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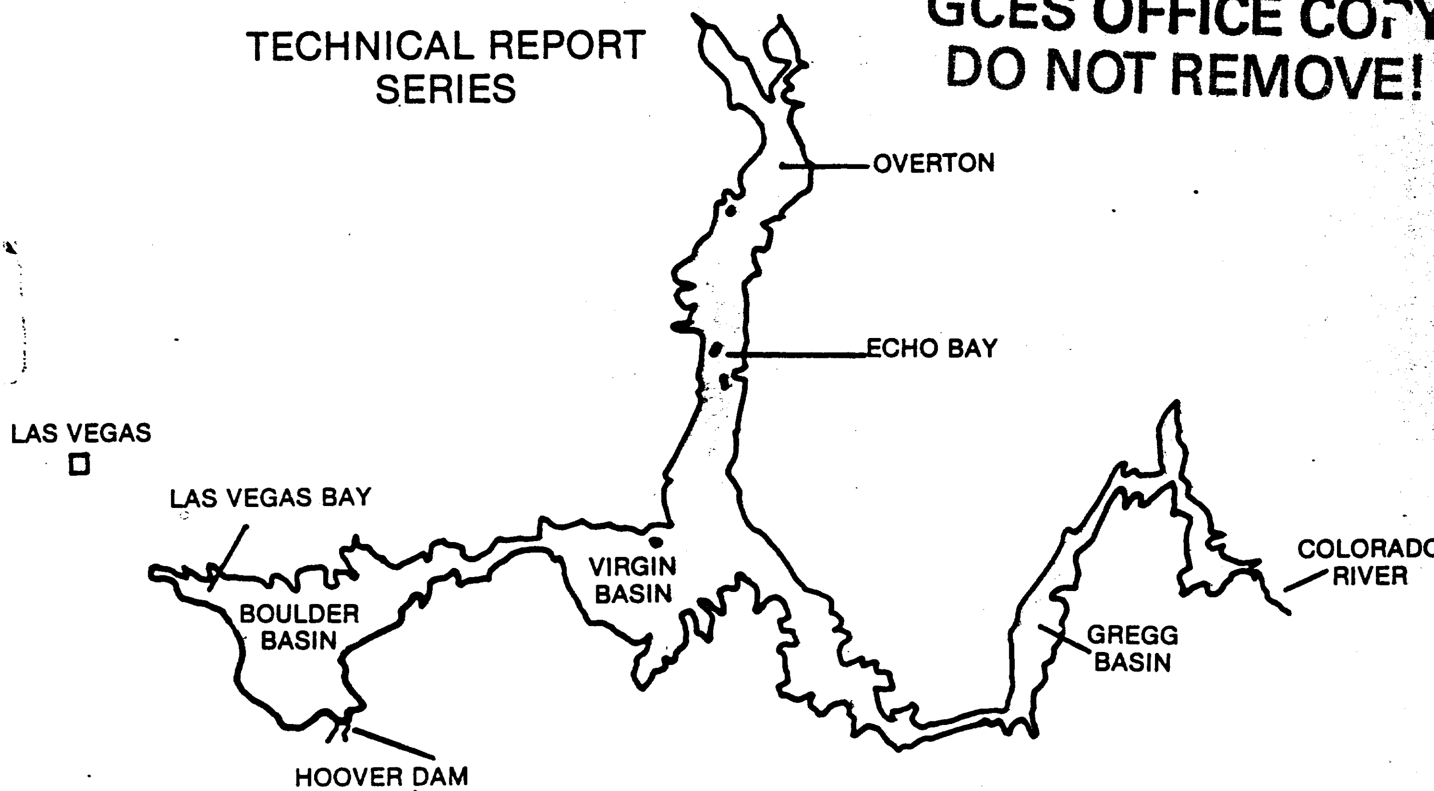
Evaluation of Possible Temperature Fluctuations from Proposed Power Modifications at Hoover Dam

John R. Baker and Larry J. Paulson

Technical Report #3

TECHNICAL REPORT SERIES



DEPARTMENT OF BIOLOGICAL SCIENCES
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LAS VEGAS

EVALUATION OF POSSIBLE TEMPERATURE FLUCTUATIONS FROM PROPOSED POWER MODIFICATIONS OF HOOVER DAM

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James E. Deacon: Principal Investigator

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1.0 INTRODUCTION

There are several planned alternatives for increasing the generation capacity of Hoover Dam to help meet peak power demands. These alternatives include: (a) uprating the existing generating units, (b) replacing or adding one or more generating units and (c) adding reversible pumped-storage hydroelectric units. Since the existing generators are at the end of their economic life and have to be replaced, their uprating has been scheduled as routine maintenance. This will increase the generating capacity of the Hoover Dam powerplant from 1240 MW to 1810 MW, but the anticipated capacity for meeting power demand is 2300 MW. Therefore, modifications (alternatives B and C) are also being considered to obtain an additional 500 MW from Hoover Dam.

The proposed modification of Hoover Dam will alter the existing daily discharge regime, but because of water requirements downstream, the total volume of water discharged over an annual period will remain the same. To meet peak power demands with the proposed alternatives, the daily discharge cycle will be changed to longer periods of low flow (evening-early morning) and shorter periods of peak flow (midafternnon-dusk). The peak discharge rate will increase to 76,000 $ft^3 \cdot sec^{-1}$ (Table 1), but minimum flows of 2000 $ft^3 \cdot sec^{-1}$ will be maintained with alternatives A and B when the elevation of Lake Mohave is below 630 ft. Since the water of Lake Mohave extends to the tailrace of Hoover Dam when lake elevations are greater than 630 ft., minimum flows of 2000 $ft^3 \cdot sec^{-1}$ will be unnecessary and hence zero discharge at night may occur. With reversible pumped-storage (alternative C), some of the water used for generating during peak power demands would also be pumped back to Lake Mead at night at a rate of up to 25,000 $ft^3 \cdot sec^{-1}$. This will cause reverse flows in the river section, and could pull Lake Mohave water to the dam.

Table 1 Minimum and maximum discharge required for proposed power modifications of Hoover Dam (U.S. Water and Power Resources Service estimates).

Discharge	Present Condition	Alternative A	Alternative B	Alternative C
Maximum Flow ($ft^3 \cdot sec^{-1}$)	35,000	49,000	62,000	76,000
Minimum Flow* ($ft^3 \cdot sec^{-1}$)	*2,000	2,000	2,000	-25,000**
Megawatt Capacity	1,340	1,810	2,300	2,800

Alternative A, B = uprating and/or replacement of conventional generating units

Alternative C = reversible, pumped-storage generating units

*Minimum flow when Lake Mohave elevation is below 630 ft.

**Maximum reverse discharge

Hoover Dam has two sets of intake gates located at elevation 1045 ft. and 900 ft. on the four intake towers. The upper gates (1045 ft.), with few exceptions, have not been used since 1954, but, with the addition of generating units (alternative B) or the installation of reversible pumped-storage units (alternative C), one upper gate on the Arizona Tower would be used in conjunction with the four lower gates to facilitate the higher flows.

We have previously reported (Paulson, Baker and Deacon 1980) that the discharge temperature could increase and undergo daily fluctuation due to withdrawal of increasing amounts of warmer water form Lake Mead at higher peak discharge. The U.S. Water and Power Resources Service therefore initiated this investigation to determine to what extent discharge temperature from Hoover Dam and thermal stratification in Lake Mead would change with discharges under the following conditions: (i) all four intakes on the upper gates (ii) all four intakes on the lower gates, (iii) from a combined use of one upper gate and four lower gates.

