DRAFT SCIENCE PLAN TO ACCOMPANY ENVIRONMENTAL ASSESSMENT FOR A TEMPERATURE CONTROL DEVICE FOR GLEN CANYON DAM

Prepared by

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for

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INTRODUCTION

The Glen Canyon Dam Environmental Impact Statement (USDOI 1995) and the Record of Decision (USDOI 1996) for the dam's operation included an agreement between federal, tribal and state entities to establish a secondary population of humpback chub (*Gila cypha*) within Grand Canyon. Under current operations, mainstem water temperature is considered to be a limiting factor of mainstem recruitment for humpback chub and other native fish: mainstem water temperatures (8-12° C) are too low for spawning, and larval and young-of-year survival. Certain operational and physical mechanisms are available to promote mainstem warming. These include changing discharge patterns and/or changing the level at which water is withdrawn from the Lake Powell Reservoir. The former mechanism refers to steady flow operations, while the latter refers to a selective withdrawal approach. Previous evaluation of these two mechanisms suggests that selective withdrawal would likely provide a greater potential to increase temperature for native fish in the Colorado River ecosystem (USDOI 1995).

ENVIRONMENTAL ASSESSMENT FOR TEMPERATURE CONTROL DEVICE

In January 1999, a draft environmental assessment for the construction and operation of a temperature control device was released by the Bureau of Reclamation. The review period associated with the draft was initially 60 day, but was subsequently extended by 30 days. Included in the comments was the suggestion that a science plan for operations be included in the draft. In June 1999, the Bureau of Reclamation requested that Grand Canyon Monitoring and Research Center develop a draft science plan that would accompany the environmental assessment.

DRAFT SCIENCE PLAN OUTLINE AND OBJECTIVES

The draft plan developed by Grand Canyon Monitoring and Research is considered to be an outline for implementation and includes:

1. Identification of the objective for the temperature control device;
2. Defining hypotheses related to humpbackchub life history and providing biological and environmental parameters needed to meet the objective;
3. Providing operational scenarios that are associated with these hypotheses;
4. Identifying associated resources and developing testable hypotheses associated with them and the operational scenarios;

5. Providing a schedule for implementation that includes adecision making/risk management assessment.

The plan is intended to be a straw-man. A workshop to be convened in November 8-10, 1999 will be used to improve the plan, through data sharing/information exchange and to specifically refine hypotheses and the schedule for implementation. Following the workshop, the plan will be revised and included with the final draft for the environmental assessment. All steps need to be completed in a sequence that assures that the underlying objectives are met and predicted results are verifiable or studied in a manner that provides alternative explanation for results. Lastly, based on the soundness of implementing the construction, a process must be must be developed for operating this withdrawal structure that takes into account acceptable threshold limits for resources associated with temperature modifications. In accordance with the GCD EIS, evaluating and determining the design, feasibility and effectiveness of a selective withdrawal program is the role of the Bureau of Reclamation (BOR). The U.S. Fish and Wildlife Service in consultation with Arizona Game and Fish Department is responsible for recommending to BOR whether the program should be implemented. The scheduling component of the plan insures that decisions prior to construction are made, and that decisions associated with operations can be made with the best available information.

BACKGROUND ASSOCIATED WITH BIOLOGICAL OPINION AND REASONABLE AND PRUDENT ALTERNATIVE ASSOCIATED WITH MAINSTEM TEMPERATURE WARMING

The humpback chub was first described in 1946 (Miller), twelve years prior to the construction of Glen Canyon Dam. In 1978, the US. Fish and Wildlife Service issued a jeopardy opinion (US Fish and Wildlife 1978): "that the past, present and future operations of the dam jeopardized the continued existence of the humpbackchub. A recommendation from this opinion was to conduct studies to: determine the potential impact of warming the release water: determine the ecological needs of the species; determine relationships between mainstem and tributaries utilized by the species; and develop methods to reduce constraining factors of low temperature and frequent fluctuations." The latter point refers to seasonally adjusted steady flows.

