PRELIMINARY LOW-FLOWS STUDY IN THE LEES FERRY TAILWATER BELOW GLEN CANYON DAM

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1. INTRODUCTION & OVERVIEW

HOW MUCH DO MINIMUM ***MLFF*** DAM RELEASES REDUCE AQUATIC HABITAT?

In Glen Canyon (Fig. 1), the above question is of interest relative to the river's food base and rainbow trout fishery, as well as native fish downstream that feed on the drifting benthic invertebrates that originate in the 25-km long tailwater (Cross et al. 2012, 13, Kennedy et al. 2013). Since 1996, 65% of annual dam releases have been at the minimum volume of ~10.2 km^3 (Fig. 2), but releases of 142 m^3/s (5,000 cfs) have occurred only rarely; mostly as flow experiments (Jan.-Mar. 2003-5) intended to limit trout spawning success (Fig. 3, Korman et al. 2011, Melis et al. 2012). A concern is that lower stages associated with 142 m^3/s flows during the WY 2014 annual release schedule (~9.2 km^3) might negatively affect the river ecosystem's food base and possible result in poorer trout fishery conditions.

Korman et al. (2005) report that about 49% of the 25 km tailwater consists of relatively low-angle shoreline habitat (mean gradient ~11%); habitats are known to be important rearing areas for juvenile rainbow trout after fry emerge from gravel redds during spring, summer and fall. Shallow cobble bar habitats are also known to be areas of higher aquatic food production for fish (Kennedy et al. 2013). Dam releases are allowed at 142 m^3/s between 1900 & 0700 hours in spring and fall months and they might influence spatial and seasonal patterns of drifting invertebrates (Fig. 4), but these food base data were not collected during previous low-flow experiments when minimum releases were 142 m^3/s.

As a consequence, it is not currently possible to predict how such low-flow dam operations may influence the trout fishery or the food base. However, Korman et al. (2011, 12) report that spring-timed controlled floods and steady releases from Glen Canyon Dam, such as those that occurred in 1996, 1997, 2000, 2008 and 2011, tend to increase early life stage survival of juvenile rainbow trout below the dam, and this survival is apparently tied to low angle shorelines that provide cover & food to juvenile trout at key early-life stages.

Photo: © Eric Engbretson, used with permission

Rainbow Trout (*Oncorhynchus mykiss*)

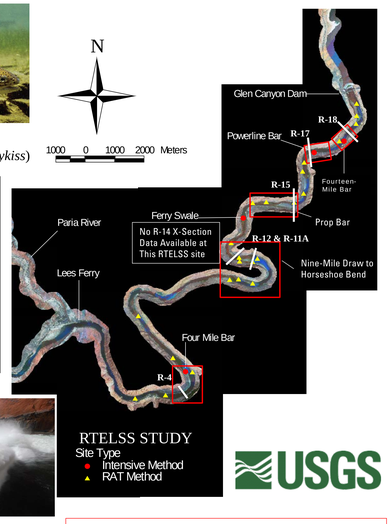


FIGURE 1. Glen Canyon National Recreation Area – Lees Ferry tailwater extends 25 km downstream from Glen Canyon Dam downstream to the boundary of Grand Canyon National Park. Four sites (red dots) have been studied since 2003 where rainbow trout early life stage survival has been tied to dam operations.

Photo: Anne Phillips, U.S. Geological Survey

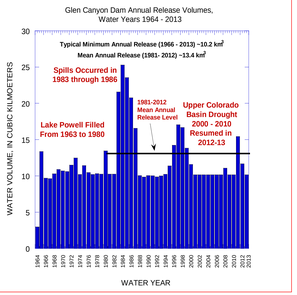


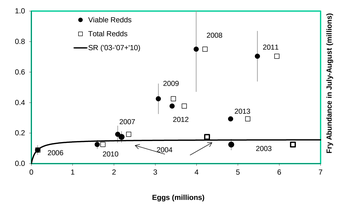
FIGURE 2. The annual release volumes from Glen Canyon Dam [1964-2013]. Minimum annual volumes have been released about 2/3 of the time in the last half-century; years in which low flows of 142 to 227 m^3/s are most likely in fall and spring seasons when low-angle nearshore channel habitats would be dewatered.

