SUMMER THERMAL CHARACTERISTICS OF THREE SMALLMOUTH BASS STREAMS OF SOUTHEASTERN OKLAHOMA

By

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TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Research on the effects of silivicultural practices on environmental quality has led to the formulation of Best Management Practices (BMP's) to protect the environment. These BMP's allow industrial operations personnel to establish timber management policy and regulatory agencies to develop criteria which ensure environmental quality.

The establishment of streamside management zones is an important BMP in maintaining the protection of aquatic ecosystems (Brazier and Brown, 1973; Dunne and Leopold, 1978). Maintenance of tolerable water temperatures is one important aspect of BMP's. The temperature of natural waters is governed by the amount of heat that the water receives. Most heat is contributed to streams by incident solar radiation (Brown, 1969). To maintain water temperatures, the amount of incident solar radiation must be controlled and in natural environments, this control is accomplished by vegetative shading (Hewlett and Fortson, 1982).

Both state and federal laws are involved in the preservation of aquatic resources. The Clean Water Act of 1977 requires states to develop BMP's for Streamside Management Zones (SMZ's) (United States Code, 1977). In addition, states must set water quality standards. Oklahoma's Revised Water Quality Standards were published by the Oklahoma Water Resources Board in 1982 and provisionally accepted by the Environmental Protection Agency (Goetzl and Siegel, 1980). In this document, the board specifies that "at no time shall heat be added to any stream in excess of the amount that will raise the temperature of the receiving water more than 2.8 C (5 F)." Additionally, water temperatures attributable to man made causes must not exceed 32.2 C (90 F) in any waters and must not exceed 28.9 C (84 F) in smallmouth bass streams (Oklahoma Water Resources Board, 1982).

In response to the Clean Water Act of 1977 and state water quality standards, the Oklahoma Division of Forestry (1982) published BMP guidelines that imply a relatively short-lived (one year) temperature increase would result from logging near streams. The short-lived temperature increase is based on assumed rapid revegetation of the SMZ and limited yearly harvesting in SMZ's. The consequences of opening the stream to radiation would be spread over several years and thus minimized by adoption of the BMP guidelines (Oklahoma Division of Forestry, 1982).

In southeastern Oklahoma, activity by forest industry has increased during the last ten years (Towell et al., 1982). Commercial forest harvesting and the logging and grazing practices of small, non-industrial landowners and cattlemen has generated concern from local citizens and organizations about potential impacts on smallmouth bass (Micropterus dolomieui).

The Forestry Department at Oklahoma State University, together with the Weyerhaeuser Company, and the Cooperative Fisheries Unit at Oklahoma State University cooperated in a project to evaluate stream temperature characteristics in forested settings of southeastern Oklahoma. The research study presented in this thesis is a primary part of the cooperative project.

The study objectives are:

1. To characterize stream temperature regimes of smallmouth bass streams in completely forested settings in southeastern Oklahoma during critical, summer, low-flow periods.

2. To determine the influence of natural shading by vegetation on stream temperature regimes during critical summer periods.

3. To evaluate the applicability of existing forest stream temperature models for southeastern Oklahoma.

The information obtained from analyzing small forest openings on three southeastern Oklahoma streams was an indicator of potential impacts that SMZ vegetation removal can have on stream temperatures in the region. Land managers may use this information to understand the potential effects of SMZ vegetation manipulation.

CHAPTER II

LITERATURE REVIEW

Temperature plays a fundamental role in determining the specific inhabitants of an aquatic ecosystem and is therefore of vital concern to the watershed manager. Management decisions that could alter the thermal characteristics of natural waters require the watershed manager to understand energy exchange processes in the system and how organisms in the stream environment react to temperature changes.

Significance of Water Temperature

Water temperature changes can cause biological or physical-chemical alterations in the system. Biological effects differ and are based on the individual organism's ability to withstand changes in the temperature of the surrounding environment. Physical-chemical effects are a result of chemical reactions in water, and the subsequent physical characteristics of aquatic ecosystems, being a function of temperature.

