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EVIDENCE FOR THE FAILURE OF THE MODIFIED LOW FLUCTUATING FLOW ALTERNATIVE (MLFFA) TO BENEFIT MOST ECOLOGICAL RESOURCES IN GRAND CANYON

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Introduction

Recently a series of multi attribute utility analysis (MATA) workshops were used to elicit preferences of Grand Canyon Technical Working Group (TWG) members for policy options involving flow variation and control of exotic fishes in the Colorado River below Glen Canyon Dam (GCD). A surprising result from the analysis was that many TWG members appear to prefer more variable diurnal flow policies than the Modified Low Fluctuating Flow (MLFF) policy that has been in place since the early 1990s (Figure 1). This is understandable in the case of stakeholders whose interest is primarily in efficient power production from GCD, because the MLFF policy has been quite costly (it has reduced potential value from power production by $50 million/year or more). However, there was also considerable support for more variable diurnal flows from stakeholders concerned about ecological performance measures, particularly recovery of the endangered humpback chub and management of sediment resources. These stakeholders were apparently responding to comments from scientists that the MLFF policy has not provided benefits to humpback chub and sediment resources as predicted in the EIS (BOR 1995).

Here we review the data presented to TWG during the MATA process to justify predictions of continued humpback chub decline, relatively poor quality of the Lees Ferry trout fishery (as measured by fish size), and relatively rapid sand loss if MLFF is continued. One of the justifications for the MLFF policy was apparently an assumption or prediction that MLFF would have beneficial ecological effects relative to the more violent diurnal flow variations that preceded it. We show that no such beneficial effects are evident in the ecological (except to abundance of exotic trout), and in fact the move to MLFF is correlated with a relatively sharp decline in humpback chub recruitment. We note that in the case of humpback chub, a move to summer-fall steady flows (as favored by some TWG members during the MATA workshops) could well produce beneficial effects on chub recruitment. We review evidence that there would likely be little impact of moving away from MLFF on other Grand Canyon resources, including riparian vegetation and cultural resources.

Changes in humpback chub recruitment and abundance

The only remaining reproducing population of humpback chub in Grand Canyon is apparently the population that spawns in the Little Colorado River (LCR). Based on recaptures of fish that have been PIT tagged since 1989, some 15-20% of the adult fish in this population die each year due to natural causes. For a sustainable population, these losses must be replaced through recruitment, and the evidence now available from size composition and growth sampling in the LCR and Colorado River mainstem is that the recruitment now consists mainly of juveniles that have spent most of their pre-adult life (3-4 yrs) in the LCR.

Mark-recapture estimates of population size and trend indicate that recruitment has not replaced natural losses from the LCR population for at least the last decade, and probably much longer (Figure 2). There has been a downward trend averaging around 14% per year in adult abundance since the initiation of intensive monitoring programs in the early

1990s, indicating that recruitment has been only about half of that needed to sustain or stabilize adult population size.

Hoop net catch-per-effort indices of juvenile abundance (recruitment measured at age 1) indicate that there was a relatively sudden decline in recruitment sometime around 1990 (Figure 3). The size composition of the population was sampled very intensively in the 1991-1993 period, and from this size composition we can assign probable ages to the fish that were present during that period and we can back-calculate how many recruits must have entered the population during the 1980s in order to have produced these early 1990s survivors (Figure 3). This recruitment back-calculation indicates that recruitment was probably declining even before 1990, quite possibly following a period of strong recruitment during the early 1980s.

We cannot say with any confidence that the decline in recruitment that apparently occurred in the early 1990s was caused by the move to MLFF flows; it could equally well have been due to some unmonitored change in the carrying capacity or mortality conditions in the LCR. However, we can say with confidence that MLFF was not effective at reversing the decline or at providing sufficiently good habitat conditions in the CR mainstem to allow enough recruitment for the population to be sustained. That is, MLFF had either a negative effect or no effect at all, but it certainly did not have a measurable beneficial effect on humpback chub.

There is a good chance that juveniles dispersing into the mainstem in summer and fall would be able to grow, survive, and return to the LCR for extended rearing if they were to encounter (1) reduced predation by exotic trout due to mechanical removal treatments, and (2) relatively warm spatial refuges in nearshore locations, as would be created by steady flow conditions in late summer and fall. The Low Summer Steady Flow LSSF experiment demonstrated that such lateral warming of backwater areas can be quite dramatic. A Summer-Fall Steady Flow (SFSF) experiment would need to maintain conditions for backwater warming from the time of the first summer freshet that disperses juveniles into the mainstem, until around November 1 when the equilibrium temperature in standing backwaters decreases (due to nighttime cooling) to about the same as the mainstem temperature.

Depending on how much it increases summer and fall temperatures in the main water flow, a temperature control device (TCD) could considerably enhance the thermal effects of SFSF on backwaters (and perhaps even make steady flows unnecessary). Juvenile chub are unlikely to exhibit normal first-year growth unless water temperature is at least 18 degrees C in late summer; it is doubtful that such a large impact (4-5 degrees above the temperature now seen in the mainstem near the LCR at that time of year) would be achieved by a TCD alone, if that TCD were also planned to avoid GCD release temperatures high enough to cause negative impacts on the Lees Ferry trout population.