In 1993, in association with the environmental impact statement for the operations of Glen Canyon Dam, and its proposed action for operations (see EIS, U.S. Bureau of

Reclamation 1995), the Bureau of Reclamation requested formal section 7 consultation with the U.S. Fish and Wildlife Service. A final biological opinion was issued on December 21, 1994 (US Fish and Wildlife 1994). Included in the opinion were four elements with sub-elements of the reasonable and prudent alternative that pertained to native fish and specifically to humpbackchub. Element 1 subsection B requires that "Reclamation shall implement a selective withdrawal program for Lake Powell waters and determine feasibility using the following guidelines.

i. Review historic information and employ existing modeling with possible updates using alternative reservoir and operating conditions to prepare a set of possible scenarios of temperature changes in the mainstem.

ii. Determine from the literature, experimentation, and consultation with the AGFD, Native American Tribes, National Park Service, Service, and other native fish species experts the anticipated effects on native fish populations which may result from implementation of temperature changes from a selective withdrawal structure. Determine the range of temperatures for successful larval fish development and recruitment and the relationship between larval/juvenile growth and temperature.

iii. Assess the temperature induced interactions between native and non-native fish competitors and predators.

iv. Assess the effects of temperature, including seasonality ad degree, on Cladophora and associated diatoms, Gammarus, aquatic insects and fish parasites and disease.

v. Evaluate the effects of withdrawing water on the heat budget of Lake Powell, effects of potentially warmer inflow into Lake Mead, and the concomitant effects on the biota within both reservoirs. Evaluate the temperature profiles along the heat budget for both reservoirs.

vi. Evaluate effects of reservoir withdrawal level on fine particulate organic matter and important plant nutrients to understand the relationship between withdrawal level and reservoir and downstream resources.

Some of these elements are shared with elements that are associated with the steady flow RPA (Element 1. C.), particularly with regard to temperature affects on recruitment and growth, and Element 4-- the second spawning aggregation of humpback chub downstream of Glen Canyon Dam. Theobjective of all elements are to increase recruitment of humpbackchub below Glen Canyon Dam.

I. OBJECTIVE FOR SELECTIVE WITHDRAWAL FROM LAKE POWELL

The management objective for using a selective withdrawal mechanism is *to have the capabilities to seasonally regulate temperature that benefit native fish spawning and recruitment through selective withdrawal of water at different levels in the reservoir.* The current condition of withdrawals from Lake Powell is characterized by cold, seasonally constant temperature released from Glen Canyon Dam. The source of withdrawal is hypolimnetic the penstocks are located at this level. In the case of Glen Canyon Dam, a selective withdrawal structure could have the effect of releasing water at temperatures that promote spawning and subsequent recruitment of native fish in the mainstem. This science plan is intended to use the objective of selective withdrawal for the benefit of native fish to determine the physical parameters that need to be defined with operations of the devise. Physical parameters are defined by the life history requirements of humpbackchub.

II. HUMPBACK CHUB STATUS, LIFE HISTORY AND HYPOTHESES

Humpback chub (Gila cypha) is a cyprinid fish species that is endemic to the Colorado River drainage basin. It is represented within the basin by six populations five in the upper basin, and one in the Grand Canyon. The population in the Grand Canyon represents the one of largest of these populations (ca 8,000-10,000). Within the Grand Canyon, individuals have been found to occur in concentrated numbers, or aggregates, at nine geographic locations along the276 mile stretch between Lees Ferry and Lake Mead (table 1). Among these aggregations, evidence of successful spawning and recruitment occurs at the LCR location. Young fish, <150 mmare found in the mainstem associated with these aggregates, but their origin is not well understood: their origin being either the Little Colorado River, or localized recruitment. Likewise, the relationships that these aggregates have to one another are also not understood. Again, these aggregates may represent cohorts of fish that dispersed from the Little Colorado River that still utilize the tributaries for spawning, or represent pre-dam individuals that have had limited recruitment success, or they may represent a mix of both. A population genetics study whose objective is to help clarify these relationships is under review for funding. The timeframe for completion of the project istwo-years.

Table 1. Grand Canyon aggregate locations and numbers of humpbackchub by river mile from Lees Ferry (adapted from Valdez andRyel 1995).

River mile	YOY	Juvenile	Adult	Total	Pop. Estimate
30	14	0	26	26	52
57-65	1830	1293	1524	4647	2682-4281
65-76	778	226	15	1019	ne*
83-92	13	2	9	24	ne
108	4	13	27	44	57
114-120	0	7	17	24	ne
126-129	1	4	124	129	98
155-156	0	0	7	7	13
212-213	0	0	6	6	5

*no estimate available due to low numbers of recapture

Habitat. These fish exist in a canyon bound habitat consisting of boulders, talus slope, vegetated and sandy shoreline, and eddy return-channels formed below rapids (Miller and Hubert 1990). Velocities of the water vary from swift water associated with the runs to more quiescent velocities along the shore, eddys and upstream pools that form above rapids. Humpback chub adults are found along the shorelinein associateion with shoreline -eddy habitat (Miller and Hubert 1990, Valdez andRyel 1995). Fish less than 150 mm, are most often associated with vegetated shoreline, return channels and eddys (Converse et al 1998). Within these habitats, those micro-habitats that provide lower velocities (e.g., eddy fences, among boulders) appear to be preferred (Kaeding and Zimmerman 1983; Maddux et al 1987; Valdez and Ryel 1995). Depth preferences increase as fish increase in length: <100 mm fish are found within 50 cm of surface, while larger fish, >150 mm are found in depths that range from 1 to 12 m (Valdez and Ryel 1995).

