PROPOSED LONG-TERM EXPERIMENTAL PROGRAM OF FLOWS AND MANAGEMENT ACTIONS IN THE COLORADO RIVER BELOW GLEN CANYON DAM

submitted by

Western Area Power Administration, Arizona Game and Fish Department, and the Federation of Fly Fishers

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1 INTRODUCTION

Western Area Power Administration (Western), Arizona Game and Fish Department (AGFD), and the Federation of Fly Fishers (FFF) have recently proposed that an integrated set of flow and non-flow actions be pursued as the long-term experimental program below Glen Canyon Dam. The purpose of this proposed integrated program is to provide a set of benefits to a variety of resources including the:

- Grand Canyon population of the humpback chub (*Gila cypha*);
- Sediment resources (conservation) in the Grand Canyon critical reach over the long-term;
- Aquatic food base;
- Value of the power resource; and
- Lees Ferry trout fishery.

Although all of these resources are expected to benefit from the proposed integrated program, the primary focus is on the humpback chub. This program capitalizes on the information gathered to date on the status and trajectory of the humpback chub population, flows thought to benefit that population and the resources on which it depends, and non-flow management actions that would be effective in controlling nonnative predators and competitors of chub.

Several flow experiments have been tested since the ROD, including beach-habitat building flows (BHBF) (1996, 2004), habitat maintenance flows (1997, 2000), low steady summer flows (2000), winter fluctuations (2003–2005), and near steady flows (2005). Except for these relatively short-term experimental releases, modifications to the modified low fluctuating flows (MLFF) of the ROD have not been discussed or recommended by the Adaptive Management Program (AMP) committees or planned by the U.S. Bureau of Reclamation (Reclamation). However, recent findings presented at the Glen Canyon Monitoring and Research Center (GCMRC) Science Symposium and during the recent Technical Working Groups (TWG) Knowledge Assessment Workshop, indicate that Glen Canyon flows different from the MLFF during certain times of the year are likely to move the Colorado River ecosystem in the Grand Canyon closer to the stated purposes of the Glen Canyon Dam EIS preferred alternative, and to protect and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established.

Table 1. Experimental Program Elements 1998 to 2011.[1]

Water Year	Dominant Dam Operation	Mechanical Removal	Temperature Control Device (TCD)	Beach/Habitat Building Flow	Humpback Chub Comprehensive Plan Research	Humpback Chub Comprehensive Plan Habitat
1998	MLFF with habitat maintenance flow	No removal	No TCD	No BHBF	No activities	No activities
1999	MLFF only	No removal	No TCD	No BHBF	No activities	No activities
2000	MLFF with low summer steady flows and habitat maintenance flow	No removal	No TCD	No BHBF	No activities	No activities
2001	MLFF only	No removal	No TCD	No BHBF	No activities	No activities
2002	Same as previous	No removal	No TCD	No BHBF	No activities	No activities
2003	MLFF with experimental fluctuating flows	Trout removal	No TCD	No BHBF	No activities	No activities
2004	Same as previous	Same as previous	No TCD	No BHBF	No activities	No activities
2005	MLFF with experimental fluctuating flows and fall testing	Same as previous	No TCD	Fall BHBF	No activities	No activities
2006	Modified MLFF [see text for description][2]	Trout and possibly warmwater species removal[3]	Complete Draft EIS/BO	Fall BHBF dependent on sediment input from Paria and Little Colorado Rivers	Research and development of augmentation approach	Expansion of humpback chub habitat (e.g., translocation to Colorado River tributaries)
2007	Same as previous	Same as previous	Complete FEIS/BO	Same as previous	Same as previous	Same as previous
2008	Same as previous	Same as previous	Initiate construction	Same as previous	Same as previous	Same as previous

Table 1 (Cont.)

Water Year	Dominant Dam Operation	Mechanical Removal[3]	Temperature Control Device (TCD)	Beach/Habitat Building Flow	HBC Comprehensive Plan Research	HBC Comprehensive Plan Habitat
2009	Same as previous	Same as previous	Continue construction	Same as previous	Continue research or begin implementation if appropriate	Same as previous
2010	Same as previous	Same as previous	TCD operations	Same as previous	Same as previous	Same as previous
2011	Same as previous	Same as previous	Same as previous	Same as previous	Same as previous	Same as previous
2012	Same as previous	Same as previous	Same as previous	Same as previous	Same as previous	Same as previous
2013	Same as previous	Same as previous	Same as previous	Same as previous	Same as previous	Same as previous

[1] Orange indicates element not implemented, green indicates element is implemented during a particular year. MLFF = modified low fluctuating flow alternative, BHBF = beach/habitat building flow.

[2] Modifications relative to ROD flows include lower minimum flows during weekdays, but relatively higher minimum flows on Sundays with flows never dropping as low as ROD flows on Sundays; faster downramp rates; and experimentation with summer stranding flows and fall flows.

[3] Adaptively managed to be shifted to control of warmwater nonnative species as necessary.

Our proposal envisions the implementation of all of the actions described here (Table 1). Some of these actions are ongoing while others could be initiated almost immediately. Finally, others would require some research and planning before they could be implemented. We propose that these management actions be implemented as simultaneously as feasible, and that the integrated set of actions continue until the Grand Canyon population of humpback chub is considered self sustaining and that the number of chubs is sufficiently above the established recovery goal population size that discontinuing one or more of these management actions would be considered an acceptable experimental risk.

The effect on humpback chub of the management actions described here would be monitored, to the extent possible, throughout the program's implementation. Therefore, program implementation would be subject to change if scientific information and analysis was gathered that suggested an adverse effect of the program on the humpback chub population.

2 PROPOSED EXPERIMENTAL FLOWS AND ANTICIPATED EFFECTS

2.1 PROPOSED MODIFICATIONS TO THE MODIFIED LOW FLUCTUATING FLOW REGIME

The Glen Canyon Dam EIS Record of Decision (ROD) identified the Modified Low Fluctuating Flow (MLFF) alternative as the future operational regime for Glen Canyon Dam. In keeping with the adaptive management of that facility, we have proposed a modification to the MLFF that would benefit the humpback chub by controlling nonnative fish and improving the aquatic food base while providing some benefit to the power resource

The overall pattern of proposed flows and ROD flows in an 8.25 million acre feet water year is shown in Figure 1. Under our proposal, daily fluctuations would be greatest in January (5,000 to 17,000 cfs), but also relatively high in February (5,000 to 15,000 cfs), July, and August (both 8,000 to 18,000 cfs). In water years with annual volume greater than 8.25 million acre feet, release patterns consistent with the proposed pattern shown here would be developed.

As compared to ROD flows, minimum flows during the week would be lower in January, February, and March and in June, July, and August. Proposed maximum flows would be about the same as ROD maxima, but slightly higher in February, March, and April and July, August, and September, and slightly lower in January and June.

One of the main purposes of the proposed modification of flows is to improve the state of the food base in the Colorado River ecosystem. Presumably, this can be accomplished by providing higher minimum flows during the summer. During the summer, when the food base is more susceptible to the effects of exposure, flows under our proposal would not drop below 7,000 cfs. An examination of the graphs provided (Appendix A) compares the proposal with ROD flows for a typical week day for each summer month. A close examination will reveal that the minimum weekday flows under the ROD are actually higher during the summer months than the proposed flows. However, these graphs do not show possible flow patterns on Sundays.

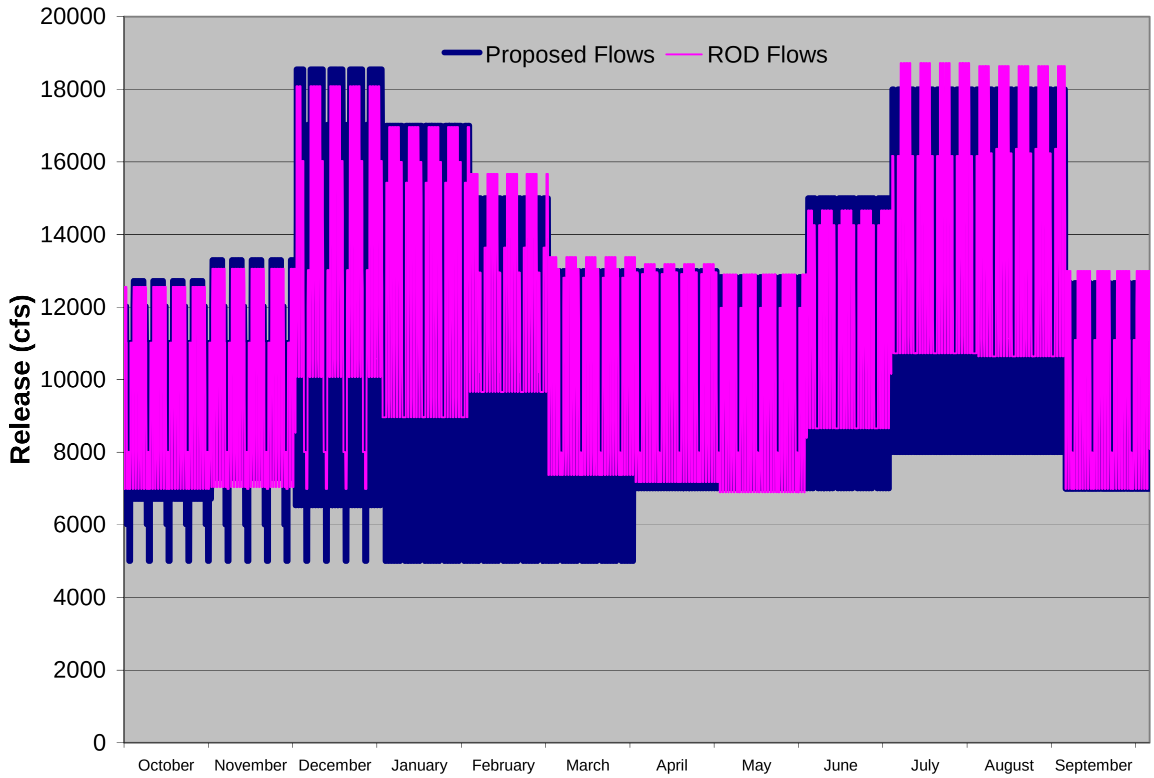

Figure 1. Proposed Glen Canyon Dam and ROD Releases from October through September.