Changes in abundance and size of trout (quality vs quantity)

Both rainbow and brown trout have increased dramatically under MLFF. Densities of rainbow trout, as evidenced by both electrofishing monitoring data and catch per effort in the Lees Ferry trout fishery, have increased by at least 5-fold (Figures 4-5), while growth and average body size have decreased (Figure 5). Brown trout abundance outside the main population concentration near Bright Angel Creek has increased even more dramatically (Figure 6).

Upstream of Lees Ferry, the rainbow trout population has benefited from two basic effects:

(1) increases in primary production (and presumably insect food production)
(2) increases in spawning success and juvenile survival.

Using the Grand Canyon Ecosystem Model (GCM), which does detailed predictions of primary production rate using diurnal stage variation and algal biomass development estimates, we estimate that primary production has increased by at least 30% since 1990. This increase in potential to support trout biomass has been dampened somewhat by shifts in community structure from algae (Cladophora) to macrophytes and from insect production to snail production, and by reduced availability of insects (increased diurnal flow fluctuation apparently promotes drift, i.e. dispersal, of insects, and trout feed mainly on such drifting organisms).

Rainbow trout populations typically show conservation of total biomass, meaning that a given area supports roughly the same total biomass whether that biomass consists of a few large fish or many small ones. This phenomenon creates a severe tradeoff in rainbow trout fisheries between quality and quantity of fish available to anglers, if quality is measured by availability of large fish. Increases in number of recruits to the Lees Ferry population, due mainly to improved juvenile survival rates over the early life period when juveniles are restricted to use near-shore areas (much more stable environments under MLFF), have led to dramatic increase in catch per effort measured in numbers of fish per angler day. But there has been a considerable decrease in the average and maximum sizes of fish caught. It should be noted that the total trout biomass per area likely depends on total flows, with lower total biomass being supported in years of low flow (more severe size-numbers tradeoffs in low flow years) like those seen recently in GC. If low flows continue, improvements in fish size under policies aimed at reducing fish density may be considerably less than expected from growth and abundance data gathered during the higher flows of the late 1980s and 1990s.

Since 2003, there has been an experimental flow treatment involving increased diurnal flow fluctuations of 5-20 kcfs from January through March., aimed at deliberately reducing rainbow trout recruitment so as to both improve fishing quality (fewer, larger fish) and reduce potential impact of rainbow trout on native fishes. Approximately 50% of the redds in 2003 in the Lee's Ferry reach were excavated after March 31, when flows resumed to normal ROD operations. The total egg deposition loss due to Glen Canyon Dam operations in 2003 ranged from 30 - 40% in the Lee's Ferry reach, with about half of this mortality being a direct consequence of the enhanced fluctuating flows in January through March (Korman et al. 2004). Three flow recommendations for Glen Canyon Dam were made based on results from a 2003 young-of-year (YoY) survey and analysis of otolith microstructure: 1) Fluctuating flows targeting YoY rainbow trout should be implemented from Apr. through July to coincide with the timing of hatch; 2) Summer steady flows very likely improve the growth of YoY rainbow trout; and 3) Sudden reductions in the minimum daily flow have the potential to strand or displace many YoY rainbow trout in the Lee's Ferry reach (Korman et al. 2004). The latter recommendation was based on an almost complete absence of fry from low angle shorelines after the reduction in the minimum flow from 10 to 5 kcfs following the labor-day weekend. An event-based approach, where flows are increased to approximately 20 kcfs for 2 days, followed by a reduction to 5 kcfs for one day, implemented on a monthly basis from May through September, would almost certainly be much more effective at reducing recruitment in the Lee's Ferry Reach than the January - March experimental flow regime implemented in 2003-2004. Steady flows could be conducted between events to increase water temperatures for native fish downstream and would not have beneficial effects for YoY rainbow trout as their densities would be controlled through the temporary reductions in minimum flow. The effectiveness of the event-based approach on rainbow trout could also be easily monitored, with results available in the same year that it is implemented.

Changes in sediment storage and transport (beach loss)

Recommendation for the MLFFA policy in the 1995 Environmental Impact Statement (EIS) for Glen Canyon Dam (BOR 1995) was in part based on the assumption that sufficient tributary-derived sediment could be stored in lower eddy environments and the bed of the mainstem until a discharge beyond powerplant capacity could be initiated between Jan. – June, when normal flood operations can legally be conducted. Recent work has demonstrated that this premise is false, and that the majority of fine sediment from the Paria River that is delivered during the monsoon season, exits Marble Canyon in a few months, well before a controlled flood could be initiated. This has prompted sediment scientists to recommend three alternate options to the ROD (Rubin et al. 2000):

- initiation of a controlled flood immediately after a tributary sediment input;
- initiation of reduced and steady flows immediately after a tributary sediment input until such time when a controlled flood can be initiated; or
- operation of a sediment pipeline coupled with controlled floods during flood control season.

There is currently little debate that ROD flows have failed to produce their intended benefits for sediment resources in Grand Canyon. During discussions at the MATA workshops, it was hypothesized that increased daily fluctuations in flow might actually reduce sediment transport rates relative to MLFFA. Because the sediment transport-water discharge relationship is non-linear, the notion here was that reduced sediment transport associated with longer periods of low flow under higher daily fluctuations would more than compensate for increased transport during the higher flows. This prediction was recognized as being quite uncertain as the discharge frequency over a day under a given flow regime, and hence the relative sediment transport rates, would depend on the total monthly volume from Glen Canyon Dam. In addition, the relative transport rates will depend on the slope of the sediment transport-discharge relationship. An analysis, to quantitatively examine this issue, was requested by the TWG and is reported here.