Radio tagged fish show high site fidelity, with movement on average being 1.3 km (Valdez and Nilson 1982; Valdez and Ryel 1995). Behavior of chub in the upper basin (Archer 1985) do not indicate that this species migrate large distances compared to flannelmouth suckers, or the Colorado pikeminnow. This assumes that habitats where chub are found are sufficient for all life stages of chub.

Dietary requirements for chub suggest that these fish are generalist/opportunistic feeders. Gut contents of humpback chub have found the presence of both terrestrial and aquatic insect fauna (Tyus and Minckley 1988, Kaeding and Zimmerman 1983, Valdez and Ryel 1995), food scraps from dumped in the river by humans, and young fish (Kaeding and Zimmerman 1983; Stone 1999). Insect fauna include simulids, chironomids, gammarus and crickets.

Spawning and recruitment. The life history of the species follows a pattern similar to other endemic fish species found in the Colorado River basin. The majority of adults (>350 mm) exhibit spawning condition in early spring and spawning by humpback chub occurs generally between late March to May. Spawning ques are believed to include hydrology, water temperature and photoperiod. Genotype may also influence time of spawning: individual that originate from tributaries may spawn at a time that is different from those individuals that have a mainstem origin. The previously noted populations genetics projects should help clarify this question as would controlled studies that examine environment by genotype interactions. Other variables influencing subsequent gonadal maturation and release could include water quality parameters (e.g., turbidity), substrate and pheromone levels, and degree days.

Gonadal development of fish collected in Grand Canyon begins between December and February and continues through April. Spawning has been reported to take place between April and July based on larval collections (Angradi et al 1992; AGFD 1993). Individuals in the upper basin are reported to spawn in May to July (Valdez and Clemmer 1982; Archer et al 1985). The delay associated with the upper basin individuals may be a reflection of photo-period differences. Stream flow and temperature indicate that spawning occurred historically on the peak or descending limb of the hydrograph and maximum daily temperatures vary between 11.5 and 23 C (Angradi et al 1992; Valdez and Clemmer 1982; Kaeding et al 1990).

Chub eggs attach to rocky substrates. Data collected from raceway spawning and growth studies indicate that temperature affects hatching time and development. Hatching success is lower for lower temperatures: 62 % for eggs in 16-17 °C water vs. 84% success for eggs in 19-20 °C water (Hamman 1982). Optimum temperature of 20 °C for hatching is suggested as warmer temperatures indicate reduced hatching success (Bulkley et al 1982; Hamman 1982; Marsh 1985). Hatching time increases with lower temperatures and is associated with sub-lethal effects on larvae including stunting or deformities (Marsh 1985).

Growth rates of larvae are also affected by temperature. Experimental studies documenting growth rates for humpback chub in 20°C tanks averaged 10.63 mm/30 days (Lupher and Clarkson 1994) while fish in 10°C tanks grew at 2.30 mm/30 days. These data indicate that humpback chub growing in 20°C water would need at least 141 to 198 days of this temperature water to reach 50 to 70 mm lengths respectively. Fish grown in 10°C tanks would need 652 days to grow 50 mm. If growth response to temperature increased by 0.83mm for every °C increase, then humpback chub grown at 16°C need at least 206 days to reach 50 mm (7.28 mm/30 days), roughly 6 months at 16°C. A table for estimated growth rates by temperature for fish to reach 50 mm (approximately size for young of the year, Valdez 1982) is provided below (Table 2).

Table 2. Estimate growth rate of HBC by water temperature. Adapted from Lupher and Clarkson, 1994.

Temperature °C	Growth rate mm/30 days
10	2.3
11	3.1
12	2.9
13	4.7
14	5.6
15	6.4
16	7.2
17	8.1
18	8.9
19	9.7
20	10.6

HYPOTHESES ASSOCIATED WITH HUMPBACK CHUB POPULATIONS THAT ARE PERTENENT TO SELECTIVE WITHDRAWL

As state previously, the objective for implementing a selective withdrawal device is to benefit recruitment of humpbackchub aggregates below Glen Canyon Dam. Two possible hypotheses are available to explain the present distribution ofchub aggregates in Grand Canyon (Valdez andRyel 1995).