Western's scheduled demand for electrical power is significantly less on Sunday. Sunday is considered an “off peak” time period, just like nighttime hours during the week. Western can take advantage of the flexibility under the ROD to save water on Sunday. This is done by reducing the peak flows on Saturday to something less than the ROD allows. With a lower Saturday peak, Western can now reduce flows on Sunday to 5,000 cfs during the 7 PM to 7 AM nighttime hours. Under the ROD, an 8,000 cfs minimum is required during the remaining daytime hours. This is referred to as "stepping down into Sunday". Western often uses this method to plan the week. In fact, Western and Reclamation have had discussions with the fishing guides about this practice over the years and has sometimes agreed to limit its use voluntarily depending on the state of the trout population at Lee Ferry.

Under our proposal, Western would agree to suspend this practice altogether in order to provide Sunday minimum flows that do not differ from the weekday minimum flows (i.e., 7,000 to 8,000 cfs depending on the summer month). The proposed flows therefore, commit to a higher minimum flow throughout the summer season as compared to the minimum flow that would occur during nighttime hours under the ROD.

In addition to differences in maximum and minimum flows, the proposed flow regime differs from ROD flows in the on-peak duration (generally longer in the proposed regime as compared to ROD flows; Figure 2) and the downramp rate (slightly greater in the proposed regime; Figure 2).

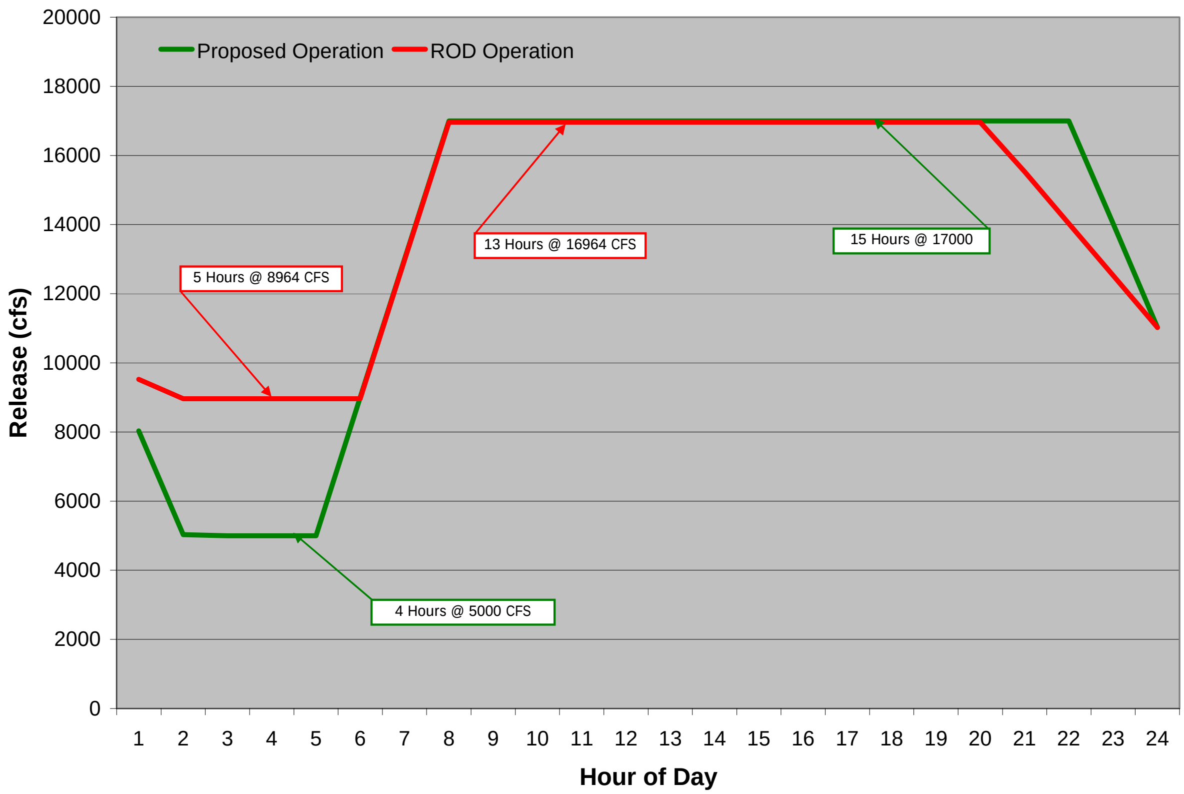

Figure 3. Proposed Hourly Pattern of Releases for a Weekday in January.

During the winters of 2003, 2004, and 2005, daily fluctuations between 5,000 and 20,000 cfs were implemented in an attempt to reduce the recruitment of rainbow trout in the main channel, and also to reduce competition and predation of trout species on humpback chub. These fluctuations were intended to reduce survival of trout eggs and young. As an incidental benefit, they were intended to increase the average size and health of trout in the Lees Ferry fishery by reducing recruitment and density, and thus lowering competition.

Evidence presented by Korman at the 2005 GCMRC Science Symposium (Korman et al. 2005a), suggests that recently there may be little mainstem spawning and recruitment of rainbow trout downstream of the Paria River, the area the AMP wants to manage for native fishes. Korman also speculated that the Lees Ferry population serves as the source of the trout that occur near the Little Colorado River. If the Lees Ferry reach is the source of the fish that prey on and compete with humpback chub at and downstream of the Little Colorado River, control of the Lees Ferry population using dam operations could provide an important benefit for humpback chub.

The fluctuations tested did not strand or increase mortality of many adult fish, but it did reduce reproductive success by affecting the thermal regime at some redds (Korman et al. 2005b). Fluctuating flows are also thought to have disoriented and stranded some larval and juvenile fish. Given the possible link between the Lees Ferry trout production and trout abundance in mainstem habitat of the humpback chub, continued implementation of fluctuating flows appears to be warranted. Because another of the AMP goals is to maintain a healthy sport fishery at Lees Ferry, the overall effect of fluctuations on the quality of the trout fishery should be evaluated during the study period.

Proposed maximum daily flows would be less than those tested in 2003 through 2005, however, proposed minimum daily flows from January through March would be the same (i.e., 5,000 cfs; Figure 1 and 3). Because Korman et al. (2005b) determined that the majority of redds occurred at elevations below the 8,000 cfs flow, the proposed flow regime should effectively expose redds and adversely effect reproductive success. Because most spawning occurs in mid-March (Korman et al. 2005b), fluctuations at this time of the year are expected to have the greatest impact on reproductive success of trout. The effectiveness of the proposed winter fluctuation pattern would be tested and compared to the results of Korman et al. (2005b).

Helwig and Leibfried (Appendix B) reviewed the literature regarding the aquatic food base in the Colorado River below Glen Canyon Dam and the effects of flow magnitude and fluctuating flows on standing crop and drift. Their evaluation suggests that increased flows can increase standing crop of the food base and that fluctuations can induce drift, thus increasing the availability of food to fish. However, they also identified uncertainties associated with the specifics of these relationships that could be evaluated in a long-term experimental program.

2.2 OTHER FLOW EXPERIMENTS

In addition to the proposed daily, weekly, and annual pattern described above, the proposed experimental flow regime would include a number of other experiments that would be used to refine operations to perform specific tasks. Included are nonnative fish management flows (e.g., summer stranding flows), fall steady flows to benefit young humpback chub, and tests of the effects of ramp rate on sediment transport. The specifics of the flows that would be tested in these experiments would be subject to adaptive management, but are discussed below.

Summer Stranding Flows

The conceptual design of a summer stranding flow to control young-of-the-year (YOY) trout was proposed by Korman et al. (2005) based on observations made during their study of the effects of winter fluctuating flows and on the scientific literature. Stranding flows would target trout, specifically larvae and juveniles.

Korman et al. (2005b) observed that YOY trout generally occupied the daily minimum flow elevation even after flows rose during the day, and thus avoided stranding when flows fluctuated. They noted substantial decreases in density following the early September reduction in the minimum daily flow from 10,000 to 5,000 in 2003 and 2004. Based on their observations and a review of the literature, they identified that the factors that affect the extent of stranding include channel morphology, substrate, fish size and age, species, time of day, exposure frequency, season, temperature, and the rate of stage change. The extent of stranding has been observed to be highest in low-angle habitats, such as Lees Ferry, with abundant cover. Small brown trout (50 cm) have been shown to be more vulnerable to stranding than larger juveniles.

Stranding rates tended to increase at lower water temperatures and were highest if flow reductions occurred during daylight hours. A decrease in the down-ramping rate from 60 cm/hr. to 10 cm/hr was shown to reduce stranding of brown trout YOY by 50%.

Based on these observations they hypothesized that if higher flows were maintained for an extended period of time, young fish would eventually move to those higher elevations. Thus, an effective stranding flow would be one that maintained elevated flows (e.g., 15,000 cfs) for 2 or 3 days and was followed by a very sharp drop in flows to a minimum flow level (e.g., 7,000 cfs). The most effective timing of such a flow would be when large numbers of YOY trout are present, but avoidance of impacts to other resources should also be a consideration. Thus, a stranding flow in the period of June, July, or August should be considered.

Despite the expectation that a summer stranding flow could be effective in controlling trout numbers, and thus competition with and predation of humpback chub, a number of uncertainties exist that should be evaluated during experimentation. For instance, an observed reduction in small fish following a sharp drop in flows could reflect transport out of the reach rather than mortality. Stranding mortality of YOY fish ultimately may not affect the size of the adult population if survival at this life stage is not a limiting factor for the population or if compensatory mechanisms effectively negated the effect of increased mortality. There is also the potential for stranding of native fish species. These factors can be evaluated during stranding experiments.

Fall Flows

Monsoonal rains flush juvenile humpback chub from the Little Colorado River into the colder Colorado River, where presumably there is higher mortality. To offset this impact, it has been suggested that, after heavy runoff in the Little Colorado River, Glen Canyon Dam releases should be steady to reduce impacts to juveniles that enter the mainstem until these juvenile fish have grown large enough to increase overwinter survival. These flows could be steady or nearly steady, and are currently being considered for September and October. This operational pattern could become an important component of an overall dam release strategy if it is shown to benefit young humpback chub and ultimately contribute to recovery.

Ponding Flows

Ponding flows are those relatively high mainstem flows that produce a quiet water area near the mouth of the Little Colorado River. This ponded area gives young humpback chub a place to grow before they enter the harsher conditions of the main channel Colorado River. It has been hypothesized that this area is important to increasing the survival of young humpback chub. The timing of ponding flows has generally been considered for the spring. Although ponding flows have been provided in the past, their effectiveness has not been demonstrated and is considered very uncertain. Ponding flows could be considered for incorporation into the proposed long-term experimental program especially in high water years or in years when equalization releases are needed.