The WAPA Hydro LP model was run under monthly volumes ranging from 400-1,000 thousand acre-feet (TAF) for four flow scenarios (Table 1). The model predicted discharge every hour for a one-week period for each volume and flow regime combination. Three alternate sediment rating curves at the Grand Canyon gage, developed over 3 one-week periods in Mar, May, and July, 2003, were used to predict the sand concentration as a function of water discharge for each hour (Table 2). Total sand transport for the week under reach rating curve was then computed as the sum of products between predicted hourly sand concentrations and volumes. It is important to note that the sand transport for a given discharge will depend on the grain size and quantity of sand on the bed and predictions should not be used to forecast future sand transport rates. We therefore standardized the transport predictions for each flow scenario by the corresponding value under MLFFA (i.e. Y = 100 * (x-MLFFA)/MLFFA), where x is the transport rate under any flow regime for a given GCD volume and MLFFA is the corresponding rate under the MLFFA flow).

Table 1. Summary of flow regime characteristics for which sediment transport rates were computed.

Regime	Daily Variation (kcfs)	Min/Max (kcfs)	Upramp/Downramp Rate (kcfs/hr)
MLFFA	5, 6, 8 (volume dependent)	5/25	4/1.5
5-20	5-20	5/20	5/2.5
5-25	5-25	5/25	5/2.5
STEADY	0	Volume dependent	0

Table 2. Sand concentration (mg/l) vs. water discharge (cfs) relationships at the Grand Canyon gage, 2003 (D. Topping, GCMRC, unpublished data).

Period	Daily Range (kcfs)	Equation	R^2
March 6-11	5-20	Y=9.29e-16*q^4.08	0.97
May 5-11	7.5-13.5	Y=9.96*e-22*q^5.49	0.91
July 4-8	10.5-18.5	Y=4.80e-20*q^5.07	0.93

The Hydro LP model predicted that maximum flows under each scenario would be maintained for at least 12 hrs of each day during normal weekday operations (Fig. 7). Scenarios that allowed for higher maximum flows therefore had higher transport rates than under MLFFA, even though the MLFFA regime had higher minimum flows (Fig. 8). At lower monthly volumes of 400 and 500 TAF, the 5-20 and 5-25 kcfs regimes produced similar transport rates, which were 40% and 140% higher than MLFFA rates, respectively, based on the Mar 6-12, 2003 rating curve. Under higher volumes, sand transport under the 5-25 kcfs regime was considerably higher than under the 5-20 kcfs regime. Under the range of volumes that were examined, the steady flow alternative had transport rates that were 50-80% less than those under MLFFA. Riverware predicts that

50% of the monthly release volumes from Glen Canyon Dam between 2004 and 2010 will be between 600 and 800 thousand Acre-Feet (Fig. 9). Under these volumes, the most conservative sand transport relationship (lowest slope, Table 2) predicted that the 5-20 kcfs scenario will increase transport rates by 50% (800 TAF) to as much as 200% (600 TAF) relative to MLFFA. The relative differences among scenarios were also dependent on the slope of the sand transport relationships (Table 3). The March rating curve had the lowest slope and produced the smallest differences between scenarios (Table 2). The basic conclusion drawn from the analysis was independent of the rating curves that were used; increased daily fluctuations in flow increase the transport rate of sand past out of Grand Canyon.

While this analysis has demonstrated that the steadier the flows, the higher the retention of sand in Grand Canyon, it does not necessarily imply that increased daily fluctuations in flows should not be considered by the TWG. If increased daily fluctuations lead to an increase in the probability of conducting sediment-retention flows or better-timed floods, the net effect for the sediment resource in Grand Canyon could be beneficial. However, in the absence of increased flexibility on the timing of controlled floods, increased daily fluctuations in flow will certainly increase the rate at which sand resources in Grand Canyon are being lost.

Table 3. Change in the sand transport rate at the Grand Canyon gage under 3 flow scenarios (see Table 1) relative to the transport rate under MLFFA. Relative rates are expressed as a percentage.

		5-20	5-25	Steady
Mar 6-12				
	400	42	42	-81
	500	140	140	-74
	600	216	287	-72
	700	147	351	-65
	800	48	188	-66
	900	-1	138	-60
	1000	-19	81	-56
May 5-11				
	400	63	63	-89
	500	234	234	-84
	600	390	562	-83
	700	241	719	-76
	800	64	323	-78
	900	-4	219	-73
	1000	-29	120	-69
July 4-8				
	400	57	57	-87
	500	203	203	-81

600	330	465	-80
700	210	585	-73
800	59	278	-75
900	-3	193	-70
1000	-26	108	-65

Changes in the riparian community (vegetation and animals)

MLFF led to decreases in maximum daily flows as well as increases in minimum daily flows. These decreases have allowed terrestrial vegetation like tamarisk and willow to invade more beach and cobble area, and have probably reduced the recharge rate of groundwater used by plants like mesquite that were naturally restricted to above the natural seasonal high water line. The LSSF experiment was associated with formation of a strong cohort of tamarisk within what is normally the MLFF varial zone, and this cohort has been able to survive diurnal flooding for three years now. Most likely a return to higher daily maximum flows would be accompanied by a similar lack of, or very slow, response by the vegetation that has developed within the MLFF varial zone. The LSSF experiment also demonstrated that the timing of planned beach habitat building flows and other flow variations can be critical in establishing or preventing good seeding conditions for species like tamarisk.

