

**THERMAL ENVIRONMENT
OF THE
DEVILS HOLE PUPFISH**
(Cyprinodon diabolis)

January 2003

Report prepared by:

Douglas L. Threlhoff

and

Linda Manning

**THERMAL ENVIRONMENT
OF THE
DEVILS HOLE PUPFISH
(*Cyprinodon diabolis*)**

Table of Contents

Executive Summary

Introduction

Methods

Results

- Devils Hole, 5-meter Shelf
- Devils Hole, Middle of Spawning Shelf
- Devils Hole, Under Stevens Recorder
- Devils Hole, Along West Wall of Spawning Shelf
- Devils Hole, Southern End of Spawning Shelf
- School Spring Refugia, Deep Chamber and Shallow Shelf:
- Point of Rocks Refugia, Deep Chamber and Shallow Shelf

Discussion

- Historical Trends in Devils Hole Water Temperature
- Devils Hole Water Temperature in Comparison to Other Amargosa River Wetland Habitats
- Ova, Eggs, and Embryos: Limiting Factors in a High Temperature Environment
- Heat Tolerance of Adult Pupfish and the Relationship to Embryos and Eggs
- Other Water Temperature-Related Effects Not Directly Linked to Eggs and Embryos
- The Devils Hole Pupfish and the Pupfish Spawning Shelf: Two Inherent Limiting Factors

Synthesis and Conclusion

Management Recommendations

Literature Cited

THERMAL ENVIRONMENT OF THE DEVILS HOLE PUPFISH

Executive Summary

Ongoing concerns about a decline in the number of Devils Hole pupfish (*Cyprinodon diabolis*) in Devils Hole, Nevada have prompted a number of studies that are designed to identify the causal factors for the downward trend. Because the thermal regime of a habitat may affect a fish's metabolism, activity level, reproductive success, behavior, and demography, digital data loggers were installed at five locations within Devils Hole to continuously monitor water temperature between 1999-2001. Data loggers were also installed at four locations within two refugia that are used to maintain backup populations of the species. Data collected within the Point of Rocks refugium suggests that the thermal regime at this site is consistently cooler than that of Devils Hole. The upper water temperatures in the School Spring refugium are sometimes comparable to Devils Hole, but maintenance-related problems infrequently cause significant water temperature changes that result in high mortality rates of fish. Water temperatures in Devils Hole were found to possess pronounced temporal and spatial differences. The thermal regime five meters below the pupfish spawning shelf is essentially invariant at 33.5-33.99° Celsius and water temperatures on the southern-most end of the spawning shelf were consistently between 33 and 34° between February and August, 2001. In contrast to several published reports that suggest the Devils Hole water temperatures is a constant 32 or 33°, the water temperature in the middle, southeastern, and western portions of the spawning shelf were found to fluctuate several degrees when direct sunlight was present on the spawning shelf. During the summer months of May, June, and July each year, daily high water temperatures on the middle of the spawning shelf consistently went as high as 35.0 to 36.49° for a period of four to six hours. Daily high temperatures on the southeastern end of the spawning shelf under a Stevens-brand water level recorder were slightly cooler (i.e. 34.0 to 35.99°) during these same months, and the length of time when temperature increased was shorter than what occurred in the middle of the spawning shelf, i.e. 3 to 4 1/4 hours. An area along the western margin of the spawning shelf experienced daily high water temperatures that were roughly similar to those underneath the Stevens recorder. One flash flood event on September 3, 2001 caused 23.8-26.5° temperatures that lasted a few minutes to an hour. On rare occasions, when high-amplitude tide cycles occurred during cooler winter months, low temperatures on the order of 26-29° infrequently occurred underneath the Stevens recorder. Several studies involving the reproductive biology of various pupfish taxa suggest the water temperature regime in Devils Hole is near the upper maximum threshold for successful egg production and fry recruitment. Small increases in water temperature on the order of one or two degrees above 33° may be sufficient to greatly decrease or eliminate successful recruitment of Devils Hole pupfish. There is limited evidence that suggests the thermal regime in Devils Hole has increased one to three degrees during the past 20-30 years. The decline in fish numbers may be related to this apparent temperature increase. If water temperatures in Devils Hole have not increased in recent years, there is still the potential that small increases in water temperature have to potential to reduce the

reproductive output of the species. A number of management actions and studies are proposed to enhance the fish populations in Devils Hole and the refugia, and further understand the relationship between the ambient water temperature and the pupfish's reproductive ecology.

Introduction

The Devils Hole pupfish naturally occurs at the single locality known as Devils Hole. The only other extant populations of the fish consist of artificial populations that are maintained at three separate concrete tanks that are commonly referred to as refugia. Two of the refugia occur within the boundary of the Ash Meadows National Wildlife Refuge in Nye County, Nevada, while the third facility is located at the base of Hoover Dam near the city of Las Vegas, Nevada.

From a biological and evolutionary standpoint, the Devils Hole pupfish is a remarkable animal. The fish has a natural distribution that is confined to a single locality; the documented population size during the past 30 years has never exceeded 566 animals; and the species has, in effect, been trapped within the smallest known habitat for any vertebrate species for 10,000 to 50,000 years. Beginning in 1997, the maximum annual number of fish in the natural habitat began a decline in numbers, and by 2002 only 196 fish were seen during the fall pupfish count.

In order to identify and understand the factors that may be responsible for the decline in pupfish numbers, a variety of studies have recently been initiated. This paper has been written in an effort to summarize water temperature data that has been collected at several locations within the pupfish's natural habitat and in two of the three refugia. Water temperature has been selected as one of the variables for investigation because:

1. Few freshwater fish species inhabit a thermal regime that is as consistently warm as 33+ ° Celsius (C) temperatures in Devils Hole.
2. Water temperature has a profound influence on behavior, metabolism, reproductive success, and the distribution of fish because they are cold-blooded animals.
3. With the exception of sporadic and infrequent instantaneous water temperature data that have been collected by various investigators, there appears to be few, if any datasets that provide in-depth water temperature data in Devils Hole and the Ash Meadows refugia.
4. Recent concerns about the sensitivity of other aquatic ecosystems (e.g. coral reefs) to subtle changes (1° C) in water temperature raises the potential that Devils Hole may be influenced by potential climate changes in the Mojave Desert.

Methods

Water temperature was measured on a continuous basis with the aid of digital data loggers that were deployed at several locations within Devils Hole and the School Spring and Point of Rocks refugia within the boundary of the Ash Meadows National Wildlife Refuge. The data loggers consisted of Tidbit brand data loggers (Figure 1) that are manufactured by the Onset Computer Corporation. Manufacture specifications suggest the data loggers are able to record temperatures between -5 and 37°C , have an accuracy of $\pm 0.25^{\circ}\text{C}$ and a resolution of $\pm 0.2^{\circ}\text{C}$ at temperatures that are typical for Devils Hole. The units are approximately two centimeters (cm) in diameter and one cm thick, and are rated as having a response time of three minutes or less in water. Because the company has received reports that some data loggers may not be accurate at higher temperatures, a variety of temperature tests were conducted with some of the same data loggers that were used during this project. The results of these tests are contained with Appendix B, and suggest that the tested data loggers performed within the manufacturer specifications.



Figure 1. Photograph of a Tidbit-brand digital data logger that was used to measure water temperature in Devils Hole pupfish habitats.

Data loggers were deployed at five locations within Devils Hole between 1999 and 2001. Figure 2 provides a schematic of locations where data loggers were deployed in Devils Hole. These areas include:

1. The 5-meter deep shelf immediately below the water level stilling well.
2. The middle of the pupfish spawning shelf.
3. A location directly underneath the northwest corner of the plywood platform that supports a Stevens-brand water level recorder.

4. A position along the western edge of the pool due west of the Stevens water level recorder.
5. A location at the southern-most end of the spawning shelf.

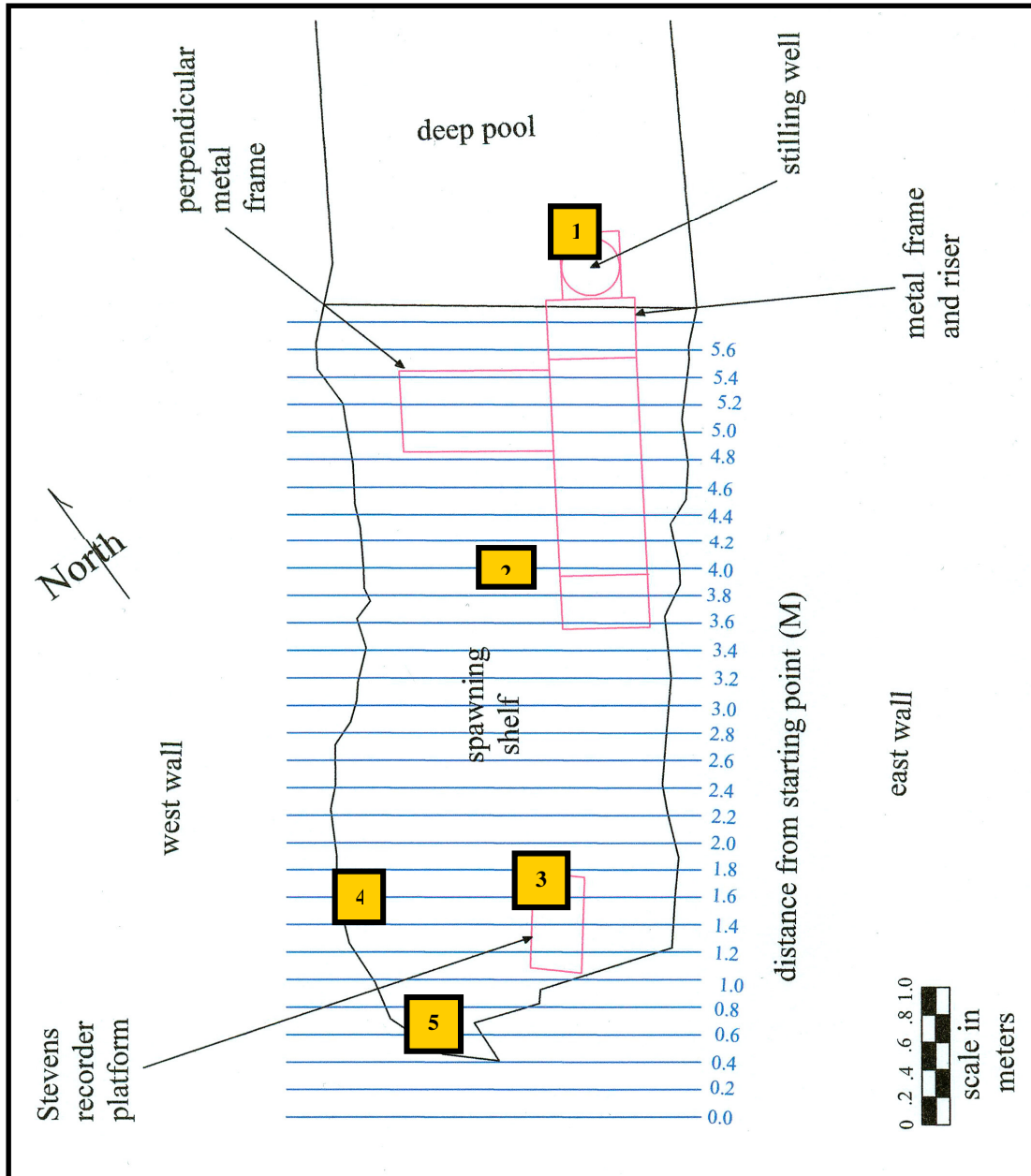


Figure 2. Schematic of data logger deployment locations within Devils Hole. The grid with distances from a starting point was developed to geo-reference samples collected during the Devils Hole bioenergetics study. Numbers refer to data logger deployment locations. 1=deep data logger on 5-meter deep shelf; 2=middle data logger; 3=Stevens recorder data logger; 4=west wall data logger; 5=south end of spawning shelf data logger.

Two data loggers were also deployed in each of the two Ash Meadows refugia; one data logger was placed in the deep chamber of each refugium and a data logger was also placed in the center of the shallow shelf area of each facility.

The period of record at each data logger's deployment location is listed in Table 1. In Devils Hole, locations in the middle of the spawning shelf and underneath the Stevens recorder were monitored on a nearly continuous basis from January 1, 1999 through December 31, 2001. The 5-meter deep shelf was monitored from early September 1999 through mid-April 2000. The area along the western wall of the spawning shelf due west of the Stevens recorder was monitored from September 2000 through December 2001. The area near the southern end of the spawning shelf was monitored from February to August, 2001. Data loggers in the refugia were deployed from September 1999 through July of 2000, with the exception that the monitoring of the shallow shelf of the School Spring refugia was discontinued in February 2000.

A continuous collection of water temperature data between January 1999 and December 2001 did not occur for a variety of reasons. Data collected by the data loggers that were placed along the west wall and underneath the Stevens recorder were discarded on several occasions because daily low tide cycles may have created a situation where data loggers were exposed to the air. Air temperature and water level data were simultaneously collected at Devils Hole during the period when water temperature data were collected. In instances when water temperatures equaled local air temperatures and a low tide cycle occurred, data were discarded in order to eliminate the potential that erroneous data were included in subsequent analyses.

At each location where data loggers were deployed, the devices rested on the bottom substrate. Data loggers were programmed to take instantaneous readings at 15-minute intervals. All of the measurements were recorder in degrees Celsius. Most of the readings were recorded on the quarter hour. Water depths at monitored sites varied by location (Table 1). Water depths in Devils Hole vary because the pool level experiences a maximum daily tidal fluctuation of up to six to eight centimeters. The values in Table 1 should typically represent the minimum depth of water over the data loggers.

Data analysis of temperature data was performed by 1) generating continuous time series graphs for all of the monitored locations and 2) by creating tables that proved summaries of the number of 15 minute readings for half degree increments of water temperature.

Results

Water temperature data were also not available during periods when data loggers were removed from their respective locations for reprogramming, or when the devices were removed during pupfish counts or similar activities. Collection of water temperature data at some location in Devils Hole were also influenced by earthquakes that occurred on September 30, 1999, and October 18, 1999 and a rainstorm that occurred on September 3, 2001. During these two types of natural events, some of the data loggers were moved

laterally or became buried by gravel until the data loggers were repositioned in their original locations. The collection of data in Devils Hole was interrupted between January 17, 2000 and February 10, 2001 when vandals entered Devils Hole and stole the four data loggers that had been deployed.

Data logger deployment Location	Approximate water depth (cm)	Deployment dates	
		From	To
Devils Hole			
• 5 meter deep shelf	500	09/07/99	04/14/00
• middle of spawning shelf	45	01/01/99	12/31/01
• under Stevens recorder	10-15	01/01/99	12/31/01
• along west wall of spawning shelf	9-6	09/02/00	12/31/01
• southern end of spawning shelf	10-15	02/10/01	08/11/01
School Spring refugia			
• Deep chamber	~300	09/24/99	11/17/01
• Shallow shelf	~50	09/24/99	02/11/00
Point of Rocks refugia			
• Deep chamber	~300	09/24/99	11/17/01
• Shallow shelf	~50	09/24/99	04/07/01

Table 1. Deployment history for temperature data loggers placed in Devils Hole pupfish habitats.

Water temperatures in locations with Devils Hole pupfish were found to possess pronounced temporal and spatial differences. A brief synopsis for each of the water temperature sampling locations is provided below. Appendix A contains graphs of continuous time series of water temperature data for each location and tabular data that summarizes the number of 15 minute readings that were recorded at various water temperatures.

Devils Hole, 5-meter Shelf: temperatures on 5-meter deep shelf below the pupfish spawning shelf were found to be extremely stable during the entire period when data loggers were deployed. Between September 1999 and April 2000, 19,276 of the 19,279 instantaneous readings that were collected were found to occur between 33.5 and 33.99°. No other location in Devils Hole possessed such a consistently stable water regime, irrespective of the season or time of day. The invariant temperature did not deviate, even when a two to three foot high wave in Devils Hole developed as a result on an earthquake near Oaxaca, Mexico on September 30, 1999.

The location where the data logger was deployed never experienced direct sunlight because the sampling location was immediately below the water monitoring stilling well mounted on the northern end of the spawning shelf, and the geometry of Devils Hole precludes direct illumination from the sun's rays at this location. It is not known if the more northerly portion of the 5-meter shelf, which does experience direct sunlight during

the summer months, also possesses a constant water temperature or if the temperature varies on a daily basis.

Devils Hole, Middle of Spawning Shelf: water temperature at this location varied on a temporal basis, and was primarily affected by the amount of solar incidence on the pupfish spawning shelf. During the period between mid-October and mid-February in each of the three years when monitoring took place, the water temperature in the middle of the pupfish spawning shelf typically ranged between 32.6 and 33.6°. After mid-February in each of the three years, the maximum daily water temperature increased as the number of daylight hours increased. By mid to late April of each year, the maximum daily water temperature routinely reached 35.0 to 35.5°. Maximum daily high temperatures for the year typically peaked and were routinely sustained in mid-June, when temperatures were in the range of 35.0 to 36.3°. The minimum daily temperature during the months of June in 1999 and 2000 were usually between 33.22 and 33.44°, and the minimum mean June temperature in 2001 was 33.84°. Following the summer solstice on June 21, the water temperature decreased each year as the number of daylight hours decreased. In July and August of 1999 and 2000 water temperatures typically did not rise above 35°. In 2001, the maximum daily water temperature followed this trend in July, but in mid-August, the daily high temperatures routinely reached 36° during several days of the month. The period between early September and mid-October of each year generally saw a decrease in water temperature, and measurements above 34.5° became less common. On September 3, 2001, an unusually cool water temperature of 26.54° occurred in the middle of the spawning shelf for a few minutes as a thunderstorm created a flashflood event that carried water and gravel onto the spawning shelf.

The daily increase in water temperature as a result of direct illumination on the spawning shelf typically resulted in a rapid increase in temperature that was quickly reversed when the sun moved to a location behind the hillside that surrounded the Devils Hole cavity (Figure 3).

An evaluation of water temperature data collected at 15 minute intervals on the 15th day of each month between March and August, 2001 demonstrate that elevated water temperatures exist in the middle of the Devils Hole pupfish spawning shelf for varying amounts of time (Figure 4 and Table 2). The minimum daily water temperature on the 15th day of March and September in 2001 was between 33.64 and 33.4°, and was 34.04° during the months of April, May, June, July, and August. The maximum daily water temperature and the length of time that elevated temperatures occurred on the spawning shelf on the 15th day of each month between April and August was significantly influenced by monthly variations in the angle of the sun above the horizon and the geometry of Devils Hole. The maximum daily water temperature was consistently between 35.06 and 36.09° between April and August, and during the months of May, June and July, elevated water temperatures on the shelf existed for a period of four to six hours. Daily high water temperatures and the length of time that elevated water temperature occurred did not appreciably decrease until September.

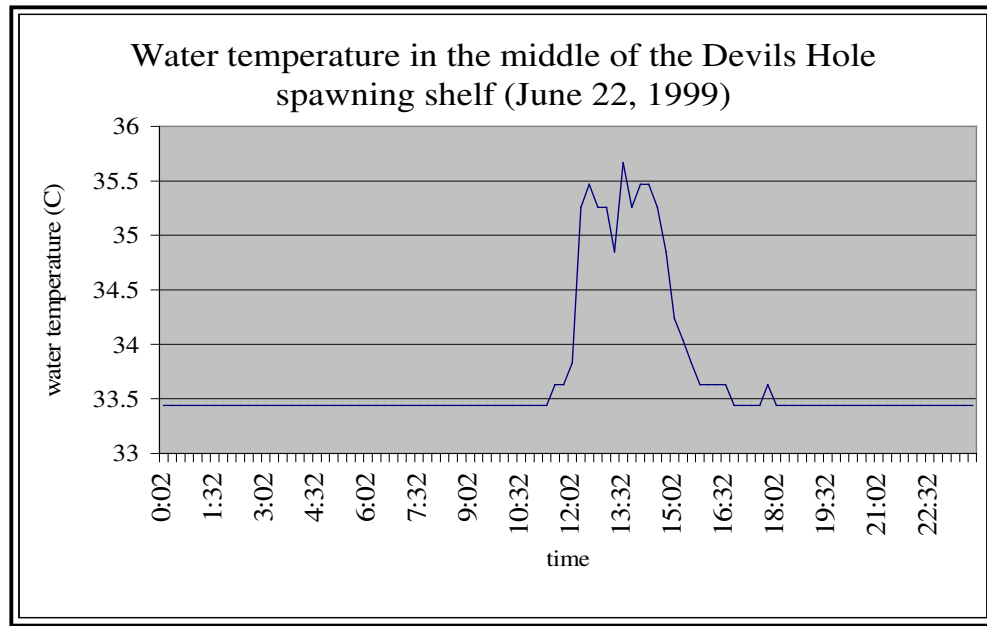


Figure 3. Daily variation in water temperature in the middle of the pupfish spawning shelf in the Devils Hole pool on June 22, 1999. Note the rapid increase in water temperature that resulted when sunlight was present on the shelf substrate, and the quick decline in temperature after the sun moved behind a hillside and direct illumination was terminated.

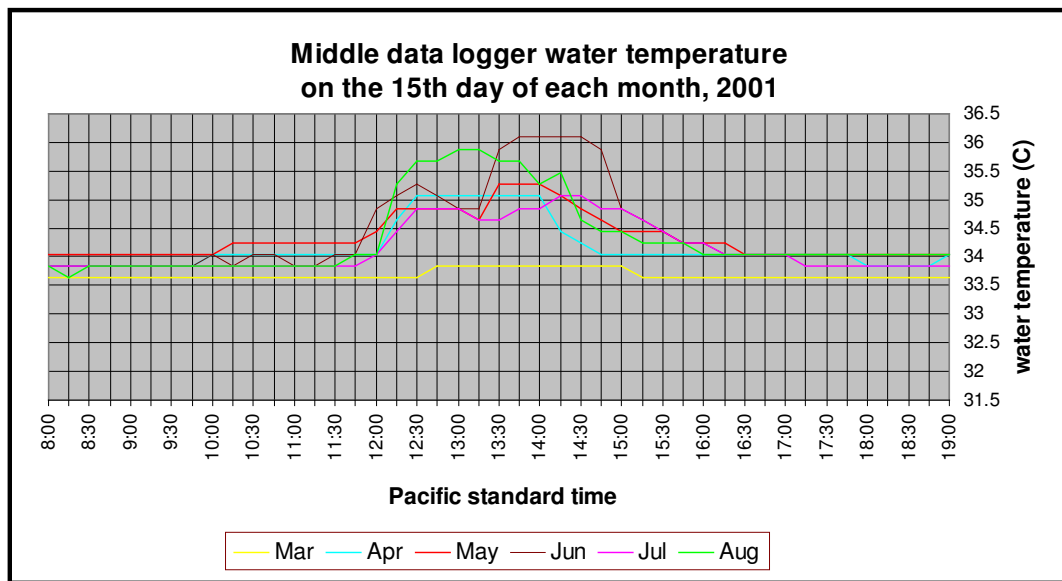


Figure 4. Continuous water temperature data collected at 15 minute intervals in the middle of the Devils Hole pupfish spawning shelf on the 15th day of each month, 2001.