Electrical Power Production Experiments

ROD flows were intended to improve the status of a set of natural resources in the Colorado River Ecosystem. The operational parameters of these flows were conservatively chosen to ensure that the anticipated benefits to these resources would be achieved, and operational parameters were to be reexamined and modified as appropriate through an adaptive management process. However, there has been very little experimentation directed at the operating parameters themselves. For example: would an increase in the downramp rate have a measurable and deleterious effect on sediment retention of Marble Canyon beaches? Does an increase in the daily variation produce additional drifting food for trout and humpback chub? Can New Zealand mud snails be reduced by a higher daily variation? Korman et al. (2005) reviewed the literature on the effects of ramp rate on stranding and determined that a decrease in the down-ramping rate from 60 cm/hr. to 10 cm/hr was shown to reduce stranding of brown trout YOY by 50%. The downramp rate tested during 2003 through 2005 was approximately 15 cm/hr.

We propose short-term experimentation with operational parameters. This likely includes the modification of more than one operating parameter at a time since recent analysis show very little power benefit from the liberalization of just one parameter. These experiments could be conducted at any time of the year; however, they may be concentrated in the winter months when the most benefit to power resources might be achieved with little harm to other resources.

2.2 PROPOSED NON-FLOW MANAGEMENT ACTIONS AND ANTICIPATED EFFECTS

Temperature Control Device

Before Glen Canyon Dam was constructed, the seasonal cycle of the Colorado River included a natural warming trend in the late summer as the water temperature would increase from the near freezing winter temperature to approximately 29^{o}C. Since the dam was constructed, the temperature of the water released has become relatively steady at between 7 and 10°C because the water is drawn year round from the deep, fixed-level penstock intakes. Near the dam, these cold releases are tolerated by the trout fishery, but as this water moves downstream, it only warms to about 15.5°C which is not warm enough to allow humpback chub to reproduce in the mainstem of the Colorado River. Cold summertime water from these hypolimnetic releases can inhibit hatching and survival of eggs and larvae and it is believed that juvenile humpback chub (<50 mm TL) can experience thermal shock as they descend into the mainstem Colorado River from seasonally warmed tributaries.

Recent drought conditions have resulted in warmer releases as reservoir elevations have dropped. However, without a TCD, future increases in reservoir elevations predicted in the latest 24-month study (Reclamation 2005) will result in increasingly cooler release temperatures and potentially harmful effects on humpback chub. It is essential that planning for these cooler release temperatures proceed and that the original plans for installation and operation of a TCD be put back on track. The Science Advisory Board has recommended a pilot program to install temperature control devices on two of the units at Glen Canyon Dam. We propose that this recommendation be implemented over the next few years (Table 1). However, because analyses indicate that placing temperature control devices on only two-units may not be sufficient to increase the temperature of the river to levels that will promote reproduction by humpback chub, we propose that consideration be given to the planning and compliance work needed to construct temperature control devices on enough units to increase water temperature below the Little Colorado River to levels that would improve the survival of larval and juvenile humpback chub.

Because increasing water temperatures in the mainstem Colorado River could potentially improve conditions for some warmwater nonnative fishes that compete with or prey on humpback chub, additional experimentation could be warranted. The goal would be to determine the appropriate combination of cold and warmer water withdrawals needed to benefit the native endangered fish, while controlling benefits to warmwater nonnative fishes in the system.

Continued Efforts toward Humpback Chub Augmentation

The status of the humpback chub population in the Colorado River ecosystem could potentially be improved through artificial augmentation methods (i.e., stocking). We propose that a stocking program be developed and continued until the population of humpback chub in the Colorado River ecosystem becomes self-sustaining.

Establishment of a captive broodstock could provide a genetic refugium for humpback chub. However, releasing propagated individuals from this broodstock into the wild could pose biological risks such as genetic introgression, inbreeding depression, domestication, and a potential to decrease the genetic effective population size of the wild population (Van Haverbeke and Simmonds 2004). As part of developing a captive broodstock program, a captive broodstock management plan should be developed, an adequate facility for holding fish should be identified, and a formal stocking plan should be developed. The humpback chub currently being held at Willow Beach National Fish Hatchery could serve as a starting point for such a program (Van Haverbeke and Simmonds 2004).

In addition, consideration should be given to developing grow-out ponds, where larval or juvenile fish could be held in a predator-free environment until they are large enough to survive and be reintroduced into the Colorado River ecosystem. The fish to be maintained in these ponds could originate from captive adults spawned in captivity as part of a broodstock program or could be obtained by capturing wild larvae or juveniles. A recent idea is that grow-out ponds could be constructed at the mouth of the Little Colorado River or the mouth of the Paria River.

Efforts to Increase the Geographical Extent of Occupied Humpback Chub Habitat in the Colorado River Ecosystem

In order to expand the areas inhabited by humpback chub and to protect the Grand Canyon population of humpback chub from potential catastrophic events in the Little Colorado

River, it has been proposed that YOY humpback chub be translocated to other Grand Canyon tributaries.

Translocation activities were initiated in the Little Colorado River during August 2003 and August 2004 by capturing YOY humpback chub in the lower portion of the Little Colorado River and moving them to locations in the Little Colorado River upstream of Chute Falls (a natural barrier). Results of monitoring indicate that at least some of the translocated fish survived and grew well in the upper portion of the Little Colorado River (Sponholtz et al. 2005). This resulted in an expansion of the inhabited range of humpback chub by 4 km and there were indications during 2005 that some of the translocated fish were in spawning condition. It is not yet known whether offspring were produced by these fish. Expansion of the population above Chute Falls, while potentially beneficial, would not remove susceptibility of the population to a catastrophic event in the Little Colorado River.

Initial efforts to expand translocation activities would include research and field experimentation to identify candidate streams and to determine where translocated fish would be likely to survive. Although the goal would be to produce a fully self-sustaining humpback chub population outside the Little Colorado River, even establishing additional areas that contain fish that do not reproduce would result in improved protection for humpback chub in Grand Canyon. It is anticipated that monitoring would be required to evaluate the success of translocation efforts, to track the status of translocated fish, and to improve knowledge about the biological requirements of humpback chub.

Some initial work has been done to rank potential tributary sites (Stevens 2005) based on a variety of criteria. These criteria included the presence of barriers to fish movement, the abundance of nonnative predators, abundance of native fish, habitat suitability (e.g., temperature regimes), perceived ability to remove nonnatives, and jurisdictional issues. Compared to the Little Colorado River, which presently contains the best known available conditions for YOY humpback chub, the tributaries that ranked the highest were Bright Angel Creek and Shinumu Creek.

Mechanical Removal of Nonnative Fishes

The presence of nonnative fishes in habitats occupied by humpback chub is considered one of the major threats to survival of humpback chub populations in Grand Canyon. In addition to implementing selected flow-related actions to reduce the numbers of nonnative fishes in occupied areas, we believe that mechanical removal actions should also be conducted.

Since January 2003, mechanical removal using electrofishing has been conducted on an experimental basis in the Colorado River. The current mechanical removal efforts, which are ongoing, target a 24-km reach of the Colorado River that extends from 8 km upstream to 16 km downstream of the Little Colorado River. These efforts have been primarily intended to remove rainbow and brown trout, which are known predators of juvenile humpback chub. Over 16,000 trout were removed from the treated reach of river during 2003 and 2004 and there are indications that the abundance of trout within the reach dropped by over 50% during that time (Coggins and Yard 2005).

In addition to electrofishing, weirs or other fish-trapping methods could be used to remove trout from tributaries. This technique may be useful for controlling trout spawning in Colorado River tributaries by removing adult trout as they move into tributary spawning areas. In 2002, a feasibility study was initiated in Bright Angel Creek, a known spawning tributary used by brown trout, to evaluate trout capture potential using a weir. During the 64 days the weir was in use, 423 brown trout and 188 rainbow trout, ranging in size from 210 to 620 mm, were captured (SWCA Environmental Consultants 2005). This study indicated that fish-trapping methods could be an efficient and cost-effective way to remove non-native salmonids from native fish habitat and to reduce trout spawning success in tributaries. If Colorado River tributaries, such as Bright Angel Creek, are selected as sites for introducing translocated humpback chub juveniles (see above), such methods could be extremely valuable for reducing the numbers of nonnative fishes in the tributaries or for controlling access by nonnative fishes.

We propose that mechanical removal efforts be continued as part of the long-term integrated experimental program. If water temperatures increase as a consequence of natural conditions (e.g., low flows and low reservoir elevations) or because of the construction and operation of a temperature-control device, there is a possibility that warmwater nonnative fish species could expand to areas currently utilized by YOY humpback chub. To combat such expansions, mechanical removal efforts should be adapted, as necessary, to target other species, in addition to trout, that are identified as being the dominant predators and competitors with humpback chub.

