Water Quality below Glen Canyon Dam – Water Year 2000

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DRAFT

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Introduction

The purpose of this report is to present information collected during the past year by the Grand Canyon Monitoring and Research Center (GCMRC) Integrated Water Quality Program (IWQP) to inform stakeholders, scientists, and the general public on conditions in Grand Canyon related to the operation of Glen Canyon Dam.

The IWQP is designed to respond to several Information Needs developed by the Grand Canyon Adaptive Management Program Technical Work Group (TWG) to accomplish a series of Management Objectives for the operation of Glen Canyon Dam. The IWQP directly addresses information needs for chemical concentrations, nutrient levels, and water temperature patterns in releases from normal dam operations and TCD operations. This information can further be used to support evaluation of the effects of these operations on the aquatic food base, trout populations, native fish survival, parasites and disease organisms, interactions between native and non-native fish, aquatic food base to Lake Mead, and effects to reservoir limnology and heat budgets.

Because the downstream components of the IWQP are conducted below Glen Canyon Dam and directly address resources downstream of the dam, they are supported entirely by the Grand Canyon Adaptive Management Program. Activities upstream of Glen Canyon Dam are currently supported by Bureau of Reclamation Operation and Maintenance funds.

Continuous Tailwater Monitoring

The objective of the tailwater monitoring program is to characterize the quality of water released from Glen Canyon Dam and measure changes occurring in the tailwater below Glen Canyon Dam. These conditions are the result of short-term and long-term climatological and hydrological processes in the Colorado River basin, advective and convective mixing processes within Lake Powell, and the operation of Glen Canyon Dam. The water quality of Glen Canyon Dam releases forms a baseline from which changes occur downstream, directly affecting the aquatic ecosystem. A twelve-year period of record exists for these data.

Methods

The primary instrumentation used for this monitoring program are Hydrolab Recorders, multi-parameter sondes capable of submersible measurement of temperature, specific conductance, pH, and dissolved oxygen and logging these readings at specified intervals.

The current logging interval is 20 minutes. Monitors are downloaded, serviced, and recalibrated on a monthly basis. Monthly chemical sampling for nutrients and major ions, and biological sampling for chlorophyll, phytoplankton, and zooplankton is also performed inside Glen Canyon Dam and at Lees Ferry.

Three stations are currently monitored. The primary point of measurement for Glen Canyon Dam releases, Colorado River below Glen Canyon Dam (CRBD), is located in a perforated pipe attached to the concrete wall below the hollow jet tubes of the river outlets works, approximately 50 meters downstream of the generator outlets. This site shows effects of reaeration of releases from turbulence in the tailrace, adding noise to dissolved oxygen readings. Because of this, an additional site, Colorado River at Glen Canyon Dam Draft Tube (CRDT), is located inside the dam and samples water from one of the dam's eight draft tubes, immediately below the generator turbines. Water is routed to the recording instrument through a closed flow cell before any atmospheric exposure. This site is prone to periodic generator shut downs and therefore is not a reliable site for continuous monitoring but it provides more accurate information on the actual dissolved oxygen concentrations of dam releases.

The third site, Colorado River at Lees Ferry (CRLF), is a mid-channel buoy deployment, sometimes prone to changing flow velocities and algae and debris collecting or growing on the instrument, complicating interpretation or verification of dissolved oxygen readings.

Due to quality assurance problems with pH and dissolved oxygen measurements, which are described below, four YSI Model 6920 multi-parameter sondes were recently acquired and deployed. These sondes are capable of measuring turbidity in addition to the other four parameters, do not have the flow sensitivity of the Hydrolab Recorders for dissolved oxygen measurements, and may have reduced pH drift. Performance of these units will be evaluated as comparison data become available.

Results

Historical Patterns and Trends

A yearly cycle of temperature and conductivity patterns in Glen Canyon Dam releases is shown in Figure 1

