Mainstem and Tributary Temperature Monitoring in Grand Canyon, AZ

By

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Prepared for the Grand Canyon Montioring and Research ~~Station~~ Center

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Aknowledgements

This report was prepared for the Grand Canyon Monitoring and Research Center to summarize monitoring efforts important to native and endangered fish in Grand Canyon. Mike Yard and Allen Haden were instrumental in the program design and implementation. We aknowledge the USGS for invaluable discharge and water temperature data. The Glen Canyon Environmental Studies provided logistical and administrative support.

ABSTRACT

The Grand Canyon Monitoring and Research Center (formerly GCES) has been monitoring mainstem water temperature of the Colorado river through Grand Canyon and in key tributaries in Grand Canyon since October 1991. The data are used by multiple agencies and institutions including Arizona Game and Fish, Northern Arizona University, Arizona State University and the U.S. Fish and Wildlife Service to quantify and evaluate thermal characteristics of endangered fish habitat. Furthermore, it is essential data for development of an in stream warming model in order to evaluate the feasibility of a selective withdrawal system on Glen Canyon Dam. These data undergo a stringent quality assurance review and are then entered into the GCMRC water quality database. All data is geo-referenced to be integrated with existing data in the GCMRC GIS database. Evaluation of thermal conditions in both the tributaries and the mainstem is important in defining critical habitat for threatened and endangered native fish and in making informed adaptive management decisions based on the aquatic resources responses to dam operations.

IDENTIFICATION OF RESEARCHERS

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William Vernieu, GCMRC

OBJECTIVE

The GCMRC water temperature monitoring program is designed to quantify temperature in all major tributaries utilized by threatened and endangered fish. In addition we measure in stream temperature warming in the mainstem throughout Grand Canyon. The mainstem monitors are placed approximately 50 km apart in both wide and narrow reaches of the canyon to better characterize the warming pattern.

INTRODUCTION

The native fish of Grand Canyon evolved under a seasonally varying temperature regime in the Colorado River. Since the closure of Glen Canyon Dam (GCD) in 1963, that system has been drastically altered throughout the canyon with a mean reduction in water temperature at Lees Ferry (14.5 miles downstream from GCD) from 14 °C to 9 °C. In addition, there was an overall reduction in seasonal variability. Water temperature at Lees ferry prior to filling of Lake Powell varied from 0 °C to 30 °C. After initial filling of Lake Powell it ranged between 7 °C and 15 °C (FIG 1).

Figure 1: Colorado river temperature at Lees Ferry pre and post Glen Canyon Dam.

Since the mainstem river has cooled due to the hypolimnetic releases from Glen Canyon Dam, tributary mouths and backwaters have become increasingly important for native fish habitat. These fish rely on the seasonally warm temperatures which more closely approach the preferred temperatures for spawning, and rearing of larval and juvenile fish (Maddux, et al., 1987; Valdez, et al., 1992). Humpback chub (Gila cypha), flannel mouth sucker (Catostomus latpinnis), bluehead sucker (Catostomus

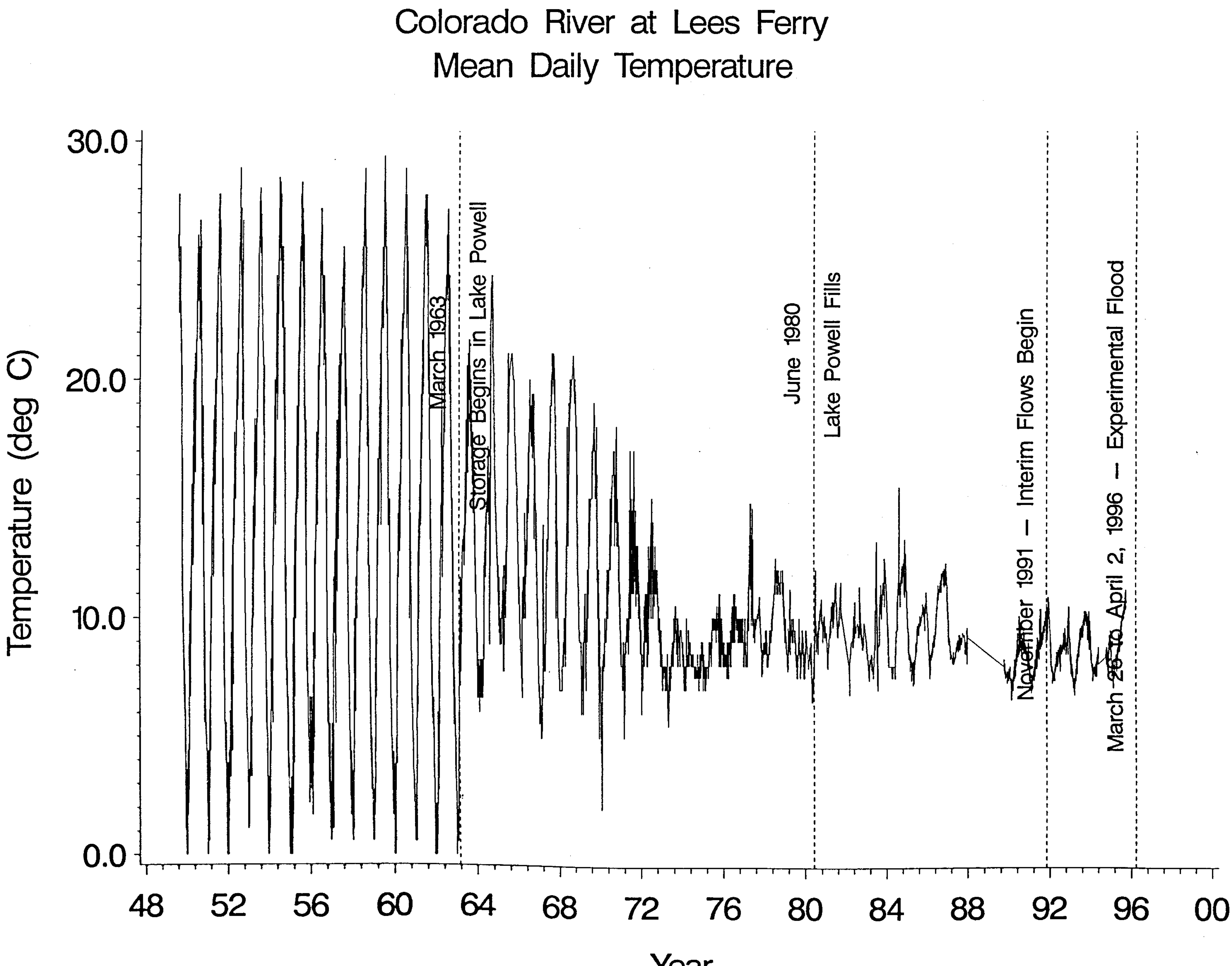

Figure 1. Colorado River temperatures at Lees Ferry. The closure of Glen Dam occurred in August, 1962.

discobulus), and speckled dace (Rhinichthys osculus), require between 16 and 22 in order to spawn (Lechleitner, 1992). In fact, all documented spawning by native fishes from 1985 to 1992 has occurred in warm tributaries (Valdez, 1992). Temperatures in Grand Canyon tributaries typically warm to spawning temperature from early March (e.g., Nankoweap Creek) to May (e.g., Shinumo Creek). Although spawning cues for native fishes in Grand Canyon are not entirely known, it is thought to be largely dependent on achieving an optimal temperature for ovulation. Photoperiod, hydrologic cycle and imprinting also may have an influence in staging and gamete development (Goman, in press).

The GCMRC tributary temperature monitoring program is designed to help define thermal characteristics (daily variation, seasonal variation, year to year variability) of habitats presently being used for spawning and rearing of larval fish.

A biological opinion issued by the Secretary of the Interior in 1978, produced seven conservation measures designed to recover the endangered humpback chub population in Grand Canyon. Conservation Measure 7 identifies the need to establish a second mainstem spawning population in Grand Canyon in case of a catastrophic loss of the Little Colorado River spawning population. To address this need, the Bureau of Reclamation has proposed retrofitting Glen Canyon Dam with a selective withdrawal structure to draw seasonally warmer water off the epilimnion of Lake Powell. To evaluate the effectiveness of this, a temperature model of Lake Powell to predict potential release temperatures and an in stream warming model in Grand Canyon is being developed by the Denver Technical Center and Bureau of Reclamation. Knowledge of longitudinal temperature patterns in the Colorado river mainstem throughout Grand Canyon is required to provide critical data for the development of the warming model and to evaluate the modeling results. The mainstem monitoring program is designed to answer the question which addresses whether adequate warming can occur in the system to provide optimal spawning temperature in a critical reach at the right time of year?

History of Temperature Monitoring in Grand Canyon

The USGS has been monitoring water temperature at Lees Ferry since 1949. At first it was a USGS hydrologic technician going down to the water's edge at approximately the same time of day to hold a thermometer in the water and record the results. Today sophisticated equipment transfers the data, collected at 30 minute intervals, via satellite to the ADAPS system accessible through the internet. These data were used to compile Figure 1. Historical data was also collected near Phantom Ranch (1940-1976, 1983-1987, 1990-1993). During the Phase II Glen Canyon Environmental studies (1990-1995) the USGS was contracted to monitor water temperature at several locations in Grand Canyon in the mainstem Colorado as well as several tributaries. This data is published in the USGS Open-File Report 97-250 (1997).

Glen Canyon Environmental Studies has been monitoring water temperature as described in this report since 1991. Sites below Diamond Creek have been discontinued as of July, 1999.

METHODS

STUDY AREA

The GCMRC water temperature monitoring program is designed to quantify temperature in all major tributaries utilized by threatened and endangered fish (Fig 2, Table 1). Tributary sites were chosen in response to the needs of fishery and aquatic foodbase researchers. Thermistors are also placed approximately every 50 kilometers through the mainstem corridor in the Colorado river from Glen Canyon Dam to Lake Mead. Mainstem locations were determined based on historical USGS data collection sites. Additional sites (RM 127 and RM 194) were added to maintain the distance between sensors at approximately 50 kilometers. Thermistors are placed along the margin of the river at an average depth of one meter in the main channel of the river avoiding any eddies, tributary embayments or backwaters that may not mix sufficiently with the mainstem water. Due to the turbulance and frequent rapids in this system it is assumed that the river is well mixed. Table 1 summarizes the location of thermal sampling sites and identifies the collection period for each station. All sites are geographically located and referenced within the GCMRC Geographic Information System (GIS).

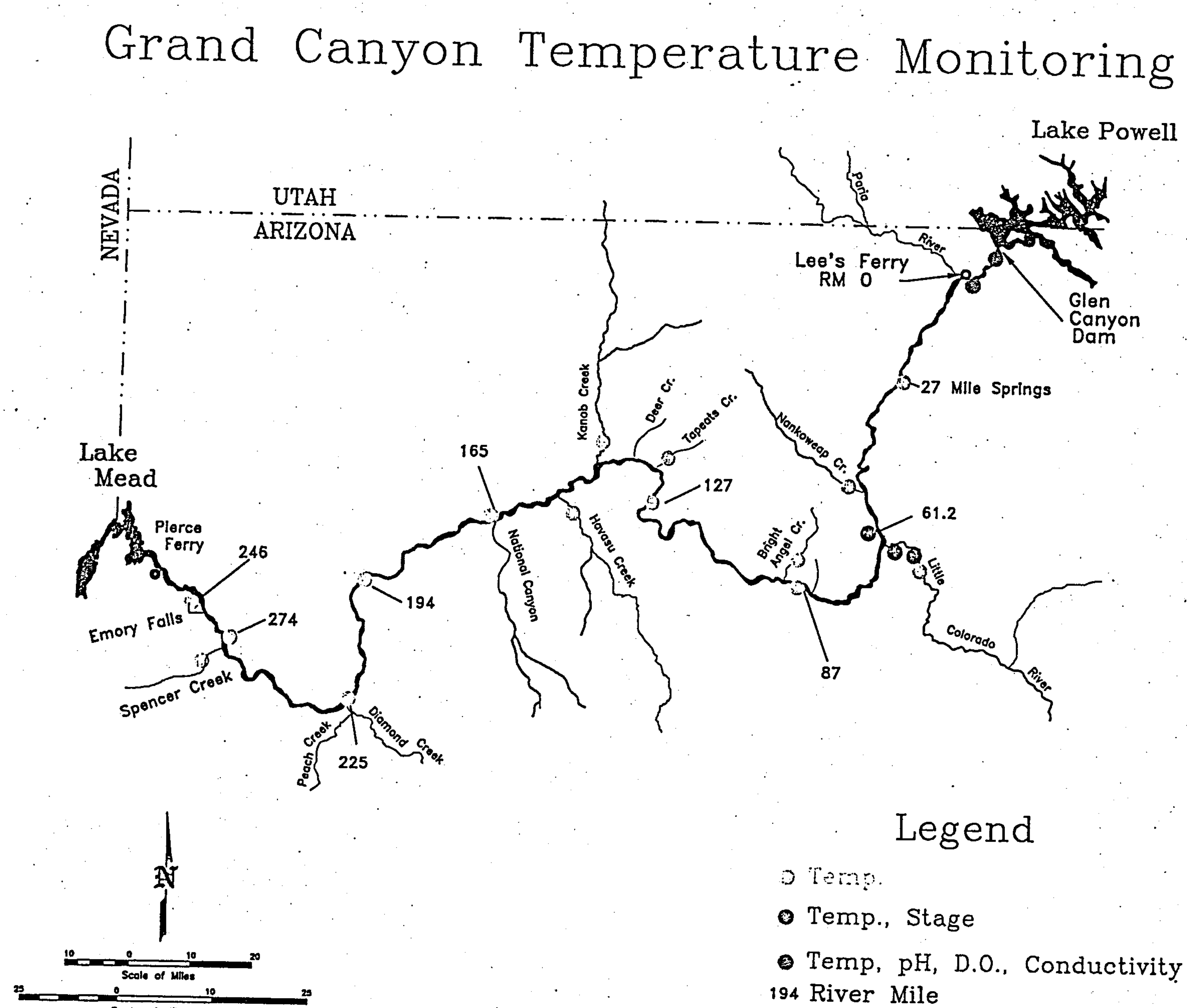

Figure 2. Location map of thermal sampling sites in Grand Canyon

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Table 1. GCMRC thermal sampling locations and period of record

Tributary(tb) or Mainstem(ms) River Kilometer	Location (Lat/Long)	Location Description	Start of Period of Record
Below GC Dam (ms,-23.2L)	36°55'18" 111°28'58"	mainstem,Off dock below GC dam	Hydrolab
Paria River (tb, 0.32R)	36°52'20" 111°35'38"	near USGS gage	
Lees Ferry (ms, 0L)	36°51'53" 111°35'15"	mainstem, near USGS gage	Hydrolab
Nankoweap Ck (tb, 84.6R)	36°18'15" 111°52'02"	500 m's from confluence	16 OCT 90
Above LCR confluence (ms,99.1R)	36°12'08" 111°48'59"	mainstem, above LCR, @ USGS gage	
LCR (tb,99.2)	36°11'25" 111°47'20"	approximately 2 km's upstream	24 MAR 93
Near Phantom Ranch (ms,142.0L)	36°06'05" 112°05'08"	mainstem, @ USGS gage site above Kaibab bridge	RTM2000
Bright Angel Ck (tb,142.1)	36°06'26" 112°05'44"	20 m downstream from first bridge	28 OCT 95
Shinumo Ck (tb,176.1)	36°15'14" 112°24'11"	~ 0.5 km upstream from confluence	24 OCT 90
Middle Granite Gorge (ms,205.1R)	36°17'35" 112°29'50"	mainstem, 1 km above rapid at river mile 127	RTM2000
Tapeats Ck (tb,216.6)	36°22'30" 112°27'50"	200 m's upstream from confluence	
Kanab Ck (tb,232.3)	36°23'31" 112°37'49"	300 m's upstream from confluence	25 OCT 90
Havasu Ck (tb,254.2)	36°18'02" 112°45'24"	1 km upstream from confluence	24 JAN 92
Above National Cyn (ms,268.9R)	36°06'11"112° 05'44"	mainstem, USGS gage site above National Cyn	RTM2000
Lower Canyon (ms, 314.3L)	36°05'22" 113°15'25"	mainstem, upstream from 194 mile canyon	RTM2000
Above Diamond Ck (ms, 365R)	35°46'25" 113°21'46"	mainstem, USGS site above Diamond Creek	RTM2000
Spencer Ck (tb,398.5)	35°48'25" 113°38'40"	400 m upstream from confluence	09 APR 93

Instrumentation

Temperature monitors and loggers currently being used were chosen because of their ease of transport, ease of download, large storage capacity, low cost and low visual impact. Two different types of instruments are currently being used to record temperature data:

1. Ryan Instruments RTM2000 model temperature data collectors are used in most tributaries and in the mainstem. RTM2000 model temperature monitors have a storage capacity of 16,256 records (approximately 300 days at 30 - minute intervals). They have a temperature range of -32 °C to +70 °C and an accuracy of +/- 0.5 °C.

