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Colorado River Water Temperature Modeling Below Glen Canyon Dam

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COLORADO RIVER WATER TEMPERATURE MODELING BELOW GLEN CANYON DAM

BY

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GLEN CANYON ENVIRONMENTAL STUDIES

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This study presents an analysis of Colorado River temperature modeling below Glen Canyon Dam, Arizona. The potential of raising the water release temperatures at the dam by modifying dam penstocks with multiple-level reservoir intakes is discussed. Predicted temperatures of waters drawn from Lake Powell by such intake structures are calculated with a computer model for both four and eight modified penstocks. The temperature change of this warmer water as it moves downstream through the Grand Canyon is then evaluated using both a computer-generated temperature function and a simplified graphical method. Multiple-level intake structures on all eight of Glen Canyon Dam's penstock intakes would increase river temperatures, but not to pre-dam levels. The river temperature models calculate only a modest increase in water temperature from Lees Ferry to Diamond Creek.

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ABSTRACT

This report is part of the Glen Canyon Environmental Studies, which have the overall objective of measuring and defining the impacts of the operation of Glen Canyon Dam on the environment along the Colorado River in Grand Canyon National Park. The purpose of this study is to make a preliminary evaluation on the possibility of increasing the Colorado River water temperature releases from Glen Canyon Dam to provide a native, pre-dam, warm-water fishery in the Grand Canyon while maintaining a cool-water trout fishery immediately below the dam.

This study presents an analysis of Colorado River temperature modeling below Glen Canyon Dam, Arizona. The potential of raising the water release temperatures at the dam by modifying dam penstocks with multiple-level reservoir intakes is discussed. Predicted temperatures of waters drawn from Lake Powell by such intake structures are calculated with a computer model for both four and eight modified penstocks. The temperature change of this warmer water as it moves downstream through the Grand Canyon is then evaluated using both a simplified graphical technique and a computer-generated temperature model.

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INTRODUCTION

Prior to completion of Glen Canyon Dam, the Colorado River water temperature seasonally ranged from 32.4°F to 82.4°F (1949-1962). Since the completion of the dam, the seasonal water temperatures have decreased and now range between 41.9°F to 64.4°F (1962-1976) (Turner and Karpiscak, 1980). The river water temperature at the Lees Ferry gaging station for the months of May through October 1977-83 averaged around 50°F.

The cooling of Colorado River water adversely affected the native fishery in the Grand Canyon, but it created a trophy trout fishery below the dam. On May 28, 1978, the U.S. Fish and Wildlife Service (F&WS) issued a Biological Opinion stating that the dam was "jeopardizing the continued existence of the humpback chub and is limiting and rendering unsuitable the recovery of a reach of the Colorado River known to support Colorado River squawfish." The F&WS presented four reasonable and prudent recommendations that would work toward remedying the situation. Two of the four recommendations directly concerned the thermal conditions of the river in the Grand Canyon:

1. Study the impact of warming releases from Glen Canyon Dam.
2. Reduce or eliminate known constraining factors of low temperatures and frequent flow fluctuations.

Prior to addressing the impact of warming the releases from the dam, it was necessary to determine if the release temperatures could be raised and, if so, how the thermal conditions throughout the Grand Canyon would be modified. This study was a preliminary effort to address these questions.

Water can be released through Glen Canyon Dam by three routes: power plant releases, river outlet tubes that bypass the generators, and spillways. The primary operating objectives of the dam are power generation and water storage; therefore, the majority of water is and will continue to be routed through the power plant. Bypassing the generators or spilling water is avoided if possible. The U.S. Bureau of Reclamation manages releases from the dam in order to maintain a water level in Lake Powell that will always be above the minimum power elevation of 3490 feet. The dam has eight generators, each fed by a 15-foot diameter penstock tube drawing water from the upstream side of the dam, passing it through the generators, and discharging it downstream in the tailwater (Figures 1 & 2). Each penstock is surrounded by a trashrack structure preventing debris from being drawn into the turbines and causing damage. The penstock intakes are at an elevation of 3470 feet. The decision to place the intakes at this elevation was based on predicted reservoir operations and the amount of head, reservoir height, required to efficiently operate the