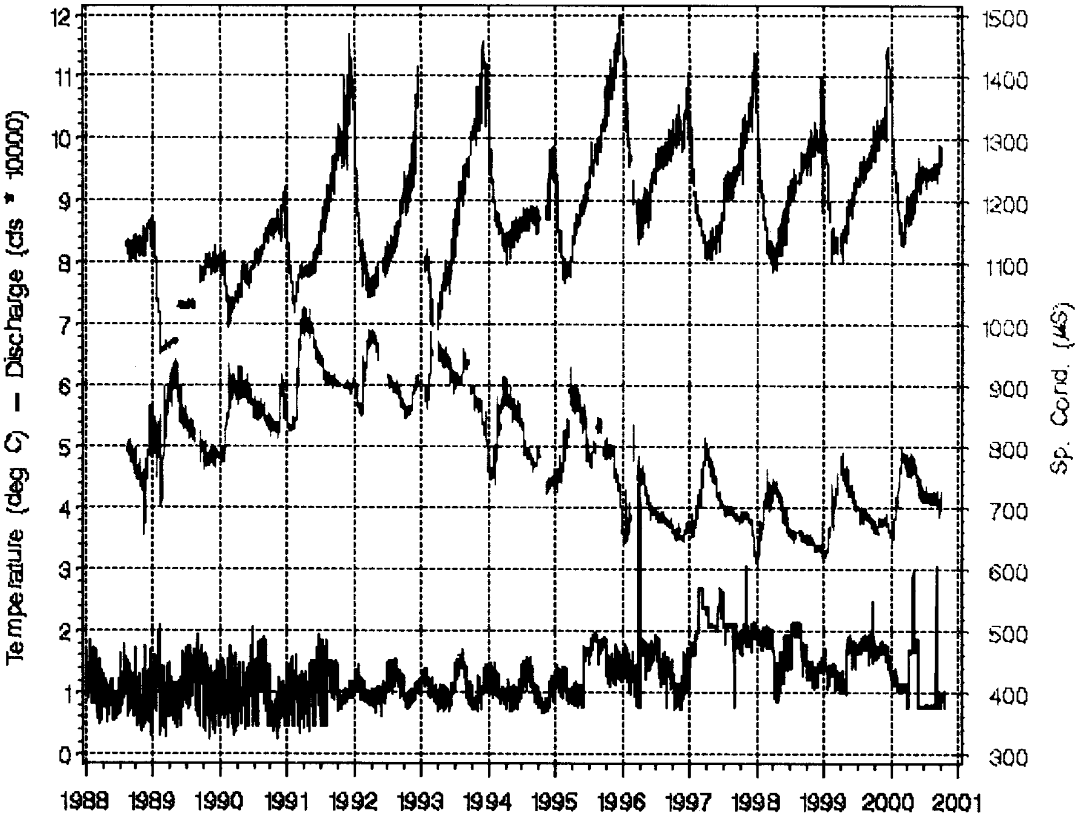

Figure 1 Water quality patterns below Glen Canyon Dam

The quality of dam releases is largely a function of density patterns in the reservoir immediately upstream of the dam. The penstock withdrawal zone is fixed at an elevation of 3470 ft amsl. Density is primarily determined by water temperature and dissolved mineral content, increasing with lower water temperatures and higher conductivity. Therefore, temperature and conductivity (a function of dissolved mineral content) of dam releases follow an inverse pattern to each other as the density of dam releases changes.

Release temperature increases as the reservoir warms through the summer months. Conductivity decreases as the water near the dam is influenced by the previous spring's runoff. With autumn and early winter surface cooling, the epilimnion of the reservoir mixes to greater depths, deepening the thermocline, and warming the water near the thermocline. With the deepening thermocline, the epilimnion begins to influence the penstock withdrawal zone, dominating releases by the end of the year. The cooling epilimnetic water is still warmer than deeper waters of the reservoir and releases reach their maximum temperature at this time. Because the surface of the reservoir is more dilute due to influence of the previous season's snowmelt runoff, release conductivity reaches a minimum value at this time of epilimnetic withdrawal.

Once epilimnetic withdrawal has been established, releases cool rapidly with the continued cooling of the mixed surface layer of the reservoir. By late February or early March, winter cooling has reached a maximum, the conductivity of the epilimnion increases, and minimum temperatures and maximum conductivity levels appear in dam releases. An upwelling of the hypolimnion due to displacement influences of high-density winter inflows to the reservoir may also affect these patterns. Because of the proximity of the zone of maximum stratification to the penstock level, storms on Lake Powell can cause significant temporary shifts in release water quality during this period due to oscillations of stratification within the reservoir caused by the weather disturbance.

With spring surface warming, the reservoir begins to stratify, isolating the penstock withdrawal zone from surface processes and terminating epilimnetic withdrawal. Through the upcoming summer months release temperature gradually increases and conductivity decreases.

Glen Canyon Dam release temperature has varied in the last decade between 7 and 12 deg C. Specific conductance levels have ranged between 600 and 1000 µS (390 to 650 mg/L TDS) and typically fluctuate by around 200 µS (130 mg/L TDS) on an annual basic. During the middle 1990s there was a decreasing trend in salinity of dam releases, corresponding to above average inflows from the Upper Colorado River basin.