3 REFERENCES

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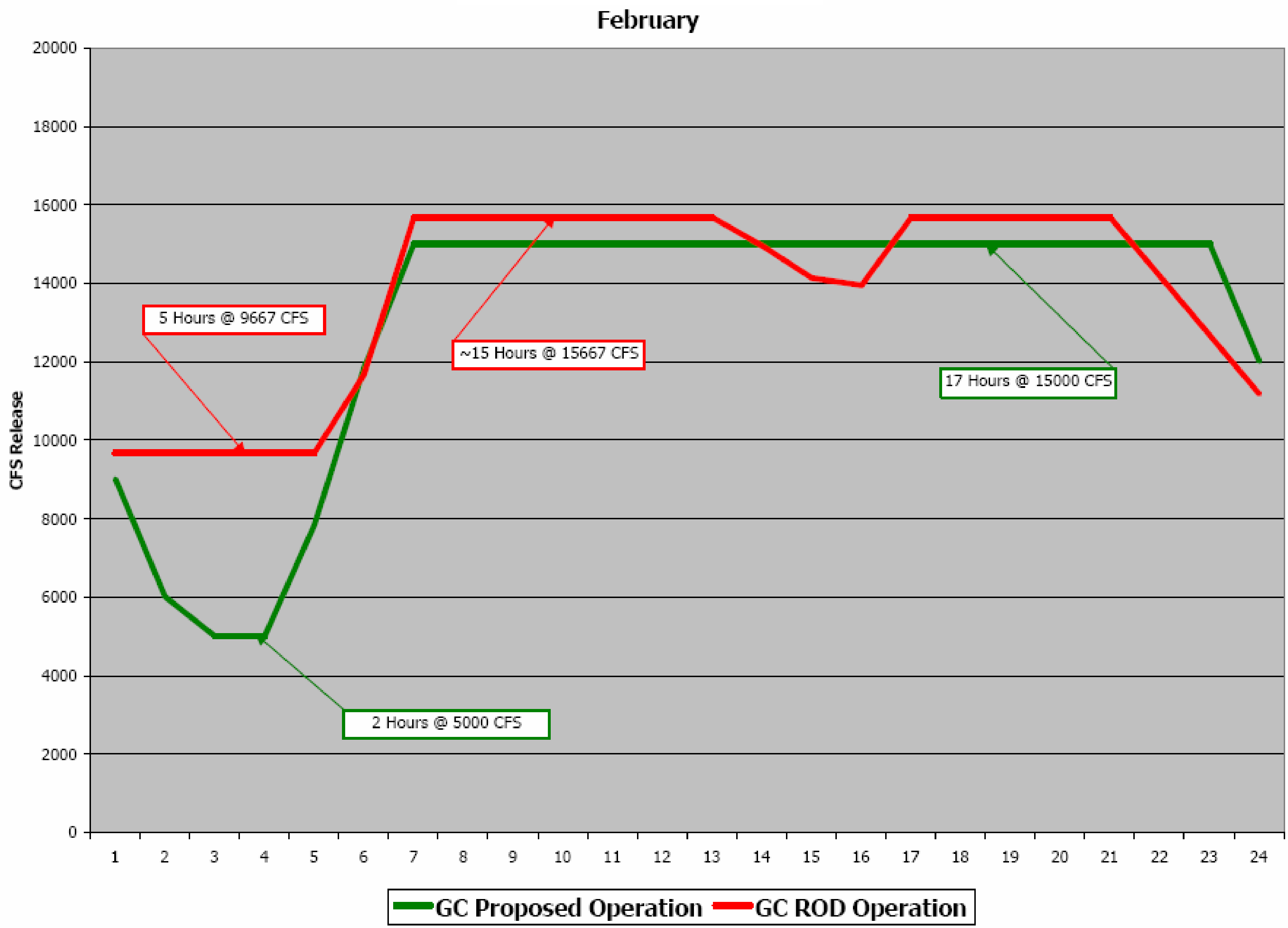
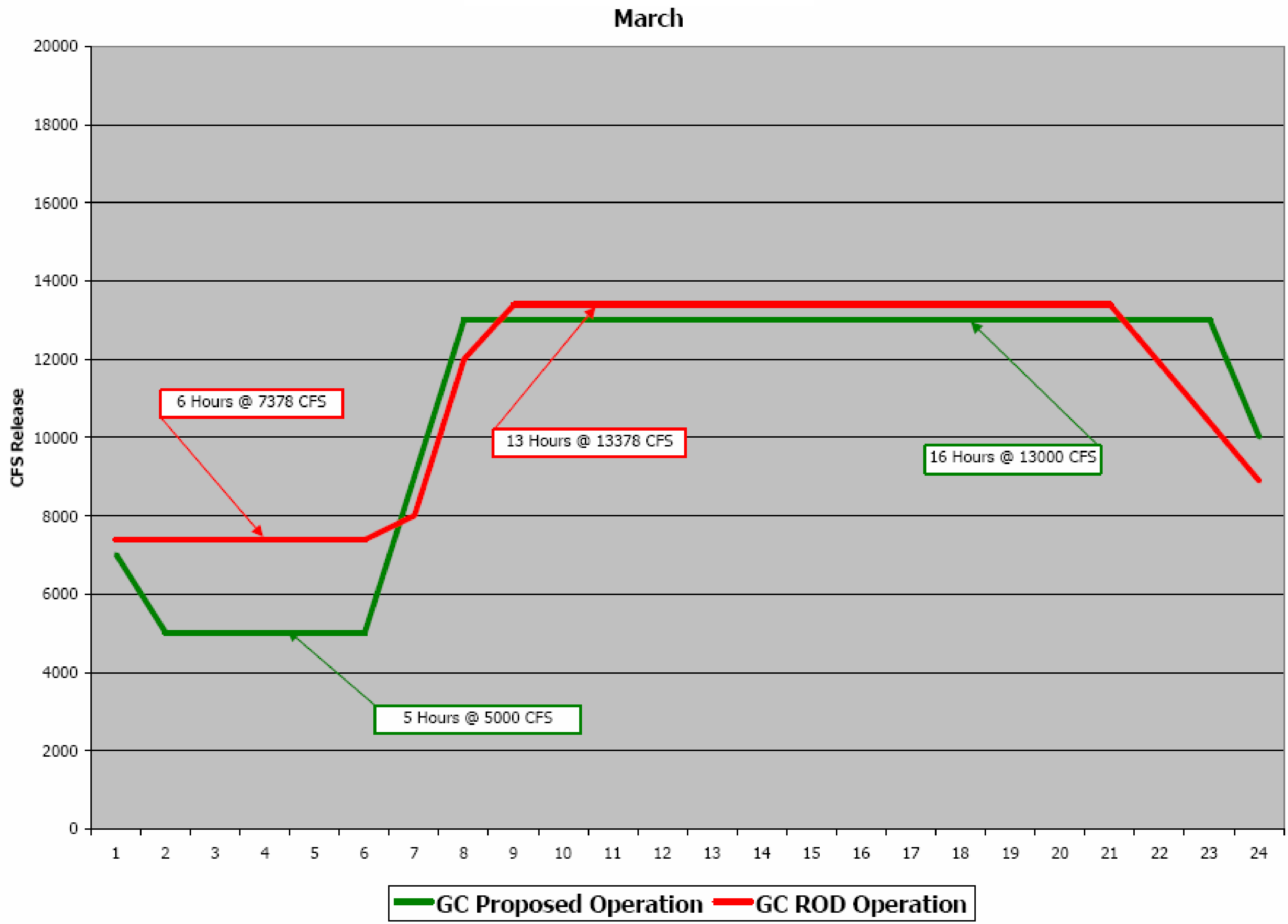
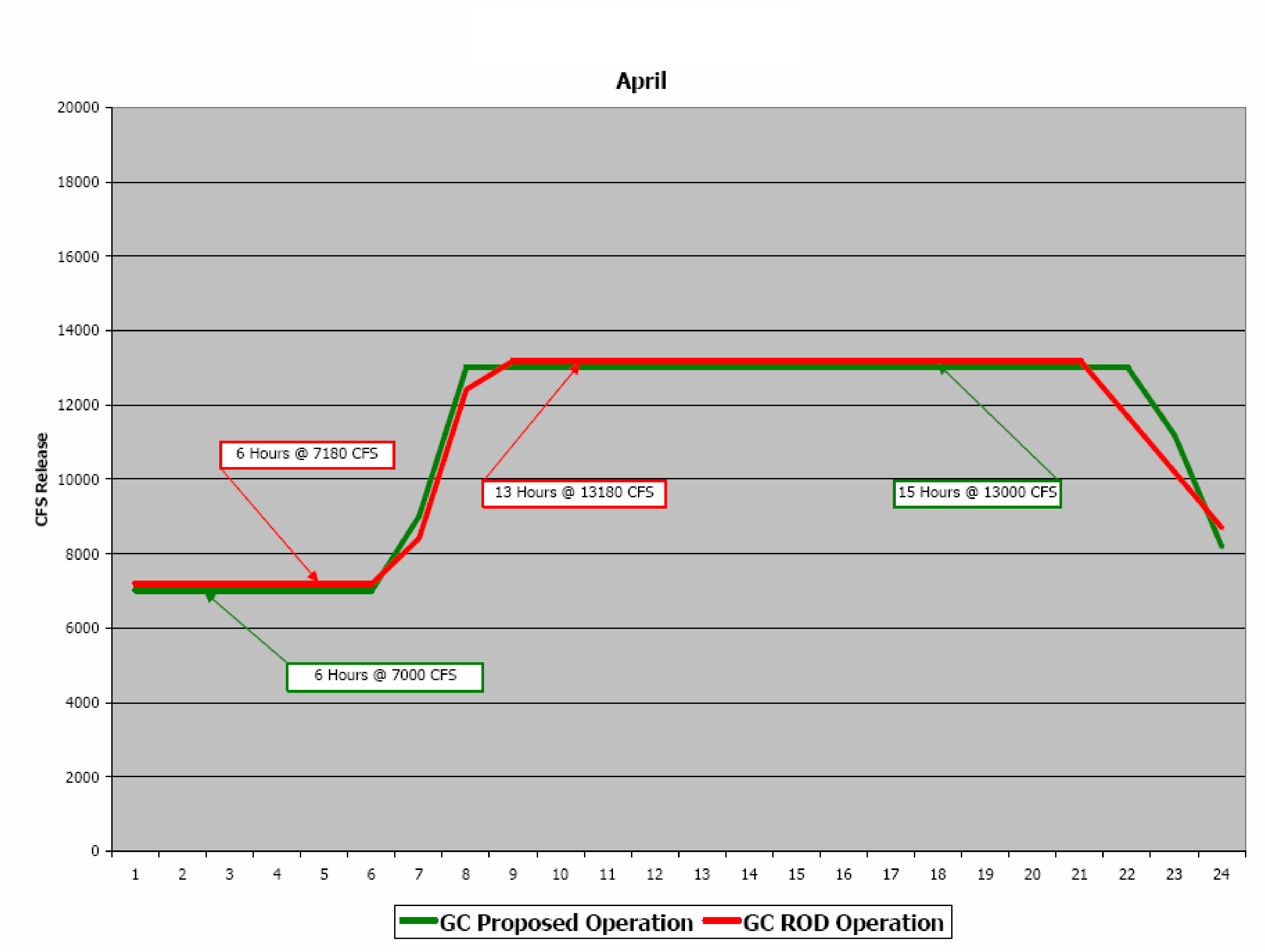
APPENDIX A