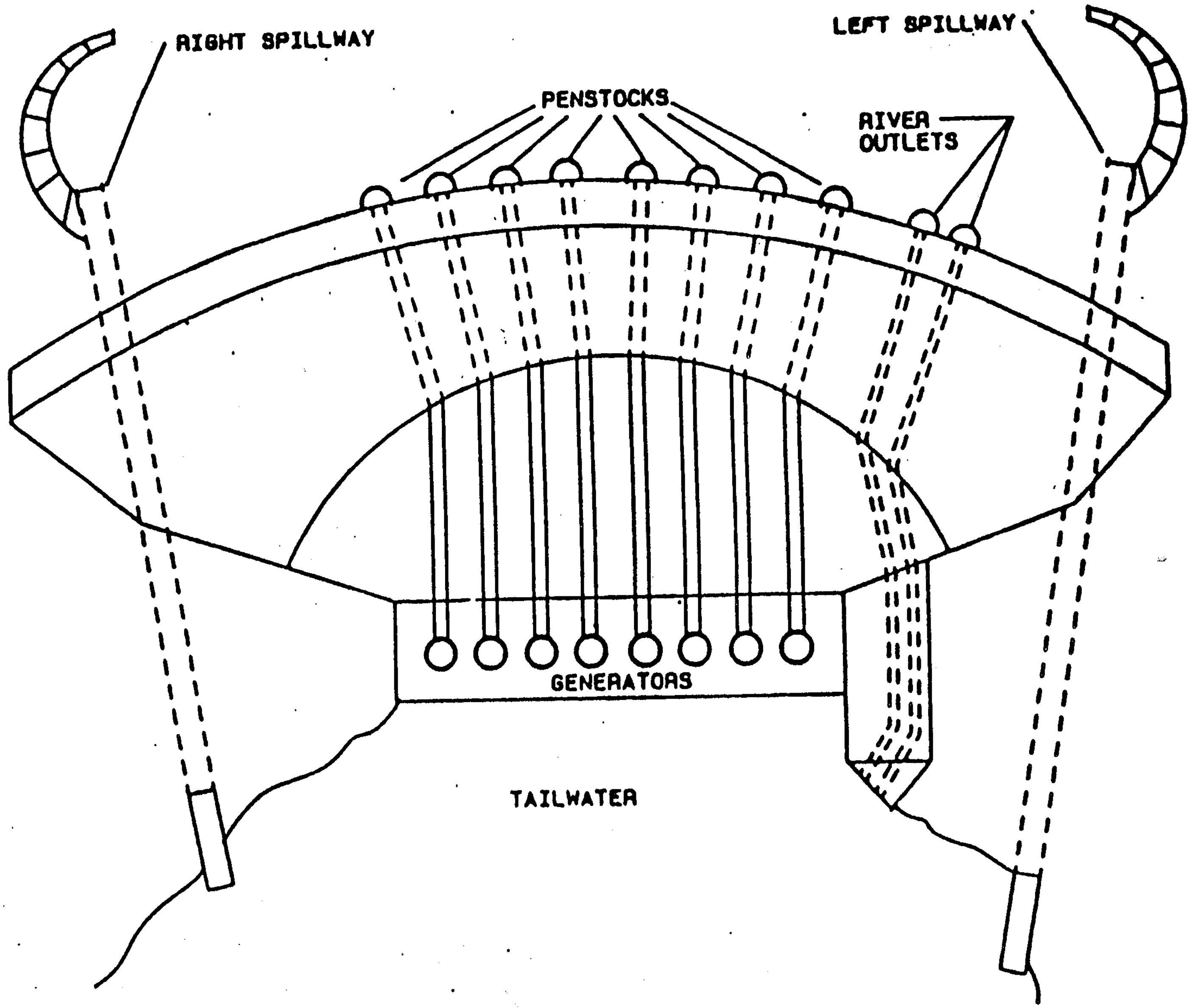

Figure 1. Overhead view of Glen Canyon Dam.