2.0 EXPERIMENTAL APPROACH AND DATA SOURCES

Two experiments were conducted in cooperation with the U.S. Water and Power Resources Service to evaluate the effects of discharge rate from the upper and lower gates at Hoover Dam on discharge temperature and temperature structure in Lake Mead. Hoover Dam was alternately operated from the four lower gates and four upper gates in consecutive 24 hour periods over the daily power cycles on 18-19 August and 22-23 August, 1979. Temperature profiles were made at four-hour intervals at four stations in Lake Mead during these periods (Fig. 1). Discharge temperature was determined from generator bearing feed temperature which is monitored at two-hour intervals by the Department of Water and Power of the City of Los Angeles. Temperature data were taken from U.S.G.S. Water Resources Data for Nevada (1941-1978)

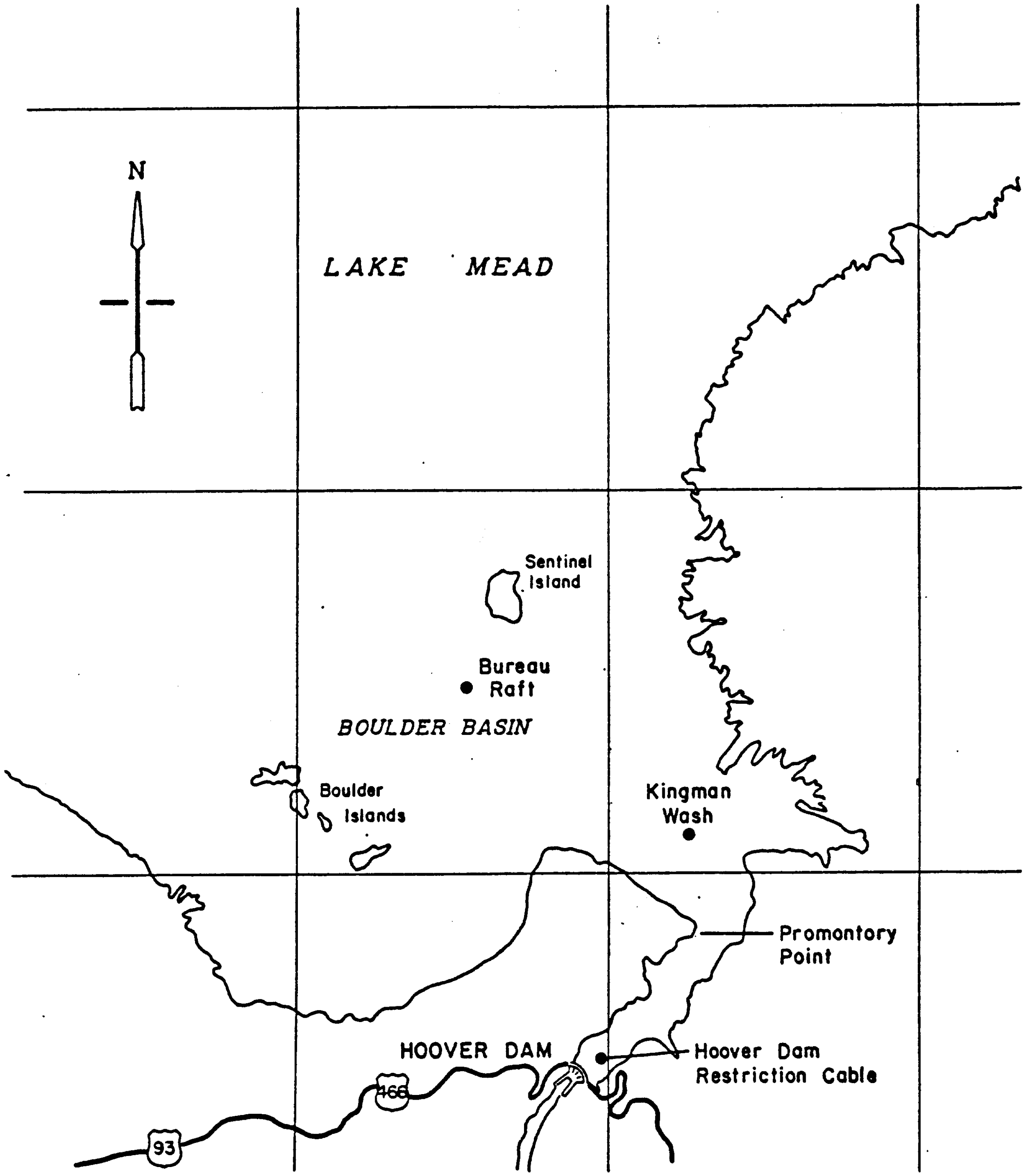

Figure 1 Location of sampling stations in the Boulder Basin of Lake Mead.

to evaluate historical temperature changes when Hoover Dam was seasonally operated from either the four upper and four lower intake gates, prior to 1954.

3.0 HISTORICAL TEMPERATURE DATA AND OPERATION OF HOOVER DAM

3.1 Discharge Temperatures

Since 1954 Hoover Dam had been operated, with few exceptions, from the lower gates. Prior to that, when the elevation of Lake Mead exceeded 1175 ft., the upper gates were used periodically (Jonez and Sumner 1954) to overcome hydraulic problems which developed when the lower gates had to be closed. The use of the upper gates from 1941-1954 resulted in a seasonal cycle in discharge temperatures ranging from 11°C in the winter to 20°C in late summer and fall (Fig. 2). This occurred due to withdrawal of warmer metalimnetic water through the upper gates. In 1946 and 1951, discharge temperatures remained low because of low Lake Mead elevations and continous use of the lower gates throughout the year. Since 1954, the lower gates have been used regardless of lake elevation, and discharge temperatures have remained relatively constant (12-13°), due to withdrawal of hypolimnion water from Lake Mead. Historical data on Lake Mead at and below Hoover Dam show that the discharge temperature generally exceeds that in the lake at the depth of the intakes by 0.5-2.0°C (Fig. 3) when both the lower and upper gates are in operation. Correlation coefficients of the relationships between rate of discharge and discharge temperature were $r = 0.13$ ($n = 34$) for the upper gates and $r = 0.28$ ($n = 55$) for the lower gates, indicating the increased temperature is apparently not related to rate of discharge as previously theorized (Paulson et al. 1980). The 0.5-2.0°C increases in discharge temperature may be caused by assimilation of heat from the generating process or from solar radiation in the tailrace below the Dam. This emphasized