Month	Middle of spawning shelf			Underneath the Stevens recorder		
	Minimum	Maximum	# of hours above minimum	Minimum	Maximum	# of hours above minimum
March	33.64	33.84	2 1/4	32.93	33.32	1
April	34.04	35.06	2 1/4	32.93	34.32	4 1/2
May	34.04	35.26	6	32.93	33.52	4 1/4
June	34.04	36.09	4	32.93	33.92	3
July	34.04	35.06	5	33.12	35.55	3 1/2
August	34.04	35.88	3 1/2	33.12	34.93	2 1/2
September	33.84	34.85	2	No data	No data	No data

Table 2. Thermal characteristics for the locations near the middle and southeast corner (i.e., under the Stevens recorder) of the Devils Hole pupfish spawning shelf.

Devils Hole, Under Stevens Recorder: the thermal regime at this location was especially influenced by the shallow water depths at the sampling location, and colder air temperatures that occurred during the cooler months of the year. The shallow water depths underneath the Stevens recorder frequently made it necessary to discard data that could not reliably be used because there was not always an ability to conclusively determine if the data logger was submerged at all times. The time series data present in appendix A are therefore discontinuous, but represent data that can be considered to be reliable because suspect data have been discarded.

Water temperatures between 32.0 and 36.5° underneath the Stevens recorder were common between the middle of October and the middle of March each year. During these five months, water temperatures occasionally dipped for a few hours to 30.0 to 31.0° when daily low tide cycles coincided with cooler air temperatures and nighttime hours. By the beginning or middle of April, the maximum daily water temperatures began to increase as sunlight intensity increased on the pupfish spawning shelf. By the end of April of each year, the maximum daily water temperature rose to 35.1 to 35.8°. Cooler temperatures in April and May of 1999 in 2000 infrequently occurred during low tide cycles, and on a few occasions the water temperatures dropped to 28.87 to 30.7°. The daily low water temperatures in 2001 during the months of April and May rarely went below 32.5°. During the summer months of June and July, the daily high water temperatures varied between years and were between 34.2 and 36.3° in 1999 and 2000, and between 33.9 and 35.8° in 2001. The mean daily low temperature during June and July for all three years was routinely between 29.8 and 33.2°. As the length of the daylight hours decreased in August and September, the mean daily high and low water temperature also decreased, and daily temperatures rarely went above 32.7 to 33.3°. In late September and much of October of 2000, unusually cool water temperatures occurred for a period of an hour or less during low tide events, and on occasion the water temperature dropped to 25.8 to 28.7°. On September 3, 2001, the water temperature

dipped as low as 23.82° during a rainstorm that brought flash flood waters in Devils Hole.

An evaluation of water temperature data collected at 15 minute intervals on the 15th day of each month between March and August demonstrate that elevated water temperatures exist underneath the Stevens recorder on the Devils Hole pupfish spawning shelf for varying amounts of time (Figure 5 and Table 1). The temporal pattern of increases in daily maximum water temperature and increases in the length of time when elevated temperatures are coincident with direct sunlight are similar to those in the middle of the spawning shelf, but the magnitude of thermal regime change is less pronounced. Underneath the Stevens recorder, the daily high water temperatures are less than 35° during every month except July, and the length of time that elevated temperatures exist when sunlight shines on the shelf is typically 1 to 1 1/2 hours less than those that occur in the middle of the spawning shelf.

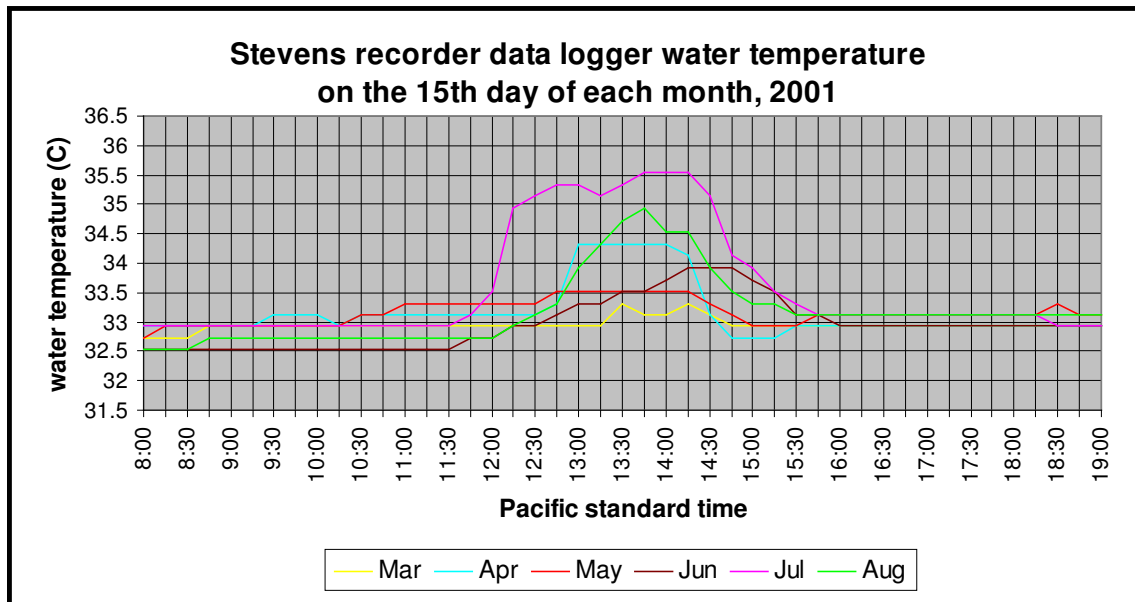


Figure 5. Continuous water temperature data collected at 15 minute intervals underneath the Stevens recorder on the 15th day of each month, 2001.

Devils Hole, Along West Wall of Spawning Shelf: this location was only monitored for a period of 15 months, and the temperature regime along the western wall of the Devils Hole pool was somewhat similar to the pattern underneath the Stevens recorder. In September 2000, the water temperatures routinely fluctuated between 30.4 and 35.5°. Low tide cycles and cool to cold air temperatures had a significant impact on water temperatures during the period between early October and the middle of November in 2000, when water temperatures occasionally dipped down to 24.3 to 25.0°; during this same time, the daily high water temperature rarely went above 32.5°. Between mid-February and early April 2001, the water temperature normally fluctuated between 28.7 and 33.2° along the southwest wall. Beginning in April, the daily high water temperatures

began to increase as the sun began to strike the spawning shelf and day length and the sun's elevation in the sky increased. The minimum water temperature during this month was consistently above 31°, and between April and June the daily high water temperature was consistent between 34 and 35°. Between June 10 and August, the daily high temperature was between 35 and 36°; on one occasion the temperature spiked as high as 37.7°. On September 3rd, 2001, a rainstorm caused the water temperature to drop to 24° for a several minutes. By mid-October, elevated water temperatures abated, and during the rest of the year the typical temperature regime was between 29 and 33°. The exception to this generalization occurred on multiple occasions for a period of an hour or two when temperatures dropped to 25.8° during low tide events and instances when the air temperature was especially low, and on two occasions the temperature in December dropped to 17.1° and 12.8°.

Devils Hole, Southern End of Spawning Shelf: the water temperature on the southern end of spawning shelf between February 10 and August 11, 2001 was consistently between 33 and 34°. This fact generally due to positioning of the data loggers in a small “pothole” like area at the very southern end of the spawning shelf. This area was shielded from direct sunlight and probably was influenced by intermittent upwelling of water from deeper depths.

School Spring Refugia, Deep Chamber and Shallow Shelf: water temperatures on the shallow shelf and the deep chamber in the School Spring refugia were consistently with one degree of one another; the data for both locations will therefore be described in a single narrative. The water temperature in the refugia was consistently between 23 and 28° between September 24 and October 7, 1999. On October 8, a sudden spike in water temperature increased the thermal regime to 36 to 38° for a period of one hour. The increase in water temperature was followed by a large-scale die off in fish numbers. After the initial temperature spike, the thermal regime entered a relatively stable period, and temperatures were commonly between 30 and 33.5°. Starting the third week of October 1999, the water temperature began a consistent downward decline, and by the first week in November, the temperatures as low as 15 to 17° occurred. In mid-November, water temperature gradually increased 10-11° over the course of a week, and through the month of December 1999, water temperatures were generally between 30 and 32°.

In 2000 the School Spring refugium water temperatures increased gradually from an average of 31 in January to an average of 34.5° in late July. On February 11th, the data logger in the shallow shelf area was lost when the fishing line tether that anchored the data logger was cut, and the unit could not be recovered from the fine silt that covered the shallow shelf. Water temperature data for the rest of 2000 and 2001 was only available for the deep chamber in the refugia. After August 2000, the water temperature in the refugia declined, and by December, the water was typically between 30 and 32°. In 2001, water temperatures between January 1 and mid-May varied between 28 and 33.6°. During the second half of May, water temperatures gradually declined from 32 to 23°. By early June, this trend began to reverse itself, and by mid-June, water temperatures were between 29 and 31°. During the second half of the year, the water in the refugia was

generally between 29 and 34°. During the first half of November 2001, the water temperature declined from 32 to 23° over a weeklong period, and then recovered to 32° by the middle of the month.

Point of Rocks Refugia, Deep Chamber and Shallow Shelf: water temperatures on the shallow shelf and the deep chamber in the Point of Rocks refugia were consistently within one to two degrees of one another; the results that describe changes in water temperatures for both locations will therefore be described in a single narrative. Water temperatures in the Point of Rocks refugia tended to always be cooler than those in the School Spring refugia; this fact was due to the fact that the water delivery systems for the two facilities are completely different. The School Spring refugia water is obtained from a well that pumps water in excess of 100°. Before water is delivered to the refugium, it is held in a cooling tank and then sent to the tank holding the fish. The Point of Rocks refugium obtains its water from a small spring located a few hundred meters west of the refugium. The water temperature of this spring is generally constant at 85-90° F. During the last three months of 1999, water temperatures at this site fell as low as 20 and at times were as high as 30.5; during most of this period the temperatures were between 25 and 29°. During 2000, most water temperatures were found to occur between 29 and 32°, and in 2001, most temperatures were between 30 and 32.5.

Discussion

Because pupfish populations in the two Ash Meadows refugia have not experienced unexplained and chronic population declines during the past several years, they will not be discussed further in this report.

In order to more fully understand the implications of the water temperature data that was collected in Devils Hole between 1999 and 2001, it is necessary to understand how Devils Hole water temperatures may have changed over time, and how the recently collected temperatures data may affect the Devils Hole pupfish. The latter topic is addressed in detail below by synthesizing the large amount of field and laboratory data that has been collected for other pupfish species.

Historical Trends in Devils Hole Water Temperature

A number of published accounts have provided water temperature data for Devils Hole. These data are summarized in Table 3. These values suggest that, with the possible exception of those collected by Gustafson and Deacon (1998), collectively suggest that the historical water temperatures in Devils Hole have been relatively constant. In Robert Rush Miller's classic text on pupfish taxonomy (1948), he provides a range of water temperature data that was collected by several investigators and summarized the data by stating that "...their readings show that it is remarkably constant seasonally and yearly." and that "The variation [in Devils Hole water temperature] of 32.8° C to 33.9° C represents records during all seasons of the year over a period of 15 years." One published account that specially describes the water temperature regime in the deeper

pool below the spawning shelf has stated that the water temperature remains a relatively constant 32° to a depth of at least 27 meters (Baugh and Deacon (1983).

Date of visit	Time of water temperature measurement	Reported temperature (°C)	Reference
March, 1930	???	93	Wales (1930)
April or May, 1939	???	33.5	Sumner and Sargent (1940)
1930-1947		Range 32.8-33.9, N=8, mean= 33.0	Miller (1948)
January 22, 1953	???	92	Walker and Eaken (1963)
1960?	???	33.4	La Rivers (1962)
December 9, 1966	???	92	Naff (1973)
December, 1966	???	33.5	Dudley and Larson (1976)
1967-1968, multiple measurements	???	33.4-34.0	James (1968)
April 1996	All day	32.1-33.8	Gustafson and Deacon (1998)
May 1997	All day	31.0-36.0	
June 1996	All day	32.5-34.2	

Table 3. Historical water temperature data for Devils Hole.

In contrast to most of the above-mentioned records, the data collected during the field work between 1999-2001 demonstrate that the water temperature in Devils Hole is not constant, and that the thermal regime between April and September consistently reached extremes that were as great as 35 to 36.5° Celsius. The data collected on the 5 meter shelf in 1999 and 2000 documented a constant temperature of 33.5 to 33.99°, in contrast to the 32° that were apparently recorded in the 1970s and early 1980s.

The three most likely explanations for the apparently discrepancy between historical and current water temperatures would appear to be that:

- A) The thermal regime in the aquatic environment of Devils Hole has increased, at least during those months when sunlight hits the spawning shelf.
- B) The historical data were not collected during a time of day or year when sunlight was shining on the spawning shelf, and there was not an ability to collect data during the period when elevated temperatures occurred.

C) Differences in instrumentation or the precise locations where historical data were collected are dissimilar to methods and techniques used in 1999-2001 and do not allow accurate comparisons and contrasts between old and new data.

The likelihood of explanation B appears to be lower, however, because Miller's 1948 monograph specifically mentions that temperature measurements were made during several months of the year, and James' (1969) thesis suggests that temperature was routinely monitored during her visits to Devils Hole; several of these visits occurred during months when water temperatures should have been elevated during periods when direct sunlight shone on the spawning shelf. There is a potential that explanation C is possible to some degree because documentation that describes where the historical data were collected can not be found. It is likely that many of the values that are listed in Table 3 were recorded near the southern or south-eastern end of the spawning shelf because this location is the area that is most easily accessed by Devils Hole visitors. Water temperatures underneath the Stevens recorder between 1999 and 2001 were lower than those that were found in the middle of the spawning shelf, but they are periodically higher than the values listed in Table 3. It therefore seems most likely that explanation A is true, i.e. water temperatures have increased slightly in Devils Hole, at least during periods when direct sunlight occurs on the spawning shelf.

Devils Hole Water Temperature in Comparison to Other Amargosa River Wetland Habitats

Devils Hole is located in the Amargosa River drainage along the Nevada-California border. A number of aquatic habitats along the Amargosa River are inhabited by various species or subspecies of pupfish. Depending on the specific location and the month of the year, portions of some of these aquatic environments are approximately the same temperature or warmer than the temperatures that exist at Devils Hole. In the Ash Meadows area, the spring source of Scruggs Spring which is occupied by the Warm Springs pupfish (*Cyprinodon nevadensis pectoralis*) has a temperature of 33° (Dudley and Larson 1976), and the orifice of Kings Pool, which has a temperature of 32°, is occupied by the Ash Meadows Amargosa pupfish (*Cyprinodon nevadensis mionectes*). Immature Ash Meadows Amargosa pupfish that were less than 15 millimeters (mm) in length have been observed to use shoreline areas of the upper Crystal Marsh in Ash Meadows that were as much as 36° (Threlhoff 1991). The now extinct Tecopa pupfish (*Cyprinodon nevadensis calidae*) utilized portions of the South Tecopa Hot Spring outflow that was 41-42° (Miller 1948), and the Amargosa River pupfish (*Cyprinodon nevadensis amargosae*) has been observed to be common in 42° water of the outflow of an artesian well known as Tecopa bore (Brown 1971). Portions of the marsh that is occupied by the Saratoga Springs pupfish (*Cyprinodon nevadensis nevadensis*) become extremely warm during the summer months, and may reach temperatures as high as 45° (Sada et al. 1997).

All of the above-mentioned aquatic habitats have thermal regimes that are dissimilar to that of Devils Hole in one or more ways, however. With the exception of the thermal spring sources, none of the aquatic habitats along the Amargosa River are as warm as

Devils Hole on a consistent basis, i.e., only a few have thermal regimes that are 33 or more degrees on a daily, seasonal, and yearly basis. All of the springs that do have orifices with temperatures that are 33° or higher also have outflows that become progressively cooler as the distance from the orifice increases. As an example, measurements on September 26, 1942 along the North Tecopa Hot Spring outflow demonstrated that water temperature cooled from 42.1° at the source to 32° at a point ~300 meters from the source (Miller 1948). Larger marshes that have shoreline areas that are warmer than Devils Hole during the summer months also are much larger in size. Saratoga Springs marsh and lower Crystal marsh during the summer are approximately 20,518 and 34,800 square meters (m²) in size respectively (Threlhoff 1991, Sada et al. 1997). These marshes also have much greater habitat heterogeneity than Devils Hole and do not have high water temperatures through the entire marsh, particularly where large amounts of emergent vegetation is present.

In contrast, the 12.11 square meters of the Devils Hole pupfish spawning shelf limits the amount of habitat diversity and microhabitats that are available to the pupfish; the shelf lacks emergent vegetation that might help to moderate high water temperatures that are caused by direct sunlight; and the deeper pool below the spawning shelf does not provide a thermal refuge that offers a substantially lower water temperature on a temporal or spatial basis. Collectively these characteristics create a thermal environment that is at a consistently high temperature, and the behavioral movements that are used by many, if not all, pupfish species to regulate their body temperatures (Barlow 1958, Feldmeth 1981) are an option that has limited utility for the Devils Hole pupfish. The ability to access cooler microhabitats during a portion of a particular 24 hour period has been thought to be important because the cooler periods (e.g. 22-32°) may act as important diel recovery or repair periods that may be necessary after fish have been exposed to temperatures near their upper thermal limits (Lowe and Heath 1969).

Devils Hole, is therefore unique among other pupfish habitats because it has several characteristics that, when taken in combination, trap the fish at an elevated temperature that they can not escape.

Ova, Eggs, and Embryos: Limiting Factors in a High Temperature Environment

A number laboratory studies have demonstrated that elevated water temperatures create measurable and often times significant effects that influence egg viability, hatching, and larval survival. Collectively, these studies demonstrate that even when adult and juvenile pupfish are able to tolerate, and may even prefer, water temperatures in excess of 34°, the earliest life stages that have a direct influence on the size and persistence of a pupfish population are especially sensitive to elevated water temperatures.

Aquarium studies conducted with a spectrum of water temperatures have provided evidence that the water temperature that female pupfish are acclimated to has a measurable impact on egg viability. These studies suggest that oogenesis is the most sensitive life history stage, and that a female's exposure to elevated temperatures can lead to incomplete oocyte maturation and noticeable egg abnormalities (Gerking 1981).

The most thorough developmental studies that have utilized pupfish collected along the Amargosa River drainage have utilized Saratoga Springs pupfish that were acclimated for 21 days at constant water temperatures and then exposed to constant water temperatures between 18 and 36° (Shrode and Gerking 1977, Gerking 1981). These studies have demonstrated that:

1. As water temperature increased from 30 to 36°, the mean proportion of days on which spawning occurred decreased, and nearly went to 0 at 36° (Figure 6A). At fluctuating temperatures between 28 and 38° or 30 and 39°, spawning occurred on approximately 22 percent of the days during the studies, as compared to spawning that occurred on 52% of the days when water temperatures fluctuated between 28 and 36° or 28 and 32°.
2. The mean number of eggs produced per spawning decreased as water temperatures increased (Figure 6B). As the constant thermal regime increased from 30 to 36°, the number of eggs produced declined from 10 eggs at 30° to 0 eggs at 36°. At fluctuating temperatures between 28 and 36° or 28 and 32°, the number of eggs produced during each spawning varied from 5.5 to 7.0, while the number of eggs produced at fluctuating temperatures between 28 and 38° or 30 and 39° was between 0.5 and 2.5.
3. Egg hatching success declined precipitously for eggs that developed and were incubated in progressively warmer water (Figure 6C). The percent normal hatching rate declined from 78% at 30° to 10% at 32°, and fell to 3% at 34°.
4. The mean number of eggs produced per gram of weight for each female declined from 8 at 30° to 0.5 at 36°.
5. At 32° and above, females produce a number of eggshells that do not contain yolk.
6. A significant inverse relationship exists between yolk diameter and water temperature, with smaller eggs being produced at higher constant and higher fluctuating temperatures.
7. The percentage of eggs that hatched when they were exposed to identical temperatures during oogenesis and incubation declined dramatically from ~78% at 30° to 0% at 36°.
8. Breeding coloration and spawning behavior may be normal at higher temperatures, e.g. 34 to 36°, but normal egg development is limited to cooler temperatures.

These results suggest that the thermal tolerance for oogenesis is narrower than the temperature tolerance of eggs during the period between spawning to hatching, and the temperature limits that govern normal adult or juvenile behavior or spawning. They also suggest that the acclimation temperature of the female during egg development affects the quality of eggs that are laid. Experiments conducted by these same investigators also suggest the reproductive temperature tolerance of Saratoga Springs pupfish, i.e. the ability of females to produce eggs that can successfully hatch when they develop at high temperatures could not be broadened, even when the fish's entire life was spent at higher temperatures (Gerking et al. 1979). These researchers also found that temperature compensation does not occur and that "...tolerance limits are fixed and fish trapped in

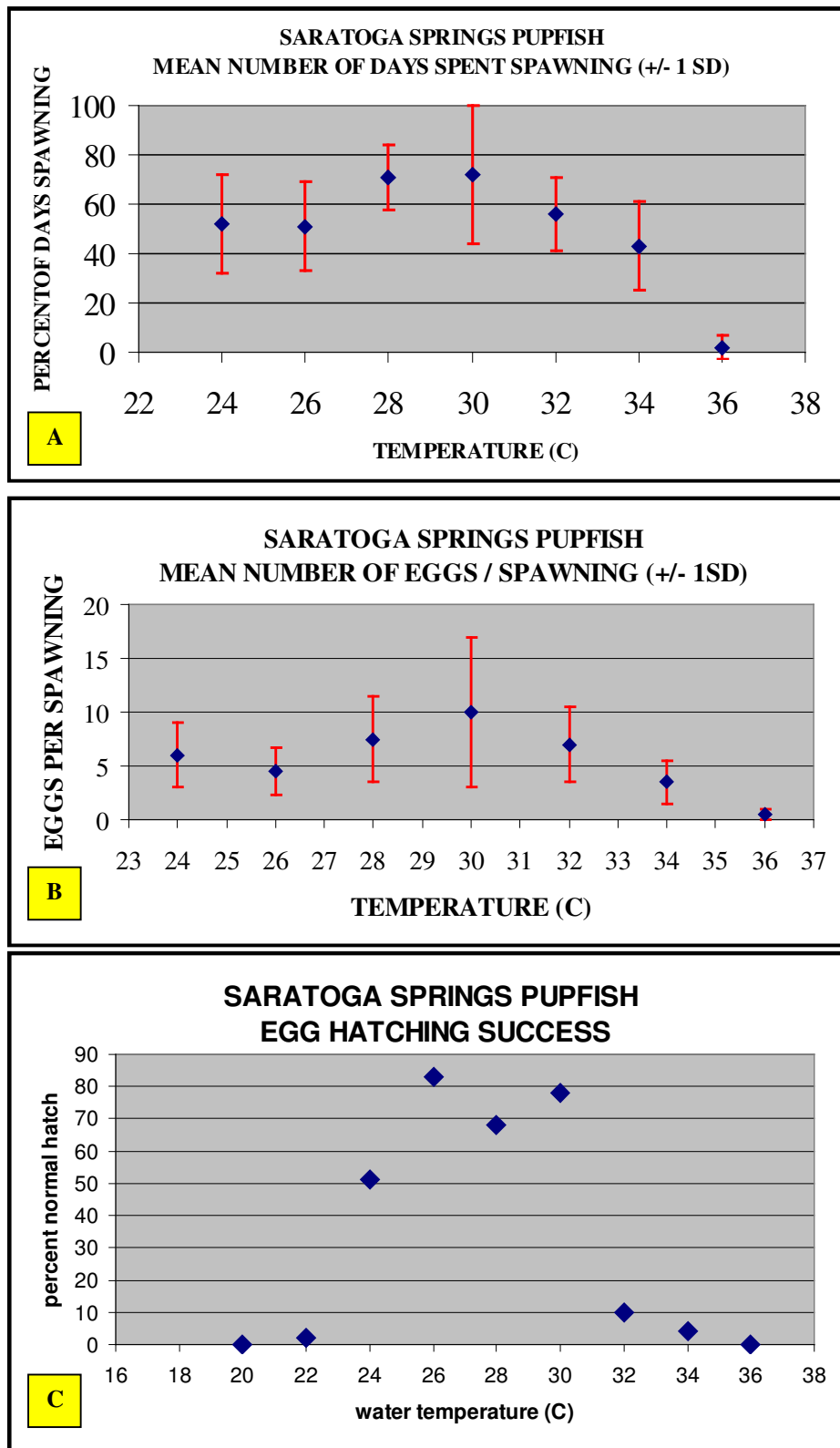


Figure 6 A, B, and C. Effects of constant water temperatures on various reproductive attributes of the Saratoga Spring pupfish. Data from Shrode and Gerking (1977) and Gerking (1981). Error bars represent one standard deviation.

water with marginal temperatures cannot adapt their reproductive performance to a satisfactory level, even though they are exposed to these conditions for a whole generation.” (Gerking 1981).