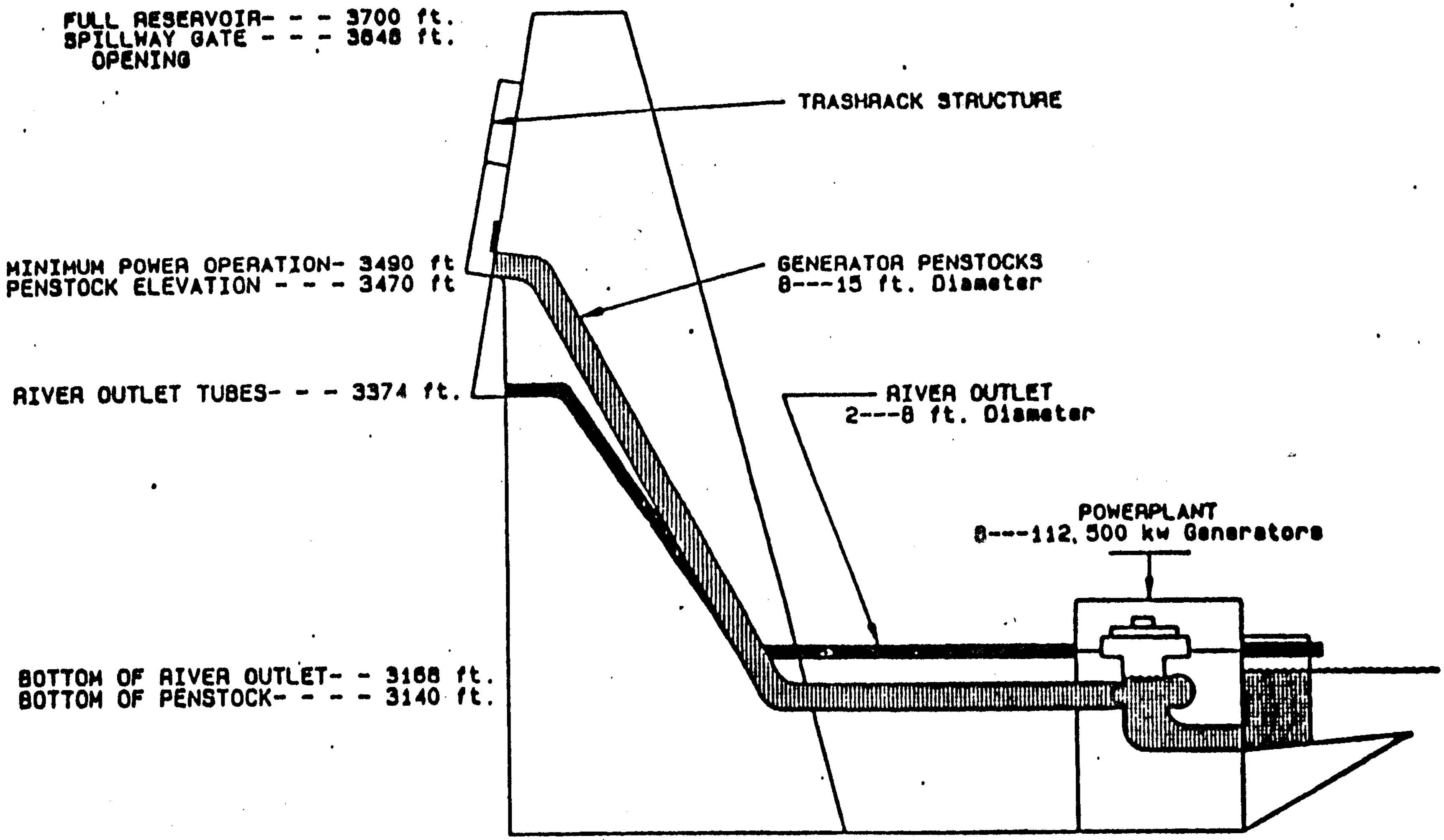

Figure 2. Side view of Glen Canyon Dam.

generators. The generator discharge is at elevation 3140 feet; consequently, the water drops 330 feet from the penstock intakes. The surface elevation of Lake Powell seasonally varies, depending on anticipated and actual runoff from the Upper Colorado River Basin. Since the filling of Lake Powell in 1980, the elevation has ranged from approximately 3670 to a full reservoir of 3700 feet. Therefore, the depth to the penstock intakes during this time period has varied from 200 to 230 feet below the surface of the lake.

The hydrologic and limnological characteristics of Lake Powell have been discussed in detail by Merrit and Johnson (1977), Reynolds and Johnson (1974), and Edinger and Buchak (1982). They found the lake meromictic (a lake with incomplete circulation), but with a strong, warm monomictic (a warm-water lake turning over once per year) thermal circulation in the upper 230 feet. The seasonal longitudinal and vertical temperature structure is defined by inflow densities, heat exchange, and fall overturn. During the summer months, an epilimnion with a depth of 23-50 feet is typically developed. An epilimnion is the upper layer of warm water in the lake containing more oyxgen than the lower layers. Summer surface temperatures have reached 79°F. A strong thermocline, ranging in thickness from 30-50 feet, seasonally forms below the warm epilimnion. The thermocline is the layer of water between the warmer, surface zone, and the colder, deep-water zone. From the bottom of the thermocline to the lake bed, the temperatures are isothermal and vary between 43°F and 45°F. The epilimnion and thermocline typically turnover each fall as ambient air temperatures decrease.

Based on these reservoir characteristics and the level of penstock intakes, the water drawn through the dam is consistently from the isothermal zone of the reservoir, with occasional seasonal withdrawals from the bottom of the thermocline region. Consequently, the water temperature drawn into the dam is dependent on the lake elevation. For example, on September 14, 1982, the lake elevation was at 3685 feet, so the penstocks drew water from 215 feet below the lake surface at a temperature of 47°F.