Recent Patterns

Water Year 2000 exhibited an unusual release pattern from Glen Canyon Dam. Because of decreasing inflow forecasts, a decision was made to carry out the Low Summer Steady Flow (LSSF) experiment, recommneded by the US Fish and Wildlife Service for the benefit of native fish. This began on March 25, 2000 when daily fluctuations ceased and steady releases of 8000 cfs were begun. Releases were increased to 17000 cfs on April 8, 2000 and held steady until May 3, 2000, when a 3-day high flow of 30000 cfs was released, near powerplant capacity. This was followed by another 17000 cfs flow period and 2 other brief periods at 19000 cfs and 13500 cfs. On June 1, 2000, 8000 cfs was released and remained steady at this level until September 5, 2000 when another 3-day powerplant capacity flow of 30000 cfs was released. Releases were then returned to 8000 cfs and, with the exception of a brief power emergency on September 18, 2000, remained steady at that level until October 1, 2000, after which normal fluctuations were resumed.

Warming patterns under the last year's steady flow experiment (Figure 3) are compared with those of 1997 (Figure 2), a year in which flows were steady for the most part but at levels above 20000 cfs for the majority of the year. Figure 4 shows a warming increase of over 0.5 deg C from June to September of 2000 over that of the same time period in 1997.

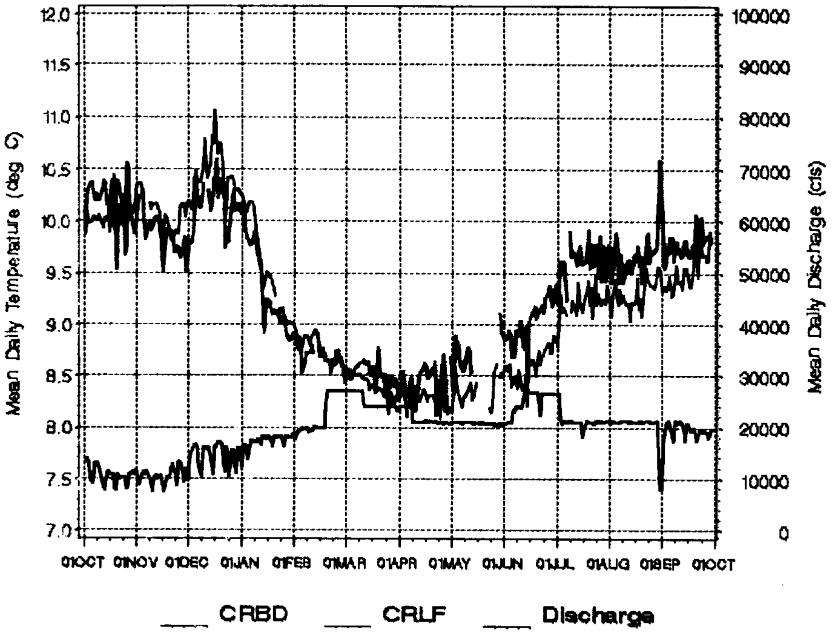