The separation between the biological and physical-chemical responses of streams is not distinct. Chemical and physical alteration of water affects the biological inhabitants. In turn, the water's biological inhabitants alter the chemical nature of the system through metabolic processes. The entire system is interdependent but the biological and physical-chemical responses are discussed separately.

Biological Effects

The metabolic processes of all aquatic organisms are temperature dependent. As temperatures increase, the production and activity of these organisms also increases (Wetzel, 1983). At the lower end of the food chain, the organisms act as the producers for the aquatic community. Producers are important in determining other inhabitants higher on the hierarchical food chain (Wetzel, 1983).

Extensive research on the effects of increased temperatures on producers has shown contradictory results. Some studies show no significant effects (MacQueen and Howells, 1978; Campbell, 1978; Anderson and Lenat, 1978; Beckett, 1978), while other studies show changes in species diversity (Guthrie and Cherry, 1978; Hillbrict-Ilkowska and Zdanowski, 1978; Guthrie, 1978; Cherry, 1979; Squires, 1979), changes in the dominant species present (Hillbrict-Ilkowska and Zdanowski, 1978; Squires, 1979), changes in total organism numbers (Weiss and Anderson, 1978; Welch and Ward, 1978; Squires, 1979; Baker and Baker, 1979), and changes in growth rates (Bott, 1975).

Change in the characteristics of producer populations has an interaction with consumer populations. The exact reaction of consumers to a temperature change depends on the producer's reaction plus the direct effect on the consumer (Wetzel, 1983).

Direct effects of temperature changes on consumers varies. Consumers may shift their primary food source from one species to another. Reproductive characteristics, such as spawning traits and gonadal development, can be disrupted. Largemouth bass (*Micropterus salmoides*) spawned out of season when temperatures were increased from 16 C to

23 C (Jackson, 1979) and smallmouth bass spawned when water temperatures remained near 15 C (Latta, 1963).

Embryonic development occurs in a limited temperature range and can also be disrupted. Smallmouth bass embryo develop normally from 15 C to 25 C with mortality increasing outside this range (Kerr, 1966; Christie and Regier, 1973). Brown (1960) showed 23 C to be the maximum temperature for survival.

Smallmouth bass fry also show a strong negative reaction to higher water temperatures. At the higher temperatures, the fry become easy prey for other predators (Coutant et al., 1979). The upper lethal temperature limit of fry is 32 C (Kerr, 1966).

Growth rates are also linked to temperature. Optimum growth occurs at 25 C (Siefert et al., 1974; DeAngeles and Coutant, 1979). Variations in year-class strength may be related to the extremes of temperature experienced during the first summer of existence (Towell et al., 1982).

Juvenile smallmouth bass prefer temperatures from 28 C to 31 C in laboratory studies (Maughan et al., 1980; Barans and Tubb, 1973) and swimming speed is substantially reduced at temperatures below 20 C (Kerr, 1966). Optimum growth occurs at 26 C (Horning and Pearson, 1973), while the lethal temperature limit is 37 C (Maughan et al., 1980). Adult smallmouth bass show responses similar to those of juveniles (Ferguson, 1958).

Factors other than tolerance limits may influence the survival of aquatic species. Pathogenic bacteria also have thermal optima which generally occur at higher water temperatures (Fliermans et al., 1979; Tansey and Fliermans, 1978). For example, <u>Aermonas hydrophila</u> has an optimal temperature range of 25-35 C (Hazen, 1979) and the Flexibacter genera which are cold water organisms, have a thermal optima around 25 C (Buchanan and Gibbs, 1974). Flexibacter columnaris was responsible for large fish kills in the Columbia River drainage (Brett, 1956).

Physical-Chemical Effects

The metabolic activity of poikilothermic organisms is temperature dependent (Patton, 1973) and the utilization of oxygen and other nutrients is also temperature dependent. The content of dissolved oxygen (DO) in water is important since it is required in respiration by all aquatic aerobic life. The ability of water to dissolve and hold oxygen is inversely proportional to the water temperature (Metzger, 1968). At high water temperatures, organisms have higher metabolic oxygen demands but the water contains less DO.