The current temperature of water released from the dam could be increased by withdrawing water from the warmer upper level of the reservoir. This would be accomplished by attaching intake temperature control structures to the existing penstocks allowing withdrawal of water from various levels nearer the surface of the lake. Such a modification was made in 1978 to Flaming Gorge Dam in Utah (Schmidt et. al., 1980). At that facility, multiple-level intake structures were fabricated and retrofitted to the upstream face of the dam by hard-hat divers. Similar multiple-level intake structures could be developed for Glen Canyon Dam.

The proposed structure, featuring a series of vertically stacked shutters (or gates), would enclose each penstock intake. Different configurations of gates could be opened to vary the withdrawal level. Gate control would be automated, and adjustments would be made in relation to reservoir elevation, turbine operation, and water temperature.

METHODS

To assess the results of modifying the penstocks at Glen Canyon Dam, two separate modeling evaluations were made. The first was designed to project the temperatures of waters released from dam outlets for different possible gate elevation schemes for the proposed multiple-level intake structures, and the second, to predict the increase in temperature as the river water flows downstream through the Grand Canyon.

Before initiating the study, an analysis was made of available models, the data required for these models, and the data available for Lake Powell and the Colorado River. The reservoir outlet temperature model chosen was BSelect2, a withdrawal allocation sub-routine similar to the withdrawal portion of the U.S. Army Corps of Engineers Water Quality for River-Reservoir Systems (WQRRS) model. Using just the withdrawal portion provides an easier and quicker method for entering the data and obtaining results. The model was adapted to reflect the thermal conditions that would be available at the selected multiple-level intake gate elevations.

Two river temperature models were selected to analyze the routing of the power plant releases through the Grand Canyon: (1) "A Graphical Technique for River Water Temperature Predictions" (Graphical) (Krajewski et al., 1982), a model based on the average equilibrium temperature method; and (2) the "Stream Quality Model, Qual-II" (Qual-II), developed by the U.S. Environmental Protection Agency (Roesner, 1977a-b). These relatively uncomplex models were chosen because of the limited Grand Canyon climatological and river water temperature data available and the level of output needed for this study.

Very little atmospheric data have been collected in the Grand Canyon, except for long-term temperature and precipitation statistics collected at the National Weather Service (NWS) Phantom Ranch weather station located in the central part of the canyon. In 1983 the NWS started collecting temperature, relative humidity, wind speed, and precipitation data at the Tonto Rim weather station, located approximately 1,000 feet above the river and near Phantom Ranch.

Many years of pre- and post-Glen Canyon Dam daily Colorado River water temperature records, shown in Table 1, are available from the U.S. Geological Survey (USGS) for the Colorado River at Lees Ferry gaging station (located 15 river miles below Glen Canyon Dam) and at the Near Grand Canyon gaging station (located near Phantom Ranch, 100 river miles below the dam). River temperature data were collected during the water years 1952-53 (pre-dam) and 1977-1983 (post-dam) at the Lees Ferry station and from 1940-1976 and during part of 1983 at the Near Grand Canyon station. The 1952-53 water year was the only period when daily pre-dam river water temperature data were obtained from both sites.

Since the completion of the analysis, it was found that additional river temperature data were collected immediately below the dam by the University of Nevada at Las Vegas in 1981 and 1982 and in recent years by the Utah State Health Department. As seen in Table 2, a comparison of the temperature data collected by the University just below the dam with data from the Lees Ferry station shows some inconsistent results. The data just below the dam is up to 5°F warmer than the average monthly data collected at the Lees Ferry station. Further evaluation of this additional data will need to be done during any future studies on river temperatures.

Table 1. Pre-dam and post-dam average monthly Colorado River Temperature (°F) for Lees Ferry and Near Grand Canyon gaging stations.

	Pre-dam			Post Dam	
Month	Lees Ferry 1953	near Grand Canyon 1953	near Grand Canyon 1952–1962	Lees Ferry 1977–1983	near Grand Canyon 1970–1976
May	61.5	61.5	64.5	49.0	51.5
June	68.0	69.0	71.5	49.5	53.5
July	80.5	79.0	78.0	50.0	54.5
Aug.	79.0	77.0	78.0	49.5	55.5
Sept.	75.0	73.5	73.0	50.5	55.0
Oct.	--	62.0	62.0	50.0	54.0

Table 2. Average monthly Colorado River temperature (°F) for Lees Ferry gaging station and just below Glen Canyon Dam.