2. Onset StowAway loggers are being used in backwaters and special study areas as well as in tributaries with frequent occurrence of flash flooding. They have a storage capacity of 32,520 records (approximately 600 days at 30 - minute intervals). They have a temperature range of -39°C to +75 °C and an accuracy of +/- 0.5 °C.

Ryan Tempmentors and Onset StowAways are deployed in submersible waterproof cases. These monitors are placed inside of a steel mesh cage that provides protection against shock and acts as a weighted anchor. The cage is cabled off to a rock or tree and covered with river cobbles and rocks to hide it from view.

<u>Data Collection</u>

Temperature data are collected at 30 minute intervals. Temperature loggers are downloaded on a quarterly basis. This insures that data is not lost due to inadequate battery power or extreme hydrologic conditions and provides a reasonable schedule for maintenance, important given the harsh physical environment they are deployed in.

Information Transfer/ Data Archiving

The information collected under this project will be provided in graphical, tabular and digital formats to interested researchers, to the Bureau of Reclamation thermal modelers and published annually in a GCMRC technical report. In the future, the GCMRC water quality data will be stored and archived in the Oracle relational database which is linked to the GIS spatial database to be located at the Grand Canyon Monitoring and Research Center in Flagstaff, Arizona.

Additional deployment sites were selected as necessary to support backwater studies, thermal imagery studies and other special research projects.

DATA MANAGEMENT

Data loggers are downloaded in the field, then transferred to the GCMRC database in ASCII format. The raw data is preliminarily checked using the SAS program editor. Data is then transferred into SAS data sets and checked against field notes and for obvious outlying data points using SASGRAPH and FSVIEW. After checking to insure only quality data becomes part of the SAS database, the newly created datafile is appended to a master data set, while retaining the original subset. Data was compared to concurrent measurements performed by other agencies (i.e., USGS) and found to be comparable.

Statistical Analysis

Temperature data were analyzed using SAS611 software. A means procedure was used to generate daily means on instantaneous data sets. Univariate analysis was used to generate monthly statistics on tributary and mainstem data sets. A linear regression was performed to determine the relationship between flow and temperature. A paired t-test was used to compare USGS and GCMRC thermal data collected in the Little Colorado River. Tributary temperatures were analyzed by month to avoid making arbitrary decisions about what defines a season.

RESULTS

Comparison of USGS and GCMRC data

Results from a paired t-test, matching USGS and GCMRC data collected concurrently in the Little Colorado river found a significant difference in the two data sets (t=-16.683), however, the diffference is mininmal (mean difference = 0.155) which is within the accuracy of our instruments (+/- 0.2).

Tributaries:

Seasonal Variation:

Figures 3-9 show the period of record for each tributary. Tributary temperatures in Grand Canyon demonstrate quite different seasonal fluctuations as would be expected, considering the different drainage areas contributing to each tributary. Tributaries with large drainage areas like Nankoweap Creek and Kanab Creek have the largest seasonal warming while tributaries which are spring fed with a smaller drainage area (ie. Tapeats Creek) have a much smaller seasonal variation. For example, in Nankoweap Creek the average monthly temperature ranges from 3.7°C in November to 23.3 °C in August. In contrast Tapeats Creek temperature varies little throughout the year (10.1°C in December to 14.6°C in August). In all tributaries maximum warming occurs in July or August (Table 2). The following table and graphs depict seasonal variation by month with maximum mean and minimum water temperature shown.

Table 2: Mean Monthly Water Temperature in Grand Canyon Tributaries

	January		February		March		April		May		June	
	Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD
Nankoweap	4.4	2.5	7.9	2.8	12.1	3.8	14.4	4.1	17.6	4.3	20.6	4.5
Little Colorado R	10.5	3.5	12.9	2.6	13.9	2.4	16.1	2.6	19.5	1.7	21.0	1.9
Bright Angel Creek	6.7	1.2	9.2	1.9	10.7	2.2	12.5	2.5	-----	-----	-----	-----
Shinumo Creek	6.5	1.5	8.9	1.7	11.5	1.9	12.5	2.0	13.1	2.2	18.4	3.1
Tapeats Creek	10.2	0.8	10.9	0.9	11.6	0.9	12.1	0.9	12.5	0.9	13.6	1.4
Kanab Creek	6.6	1.8	8.7	1.9	11.5	1.8	14.5	2.8	18.6	3.0	22.6	3.2
Havasu Creek	13.2	1.0	13.9	1.3	15.3	0.9	17.0	1.4	18.9	1.6	18.8	2.2
Spencer Creek	11.6	1.3	13.7	2.0	16.5	2.5	18.7	3.0	20.1	2.4	22.9	2.9

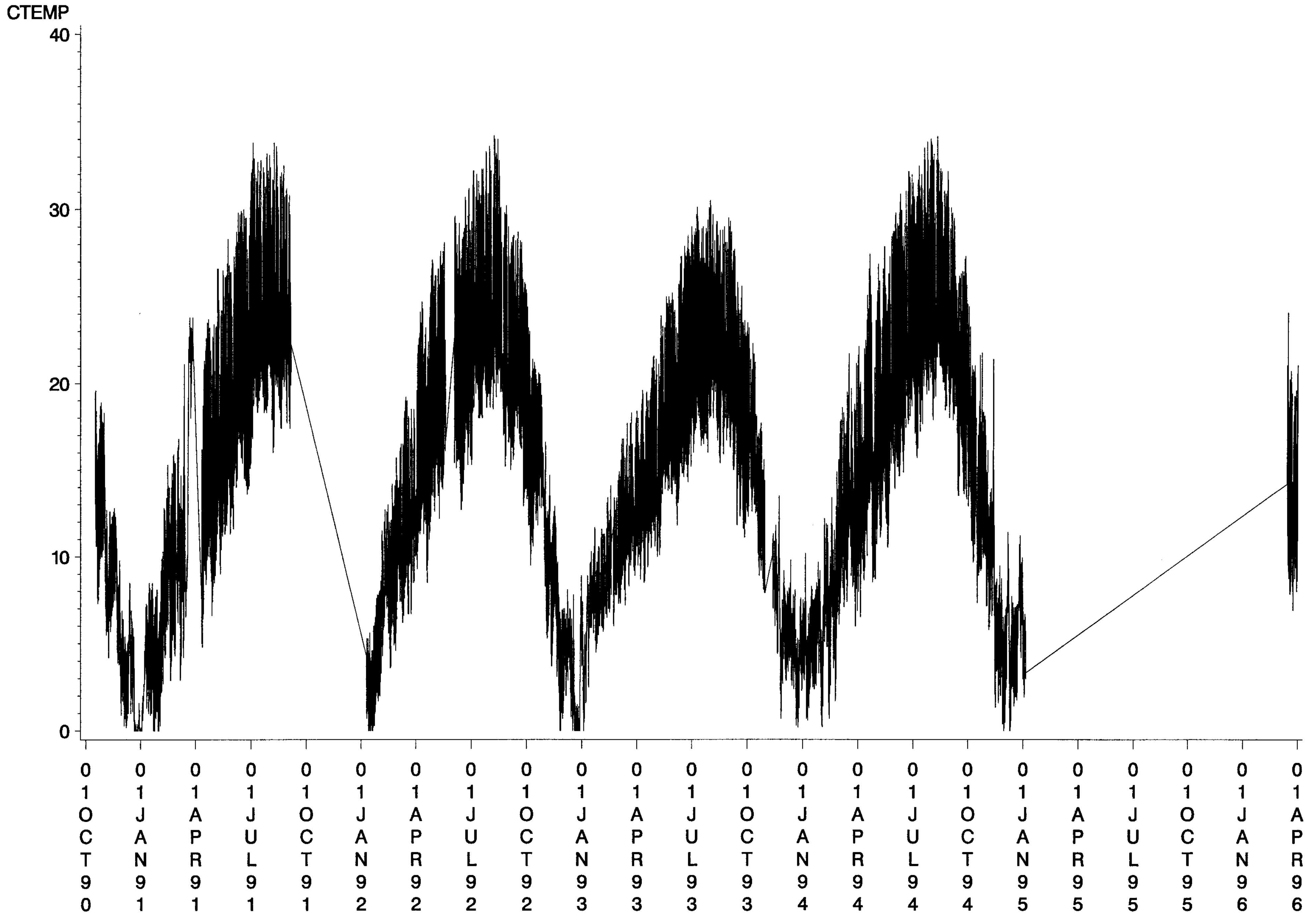
	July		August		September		October		November		December	
	Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD
Nankoweap	23.2	4.1	23.3	3.9	20.1	3.9	14.5	3.4	7.3	3.1	3.7	2.5
Little Colorado R	22.7	1.4	22.7	1.5	20.5	1.6	18.1	1.3	15.0	1.5	12.2	2.7
Bright Angel Creek	-----	-----	-----	-----	-----	-----	13.6	0.9	11.2	1.5	7.9	1.8
Shinumo Creek	21.5	2.3	22.0	2.1	18.7	2.2	14.0	1.9	9.2	2.3	6.2	2.3
Tapeats Creek	14.4	1.3	14.6	1.2	13.7	1.1	12.5	0.8	10.9	1.0	10.1	0.9
Kanab Creek	25.0	2.5	25.1	2.2	21.1	2.5	15.4	1.9	9.7	2.4	6.2	2.5
Havasu Creek	19.9	2.1	21.5	1.5	19.4	1.2	17.6	1.1	15.0	1.8	13.5	1.2
Spencer Creek	23.8	3.1	24.7	3.2	23.9	2.8	21.3	3.5	16.6	1.5	12.3	1.8

Table 3: Max and Min Monthly Water Temperature in Grand Canyon Tributaries

	January		February		March		April		May		June	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Nankoweap	11.7	0	15.9	0.2	24.1	2.9	27.4	4.8	28.8	8.5	32.2	11.6
Little Colorado R	16.0	1.6	18.2	7.1	20	7.9	23.7	8.4	24.8	14.1	26.3	16.2
Bright Angel Creek	9.7	3.5	13.1	3.5	16.1	4.6	19.8	8.0	*	*	*	*
Shinumo Creek	10.5	1.4	14.2	3.3	17.2	5.6	19.4	7.1	20.3	9.5	26.7	11.1
Tapeats Creek	12.2	8.0	13.7	8.0	14.7	8.5	15.1	9.4	15.6	11.1	17.6	11.3
Kanab Creek	11.4	0	13.6	2.8	16.5	6.9	24.9	8.2	9.2	29.5	32.8	14.8
Havasu Creek	16.0	10.2	17.5	10	18	12.9	21.2	13	15	23.6	23.6	13.4
Spencer Creek	15.9	9.5	19.9	8.8	24.8	11.9	27.3	13.3	30.4	16.2	30.6	17.3

	July		August		September		October		November		December	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Nankoweap	34.0	15.3	34.2	15.2	30.8	11.1	25.4	7.2	21.4	0	11.4	0.0
Little Colorado R	26.4	17.9	26.8	18.9	26.2	16.8	21.2	13.8	18.4	9.6	16.5	2.0
Bright Angel Creek	*	*	*	*	*	*	*	*	15.1	6.7	11.2	4.1
Shinumo Creek	27.6	16	27.7	17.1	24.6	12.9	19.4	9.3	16.0	4.1	12	0.0
Tapeats Creek	18.2	12.3	18.1	12.4	17.3	11.7	15.1	10.4	13.6	8.4	12.7	7.9
Kanab Creek	33.0	18.6	32	19	29.7	14.9	21.3	10.1	16.3	3.7	12.4	0.0
Havasu Creek	24.9	14.4	26	17.7	23.1	16.2	20.4	13.4	18.5	10.8	16.3	10.4
Spencer Creek	33.8	18.2	34.5	19	31.0	18.2	28.8	14.4	20.5	12.5	17.8	

GCMRC Temperature Data from Nankoweap Creek



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GCMRC Temperature Data from Little Colorado River