1. Fish in the mainstem representrelictual mainstem spawning populations that have had limited spawning success since the dam. The aggregates may include individuals form the Little Colorado River
2. The Little Colorado River (LCR) is the principle spawning area for the majority of the humpbackchub population in Grand Canyon and the mainstem acts as a dispersal mechanism.

If the former is true, and that genotype by environment interactions are strong isolating mechanisms between mainstem and tributary spawning individuals, then warming the water should result in mainstem spawning and potentially increased recruitment of mainstem spawners. If the latter is true, then warming may not affect mainstem spawning, but subsequent recruitment from the LCR to the mainstem may be enhanced if warmer temperatures in the mainstem are available when young fish disperse from the LCR. Either of these hypotheses would have different operational scenarios (release temperatures and release timing) associated with the use of a selective withdrawal structure. In this plan, the objectives and the operational scenarios are defined in terms of the targeted life history traits of the species of concern based on these two hypotheses.

III. OPERATIONAL SCENARIOS

Operational scenarios were developed to meet the biological needs of the humpback chub. The scenarios cover a range that varies from mimicking pre-dam temperature regimes to concentrating on flows that reduce thermal shock to young fish emerging from the LCR. Rather than restricting the science plan to a single operating scenario, we felt that examining a range of operations would provide more flexibility in operations over a range of water delivery to the reservoir. Any proposed scenario would likely then be constrained by anticipated associated resource effects, some of these resources being identified in the sub-elements of the RPA (see above). Once scenarios are identified, then physical parameters (i.e., independent variables) can be defined, determined if feasible from the reservoir's heat budget and hypotheses associated with resource effects formulated. Unless these scenarios are defined, testable hypotheses associated with humpback chub and other aquatic and terrestrial resources cannot be determined.

SCENARIO 1: Operate withdrawals that closely mimic pre-dam thermal warming of the mainstem.

An operation that could benefit Humpback chub in the mainstem the greatest may be a scenario that simulates pre-dam seasonal temperature changes. Pre-dam temperature changes show a yearly change of approximately 27 °C, going from freezing in January an peaking to 27 °C at Lees Ferry in mid July and August(Valdez and Ryel 1995). For this scenario average monthly release temperatures based on Lees Ferry temperature data would be used to gradually increase water temperatures in the mainstem. The warmest temperatures would be released in the July-August period and would follow with reduced temperatures into the fall and winter. A consideration in this plan could be to lower winter temperatures to those that are presently released. Historically, water temperatures increased by approximately 3.5 °C for each month starting in January. By the end of April temperatures approached 15 °C at Lees Ferry. Warming after April continued, but at a slower rate: 2.5 °C for each month up to August. Cooling in the mainstem after August, occurred at a rate of approximately 4.4°C for every month up to December. This scenario would require a heat budget that would allow this warming and release temperatures from the dam.

This scenario would provide support of the first hypothesis associated with humpback chub below Glen Canyon Dam and would likely benefit all identified aggregations. Associated resources would likely show the greatest effects with this scenario. Hypotheses for any resources would be developed along a temperature gradient of change.

SCENARIO 2: Operate withdrawals that will be at a level sufficient to promote spawning and recruitment by humpback chub at river mile 30 and other downstream aggregations.

The heat budget may preclude the possibility of scenario 1 and as an alternative, scenario 2 is proposed. In order to still promote mainstem spawning and recruitment of all aggregates, an operational scenario should include release temperatures that will promote spawning and recruitment at RM 30. Besides operational scenario 1, this scenario would likely have the highest release temperatures. Variables that affect meeting this scenario (e.g., available heat budget) may preclude its implementation. Included in this scenario would be gradual temperature warming prior to June to promote spawning conditions for adult fish. The release temperatures prior to May and June may be 8-12°C with subsequent release temperatures in June to 15, 16 °C.

SCENARIO 3: Operate withdrawals that will be at a level sufficient to promote spawning and recruitment by humpback chub at middle granite gorge aggregation and further downstream. The largest aggregation (table 1) occurring outside of the LCR is estimated to be the middle granite gorge aggregate (RM 126-129). Therefore, an operational scenario should be designed to benefit the fish most likely to respond positively below the Little Colorado River confluence emphasizing area(s) having the greatest number of fish. Specifically this would be the Middle Granite Gorge aggregation. Release temperature would be lower and would depend on mainstem warming to increase temperatures to those values that meet spawning and recruitment needs. However, would likely only be1 or 2 degrees less than those in scenario 2. The duration for these warmer releases would be similar for all scenarios provided so far.