Other studies with species of pupfish that do not occur in the Amargosa River drainage have also demonstrated that eggs and fry are markedly more sensitive to elevated temperatures than adult or juvenile fish. Experiments conducted with Red River pupfish (*Cyprinodon rubrofluviatilis*) demonstrated that while at least a few of this species' eggs that were incubated at 36.4° survived until they hatched, there was a 75 percent decrease in egg survival as the incubation temperature increased from 34.2 to 36.4° (Echelle et al. 1972). Two larvae incubated at 35.8° had curled tails and swam in tight circles after they hatched, and probably would not have survived in a typical outdoor environment. This study utilized eggs from females that were maintained in 25-30°, and the eggs were derived from ova that were not exposed to the higher 33°+ degree temperatures that prevail in Devils Hole. Other studies have exposed adult Red River pupfish to two constant temperature regimes that consisted of 15 and 30° (Echelle et al. 1973). These studies demonstrated that adult fish that were held in warmer control chambers had, on average, lower mean egg diameters, lower gonosomatic indices, and lower absolute ovarian mass. Echelle et al. (1973) inferred that at higher temperatures, a higher proportion of assimilated energy is diverted to the production of somatic tissue, and less energy is diverted to development of ovarian tissue. These same authors also suggested that the lower reproductive state of the pupfish in the warmer experimental regime was the result of suppression of the early stages of oogenesis.

Studies with an another cyprinodont fish, *Fundulus confluentus*, have experimentally demonstrated that when this species is held for 45 days in two separate aquaria that were either 15 or 30°, the higher temperature water induced later phases of oocyte maturation, but retarded development of the earlier phases of oocyte development (Harrington 1959). This same study led the investigators to speculate that “...the retardation of early oogenesis by higher temperature reinforced by long days [i.e. 15 hours of daylight] suggests that either or both the amplitude of ovoposition and the number of spawners may be greater toward the each end of the spawning period, when temperatures are lower and days are shorter”.

Two separate studies that quantified the effects of different temperature regimes have also have been done with the desert pupfish (*Cyprinodon macularius*). Crear and Haydock (1971) reared desert pupfish at 22° for a period of four months. Following this acclimation period, pairs of fish were allowed to spawn in 22° water and the fertilized eggs were immediately placed in aerated chambers that were either 22 or 27°. The eggs that were placed in freshwater at 22° had a hatching success of 54%; the eggs that were placed in a 27° water bath had a 5.0 to 5.4% hatching success. Another study evaluated the effects of incubating eggs in a variety of temperature and dissolved oxygen regimes after the adults had been reared in 26-28° water (Kinne and Kinne 1962). This in-depth study yielded several important discoveries that can be summarized as follows:

1. Eggs that were incubated in approximately 100% air-saturated seawater of 35 p.p.t. salinity experienced markedly greater mortality at temperatures that were above 34° than at temperatures below 34° (Figure 7).
2. As water temperatures increase and exceed 34°, embryonic development decreases rapidly.
3. 100% of the eggs that were incubated at a constant temperature that equaled or exceeded 36.2° failed to hatch.
4. The thermal stability of embryos varies over time, and the stages between fertilization and gastrulation and the period toward the end of embryonic development appear to be especially sensitive to temperature.
5. An increase in water temperature from 12 to 23° during a 20 minute time frame killed eight of the nine embryos that were monitored; the ninth individual had structural and functional abnormalities and died four days after it hatched.
6. The mean total hatching length of fry that were incubated at 30, 32, 34, and 35° were 5.0, 4.3, 3.9, and 3.65 mm, respectively, thereby suggesting that fry that were hatched at high temperatures had a lower body condition than fry that were incubated at lower temperatures.
7. At 70% air saturation, the upper lethal temperature of incubation where 100% of the embryos died is 27.5 to 28° in freshwater.
8. “mortality rates proved, furthermore, to be a function of the light intensity to which eggs were exposed, and the quality and quantity of food offered to the parents.”
9. “...conditions of hypoxia tend to be more effective in stagnant water than in moving water of the same oxygen levels.”

Collectively these findings have direct application to Devils Hole because the water temperatures at this site consistently exceed the thresholds that caused 100% mortality of the embryos in the Kinne and Kinne (1962) study or caused markedly reduced reproductive activity in Saratoga Springs pupfish; the dissolved oxygen levels in Devils Hole are almost always lower than oxygen levels used in all of the above-mentioned laboratory studies; and the water in Devils Hole appears to have little or no current, which may suggest that flowing water conditions are not available to ameliorate elevated water temperatures or stagnant dissolved oxygen conditions.

Heat Tolerance of Adult Pupfish and the Relationship to Embryos and Eggs

The thermal tolerance of various species and subspecies of adult pupfish from the Amargosa River have been studied by multiple researchers. Investigations have revealed that individuals acclimated to progressively higher temperatures have an elevated thermal tolerance (Feldmeth et al. 1974).

Other studies, however, have demonstrated that pupfish have a finite ability to adapt to elevated thermal regimes. Studies that utilized Ash Meadows Amargosa pupfish, Devils Hole pupfish, Saratoga Springs pupfish, and Warm Springs pupfish that were not acclimated to the same temperature demonstrate that the mean upper temperature that

resulted in death of each pupfish taxa was within a one degree Celsius range (Brown and Feldmeth 1971, Feldmeth 1981). In studies where Amargosa River pupfish and Saratoga Springs pupfish were acclimated to 25 for 29° days, the upper lethal temperature of the two species was within one degree of each other (Brown and Feldmeth 1971). Both of these studies suggest that different populations of adult fish from different habitats along the Amargosa River had similar abilities to withstand extreme temperatures. Laboratory studies with Cottonball Marsh pupfish (*Cyprinodon salinus milleri*) and Amargosa River pupfish that were acclimated to 25° revealed that the critical thermal maximum for the two species was 40.7 and 40.8°, respectively (Otto and Gerking 1973, Brown and Feldmeth 1971). Thus, the critical thermal maximum for adult fish in two different species that were acclimated at the same temperature is essentially identical. These finding have led to a conclusion that a portion of the *Cyprinodon* genome consists of a strongly co-adapted, homeostatic, metabolic core of enzymes that have not evolved as a result of exposure to different thermal regimes, and that the temperature tolerance in different species are essentially controlled by a gene or genes that are shared by multiple pupfish taxa (Turner 1974).

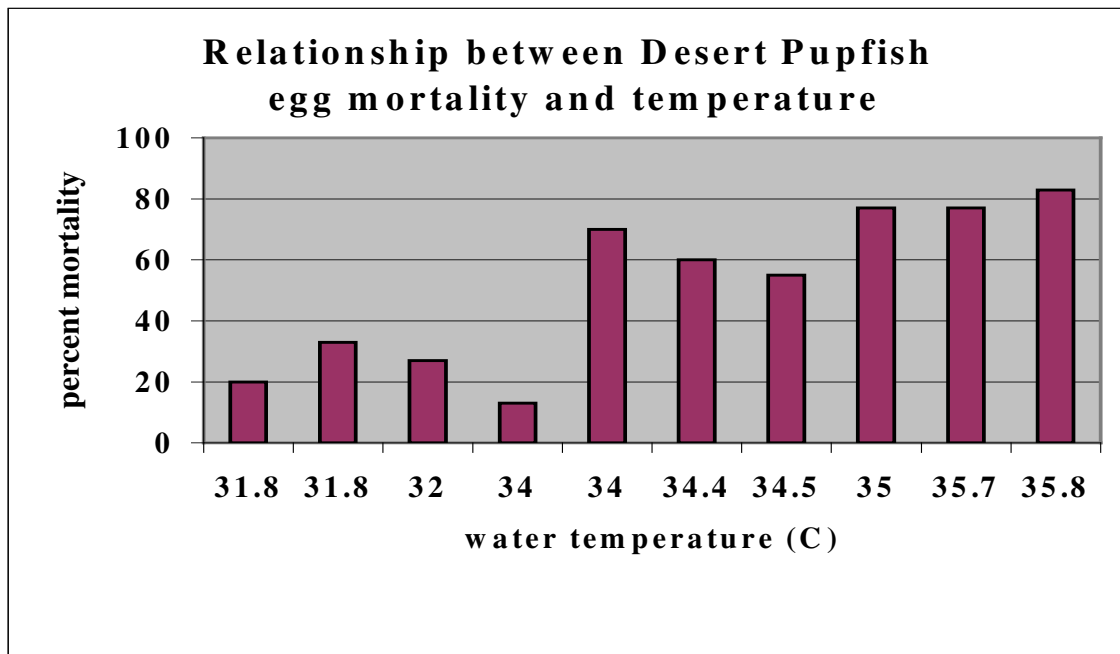


Figure 7. Percent mortality of desert pupfish embryos exposed to different water temperatures at approximately 100% air-saturated seawater of 35 p.p.t. salinity. Data from Kinne and Kinne (1962).

In an ironic twist of fate, confinement of a pupfish population to a thermal spring with a constant temperature may lead to a decreased scope of thermal tolerance (Hirshfield et al. 1980), thereby leading to a small but significant reduction in the ability to deal with environmental variability and thereby result in a narrower thermal niche (Feldmeth 1981).

Collectively, these studies suggest that adult pupfish along the Amargosa River share a common thermal tolerance when they are acclimated at the same temperature, and that taxa that are confined to a constant thermal regime (i.e. Devils Hole pupfish) may in fact have a narrower temperature tolerance than individuals that are exposed to environments that fluctuate 10 degrees or more. Because the thermal tolerance of adult pupfish throughout the Amargosa River is essentially the same, it is reasonable to expect that the thermal tolerance of Devils Hole pupfish eggs and embryos is similar to the different subspecies of *Cyprinodon nevadensis* that are also found in the same river drainage. If this relationship is true, it suggests that a one or three degree Celsius increase in temperature in Devils Hole above the level that has historically been recorded may be sufficient to kill embryos over a large fraction of the shelf. The relationship would also suggest that female Devils Hole pupfish may be experiencing elevated temperature regimes that further degrade their ability to produce viable eggs.

Other Water Temperature-Related Effects Not Directly Linked to Eggs and Embryos

Different water temperature regimes have a direct influence on multiple facets of the ecology of cyprinodont fish besides those that relate to eggs and embryos. Experiments have shown that spermatogenesis in adult killifish (*Fundulus heteroclitus*) is responsive to different temperature regimes (Burger 1939). The effects of elevated thermal regimes on the spermatogenic cycle of adult pupfish have not been documented. It has been shown, however, that *Fundulus* exposed to low temperatures did not produce viable sperm, and it might be reasonable to assume that at some point, elevated temperatures may create the same result.

Because fish are poikilotherms, water temperature has a direct influence on food intake and conversion of food to fish tissue. Young desert pupfish from water that exceeded 35° at Quitobaquito Spring, Arizona appeared to be hyperactively feeding, and it is likely that this feeding strategy was at least partially attributable to a high metabolic condition created by elevated temperatures (Lowe and Heath 1969). When these animals were dissected, their stomachs were found to be full, thereby suggesting that life in high temperature water would result in the need for a substantial source of energy that could be consumed and then assimilated. A more detailed investigation involving energy consumption and assimilation with desert pupfish from the Salton Sea were reared in saline water (35 p.p.t.), and suggested that growth rates in young fish were optimum at 30° at were slightly lower at 35° (Kinne 1960). This same study also showed that efficiency of food conversion is maximal at 20°, and decreases as temperature increases. At 35°, fish were found to have high metabolic rates and the lowest food conversion rates of any of the temperature regimes that were used during the laboratory studies. The optimum temperature for growth also was found to shift downward with increasing age: in young fish, a 30° temperature was optimum for growth, but in fish that were 28-30 weeks old, the optimum thermal regime for growth was in the 22-26° range. Small increases in Devils Hole water temperature might be expected to increase pupfish food intake as metabolism increases, but it is likely that the ability to assimilate or convert this food to biomass would be incrementally decreased. Because Devils Hole pupfish live in an energy limited environment (Deacon and Deacon 1979, Wilson and Blinn 2001), an

increase in food consumption rates may further tax already limited food resources, which in turn may affect the resources that females need as they produce ova.

The relatively high temperatures in Devils Hole, particularly on the spawning shelf, are also likely to influence the amount and types of food resources that are available to the pupfish. An amphipod belonging to the genus *Hyalella* is present in Devils Hole, and acts as a food resource for at least some pupfish (Minckley and Deacon 1975). Studies with another amphipod, *Hyalella montezuma*, have shown that survivorship of juveniles that are exposed to 30° is significantly less than when young animals are exposed to 27.5° temperatures (Oberlin and Blinn 1997). Temperature tolerance data for the multiple species of ostracods that are present in Devils Hole are not available. If, however, these animals are sensitive to changing thermal regimes, an increase in water temperature might explain the consistent presence of ostracods in pupfish stomachs that were collected between 1967 and 1969, but their complete absence on the spawning shelf when substrate samples were collected at two month intervals in 1999 and 2000 (Dean Blinn, Northern Arizona University, pers. comm.). In short elevated water temperatures probably have the potential to affect multiple species in Devils Hole. If this is true, it may be possible that a portion of the food resources in Devils Hole could be made increasingly scarce if water temperatures increase. This effect could have serious consequences, especially during the winter months when pupfish food is in short supply.

The Devils Hole Pupfish and the Pupfish Spawning Shelf: Two Inherent Limiting Factors

The importance of the shallowly flooded rock shelf in Devils Hole in the context of successful pupfish reproduction has long been recognized (James 1969, Deacon and Deacon 1979). This fact was clearly demonstrated when local groundwater pumping activities eliminated most of the water over the spawning shelf in the early 1970s and the pupfish population plummeted to 127 individuals in 1972. The spawning shelf is only 2.5 meters wide and 5.5 meters long. The depth of water on the shelf is 0 cm on the south end of the shelf, and gradually increases to a depth of 80 cm before descending precipitously to another shelf that lies in 3 meters of water. Recent studies have concluded that larval fish are absent from the 5-meter shelf and that their absence is likely due to low oxygen levels that are related to a general lack of algae production on that shelf (Gustafson and Deacon 1998). Because elevated dissolved oxygen levels are apparently necessary to promote the survival and development of eggs and embryos, and the vast majority of the underwater environment that is utilized by adult pupfish lacks well developed algal growth, the long term persistence of the Devils Hole pupfish is inherently tied to the maintenance of a suitable nursery area on the spawning shelf. As the history of the 1970s has shown, factors that degrade the quality of the nursery habitat on the spawning shelf are likely to have serious consequences that affect the number of pupfish in Devils Hole.

The Devils Hole pupfish also has multiple life history characteristics that make it inherently vulnerable to stochastic extinction events. Each individual only has a life span of 1 to 1 1/2 years (James 1969, Deacon et al. 1995). Genetic diversity of the species, and the genome that is presumably available to react to changing environmental conditions is extremely low relative to other pupfish species (Turner 1974, Echelle and

Dowling 1992, Duvernell and Turner 1999, Wilcox 2001) and the effective population size for the population of animals in Devils Hole is probably less than 50 individuals. Monitoring of the species during the past 30 years has never shown that the species is capable of the explosive population growth that is common to other pupfish taxa. The number of eggs produced per female is very low compared to other *Cyprinodon* taxa (Minckley and Deacon 1973), and the viability of eggs that were laid in a laboratory setting that was designed to mimic *in-situ* conditions was extremely low (Deacon et al. 1995).

The combination of inherit and immutable life history traits and the constraints of having one small nursery area therefore makes successful recruitment of young animals into the Devils Hole pupfish population essential on a yearly basis. The inability to successfully produce large to modest numbers of young that are recruited into the population each year will reduce the overall size of the population, and small populations are disproportionately at greater risk of extinction.

Synthesis and Conclusion

Water temperature affects the metabolism, activity level, reproductive success, behavior, and population structure of fish populations. Very few fish populations live in a thermal regime that is as consistently warm without an ability to escape to cooler microhabitats as the pupfish that inhabit Devils Hole. This fact therefore has a significant impact on the ecology of the fish and the plant and animals species that share that ecosystem. The warm thermal regime also creates stresses that likely affect the reproductive output of the adults that engage in spawning activity.

Most of the genetics studies that have explored the genetic properties of the different pupfish taxa along the Amargosa River have shown that genetic differences between the different species and subspecies are not markedly different. Other studies that have explored the thermal tolerances of adult pupfish in the Amargosa River drainage and elsewhere have shown that it does not vary by more than 2-3°. These studies collectively suggest that the physiology and embryonic ecology of the *Cyprinodon diabolis* and *Cyprinodon nevadensis* are likely similar, and that the latter species can serve as a useful surrogate for inferring the reproductive ecology of the Devils Hole pupfish.

A number of laboratory studies have demonstrated that when pupfish ova undergo oogenesis at water temperatures that become progressively warmer above 30°, the viability of the eggs that are produced and then spawned is measurably lower. Above 32°, egg development temperature tolerances rapidly decrease with each one degree rise in temperature. All of the Devils Hole pupfish females that produced ova in 1999 through 2001 were, with few exceptions, constantly exposed to water temperatures that were at least 33. If female pupfish remained on the spawning shelf during a significant portion of the season when spawning has been historically noted, i.e. March-June, they were also exposed to temperatures that were as high as 35-36° for a period of three to six hours.

When other pupfish taxa are exposed to these sorts of thermal regimes, reproductive success was virtually zero.

Other investigations suggest that young embryos are, at least during some portion of their development, sensitive to temperatures in excess of 33°. It is critical to remember that most of the eggs and embryos that were used during various laboratory studies had the benefit of developing in oxygenated conditions that do not routinely exist in Devils Hole. The process of embryonic development in the 35-80% oxygen saturation conditions that exist in Devils Hole (Deacon et al. 1995) therefore is likely to create an environment that is more stress than any of the embryos experienced in many of the above-mentioned laboratory studies.

It is important to remember that, unlike adult and juvenile fish, eggs, embryos, and early fry are not capable of moving to more benign thermal regimes if temperatures become extreme; they must experience the full brunt of the thermal regime where they are laid until development progresses to a point where they become mobile. In that sense, the Devils Hole spawning shelf serves as a nursery when environmental conditions are favorable, and as a population sink when conditions become adverse.

It is likely that the combination of high temperature, and effects of other environmental stresses in Devils Hole including but not limited to, low oxygen, act to inhibit successful reproduction. It is also likely that these factors act, at a minimum in an additive manner, and more likely in a synergistic fashion. Because low oxygen levels and high water temperatures each have the ability to kill eggs and embryos, and because both of these environmental attributes exist as extreme conditions in the Devils Hole environment, it is likely that small changes in either variable will significantly influence recruitment and the overall size (and ultimately the persistence) of the endemic pupfish population.

The water temperature data that is available for Devils Hole suggests that the water temperature at this site may have increased over time. If two to three degree increases in the daily high water temperature across the pupfish spawning shelf have occurred during the past seven years, these elevated temperatures may be responsible for all or part of the apparent decline in fish numbers since 1996. If increases in water temperature have not occurred during the past seven years, the immutable nature of the pupfish's reproductive biology makes this species susceptible to population declines if the water temperature does increase in the future.

The number of Devils Hole pupfish during the last seven fall pupfish counts has been on a consistent downward trend. The number of fish observed during the spring pupfish counts has not thus far experienced a downward turn. This may suggest that the overall decline in fish numbers is due to reductions in lower reproductive output during the spring and summer months, and that the overall carrying capacity of Devils Hole, at least during the winter months, is not responsible for the decline in fish numbers.

Recruitment in pupfish numbers in 2001, unlike all of the previous 30 years of population counts, did not occur. As the number of pupfish becomes smaller, the effective

population size decreases, and the potential for significant fry recruitment becomes less. This fact suggests that proactive management of the species becomes increasingly more imperative as fish numbers dwindle. Potential options for increasing the persistence of the pupfish population in Devils Hole are provided below.

Management Recommendations

1. Only three backup populations of the Devils Hole pupfish occur. In the event of a complete loss of pupfish in Devils Hole, the refugia fish will offer the only hope of restoring the species to its native habitat. Each of the refugia have a unique set of attributes that limit their success in maintaining consistent numbers of fish. Many of the problems related to the refugia have historically been related to maintenance problems. Some of these problems are readily fixed, and others will require the development of redundant mechanisms or monitoring protocols that increase the potential that target temperatures can be maintained. The limitations and benefits of the refugia have been summarized by Threlhoff (2002), and indicate that successful refugia management will require considerations related to the maintenance of the entire pupfish genome.
2. Carefully controlled laboratory experiments should be conducted with an effort to better understanding the relationship between Devils Hole pupfish's reproductive ecology and ambient water temperatures. Dollars for completing this task are currently available in the Death Valley National Park budget. If Devils Hole pupfish can not be used for the experiments, the Ash Meadows Amargosa pupfish can likely used as a surrogate.
3. Managers should explore mechanisms that would reduce the temperature on the Devils Hole pupfish spawning shelf. It will obviously be necessary to utilize a mechanism that does not affect the primary productivity in the Devils Hole ecosystem. It may be most prudent to conduct a pilot study on a small portion of the spawning shelf. In the event that a management action is exercised, it will be critical to coincidentally conduct a carefully crafted monitoring effort to assess the success or failure of the management action.