	USGS Gaging Station (at Lee's Ferry station)			University of Nevada (just below the Dam)	
Month	1977-83	1981	1982	1981	1982
May	49.0	50.0	49.0	55.0	53.5
June	49.5	51.0	49.0	47.5	44.5
July	50.0	50.0	49.0	53.0	54.0
Aug.	49.5	49.0	49.0	54.5	50.0
Sept.	50.5	51.0	50.0	--	50.5
Oct.	50.0	50.0	48.0	51.0	48.5

OUTLET TEMPERATURE MODELING (BSelect2). The BSelect2 model was calibrated using reservoir water temperature data collected near the dam at Wahweap Bay by the U.S. Bureau of Reclamation. These data have been collected usually from six to eight times per year since the closure of the dam. The water temperature is measured at the reservoir water surface and at 50-foot intervals to the bottom elevations of 3200 and 3190 feet.

Release temperatures were calculated for two scenarios with temperature control multiple-level intake structures installed on (1) all eight of Glen Canyon Dam's penstock intakes, and (2) just four of the intakes. While both options were investigated, temperature control structures would be needed on all of the dam's intakes, both to attain maximum temperature increase when all eight intakes were in use for high power production, and to retain the flexibility of choosing which turbines (i.e., penstock intakes) to use during times of lower power production. The dam is regularly used for peaking power generation, which means all eight intakes are used on a variable but regular basis.

In the model, gate elevations on the proposed temperature control structures were arranged after examining the last 10 years of reservoir water surface fluctuation records and assuming some structural limitations. Two different gate configurations were selected so that consistent release temperatures could be maintained for the different reservoir elevations occurring from year to year. It was assumed that the highest gates on the structure would need to be 30 feet or more below the reservoir water surface to avoid developing a vortex on the reservoir water surface near the dam. Since completing the analysis, it has been suggested that the 30 feet may have to be increased to 45 feet, resulting in a slight decrease in the temperature of the releases calculated by this study.

With a maximum reservoir water surface of 3700 feet, gate inlet elevations on four of the eight temperature control multiple-level intake structures were set at 3470, 3540, 3580, 3620, and 3660 feet. Gates on the other four structures were set at elevations of 3470, 3520, 3560, 3600 and 3640 feet. If a total of only four structures were installed, it was assumed that two would have the first gate arrangement, and the other two would have the second gate arrangement.

The model was run using an outflow of 28,000 cubic feet per second (cfs), which is near the full power release of the dam when all eight turbines are operating. Under the present operation scheme, all eight turbines are normally used for peaking-power purposes on a daily basis during the months of June, July, August, and September. The model was run to give the maximum possible release temperature using the highest available intake gate levels. The full power release, 28,000 cfs, was also assumed for the option using four multiple-level intake structures.

The simulations were based on conditions existing at specific times in the past: the months of May through October in 1977, 1978, 1980, and 1982.

RIVER TEMPERATURE MODELING. The Graphical model equations provide a straightforward technique for estimating downstream water temperatures on the basis of meteorological conditions, including solar radiation, cloud cover, air temperature, wind speed, relative humidity, and atmospheric pressure. This model is capable of providing reasonable results given the minimal data collected in this study area.

The Qual-II method is a comprehensive and versatile stream quality model able to simulate up to 13 water quality constituents. The temperature constituent was the only one used for this study. This model allows the study area stream system to be subdivided into different reaches and to allow for tributary flows. The meteorological data used is similar to the data used by the Graphical model.

Both the Graphical and Qual-II models were calibrated, as shown in Table 3, by using the monthly average temperatures collected by the USGS during 1983 at the five sediment sample stations: Lees Ferry (River Mile [RM] 0), Little Colorado River (RM 61), Phantom Ranch (RM 87.5), National Canyon (RM 166), and Diamond Creek (RM 225). The flow release during August 1983 was approximately 28,000 cfs except for the first 10 days when an additional 8,500 cfs was released through the hollow jets. The 1983 data were used because they were collected simultaneously throughout the study area. Modeling simulated conditions of the 225 river miles from Lees Ferry to Diamond Creek. Modeling did not start at the dam because during the time of analysis river temperature data from the dam to Lees Ferry were unavailable.

Table 3. Measured and model calibrated average August Colorado River Temperatures (°F).

Location	USGS 1983 (measured)	Graphical Model (calibration)	Qual II Model (calibration)
Lees Ferry--Mile 0	50.9	50.9	51.0
Little Colorado--Mile 61.5	52.9	52.8	53.2
Grand Canyon--Mile 87.5	54.0	53.6	53.9
National Canyon --Mile 166.5	55.4	55.6	56.0
Diamond Creek--Mile 225.5	57.9	57.4	57.9

The river temperature models were calibrated with Grand Canyon atmospheric data and the best available long-term atmospheric data collected at several other sites, including weather stations located at Las Vegas and Phoenix, several hundreds of miles from the Grand Canyon. Model input requirements and the extent of available input data determined the level of calibration and verification. The insufficient meteorological and water quality data required that adjustments be made to the input data.