Under MLFF, some backwater areas initially developed quite diverse and productive plant and animal communities due to protection from diurnal flooding and scouring. But without natural scouring and renewal events, these areas are undergoing vegetation succession and gradual accumulation of sediments and will likely eventually lose their diverse character.

Changes in cultural resources

Mass storage and transport models are not yet available to accurately predict the net total impact, through combined water and aeolian processes, of altered diurnal flow regimes on amount and distribution of sand available to protect cultural resources. One complicating factor in such modeling is that much of the sand now subject to aeolian movement is from large sand deposits that occurred during major floods well before GCD; such deposits are likely losing mass slowly, independent of managed water flows, and hence would result in exposure of some cultural sites no matter how the water is managed.

Discussion: should MLFF be abandoned?

The MLFF provides an excellent example and warning to practitioners of adaptive management about the difficulties that scientists encounter in trying to determine the ecological impact of a policy change when only before-after monitoring data are available. We can develop suspicions about possible unintended side effects of the change (e.g. on native fishes), but it is always possible to explain away any such apparent effects as being due to some other factor that happened to change at the same time. Had at least one alternative flow regime, with more violent diurnal fluctuations, been implemented for a few years during the 1990s as an alternative experimental treatment for comparison to MLFF, we would be in a much better position to rule out alternative explanations. So from the standpoint of adaptive management, MLFF should not be abandoned entirely but rather treated as just one of several flow management options to be compared in a long-term experimental plan.

MLFF has obviously benefited some stakeholders, particularly the recreational rafting community and trout fishers who care more about catching lots of fish than catching big fish. Such benefits will certainly lead to pressure from those stakeholders to at least include the policy among future experimental treatments and to seek other ways to mitigate any negative ecological impacts that it may have (e.g. by mechanical removal of exotic predators, use of beach habitat building flows to conserve sediment resources).

But because MLFF does not appear to be a win-win option for all stakeholders, it raises an important ethical issue about who should bear the costs of continuing it. At present, power utilities and their ratepayers are essentially subsidizing, at considerable cost, improvement in the quality of Grand Canyon for some recreational uses. It is one thing to impose such cost to deal with some broad public interest such as protecting an endangered species, but quite another one to impose it for the benefit of particular stakeholders. This issue needs to be addressed openly and quickly as part of the overall adaptive management planning process, before it leads to a breakdown in the collaboration among stakeholders that has made adaptive management possible in Grand Canyon in the first place.

References

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Korman, J., M. Kaplinski, J. Hazel, T. Melis, J. Sneep, and C. Magirl. 2004. Effects of fluctuating flows from Glen Canyon Dam on the early life history stages of rainbow trout in the Lee's Ferry reach of the Colorado River, FY2003 Draft report prepared by Ecometric Research for GCMRC.

Rubin, D.M., D.J. Topping, J.C. Schmidt, J.Hazel. 2000. Summary and discussion of recent research findings related to dam operations and sand bar resources of the Colorado River ecosystem. Memo to Barry Gold, GCMRC, Aug. 29, 2000.

Figure 1. Changes in daily maximum and minimum flow below Glen Canyon Dam since 1948. Modified Low Fluctuating Flow regime (MLFF) appears after 1990.

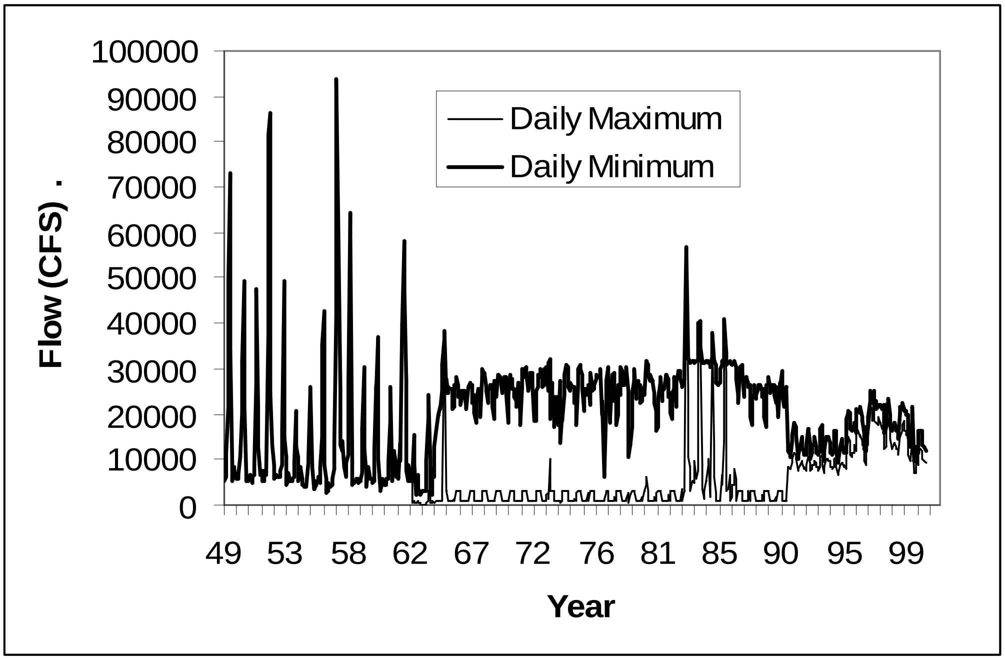


Figure 2. Trends in humpback chub population size in Grand Canyon as evidenced by various estimation procedures based on PIT tagging data.