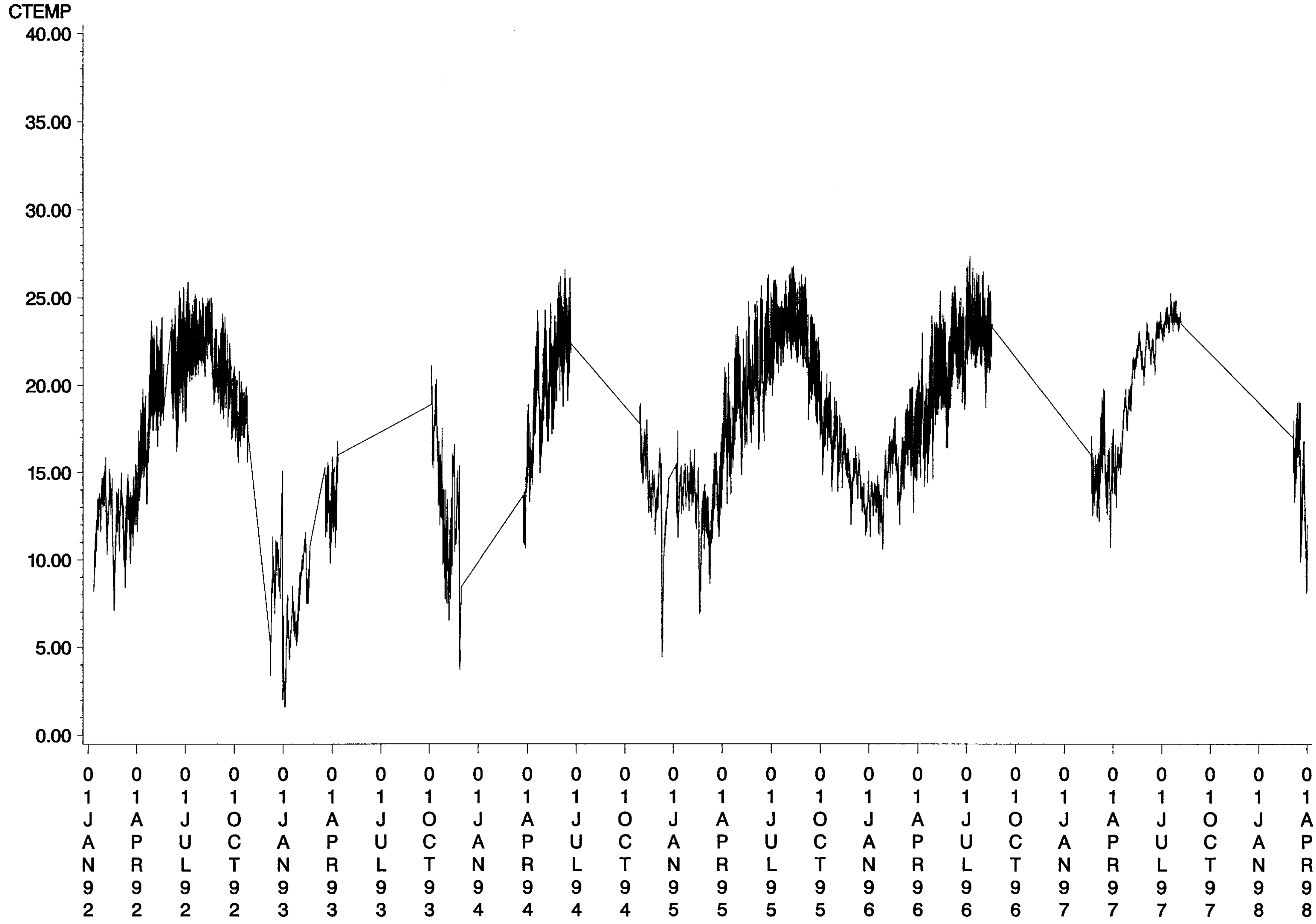

FIG4

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GCMRC Temperature Data from Bright Angel Creek