GLEN CANYON DAM - Photograph: T. Ross Reeves, Bureau of Reclamation

High Flows & Stable Flows are known to disproportionately benefit exotic trout upstream of Grand Canyon, but are also GCD operations most likely to rebuild & maintain eroded sandbars of the Colorado River ecosystem – Is there an optimal frequency of HFEs & daily release patterns that can balance tradeoffs?

2. RAINBOW TROUT RESPONSES TO DAM OPERATIONS & INVERTEBRATE DRIFT IN THE GLEN CANYON TAILWATER

BACKGROUND



(**below**) Colorado River Flow (Water Years 2003-13) at Lees Ferry USGS streamgage, ~25 km below Glen Canyon Dam

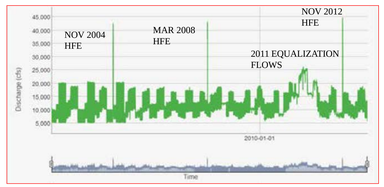


FIGURE 3. (top-left) relationships between number of eggs (open squares) and number of viable eggs (filled circles) deposited by exotic rainbow trout in the 25 km-long tailwater below the dam, and resulting age-0 population size on July 15, 2003–2013 (no data collected in 2005). The black line (Beverton-Holt curve) shows typical relationship. Light-gray vertical lines represent the 95% confidence limits for abundance estimates. (modified after Korman et al. 2011, with data from high-steady 2011 flows & fall 2012 HFE - left).

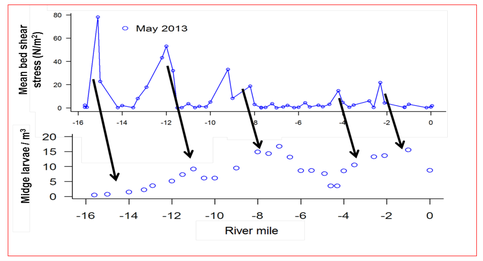


FIGURE 4. (above) river bed shear stress relative to non-biting midge drift concentrations at 26 drift sampling sites between Glen Canyon Dam and Lees Ferry. Midge drift is highly variable in space and is directly related to shear stress conditions 0.25 miles upstream of sampling sites. These drifting invertebrates were sampled during at a steady river discharge of 227 m^3/s; a flow associated with about 327 ha of wetted channel habitat area in the 25-km long tailwater.

3. METHODS - ESTIMATING LOW-FLOW AREA CHANGES

Existing January 2000-era channel geometry data (24 two-dimensional cross sections), established by the Bureau of Reclamation in 1956, were used to assess low-flow aquatic habitat area changes (Grams et al. 2007). Only six of the sections (shown in **bold** in Table 1 & Fig. 1) cross low-angle shorelines, and even those are not ideally located relative to channel areas thought to be most vulnerable to low flow dewatering (point & channel-margin gravel bars) within 5 study segments (***Four-Mile Bar, Nine-Mile Draw-to-Horseshoe Bend, Prop Bar, Powerline Bar, and Fourteen-Mile Bar***). Although ***Ferry Swale*** (river mile -11.2) is also a long-term trout spawning study site (Fig. 1), there was no cross section data at that site for use in the analysis. Channel characteristics, such as river aspect (proxy for variability in annual solar insolation) were also considered, as well as available biological monitoring data (aquatic drift, insect emergence and historically important areas for trout spawning & redds, Table 1, Figs. 3 & 4).