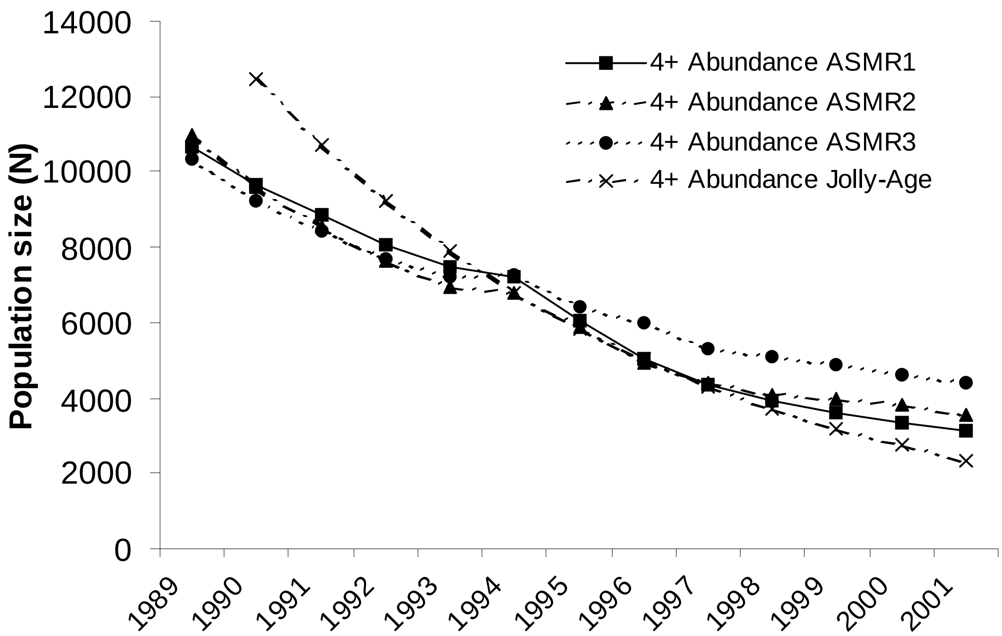
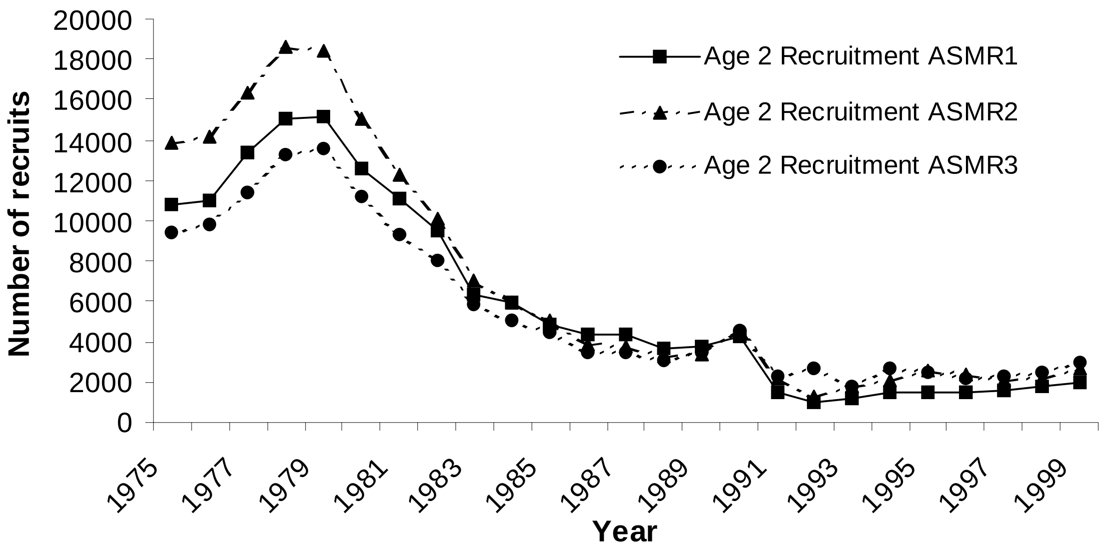


Figure 3. Trends in humpback chub recruitment estimated by analysis of PIT tags and from hoop net catch rates near the mouth of the Little Colorado River.