The Graphical model was calibrated assuming the same August 1983 atmospheric conditions for the total 225 river miles from Lees Ferry to Diamond Creek. The different reaches were not modeled separately, because with a few minor adjustments to the input conditions, the model simulated the August 1983 river temperature data collected at the five sampling stations.

The Qual-II model was divided into four river reaches corresponding to the five USGS sediment sampling stations: Reach 1 (Lees Ferry to the Little Colorado), Reach 2 (Little Colorado to Phantom Ranch), Reach 3 (Phantom Ranch to National Canyon), and Reach 4 (National Canyon to Diamond Creek). The average velocities for each reach were estimated using the SSARR (Streamflow Synthesis and Reservoir Routing) model (U.S. Army Engineering Division, 1975) calibrated for the Colorado River by the Durango Projects Office.

Both calibrated models were run using initial starting river temperatures at Lees Ferry of 62°F. A starting temperature of 70°F, the calculated upper limit of the dam's outlet water temperature from the BSelect model, was also tested. The temperature of 62°F was used because the trout fishery below the dam would still prosper, and it was hoped that the river temperatures would approach the pre-dam conditions 60 river miles downstream at the Little Colorado River confluence. The Little Colorado River is one of the existing native fish spawning areas below the dam, and the warming of the Colorado River water below Glen Canyon Dam could increase those activities throughout the canyon.

RESULTS AND DISCUSSION

OUTLET TEMPERATURE MODELING (BSelect2). The BSelect model gave predicted release temperatures from the dam for the eight intake structure and four intake structure options based on the May-October 1977, 1978, 1980, and 1982 release patterns, see Table 4 and Figure 3. These predicted temperatures were then compared to the pre-dam, 1953, and post-dam, 1977-1983, measured temperatures from the Lees Ferry station. The eight intake structures can increase the river release temperatures 5-18°F over present conditions, but this is still 7-16°F cooler than pre-dam conditions. The four intake structure options would increase release temperatures only slightly, 2-9°F, over present conditions.

RIVER TEMPERATURE MODELING. The Graphical and Qual-II river temperature modeling results and the 1953 and 1983 measured river temperature data for August, see Table 5 and Figure 4, show that river temperature increase is minimal as water flows from Lees Ferry to Diamond Creek. Assuming an initial river temperature of 62°F at Lees Ferry, the models calculated the temperature increase to the Little Colorado to be only 1-2°F, and the maximum increase to Diamond Creek to be only about 6 °F. Similar results were found when the models were run for the months of June, July and September using the same initial river temperatures. The 1983 measured river temperatures showed that, with an initial temperature of 50.9°F at Lees Ferry, the increase to the Little Colorado was 2°F, and the increase to Diamond Creek was approximately 7°F. The small increase in water temperature as the river flows downstream is probably due to the high velocity of the river and the deep channel. These factors reduce both the time and the area of exposure to atmospheric conditions within the canyon that could warm the waters during the months of June through September.

Table 4. BSelect modeled results and measured averaged monthly Colorado River temperatures (°F).

	"BSelect" modeling results river temperature just below the Dam					USGS Gaging Station at Lee's Ferry	
Month	1977	1978	1980	1982	Average	1977-1983	1953
May	--	--	55.0*	54.0*	54.5*	49.0	61.5
	--	--	(51.0)	(51.0)	(51.0)		
June	65.0*	64.0*	58.0*	60.0*	61.5*	49.5	68.0
	--	(58.0)	(52.0)	--	(55.0)		
July	63.0*	--	65.0*	66.0*	64.5*	50.0	80.5
	(56.0)	--	(56.0)	--	(56.0)		
Aug.	64.0*	--	70.0*	69.0*	67.5*	49.5	79.0
	(56.0)	--	(61.0)	--	(58.5)		
Sept.	70.0*	--	68.0*	69.0*	69.0*	50.5	75.0
	(59.0)	--	(59.0)	--	(59.0)		
Oct.	--	--	64.0*	63.0*	63.5*	50.0	--
	--	--	(57.0)	(56.0)	(56.5)		

*8-intake structure option
( ) 4-intake structure option

Table 5. Average August Colorado River temperatures (°F), measured and routing modeled results.