Smallmouth bass embryo show a negative response when subjected to dissolved oxygen concentrations less than 5.5 mg/l (Maughan et al., (1980) and fry show a negative response at 4.4 mg/l. Juvenile and adult smallmouth bass show responses similar to that of fry with optimal suitability at 8.0 mg/l DO content (Siefert et al., 1974; Maughan et al., 1980). To place this in proper perspective, water at 15 C can hold 10.0 mg/l DO at saturation (Wetzel, 1983).

Lin and Erickson (1973) reported increased nutrient utilization rates of aquatic organisms at higher temperatures. Increased nutrient utilization rates increase the production of metabolic by-products. These by-products may be simple carbon, oxygen, and/or hydrogen compounds or they may be complex organic molecules. Metabolic by-products can in turn affect organisms directly and indirectly.

Wickstrom (1980) observed the decreasing temperature gradient downstream of a thermal spring and found measureable changes in alkalinity, phosphates, and silica. The significance of the thermogradient in establishing the physical-chemical properties was not definite, but a strong correlation was evident. Possible explanations for observed ionic concentration differences along a thermogradient as well as the existence of certain metabolic by-products could be temperature's effects on reactions, reaction rates, and solubility. A chemical reaction has a temperature dependent equilibrium constant. As temperatures change, the equilibrium constant value changes and reactions proceed at different rates or shift toward a specific end product (Sawyer and McCarty, 1978).

Warmer temperatures will generally increase the solubility of substances in water (Snoeyink and Jenkins, 1980). Increased solubilities and reaction rates associated with higher water temperatures can potentially make more nutrients available in the system and increased nutrient availability may facilitate eutrophication. In a study of the decomposion rates of leaves in a thermal effluent plume, decay coefficients were significantly higher inside the plume than outside (Talmage and Coutant, 1980). Increased nutrient availability could also produce substantial increases in organism numbers which require more DO.

Temperature and Heat Relationships

The terms heat and temperature have often been interchanged and misused. Heat refers to the amount of energy that a body possesses, often expressed in calories. Temperature relates the "hotness" or "coldness" of a body. It measures the internal (heat) energy of a molecule or collection of molecules. The temperature and heat content relationship is illustrated by the definition of the calorie which is the amount of heat required to raise one gram of water one degree Celcius (Marion, 1979).

Temperature Change Process

The occurrence of heat in water is the result of the various inputs and outputs of energy. Water, by virtue of its temperature being above absolute zero, radiates heat. However, objects surrounding a water body also radiate heat. A transfer of heat is established, with the net direction of heat transfer being from the body of highest heat content to the body of lowest heat content. The sun is therefore the principle heat source warming streams (Reifsnyder and Lull, 1975).

The inputs and outputs of heat which a stream receives are dynamic. However, to characterize the net heat flow, the assumption is made that wind and water currents, temperature and pressure gradients and the solar radiation input can be averaged over time to give representative energy fluxes. This assumption facilitates the modeling of heat flow (Delay and Seaders, 1966).

For modeling purposes, energy fluxes can be viewed as part of an open system. An object receives heat radiated from sources which have a higher heat content. At the same time, the object radiates heat to other objects of lower heat content in its environment.

Four properties determine a stream's instantaneous energy flux. The first property is the ability of the water to radiate heat. This property is a function of the energy gradients which exist between the stream and the surrounding environment. The direction of energy flow is from locations with high energy contents to low energy locations (Reifsnyder and Lull, 1975).

A second property is the stream's reflectivity. All mass has the potential to reflect a fraction of the energy incident upon it. The amount of energy reflected is dependent upon the opaqueness of the body. A stream may simultaneously reflect incident energy and receive energy reflected from other objects (Raphael, 1962).

The third property is the stream's absorptivity. Absorptivity is also related to the opaqueness or transparency of water. Absorption of energy by a stream changes the wavelength of the incident energy. Absorbed energy of new wavelength is available to be radiated by the water if the proper energy gradients exist (Reifsnyder and Lull, 1975).

The final property is the stream's transmissivity. A transparent object has the capacity to transmit energy through it. The amount of energy transmitted is also a function of opaqueness. Transmitted energy becomes important in streams when large amounts of energy are transmitted through the water and into the stream bed, creating a heat sink. All transmitted energy is unchanged in wavelength (Reifsnyder and Lull, 1975).