Figure 2 Water year 1997 warming in Glen Canyon

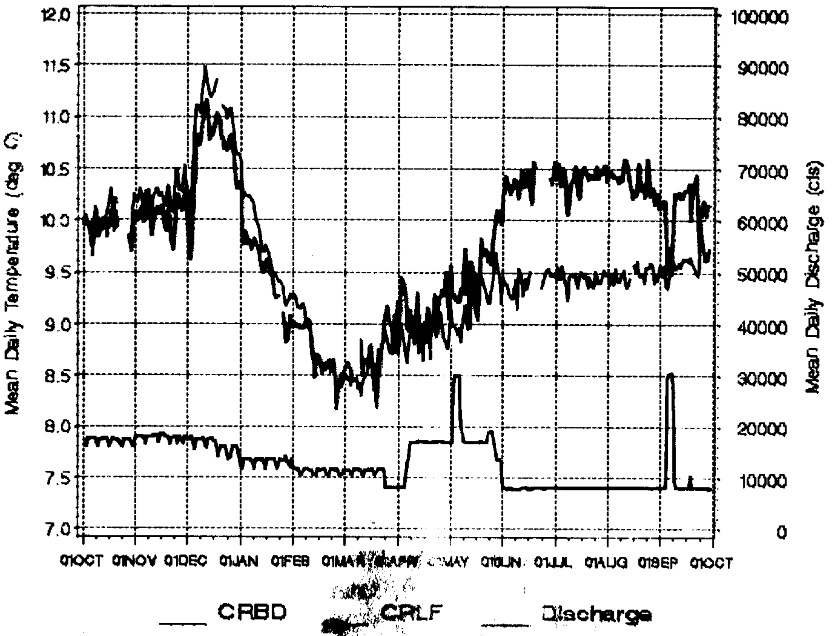

Figure 3 Water year 2000 warming in Glen Canyon

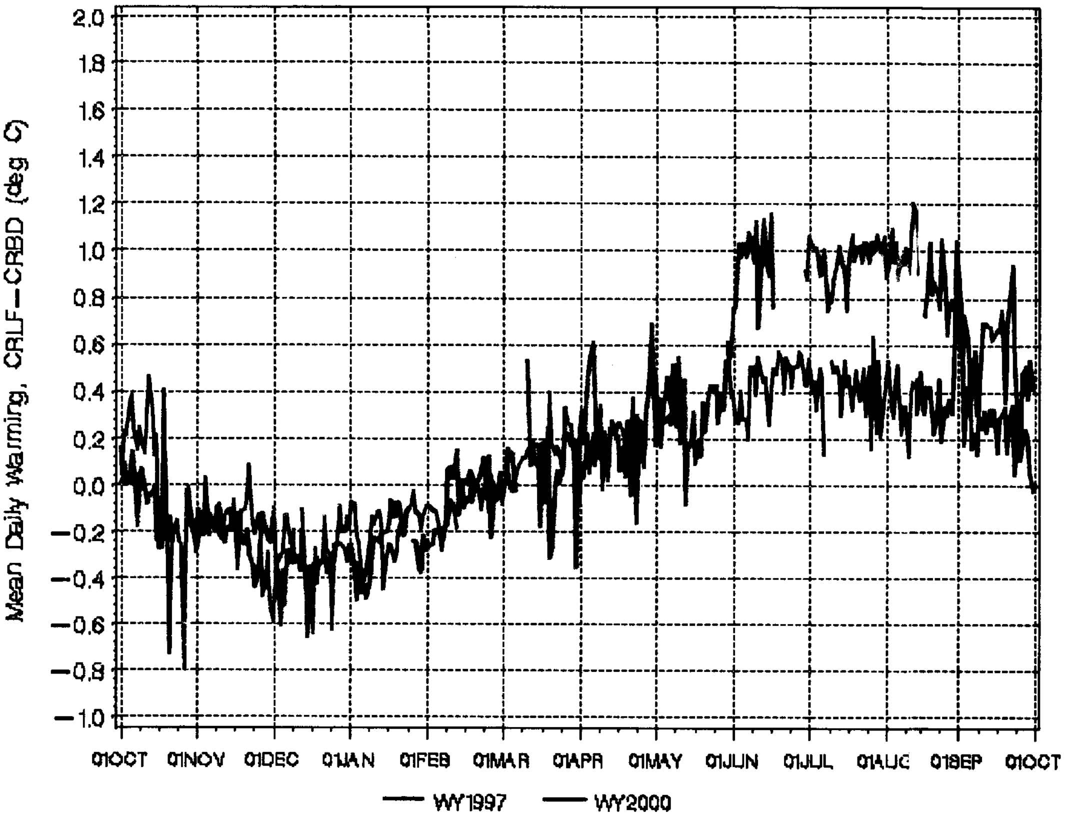

Figure 4 Comparison of warming at Lees Ferry between 1997 and 2000

Dissolved Oxygen and pH

Some quality assurance problems have been experienced with pH and dissolved oxygen measurements. Dissolved oxygen measurements can be inconsistent because of drifting debris collecting on the instruments, restricting circulation of fresh water around the probe, or the sensitivity of the probe to flow velocities. At low velocities, oxygen is consumed near the probe and measurements are artificially depressed. Due to the design of the Hydrolab pH reference junction a drift of approximately 0.20 pH units is experienced over a typical month-long deployment due to leaching of reference electrolyte. Attempts have been made to reduce these problems in the future. Verification and calibration adjustments still need to be made to these data before they can be interpreted. This information will be presented in a subsequent report. In general, recent dissolved oxygen levels below Glen Canyon Dam are between 5 and 6 mg/L. Patterns at Lees Ferry show daily fluctuations in pH and dissolved oxygen that reach a maximum in early summer, corresponding to primary productivity patterns in the Glen Canyon reach between the dam and Lees Ferry.