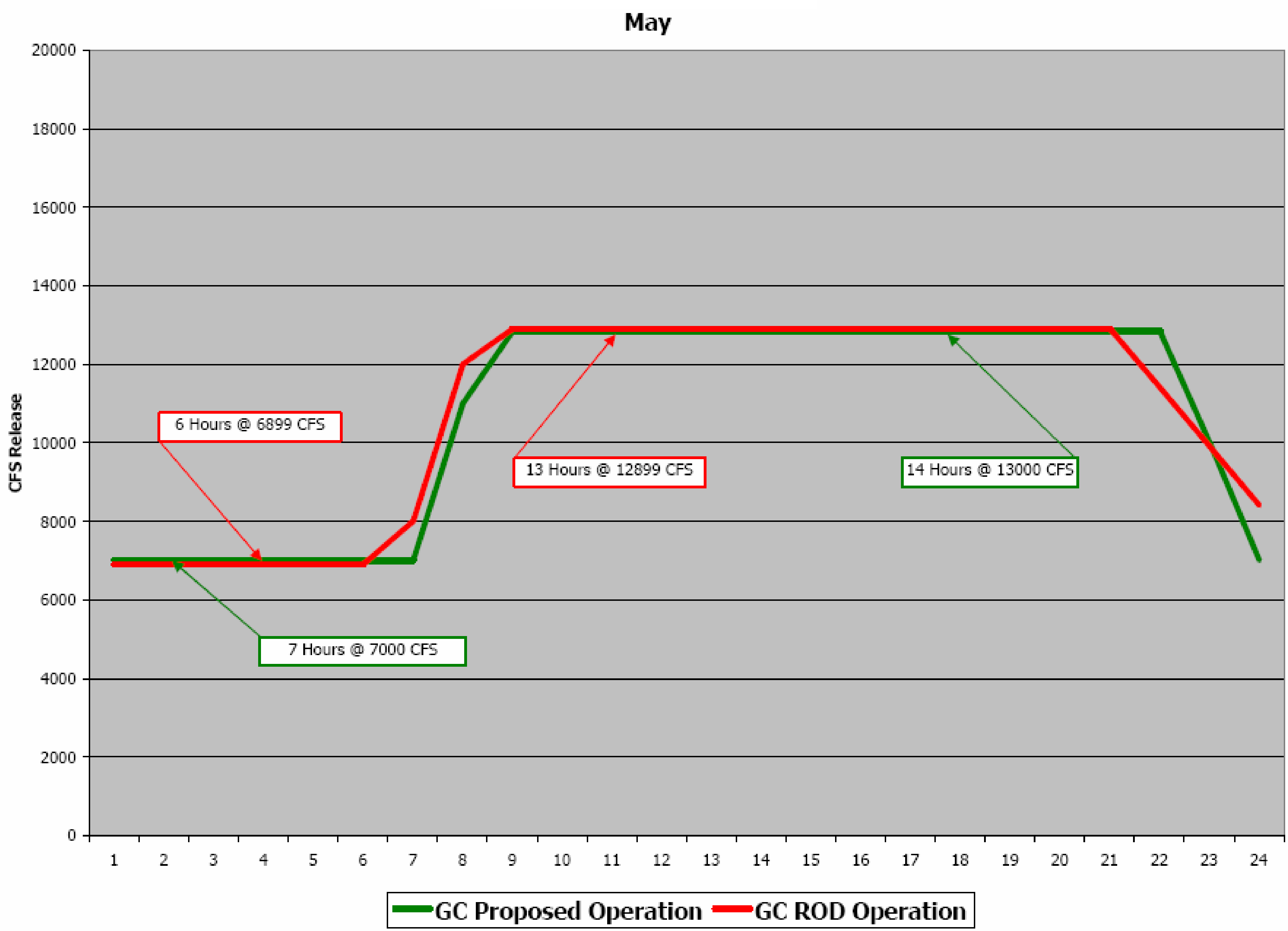
REPRESENTATIVE WEEKDAY FLOWS DURING AN 8.25 MILLION ACRE FEET WATER YEAR

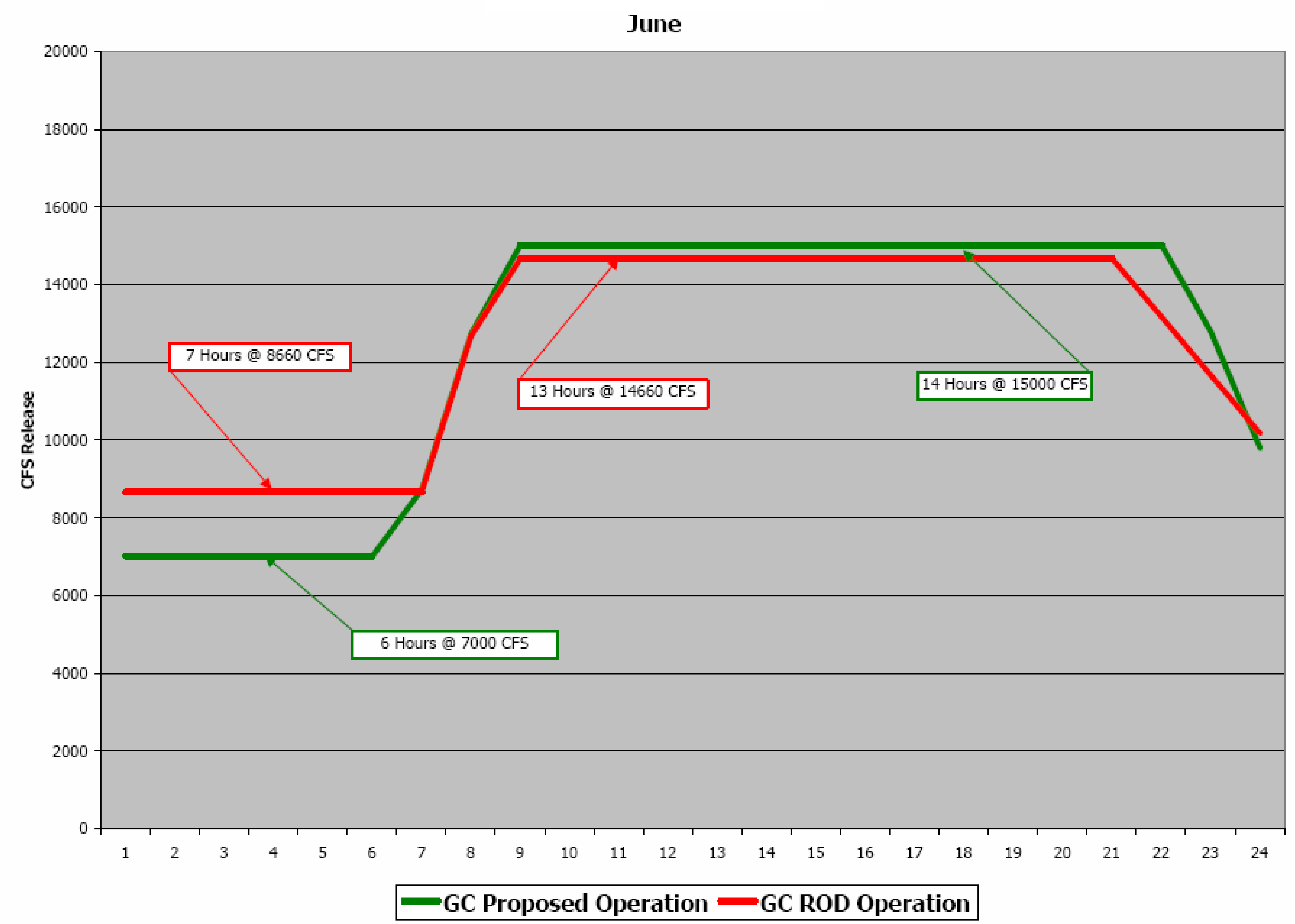

January
CFS Release
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
5 Hours @ 8964 CFS
13 Hours @ 16964 CFS
15 Hours @ 17000 CFS
4 Hours @ 5000 CFS
GC Proposed Operation
GC ROD Operation


February
CFS Release
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
5 Hours @ 9667 CFS
~15 Hours @ 15667 CFS
17 Hours @ 15000 CFS
2 Hours @ 5000 CFS
GC Proposed Operation
GC ROD Operation


March
CFS Release
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
6 Hours @ 7378 CFS
13 Hours @ 13378 CFS
16 Hours @ 13000 CFS
5 Hours @ 5000 CFS
GC Proposed Operation
GC ROD Operation


April
CFS Release
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
6 Hours @ 7180 CFS
13 Hours @ 13180 CFS
15 Hours @ 13000 CFS
6 Hours @ 7000 CFS
GC Proposed Operation
GC ROD Operation