Literature Cited

- Barlow, G.W. 1958. Daily movements of desert pupfish *Cyprinodon macularius*, in shoreline pools of the Salton Sea, California. *Ecology* 39:580-587.
- Baugh, T.M., and J.E. Deacon. 1983. Daily and yearly movement of the Devils Hole pupfish *Cyprinodon diabolis* Wales in Devil's Hole, Nevada. *Great Basin Nat.* 43(4):592-596.
- Brown, J.H. 1971. The desert pupfish. *Sci. Amer.* 225(5):104-110.
- Brown, J.H., and C.R. Feldmeth. 1971. Evolution in constant and fluctuating environments: thermal tolerances of desert pupfish (*Cyprinodon*). *Evolution* 25:390-398.
- Burger, J.W. 1939. Some experiments on the relation of the external environment to the spermatogenic cycle of *Fundulus heteroclitus* (L.). *Biol. Bull.* 77:96-103.
- Crear, D., and I. Haydock. 1971. Laboratory rearing of the desert pupfish, *Cyprinodon macularius*. *Fishery Bull.* 69:151-156.
- Deacon, J.E., and M.S. Deacon. 1979. Research on endangered fishes in the national parks with special emphasis on the Devils Hole pupfish. Pages 9-19 in R.M. Linn, editor. *Proc. 1st. Conf. Sci. Res. Nat. Parks*, vol. 1. U.S. Dept. Int. NPS Trans. & Proc. Ser. 5, Washington, D.C.
- Deacon, J.E., F.R. Taylor, and J.W. Pedretti. 1995. Egg viability and ecology of Devils Hole pupfish: insights from captive propagation. *Southwest. Nat.* 40(2):216-223.
- Dudley, W.W., Jr., and J.D. Larson. 1976. Effect of irrigation pumping on desert pupfish habitats in Ash Meadows, Nye County, Nevada. *U.S. Geol. Surv. Prof. Pap.* 927:1-52.
- Duvernell, D.D., and B.J. Turner. 1999. Variation and divergence of Death Valley pupfish populations at retrotransposon-defined loci. *Molecular Biology and Evolution* 16:363-371.
- Echelle, R.R., and T.E. Dowling. 1992. Mitochondrial DNA variation and the evolution of the Death Valley pupfishes (*Cyprinodon*, *Cyprinodontidae*). *Evolution* 46(1):193-206.
- Echelle, A.A., C. Hubbs, and A.F. Echelle. 1972. Developmental rates and tolerances of the Red River pupfish, *Cyprinodon rubrofluviatilis*. *Southwest. Nat.* 17(1):55-60.
- Echelle, A.A., S. Wilson, and L.G. Hill. 1973. The effects of four temperature-daylength combinations on ovogenesis in the Red River pupfish, *Cyprinodon rubrofluviatilis* (*Cyprinodontidae*). *Southwest. Nat.* 18(2):229-239.
- Feldmeth, C.R. 1981. The evolution of thermal tolerance in desert pupfish (genus *Cyprinodon*). Pages 357-384 in R.J. Naiman and D.L. Soltz, editors. *Fishes in North American deserts*. New York: John Wiley & Sons.

- Feldmeth, C.R., E.A. Stone, and J.H. Brown. 1974. An increased scope for thermal tolerance upon acclimating pupfish (*Cyprinodon*) to cycling temperatures. *J. Comp. Physiol.* 89:39-44.
- Gerking, S.D. 1981. The contribution of the desert pupfish (*Cyprinodon nevadensis*) to fish reproduction in stressful environments. Pages 335-356 in R.J. Naiman and D.L. Soltz, editors. *Fishes in North American deserts*. New York: John Wiley & Sons.
- Gerking, S.D., R.M. Lee, and J.B. Shrode. 1979. Effects of generation-long temperature acclimation on reproductive performance of the desert pupfish *Cyprinodon n. nevadensis*. *Physiol. Zool.* 52:113-120.
- Gustafson, E.S., and J.E. Deacon. 1997. Distribution of larval Devils Hole pupfish, *Cyprinodon diabolis* Wales, in relation to dissolved oxygen variation in Devils Hole. Unpublished report prepared for the National Park Service, Death Valley National Park. Contract No. 1443PX813095341. 61 pp.
- Harrington, R.W. 1959. Effects of four combinations of temperature and daylength on the ovogenetic cycle of a low-latitude fish *Fundulus confluentus* Goode and Bean. *Zoologica* 44:149-168.
- Hirshfield, M.F., C.R. Feldmeth, and D.L. Soltz. 1980. Genetic differences in physiological tolerances of Amargosa pupfish (*Cyprinodon nevadensis*) populations. *Science* 207:999-1001.
- James, C.J. 1969. Aspects of the ecology of the Devil's Hole pupfish, *Cyprinodon diabolis* Wales [unpublished M.S. thesis] Las Vegas: Univ. Nevada. 70 pp.
- Kinne, O. 1960. Growth, food intake and food conversion in a euryplastic fish exposed to different temperatures and salinities. *Physiol. Zool.* 33:288-317.
- Kinne, O., and E.M. Kinne. 1962. Rates of development in embryos of a cyprinodont fish exposed to different temperature-sailinity-oxygen combinations. *Can J. Zool.* 40:231-253.
- La Rivers, I. 1962. *Fishes and fisheries of Nevada*. Carson City: Nev. Fish & Game Commission. 782 pp.
- Lowe, C.H., and W.G. Heath. 1969. Behavioral and physiological reponses to temperature in the desert pupfish *Cyprinodon macularius*. *Physiol. Zool.* 42:53-59.
- Miller, R.R. 1948. The Cyprinodont fishes of the Death Valley System of eastern California and southwest Nevada. *Misc. Publ. Mus. Zool. Univ. Mich.*, 68:1-155.
- Minckley, C.O., and J.E. Deacon. 1973. Observations on the reproductive cycle of *Cyprinodon diabolis*. *Copeia* 1973(3):610-613.
- Minckley, C.O., and J.E. Deacon. 1975. Foods of the Devil's Hole pupfish, *Cyprinodon diabolis* (Cyprinodontidae). *Southwest. Nat.* 20(1):105-111.

- Naff, R.L. 1973. Hydrogeology of the southern part of the Amargosa Desert in Nevada. Masters thesis, University of Nevada, Reno.
- Naiman, R.J., S.D. Gerking, and T.D. Ratcliff. 1973. Thermal environment of a Death Valley pupfish. *Copeia* 1973(2):366-369.
- Oberlin, G.E., and D.W. Blinn. 1997. The affect of temperarure on the metabolism and behaviour of an endemic amphipod, *Hyalella montezuma*, from Montezuma Well, Arizona, U.S.A. *Freshwater Biology* 37:55-59.
- Otto, R.G., and S. D. Gerking. 1973. Heat tolerance of a Death Valley pupfish (Genus *Cyprinodon*). *Physiol. Zool.* 46(1):43-49.
- Sada, D.W., K.P. Pindel, D.T. Threlloff, and J.E. Deacon. 1997. Spatial and temporal variability of pupfish (genus *Cyprinodon*) habitat and populations at Saratoga Springs and the lower Amargosa River, Death Valley National Park, California. Report prepared for the National Park Service, Death Valley National Park. 99 pp. + 3 appendices.
- Shrode, J.B., and S.D. Gerking. 1977. Effects of constant and fluctuating temperatures on reproductive proformance of a desrt pupfish *Cyprinodon n. nevadensis*. *Physiol. Zool.* 50(1):1-10.
- Sumner, F.B., and M.C. Sargent. 1940. Some observations on the physiology of warm spring fishes. *Ecology* 21(1):45-54.
- Threlloff, D.L. 1991. Threatened and endangered species use of a restored marsh on the Ash Meadows National Wildlife Refuge. Report prepared for the U.S. Fish and Wildlife Service, Ash Meadows National Wildlife Refuge, Nevada. 22 pp. + 4 appendices.
- Threlloff, D.L. 2002. Draft annotated bibliography of articles related to the Devils Hole pupfish and refugia populations. Unpublished report prepared for Death Valley National Park. 11 pp.
- Turner, B.J. 1974. Genetic divergence of Death Valley pupfish species: biochemical versus morphological evidence. *Evolution* 28(2):81-294.
- Wales, J.H. 1930. Biometrical studies of some races of cyprinodont fishes, from the Death Valley region, with description of *Cyprinodon diabolis* n. sp. *Copeia* 1930(3):61-70.
- Walker, G.E., and T.E. Eakin. 1963. Geology and ground-water of Amargosa Desert, Nevada-California. Nev. Dept. Conserv. and Nat. Res. Ground-water Res. Recon. Ser. Rept. 14. 45 pp.

Wilcox, J. 2001. Behavioral, morphometric, and genetic surveys of natural and artificial populations of the Devils Hole pupfish, *Cyprinodon diabolis*. Report prepared for the National Park Service, Death Valley National Park. 60 pp.

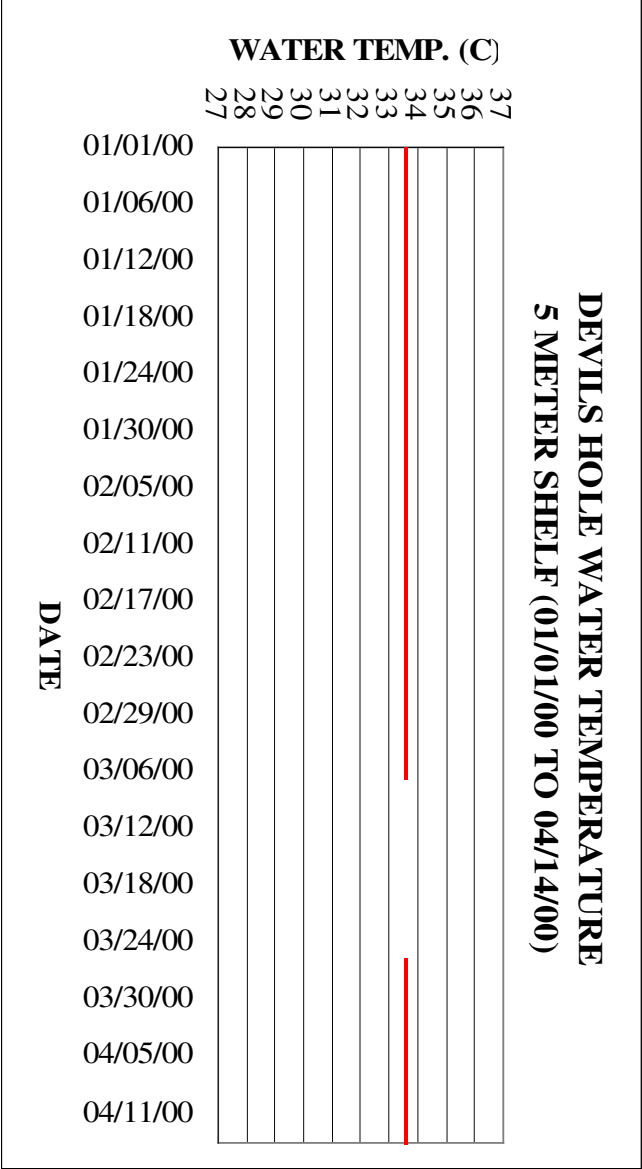
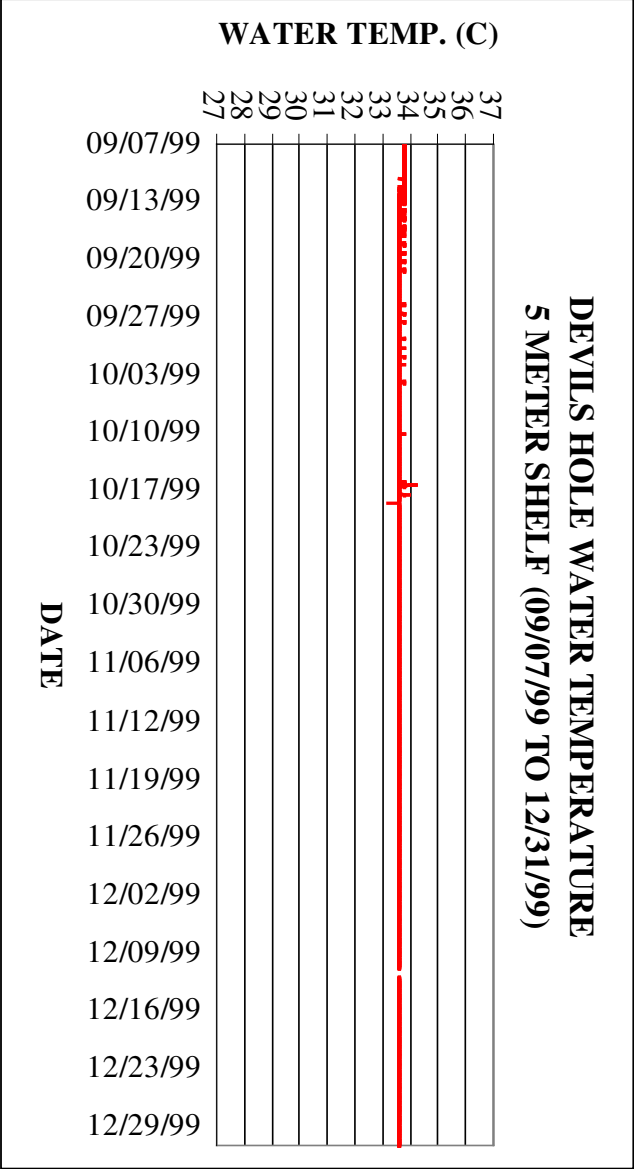
Wilson, K.P, and D.W. Blinn. 2001. Devils Hole energetics /community relationships: Death Valley National Park two-year progress report. Report prepared for the U.S. Biological Resources Division, U.S. Geological Survey. Project No. 7530. 51 pp.

APPENDIX A

INDEX TO WATER TEMPERATURE GRAPHS AND TABLES

Page	Figure: Title
A	Graph: Devils Hole water temperature 5 meter shelf (09/07/99 TO 12/31/99)
A	Graph: Devils Hole water temperature 5 meter shelf (01/01/00 TO 04/14/00)
B	Table: Devils Hole water temperature 5 meter shelf (September to December, 1999)
C	Table: Devils Hole water temperature 5 meter shelf (January to April, 2000)
D	Graph: Devils Hole water temperature midshelf (01/01/99 TO 06/30/99)
D	Graph: Devils Hole water temperature midshelf (07/01/99 TO 12/31/99)
E	Graph: Devils Hole water temperature midshelf (01/01/00 TO 06/30/00)
E	Graph: Devils Hole water temperature midshelf (07/01/00 TO 12/31/00)
F	Graph: Devils Hole water temperature midshelf (01/01/01 TO 06/30/01)
F	Graph: Devils Hole water temperature midshelf (07/01/01 TO 12/31/01)
G	Table: Devils Hole water temperature midshelf (January to December, 1999)
H	Table: Devils Hole water temperature midshelf (January to December, 2000)
I	Table: Devils Hole water temperature midshelf (January to December, 2001)
J	Graph: Devils Hole water temperature Stevens recorder (01/01/99 TO 06/30/99)
J	Graph: Devils Hole water temperature Stevens recorder (07/01/99 TO 12/31/99)
K	Graph: Devils Hole water temperature Stevens recorder (01/01/00 TO 06/30/00)
K	Graph: Devils Hole water temperature Stevens recorder (07/01/00 TO 12/31/00)
L	Graph: Devils Hole water temperature Stevens recorder (01/01/01 TO 06/30/01)
L	Graph: Devils Hole water temperature Stevens recorder (07/01/01 TO 12/31/01)
M	Table: Devils Hole water temperature Stevens recorder (January to December, 1999)
N	Table: Devils Hole water temperature Stevens recorder (January to December, 2000)
O	Table: Devils Hole water temperature Stevens recorder (January to December, 2001)
P	Graph: Devils Hole water temperature west wall (September to November, 2000)
P	Graph: Devils Hole water temperature west wall (February to December, 2001)
Q	Table: Devils Hole water temperature west wall (September to November, 2000)
R, S	Table: Devils Hole water temperature west wall (February to December, 2001)
T	Graph: Devils Hole water temperature south pothole SN568 (February to August, 2001)
U	Table: Devils Hole water temperature south pothole SN568 (February to August, 2001)
V	Graph: School Spring refugia water temp., shallow shelf (September 1999 to February 2000)
W, X	Table: School Spring refugia water temp., shallow shelf (September 1999 to February 2000)
Y	Graph: School Spring refugia water temp., deep chamber (September to December 1999)
Y	Graph: School Spring refugia water temp., deep chamber (January to June 2000)
Z	Graph: School Spring refugia water temp., deep chamber (July to December 2000)
Z	Graph: School Spring refugia water temp., deep chamber (January to June 2001)
AA	Graph: School Spring refugia water temp., deep chamber (July to November 2001)
BB, CC	Table: School Spring refugia water temp., deep chamber (September to December 1999)
DD	Table: School Spring refugia water temp., deep chamber (January to December 2000)
EE, FF	Table: School Spring refugia water temp., deep chamber (January to December 2001)
GG	Graph: Point of Rocks refugia water temp., shallow shelf (September to December 1999)
GG	Graph: Point of Rocks refugia water temp., shallow shelf (January to June, 2000)
HH	Graph: Point of Rocks refugia water temp., shallow shelf (July to December, 2000)
HH	Graph: Point of Rocks refugia water temp., shallow shelf (January to April, 2001)
II	Table: Point of Rocks refugia water temp., shallow shelf (September to December 1999)
JJ	Table: Point of Rocks refugia water temp., shallow shelf (January to December, 2000)
KK	Table: Point of Rocks refugia water temp., shallow shelf (January to April, 2001)
LL	Graph: Point of Rocks refugia water temp., deep chamber (September to December 1999)
LL	Graph: Point of Rocks refugia water temp., deep chamber (January to June, 2000)

MM	Graph: Point of Rocks refugia water temp., deep chamber (July to December, 2000)
MM	Graph: Point of Rocks refugia water temp., deep chamber (January to November, 2001)
NN	Table: Point of Rocks refugia water temp., deep chamber (September to December 1999)
OO	Table: Point of Rocks refugia water temp., deep chamber (January to December, 2000)
OO	Table: Point of Rocks refugia water temp., deep chamber (January to November, 2001)



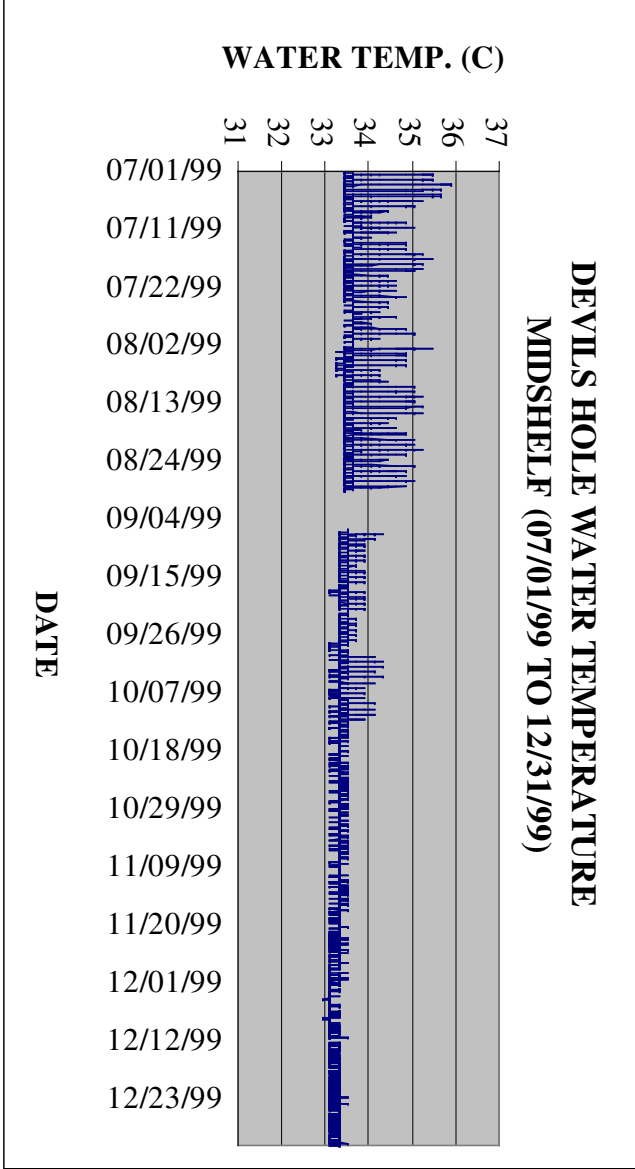
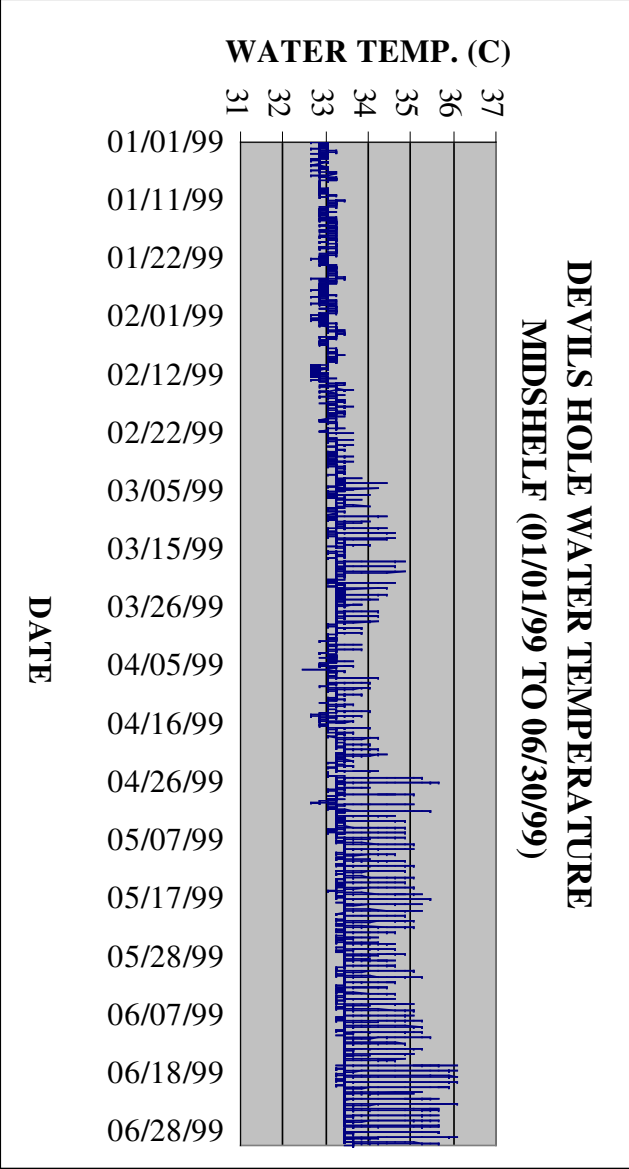
5 meter datalogger # of 15 minute readings
1999