Downstream Thermal Monitoring

The purpose of this monitoring component is to describe downstream thermal conditions in the Colorado River and its tributaries and evaluate warming patterns that vary with geomorphic reach and release patterns from Glen Canyon Dam. Thermal conditions are of significant importance to fish, aquatic invertebrates, aquatic vegetation, and other components of the ecosystem. Evaluation of warming patterns is needed to describe baseline levels, the potential for instream warming of dam releases, and provide a basis on which to evaluate the operation of a temperature control device on Glen Canyon Dam.

Thermal monitoring is performed at several sites on the Colorado River in Grand Canyon and at major tributary mouths. Submersible monitors are placed unobtrusively at ten main-channel locations on the Colorado River spaced approximately 50 km apart, and ten tributary sites in Grand Canyon (Table 2). Instruments are downloaded and serviced on a quarterly basis, in conjunction with other scheduled research trips.

Monitoring of parameters other than temperature, takes place at USGS gaging stations in Grand Canyon. GCMRC directly supports data collection efforts at the Colorado River at Lees Ferry, Colorado River above the Little Colorado River and at the Colorado River near Grand Canyon gages as part of the Integrated Water Quality Program. These gages collect temperature, specific conductance and turbidity data. The Lees Ferry Gage and Diamond Creek Gage are also national water quality monitoring sites (NASQAN). These sites collect periodic dissolved organic carbon, dissolved oxygen, bacteria counts, nitrogen, and phosphorous data. While these latter efforts are not supported by the IWQP, these data are available to downstream researchers. Sampling for these latter constituents occurs six times per year, rather then on a continuous basis.

Methods

Measurements are currently being made with Onset Stowaway XTI32 –05+37° C temperature sensors housed in submersible cases with an external thermistor lead attached to the case. This submersible case is then deployed inside a short length of 3 1/2" steel pipe and connected with plastic-coated galvanized cable to a stable object near the river's shore. Deployments are made so the unit is fully submerged during the range of expected flows but not resting on the riverbed where it can become buried in sediment. Monitors are downloaded on a quarterly basis.

Table 1 Grand Canyon Thermal Monitoring Locations

Site Code	Site Name	Type	Side	River Mile
Mainstem Thermal Monitoring Locations				
R030	Fence Fault	Mainstem		30
R061	Colorado R. above Little Colorado R.	Mainstem	R	61
R065	Lava Canyon	Mainstem		65
R076	Nevills	Mainstem		76
R087	Colorado R. near Grand Canyon	Mainstem	L	87
R127	Colorado R. at RM 127	Mainstem	R	127
R166	Colorado R. above National Canyon	Mainstem	R	166
R194	Colorado R. at RM194	Mainstem	L	194
R226	Colorado R. above Diamond Ck.	Mainstem	L	226
R246	Colorado R. above Spencer Canyon	Mainstem	R	246
Tributary Thermal Monitoring Locations				
PA	Paria R. above Lees Ferry	Tributary		1
NA	Nankoweap Creek	Tributary		52
LD	Little Colorado R. at New Site (Upstream)	Tributary		61
LU	Little Colorado R. above Mouth	Tributary		61
BA	Bright Angel Creek	Tributary		89
SH	Shinumo Creek	Tributary		109
TA	Tapeats Creek	Tributary		134
KA	Kanab Creek	Tributary		143
HA	Havasu Creek	Tributary		157
SP	Spencer Creek	Tributary		246

Results

While thermal monitoring at various locations began in 1990, data from some stations was inconsistent and incomplete. Data from some of the primary long-term stations from 1994 to present are shown in Figure 5.