Generalizations have been made in macroscale energy budgets to quantify the dynamic factors affecting the heat content of streams. These generalizations include steady state radiation of energy and continuity of energy inputs and outputs. Using the generalizations, the energy budget for a stream can be computed to yield a net temperature change.

Energy Fluxes

When the forest canopy protecting a stream from solar radiation is removed, a net heat gain is realized in the exposed stream reach (Brown and Krygier, 1967). To quantify this heat increase, the energy fluxes involved in heat transfer must be examined. Pluhowski (1972) computed the heat gains or losses in stream exposures to be:

$$H = NR + A + V + C + E + I + O \qquad (1)$$

where:

H is the change in stored heat in the stream section.
NR is the net radiation, both longwave and shortwave, incident on the water in the stream section.
A is the advected heat of groundwater and tributary water to the stream section.
V is the convective transfer of heat between the atmosphere and the stream section.
C is the heat conducted into the streambank or channel bottom in the stream section.
E is the heat exchange due to evaporation or condensation in the steam section.
O is the heat content of streamflow leaving the stream section.
I is the heat content of streamflow entering the stream section.

For sign convention, all inputs are regarded as positive and outputs are regarded as negative.

Net Radiative Flux. The net radiative flux to a stream is the summation of inputs and outputs of radiation. Net radiation is the largest flux component affecting heat content accounting for 95 percent of the total energy reaching an exposed stream (Brown, 1969).

The net radiative flux is comprised of several components. The variables of the net radiative flux were defined by Wooldridge and Stern (1979) to be:

$$NR = SD + Sd + SRI + ST + LA + LT - SRO - LS \qquad (2)$$

where:

SD   is direct shortwave solar radiation.
Sd   is diffuse shortwave solar radiation.
SRI is shortwave solar radiation reflected to the stream.
ST   is shortwave solar radiation transmitted by vegetation to the stream.
LA   is incoming longwave atmospheric radiation.
LT   is incoming longwave radiation from terrestrial objects.
SRO is shortwave radiation reflected by the steam.
LS   is longwave radiation reflected by the stream.

The amount of radiation reaching the stream is dependent upon geographical location, surrounding vegetation, topographical obstructions, altitude, time of year, atmospheric turbidity, and the orientation of the receiving stream. In the northern hemisphere, stream flow in an easterly or westerly direction has the potential to be shaded by vegetation only on the southern streambank. Streams that flow in a northerly or southerly direction are shaded only by overhanging vegetation during the noon day hours while receiving shade from either bank in the morning and evening hours (Lee, 1978).

Time of year and geographical (latitudinal) location determine the angle at which the sun's rays strike the water surface. A steeper angle of incidence yields a greater radiative flux density. Topographical obstructions such as ridges also determine the amount of solar radiation reaching the stream. The ability of vegetation to transmit radiation determines how effective shading is in reducing radiation inputs (Lee, 1978).

Atmospheric turbidity such as dust and water vapor absorbs a portion of incoming shortwave radiation as well as outgoing longwave radiation. These atmospheric particles can then re-rediate longwave radiation back toward earth or toward space. The altitude of the stream determines the thickness of the atmosphere through which an increment of radiant energy must travel and the effect of dust and water vapor (Reifsnyder and Lull, 1975).

Convective Energy Flux. A convective energy exchange occurs whenever a temperature gradient exists between the water mass and the overlying air mass. A positive energy exchange occurs when the air mass is warmer than the water. During critical summer low flow periods, the convective energy flux reinforces the radiative flux in heating the stream (Brown, 1969).

Convection results from boundary layer conduction and the subsequent transfer of heat through displacement of masses of fluid. The driving forces behind this flux are the wind speed and the air temperature gradient.

Conductive Energy Flux. Conductive energy exchange involves a transfer of heat through matter by kinetic energy from particle to particle. Conduction occurs if a temperature gradient exists between the water and the stream bed. Generally, during peak water temperatures, heat will flow from the water into the bed material which acts as a heat sink. Conversely, during the night, when water temperatures begin to lower, the stream bed may act as a heat source for the water because the direction of the temperature gradient has been reversed.