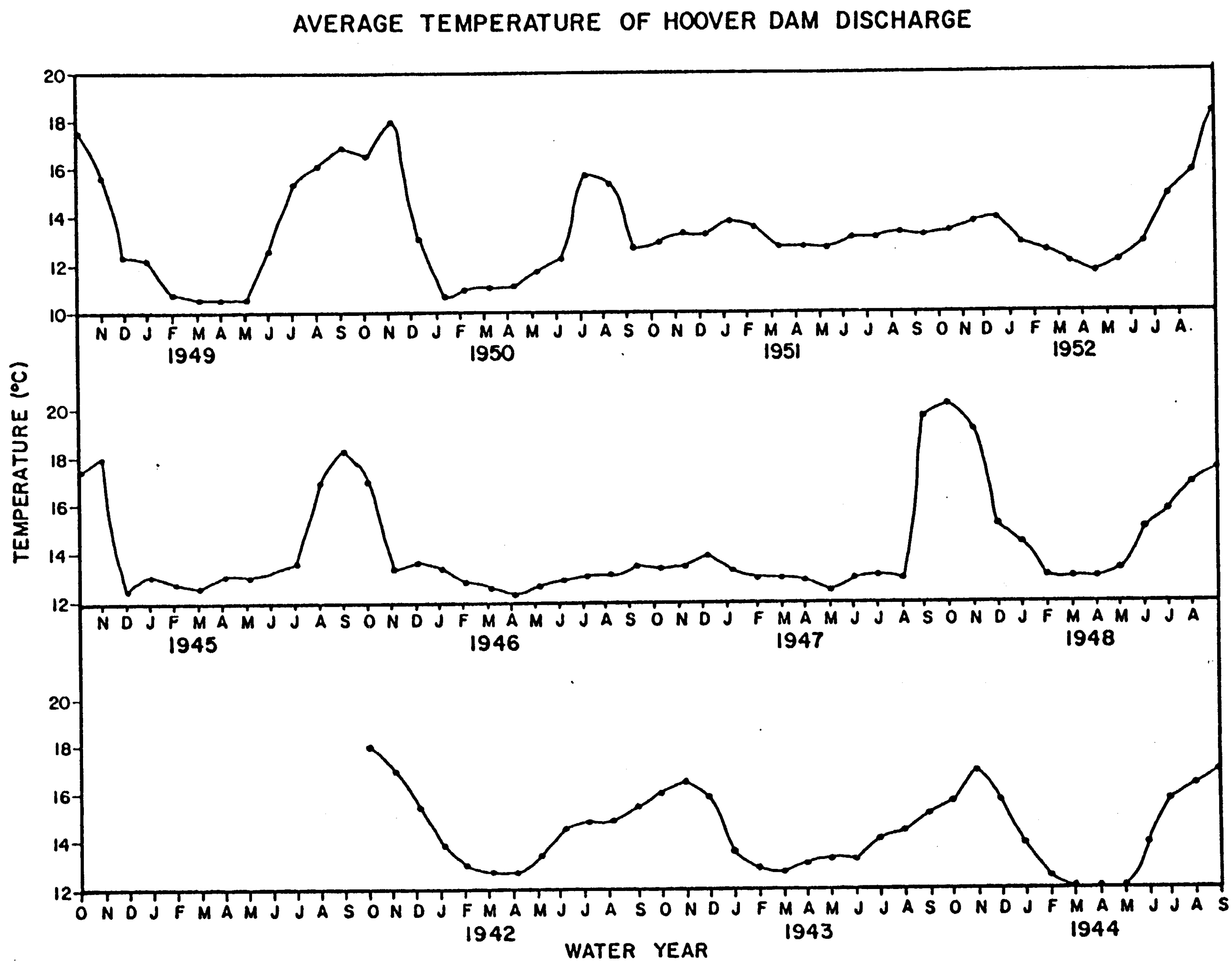

Figure 2 Temperature of discharge during operation from the upper and lower intake gates (USGS data). From Paulson et al. (1980).

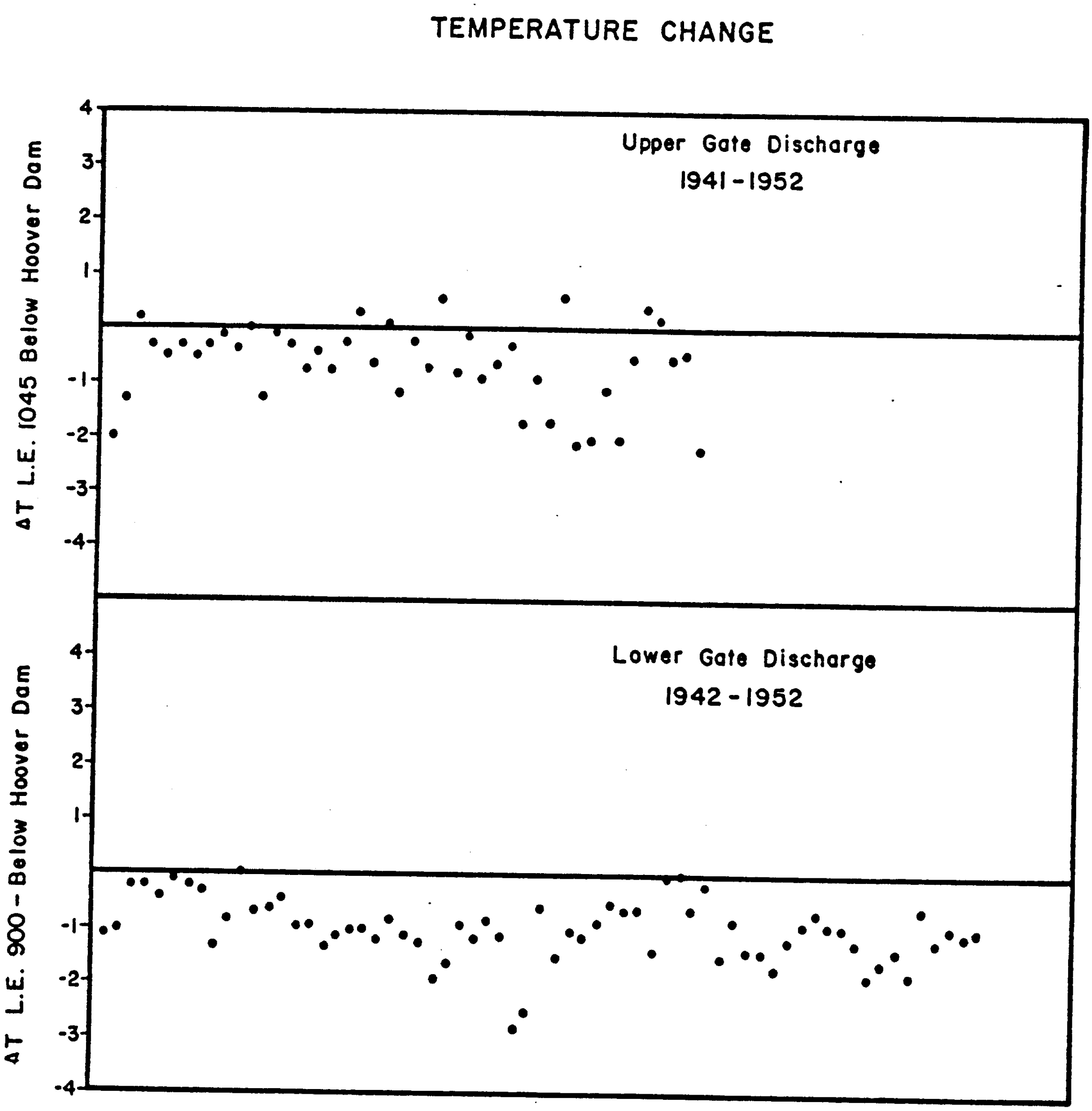

Figure 3 Change (ΔT) in temperature (°C) as water passes through Hoover Dam from upper (1045 ft.) and lower intake (900 ft.) gates. Negative readings indicate an increase in temperature. X-Axis is only relative time scale.

that the temperature change is not caused by draw-down of warmer water from Lake Mead on a high discharge cycle.

3.2 Lake Mead Thermal Stratification

Thermal stratification in Lake Mead is very similar from year to year, regardless of lake elevation or depth of discharge. There are, however, some variations in the temperature profiles taken at Hoover Dam during prolonged discharge from the upper gates (August-November 1947 and June-November 1952) and the lower gates (June-November 1946 and 1951) (Fig. 4). However there was no evidence to suggest that discharge from the upper gates would influence thermal stratification in Lake Mead. The differences in the temperature profiles probably reflect year-to-year variation in other factors such as solar heating and wind action. The principal consequence of operating Hoover Dam from the upper gates will thus be seasonal fluctuations in temperature of the discharge. The seasonal fluctuation in discharge temperatures will occur because of seasonal changes in Lake Mead water temperatures. With the development of thermal stratification in the summer the upper gates will withdraw warm metalimnetic water from Lake Mead. Much cooler water will be discharged in the winter when Lake Mead water temperatures are cooler and the lake is isothermal.