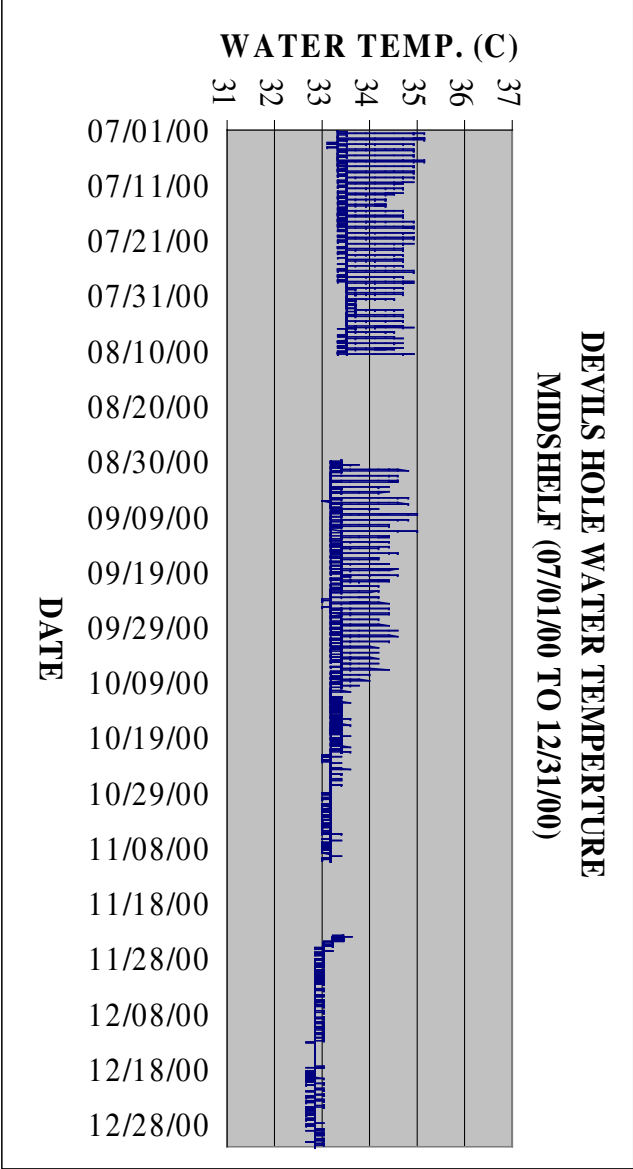
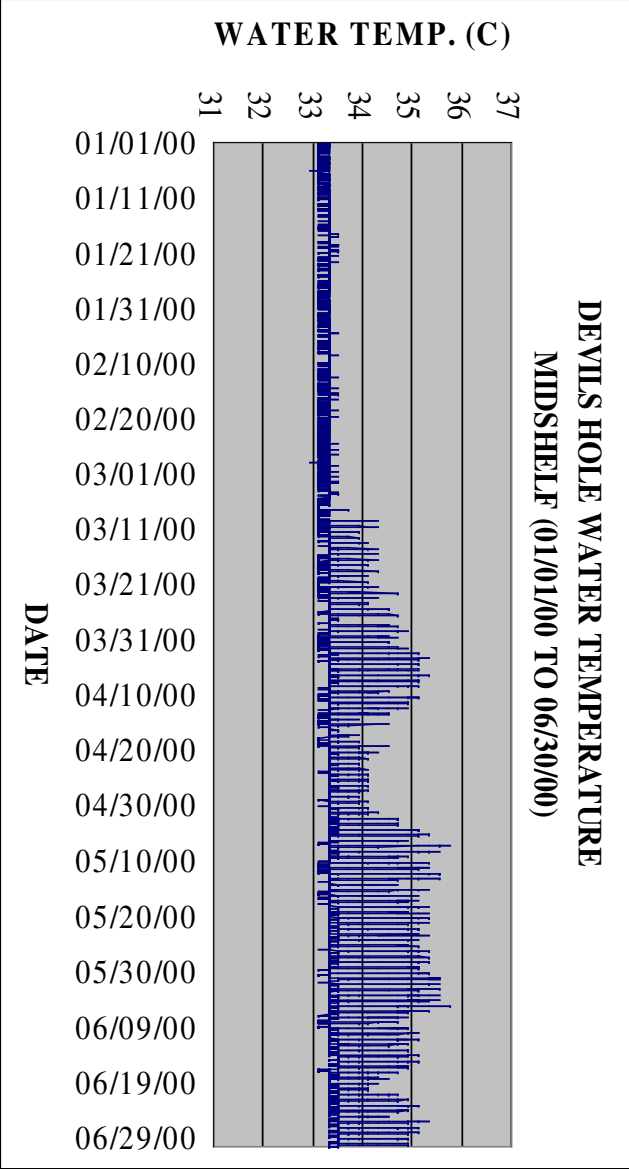
month	January	February	March	April	May	June	July	August	September	October	November	December
#taken/#possible									2329/2880	2953/2976	2880/2880	2866/2976
temp												
27.00-27.49									0	0	0	0
27.50-29.90									0	0	0	0
28.00-28.49									0	0	0	0
28.50-28.99									0	0	0	0
29.00-29.49									0	0	0	0
29.50-29.99									0	0	0	0
30.00-30.49									0	0	0	0
30.50-30.99									0	0	0	0
31.00-31.49									0	0	0	0
31.50-31.99									0	0	0	0
32.00-32.49									0	0	0	0
32.50-32.99									0	0	0	0
33.00-33.49									0	1	0	0
33.50-33.99									2329	2950	2880	2866
34.00-34.49									0	2	0	0
34.50-34.99									0	0	0	0
35.00-35.49									0	0	0	0
35.50-35.99									0	0	0	0
36.00-36.49									0	0	0	0
36.50-36.99									0	0	0	0
37.00-37.49									0	0	0	0
37.50-37.99									0	0	0	0

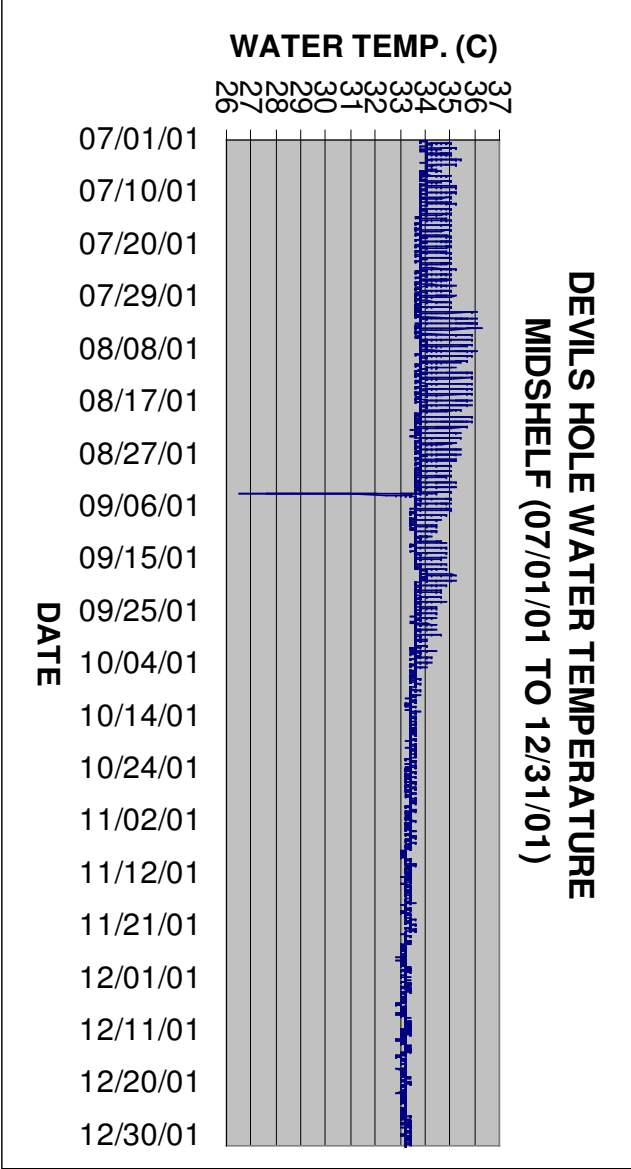
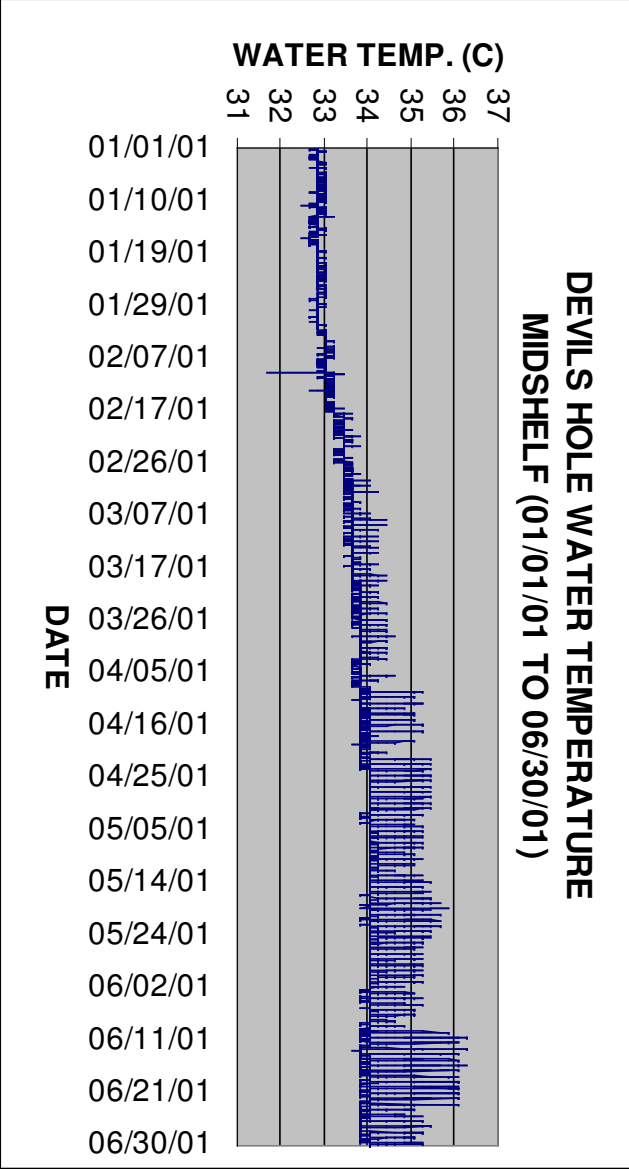
**5 meter data
logger
2000**

of 15 minute readings

month		January	February	March	April	May	June	July	August	September	October	November	December
#taken/#possible		2977/2977	2754/2784	1127/2976	1393/2880								
temp													
27.00-27.49		0	0	0	0								
27.50-29.90		0	0	0	0								
28.00-28.49		0	0	0	0								
28.50-28.99		0	0	0	0								
29.00-29.49		0	0	0	0								
29.50-29.99		0	0	0	0								
30.00-30.49		0	0	0	0								
30.50-30.99		0	0	0	0								
31.00-31.49		0	0	0	0								
31.50-31.99		0	0	0	0								
32.00-32.49		0	0	0	0								
32.50-32.99		0	0	0	0								
33.00-33.49		0	0	0	0								
33.50-33.99		2977	2754	1127	1393								
34.00-34.49		0	0	0	0								
34.50-34.99		0	0	0	0								
35.00-35.49		0	0	0	0								
35.50-35.99		0	0	0	0								
36.00-36.49		0	0	0	0								
36.50-36.99		0	0	0	0								
37.00-37.49		0	0	0	0								







midshelf 1999 # of 15 minute readings

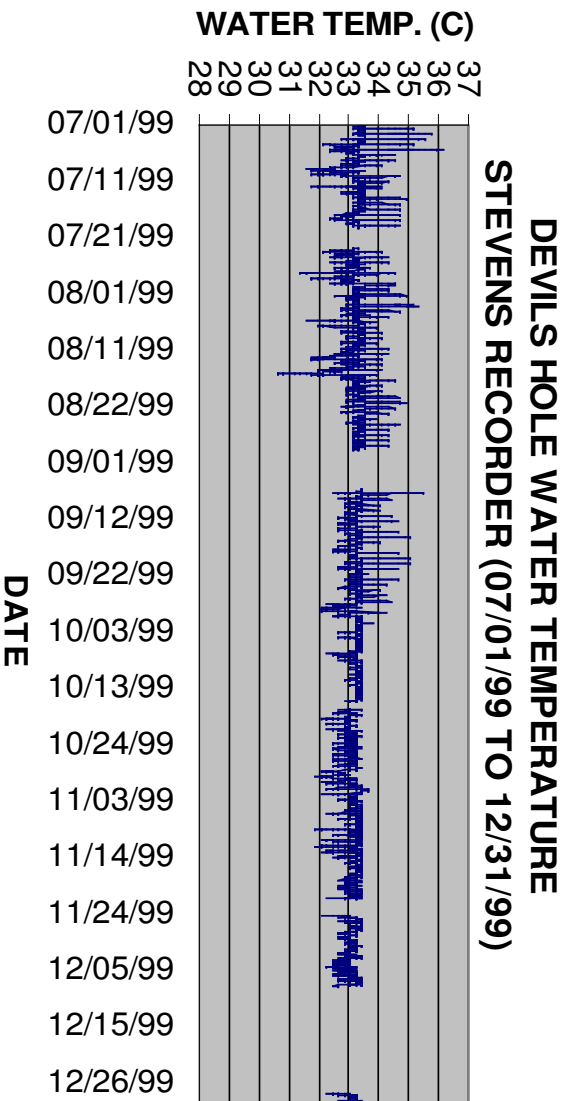
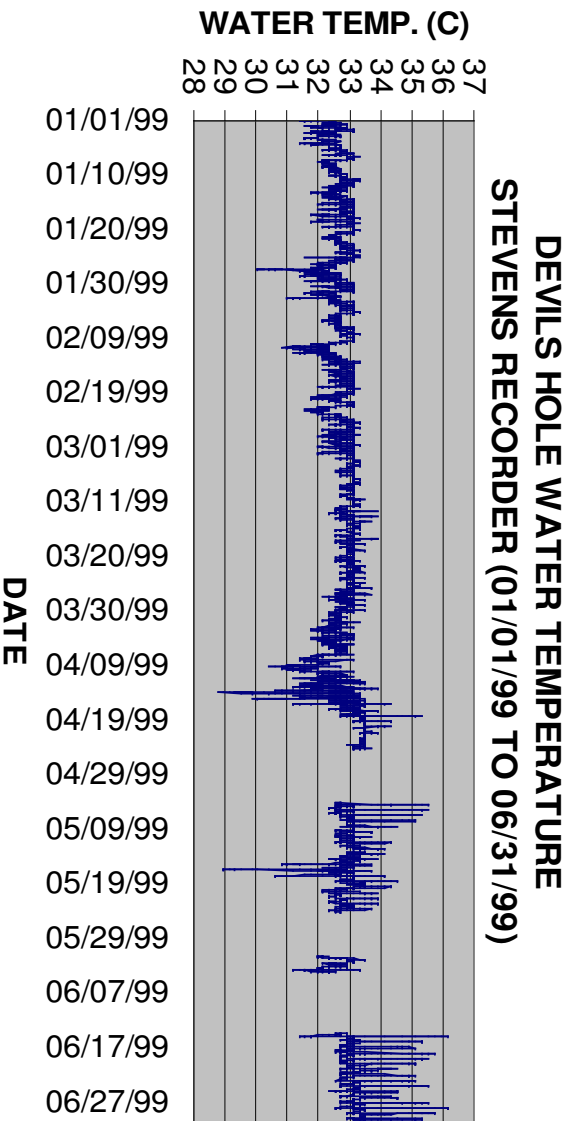
month	January	February	March	April	May	June	July	August	September	October	November	December
#taken/#possible	2976/2976	2689/2689	2946/2976	2866/2880	2976/2976	2872/2880	2972/2977	2816/2976	2330/2881	2976/2976	2880/2880	2893/2976
temp												
27.00-27.49	0	0	0	0	0	0	0	0	0	0	0	0
27.50-29.90	0	0	0	0	0	0	0	0	0	0	0	0
28.00-28.49	0	0	0	0	0	0	0	0	0	0	0	0
28.50-28.99	0	0	0	0	0	0	0	0	0	0	0	0
29.00-29.49	0	0	0	0	0	0	0	0	0	0	0	0
29.50-29.99	0	0	0	0	0	0	0	0	0	0	0	0
30.00-30.49	0	0	0	0	0	0	0	0	0	0	0	0
30.50-30.99	0	0	0	0	0	0	0	0	0	0	0	0
31.00-31.49	0	0	0	0	0	0	0	0	0	0	0	0
31.50-31.99	0	0	0	0	0	0	0	0	0	0	0	0
32.00-32.49	0	0	0	1	0	0	0	0	0	0	0	0
32.50-32.99	1013	388	0	150	0	0	0	0	0	0	0	6
33.00-33.49	1963	2294	2851	2547	2493	2157	982	1633	1175	2461	2726	2877
33.50-33.99	0	7	39	101	178	350	1620	905	1141	497	154	10
34.00-34.49	0	0	45	48	139	122	208	151	14	18	0	0
34.50-34.99	0	0	11	5	122	78	64	89	0	0	0	0
35.00-35.49	0	0	0	14	44	93	82	38	0	0	0	0
35.50-35.99	0	0	0	2	0	72	16	0	0	0	0	0
36.00-36.49	0	0	0	0	0	8	0	0	0	0	0	0
36.50-36.99	0	0	0	0	0	0	0	0	0	0	0	0
37.00-37.49	0	0	0	0	0	0	0	0	0	0	0	0

midshelf 2000 # of 15 minute readings

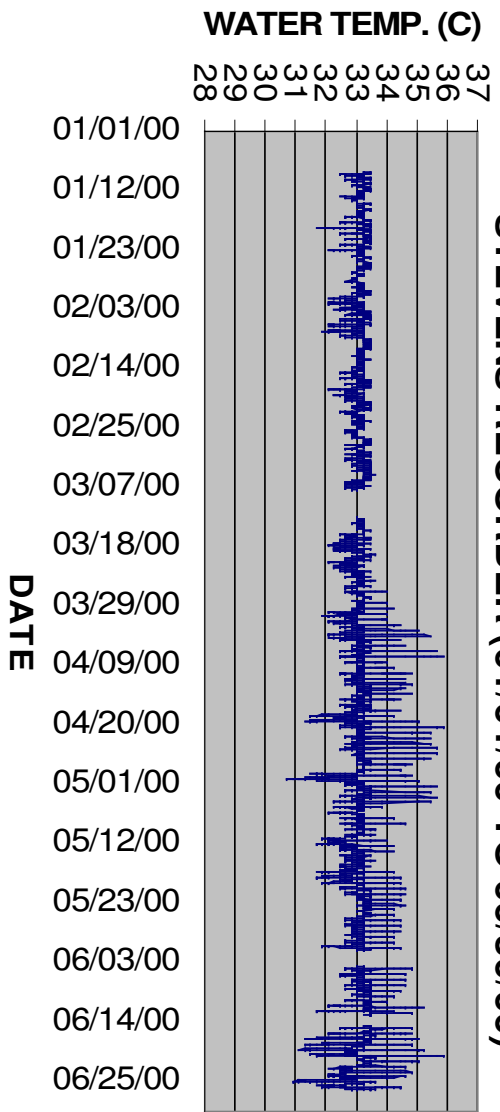
month	January	February	March	April	May	June	July	August	September	October	November	December
#taken/#possible	2936/2976	2784/2784	2977/2977	2880/2880	2976/2976	2880/2880	2976/2976	1139/2976	2880/2880	2976/2976	1594/2880	2976/2976
temp												
27.00-27.49	0	0	0	0	0	0	0	0	0	0	0	0
27.50-29.90	0	0	0	0	0	0	0	0	0	0	0	0
28.00-28.49	0	0	0	0	0	0	0	0	0	0	0	0
28.50-28.99	0	0	0	0	0	0	0	0	0	0	0	0
29.00-29.49	0	0	0	0	0	0	0	0	0	0	0	0
29.50-29.99	0	0	0	0	0	0	0	0	0	0	0	0
30.00-30.49	0	0	0	0	0	0	0	0	0	0	0	0
30.50-30.99	0	0	0	0	0	0	0	0	0	0	0	0
31.00-31.49	0	0	0	0	0	0	0	0	0	0	0	0
31.50-31.99	0	0	0	0	0	0	0	0	0	0	0	0
32.00-32.49	0	0	0	0	0	0	0	0	0	0	0	0
32.50-32.99	1	1	0	0	0	0	0	0	42	116	466	2495
33.00-33.49	2953	2767	2782	2372	1947	1339	799	258	2566	2788	1126	481
33.50-33.99	22	16	125	353	694	1183	1800	771	142	65	1	0
34.00-34.49	0	0	41	70	49	84	116	46	93	7	0	0
34.50-34.99	0	0	29	52	140	217	247	64	32	0	0	0
35.00-35.49	0	0	0	33	129	50	14	0	5	0	0	0
35.50-35.99	0	0	0	0	17	7	0	0	0	0	0	0
36.00-36.49	0	0	0	0	0	0	0	0	0	0	0	0
36.50-36.99	0	0	0	0	0	0	0	0	0	0	0	0
37.00-37.49	0	0	0	0	0	0	0	0	0	0	0	0
37.50-37.99	0	0	0	0	0	0	0	0	0	0	0	0
38.00-38.49	0	0	0	0	0	0	0	0	0	0	0	0

midshelf 2001 # of 15 minute readings

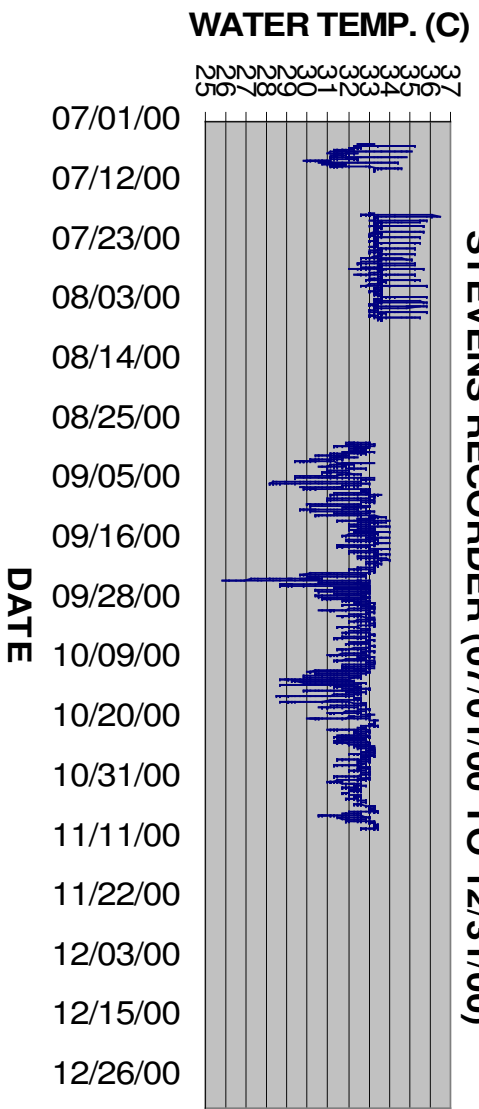
month	January	February	March	April	May	June	July	August	September	October	November	December
#taken/#possible	2977/2977	2688/2688	2976/2976	2673/2880	2976/2976	2880/2880	2976/2976	2971/2976	2880/2880	2976/2976	2876/2880	2976/2976
temp												
27.00-27.49	0	0	0	0	0	0	0	0	1	0	0	0
27.50-29.90	0	0	0	0	0	0	0	0	1	0	0	0
28.00-28.49	0	0	0	0	0	0	0	0	0	0	0	0
28.50-28.99	0	0	0	0	0	0	0	0	1	0	0	0
29.00-29.49	0	0	0	0	0	0	0	0	2	0	0	0
29.50-29.99	0	0	0	0	0	0	0	0	0	0	0	0
30.00-30.49	0	0	0	0	0	0	0	0	0	0	0	0
30.50-30.99	0	0	0	0	0	0	0	0	1	0	0	0
31.00-31.49	0	0	0	0	0	0	0	0	0	0	0	0
31.50-31.99	0	0	0	0	0	0	0	0	0	0	0	0
32.00-32.49	2	1	0	0	0	0	0	0	2	0	0	0
32.50-32.99	2445	229	0	0	0	0	0	0	2	0	2	26
33.00-33.49	530	2339	253	0	0	0	0	3	153	1851	2813	2950
33.50-33.99	0	119	2576	1463	106	1095	1755	2285	2365	1101	61	0
34.00-34.49	0	0	146	1045	2461	1414	842	402	245	24	0	0
34.50-34.99	0	0	1	58	176	143	208	64	78	0	0	0
35.00-35.49	0	0	0	107	225	133	171	99	29	0	0	0
35.50-35.99	0	0	0	0	8	41	0	108	0	0	0	0
36.00-36.49	0	0	0	0	0	54	0	10	0	0	0	0
36.50-36.99	0	0	0	0	0	0	0	0	0	0	0	0
37.00-37.49	0	0	0	0	0	0	0	0	0	0	0	0
37.50-37.99	0	0	0	0	0	0	0	0	0	0	0	0
38.00-38.49	0	0	0	0	0	0	0	0	0	0	0	0