SCENARIO 4: Operate withdrawals that will be at a level sufficient to reduce thermal shock to young fish decending from tributaries, particularly the Little Colorado River, and into the mainstem.

If humpback chub residing in Colorado River mainstem are derived principally from tributaries, including the Little Colorado River, then spawning in the mainstem may not be a critical objective. Rather, survivorship of young-of-year dispersed from these tributaries that augment mainstem aggregatesmay be the objective for operations. Operational scenarios in this case would need to be designed to reduce thermal shock to young fish that move from tributaries and into the mainstem. The duration and timing of this scenario would be differentthan the previous three scenarios.

All four scenarios provided here operateunder the objective of spawning and recruitment but with different hypotheses associated with the humpbackchub life history. The interplay of the physical, biological and institutional variables either may preclude one or more of these operational scenarios, or may indicate that all scenarios are possible. Additionally, the relationship of the mainstem aggregations to the LCR population may reveal that all operational scenarios benefit the species at different periods. Therefore, this plan does not recommend concentrating on one single operational scenario until the population dynamics are better understood.

IV. VARIABLES DEFINING OPERATIONAL SCENARIOS

As is evident in the previous section, the operational scenarios for the selective withdrawal can be differentiated by underlying hypotheses. For any one of these scenarios, there are a set of biological and physical variables that define the release temperatures (i.e., maximum, minimum), thermal duration and range. These are the independent variables that we have to define effects on native fish and associated resources. The biological variables are tied to humpbackchub spawning and recruitment requirements. The physical variables are tied to reservoir and downstream warming dynamics. Defining the biological requirements provide a better method to evaluate the physical requirements needed to meet operational scenarios.

Biological variables. The biological variables that we have focused on are temperature requirements needed by humpbackchub to spawn, larval and YOY growth rates to facilitate over-wintering survivorship and reducing the likelihood of predation. This information is described previously in this plan.

1. Target temperatures for mainstem spawning should be a minimum of 16°C optimum temperature is 20°C.
2. Target spawning time in the mainstem is estimated as May-June. Consequently mainstem temperatures need to achieve minimum levels of 16°C by this time frame, these temperatures would be slightly higher for scenario 1.
3. Duration for warm water temperatures is dependent on water temperature. We estimate for scenario 2 that temperatures at 16°C for 206 day is required for fish to reach 50 mm lengths.
4. Temperatures releases for scenario 4 must be sufficient to reduce thermal shock. This threshold level is not determined currently, andbe sustained at these temperatures while young fish descend and become established in the mainstem (ca. 120-160 days).

Physical Independent Variables. Given the biological targets of at least 16°C for both spawning and growth at RM 30 in May and June, release temperatures from the dam can be determined. Incremental warming for month prior to May should also be considered for both scenarios 1and 2 when determining the available warm water releases.

The determination of release temperatures from the dam are based on the rate of warming that occurs in the mainstem once it is discharged. Mainstem water temperature is dependent on discharge volume, flow rate, time of year and distance from Glen Canyon Dam. Low volume discharges show a slight increase in the rate of warming Korn and Vernieu, 1998). Rates of warming for high, medium and low discharges have not been determined for this plan, but could be developed. An average warming rate for the Colorado River mainstem are based on mainstem temperature data collected for the years 1991 through 1998 (Korn and Viernieu 1998). This average rate is a representative rate for a range of hydropower operations encountered during research flows, modified low fluctuating flows and during high and low reservoir pool elevations. Maximum warming in the mainstem occurs in June and decreases in the following months.

To reach a target temperature of at least 16°C at RM 30, in June then releases from GCD need to be at least 15°C. Release temperatures of 16°C in June would result in temperatures of 17.5°C which is approaching values that increases hatching success greater than 62%. Mainstem water temperatures downstream of RM 30 for releases of 15-17°C appear in Table 4. Temperature releases in June may be slightly lower than temperatures in following months to reach the downstream target temperatures. For example, releases in June of 16°C will result in adequately warm temperatures at RM 30 and optimum hatching temperatures of 20°C in the middle granite gorge. Yet, to maintain these temperatures in months following September, release temperatures will need to be increased to 17°C. For this reason, growth rates will likely decrease for all young fish even under increased temperature releases.

Table 4. Estimated downstream mainstem temperatures with corresponding discharge temperature based on warming rates from Korn and Vernieu (1998).