4.0 RESULTS AND DISCUSSION

4.1 Discharge Temperatures During Experimental Releases

The discharge from Hoover Dam on 18-19 August, 1979 ranged from 3,800 to 18,000 $ft^3 \cdot sec^{-1}$, typical of low discharge periods. Typical high discharge periods occurred on 22-23 August, 1979 and ranged from 3,800 to 33,000 $ft^3 \cdot sec^{-1}$. The upper gates were used on 19 and 23 August to determine to what extent this would increase discharge temperature during periods of low and high discharge.

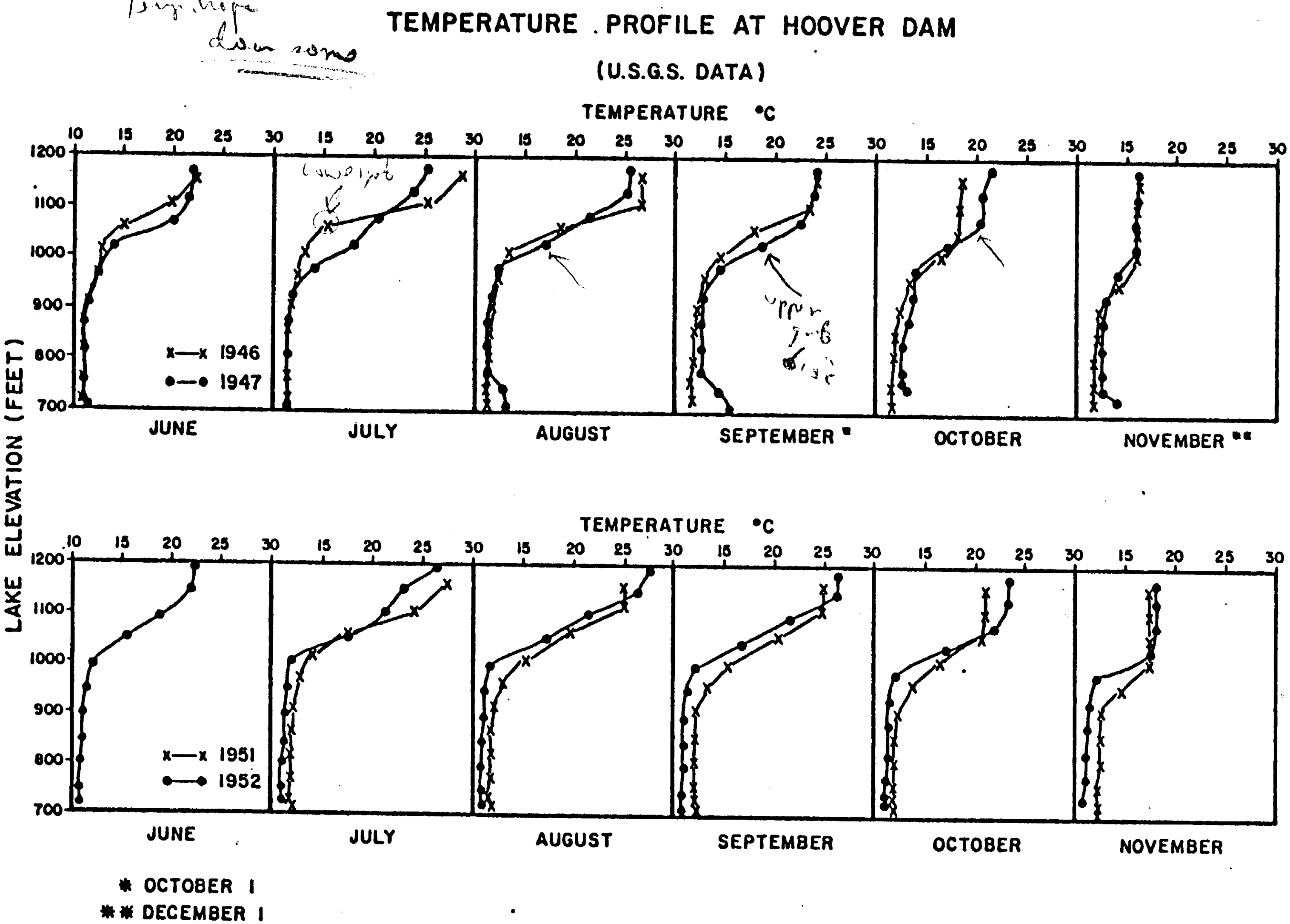

Figure 4 Temperature profiles in Black Canyon, Lake Mead during operation from upper and lower intake gates. From Paulson et al. 1980.

A slight increase in discharge temperature from 12°C to 13°C occurred on 19 and 23 August when the discharge was shifted to the upper gates. During these periods, the lake elevation was 1196 ft., and the hypolimnion extended above the elevation of the upper gates (1045 ft.). Consequently, only cold water was drawn to the upper penstocks during the experimental releases, and the temperature did not change appreciably. At lower lake elevations, the depth of thermal stratification will remain similar to that at higher elevations but the hypolimnion will become greatly reduced. This is evident in the temperature profiles made at Hoover Dam in July 1964, 1971 and 1978 (Fig. 5) when lake elevations were 1125, 1150 and 1180 ft. respectively. Since the intake gates are at a fixed elevation, withdrawal water from the upper gates will originate from regions with differing temperatures as lake elevation changes (Fig. 5). Consequently, at low lake elevation, operation from the four intakes on the upper gates causes a signficant increase in discharge temperature due to withdrawal of metalimnion water. However, the volume of the hypolimnion is sufficient to accommodate discharge from the four intakes on the lower gates, and thus to maintain a constant temperature, regardless of lake elevation.

The rate of discharge had no obvious effect on discharge temperatures when either the lower or upper gates were used (Fig. 6). On 18 and 22 August, when the lower gates were in operation, daily discharge cycles varied from minimum flows of about 4,000 to peak flows of 18,000 and 32,000 $ft^3 \cdot sec^{-1}$, repectively. However, discharge temperatures on those days remained relatively constant at 12°C. Discharge temperatures did increase to 13°C after about 4 hours of operation on the upper gates, however, but there was no difference in discharge temperature on 19 August when the peak discharge was 18,000 $ft^3 \cdot sec^{-1}$ compared to 23 August when the peak discharge was 32,000 $ft^3 \cdot sec^{-1}$. Therefore, even by nearly doubling