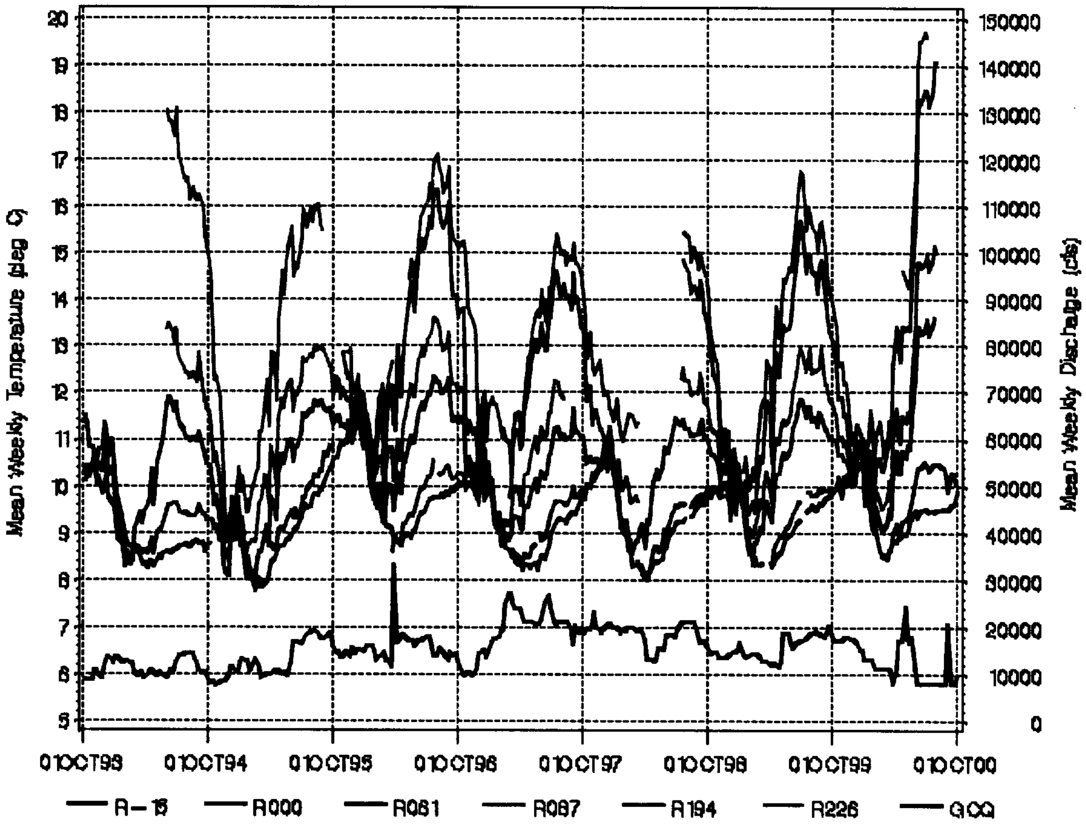

Figure 5 Mean weekly temperature in Grand Canyon. Discharge is shown in black.

Figure 5 shows dramatic warming in Grand Canyon in WY 2000 due to the steady 8000 cfs flows that were released for much of the summer. Figure 6 shows WY 2000 data in greater detail. This figure shows a large increase in temperature at downstream stations when releases reached 8000 cfs on June 1, 2000. By the middle of June 2000, warming above dam releaes at Diamond Creek of 10.0 deg C (0.026 deg C/km) was recorded with an average flow level of 8000 cfs. This translates to an average distance of 39 km for each degree C of warming (38.8 km/deg C), by dividing the distance from Diamond Creek (388 km) by the amount of warming. (Data collected since July 2000 has not yet been retrieved and will be added to this report when available.)

By comparison, Figure 7 displays warming patterns during WY 1997, when average discharge during the middle of June 1997 was 26000 cfs and 4.9 deg C (0.0127 deg C/km) of warming at Diamond Creek was achieved, about 50% lower than WY 2000 rates. This corresponds to an average distance of 79 km for each degree C of warming

(79 km/deg C). A comparison of mid-June warming rates for various stations during the past seven years is shown in Table 2.

