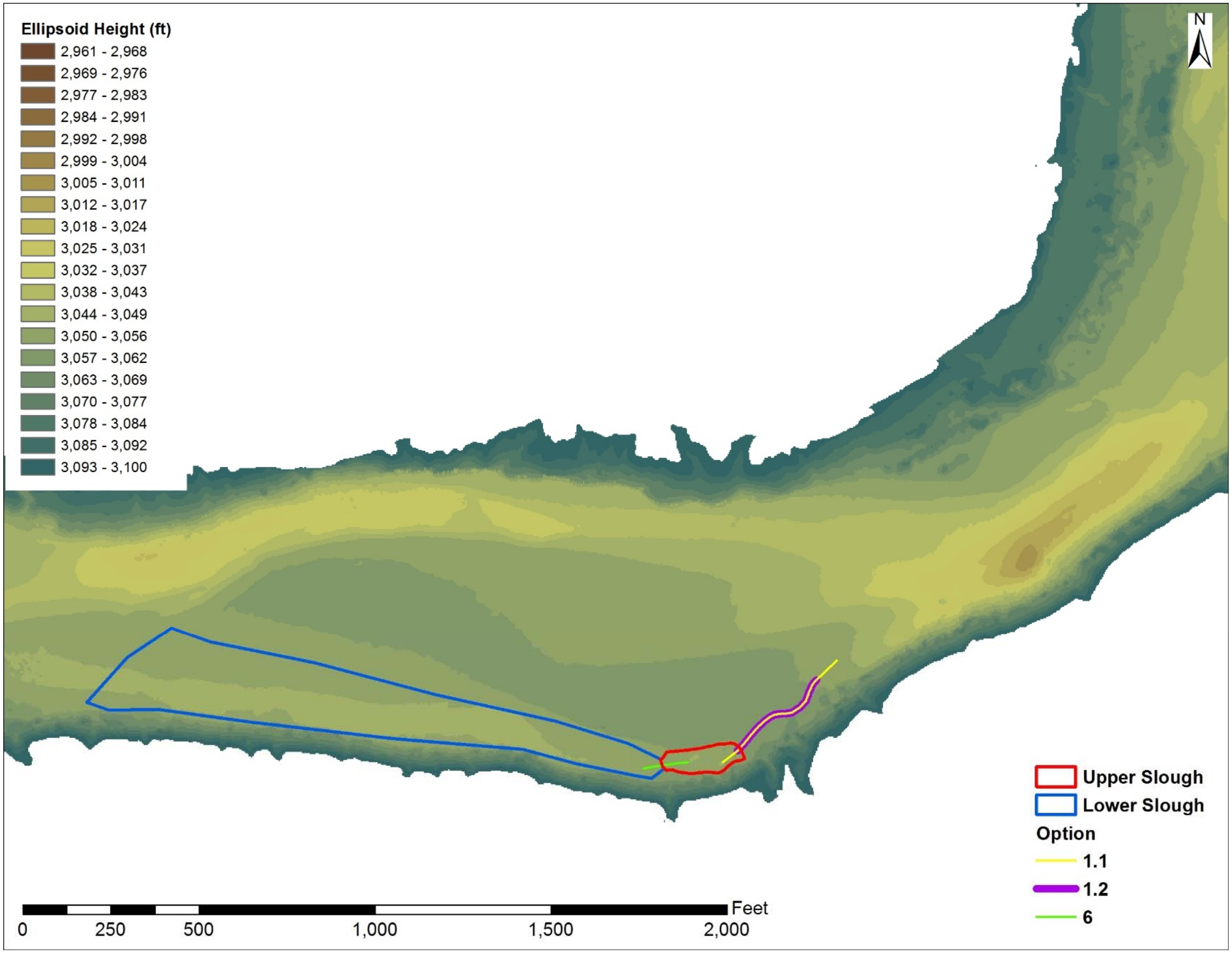


Figure 15. Select Glen Canyon Slough temperature reduction options.