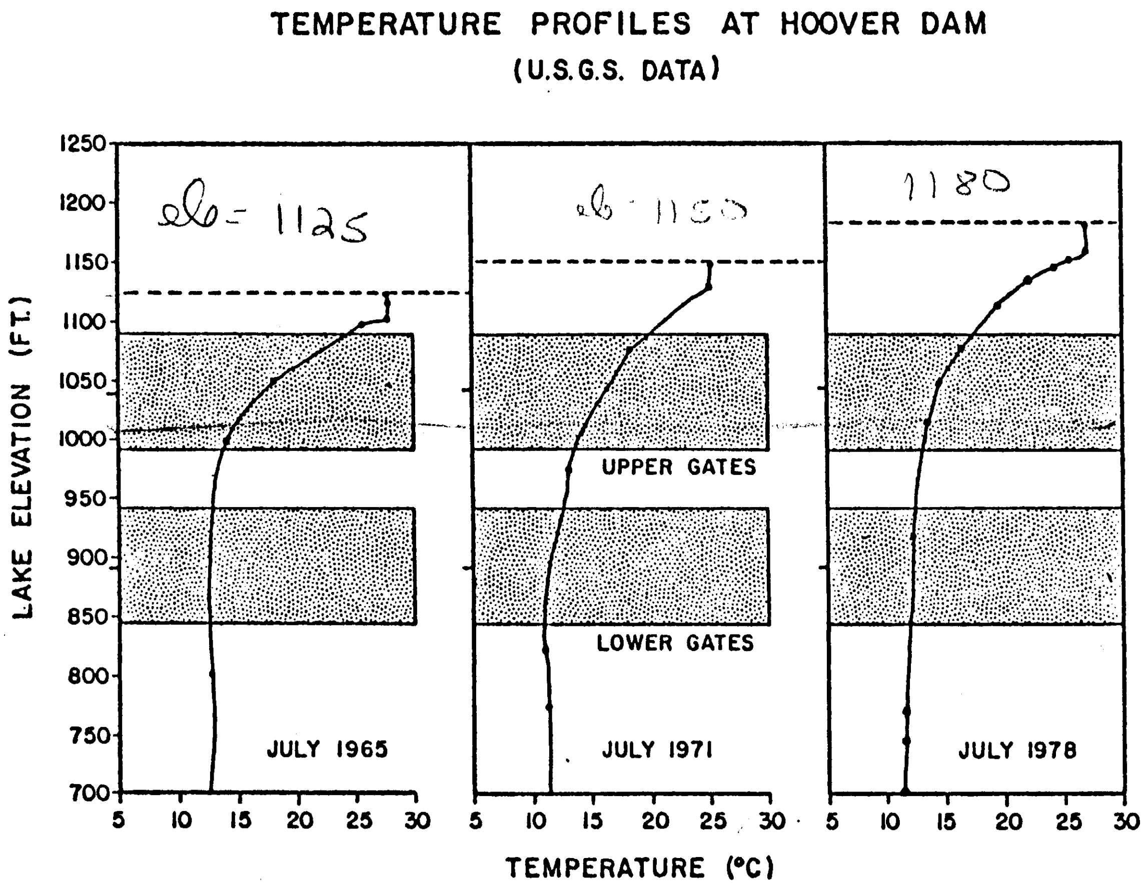

Figure 5 Temperature profiles versus lake elevation in Black Canyon, Lake Mead. From Paulson et al. 1980.

HOOVER DAM DISCHARGE RATES AND DISCHARGE TEMPERATURES
(USGS DATA)

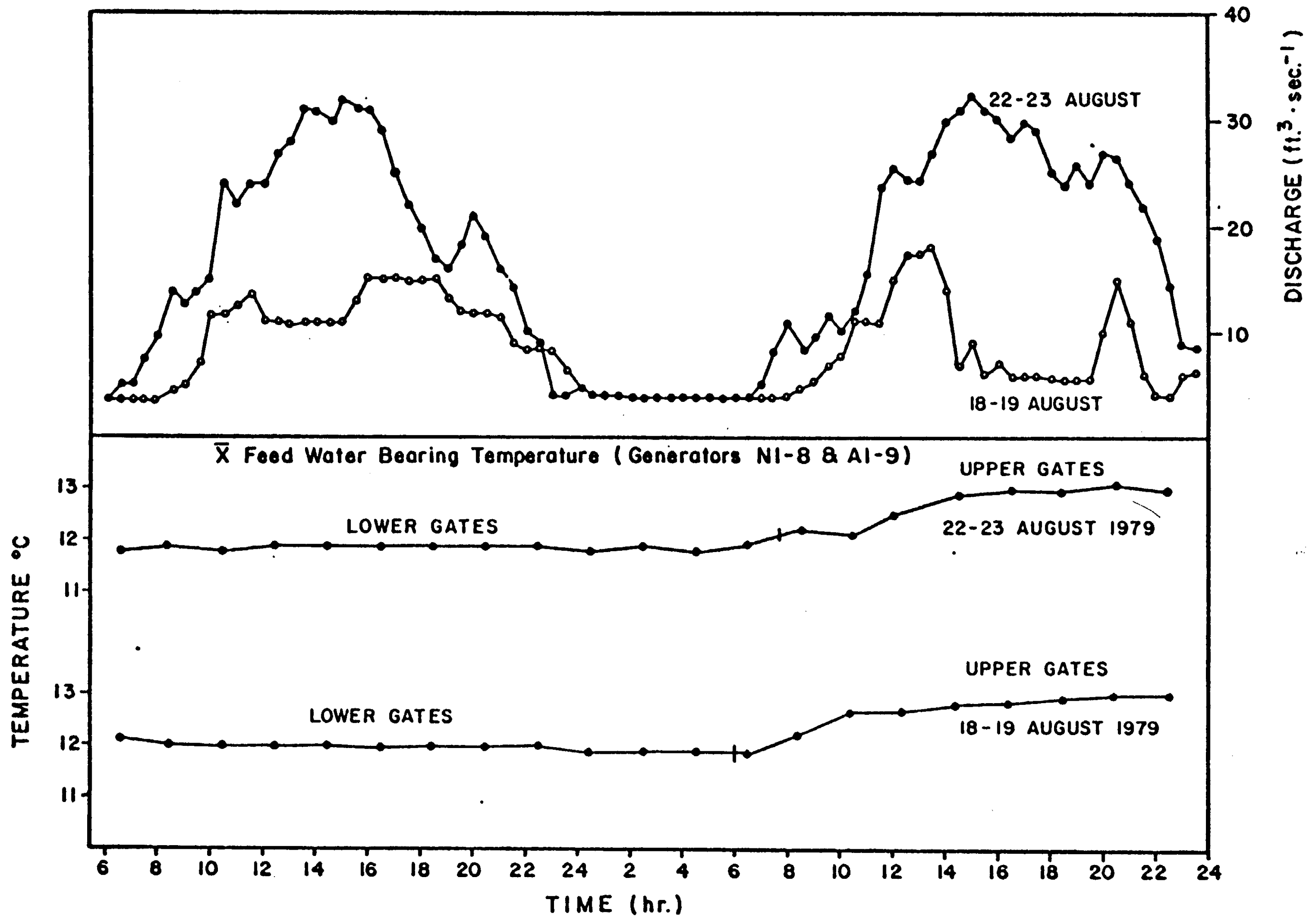

Figure 6 Hoover Dam discharge rates and discharge temperature on 18-19 and 22-23 August 1979.

discharge from the upper gates, there was not a disproportional amount of warmer water pulled down from the upper water column of Lake Mead.

These discharge rates were not as great as those that will occur with the proposed modifications of Hoover Dam. However, it appears that the higher discharge rates will not substantially increase, or cause large daily fluctuations in, discharge temperatures. This is partially substantiated by preliminary modeling of discharge temperatures by the U.S. Water and Power Resources Service using a discharge model developed for the Corp of Engineers. Temperature and conductivity data measured at Hoover Dam in July and September 1978 at an elevation of 1184 ft. were used in that model. The following assumptions were made:

(i) Peak flows were 62,000 $ft^3 \cdot sec^{-1}$.

(ii) One upper gate (Arizona tower) was operated in conjunction with the four lower gates and the flow through the upper gate was ~~10,312~~ $ft^3 \cdot sec^{-1}$ at the peak discharge rate.

(iii) Lake Mead elevation was 1120 ft.

(iv) Temperature and conductivity gradients measured in July and September, 1978 at Hoover Dam for a lake elevation of 1184 ft. were representative of those at a lake elevation of 1120 ft.

The lake elevation of 1120 ft. was used because at that elevation the upper gate is within the metalimnion (Fig. 5) and because predicted lake levels until the year 2000 indicate that lake elevation will not go below this level. The use of one upper gate on the Arizona intake tower will be required for Hoover Dam modification (alternatives B and C).