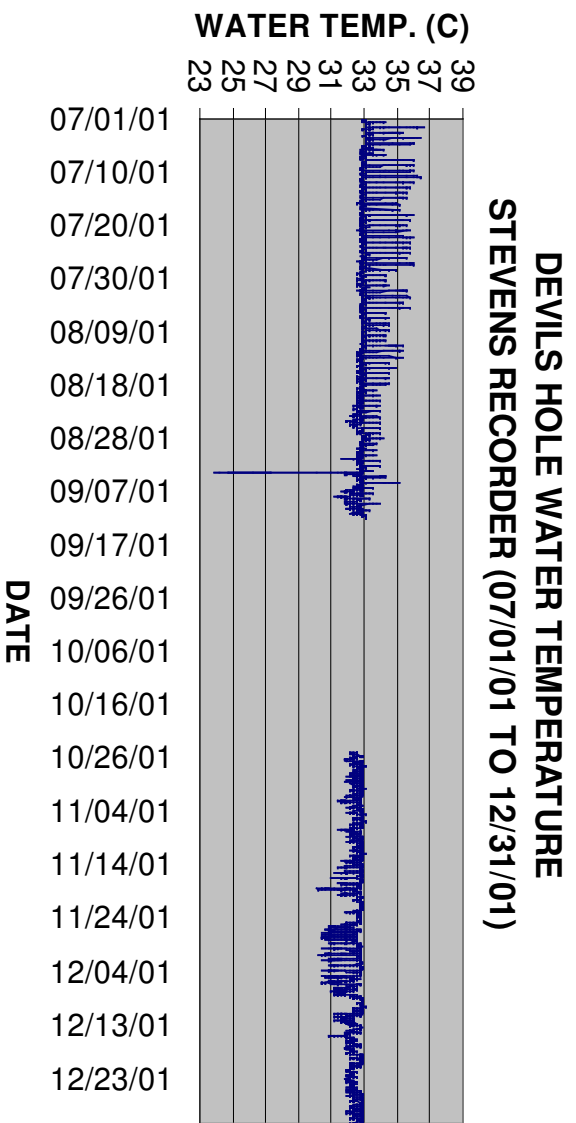
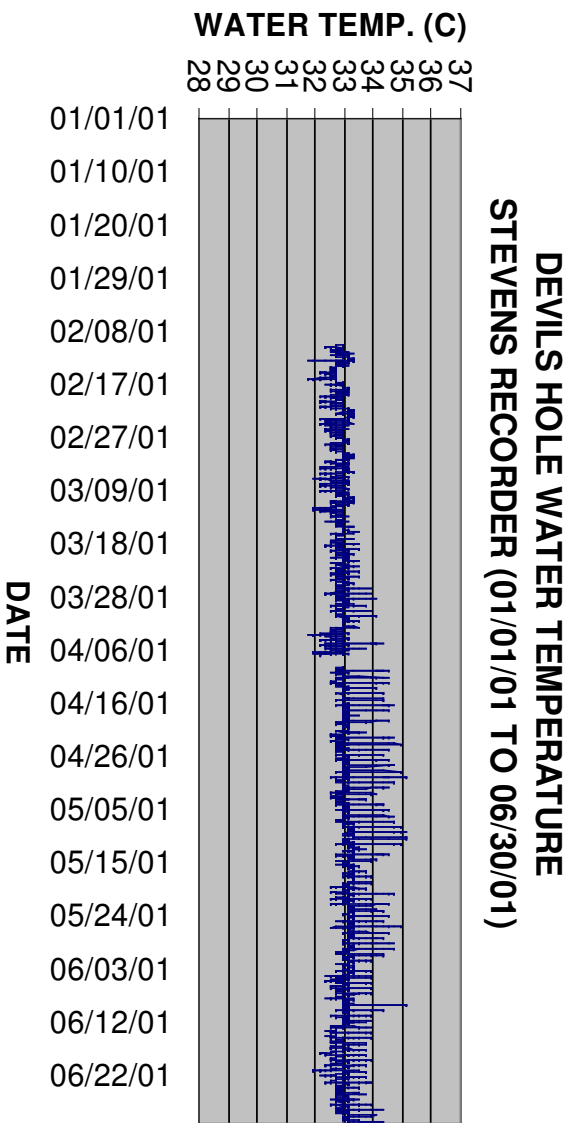


**DEVILS HOLE WATER TEMPERATURE
STEVENS RECORDER (01/01/00 TO 06/30/00)**



**DEVILS HOLE WATER TEMPERATURE
STEVENS RECORDER (07/01/00 TO 12/31/00)**





Stevens recorder 1999

of 15 minute readings

month												
#taken/#possible	2976/2976	2689/2689	2946/2976	2262/2880	1896/2976	1825/2880	2588/2976	2814/2976	2330/2880	2836/2976	2573/2880	1056/2976
temp	January	February	March	April	May	June	July	August	September	October	November	December
27.50-29.90	0	0	0	0	0	0	0	0	0	0	0	0
28.00-28.49	0	0	0	0	0	0	0	0	0	0	0	0
28.50-28.99	0	0	0	2	4	0	0	0	0	0	0	0
29.00-29.49	0	0	0	6	4	0	0	0	0	0	0	0
29.50-29.99	0	0	0	4	1	0	0	0	0	0	0	0
30.00-30.49	7	0	0	12	2	0	0	0	0	0	0	0
30.50-30.99	7	7	0	35	14	0	0	15	0	0	0	0
31.00-31.49	12	37	0	102	8	7	2	6	0	0	0	0
31.50-31.99	258	208	8	278	9	59	52	45	0	1	3	0
32.00-32.49	591	475	51	306	106	86	109	81	74	186	95	36
32.50-32.99	1442	1261	1301	619	907	649	488	426	356	404	291	252
33.00-33.49	659	700	1539	370	631	673	1186	1428	1762	2244	2174	768
33.50-33.99	0	0	47	506	152	172	550	671	52	1	10	0
34.00-34.49	0	0	0	15	34	35	98	102	58	0	0	0
34.50-34.99	0	0	0	3	10	67	76	37	17	0	0	0
35.00-35.49	0	0	0	4	11	50	16	3	11	0	0	0
35.50-35.99	0	0	0	0	3	19	10	0	0	0	0	0
36.00-36.49	0	0	0	0	0	8	1	0	0	0	0	0
36.50-36.99	0	0	0	0	0	0	0	0	0	0	0	0

Stevens recorder 2000

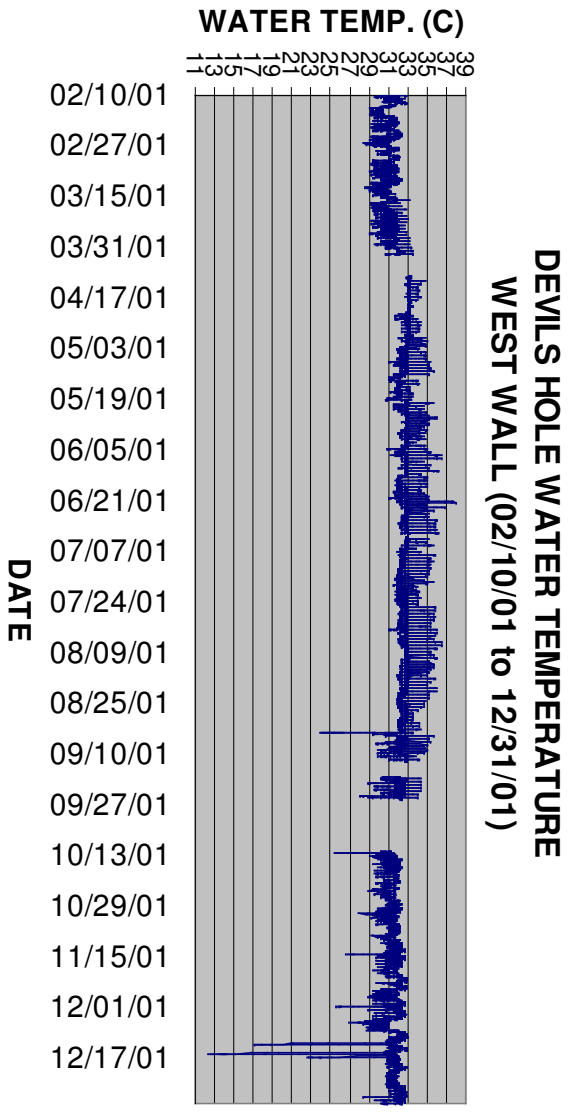
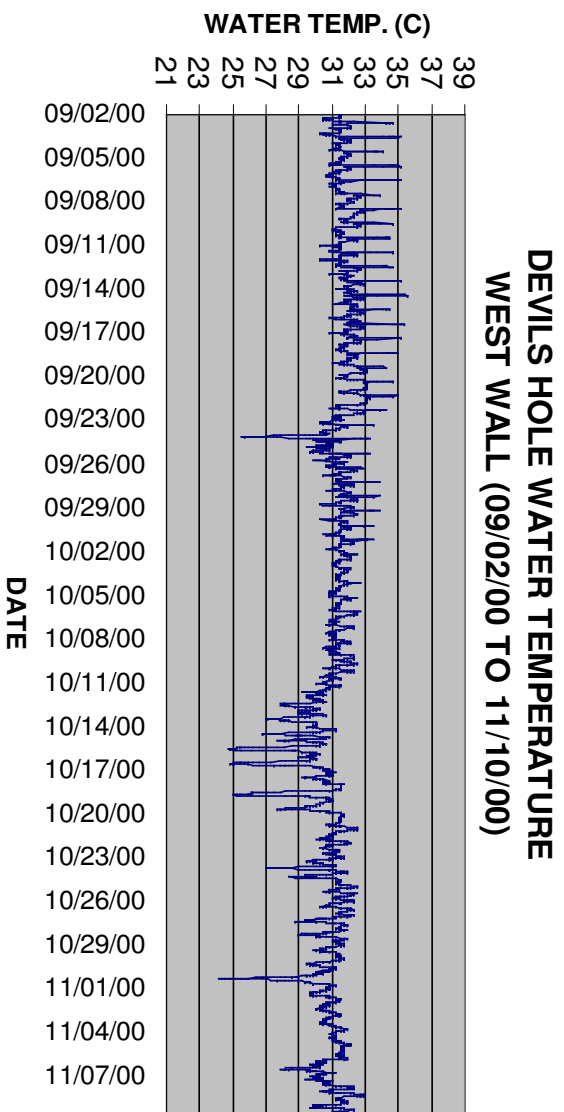
of 15 minute readings

month												
#taken/#possible	2257/2976	2784/2784	2477/2976	2880/2880	2976/2976	2016/2880	1824/2976	788/2976	2880/2880	2976/2976	864/2880	0/2976
temp	January	February	March	April	May	June	July	August	September	October	November	December
24.50-24.99	0	0	0	0	0	0	0	0	0	0	0	0
25.00-25.49	0	0	0	0	0	0	0	0	0	0	0	0
25.50-25.99	0	0	0	0	0	0	0	0	2	0	0	0
26.00-26.49	0	0	0	0	0	0	0	0	2	0	0	0
26.50-26.99	0	0	0	0	0	0	0	0	4	0	0	0
27.00-27.49	0	0	0	0	0	0	0	0	3	0	0	0
27.50-27.99	0	0	0	0	0	0	0	0	3	0	0	0
28.00-28.49	0	0	0	0	0	0	0	0	21	2	0	0
28.50-28.99	0	0	0	0	0	0	0	0	15	16	0	0
29.00-29.49	0	0	0	0	0	0	0	0	27	37	0	0
29.50-29.99	0	0	0	0	0	0	6	0	81	39	0	0
30.00-30.49	0	0	0	0	0	0	8	0	94	53	0	0
30.50-30.99	0	0	0	4	0	3	27	0	164	68	14	0
31.00-31.49	0	0	0	27	0	42	118	18	249	241	37	0
31.50-31.99	1	1	1	47	44	36	70	23	216	214	84	0
32.00-32.49	68	124	157	137	209	184	117	77	431	536	234	0
32.50-32.99	219	455	396	395	599	314	134	64	477	923	232	0
33.00-33.49	1969	2204	1898	2075	1921	1182	837	371	1035	847	263	0
33.50-33.99	0	0	12	39	63	76	336	187	42	0	0	0
34.00-34.49	0	0	13	76	112	101	68	18	14	0	0	0
34.50-34.99	0	0	0	37	10	62	24	7	0	0	0	0
35.00-35.49	0	0	0	30	16	12	54	8	0	0	0	0
35.50-35.99	0	0	0	13	2	4	20	15	0	0	0	0
36.00-36.49	0	0	0	0	0	0	4	0	0	0	0	0
36.50-36.99	0	0	0	0	0	0	1	0	0	0	0	0
37.00-37.49	0	0	0	0	0	0	0	0	0	0	0	0

Stevens recorder 2001

of 15 minute readings

month												
#taken/#possible	0/2976	1749/2689	2976/2976	2673/2880	2976/2976	2880/2880	2976/2976	2971/2976	1056/2880	672/2976	2876/2880	2976/2976
temp	January	February	March	April	May	June	July	August	September	October	November	December
23.50-23.99	0	0	0	0	0	0	0	0	1	0	0	0
24.00-24.49	0	0	0	0	0	0	0	0	1	0	0	0
24.50-24.99	0	0	0	0	0	0	0	0	2	0	0	0
25.00-25.49	0	0	0	0	0	0	0	0	1	0	0	0
25.50-25.99	0	0	0	0	0	0	0	0	0	0	0	0
26.00-26.49	0	0	0	0	0	0	0	0	1	0	0	0
26.50-26.99	0	0	0	0	0	0	0	0	0	0	0	0
27.00-27.49	0	0	0	0	0	0	0	0	2	0	0	0
27.50-27.99	0	0	0	0	0	0	0	0	0	0	0	0
28.00-28.49	0	0	0	0	0	0	0	0	0	0	0	0
28.50-28.99	0	0	0	0	0	0	0	0	0	0	0	0
29.00-29.49	0	0	0	0	0	0	0	0	0	0	0	0
29.50-29.99	0	0	0	0	0	0	0	0	0	0	0	0
30.00-30.49	0	0	0	0	0	0	0	0	1	0	18	17
30.50-30.99	0	0	0	0	0	0	0	0	1	0	82	81
31.00-31.49	0	0	0	0	0	0	0	0	7	0	80	124
31.50-31.99	0	11	10	20	0	10	0	7	95	22	276	345
32.00-32.49	0	132	122	59	0	65	0	85	134	193	497	1137
32.50-32.99	0	1248	2256	1846	845	1627	1481	1956	693	453	1913	1268
33.00-33.49	0	358	552	597	1810	932	1039	647	84	4	10	4
33.50-33.99	0	0	33	46	189	230	138	156	25	0	0	0
34.00-34.49	0	0	3	51	69	9	69	50	5	0	0	0
34.50-34.99	0	0	0	51	57	4	66	35	2	0	0	0
35.00-35.49	0	0	0	3	6	3	71	25	1	0	0	0
35.50-35.99	0	0	0	0	0	0	98	10	0	0	0	0
36.00-36.49	0	0	0	0	0	0	13	0	0	0	0	0
36.50-36.99	0	0	0	0	0	0	1	0	0	0	0	0



Westwall recorder 2000

of 15 minute readings

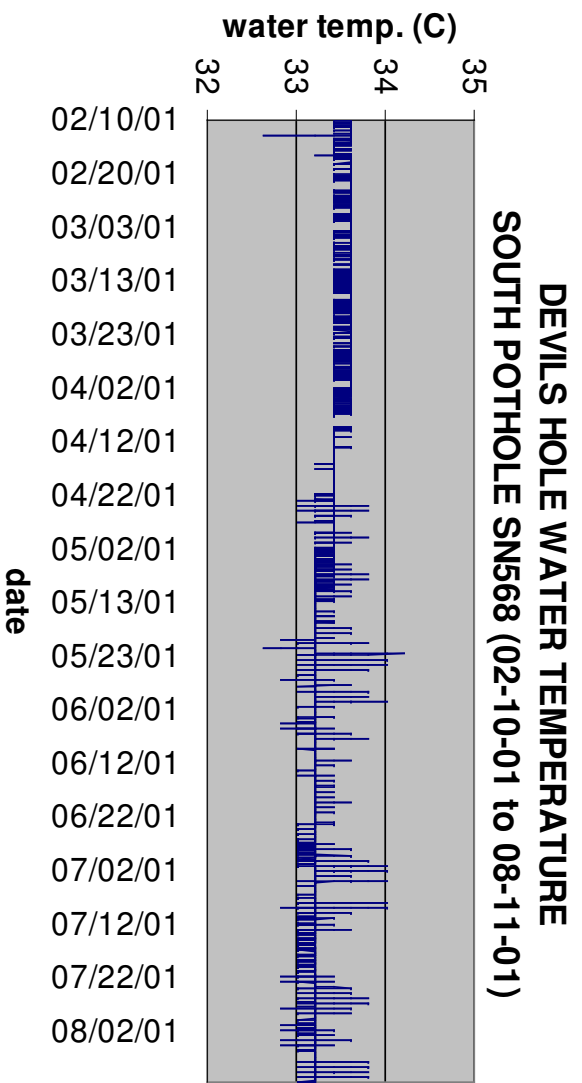
Month				
#taken/#possible	2784/2880	2976/2976	905/2880	0/2976
Temp	September	October	November	December
24.00-24.49	0	0	2	0
24.50-24.99	0	11	3	0
25.00-25.49	0	21	1	0
25.50-25.99	3	14	3	0
26.00-26.49	2	12	1	0
26.50-26.99	3	19	2	0
27.00-27.49	3	22	3	0
27.50-27.99	3	22	5	0
28.00-28.49	2	55	9	0
28.50-28.99	3	62	9	0
29.00-29.49	3	127	16	0
29.50-29.99	21	158	58	0
30.00-30.49	84	376	184	0
30.50-30.99	253	630	237	0
31.00-31.49	521	654	138	0
31.50-31.99	835	537	180	0
32.00-32.49	388	220	35	0
32.50-32.99	390	33	19	0
33.00-33.49	130	2	0	0
33.50-33.99	45	1	0	0
34.00-34.49	28	0	0	0
34.50-34.99	49	0	0	0
35.00-35.49	15	0	0	0
35.50-35.99	3	0	0	0
36.00-36.49	0	0	0	0

westwall recorder 2001

of 15 minute readings

month												
#taken/#possible	0/2976	1749/2689	2976/2976	2236/2880	2976/2976	2876/2880	2880/2976	2971/2976	1824/2880	1920/2976	2876/2880	2976/2976
temp	January	February	March	April	May	June	July	August	September	October	November	December
12.00-12.49	0	0	0	0	0	0	0	0	0	0	0	1
12.50-12.99	0	0	0	0	0	0	0	0	0	0	0	1
13.00-13.49	0	0	0	0	0	0	0	0	0	0	0	1
13.50-13.99	0	0	0	0	0	0	0	0	0	0	0	2
14.00-14.49	0	0	0	0	0	0	0	0	0	0	0	4
14.50-14.99	0	0	0	0	0	0	0	0	0	0	0	0
15.00-15.49	0	0	0	0	0	0	0	0	0	0	0	1
15.50-15.99	0	0	0	0	0	0	0	0	0	0	0	0
16.00-16.49	0	0	0	0	0	0	0	0	0	0	0	1
16.50-16.99	0	0	0	0	0	0	0	0	0	0	0	1
17.00-17.49	0	0	0	0	0	0	0	0	0	0	0	3
17.50-17.99	0	0	0	0	0	0	0	0	0	0	0	2
18.00-18.49	0	1	0	0	0	0	0	0	0	0	0	5
18.50-18.99	0	0	0	0	0	0	0	0	0	0	0	2
19.00-19.49	0	0	0	0	0	0	0	0	0	0	0	0
19.50-19.99	0	0	0	0	0	0	0	0	0	0	0	1
20.00-20.49	0	0	0	0	0	0	0	0	0	0	0	2
20.50-20.99	0	0	0	0	0	0	0	0	0	0	0	1
21.00-21.49	0	0	0	0	0	0	0	0	0	0	0	1
21.50-21.99	0	0	0	0	0	0	0	0	0	0	0	1
22.00-22.49	0	0	0	0	0	0	0	0	0	0	0	1
22.50-22.99	0	0	0	0	0	0	0	0	0	0	0	3
23.00-23.49	0	0	0	0	0	0	0	0	0	0	0	2
23.50-23.99	0	0	0	0	0	0	0	0	1	0	0	4
24.00-24.49	0	0	0	0	0	0	0	0	1	0	0	1
24.50-24.99	0	0	0	0	0	0	0	0	1	0	0	2
25.00-25.49	0	0	0	0	0	0	0	0	3	1	0	1
25.50-25.99	0	1	0	0	0	0	0	0	0	1	4	2