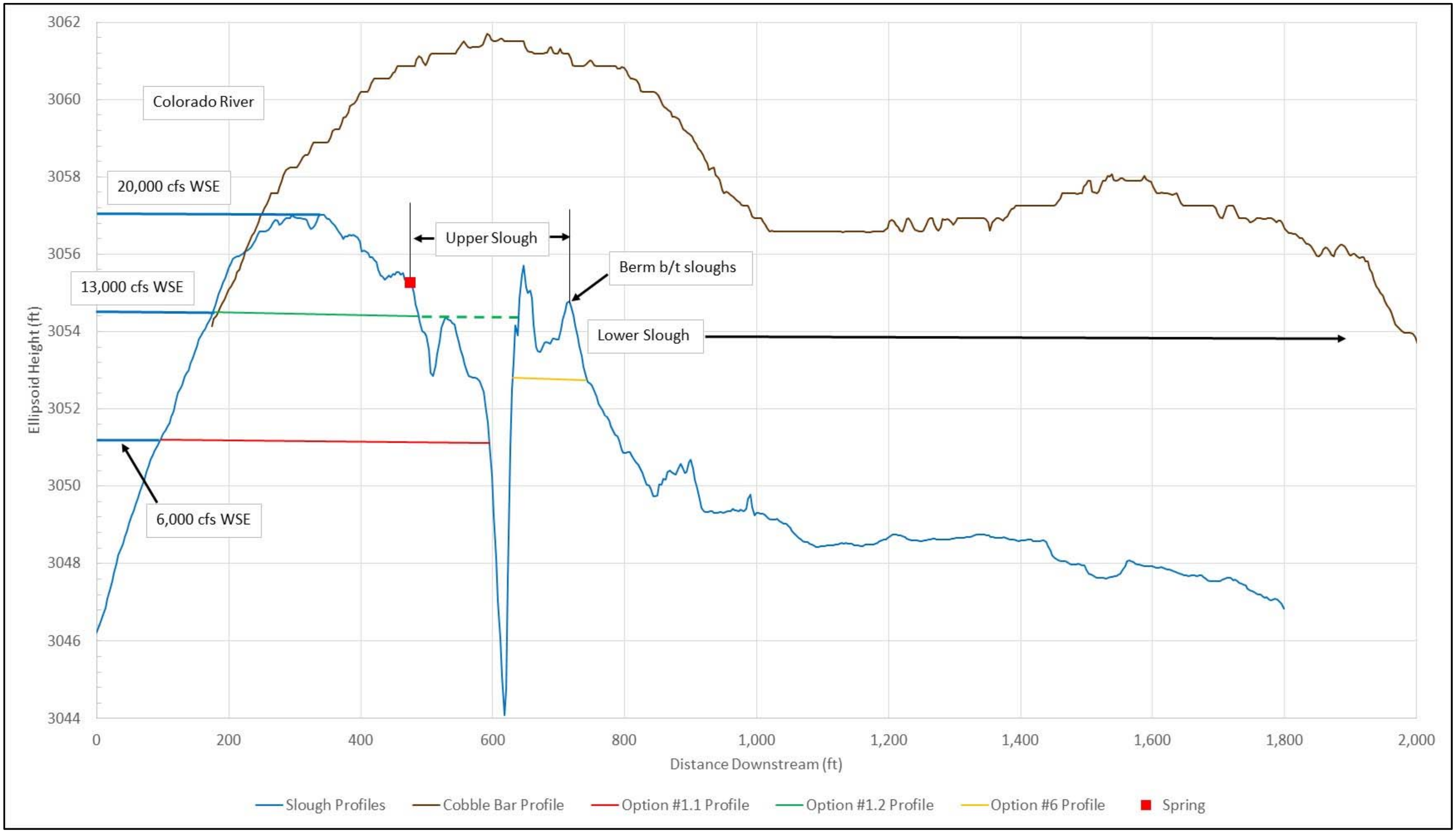


Figure 16. Existing ground surface profiles highlighting select design options.

References

Coddington, O., Lean, J. L., Pilewskie, P., Snow, M., & Lindholm, D. (2016). A Solar Irradiance Climate Data Record. *Bulletin of the American Meteorological Society, 97*(7), 1265-1282. doi:10.1175/bams-d-14-00265.1

Foster, M., Galic, D., Wille, K., and Warren A. (2017). *Hydraulic study to determine the potential impact of the controlled removal of the Idaho-shaped rock slab on power generation.* Glen Canyon Dam, Colorado River Storage Project, AZ. Technical Report No. SRH-2017-20. U.S. Department of the Interior, Bureau of Reclamation. April 2017.

Lai, Y. (2000). Unstructured grid arbitrarily shaped element method for fluid flow simulation. *AIAA Journal, 38*(12), 2246-2252.

Lai, Y. (2008). *SRH-2D version 2: Theory and User's Manual. Sedimentaiton and River Hydraulics - Two-Dimensional River Flow Modeling.* Denver, CO: U.S. Department of the Interior, Bureau of Reclamation, Technical Service Center.