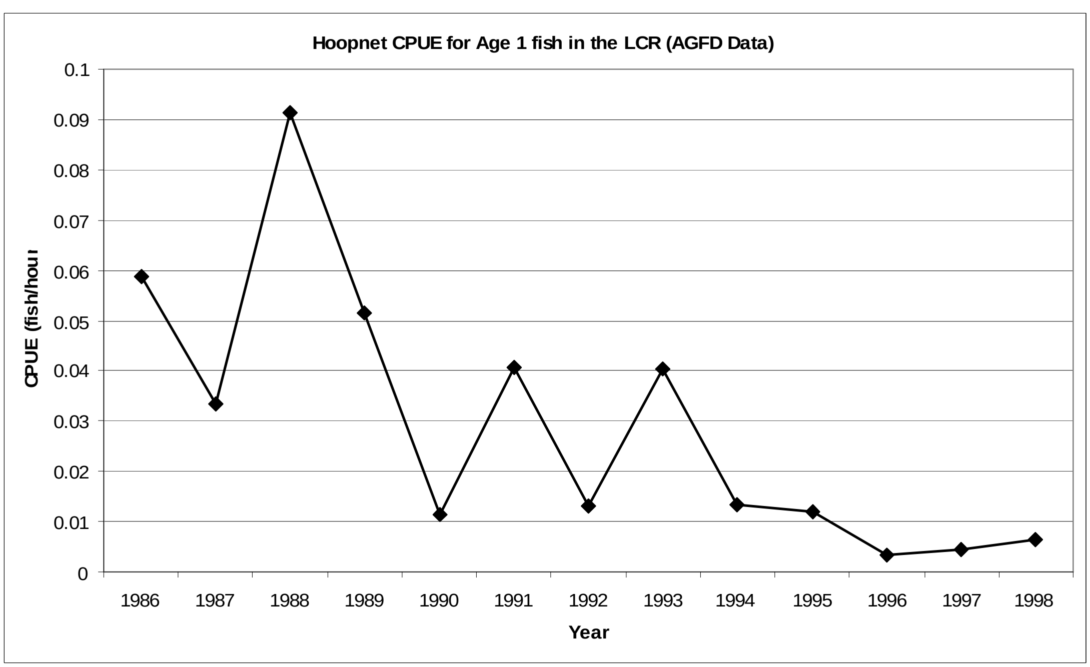


Figure 4. Trends in abundance of rainbow trout in Grand Canyon and Glen Canyon since initiation of MLFF flows**.**

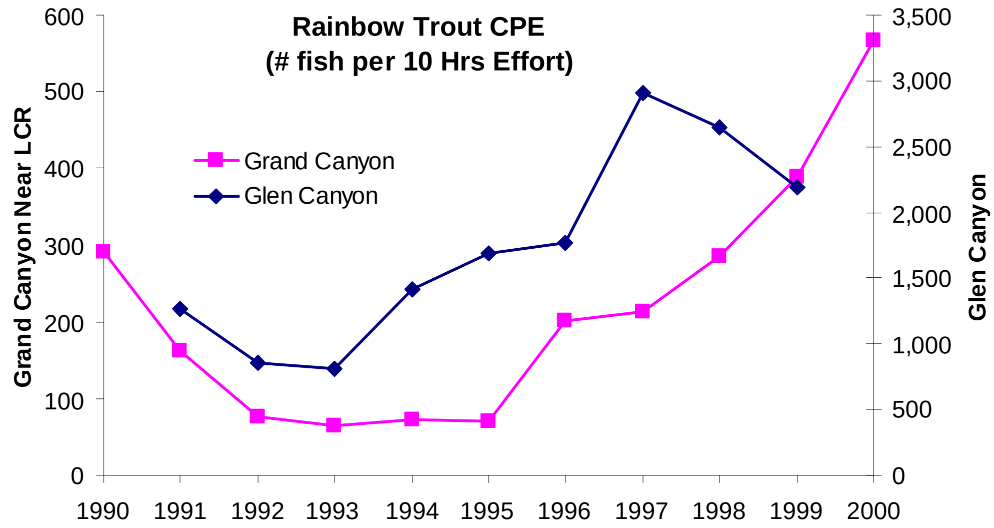


Figure 5. Trends in abundance and mean size of rainbow trout in the Lee's Ferry fishery, comparing population model reconstructions to observed trend index data prior to 2000.