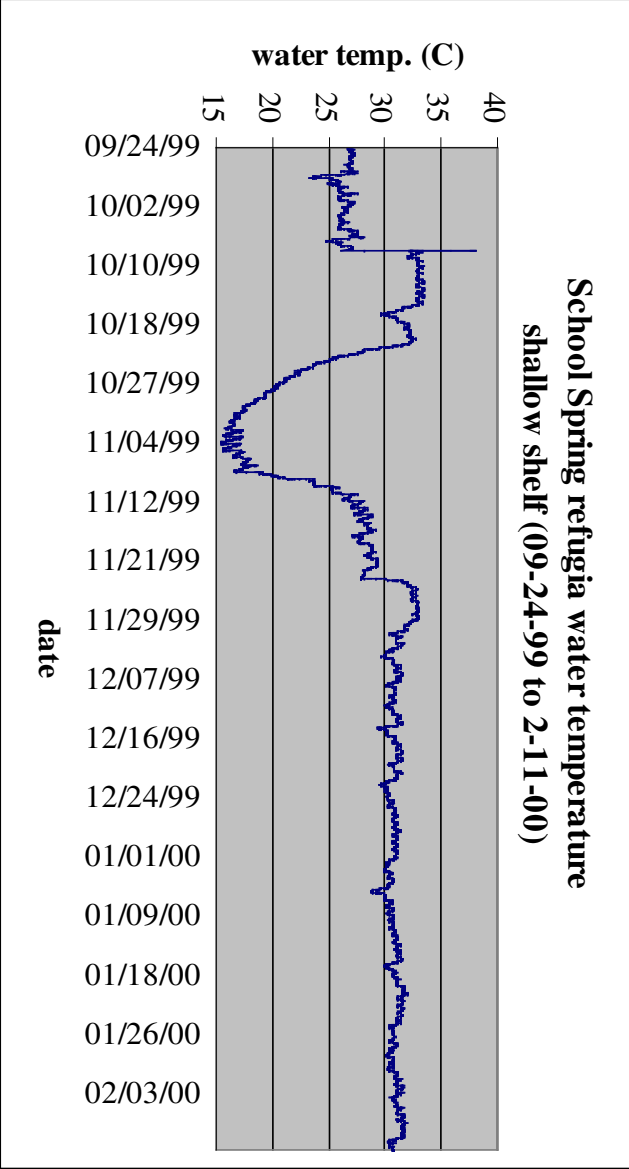
26.00-26.49	0	0	0	0	0	0	0	0	2	1	2	1
26.50-26.99	0	0	0	0	0	0	0	0	0	2	1	1
27.00-27.49	0	0	0	0	0	0	0	0	1	4	5	1
27.50-27.99	0	0	0	0	0	0	0	0	0	1	1	7
28.00-28.49	0	6	2	0	0	0	0	0	8	2	1	13
28.50-28.99	0	16	6	0	0	0	0	0	8	3	5	10
29.00-29.49	0	100	151	0	0	0	0	0	20	18	25	38
29.50-29.99	0	340	350	0	0	0	0	0	52	101	92	109
30.00-30.49	0	186	361	0	0	0	0	0	64	129	168	110
30.50-30.99	0	284	625	13	11	3	0	0	115	484	484	315
31.00-31.49	0	350	726	8	148	25	10	11	142	571	771	688
31.50-31.99	0	212	516	48	220	130	88	15	178	384	455	536
32.00-32.49	0	213	201	161	692	662	1145	820	641	218	652	662
32.50-32.99	0	40	22	237	1211	1539	1123	1519	457	0	210	437
33.00-33.49	0	0	16	1625	392	139	162	298	27	0	0	2
33.50-33.99	0	0	0	67	55	54	74	59	24	0	0	0
34.00-34.49	0	0	0	69	108	111	96	63	46	0	0	0
34.50-34.99	0	0	0	5	73	70	50	24	10	0	0	0
35.00-35.49	0	0	0	3	55	77	89	99	20	0	0	0
35.50-35.99	0	0	0	0	9	31	36	46	3	0	0	0
36.00-36.49	0	0	0	0	2	24	7	17	0	0	0	0
36.50-36.99	0	0	0	0	0	4	0	0	0	0	0	0
37.00-37.49	0	0	0	0	0	1	0	0	0	0	0	0
37.50-37.99	0	0	0	0	0	6	0	0	0	0	0	0
38.00-38.49	0	0	0	0	0	0	0	0	0	0	0	0
38.50-38.99	0	0	0	0	0	0	0	0	0	0	0	0
39.00-39.49	0	0	0	0	0	0	0	0	0	0	0	0
39.50-39.99	0	0	0	0	0	0	0	0	0	0	0	0



south pothole 2001(SN568)

of 15 minute readings

month		January	February	March	April	May	June	July	August	September	October	November	December
#taken/#possible		0/2976	1749/2689	2977/2976	2673/2880	2976/2976	2880/2880	2976/2976	1007/2976	0/2880	0/2976	0/2880	0/2976
temp													
31.00-31.49		0	0	0	0	0	0	0	0	0	0	0	0
31.50-31.99		0	0	0	0	0	0	0	0	0	0	0	0
32.00-32.49		0	0	0	0	0	0	0	0	0	0	0	0
32.50-32.99		0	1	0	0	4	2	5	3	0	0	0	0
33.00-33.49		0	478	592	2348	2922	2862	2926	988	0	0	0	0
33.50-33.99		0	1270	2385	325	44	16	38	16	0	0	0	0
34.00-34.49		0	0	0	0	6	0	7	0	0	0	0	0
34.50-34.99		0	0	0	0	0	0	0	0	0	0	0	0
35.00-35.49		0	0	0	0	0	0	0	0	0	0	0	0
35.50-35.99		0	0	0	0	0	0	0	0	0	0	0	0
36.00-36.49		0	0	0	0	0	0	0	0	0	0	0	0
36.50-36.99		0	0	0	0	0	0	0	0	0	0	0	0

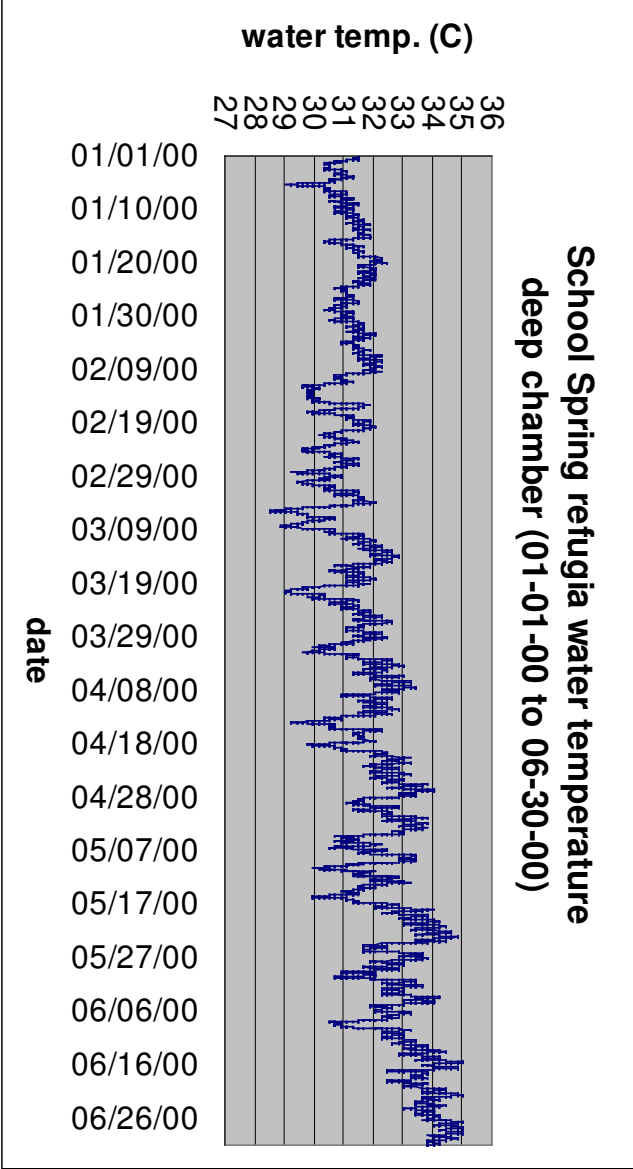
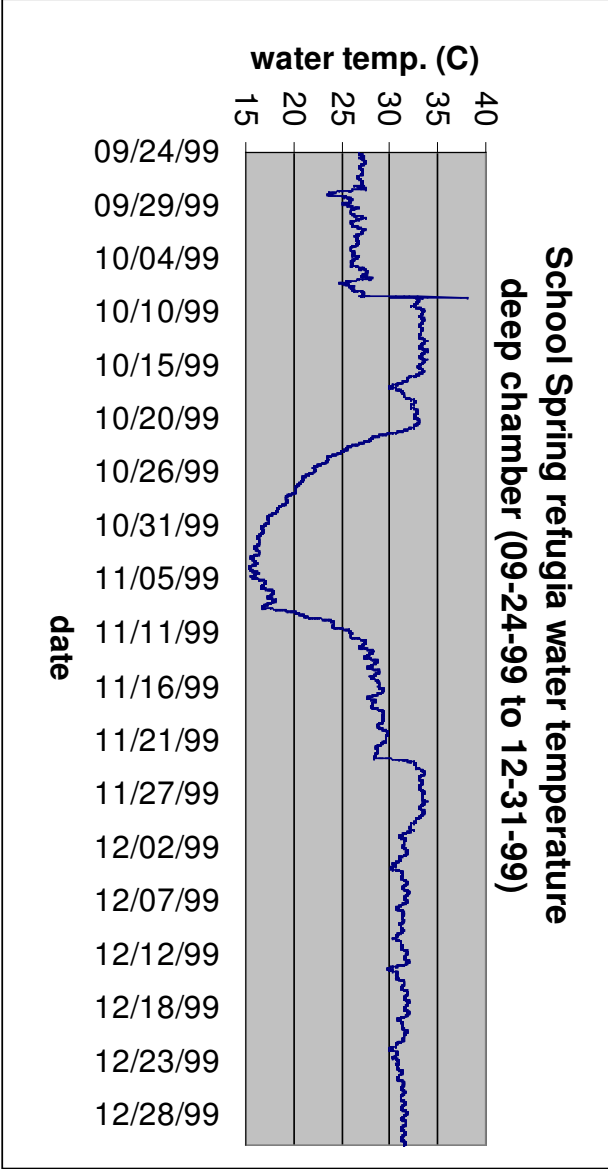


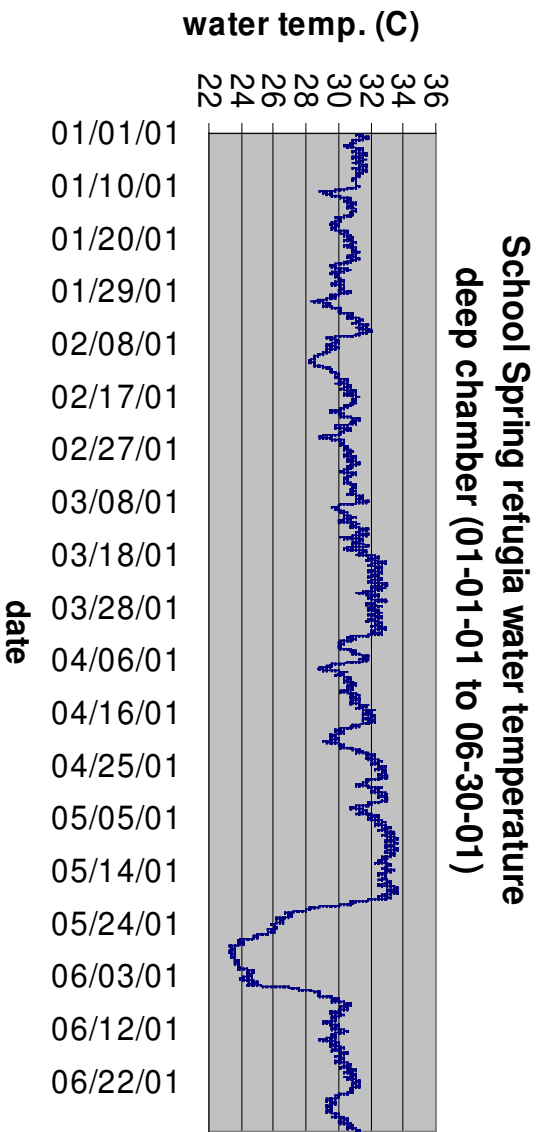
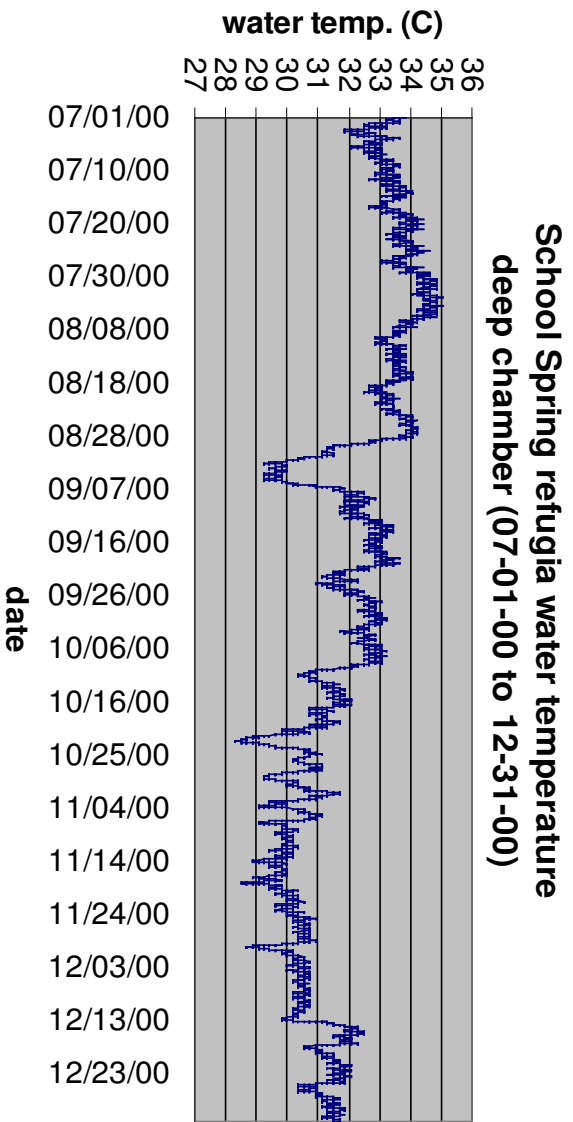
School Spring shallow shelf 1999-2000

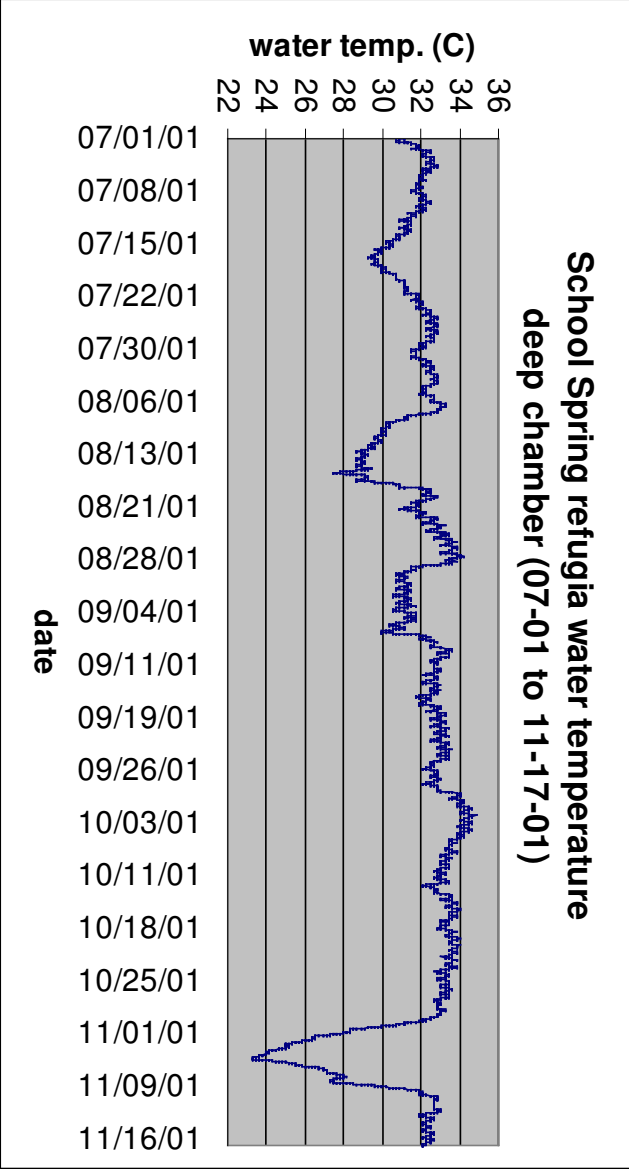
of 15 minute readings

	Sep-99	Oct-99	Nov-99	Dec-99	Jan-00	Feb-00
#taken/#possible	743/2881	2976/2976	2880/2880	2976/2976	2976/2976	1012/2784
temp						
15.00-15.49	0	0	14	0	0	0
15.50-15.99	0	0	99	0	0	0
16.00-16.49	0	0	139	0	0	0
16.50-16.99	0	86	255	0	0	0
17.00-17.49	0	82	124	0	0	0
17.50-17.99	0	33	75	0	0	0
18.00-18.49	0	47	12	0	0	0
18.50-18.99	0	30	14	0	0	0
19.00-19.49	0	88	15	0	0	0
19.50-19.99	0	22	10	0	0	0
20.00-20.49	0	69	19	0	0	0
20.50-20.99	0	38	19	0	0	0
21.00-21.49	0	63	10	0	0	0
21.50-21.99	0	24	6	0	0	0
22.00-22.49	0	69	5	0	0	0
22.50-22.99	0	19	1	0	0	0
23.00-23.49	2	25	9	0	0	0
23.50-23.99	27	54	75	0	0	0
24.00-24.49	9	17	6	0	0	0
24.50-24.99	10	29	6	0	0	0
25.00-25.49	41	50	68	0	0	0
25.50-25.99	148	193	22	0	0	0
26.00-26.49	86	220	30	0	0	0
26.50-26.99	290	159	75	0	0	0
27.00-27.49	112	116	81	0	0	0
27.50-27.99	8	70	221	0	0	0
28.00-28.49	2	39	362	0	0	0
28.50-28.99	4	9	263	0	32	0
29.00-29.49	0	11	126	20	29	0
29.50-29.99	1	34	2	86	78	0
30.00-30.49	0	40	5	597	804	73
30.50-30.99	2	63	15	1428	1193	340
31.00-31.49	0	68	19	748	585	329
31.50-31.99	0	147	160	97	255	270
32.00-32.49	1	205	77	0	0	0
32.50-32.99	0	345	382	0	0	0

33.00-33.49	0	408	59	0	0	0
33.50-33.99	0	0	0	0	0	0
34.00-34.49	0	0	0	0	0	0
34.50-34.99	0	0	0	0	0	0
35.00-35.49	0	0	0	0	0	0
35.50-35.99	0	1	0	0	0	0
36.00-36.49	0	0	0	0	0	0
36.50-36.99	0	0	0	0	0	0
37.00-37.49	0	0	0	0	0	0
37.50-37.99	0	1	0	0	0	0
38.00-38.49	0	2	0	0	0	0







School Spring deep chamber 1999

# of 15 minute readings				
#taken/#possible	743/2881	2976/2976	2880/2880	2976/2976
temp	September	October	November	December
15.00-15.49	0	0	21	0
15.50-15.99	0	0	209	0
16.00-16.49	0	0	202	0
16.50-16.99	0	85	95	0
17.00-17.49	0	90	91	0
17.50-17.99	0	24	93	0
18.00-18.49	0	49	16	0
18.50-18.99	0	27	6	0
19.00-19.49	0	99	10	0
19.50-19.99	0	21	8	0
20.00-20.49	0	77	16	0
20.50-20.99	0	69	15	0
21.00-21.49	0	24	19	0
21.50-21.99	0	25	7	0
22.00-22.49	0	66	6	0
22.50-22.99	0	19	5	0
23.00-23.49	4	61	8	0
23.50-23.99	26	18	35	0
24.00-24.49	9	16	43	0
24.50-24.99	13	33	8	0
25.00-25.49	25	31	5	0
25.50-25.99	134	122	71	0
26.00-26.49	91	257	14	0
26.50-26.99	227	181	30	0
27.00-27.49	200	162	93	0
27.50-27.99	3	62	140	0
28.00-28.49	3	19	179	0
28.50-28.99	2	11	377	0
29.00-29.49	2	9	224	0
29.50-29.99	0	21	112	34
30.00-30.49	1	31	2	124
30.50-30.99	0	46	4	579
31.00-31.49	2	99	17	1497
31.50-31.99	0	60	18	676
32.00-32.49	1	194	125	67
32.50-32.99	0	180	84	0

33.00-33.49	0	551	352	0
33.50-33.99	0	134	120	0
34.00-34.49	0	0	0	0
34.50-34.99	0	0	0	0
35.00-35.49	0	0	0	0
35.50-35.99	0	0	0	0
36.00-36.49	0	0	0	0
36.50-36.99	0	0	0	0
37.00-37.49	0	1	0	0
37.50-37.99	0	0	0	0
38.00-38.49	0	2	0	0
38.50-38.99	0	0	0	0

School Spring deep chamber 2000

of 15 minute readings

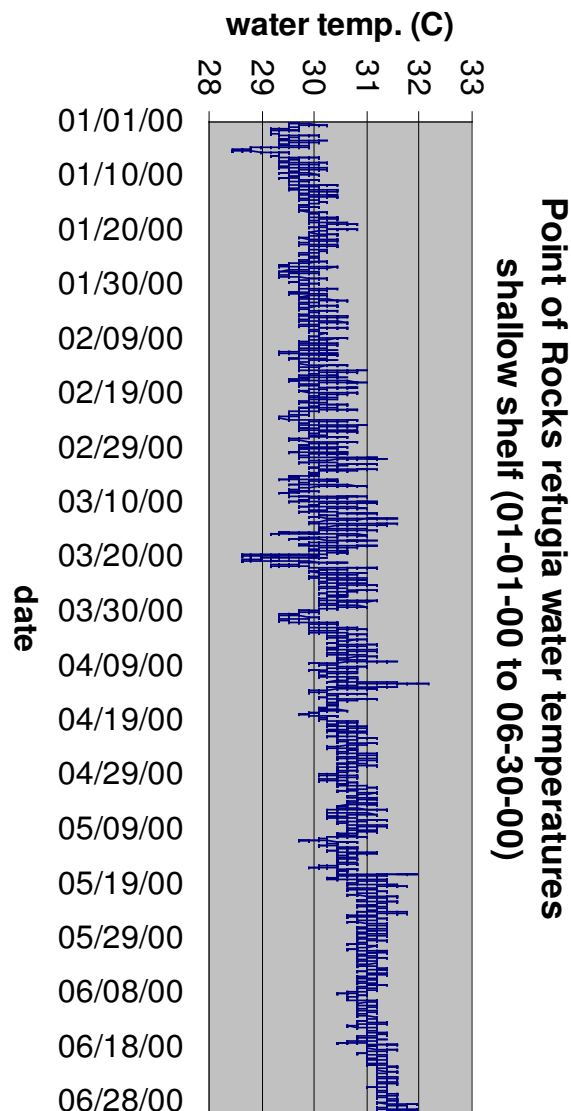
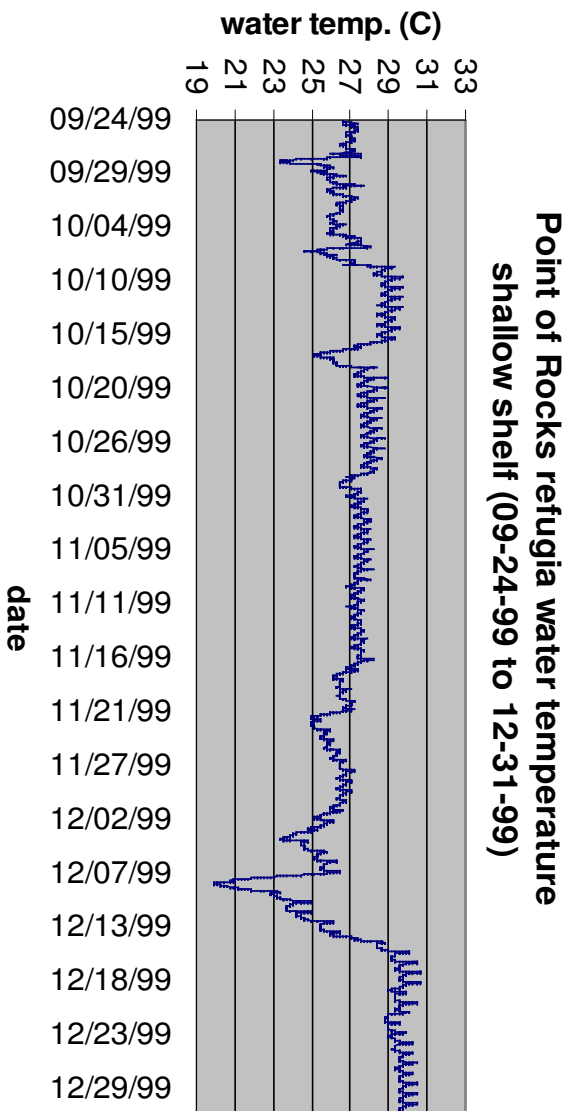
#taken/#possible	2976/2976	2784/2784	2976/2976	2880/2880	2976/2976	2880/2880	2977/2977	2976/2976	2880/2881	2876/2976	2880/2880	2976/2976
temp	January	February	March	April	May	June	July	August	September	October	November	December
27.50-27.99	0	0	0	0	0	0	0	0	0	0	0	0
28.00-28.49	0	0	0	0	0	0	0	0	0	19	0	0
28.50-28.99	0	0	44	0	0	0	0	0	0	88	89	0
29.00-29.49	38	40	196	21	0	0	0	0	107	179	338	0
29.50-29.99	28	437	280	90	20	0	0	0	285	152	1049	125
30.00-30.49	133	266	217	61	65	0	0	0	90	296	711	593
30.50-30.99	825	572	423	230	172	84	0	0	57	588	578	789
31.00-31.49	1261	788	814	396	473	39	0	183	198	541	89	725
31.50-31.99	516	515	526	460	339	23	14	21	320	287	26	552
32.00-32.49	175	166	392	779	464	350	185	43	641	312	0	192
32.50-32.99	0	0	84	481	322	289	341	192	660	372	0	0
33.00-33.49	0	0	0	303	589	642	1090	920	512	142	0	0
33.50-33.99	0	0	0	49	314	538	728	805	10	0	0	0
34.00-34.49	0	0	0	10	166	610	499	503	0	0	0	0
34.50-34.99	0	0	0	0	52	222	120	305	0	0	0	0
35.00-35.49	0	0	0	0	0	83	0	4	0	0	0	0
35.50-35.99	0	0	0	0	0	0	0	0	0	0	0	0