The predicted discharge temperatures from the lower and upper gates were very similar to the lake temperatures at the depth of the intake gates (Table 2). Predicted discharge temperatures with the combined flow

Table 2 Lake Mead water temperature and predicted discharge temperatures with one upper gate operating in conjunction with the four lower gates at a discharge rate of 62,000 $ft^3 \cdot sec^{-1}$ (upper gate 10,312- lower gates 51,679 $ft^3 \cdot sec^{-1}$).

<table>
<tr><th></th><th></th><th>Lake Temperature °C at Depth of Intake</th><th>Predicted Gate Temperature °C</th><th>Predicted Discharge Temperature °C</th></tr>
<tr><td>Upper Gate</td><td>July</td><td>19.0</td><td>19.0</td><td rowspan="2">13.6</td></tr>
<tr><td>Lower Gate</td><td>July</td><td>12.7</td><td>12.7</td></tr>
<tr><td>Upper Gate</td><td>Sept.</td><td>22.5</td><td>19.6</td><td rowspan="2">14.4</td></tr>
<tr><td>Lower Gate</td><td>Sept.</td><td>12.9</td><td>13.4</td></tr>
</table>

* These results were determined by Dave Sobek of the Water and Power Resources Service, Boulder City and are preliminary, pending final review by the Engineering and Research Center, Denver, Colorado.

from one upper and four lower gates were less than 2°C higher than lake temperatures at the depth of the lower gates. This indicates that discharge temperatures will not be substantially increased by high discharge rates or with the use of the one upper gate. Predicted daily variations in discharge temperatures were less than 1.5°C resulting from the shift to the one upper gate during high discharge.

Higher discharge temperatures, as well as daily fluctuations in discharge temperatures, were of primary concern with the proposed alternatives for increasing peaking power from Hoover Dam. The river section below Hoover Dam has been a very valuable trout fishery and is critical habitat for razorback suckers (Miller et al. 1980). Higher water temperatures or extreme daily variations in water temperatures could have a detrimental impact on these fish populations. Jonez and Sumner (1954) reported a severe outbreak of the external parasitic copepod Lernia sp. on trout in 1952 when discharge temperatures increased to 18°; therefore discharge temperatures should be maintained below this level.

Based on data collected in August 1979, it appears that high discharge through the lower gates will not result in warmer discharge temperatures. The planned operation of using one of the upper gates in conjunction with the four lower gates will cause only a slight increase in discharge temperatures. Excluding pumped-storage (alternative C), the Corp of Engineers' model at extreme conditions of low lake elevation (1120 ft.) and high discharge rates (62,000 $ft^3 \cdot sec^{-1}$), predicted that discharge temperatures would only increase by about 2° (12.5° to 14.5°C) with daily variations of less than 1.5°. Even if actual discharge temperatures were 1-2° higher, they would have little or no effect on the trout fisheries and razorback suckers below Hoover Dam.

Discharge temperature with pumped-storage would probably not be much greater. However, during the pumping cycle, warmer Lake Mohave water would be drawn up into the river section increasing temperatures there. If the pumping periods are long enough to withdraw water from as far down as mile 24, water at temperatures greater than 20° would be pulled up to the dam. Large daily fluctuations in temperatures could therefore occur because of cold water discharge from Lake Mead during the generation cycle and the extension of warmer Lake Mohave water up to the dam during the pumping cycle. Although it cannot presently be quantified, these temperatures could have an adverse effect on the trout fisheries.

4.2 Lake Mead Thermal Stratification During Experimental Releases

The high discharge rates in August, 1979 did not have a marked effect on thermal stratification in Lake Mead. The temperature isotherms at four stations in Black Canyon and Boulder Basin on 22 August (Fig. 7) showed no apparent difference when the lower gates were in operation. There was some indication that the 16-18° isotherms were pulled down, and the 11-12° isotherms were elevated, at the Hoover Dam station on 23 August when the upper gates were in operation (Fig. 8). The upper gates, therefore, did have some minor influence on the temperature structure of the metalimnion. However, even with the proposed modifications to Hoover Dam and discharges of 62,000 $ft^3 \cdot sec^{-1}$, less than 11,000 $ft^3 \cdot sec^{-1}$ would be withdrawn through the upper gate. This is considerably less than the 32,000 $ft^3 \cdot sec^{-1}$ discharged on 28 August, and therefore thermal stratification will not be altered significantly with the higher discharges required for the power modifications.

Oscillations of the thermocline did occur during the low discharge period (18-19 August) as the hypolimnetic water mass that was set in motion by the preceeding high discharge cycle collided with the dam. This created

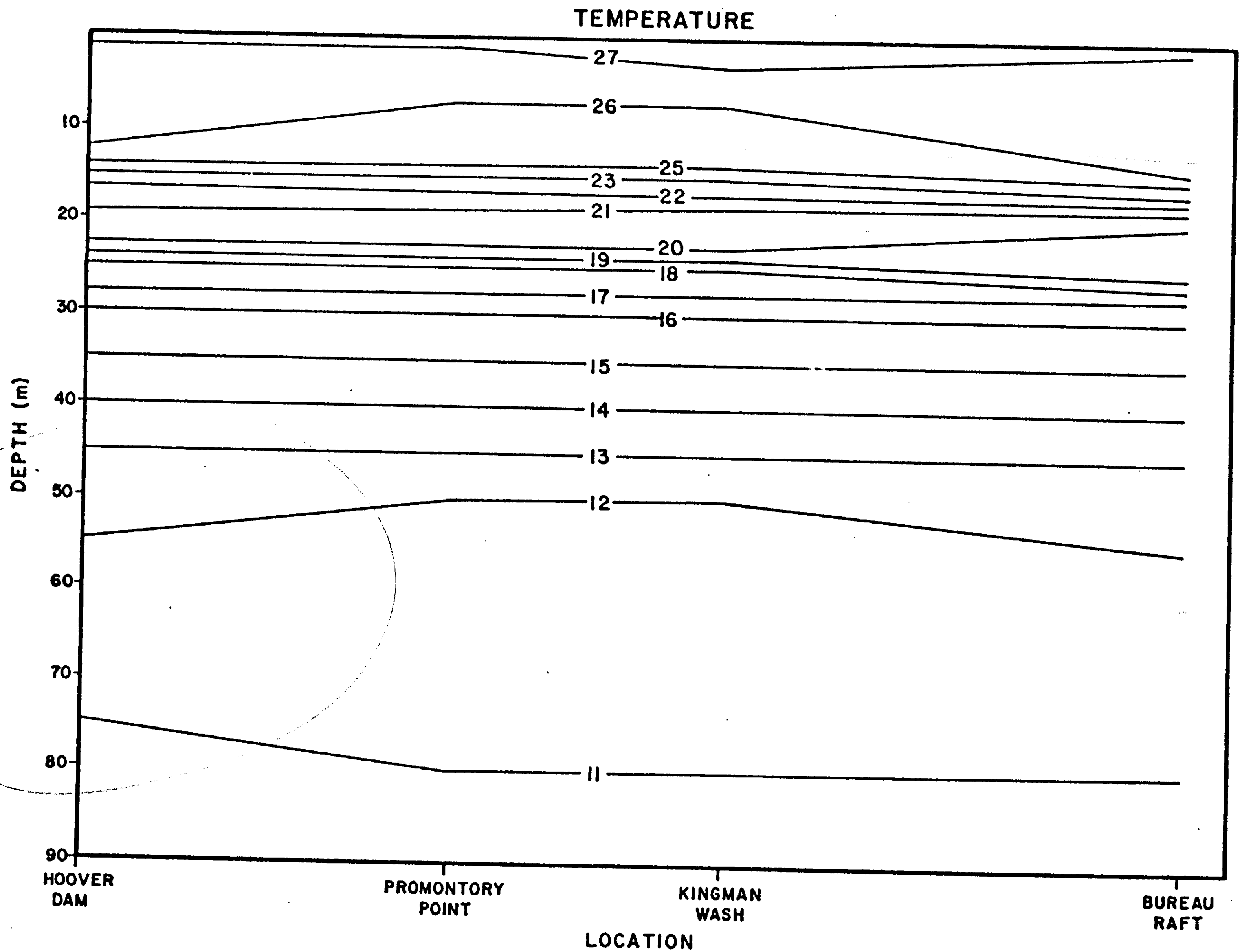

Figure 7 Temperature (°C) isotherms for Boulder Basin on 22 August 1979.