Brown (1972) found that up to 18 percent of the incoming heat load was conducted to a bedrock stream bed of green breccia. In gravel or porous streambeds, circulating water prevented the establishment of pronounced temperature gradients. Conductive heat transfer was also restricted by the point contacts of the gravel particles themselves. For porous bed material, ponding or pooling of water may increase the conductive flux by decreasing water circulation.

Evaporative Energy Flux. Condensation or evaporation at the water surface adds or releases heat to the system, respectively. When the vapor pressure of the air is less than the saturated vapor pressure of air at the temperature of the surface water, water evaporates into the air. Heat is removed by this process through the energy required to change the water from the liquid state to the gaseous state and by the physical removal of water molecules containing heat.

Logging and Stream Temperatures

The importance of managing vegetation along streams for control of water temperatures has been a major concern in the last 30 years. However, earlier observations had pointed to potential heating problems when streamside vegetation was removed. Titcomb (1926) noted temperature increases of 5.6 C in streams after clearcutting. Munns (1948) suggested clearcutting caused several detrimental effects to water quality, one problem being rises in stream temperature.

Greene (1950) saw a need for quantitative data and monitored two watersheds at Coweeta Hydrologic Laboratory, North Carolina. One watershed was cleared and farmed, the other left as a control. The maximum temperature observed on the farmed watershed was 26.1 C compared to 18.9 C for the control. Greene proposed management of the riparian zone to preserve shade.

Johnson (1953) postulated that tributary streams also needed to be shaded to maintain their cooling effect on the receiving streams and advocated an 18.3 m wide buffer strip be maintained on either side of tributary streams. Stoeckeler and Voskuil (1959) affirmed the

Johnson postulate. They recorded temperatures of a small Wisconsin stream in an open meadow before and after it was diverted through 56.7 m of shade. After diversion, maximum temperatures dropped from 15.6 C to 9.4 C.

Eschner and Larmoyeux (1963), Hornbeck and Reinhart (1964), and Reinhart et al. (1963) noted stream temperature changes following four different silvicultural treatments at Fernow Experimental Forest in West Virginia. A clearcut treatment caused water temperature increases of 4.4 C over an uncut control watershed. Temperature changes on the other three selective cut treatments were recorded as "slight" and "not appreciable," reflecting the amount of timber left standing because it was unmerchantable (Table I).

Levno and Rothacher (1967) used linear regression to compare maximum weekly temperatures in three Oregon watersheds. No significant differences were found before treatment. One watershed was clearcut, another received a 25 percent patchcut with an additional eight percent of land area cleared for roads and skid trails. The channel of the latter treated watershed was also scoured to bedrock by a flood. Maximum water temperatures as reported by Wooldridge and Stern (1979), were 23.9 C in the clearcut watershed and 25.0 C in the patchcut watershed with the scoured channel. The third watershed, left as a control, had a maximum temperature of 16.1 C (Table I).

Brown and Krygier (1967) noted monthly maximum temperatures in an Oregon stream were 7.8 C higher after clearcutting than water temperatures in a shaded control stream. Measurements showed that radiation under the protective canopy was 0.3 to 0.4 langleys per minute (ly/min) while radiation measurements in the exposed stream were 1.1 to 1.2 ly/min