Month	Discharge temperature °C and warming factor	30 (RM)	60 (RM) LCR	127 (RM)	194 (RM)	209 (RM)	226 (RM)
June	15, 16, 17 (0.035°C/mi)	16.5 17.5 18.5	17.6 18.6 19.6	19.9 20.9 21.9	22.3 23.3 24.3	22.8 23.8 24.8	23.4 24.4 25.4
July	15, 16, 17, (0.033°C/mi)	16.4 17.4 18.4	17.4 18.4 19.4	19.6 20.6 21.6	21.8 22.8 23.8	22.3 23.3 24.3	22.9 23.9 24.9
August	15, 16, 17 (0.030°C/mi)	16.3 17.3 18.3	17.2 18.2 19.2	19.2 20.2 21.2	21.2 22.2 23.2	21.7 22.7 23.7	22.2 23.2 24.2
September	15, 16, 17 (0.028°C/mi)	16.2 17.2 18.2	17.1 18.1 19.1	18.9 19.9 20.9	20.8 21.8 22.8	21.3 22.3 23.3	21.7 22.7 23.7
October	15, 16, 17 (0.015°C/mi)	15.6 16.6 17.6	16.1 17.1 18.1	17.1 18.1 19.1	18.1 19.1 20.1	18.3 19.3 20.3	18.6 19.6 20.6
November	15, 16, 17 (0.006°C/mi)	15.2 16.2 17.2	15.4 16.4 17.4	15.8 16,8 17.8	16.2 17.2 18.2	16.3 17.3 18.3	16.4 17.4 18.4

Release temperatures are dependent upon the time that water at target temperatures is available from the reservoir and the duration that these temperatures are available. The physical variables in the reservoir's heat budget that regulate temperature rates need to be determined. Water discharged from the dam at 16°C will need to be available through mid-October to achieve optimum growing temperatures (19 to 20°C) at RM 127.

It is conceivable that growth differences will exist for YOY reproduced at RM 30 owing to differences in longitudinal warming. These fish will have grown to an estimated 38.1 mm within this same period, which is short of the targeted 50 mm size. Maintaining temperatures of 16°C through November would result in fish at RM 30 reaching a size of 47.8 mm, close to the target of 50 mm. Fish growing in the Middle Granite Gorge are estimated to reach sized of 63.6 mm, well within the required range of 1 years growth.

The thermal duration of needed increased temperatures for Operational Scenario 4, is reduced compared to the other two operational scenarios. Mean temperature data of the LCR for months June through November are 21, 22.7, 22.7, 20.5, 18.1 and 15.0°C respectively. A target temperature for the mainstem at the LCR to meet the objective to reduce thermal shock of fish entering the mainstem would be likely be between 18 and 22 degrees, although this needs to be determined. Table 4 indicates that releases of 16°C would deliver at least 18°C water in the months of July through September. Issues regarding reservoir heat budget and availability are important. Additionally, other questions that need to be addressed for this scenario are related to physiological tolerances of larval and YOY fish to reduced temperatures (e.g., Are there threshold levels for reduced temperature that induce thermal shock, and are they size dependent?).

Biological parameters for Scenario One

1. Mainstem temperatures that reach at least that icrease at a rate of 3.2 °C from January and reach 15°C by mid April, continue warming at a rate of 2.5°C and reach 26°C by mid July and descend at a rate of 4.4°C per month after August.
2. Mainstem temperatures that are above 16°C by Lees Ferry for at least 206 days following spawning.

Biological parameters for Scenario Two

1. Mainstem temperatures that reach at least 16°C by RM 30 in June (release temperatures of at least 15°C).
2. Mainstem temperatures that reach at least 16°C by RM 30 for at least 206 days following spawning (release temperatures of at least 15°C).

Biological parameters for Scenario Three

1. Mainstem temperatures that reach at least 16°C by RM 127 in June (release temperatures of at least 12°C).
2. Mainstem temperatures that reach at least 16°C by RM 127 for at least 206 days following spawning (release temperatures of at least 12°C).

Biological parameters for Scenario Four

1. Release temperatures that reach a level to reduce thermal shock (at least 18°C by RM 60?) by young fish entering the mainstem in late July through October or November from the LCR.

Physical parameters required for Scenario One

1. Determine heat budget in Lake Powell sufficient to allow releases ofthat mimic pre-dam monthly average temperatures from January to December.
2. Determination of how flow volume affects these warming rates and accompanying heat budget needs for high, medium and low volume releases.