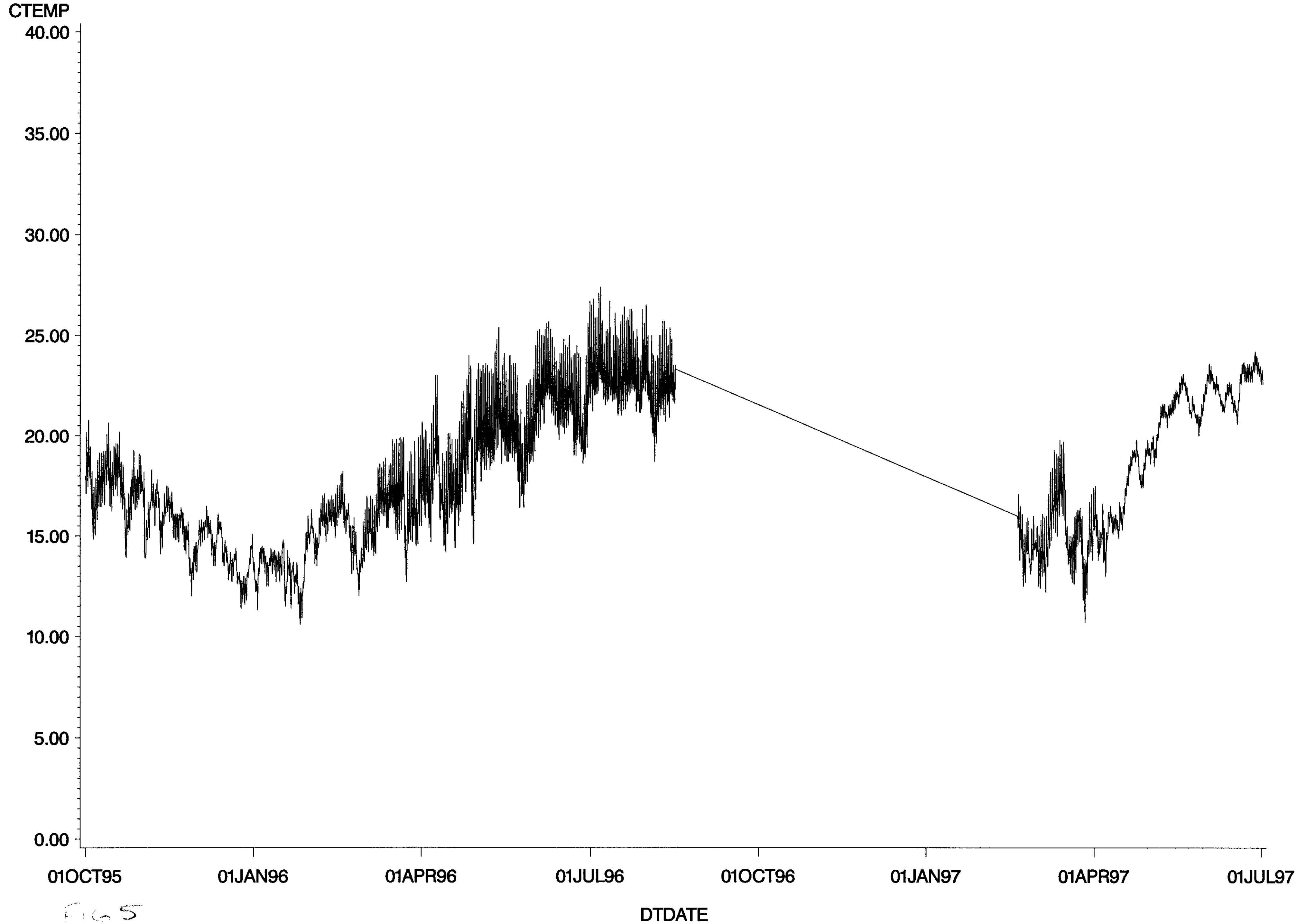


FIG 5

GCMRC Temperature Data from Shinumo Creek

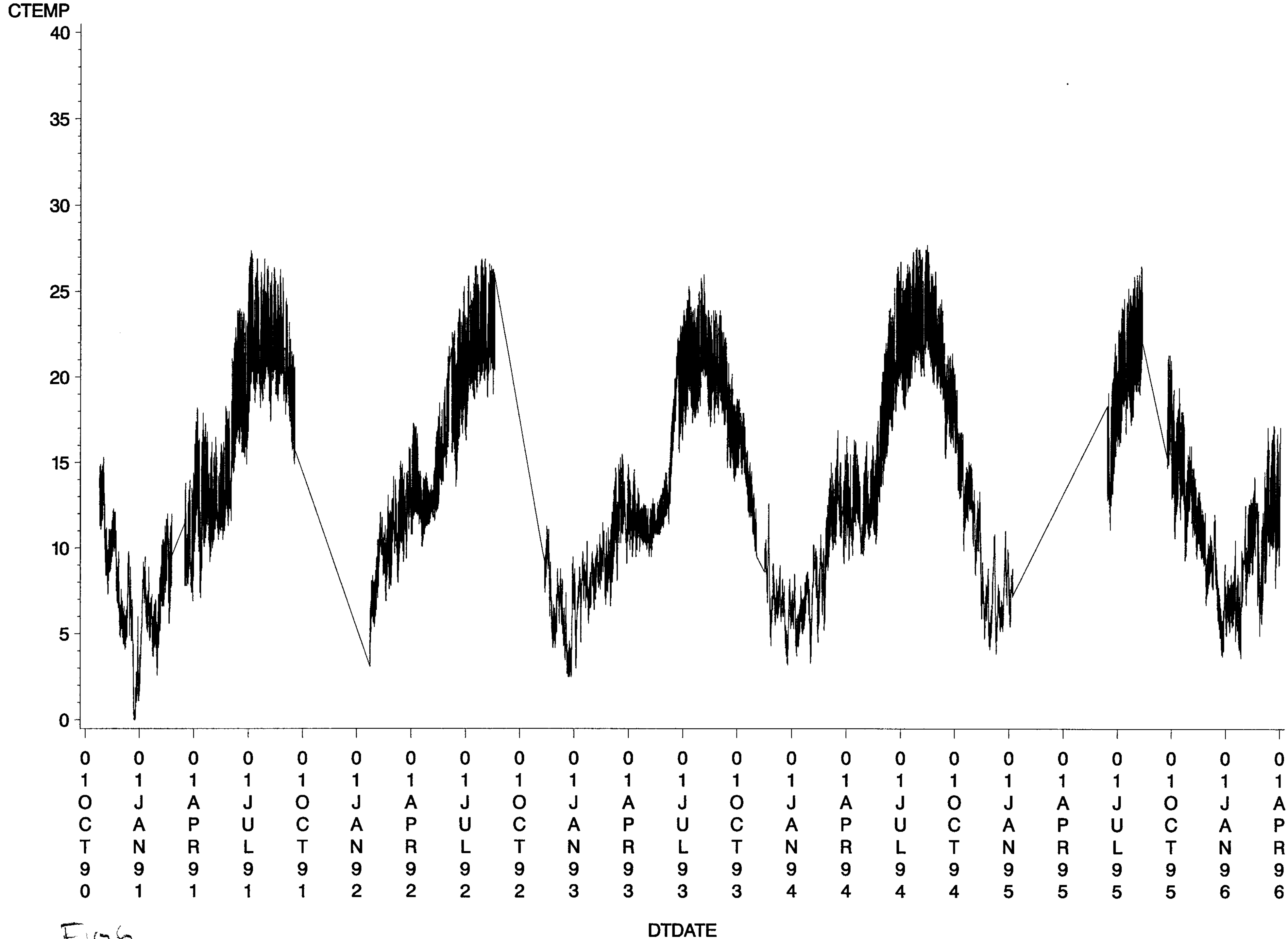


Fig6

GCMRC Temperature Data from Tapeats Creek

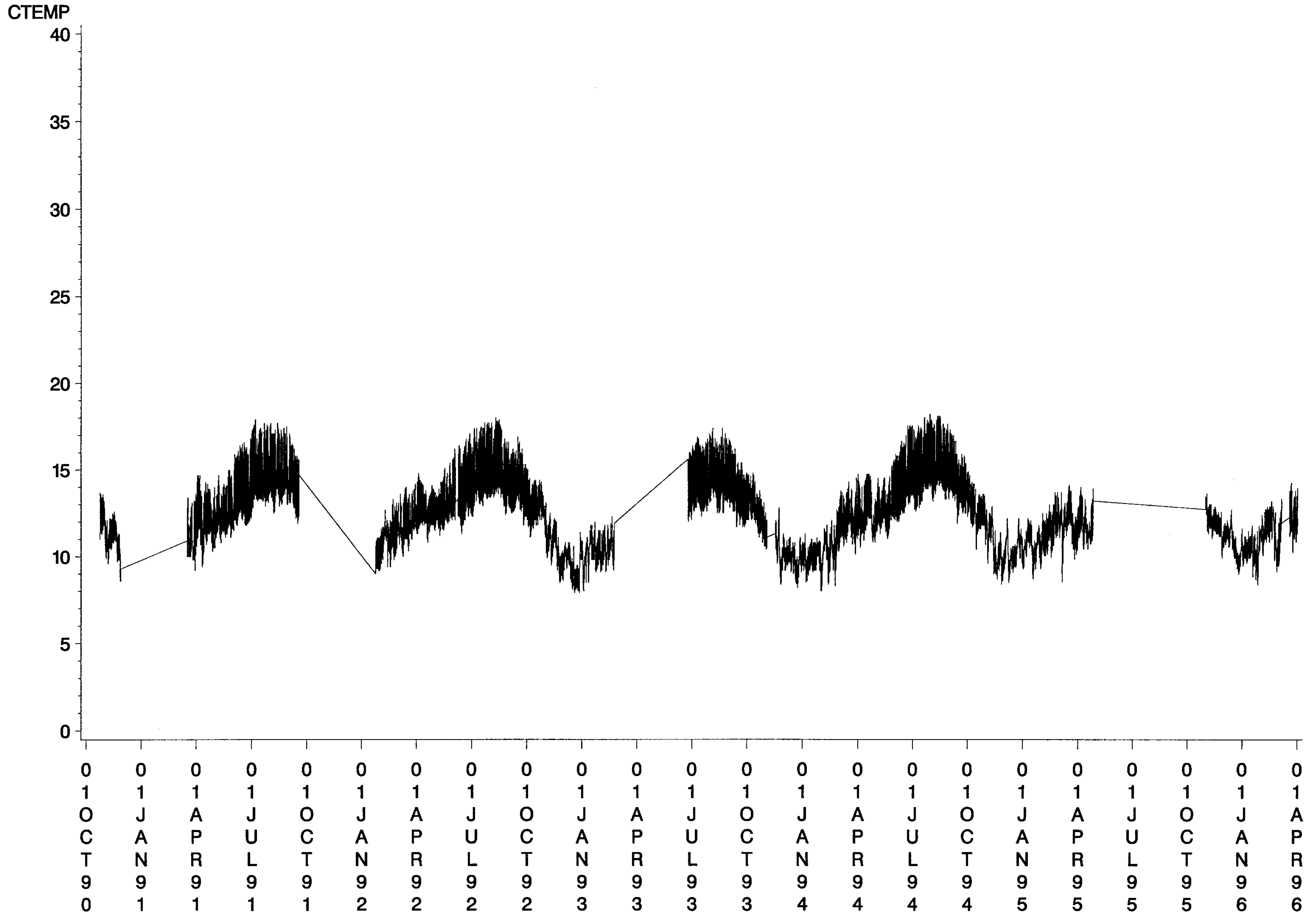


FIG 7

GCMRC Temperature Data from Kanab Creek

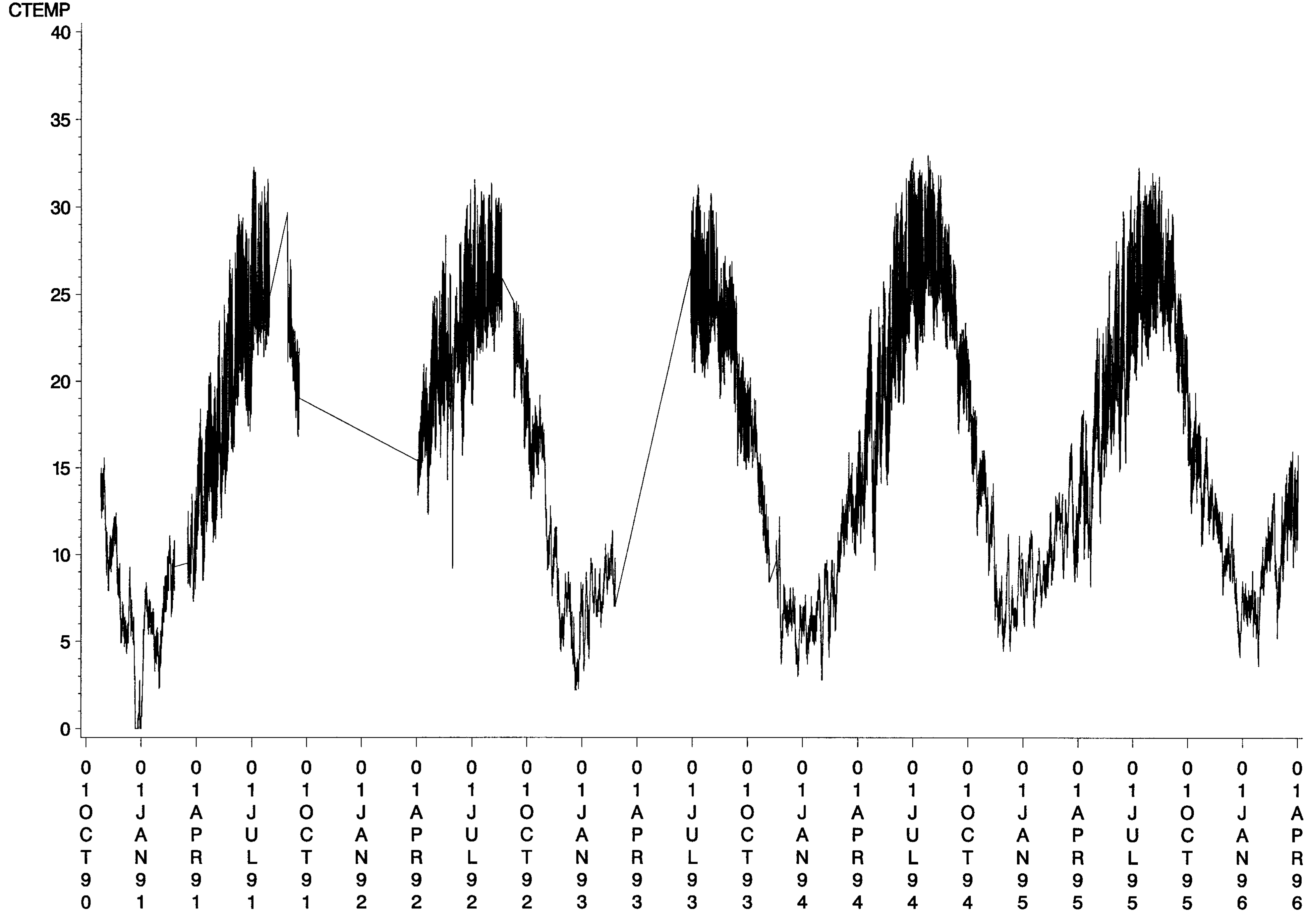
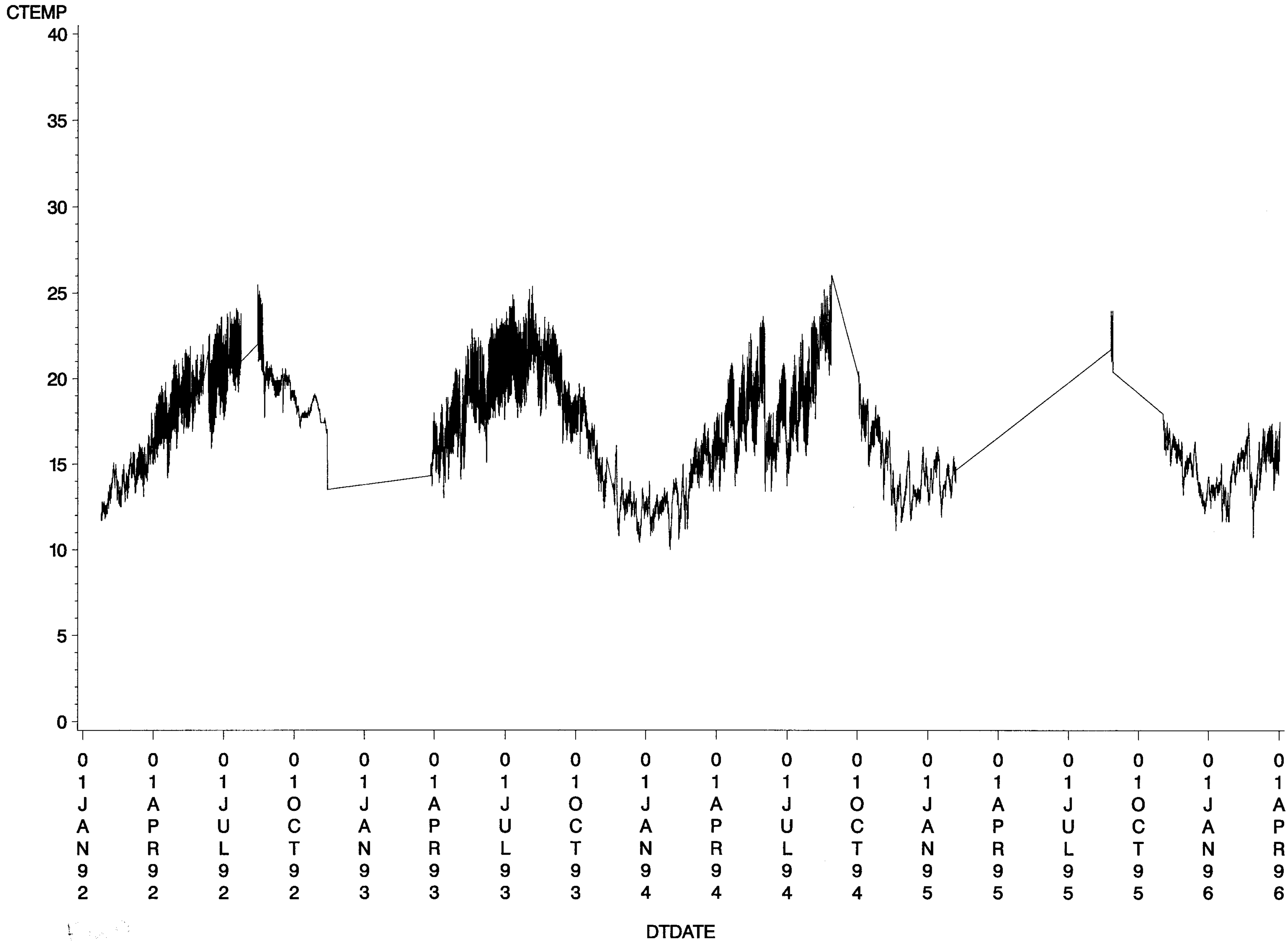


Fig 8

GCMRC Temperature Data from Havasu Creek



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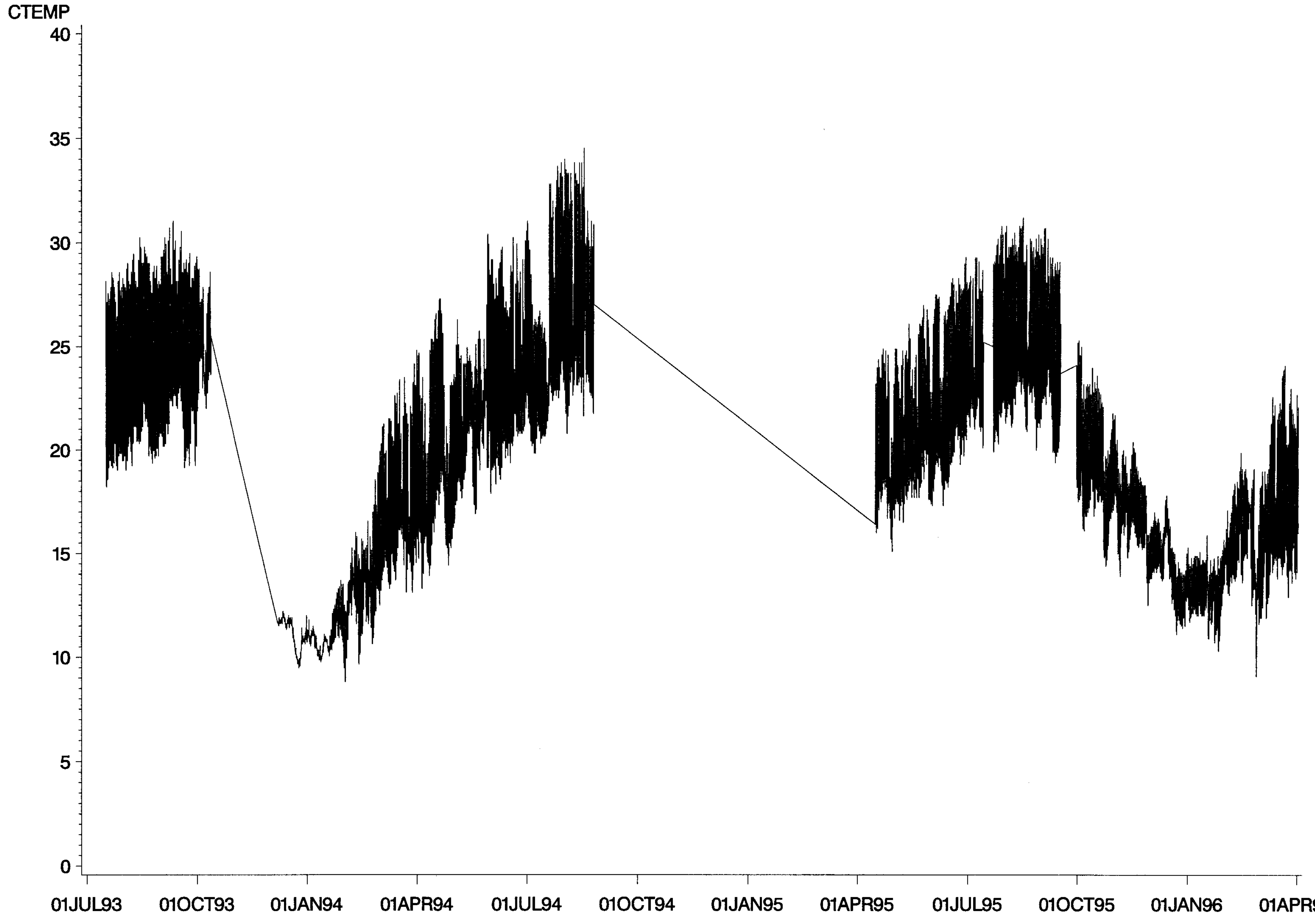
GCMRC Temperature Data from Spencer Creek