TABLE I

SUMMARY OF OBSERVED TEMPERATURE CHANGES FOLLOWING LOGGING

Study Area	Treatment	Aspect	Exposure Length meters	Max T. Increase C	Max T. Observed C	Predicted T. C	Investigator(s)
Alaska							
Maybeso Cr.	25% clearcut	ESE	----	3.3	20.6	----	Meehan, Farr, Bishop,
Harris R.	20% clearcut	E	----	5.6	19.4	----	Patric (1970)
Temperature C.	clearcut	---	567	2.2	11.7	----	
Big Boulder C.	clearcut	---	329	0.3	12.8	----	
Clear Creek #1	clearcut	---	256	1.6	5.6	----	
Clear Creek #2	clearcut	---	347	0.9	6.1	----	
Sweitzer Cr.	clearcut	---	55	0.3	8.3	----	
Montana Cr.	clearcut	---	219	0.8	8.9	----	
Twin Cr.	clearcut	---	91	1.1	11.1	----	Meehan (1970)
Falls Cr.	clearcut	---	37	0.3	13.9	----	
Ohmer Cr.	clearcut	---	73	0.6	13.3	----	
Ohmer Cr. Trib.	clearcut	---	37	0.4	11.7	----	
Blind R. Trib.	clearcut	---	91	0.8	12.2	----	
Foam Cr.	clearcut	---	110	1.1	13.3	----	
Pat's Cr.	clearcut	---	347	2.7	16.1	----	
Washington							
Entiat NF	wildfire	SW	----	5.6	15.6	----	Helvey (1972)
Meadow Cr.	clearcut	SE	16	0.1	17.8	18.0	
Pehastin Cr.	full exposure to	N	18	0.1	16.7	16.7	
	noon-day sun						Wooldridge, Stern
Creek #4330	no natural shade	W	16	0.3	11.1	11.2	(1979)
Creek #1917A	complete exposure	SW	17	0.6	14.4	14.2	
Pyramid Cr.	no natural shade	W	29	0.0	18.3	18.3	

TABLE I (continued)

Study Area	Treatment	Aspect	Exposure Length meters	Max T. Increase C	Max T. Observed C	Predicted T. C	Investigators
Washington							
Millie Cr.	clearcut	N	28	0.2	14.4	14.4	Wooldridge, Stern (1979)
Oregon							
Francis Cr.	undisturbed	SE	3042	0.6	15.0	----	
Francis Cr.	buffer strip of 3% of clearcut	SE	512	0.6	15.0	----	
Pass Cr.	two clearcuts on south band 373 m apart	ESE	393	4.4	18.9	----	
Pass Cr.	clearcut below other clearcuts on north bank	ESE	386	-0.6	17.8	----	
Deep Cr.	clearcut with 60% slash cover	N	579	2.2	15.6	----	Brown, Swank, Rothacher (1971)
Deep Cr.	9 m wide buffer strip	N	114	0.0	15.0	----	
Zinc Cr.	clearcuts upstream	N	671	4.4	18.3	----	
Zinc Cr.	shaded with groundwater inflow	N	396	-2.2	15.6	----	
Deep Cut Cr.	15 m wide buffer strip	S	168	0.0	16.1	----	
Deep Cut Cr.	no vegetation	S	46	7.2	23.3	----	
Steelhead Cr.	9 m wide buffer strip	SSW	366	1.7	18.3	----	
Little Rock Cr.	clearcut with 5 year old alder	SSE	335	2.2	24.4	----	

TABLE I (continued)

Study Area	Treatment	Aspect	Exposure Length meters	Max T. Increase C	Max T. Observed C	Predicted T. C	Investigators
Oregon							
Little Rock Cr.	thin 14 m wide buffer strip	ESE	655	0.0	24.4	----	Brown, Swank, Rothacher (1971)
Cedar Cr.	clearcut, with a 40% thin above the clearcut	ESE	1280	7.8	28.3	----	
WS 1*	clearcut	NW	2134	7.8	23.9	----	Levno, Rothacher (1967)
WS 2	25% patchcut with exposed channel	NW	396	8.9	25.0	----	
Deer Cr.	buffer strip	---	427	0.8	11.7	12.2	Brown (1969)
Berry Cr.	natural meadow	---	610	6.1	19.4	18.9	
Needle Branch	clearcut	---	----	7.8	21.1	----	Brown, Krygier (1967)
Deer Cr.	15 - 30 m buffer strip	S	----	0.0	----	----	Brown (1970)
Needle Branch	clearcut, channel cleared of debris	SSW	----	15.6	29.4	----	
Montana							
Smith R.	commercial cuts	---	----	----	14.4	----	Johnson (1953)
Wisconsin							
Coon Cr.	natural meadow	---	57	6.1	15.6	----	Stoekeler, Voskuil (1967)
Connecticut	cleared & farmed	---	792	5.6	32.2	----	Titcomb (1926)
Pennsylvania							
WSLR-2	Clearcut with herbicide application	SE	800	10.5	32.0	----	Rishel, Lynch
WSLR-3	Clearcut with 30m buffer strip	SE	----	2.2	23.0	----	Corbett (1982)