Rating curves for discharge vs. stage at the six cross-sections located within the study segments (Grams et al. 2007) were used to estimate low-flow affected areas between stage elevations associated with 227 and 142 m^3/s (8,000 & 5,000 cfs) shorelines. These width differences were then used to approximate dewatered areas within each of the five segments; multiplying the width changes by the various river segment lengths. Areas from the five segments were then summed over the 4 km subsample and used to extrapolate dewatered area to the 12 km of the Glen Canyon characterized as low-angle shoreline habitat (Table 2, for 49% of the 25 km segment, Korman et al. 2005). Stage-elevation differences from 142 to 227 m^3/s stages, cross-section scour (Grams et al. 2007), and cumulative wetted areas were also evaluated longitudinally below the dam (Figs. 5 & 6).

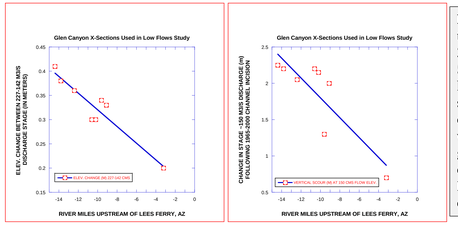
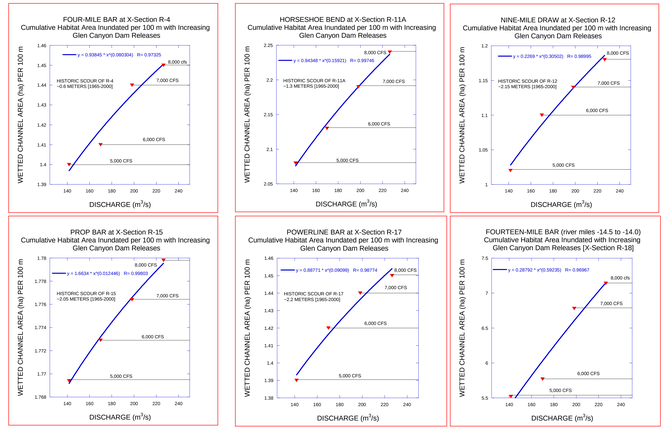


FIGURE 5. (far-left) downstream trend in elevation differences from 227 and 142 m^3/s shorelines within 5 low-flow study sites. (near-left) historical vertical channel-bed scour (1956 – 2000). Low-angle channel habitats nearer to the dam where post-dam channel scour is greatest show greater sensitivity to change in low flows. Four-Mile Bar is most robust to low-flow changes, and least scoured.

FIGURE 6. (below) comparison of cumulative channel habitat area inundated as dam releases increase from 142 to 227 m^3/s at six cross sections in the Glen Canyon tailwater. Each plot shows how much inundated channel area accumulates per unit length of over the 50 m upstream and downstream of each section. For perspective on the area changes shown here per hectometer, an NFL gridiron covers about 0.45 hectares. Sensitivity to low-flow changes varies throughout the tailwater, and is largest at Fourteen-Mile Bar (river miles -14.0 to -14.5); the site closest to the dam and where post-dam channel scouring was greatest between 1965 and 2000 (Grams et al. 2007).



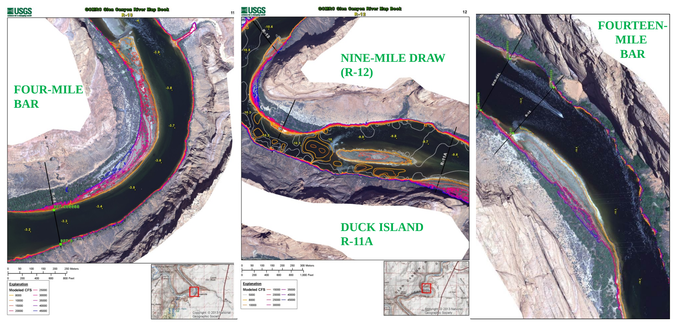


FIGURE 7. (above-left) 4-Mile (river miles -3.1 to -4.1), (above middle) 9-Mile Draw (rm -9.6 to -10.1) and (above-right) 14-Mile Bars (rm -14.0 to -14.5) study sites showing shorelines estimated at dam releases ranging from 227 to 1,274 m^3/s. High & steady dam flows that inundate large vegetated cobble bars are thought to provide critical habitat to juvenile rainbow trout after fry emerge from redds, and may be productive areas for benthic invertebrate colonization during spring and summer months.