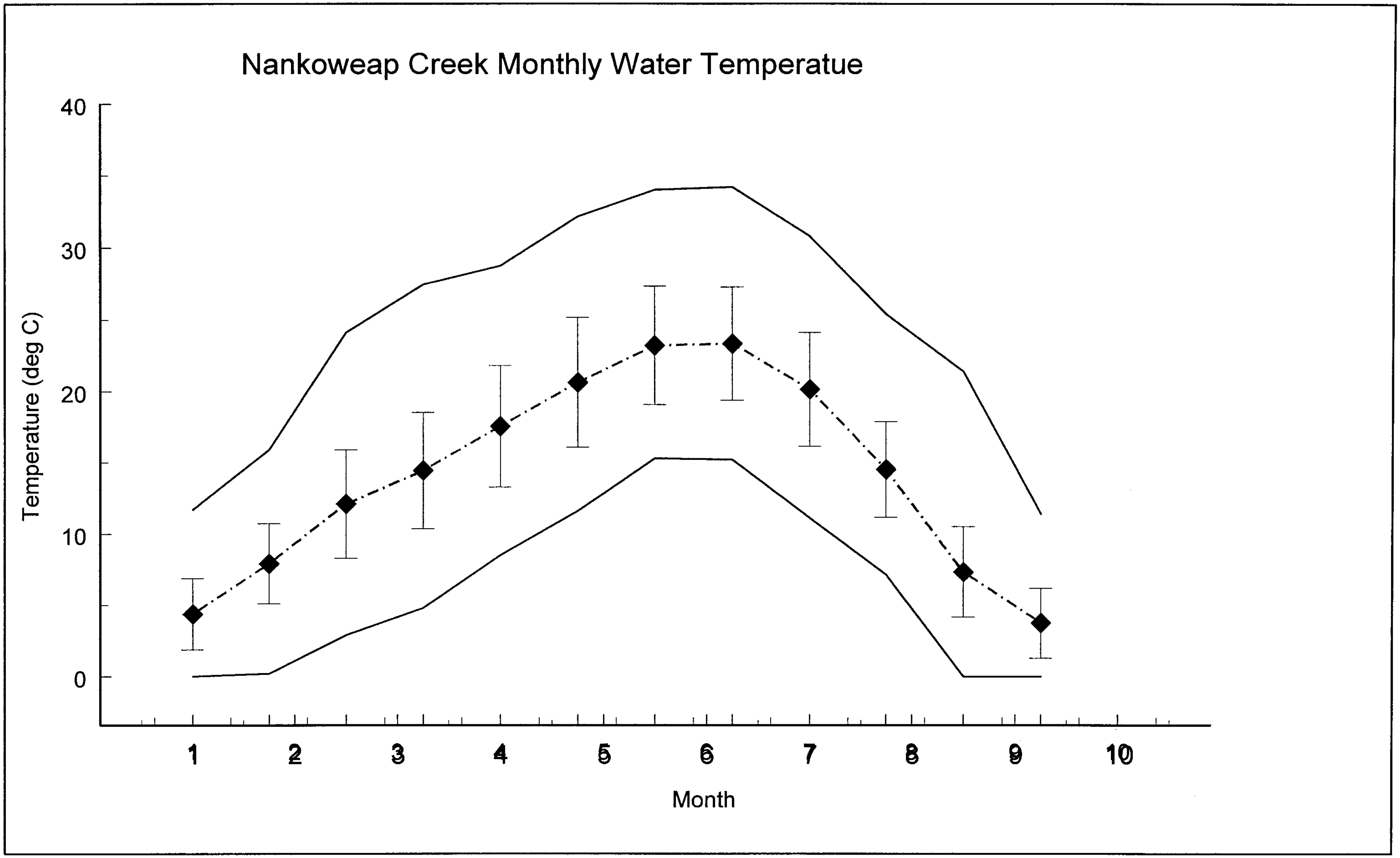


Figure 10: Monthly mean, min, max and std temperatures

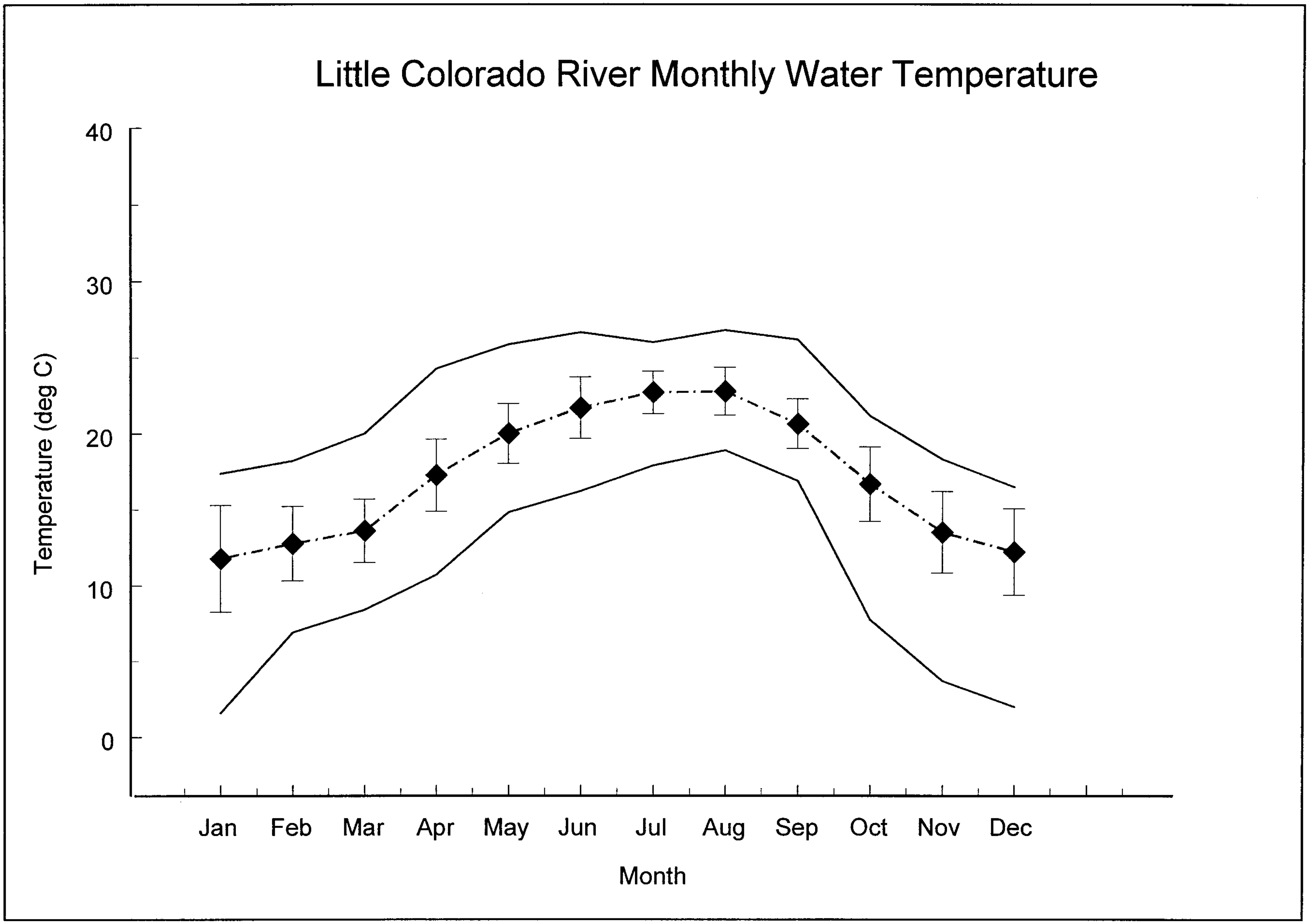


Figure 12: Monthly Mean, Min, Max and Std Temperatures

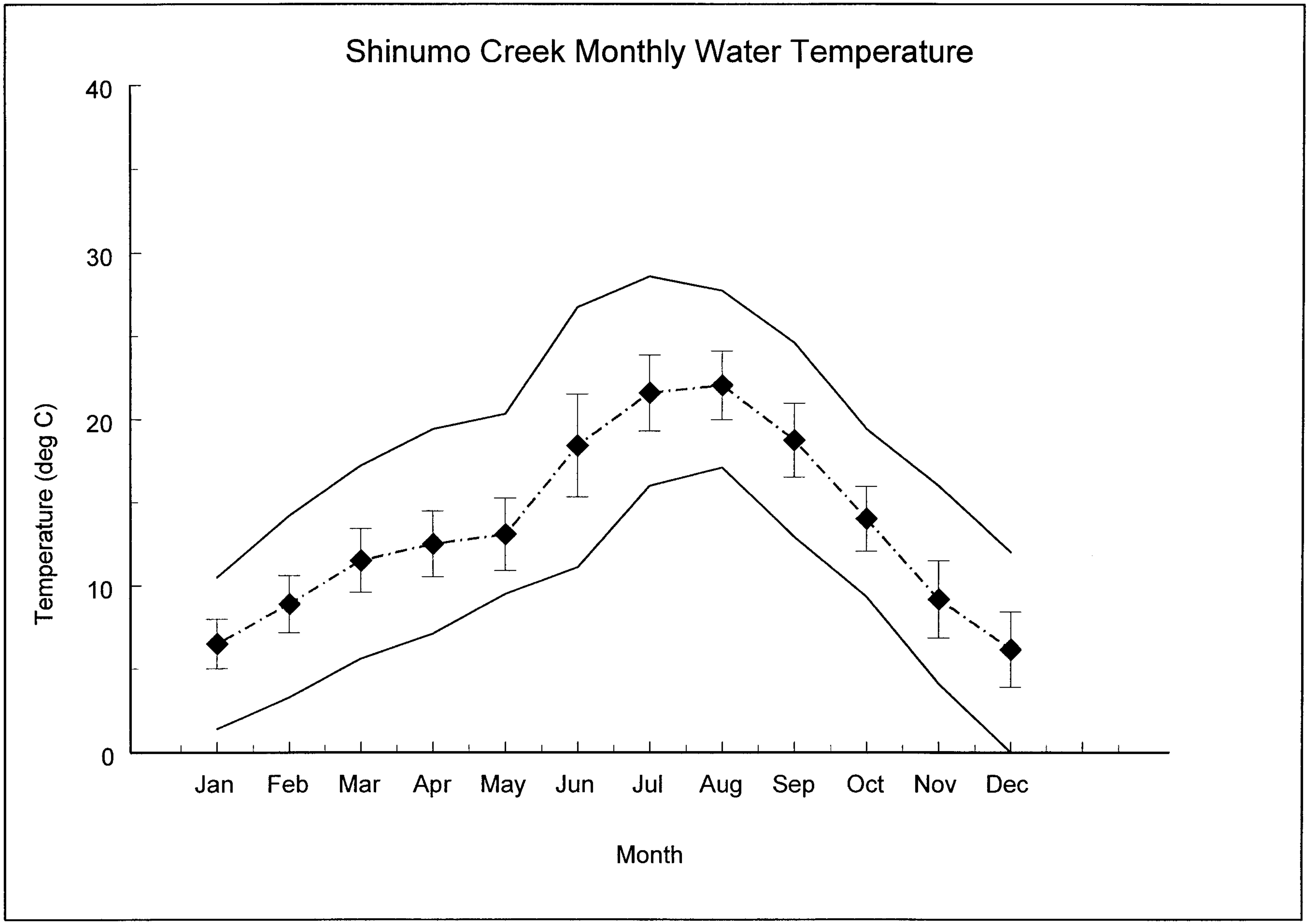


Figure 12: Monthly Mean, Min, Max and Std Temperatures

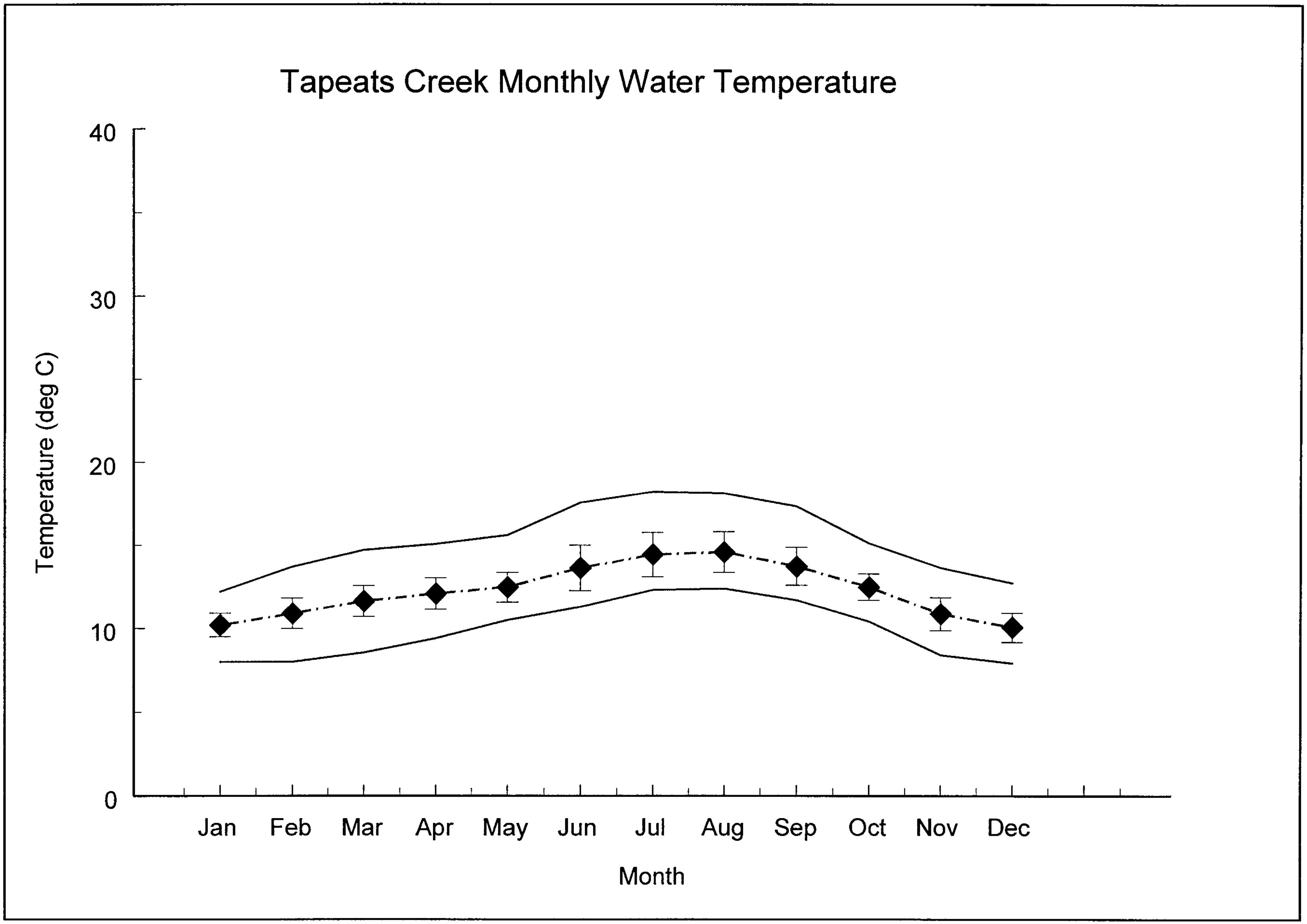


Figure 19: Monthly Mean, Min, Max and Std Temperatures

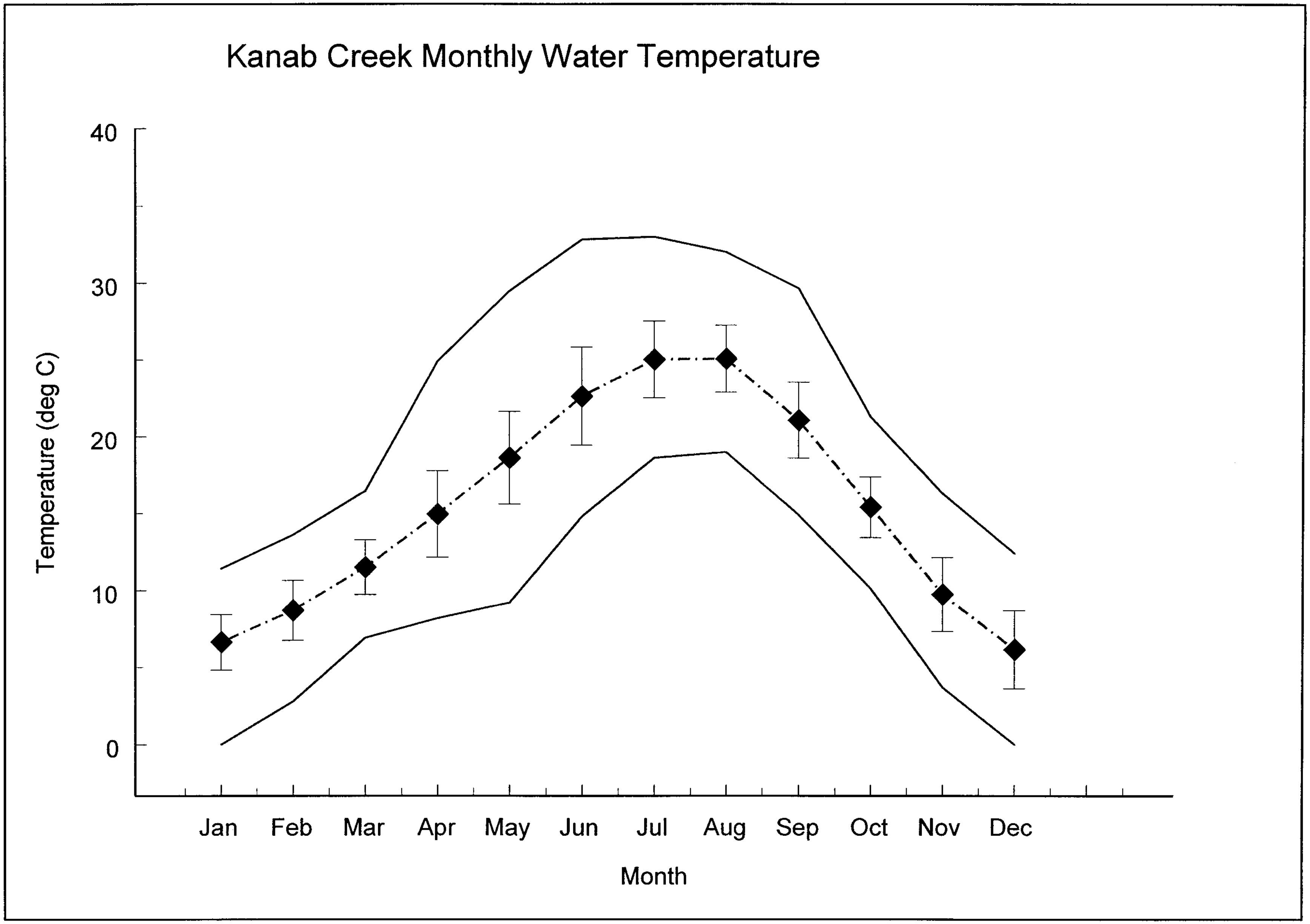


Figure 14: Monthly mean, min, max and std tempertaures

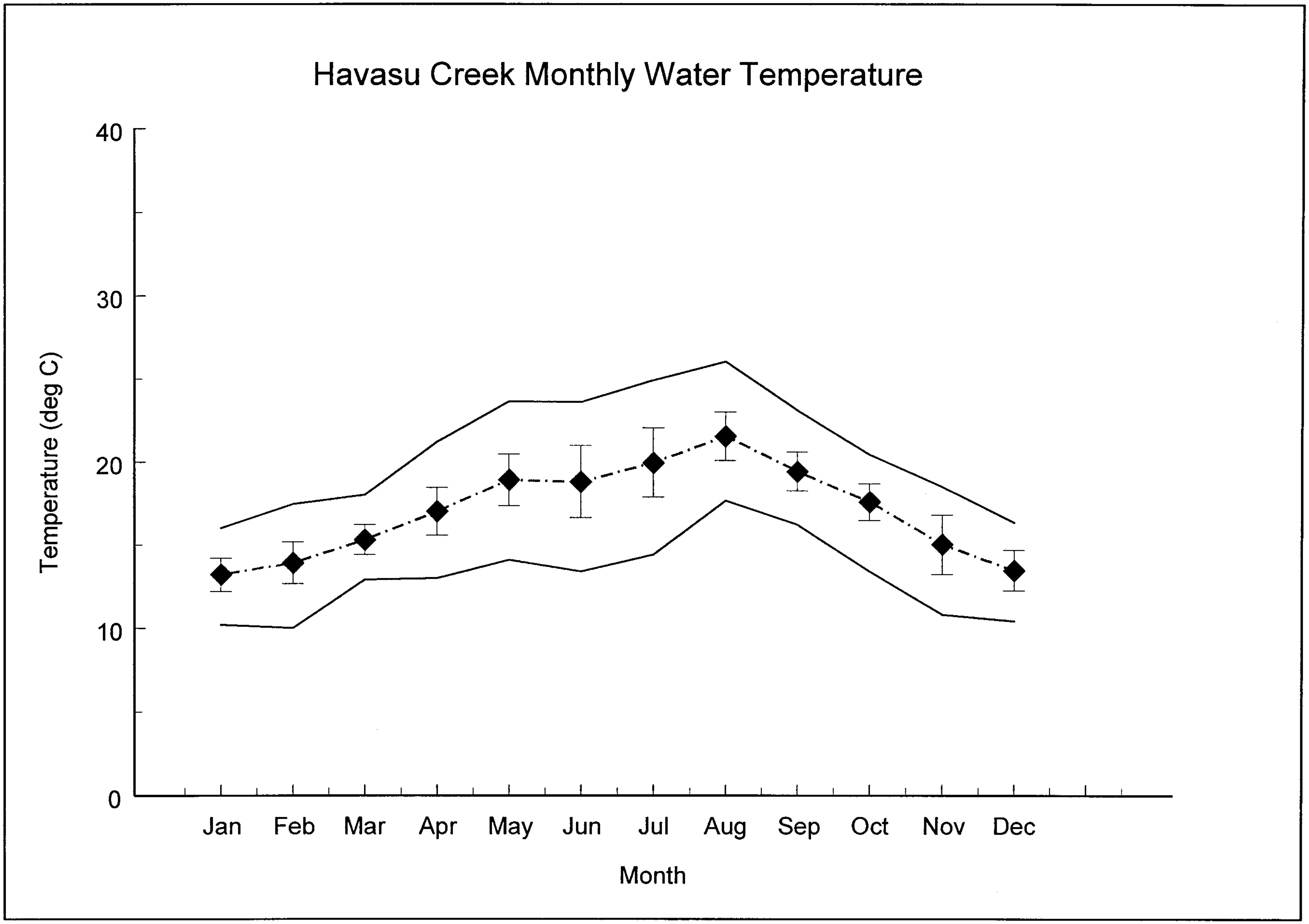


Figure 16: Monthly mean, min, max and std temperatures

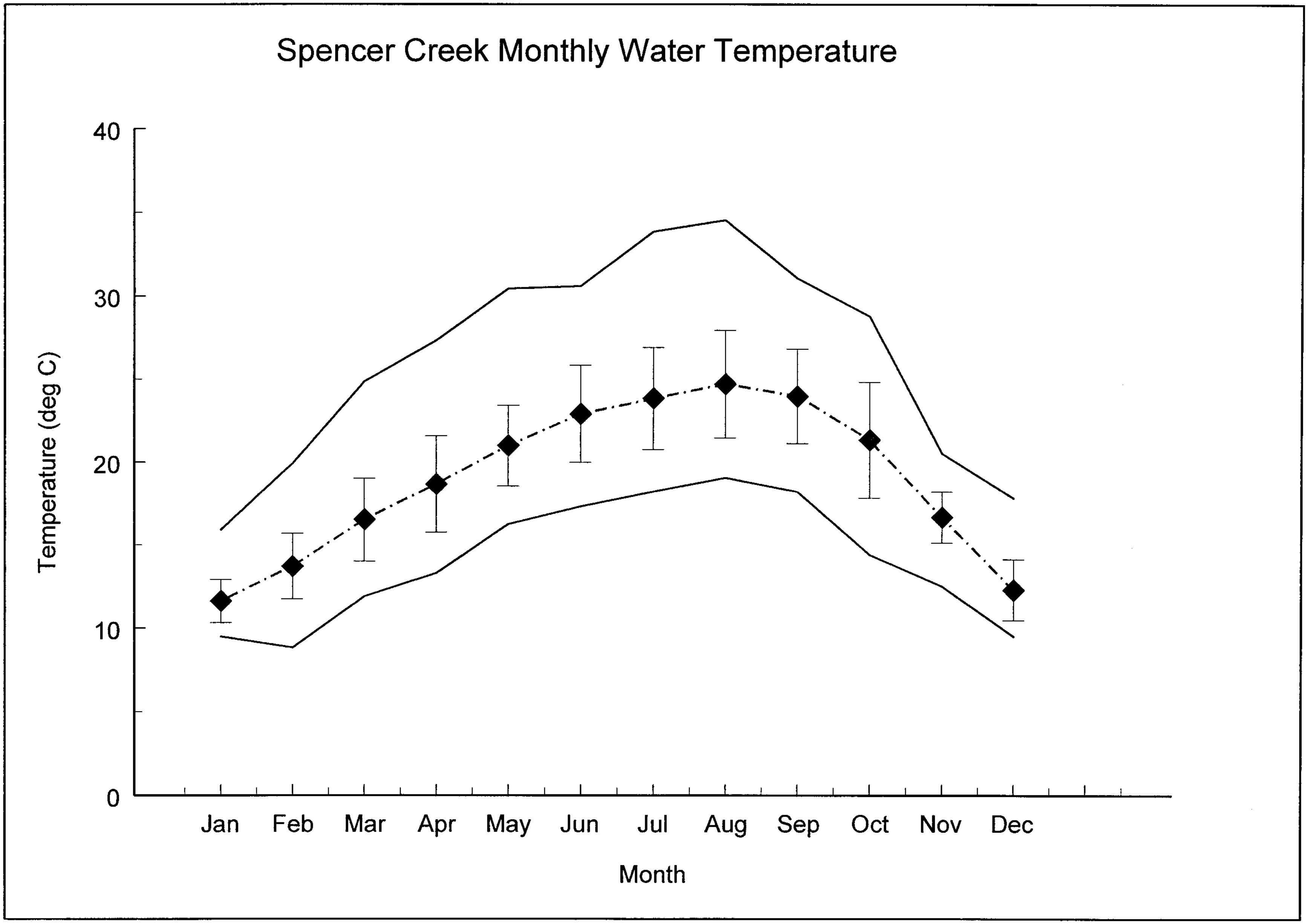


Figure 1?: Monthly Mean, Min, Max and Std Temperature

Daily Variation:

The daily range in temperature was grouped by month to determine how daily fluctuations changed seasonally. Daily warming varies seasonally within a single tributary, as expected, however the seasonal and daily variation is significantly different depending on the tributary. For example, Nankoweap Creek demonstrates a diel change of 3.8°C in December to a maximum daily warming in June of 12.2 °C. Tapeats Creek had the least range in diel change (1.2 °C in November and 3.7 °C in June and July). The following table and graphs display the daily range in temperature by month for each tributary.

Table 4: Mean Daily Range in Water Temperature by Month

	January		February		March		April		May		June	
	Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD
Nankoweap	4.5	1.4	6.3	2.1	7.6	3.1	10.6	2.6	11.2	2.7	12.2	2.2
Little Colorado R	1.4	0.9	1.5	0.6	2.7	1.0	3.7	0.9	3.7	1.3	3.8	1.7
Bright Angel Creek	2.2	0.6	2.7	0.6	4.9	1.2	6.4	1.6	-----	-----	-----	-----
Shinumo Creek	2.1	0.6	2.8	1.0	4.1	1.5	4.1	1.7	3.4	1.6	5.7	1.9
Tapeats Creek	1.4	0.4	1.7	0.5	2.1	0.7	2.2	0.7	2.4	0.6	3.7	0.6
Kanab Creek	1.5	0.4	1.8	0.6	2.37	1.1	5	1.6	6.5	2.2	7.7	2.3
Havasu Creek	0.9	0.3	1.0	0.4	1.7	0.5	2.9	0.7	3.5	1.1	3.8	1.3
Spencer Creek	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

	July		August		September		October		November		December	
	Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD
Nankoweap	11.7	2.1	10.6	2.8	10.3	2.2	7.8	2.3	5.5	1.6	3.8	1.6
Little Colorado R	3.4	1.2	2.8	1.0	3.3	0.9	1.7	0.9	1.2	0.6	1.4	1.6