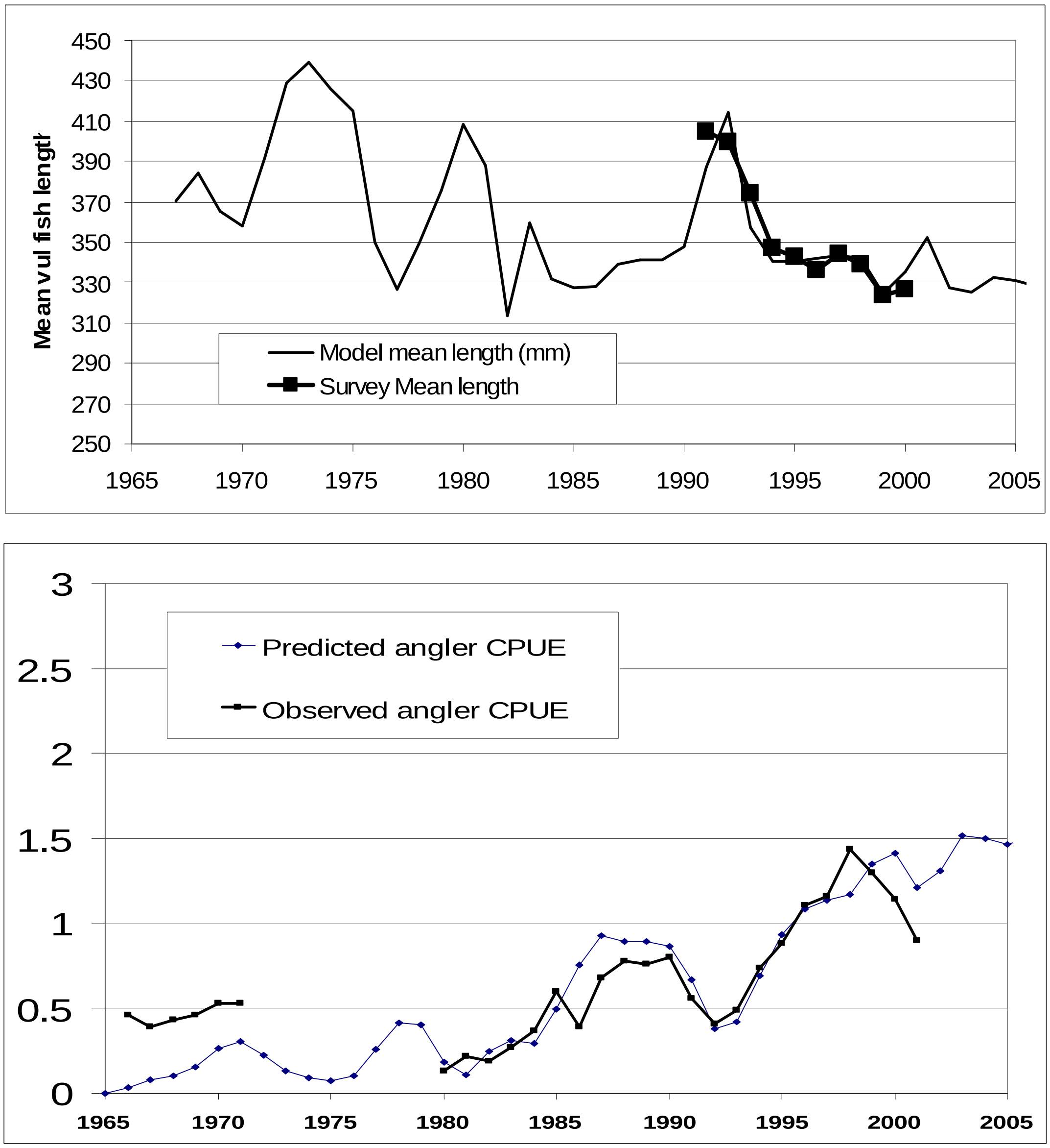


Figure 6. Trends in relative abundance of brown trout (catch per effort from electrofishing monitoring program) in Grand Canyon. Major population concentration is in the region of Bright Angel Creek (spawning area), but dramatic increases have been seen in recent years both upstream and downstream of this concentration. The increase upstream of Bright Angel (river miles RM<80) represents a growing threat to native fishes that spawn in the Little Colorado River.

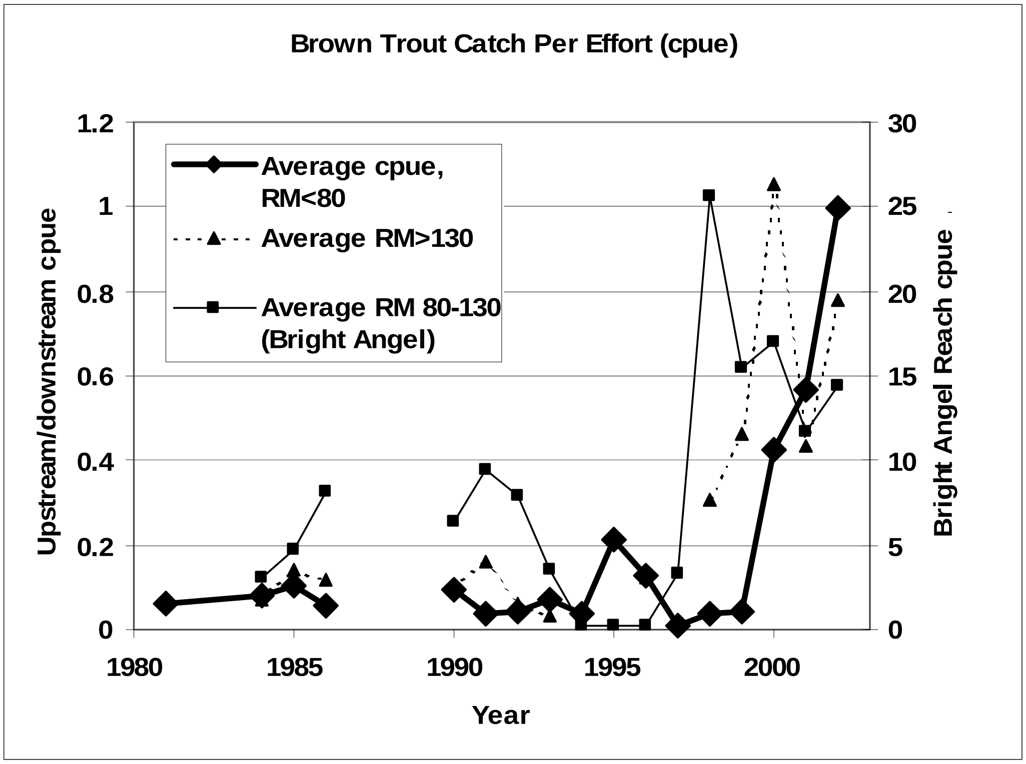


Figure 7. Hourly discharge pattern from Glen Canyon Dam for a one-week period under a release volume of 800 thousand acre-feet for 4 flow scanrios predicted by the WAPA Hydro LP model. See Table 1 for description of scenarios.