May
CFS Release
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
6 Hours @ 6899 CFS
13 Hours @ 12899 CFS
14 Hours @ 13000 CFS
7 Hours @ 7000 CFS
GC Proposed Operation
GC ROD Operation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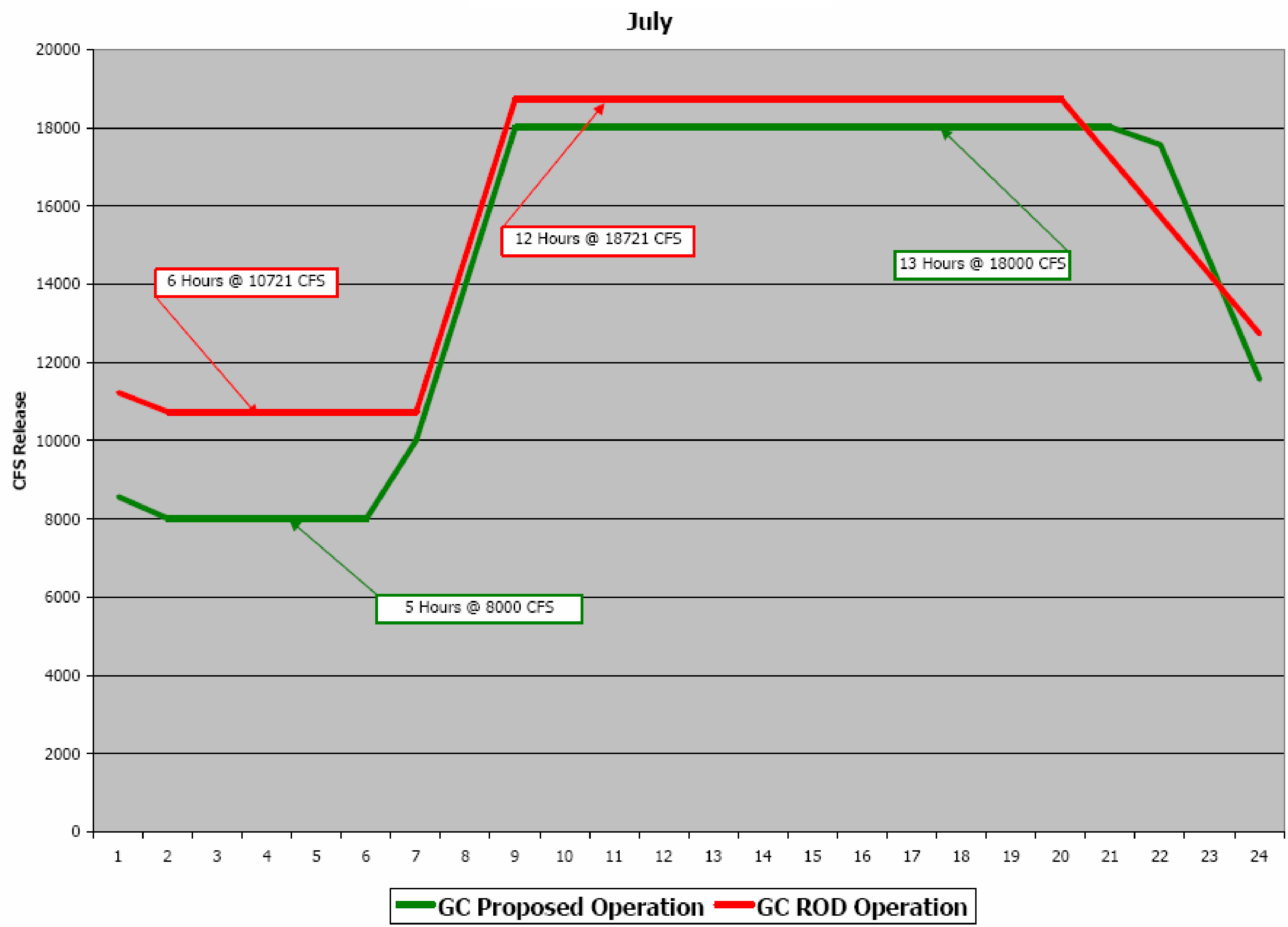
7 Hours @ 8660 CFS
13 Hours @ 14660 CFS
14 Hours @ 15000 CFS
6 Hours @ 7000 CFS
GC Proposed Operation
GC ROD Operation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6 Hours @ 10721 CFS
12 Hours @ 18721 CFS
13 Hours @ 18000 CFS
5 Hours @ 8000 CFS
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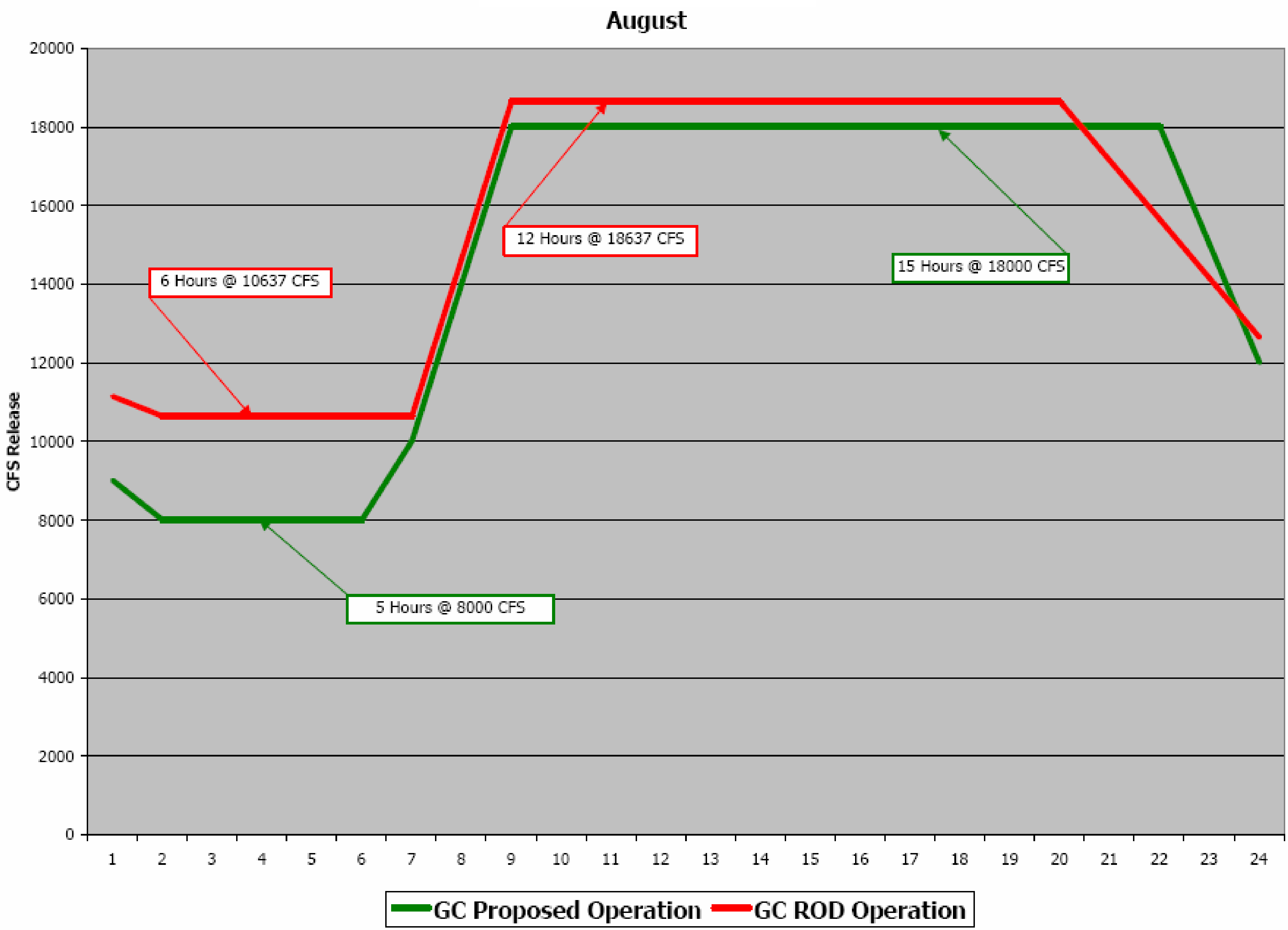
GC ROD Operation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24
6 Hours @ 10637 CFS
12 Hours @ 18637 CFS
15 Hours @ 18000 CFS
5 Hours @ 8000 CFS
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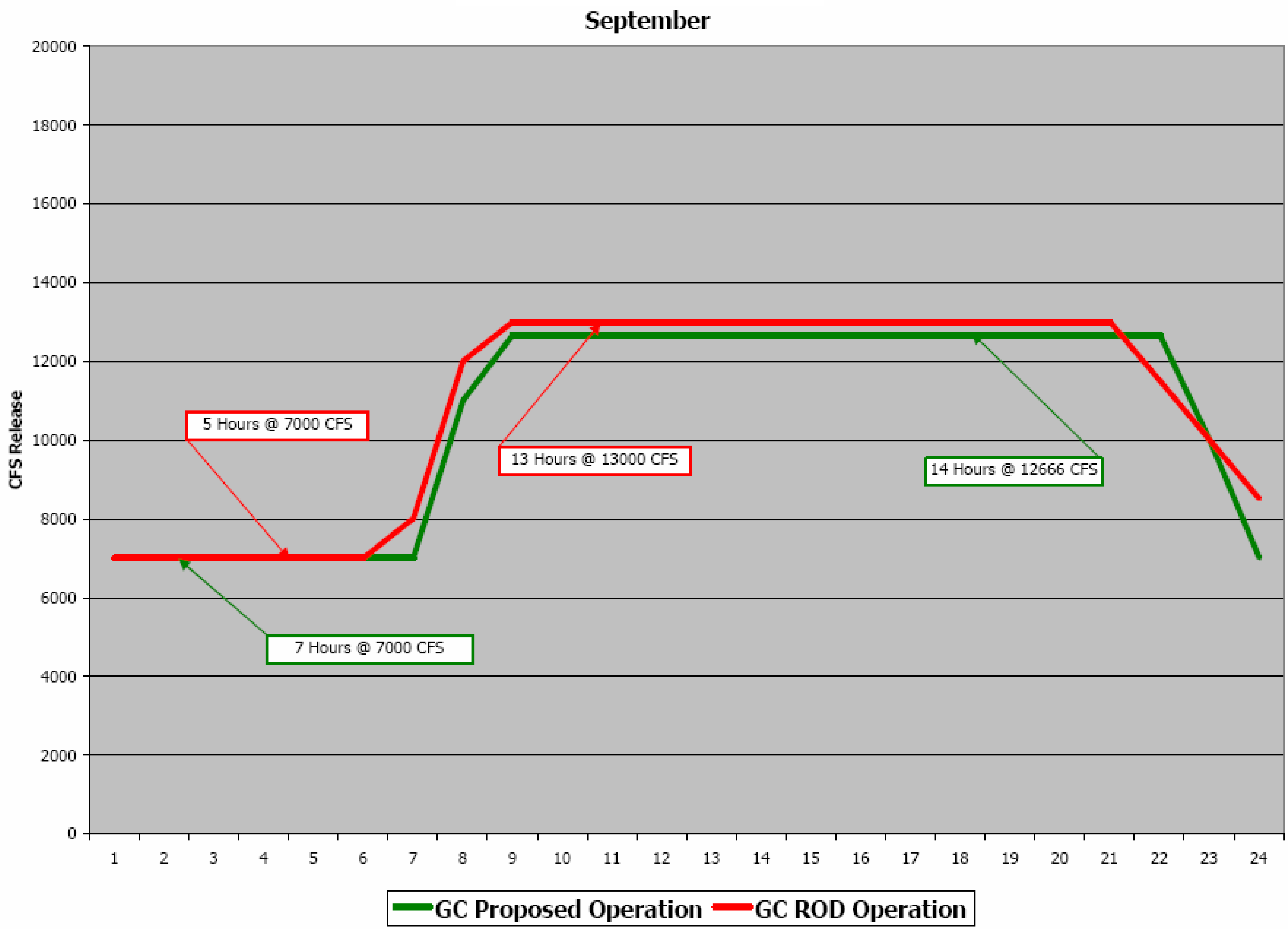
GC ROD Operation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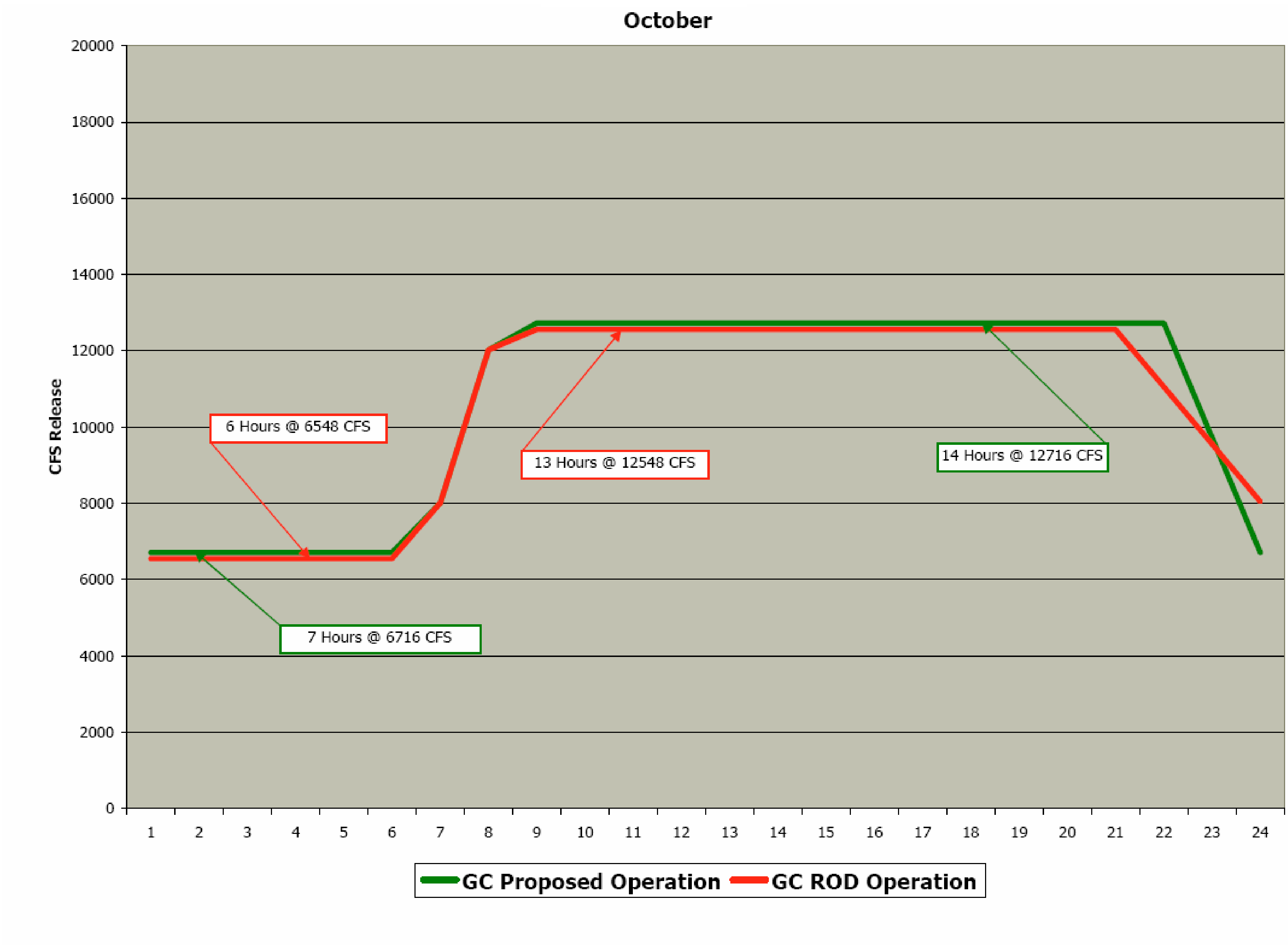
5 Hours @ 7000 CFS
13 Hours @ 13000 CFS
14 Hours @ 12666 CFS
7 Hours @ 7000 CFS
GC Proposed Operation
GC ROD Operation