Physical parameters required for Scenario Two

1. Heat budget in Lake Powell sufficient to allow releases of 15, 16 or 17°Cin June.
2. Determination of how flow volume affects these warming rates and accompanying heat budget needs for high, medium and low volume releases.

Physical parameters required for Scenario Three.

1. Heat budget in Lake Powell sufficient to allow releases of 12, 15 or 16°C for approximately 206, 154, or 141 days respectively.
2. Determination of how flow volume affects these warming rates and accompanying heat budget needs for high, medium and low volume releases.

Physical parameters required for Scenario Four

1. Heat budget in Lake Powell sufficient to allow releases of 16°C for approximately 150 days.

V. ECOSYSTEM VARIABLES RESPONDING TO TEMPERATURE CHANGES

While the goal for warming the mainstem is to promote spawning and recruitment of native fish, there are associated resources that will also respond to temperature change.

Some of these were identified in elements of the RPA (see above). Resources effects can be divided into aquatic and terrestrial resources. The aquatic resources likely to respond include water quality in the reservoir and downstream, the aquatic vegetation and invertebrates, the species associated with the sport fisheries in the reservoir and in Glen Canyon, the non-native fish in the mainstem, and recreational/cultural resources associated with any of these biological components. Terrestrial components that may show a response to temperature changes include shoreline vegetation, riparian insect fauna, breeding avifauna, and recreational/cultural resources associated with these components.

Some effects can be estimated to some extent following the determination of parameters associated with each scenario. These parameter estimates allow for model simulations and sensitivity analysis, and serve as an initial risk assessment if thermal modifications are implemented. Additionally, these simulations provide a conceptual framework for developing and testing research and operational hypotheses. Yet, due to limited information, the effects of warming on certain resources are uncertain and can be only determined during implementation, and if the response by the resource is relatively immediate (i.e., within thetime period of operations). Certain resource responses may only be evident after operations, whereas others may be difficult to separate from other intercorrelated variables. Data collection efforts should be focused on effects that can likely be attributed to temperature warming to determine the beneficial/detrimental effects of selective withdrawal.

Study sites and integrated data collection. Rather than examine resources as isolated parts, an integrated approach is proposed to determine the effects of temperature changes on the resources listed previously. We have identified seven locations that can be utilized to collect data on the effects of warming on aquatic and terrestrial resources. The sites represent locations that are in GIS reaches, or are associated with humpback chub aggregates, or are required to verify physical parameters associated with operational scenarios. The study sites are:

Location	River Mile/GIS Site #
GCD, Lake Powell Reservoir to	-15 to upstream inflows

inflow	
Glen Canyon Reach to Paria riffle	2 to –15/ Site 1 & 2 & 14
South Canyon	RM 30
Kwagunt to Cardenas	RM 55 – 72/ Site 4 & 5
Blacktail to Middle Granite Gorge	RM 120-130/ Site 7
194 to Pumpkin Springs	RM 194-213/Site 11
Separation to Lava Cliff	RM 239-246

Data that address specific hypotheses associated with identified resources would be collected in a similar fashion at all sites. For this plan, hypotheses are divided into resource areas effected by temperature change for each operational scenario.

HYPOTHESIS FOR OPERATIONAL SCENARIOS 1, 2. 3

Duration of temperature changes are similar for all of these scenarios, it is the amount of temperature change that will be the response variable for identified resources. Listed below are some of the predicted resource responses stated as alternate research hypotheses. This is not an exhaustive list of scenarios. Some may be removed as being not testable and other may be added following the workshop.

Water Quality

Lake Powell Reservoir

H1: The thermal budget of the reservoir will be significantly altered

H2: Stratification of the reservoir will be altered by operations

H3: The epilimnion will be preferentially depleted.

H4: The heat budget in Lake Powell is sufficient to provide at least 12 or 15° C water to the tailwaters for the duration of the experiment.

H5: Dissolved and particulate organic matter in the reservoir will be altered to levels that effect water quality parameters important for the sport fishery

H6: Surficial discharges will decrease nutrient, ion and trace metal concentrations in the reservoir.

H7: Alteration of discharge volume will change reservoir level dynamics.

H8: Changes in discharge location may enhance entrainment of spring-flood sub-surface plume.

Downstream

H1: Water temperatures will warm at predicted rates

H2: Respiration rates will increase and alter the available chemical constituents.

H3: Nutrients concentration will be increased bysurficial withdrawls.

H4: Optical properties in the mainstem will be altered by withdrawals from the epilimnion.