Location	1983 (measured)	1953 (measured)	Graphical (modeled)	Graphical (modeled)	Qual II (modeled)	Qual II (modeled)
Lees Ferry	50.9	78.8	62.0	70.0	62.0	70.0
Little Colorado	52.9	--	63.0	70.5	63.8	71.5
Grand Canyon	54.0	77.0	63.6	70.8	64.4	72.0
National Canyon	55.4	--	64.8	71.4	66.2	73.4
Diamond Creek	57.9	--	65.7	71.8	67.7	74.6

The downstream river temperature modeling results are similar for the months of June through September because of the similarity of atmospheric and river conditions during these months. The release temperature from the dam is the determining factor for the downstream maximum river temperature in this period. The release temperature (Table 4) could vary, according to the BSelect2 model, from about 62°F for June to 70°F for August and September.

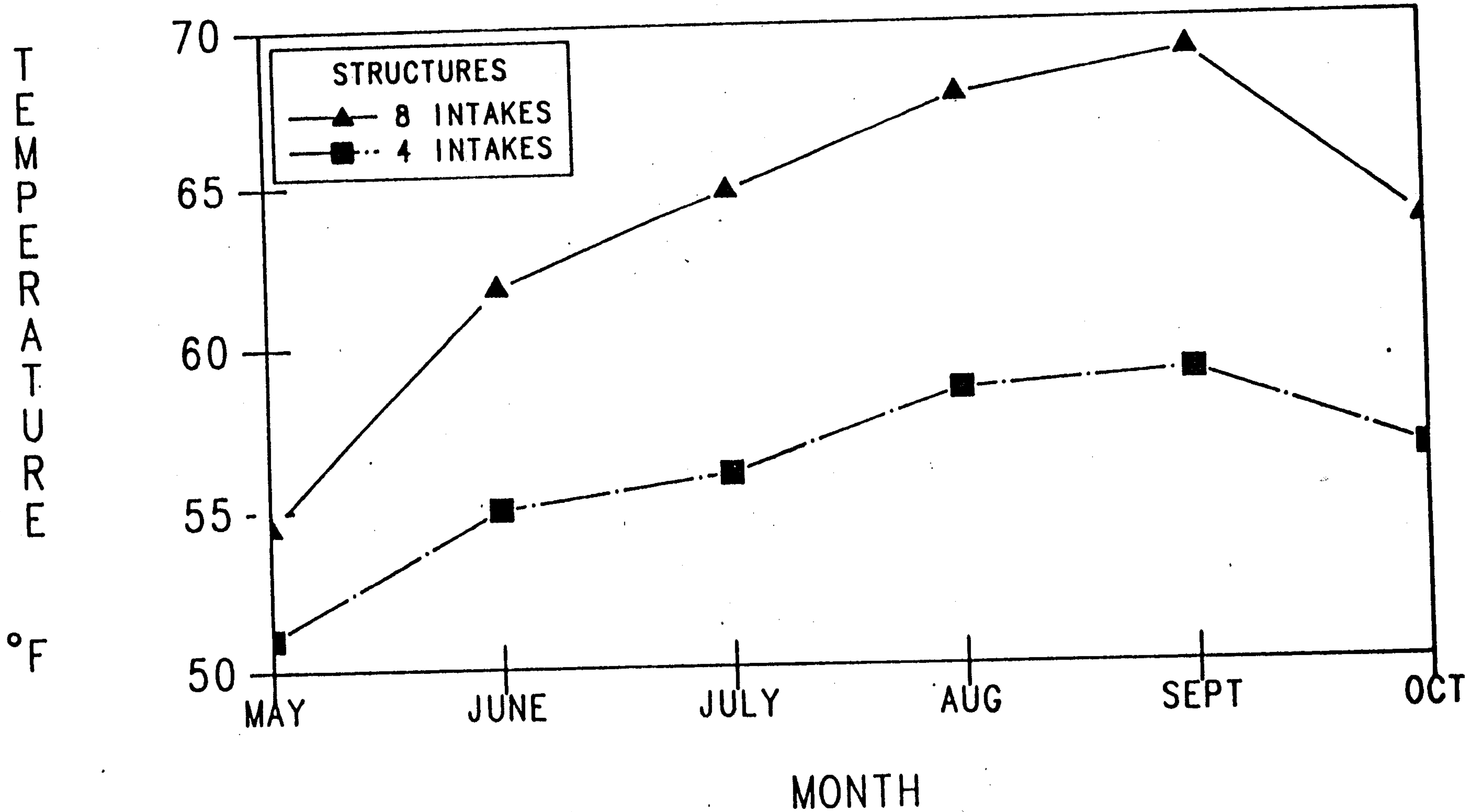

Figure 3. Predicted release temperatures from Glen Canyon Dam for eight and four multiple-level intake structures.