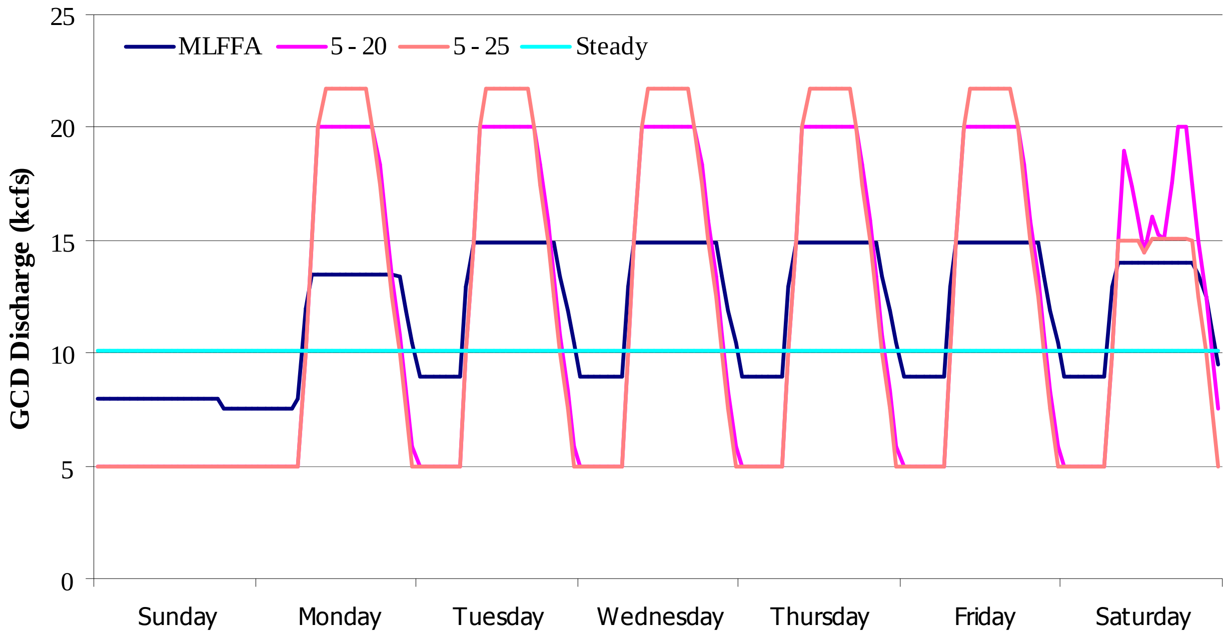


Figure 8. Relative sand transport rates at the Grand Canyon gage (based on March 2003 rating curve) as a function of the monthly release volume from Glen Canyon Dam under 3 alternate flow scenarios. See Table 1 for a description of scenarios.

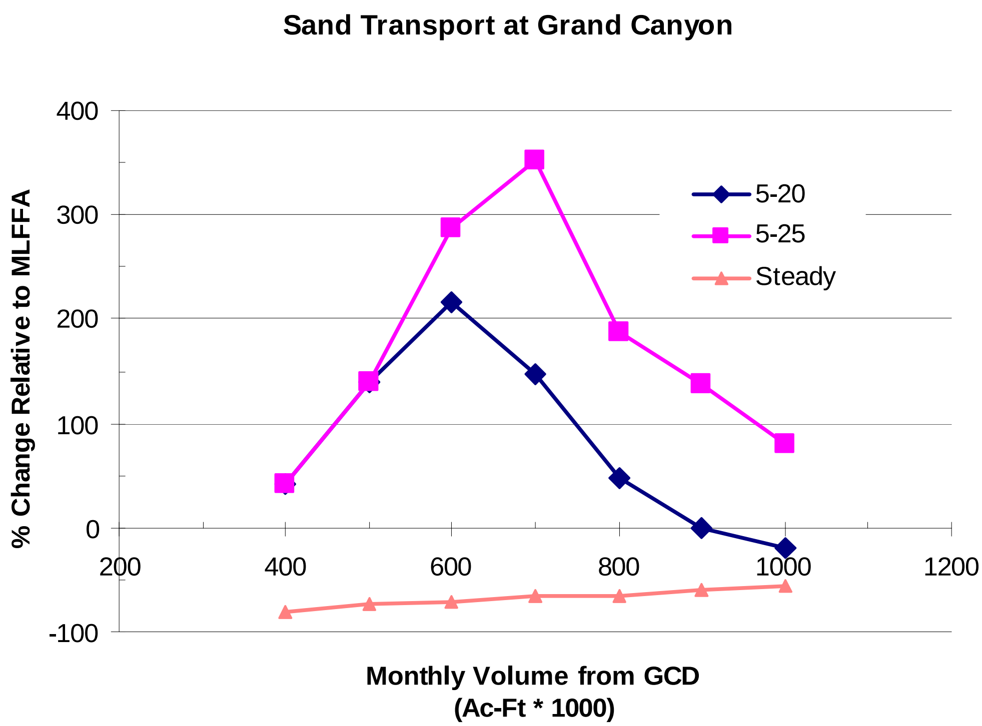


Figure 9. Frequency of monthly volumes released from Glen Canyon Dam predicted by Riveware for the period 2004-2010.