TABLE 1. CHARACTERISTICS OF FIVE LOW-FLOW STUDY SITES ANALYZED

STUDY SITE NAME	FOUR-MILE BAR (-04.1 to -03.1)	9-MILE DRAW & HORSESHOE BEND (-10.6 to -09.1)	PROP BAR (-12.4 to 11.8)	POWERLINE BAR (-13.9 to 13.5)	FOURTEEN-MILE BAR (-14.5 to -14.0)
Approximate Site Length (m)	1000	1500	600	400	500
X-Section(s) & (River Miles) for study of low-angle shorelines	R-5 (-04.4) **R-4 (-03.2)**	R-13 (-10.6) **R-12 (-10.2)** **R-11A (-09.6)** R-11 (-09.1)	**R-15 (-12.4)**	**R-17 (-13.8)**	**R-18 (-14.4)**
Vert. Elev. Δ from 227 to 142 m^3/s (2000 era) in meters	R-5 (0.39 m) **R-4 (0.20m)**	R-13 (0.30 m) **R-12 (0.30 m)** **R-11A (0.34 m)** R-11 (0.33 m)	**R-15 (0.36 m)**	**R-17 (0.38 m)**	**R-18 (0.41 m)**
Historic Vertical Scour 1965-2000 (m) ~ 150 m^3/s stage	R-5 (0.70 m) **R-4 (0.60 m)**	R-13 (2.20 m) **R-12 (2.15 m)** **R-11A (1.30 m)** R-11 (2.0 m)	**R-15 (2.05 m)**	**R-17 (2.20 m)**	**R-18 (2.25 m)**
Study Segment Aspect (annual solar insolation)	NW-SE & E-W (less variable)	E-W & N-S (less variable)	E-W (more variable)	E-W (more variable)	NE-SW (less variable)

4. ESTIMATED CHANGE – DEWATERING OF LOW-ANGLE HABITATS AT 142 m^3/s

Existing channel cross-sections in the Glen Canyon tailwater used in this study were not optimally located for assessing low-flow changes across the ~12 km of low-angle shoreline habitats in this river segment. Since this initial assessment was made using only moderately representative cross-section data available in Glen Canyon, the ~10% reduction in wetted shoreline area (**Table 2**) might best be viewed as a minimum estimate for low-angle habitat areas that are dewatered when dam releases drop below 227 m^3/s to 142 m^3/s. To determine a better estimate of habitat inundation by the river at these low stages, as well as for higher flows thought to be relevant to early life-stage survival of rainbow trout juveniles in spring/summer seasons, additional channel topography is needed. To address biological habitats and related fish and food base resources, additional data would ideally be collected across aquatic nearshore habitats of interest to biologists. New channel geometry could then be used to develop flow models that would likely yield better estimates of shoreline inundation across the range of dam operations from 142 to 1,274 m^3/s (Fig. 7) as previously done downstream within Grand Canyon National Park below the Little Colorado River confluence related to chub habitats.