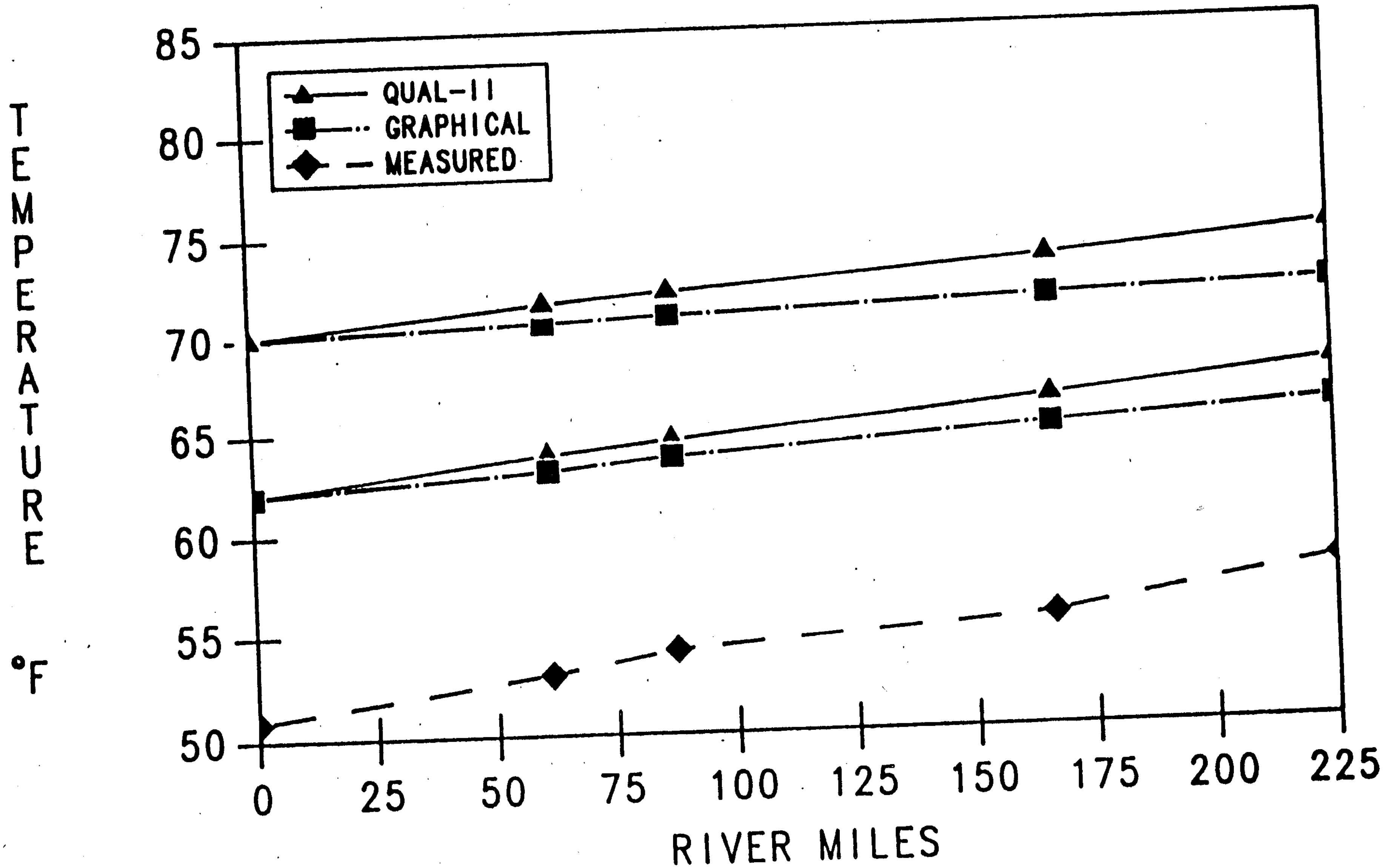

Figure 4. Graphical and Qual-II modeled (Initial temperatures of 62 °F and 70 °F) and measured August Colorado River Temperatures.

CONCLUSIONS

Multiple-level intake structures on all eight of Glen Canyon Dam's penstock intakes would increase river temperatures, but not to pre-dam levels. The Graphical and Qual-II river temperature models calculate only a modest increase in water temperature from Lees Ferry to Diamond Creek.

RECOMMENDATIONS

The Glen Canyon Environmental Study team should analyze the preliminary results from this study and weigh the positive and negative benefits of increasing the Colorado River water temperature. If it were determined that increasing the river water temperature would be a benefit to the Grand Canyon river environment, then the team should recommend that additional in-depth studies be completed to determine its effect on the existing environment, such as the effects on Lake Powell, the trout fishery below the dam, the possible benefit to the Lake Mead fishery if nutrient inflows are increased from Lake Powell, and other related studies. An environmental impact statement would have to be prepared before any selective withdrawal could begin.

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