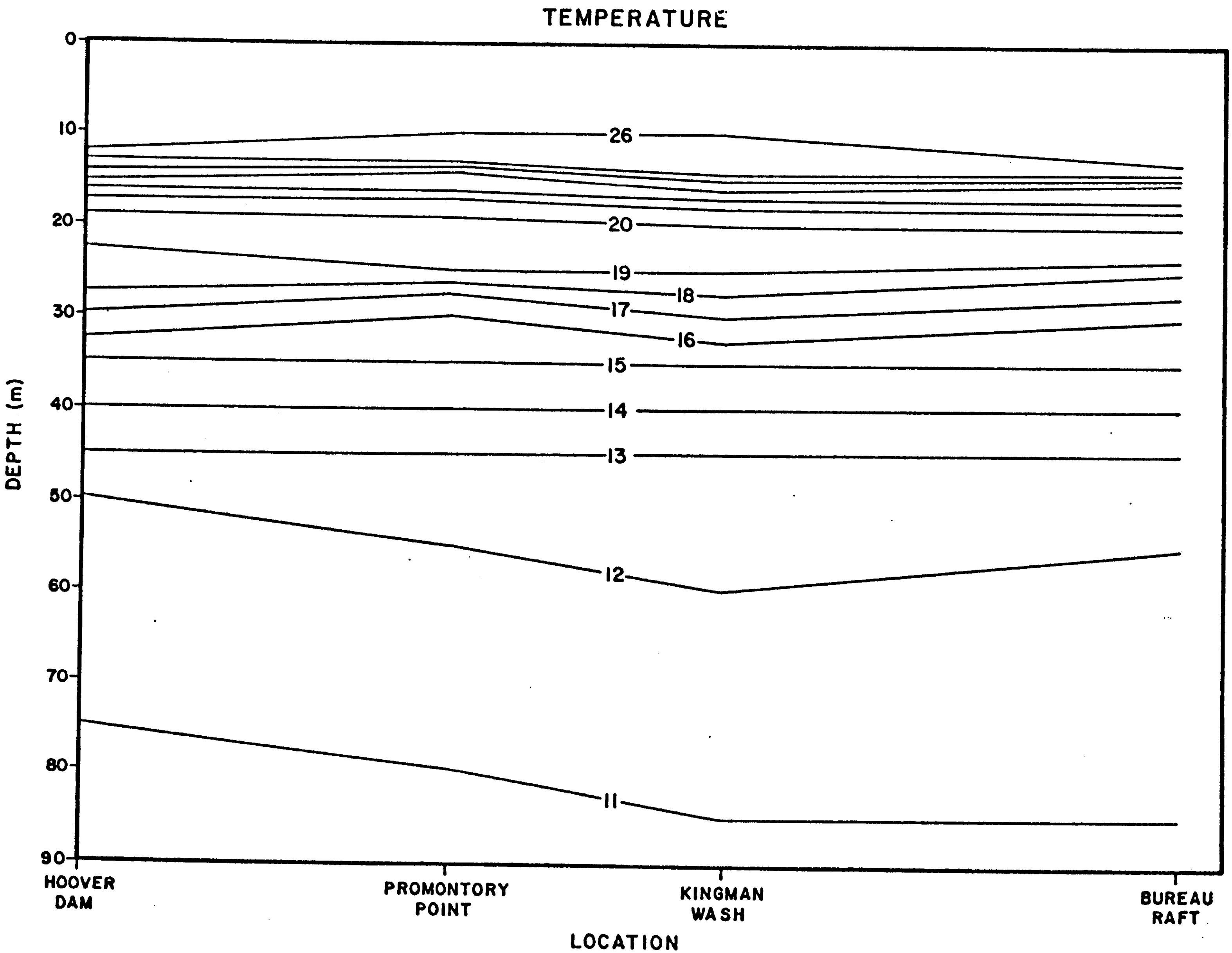

Figure 8 Temperature (°C) isotherms for Boulder Basin on 23 August 1979.

an internal hypolimnetic seiche which disrupted the temperature isotherms in both the hypolimnion and metalimnion (Fig. 9). This was most evident at stations in Black Canyon and to a lesser extent at the Kingman Wash station. The hypolimnetic seiche became less pronounced at higher discharges when the hypolimnion water mass was drawn to the penstocks. This was evident on 22 and 23 August when discharge peaks were 32,000 $ft^3 \cdot sec^{-1}$. The temperature isotherms at this time (Fig. 10) were more uniform because of the decreased action of the hypolimnetic seiche. Daily low discharges of 4,000 $ft^3 \cdot sec^{-1}$ within a high discharge period, such as those that occurred on 22 and 23 August, did not induce a hypolimnetic seiche because of the short time period (10-12 hr.) between the high daily discharge peaks. It was only with an extended period of low discharge that the hypolimnetic seiche developed. The higher proposed discharges and longer periods of low discharges with uprating and Hoover Dam modification will enhance the hypolimnetic seiche. Therefore, the temperature instability will increase at Hoover Dam, but not to the point where appreciable disruption of thermal stratification occurs.

The addition of reversible pumped-storage units (alternative C) would have a more pronounced influence on the temperature structure in Lake Mead. Although there is no way to actually determine what effect pumped-storage will have, some speculations can be made, as in our previous report (Paulson et al. 1980), using data on pumped-storage conditions at Canyon Lake, Arizona reported by Minckley and McNatt (1976). On the pumping cycle, up to 25,000 $ft^3 \cdot sec^{-1}$ of water would be forced back into Lake Mead which would disrupt thermal stratification near the dam. Reverse up-lake flows in the hypolimnion would eventually be set in motion and could cause a second, smaller upwelling where pumped-water collided with a shelf or the canyon