October
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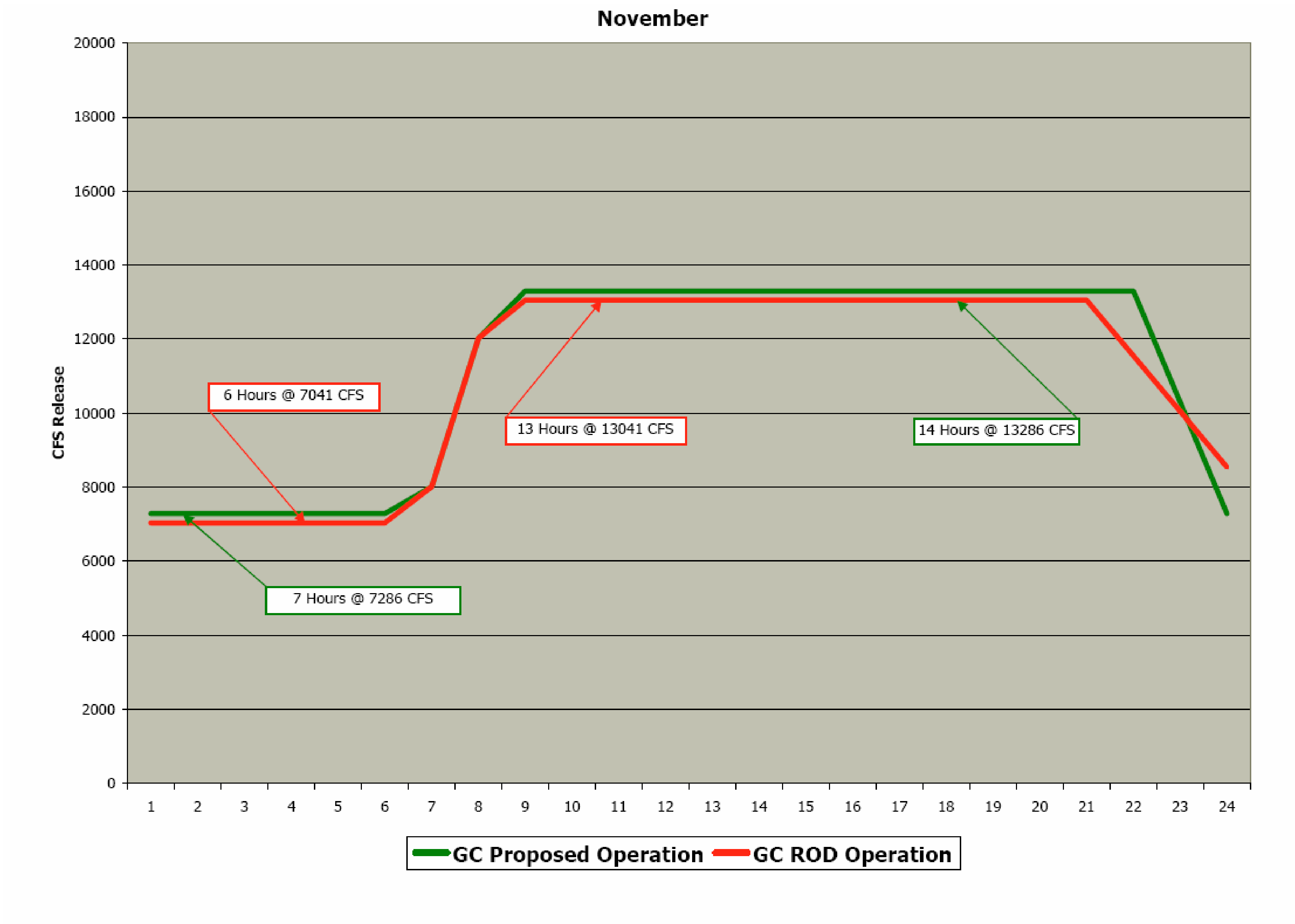
6 Hours @ 6548 CFS
13 Hours @ 12548 CFS
14 Hours @ 12716 CFS
7 Hours @ 6716 CFS
GC Proposed Operation
GC ROD Operation


November
CFS Release
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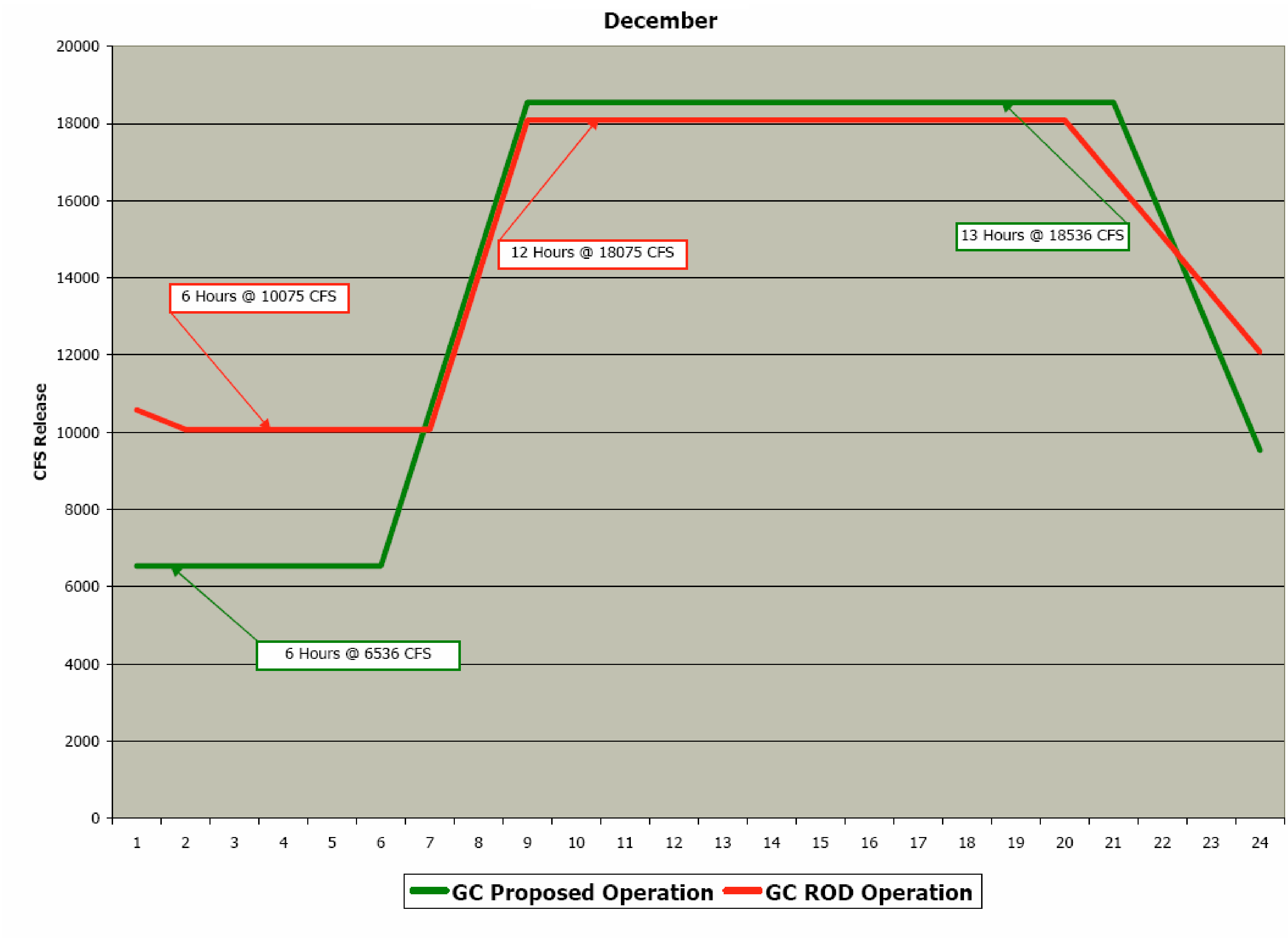
6 Hours @ 7041 CFS
13 Hours @ 13041 CFS
14 Hours @ 13286 CFS
7 Hours @ 7286 CFS
GC Proposed Operation
GC ROD Operation