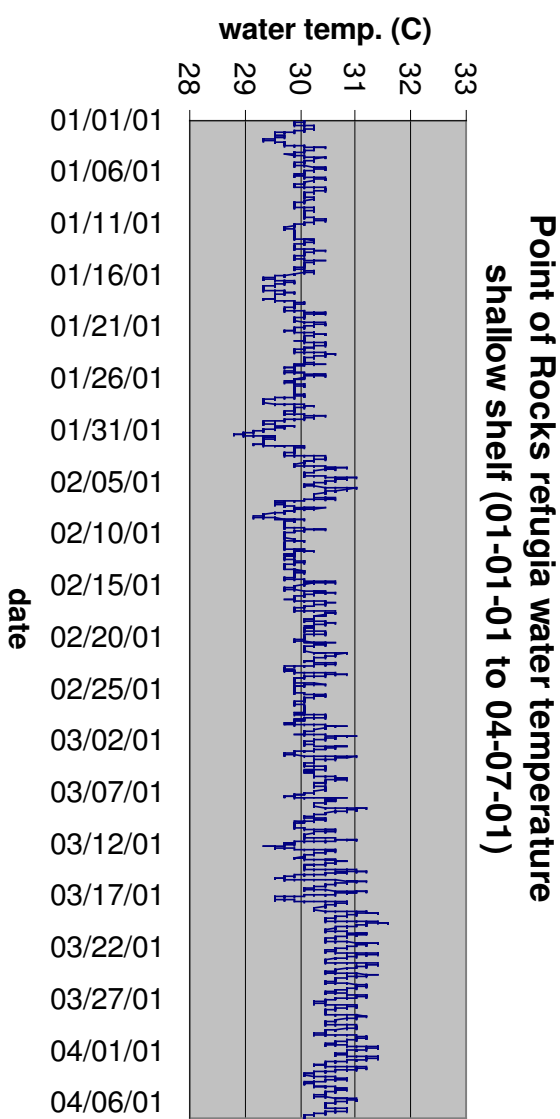
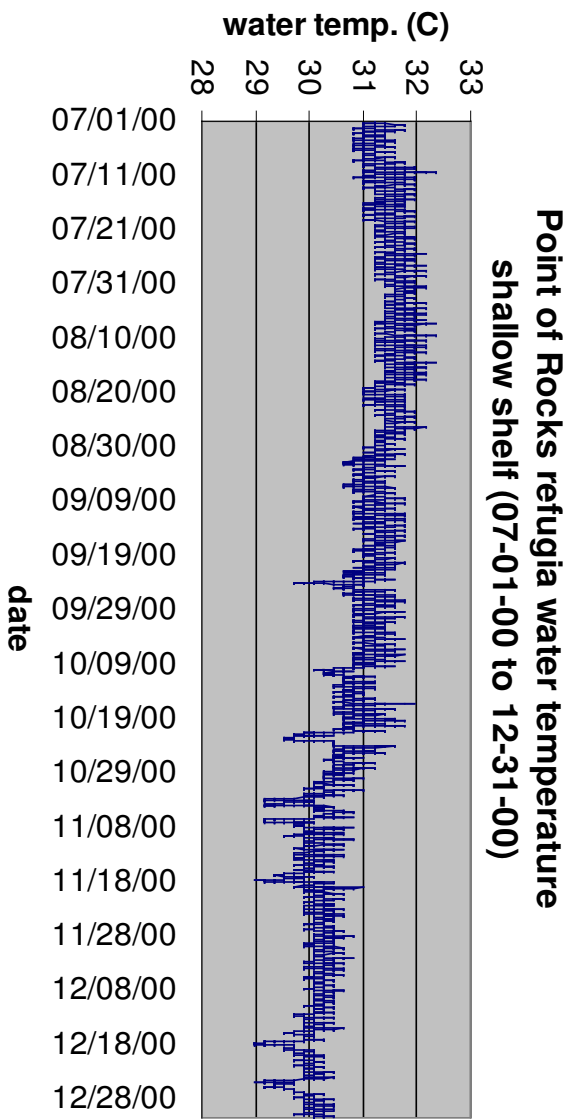
School Spring deep chamber 2001

of 15 minute readings

#taken/#possible	2976/2976	2689/2689	2976/2976	2880/2880	2976/2976	2880/2880	2977/2977	2976/2976	2881/2881	2976/2976	1579/2880	0/2976
temp	January	February	March	April	May	June	July	August	September	October	November	December
23.00-23.49	0	0	0	0	124	0	0	0	0	0	43	0
23.50-23.99	0	0	0	0	315	67	0	0	0	0	62	0
24.00-24.49	0	0	0	0	41	117	0	0	0	0	54	0
24.50-24.99	0	0	0	0	71	155	0	0	0	0	73	0
25.00-25.49	0	0	0	0	14	6	0	0	0	0	51	0
25.50-25.99	0	0	0	0	94	7	0	0	0	0	48	0
26.00-26.49	0	0	0	0	154	8	0	0	0	0	70	0
26.50-26.99	0	0	0	0	101	12	0	0	0	0	53	0
27.00-27.49	0	0	0	0	44	21	0	9	0	0	125	0
27.50-27.99	0	0	0	0	20	27	0	20	0	0	91	0
28.00-28.49	1	74	0	0	45	8	0	15	0	0	52	0
28.50-28.99	48	155	0	29	13	107	0	229	0	0	27	0
29.00-29.49	163	320	0	134	12	279	32	223	0	0	26	0
29.50-29.99	583	541	123	294	15	881	259	192	14	9	22	0
30.00-30.49	374	516	279	339	11	425	113	130	26	10	10	0
30.50-30.99	825	619	619	488	89	562	263	185	230	18	12	0
31.00-31.49	872	366	553	536	108	198	560	279	305	31	15	0
31.50-31.99	110	83	348	313	106	0	614	174	127	9	50	0
32.00-32.49	0	14	768	476	300	0	856	567	530	95	424	0
32.50-32.99	0	0	267	253	518	0	279	436	859	343	260	0
33.00-33.49	0	0	19	18	694	0	0	328	642	1370	11	0
33.50-33.99	0	0	0	0	87	0	0	158	68	681	0	0
34.00-34.49	0	0	0	0	0	0	0	31	79	337	0	0

34.50-34.99	0	0	0	0	0	0	0	0	0	73	0	0
-------------	---	---	---	---	---	---	---	---	---	----	---	---





Point of Rocks shallow shelf 1999

# of 15 minute readings				
#taken/#possible	672/2881	2976/2976	2880/2880	2976/2976
temp	September	October	November	December
19.00-19.49	0	0	0	0
19.50-19.99	0	0	0	12
20.00-20.49	0	0	0	24
20.50-20.99	0	0	0	34
21.00-21.49	0	0	0	30
21.50-21.99	0	0	0	16
22.00-22.49	0	0	0	11
22.50-22.99	0	0	0	29
23.00-23.49	6	0	0	65
23.50-23.99	25	0	0	117
24.00-24.49	8	0	0	149
24.50-24.99	10	10	51	166
25.00-25.49	33	60	117	256
25.50-25.99	143	173	193	217
26.00-26.49	65	358	492	115
26.50-26.99	145	152	335	9
27.00-27.49	228	382	938	32
27.50-27.99	9	632	725	10
28.00-28.49	0	510	29	42
28.50-28.99	0	467	0	192
29.00-29.49	0	191	0	375
29.50-29.99	0	41	0	824
30.00-30.49	0	0	0	236
30.50-30.99	0	0	0	16
31.00-31.49	0	0	0	0

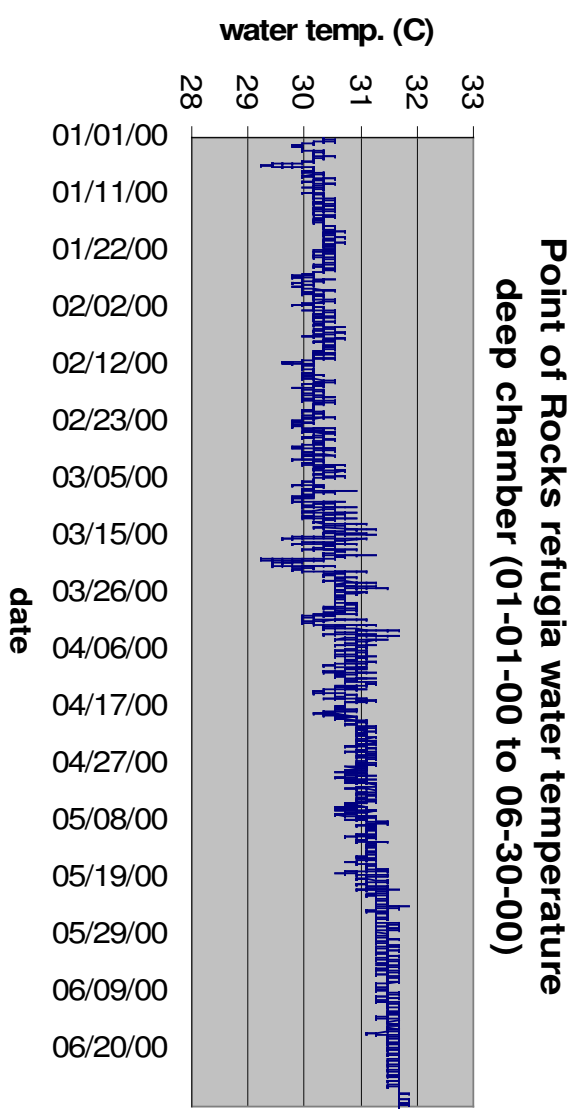
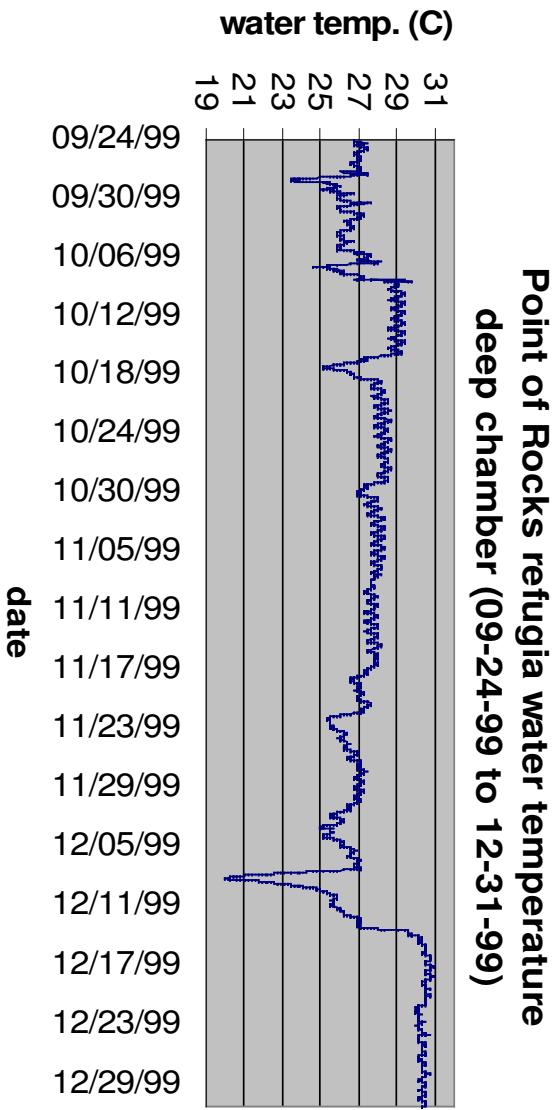
Point of Rocks shallow shelf 2000

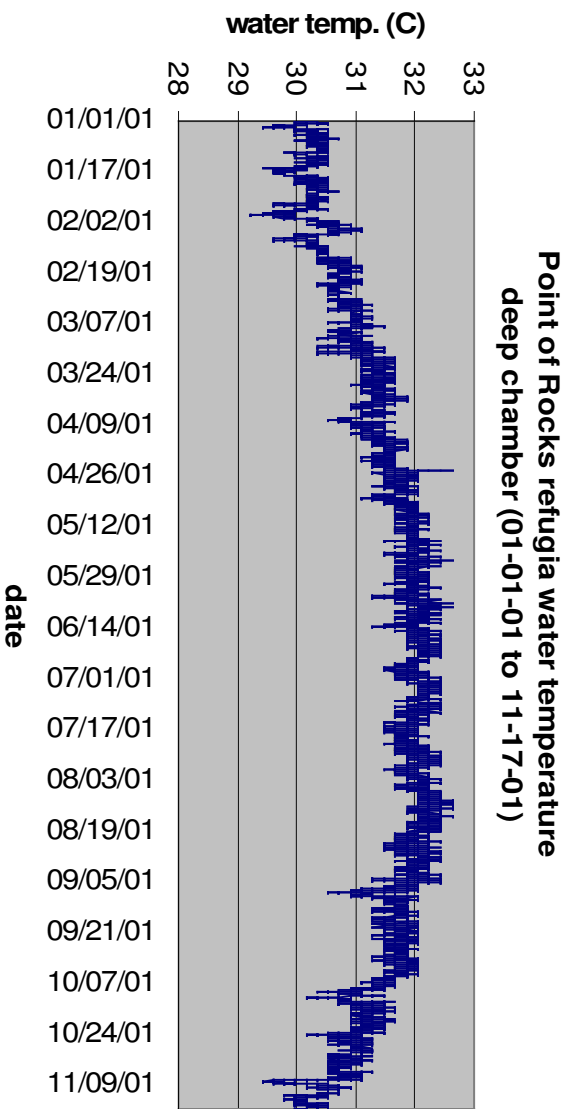
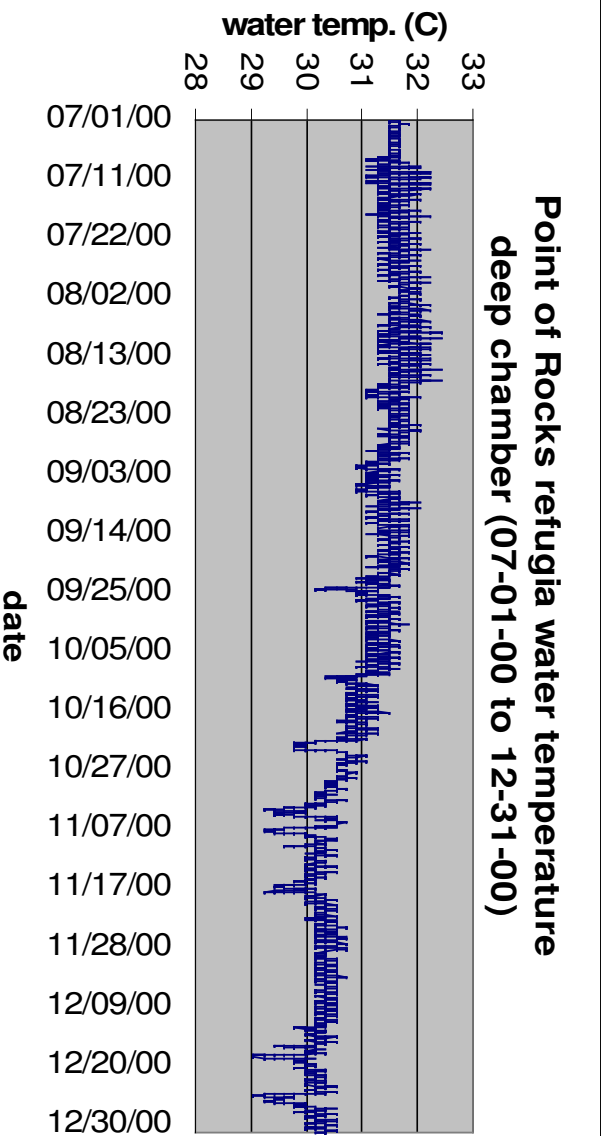
of 15 minute readings

#taken/#possible	2976/2976	2784/2784	2976/2976	2880/2880	2976/2976	2880/2880	2977/2977	2976/2976	2881/2881	2976/2976	2880/2880	2976/2976
temp	January	February	March	April	May	June	July	August	September	October	November	December
28.00-28.49	21	0	0	0	0	0	0	0	0	0	0	0
28.50-28.99	51	0	80	0	0	0	0	0	0	0	1	32
29.00-29.49	384	59	112	23	0	0	0	0	0	0	167	133
29.50-29.99	1715	1535	900	162	24	0	0	0	19	122	802	918
30.00-30.49	778	965	1245	1462	679	23	0	0	28	757	1758	1859
30.50-30.99	27	221	370	854	1059	534	134	0	603	1012	148	34
31.00-31.49	0	3	265	363	1146	2035	1626	1456	1779	955	4	0
31.50-31.99	0	0	4	14	68	288	1199	1462	451	130	0	0
32.00-32.49	0	0	0	2	0	0	17	58	0	0	0	0
32.50-32.99	0	0	0	0	0	0	0	0	0	0	0	0

Point of Rocks shallow shelf 2001# of 15 minute
readings

#taken/#possible	2976/2976	2687/2689	2876/2976	614/2880		
temp	January	February	March	April		
28.00-28.49	0	0	0	0		
28.50-28.99	30	0	0	0		
29.00-29.49	222	77	1	0		
29.50-29.99	1278	1087	276	0		
30.00-30.49	1443	1361	1385	315		
30.50-30.99	3	156	811	220		
31.00-31.49	0	6	497	79		
31.50-31.99	0	0	6	0		
32.00-32.49	0	0	0	0		





Point of Rocks deep chamber 1999

of 15 minute readings

#taken/#possible	672/2881	2976/2976	2880/2880	2976/2976
temp	September	October	November	December
19.00-19.49	0	0	0	0
19.50-19.99	0	0	0	6
20.00-20.49	0	0	0	23
20.50-20.99	0	0	0	15
21.00-21.49	0	0	0	13
21.50-21.99	0	0	0	14
22.00-22.49	0	0	0	15
22.50-22.99	0	0	0	16
23.00-23.49	7	0	0	21
23.50-23.99	24	0	0	18
24.00-24.49	9	0	0	17
24.50-24.99	10	10	0	56
25.00-25.49	46	65	95	201
25.50-25.99	107	94	54	194
26.00-26.49	73	271	219	250
26.50-26.99	215	279	493	300
27.00-27.49	179	314	648	62
27.50-27.99	2	485	1126	10
28.00-28.49	0	716	245	5
28.50-28.99	0	322	0	1
29.00-29.49	0	414	0	6
29.50-29.99	0	6	0	71
30.00-30.49	0	0	0	836
30.50-30.99	0	0	0	827
31.00-31.49	0	0	0	0

Point of Rocks deep chamber 2000

of 15 minute readings

#taken/#possible	2976/2976	2784/2784	2976/2976	2880/2880	2976/2976	2880/2880	2975/2977	2976/2976	2881/2881	2976/2976	2880/2880	2976/2976
temp	January	February	March	April	May	June	July	August	September	October	November	December
28.50-28.99	0	0	0	0	0	0	0	0	0	0	0	0
29.00-29.49	52	0	68	0	0	0	0	0	0	0	162	160
29.50-29.99	417	685	602	27	0	0	0	0	0	134	604	703
30.00-30.49	1991	1708	922	210	0	0	0	0	29	202	1484	1612
30.50-30.99	516	391	1344	1763	585	0	0	0	148	1402	630	501
31.00-31.49	0	0	40	877	2304	1412	1405	1460	1961	1144	0	0
31.50-31.99	0	0	0	3	87	1468	1454	1269	740	94	0	0
32.00-32.49	0	0	0	0	0	0	116	247	2	0	0	0
32.50-32.99	0	0	0	0	0	0	0	0	0	0	0	0

Point of Rocks deep chamber 2001

of 15 minute readings

#taken/#possible	2976/2976	2689/2689	2976/2976	2880/2880	2976/2976	2880/2880	2977/2977	2976/2976	2881/2881	2976/2976	1583/2880	0/2976
temp	January	February	March	April	May	June	July	August	September	October	November	December
28.50-28.99	0	0	0	0	0	0	0	0	0	0	0	0
29.00-29.49	57	0	0	0	0	0	0	0	0	0	26	0
29.50-29.99	707	144	0	0	0	0	0	0	0	0	240	0
30.00-30.49	1680	636	54	0	0	0	0	0	0	54	298	0
30.50-30.99	532	1815	1081	258	0	0	0	0	37	833	897	0
31.00-31.49	0	94	1597	1726	216	78	62	47	761	1598	122	0
31.50-31.99	0	0	244	751	1444	1131	1264	769	1545	391	0	0
32.00-32.49	0	0	0	143	1315	1669	1650	2117	537	100	0	0
32.50-32.99	0	0	0	1	1	2	0	43	0	0	0	0
33.00-33.49	0	0	0	0	0	0	0	0	0	0	0	0