Bright Angel Creek	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Shinumo Creek	5.9	1.2	5.1	1.4	4.3	1.0	3.4	1.1	2.2	0.5	1.8	0.5
Tapeats Creek	3.7	0.6	3.4	0.7	3.0	0.4	1.9	0.5	1.4	0.3	1.1	0.2
Kanab Creek	7.3	1.9	5.5	1.6	3.9	1.1	2.7	0.8	1.7	0.4	1.4	0.4
Havasu Creek	3.9	1.0	2.8	1.2	1.7	1.0	1.2	0.7	1.0	.5	0.8	0.3
Spencer Creek	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

Mainstem:

Mainstem river temperatures in Grand Canyon have been greatly modified since the closure of Glen Canyon Dam (Fig. 1). River temperatures near the dam now range from 6.93 °C to 12.22 °C, whereas near Diamond Creek they range from 8.4 °C to 18.6 °C (Fig. 24). Table 5 and 6 summarize the mean monthly temperature at each station on the mainstem. It is interesting to note, however, that the warmest temperatures in the upper end of the canyon occur in winter due to warmer release temperatures from the dam and actually cool longitudinally to around river mile 60 before beginning to warm again (Fig 25). Longitudinal warming in the system is highly dependent on season i.e. available warming from the sun (Fig 26). Warming rates can be roughly calculated, simply using degree centigrade change in temperature per km. (Table 7). Using this method, maximum warming from the dam to Diamond Creek (389 kilometers) occurs in June (8.1 degrees total warming or about 0.02 °C/km). The colorado river warms the least in December,when there is essentially no change in temperature overall.

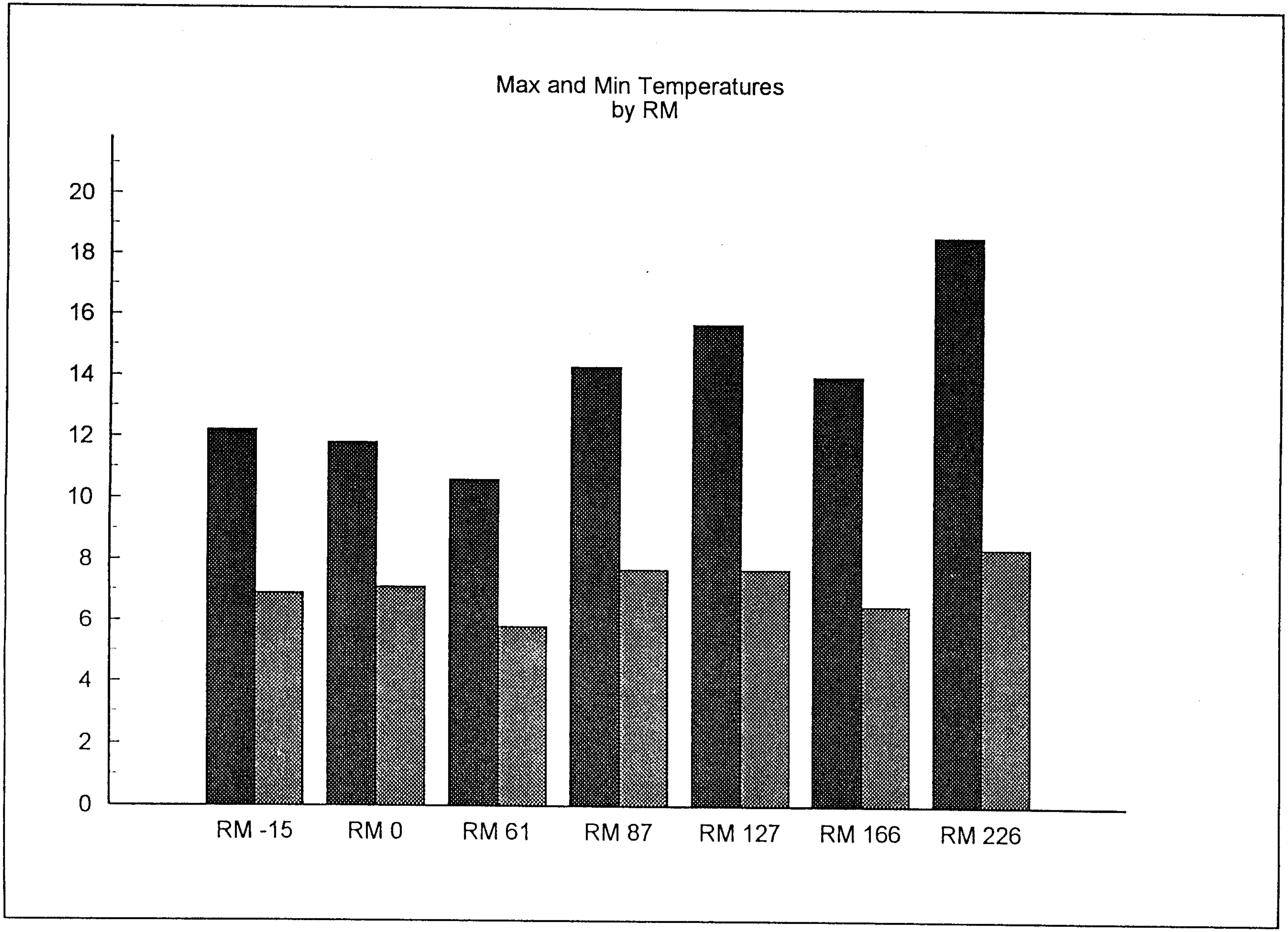


Figure 24. Minimum and maximum water temperatures at GC mainstem locations
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Table 5: Mean Monthly Water Temperature at Grand Canyon Mainstem Sites

	January		February		March		April		May		June	
	Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD
River Mile -15	9.5	0.98	8.4	0.64	8.3	0.42	8.3	0.55	8.5	0.5	8.6	0.54
River Mile 0	9.4	0.83	8.5	0.53	8.5	0.49	8.73	0.53	9.1	0.53	9.4	0.62
River Mile 61	8.4	0.63	8.1	0.43	8.7	0.52	9.5	0.58	10.6	0.67	11	0.74
River Mile 87	9.5	1.03	9.7	0.81	10.2	0.59	10.7	0.62	12.1	0.72	12.6	0.86
River Mile 127	9.6	0.93	9.6	0.95	10.6	0.62	11.4	0.66	12.8	0.56	13.6	0.96
River Mile 166	9.4	1.33	9.6	1.15	10.4	0.93	11.9	0.88	12.5	0.66	13.5	0.37
River Mile 226	10.3	0.81	10.9	0.88	11.7	0.72	12.8	0.82	14.7	0.62	16.7	1.46