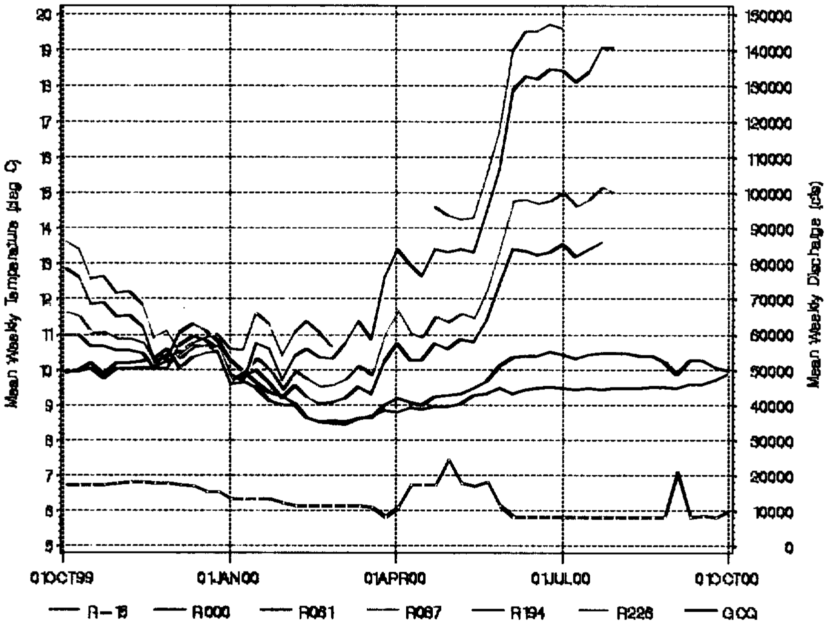

Figure 6 Grand Canyon warming patterns - WY 2000

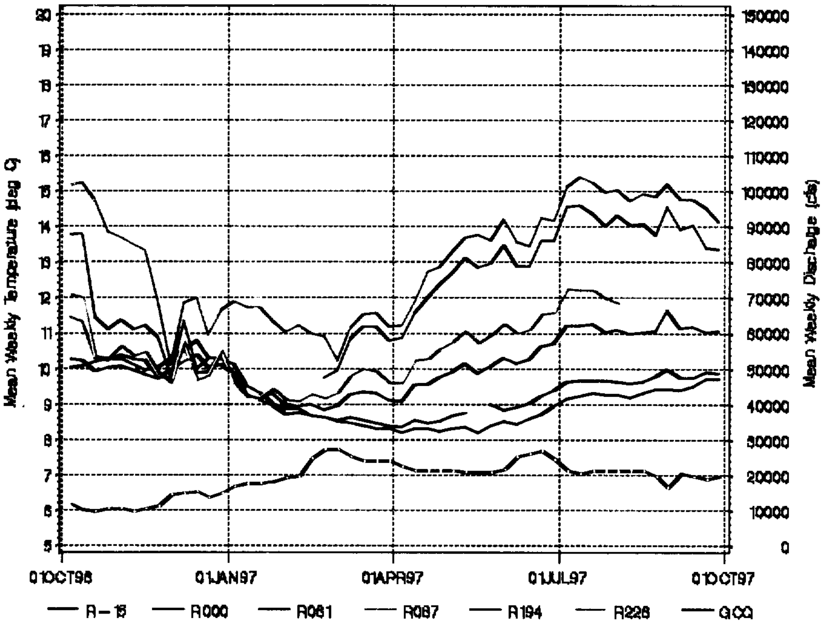

Figure 7 Grand Canyon warming patterns - WY 1997

Table 2. Mid-June warming in Grand Canyon (deg ΔT represents warming above CRBD)

Week beginning	CRBD	CRLF		R061		R087		R226		Discharge (cfs)
	T	T	ΔT	T	ΔT	T	ΔT	T	ΔT	
12JUN94	8.5	9.6	1.06	11.8	3.30	13.4	4.86	17.8	9.27	10631
18JUN95	9.1	9.3	0.20	10.8	1.70	12.0	2.84	14.6	5.51	16956
16JUN96	9.4	9.9	0.52	11.8	2.33	12.9	3.51	15.9	6.42	17189
15JUN97	8.6	9.0	0.44	10.3	1.70	11.1	2.51	13.5	4.38	26111
14JUN98	9.0	9.4	0.32	11.1	2.00	.	.	.	.	18456
13JUN99	9.2	9.6	0.37	11.4	2.26	12.4	3.22	16.0	6.77	16599
18JUN00	9.5	10.4	0.93	13.3	3.79	14.7	5.23	19.5	10.03	8008

A regression of mid-June Diamond Creek warming rates with discharge levels (Table 2) is shown in Figure 8. The number of kilometers needed for an increase of 1 deg C ranges from 39 at 8000 cfs to 79 at 26000 cfs. Korn and Vernieu (1998) have previously estimated warming rates at 48 km/deg C, using an average warming of 8.1 deg C at Diamond Creek during the month of June. Ferrari (1987) reported a model prediction of 118 km/deg C, based on 6 deg F of warming in 241 miles. Miller (1998) 57.5 km/deg C for June 1991 based on a regression of all Grand Canyon temperatures from that period. None of these estimates have included the effect of discharge levels on warming rates.