Phyto-Benthic Community

H1: *Cladophora* morphology will change in response to increase nutrient availability

H2: Surface area on *Cladophora* for diatoms to colonize will be altered

H3: Epiphytic composition and densities will be altered

H4: Benthic invertebrate composition and biomass will be altered

H5: Macroalgal composition and biomass will be altered

H9: Primary production rates will be altered

Fisheries

Native Fish

H_1: Mainstem spawning success and larval survivorship will be no different than at lower temperatures.

H2: Water released will be sufficiently warm for mainstem spawning and larval survival at all mainstem aggregation sites or in the middle granite gorge and below.

H3: The duration of warm water releases will be sufficient for larvae to reach 50mm.

H4: Native fish found in the mainstem will be infected with parasites at numbers equal to current infestation levels.

Trout

H1: The quality of the trout spawn in November to March will be no different from regular hypolimnetic releases.

H2: All class sizes of trout will grow at faster rates than in previous years.

H3: Energetics will increase and result in greater need/consumption of prey items.

H4: Parasites or infections that are reduced in their expression under current temperatures may manifest themselves to a greater degree in warmer temperatures.

Lake Powell Fishery

H1: Abundance and distribution values for sport fish species associated with upper withdrawl levels will be no different from current operation values.

H2: Energetics in the reservoir's sport fishery will be reduced from the withdrawal of warmer water from these upper levels.

Exotic predators

H1: Numbers of predators from Lake Mead will be found farther upstream than where they are currently found.

H2: Rainbow trout numbers below Shinumo will decrease.

H3: Carp numbers will increase belowShinumo

Marsh/Riparian zone

H1: Warmer temperatures may benefit exotic seedling establishment andncrease exotic species densities.

H2: Marsh vegetation composition may shift towarmer water species dominants.

Traditional Cultural Resources

H1: Ethnobotanical species abundance will be unaffected by warmer temperatures.

H2: Represented ethnobotanical species within the affected riparian/marsh zone will change along a longitudinal gradient.

H3: Mineral resources will be unaffected by warmer temperatures.

Archaeology

H1: Eroding archeological sites located within the affectedarea, will continue to erode at a rate similar to current values.

Recreation

H1: Warmer temperature may increase the incidence of swimming through rapids.

H2: Water quality associated with human health may be negatively effected by increased temperatures.

HYPOTHESES FOR OPERATIONAL SCENARIO 4

In addition to the hypotheses developed for the previous scenarios, these following hypotheses apply to scenario 4.

Native fish

H_o: Survivorship from thermal shock by LCR HBC young of the year will be no different than with water at lower temperatures.

H_a: Water released will be sufficiently warm for young of the year descending from the LCR to survive at numbers greater than in lower mainstem temperatures.

VI. SCHEDULE FOR IMPLEMENTATION

The science plan can be divided into segments of time associated with operations. Some activities can be completed prior to construction. And recommended so that if current designs need to be altered they can be. Additionally work done prior to operations can help define aspects associated with scenarios like target release temperatures and duration. Other activities can only take place during the operation of selective withdrawal device, should it be built and become operational. In this case, the efforts conducted prior to operations should be done in such a manner that data can be collected around a predicted response by an identified resource and mitigation is possible if needed. Lastly some responses by resources may not be immediately evident. These resources may require longer periods of data collection beyond the duration of operations (ca. a growing season). The schedule is divided into these categories.

Pre-construction phase (1 year)

1. Determine heat budget available for each scenario.
2. Determine current design constraints for proposed structure and relate to scenarios.
3. Provide alternative designs that may be utilized after the "testing" of the currently proposed structure (i.e., if the proposed structure is a test to see if any response is possible, then design should include consideration of expanding the proposed single upper level withdrawal to multiple levels if the "test" works, in order to optimize its utility).

Pre-operation Phase – these can be run concurrently with the pre-construction phase to some extent, although the available temperatures need to be determined before any other work can be done. Duration: 1-3 years

1. Determine the populational relationships of humpbackchub in Grand Canyon.
2. Determine threshold levels of juvenile fish with respect to temperature change.
3. Determine rates of predation on native fish by rainbow trout under different temperatures and water quality values
4. Determine life history effects of temperature on non-native fish and develop a strategy to reduce identified competition.
5. Model energetic effects of warmer temperatures in the Glen Canyon reach on the phyto-benthic and trout community.
6. Model energetic effects of warmer water withdrawal on Lake Powell fishery and food resources.
7. Develop a decision process for proceeding and for stopping the operations

Operational Phase Duration: 1-2 years.

1. Collect data around predicted hypotheses for identified resources.
2. Implement decision making process for operations.

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