	July		August		September		October		November		December	
	Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD	Mean	STD
River Mile -15	9.0	0.59	9.3	0.58	9.5	0.66	10.0	0.66	10.0	0.86	10.4	0.88
River Mile 0	9.6	0.58	9.9	0.55	10.0	0.62	9.9	0.52	9.8	0.7	10.2	0.69
River Mile 61	11.1	0.70	11.5	0.70	11.4	0.62	10.5	0.68	9.4	0.83	9.2	1.01
River Mile 87	12.7	0.36	12.6	0.41	12.4	0.56	11.5	0.72	10.4	1.45	10.4	1.18
River Mile 127	13.6	0.46	13.3	0.55	13.1	0.55	12.1	0.67	10.5	1.33	10.1	1.08
River Mile 166	13.5	0.34	13.3	0.18	12.8	0.48	12.1	0.79	10.4	1.52	9.8	1.32
River Mile 226	16.5	0.66	16.1	0.38	15.7	0.48	13.2	1.04	10.9	1.51	10.4	1.18

Table 6: Min and Max Monthly Water Temperature at Grand Canyon Mainstem Sites

	January		February		March		April		May		June	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
River Mile -15	11.74	7.35	9.92	6.93	9.23	7.31	9.57	6.93	9.77	7.27	10.05	7.39
River Mile 0	11.56	7.56	9.85	7.22	9.71	7.35	10.26	7.50	10.52	7.52	11.17	7.86
River Mile 61	10.51	5.80	9.40	6.70	10.00	7.00	11.30	8.00	12.90	8.00	13.10	8.20
River Mile 87	11.90	7.80	11.20	8.00	11.90	8.80	12.70	9.30	14.33	10.30	14.33	10.63
River Mile 127	11.90	7.98	11.70	7.50	12.20	9.19	13.20	9.86	14.30	11.10	15.70	11.30
River Mile 166	11.54	6.50	11.69	6.70	12.16	8.50	14.2	9.50	14.10	11.05	14.30	12.80
River Mile 226	11.90	8.63	12.40	9.38	13.00	9.70	14.64	11.31	16.20	13.00	18.56	13.40

	July		August		September		October		November		December	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
River Mile -15	10.28	7.60	10.50	7.86	11.19	8.11	11.45	8.28	11.74	8.19	12.22	8.24
River Mile 0	11.11	7.73	11.54	8.57	11.87	8.32	11.49	8.36	11.55	8.03	11.88	8.70
River Mile 61	14.10	8.60	13.03	9.00	13.54	9.90	12.14	8.90	10.97	7.30	11.19	5.70
River Mile 87	13.92	11.50	13.51	11.50	14.02	11.02	12.80	9.86	12.60	7.70	12.30	7.79
River Mile 127	15.06	12.30	14.50	11.90	14.96	11.80	13.70	7.70	13.00	7.70	12.30	7.70
River Mile 166	14.10	12.90	13.80	13.10	14.20	12.20	14.20	10.53	14.18	7.42	12.32	7.30
River Mile 226	18.34	14.90	17.11	14.90	16.78	14.96	15.17	11.80	13.50	8.44	12.70	8.54

Longitudinal Warming: Summer and Winter

Mean (±SD) Monthly Temperature

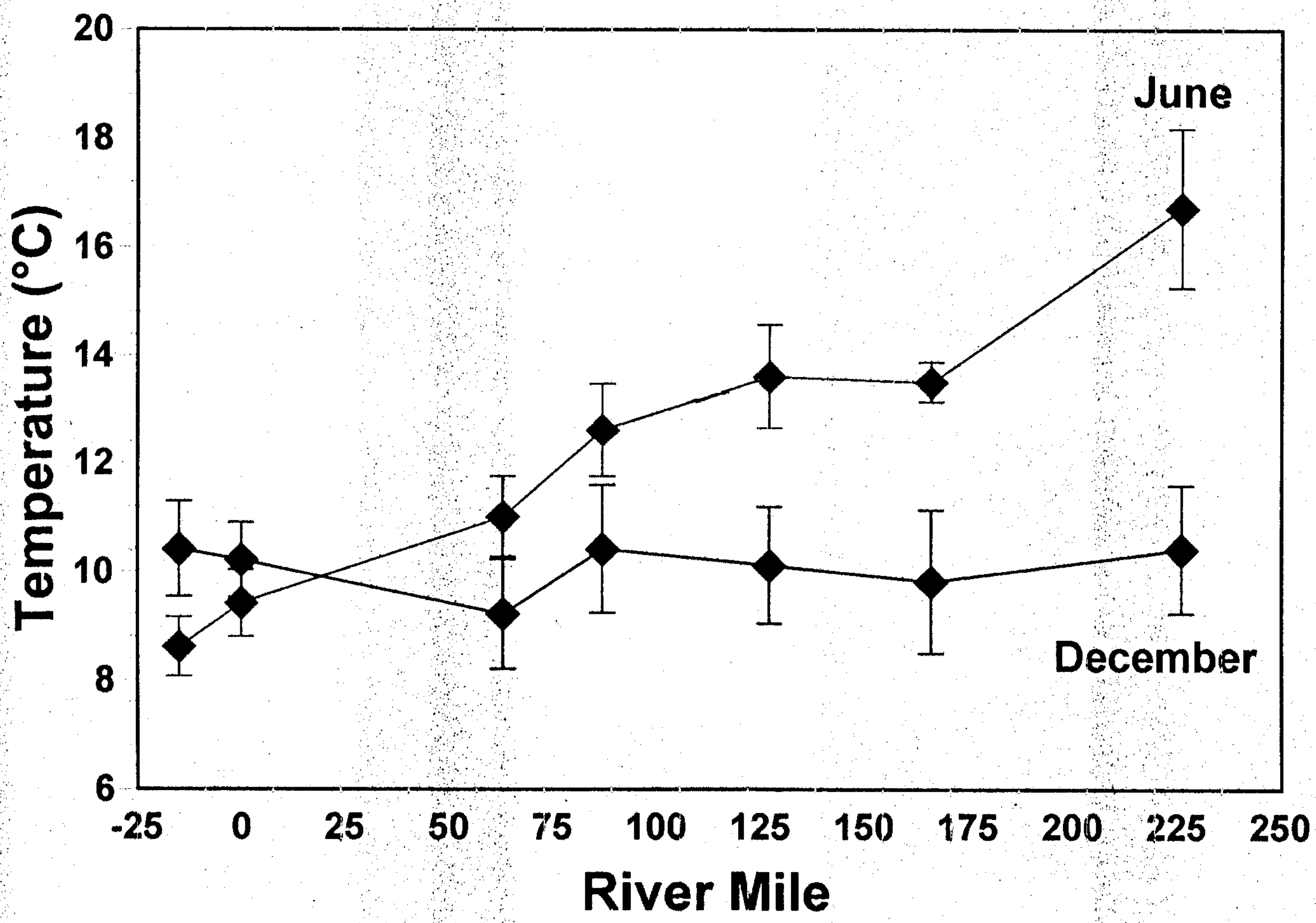

Figure 12: Warming by reach in the Colorado river in June and December

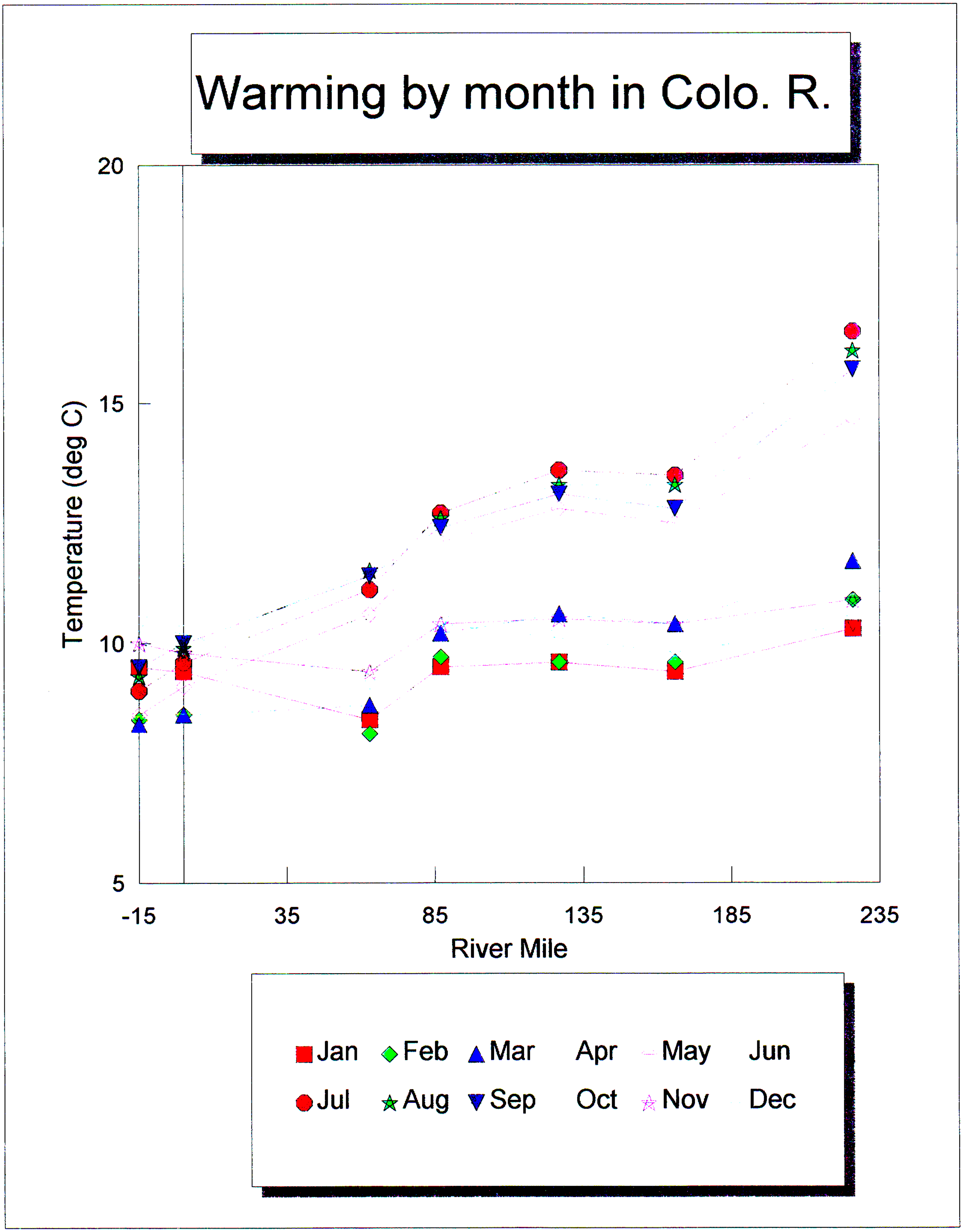

Figure 20: Longitudinal warming in Grand Canyon by month

Table 7: Warming rates of the Colorado River mainstem by month

Month	Total Warming	Warming Rate per Mile	Warming Rate per KM	Miles per Degree C
January	3.0	0.013	0.021	75
February	2.5	0.011	0.018	90
March	3.4	0.015	0.024	66
April	4.5	0.020	0.032	50
May	6.2	0.028	0.045	36.3
June	8.0	0.035	0.056	28.1
July	7.5	0.033	0.053	30
August	6.8	0.030	0.048	33.1
September	6.2	0.028	0.045	36.3
October	3.4	0.015	0.024	66.2
November	1.3	0.006	0.010	173.1
December	0.4	0.002	0.003	562.5

The maximum rate of warming in June occurs between mile 61, above the Little Colorado River (LCR), and river mile 87, above Phantom Ranch (mean=0.0298 °C/km). The least amount of warming occurs between Lees Ferry and above the LCR (mean=0.0070 °C/km) (Figure 26). Figure 27 shows the longitudinal and temporal distribution of water temperature in the mainstem through Grand Canyon overall.

In 1990 and 1991 research flows were conducted that allow us to investigate relationships between flow and warming rate. Figure 28 depicts temperature and discharge near Diamond Creek (KM 365). A simple regression of discharge vs temperature is not statistically significant (r^2 = 0.0005), however, that is regressing all instantaneous temperatures with all instantaneous discharges at one station There is

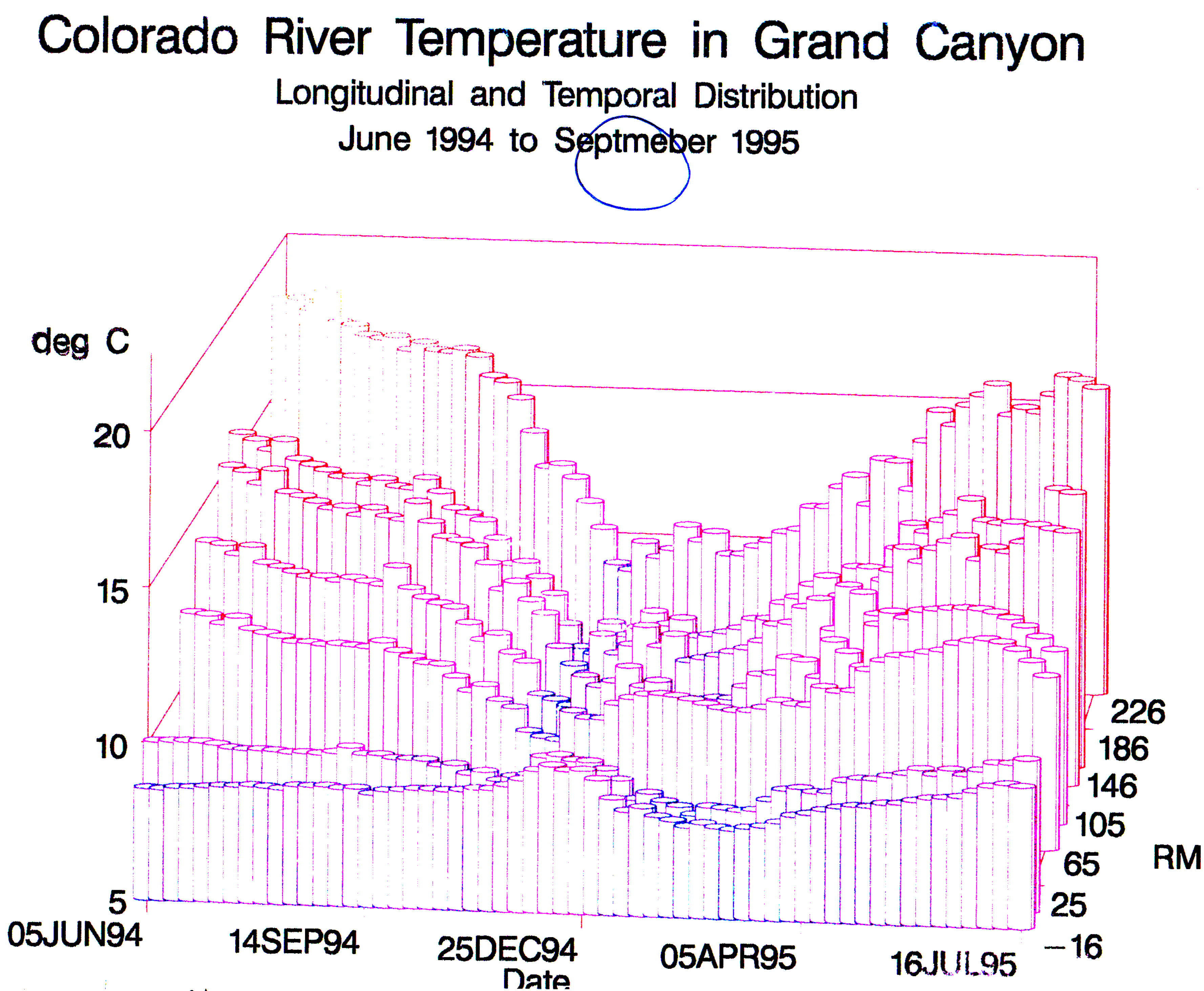

Figure 27: Longitudinal and temporal distribution of water temperature in Grand Canyon by site. Sites are located at -16,0,61,87,127,166, and 225.