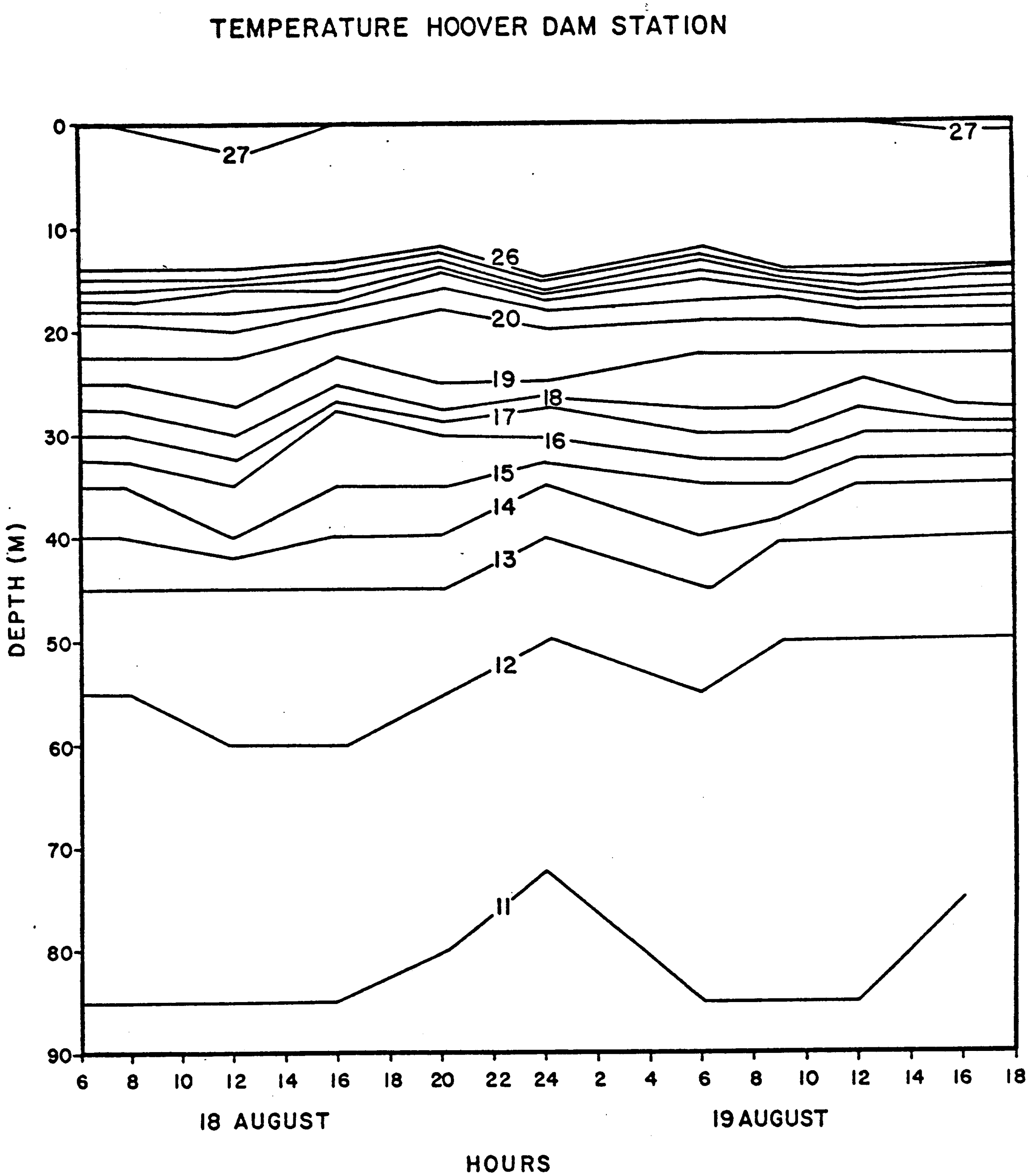

Figure 9 Temperature isotherms above Hoover Dam 18-19 August 1979.

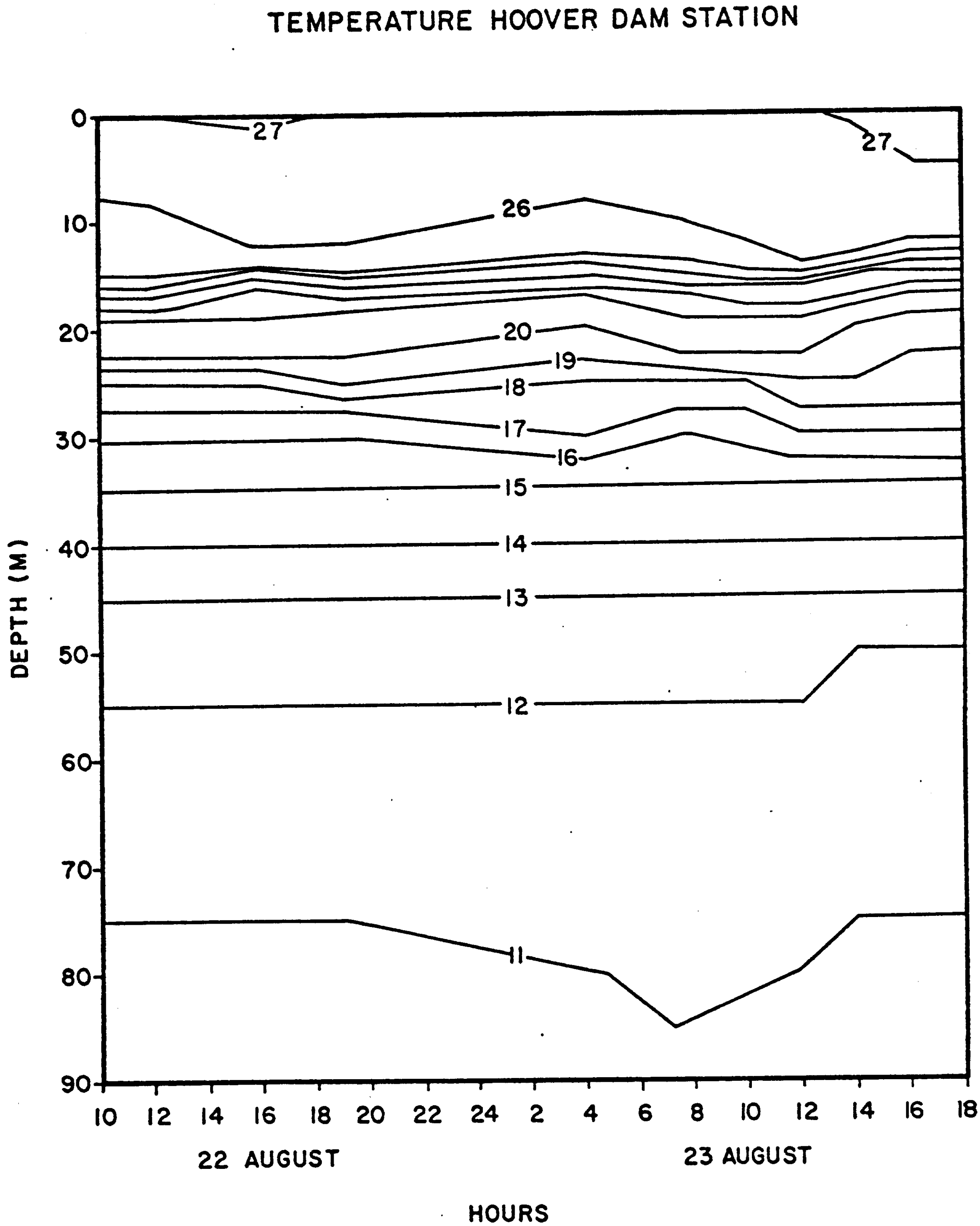

Figure 10 Temperature isotherms above Hoover Dam on 22-23 August 1979.

wall at Kingman Wash. On the generating or discharge cycle, the upwellings would dissipate and thermal stratification would again develop, but this would be less stable than prior to pumping. The cumulative effect of continual alternation of pumping and discharging could substantially disrupt thermal stratification in Black Canyon and parts of Boulder Basin (Paulson et al. 1980).

The upwelling caused by the pumping operation will increase mixing of hypolimnetic water, which has high nutrient concentration (Paulson et al. 1980), into the epilimnion, resulting in increased nutrient availability for phytoplankton productivity. However, upwelling will produce very turbulent conditions as well as cooler epilimnetic water temperatures that will tend to limit phytoplankton growth. The increase in phytoplankton productivity would probably be no greater than the fall peak in productivity that now occurs when the lake starts to overturn with recycling of hypolimnetic nutrients (Paulson et al. 1980). Increased oscillation of the thermocline will have little or no effect on phytoplankton productivity. Therefore, the proposed alternatives will not cause any serious water quality problems in Lake Mead.

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