December
CFS Release
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6000
4000
2000
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
6 Hours @ 10075 CFS
12 Hours @ 18075 CFS
13 Hours @ 18536 CFS
6 Hours @ 6536 CFS
GC Proposed Operation
GC ROD Operation

APPENDIX B

EVALUATION OF THE EFFECTS OF PROPOSED FLOWS ON THE AQUATIC FOOD BASE

DRAFT REVIEW

FOOD BASE RESTORATION FLOWS BELOW GLEN CANYON DAM

Submitted to

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INTRODUCTION

Western Area Power Administration has proposed changes in dam operations for WY 2006. This document is a preliminary review of the literature pertaining to the effects of flow regimes on the aquatic food base at Lee's Ferry.

AQUATIC FOOD BASE

The food base in any aquatic system is an important factor that has direct impacts on fish community dynamics including abundance, reproduction and recruitment, condition, and even distribution. Primary production, such as algal growth, is often the driving force for aquatic food bases. Algal growth provides food and cover for aquatic invertebrates that are consumed by fish.

The aquatic food base in the Colorado River ecosystem (CRE) was studied extensively from the early 1980s to 2001. Kennedy and Gloss (2005), with the support of studies such as Leibfried and Blinn 1987, Maddux et al. 1988, Usher and Blinn 1990, Shannon et al. 1994, Valdez and Ryel 1995, Valdez and Carothers 1998 and others, describe two distinct food webs in the CRE. The natural components of the food base in the CRE have changed with the construction and operation of Glen Canyon Dam (Stone 1964). Primary production at Lee's Ferry is driven by *Cladophora glomerata* (a long filamentous green algae), which is fed upon by chironomids and simuliids (aquatic insect larvae) and *Gammarus lacustris* (a shrimp-like amphipod) that was stocked to augment the trout food base. Studies indicate abundance of the above aquatic invertebrates in the CRE is generally proportional to the abundance of *Cladophora*. Trout and humpback chub can be generally classified as drift feeders and much of their diet consists of food items that have been suspended and are drifting in the water column (Valdez and Ryel 1995). Drift in the CRE is generally classified of as freely floating aquatic invertebrates and *Cladophora* that are then considered available to fish for consumption.

FOOD PREFERENCES

The major characteristics of the fish food base in the Colorado River below Glen Canyon Dam have been summarized as:

- The primary food items found in trout stomachs collected at Lee's Ferry were *Cladophora*, *Gammarus* and chironomids (McKinney and Speas 2001, Carothers and Minckley 1981);
- *Gammarus* and chironomid abundance increases with abundance of *Cladophora* (Leibfried and Blinn 1987);
- *Gammarus* prefers *Cladophora* as habitat and feeds on diatoms attached to the filaments (Shannon et. al 1994);
- Humpback chub feed on invertebrates approximately in proportion to their availability in the drift (Valdez and Ryel 1995).

Thus, the diatom community contained within filaments of *Cladophora* provides food resources for *Gammarus* and other invertebrates, which when present in the drift are fed upon by trout and humpback chub.

DRIFT

In reviewing the research that has been done on the impacts of fluctuating flows on the quantity of invertebrates in the drift in the CRE the following conclusions can be drawn:

- *Cladophora* quantities in drift samples increase with downstream distance (Valdez and Ryel 1995).
- Invertebrate quantities in drift samples decrease with downstream distance (Valdez and Ryel 1995, Leibfried and Blinn 1987).
- Seasonality of drift is not clear (Leibfried and Blinn 1987, Blinn et al. 1994, Shannon et al. 1996, McKinney et al. 1999).
- Drift is low during steady flows and higher during fluctuating flows (Leibfried and Blinn 1987).
- Drift of *Gammarus* increases on the ascending limb of the hydrograph (Leibfried and Blinn 1987).
- Drift of *Gammarus* increases on the descending limb of the hydrograph (McKinney et al. 1999, Valdez and Ryel 1995).
- Ramp rate has no effect on the amount of drift dislodged (Shannon et al. 1996).
- Increased flow following periods of low flow and the ascending and descending ramp rates determined drift rates (Leibfried and Blinn 1987).
- Drift was greatest when initial flow was below approximately 5,000–8,000 cfs and was increased to approximately13,000 to 18,000 cfs. Higher flow rates of the same magnitude of change did not appear to result in higher drift rates (extrapolated from Leibfried and Blinn 1987).

Thus, invertebrate quantities in the drift are increased during fluctuating flows; however, magnitude of flows and fluctuations, seasonality of fluctuations, and ramp rates that induce optimal drift of invertebrates are not clear.

STANDING CROP

In order for drifting organisms to contribute to the food base of fishes, there must be sufficient standing crop of algae and invertebrates to contribute to drift. In reviewing the research on factors that determine the standing crop of *Cladophora* and aquatic invertebrates in the CRE, the following conclusions can be made:

- Growth and abundance of *Cladophora* is determined by light and nutrient availability, water temperature, and grazing pressure (Litchman et al. 2003).

- Phosphorus may be limiting to *Cladophora* .
- Daily fluctuations of 5,000–20,000 cfs (WHAT UNIT?) result in a significant reduction of *Cladophora* (Usher et al. 1987) due to desiccation of exposed algal mats.
- Standing crop of *Cladophora* increases with increasing depth (Usher et al. 1987).
- Standing crop of *Cladophora* decreases with distance downstream (Usher et al. 1987).
- One time desiccation is less detrimental than repeated desiccation (Usher et al. 1987).
- Fluctuating flows may effect *Cladophora* abundance and diatom community structure (Usher et al 1987 and 1988).
- Nutrient stress can increase *Cladophora* fragmentation, thereby increasing drift but decreasing diatom abundance (due to less available substrate) for *Gammarus* (Usher et al. 1987).
- With increased water velocity, diatom communities would shift from loosely attached species to more closely attached communities thus impacting *Gammarus* grazing (Usher et al. 1987).
- Standing crop of invertebrates was significantly greater during summer steady flows when compared to standing crop during winter fluctuating flows (Leibfried and Blinn 1987).
- Invertebrate standing crop was reduced from 2,517 individuals per square meter in a permanently wetted sample to 772 in the zone of fluctuation during October and from 992 individuals per square meter to 44 in December (Leibfried and Blinn 1987).
- Daily fluctuations in flow reduce the standing crop of *Cladophora* (Usher et al. 1988).
- Exposure greater than 12 hours results in loss of *Cladophora* during fluctuating flows (Usher et al. 1988).
- Four hours of exposure duration freezing conditions as well as hot, dry and breezy conditions) results in greatest loss of *Cladophora* during fluctuating flows. (Usher et al. 1988).
- In 1985, standing crop was greatest during somewhat steady winter-spring high flows (25,000 cfs) as compared to fluctuating winter flows (3,500–18,000; extrapolated from Leibfried and Blinn 1987 and Valdez and Ryel 1995).
- Recovery of snail density after desiccation is rapid (1 week) but aquatic insect density requires greater than 4 months to recover (Blinn et al. 1995).

In summary, fluctuating flows have negative impacts to *Cladophora* survival and invertebrate abundance during exposure times four hours in freezing or hot windy conditions. Steady flows may increase standing crop of *Cladophora* and invertebrates especially during spring and summer months when days are longest and invertebrates are likely reproducing. The effect of fluctuating flows on food web dynamics, which determine food base abundance, is not clear.

CURRENT CONDITIONS

Knowledge of current standing crop conditions is important to determine how fluctuating flows induce optimal invertebrate drift.

- Standing crop measurements have not been conducted since 2001 (Shannon et. al 2001).
- Phytobenthos composition may be changing in the Lee's Ferry area with a decrease in Cladophora abundance and subsequent decrease in *Gammarus* abundance (Rogers et al. 2003).

Standing crop measurements of invertebrates and phytobenthos have been conducted by several researchers since 1964. A comparative investigation of current standing crop density and composition to that recorded during previous studies, when combined with flow regimes over time, may provide some insight into the impacts flow regimes on standing crops.

UNCERTAINTIES

As with any ecological system, variables other than those being studied may impact standing crop and drift dynamics and result in uncertainties regarding what most influences the invertebrate community at CRE. Specific factors requiring further investigation that may be contributing to standing crop and drift dynamics are discussed below.

- Current standing crop conditions and impacts of current ROD flows and recent BHBF to standing crop are unknown.
- Threshold velocity magnitudes and fluctuations that will sustain food base standing crop and drift are unknown.
- The quantity of standing crop and drift abundance of greatest benefit to fish is unknown.
- Effects of New Zealand mudsnail on standing crop and invertebrate density are unknown.
- Effects of low oxygen and increased temperatures on *Cladophora* and invertebrate density are unknown.
- Utility of drift or Fine Particulate Organic Matter (FPOM) to fish below Lee's Ferry is unknown.
- Changes in standing crop estimates among all previous standing crop studies relative to flow conditions during those studies have not been investigated.

Isolating the impacts of fluctuating flows on food base standing crop and drift dynamics is difficult. The impact of current ROD flows on the food base is unknown and should be measured before the implementation of new experimental flow regimes.

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