Warming Pattern during 5,000 vs 15,000 Steady Flows

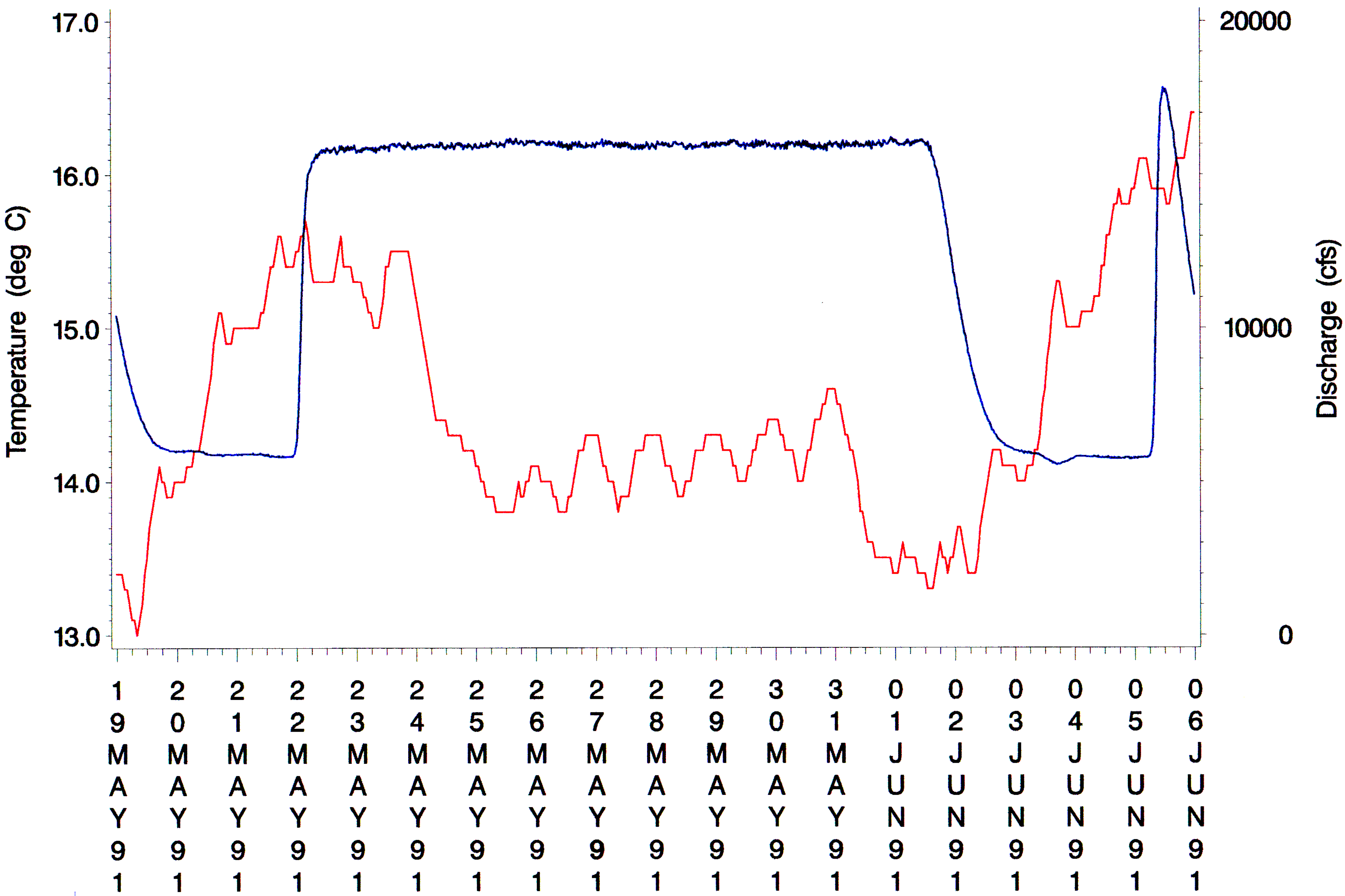

Figure 28: Warming pattern during 5,000 cfs steady flows (05/19-05/22 and 06/03-06/05) vs. 15,000 cfs steady flows (05/23-06/02).

an obvious effect of discharge on temperature, however, exactly what that relationship is will require further analysis.

The warming pattern during steady low flows continues throughout the three day test flow period, whereas most of the warming during higher steady flows (15 K) appears to occur within the first two days after which temperatures return to a new baseline, Of course, climactic conditions certainly play a role in warming patterns as evidenced by the drop in termperature near the end of the 15 K steady flow. Figure 29 shows the warming pattern in the mainstem near diamond creek with varying flow regimes compared to warming in a near by tributary during the same time period.

Figure 30 shows a comparison of 5,000 cfs steady flows vs daily fluctuating flows from 4,000 to 30,000 cfs. What appears to be of greater significance is the total volume of water being delivered each day i.e. the residence time for a single chunk of water.

Figure 31 shows a comparison of 5,000 cfs vs 15,000 cfs steady flow demonstrating a slightly higher warming rate with lower flows.

Warming in Mainstem vs. Warming in near Tributary

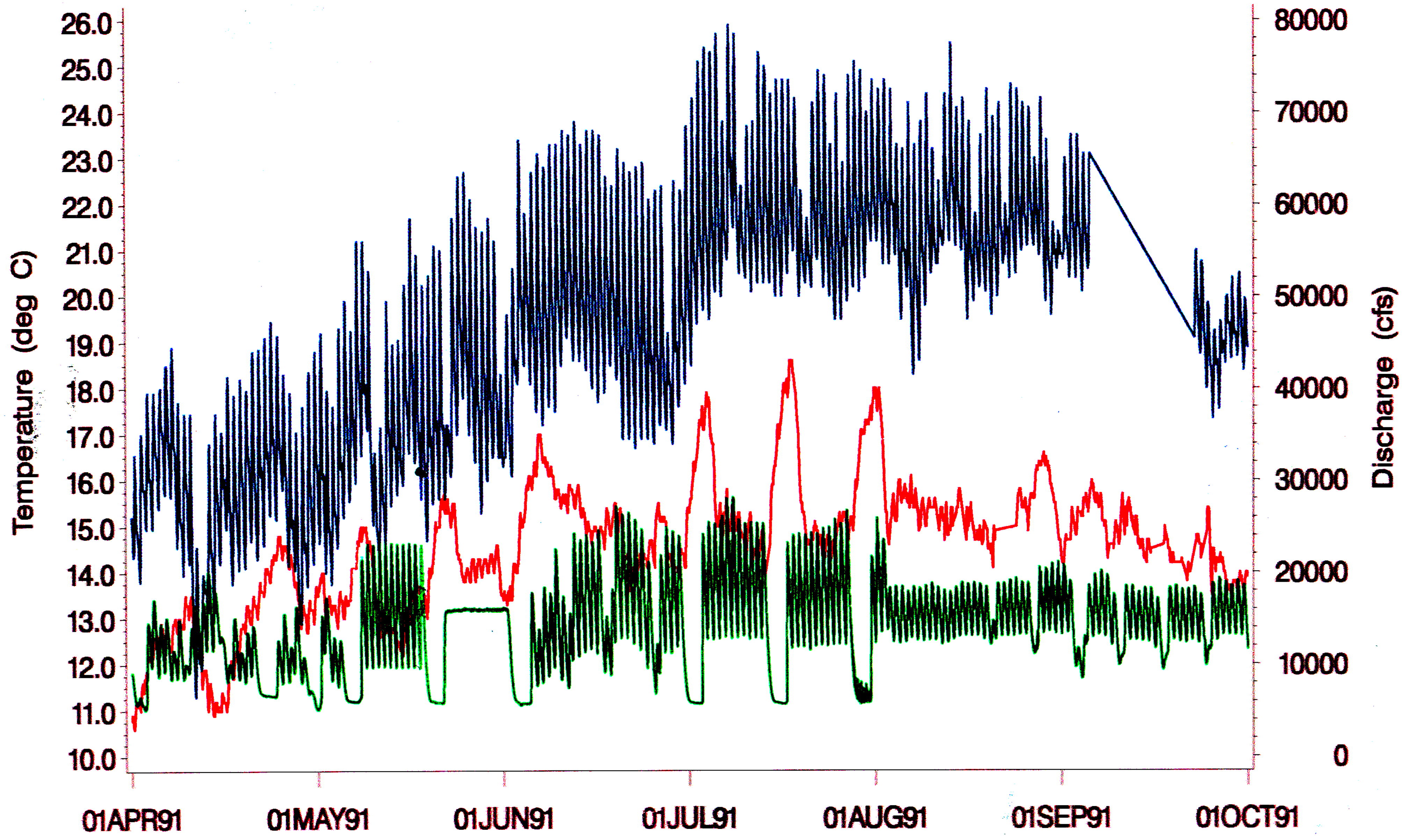

Figure 23: Warming in mainstem vs. warming in nearby tributary. Discharge in shown on bottom.

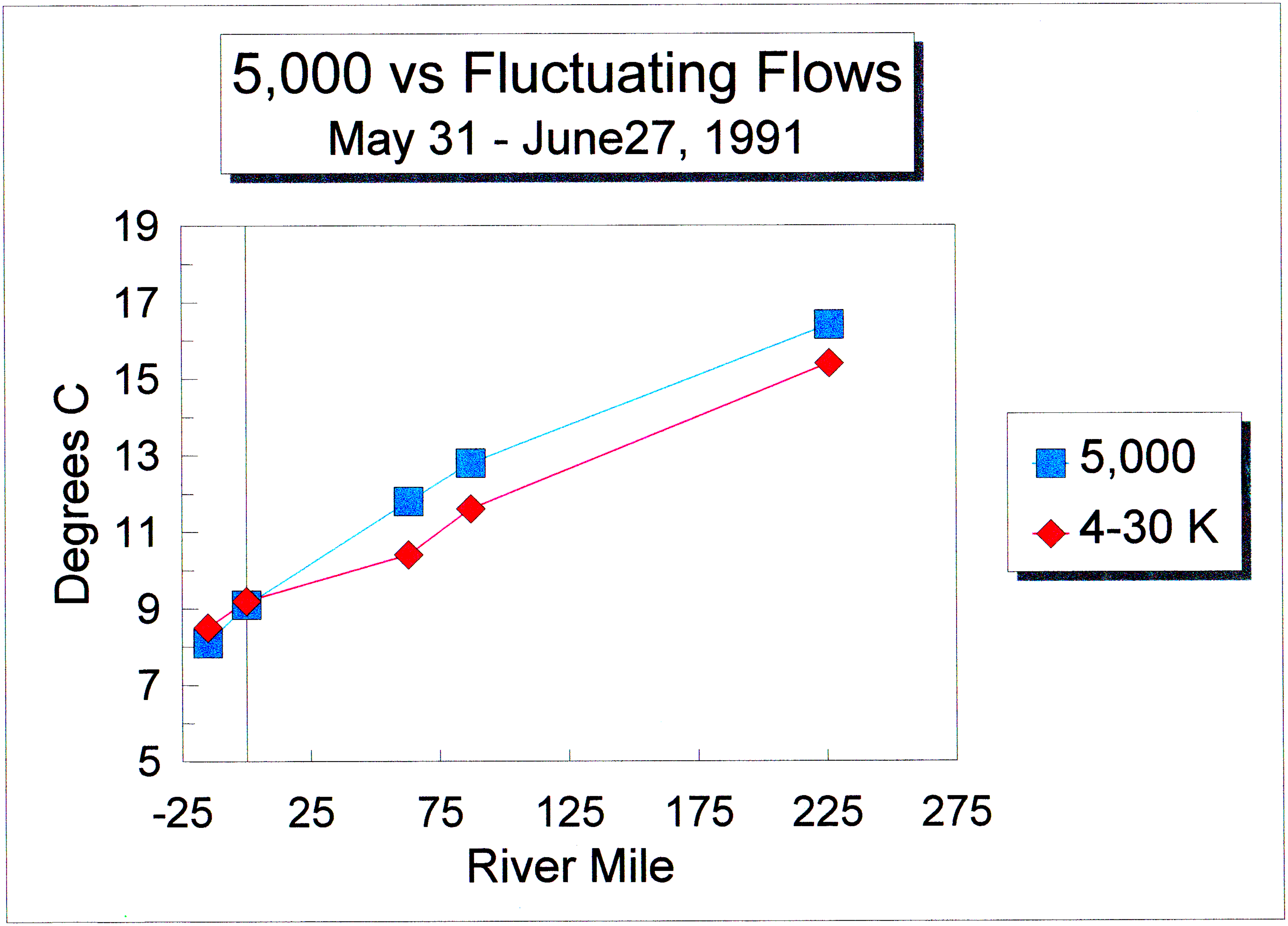

Figure 30: 5,000 cfs vs. “nomal summer” fluctuating flows.

DISCUSSION

Tributaries:

Tributaries in Grand Canyon have become increasingly important spawning areas since the closure of Glen Canyon dam. Humpback chub (Gila cypha), flannel mouth sucker (Catostomus latpinnis), bluehead sucker (Catostomus discobulus), and speckled dace (Rhinichthys osculus) all require between 16 °C and 22 °C in order to spawn and incubate the eggs. (Marsh, 1985, Matthews and Maness, 1979, McAda and Wydoski, 1985). Temperatures in Grand Canyon tributaries typically warm to spawning temperature from early March (e.g. Nankoweap Creek) to May (e.g. Shinumo Creek). Although spawning cues for native fishes in Grand Canyon are not entirely known, it is thought to be largely dependent on achieving an optimal temperature for ovulation (Gorman and Stone, in press). Photo period, hydrologic cycle and imnprinting significantly influence staging and gamete development and probably also contribute to spawning cues.

Mainstem:

Maximum warming in the mainstem of Grand Canyon occurs in June when temperatures near Diamond creek approach 17 °C . Although there is some evidence that spawning may occur near a warm spring at river mile 30, it is not consistently warm enough under present conditions to expect significant spawning. With and average warming rate of 0.0208 °C/km during June, release temperatures would have to be at least 14 °C to warm to within optimal spawning temperature near the Little Colorado River in order to encourage mainstem spawning.

RECOMMENDATIONS

Tributaries continue to be very important to the life cycles of native fishes in Grand Canyon. Each tribuatary has unique habitats specific to different species, defining that critical habitat is essential in making effective management decisions. There is much that we don't know about all the factors that contribute to successful spawning, and we recommend that the tributaries continue to be monitored for temperature and other habitat variables identified by native fish and aquatic foodbase researchers. Simplistic warming models predict a certain warming regardless of reach or time of year. Our results indicate that warming is highly dependent on available sunlight. Development of a thourough warming model, which takes ambient air temperature into account is of paramount importance in determining the effectiveness of a multiple-level withdrawal structure on Glen Canyon dam.

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