TABLE 2. PRELIMINARY RESULTS OF LOW-FLOW & LOW-ANGLE SHORELINE HABITAT AREA ASSESSMENT

STUDY SITE NAME	FOUR-MILE BAR (-04.1 to -03.1)	9-MILE DRAW & HORSESHOE BEND (-10.6 to -09.1)	PROP BAR (-12.4 to 11.8)	POWERLINE BAR (-13.9 to 13.5)	FOURTEEN-MILE BAR (-14.5 to -14.0)
Changes (Δ) in	Wetted	Cross-Section	Width at the	Five Low- Flow	Study Sites
Δs in wetted channel width (WCW) & Elev. 227 - 142 m^3/s (m) for area Δs	**R-4** (4.7)	**R-12** (16.2) **R-11A** (15.9)	**R-15** (9.6)	**R-17** (6.0)	**R-18** (32.3)
DIFF. 227 - 142 m^3/s Wetted Area	[based on **R-4**] **~0.47 ha**	[based on AVE. of **R-12** & **R-11A**] **~2.41 ha**	[based on **R-15**] **~0.58 ha**	[based on **R-17**] **~0.24 ha**	[based on **R-18**] **~1.62 ha**
				(5.32 ha/4 km)=	1.33 ha/km
Total Change in	Low-Angle	Wetted Shore	Area (m^2)	Glen Canyon	Tailwater
(25 km of Glen Canyon) Total estimated Wetted Channel Area at 227 m^3/s stage elev.				**~327 ha** (derived from 2009 digital imagery for 25 km at 227 m^3/s)	
Low-Angle (~48% or 12 km)	**Shoreline**	**Habitat of main**	**Focus in Study**	**~160 ha** (327*0.49)	**(see Korman et al. 2005)**
(12 km of Glen Canyon) Estimated total low-angle habitat area Δ between 227 – 142 m^3/s stages	**Dewatered** **(Extrapolated**	**Shoreline** **From Five Study**	**Area** **Sites [4 km])**	**~16 ha** (1.33 ha/km*12 km) or about 1,700,000 sq. ft.	**GCD - Lees Ferry at 142 m^3/s about ~10% of total wet area at 227 m^3/s stage**

5. PRELIMINARY CONCLUSIONS - LOW-FLOW HABITAT ASSESSMENT

The total area of aquatic habitat in the 25-km long tailwater at 227 m^3/s is about 327 ha, but only about 12 km of that (~49%) has been characterized by fish researchers as low-angle habitat thought to be used by juvenile rainbow trout after fry emerge from redds in spring through summer. As such, it is estimated that ~16 of approximately 160 ha of such habitat area in the Lees Ferry segment are dewatered when dam releases are reduced from 227 to 142 m^3/s. To provide some additional perspective, 16 ha is equivalent to about 35 NFL football gridirons, or about 1,700,000 square feet.

Geomorphic channel geometry data that characterize low-angle shoreline habitats in the Glen Canyon tailwater are limited to a handful of historical cross sections located between river miles -3.2 and -14.5, but none of these existing cross sections are optimally located across main areas of low-angle cobble bars. Despite this, flow and wetted habitat area relationships at these 6 lowest-angle cross sections suggest that total wetted area of low-angle habitat is reduced by about 10% when dam releases fall from 227 to 142 m^3/s (8,000 to 5,000 cfs).

Flow and stage relationships between 227 and 142 m^3/s vary by about a factor of 7 among the cross sections analyzed. Low-angle channel habitats nearest to the dam show greatest stage and inundation sensitivity to low flows over this range. These upstream sites are also ones that have been most scoured by dam operations (Grams et al. 2007). Until more representative channel geometry becomes available for low-angle portions of the channel in Glen Canyon, the information presented here should be considered as preliminary and likely only a minimum estimate.

On the basis of existing rainbow trout and food base information, it is not currently possible to determine to what extent, if any, this reduction in aquatic habitat area might have on the recreational fishery if flows at 142 m^3/s occur during fall and spring months under minimum-volume release annual operations. Whether or not a 10% reduction in wetted channel area at 142 m^3/s might significantly influence productivity of aquatic food and/or fish in the tailwater depends upon many other factors, such as what percentage of productivity occurs over the dewatered portion of the shoreline relative to the rest of the wetted channel. It might also be informative to study habitats at flows ranging from 227-1,274 m^3/s owing to the now-documented spring/summer high flow responses in the aquatic food base and rainbow trout recruitment in 2008 & 2011 (Cross et al. 2013, 2012, Kennedy et al. 2013, Korman et al. 2012, 2011, Melis et al. 2012).

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