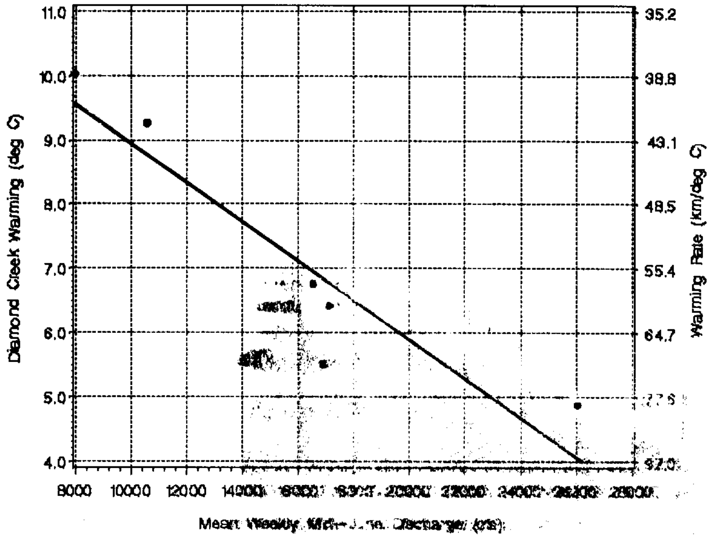

Figure 8 Warming at various discharge levels, WY 1994 to WY 2000

Intermediate Stations

Most information reported here has been from the longer-term consistently operating thermal monitoring stations. Other stations (Table 1) are in operation but have been excluded from this analysis due to insufficient or incomplete period of record. Some problems, such as exposure to air, burial in sediment, loss, and malfunctioning instruments have been experienced, resulting in incomplete records at some locations. Other locations have been added recently and have been in operation for a short time.

These stations provide important information on warming patterns within specific reaches of Grand Canyon. For example, Figure 9 shows mean daily temperatures during the period from June 1, 2000 to August 1, 2000 at four locations from just above the Little Colorado River at Mile 61 to the Grand Canyon gage near Phantom Ranch at Mile 87. The stations at Mile 65 and Mile 77 show that substantial warming occurs Mile 65, within the first four miles of the Little Colorado River, followed by a similar amount in the next eight miles at Mile 77. The remaining 10 mile reach to Mile 87 shows very little warming. The upper station is no doubt influenced by warm discharge from the Little Colorado River, as evidenced by a small discharge event during the first week. However, the fact that the stations at Mile 65 and Mile 77 show most of the warming in that reach is most likely due to the openness of that reach below Marble Canyon and its north-south aspect, contrasted to the reach from Mile 77 to Mile 88, which is in the beginning of the Inner Granite Gorge.

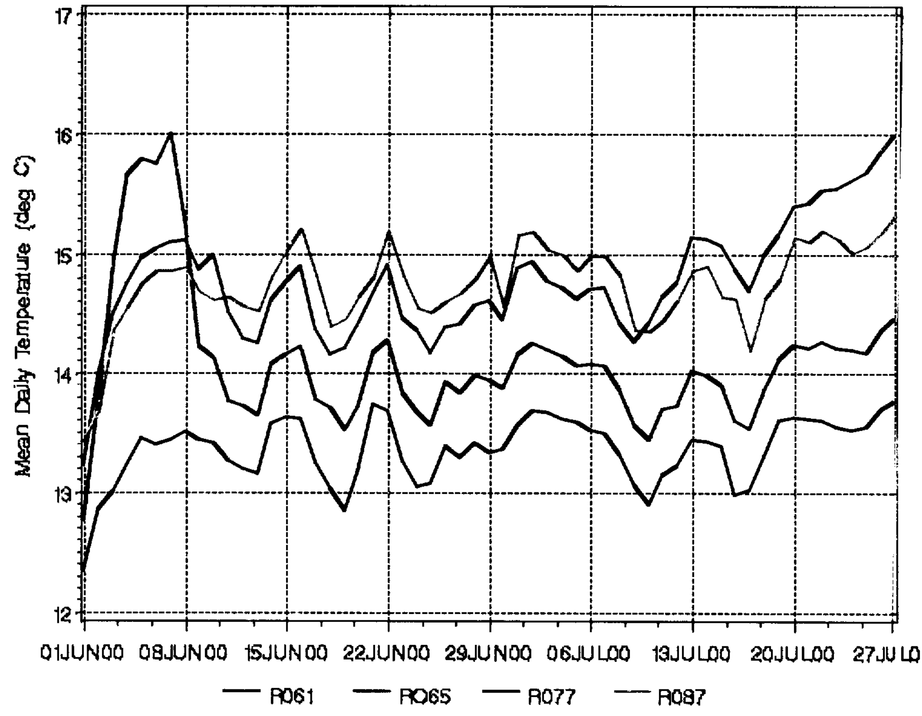

Figure 9 Warming at intermediate locations, LCR to Grand Canyon

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