TABLE I (continued)

Study Area	Treatment	Aspect	EExposure Length meters	Max T. Increase C	Max T. Observed C	Predicted T. C	Investigators
West Virginia							
WS 3	conventional buffer strip	S	----	0.8	18.6	----	Lee, Samuel (1976)
WS 3	later clearcut	S	----	5.5	25.3	----	
WS 6	clearcut	S	----	9.6	25.3	----	
WS 7	3 yr. old coppice	E	----	3.0	21.4	----	
WS 1	clearcut	ENE	----	4.4	26.1	----	Eschner, Larmoyeux (1963)
WS 2	17" dia. limit	S	----	"slight"	----	----	
WS 3	5 " dia. selective cut	S	----	0.0	----	----	
WS 5	11" dia. selective cut	NE	----	0.0	----	----	
WS 6	lower ½ of WS cut, 3 yr. later, upper ½ cut	SE	----	8.3	26.7	----	Patric, Reinhart (1971)
WS 7	upper ½ of WS cut, 3 yr. later, lower ½ cut	E	----	3.3	21.7	----	
Virginia							
Colvin Run	channel realigned	E	335	3.4	27.8	28.0	Pluhowski (1972)
North Carolina							
Brush Ridge R.	clearcut	W	61	7.2	20.0	----	Swift, Baker (1973)
WS 3	farmed	S	131	11.7	29.4	----	Swift, Messer (1971)
WS 1	canopy deadened	S	382	2.8	21.1	----	
WS 1	later clearcut	S	382	3.3	21.7	----	
WS 19	basal area reduced 22%	SW	1016	1.1	20.6	----	
WS 13	1 yr. old coppice	E	533	1.4	22.8	----	

TABLE I (continued)

Study Area	Treatment	Aspect	Exposure Length meters	Max T. Increase C	Max T. Observed C	Predicted T. C.	Investigators
North Carolina							
WS 17	6 yr. old coppice	NW	312	0.6	18.9	----	Swift, Messer (1971)
Coweeta WS	farmed	---	----	12.8	26.1	----	Greene (1950)
Coweta WS	Clearcut 38% of stream shaded by debris	S	2052	5.4	----	----	Swift (1982
Georgia							
Grant Forest WS	50% cover in 6 m buffer strip	SW	----	11.1	27.7	20.6	Hewlett, Fortson (1982)
England							
Black Burn R.	Clearcut and channel realignment	SW	503	6.5	21.5	----	Gray, Edington (1969)
Italy	removal of riparian vegetation	NW	9012	22.4	28.0	----	Vugts (1974)
British Columbia Canada							
WSA	Clearcut	S	670	4.8	21.8	----	Feller (1981)
WSB	Clearcut, slash burned	S	610	3.3	20.3	----	

*WS is an acronym for watershed.

for the same time period.

Brown (1970) compared the water temperature of streams with and without buffer strips and found no temperature increases on the stream where buffer strips were left. The stream without a buffer strip had a maximum temperature increase of 15.6 C.

Pluhowski (1972) recorded temperatures of a realigned portion of Colvin Run in northern Virginia where vegetation had been cleared and found temperatures rose 3.3 C after passing 335.5 m through the exposure. The water temperature had remained virtually unchanged for 1310.6 m above the exposure. Gray and Edington (1969) also diverted flow from a shaded channel to one devoid of vegetation and recorded a temperature increase of 6.5 C in the exposure (Table I).

Mehan (1970) studied stream temperatures passing through vegetation clearings of different lengths in Alaska. He found that generally, stream temperature increases were greatest for the longer clearings (Table I). Variance from this trend was probably due to differences in the travel time of water through the openings.

Meehan et al. (1969) showed that removing streamside vegetation increased the number of days above a set temperature limit when compared to a control stream and the same temperature limit. When both streams exceeded the temperature limit, the higher temperatures persisted longer on the clearcut stream.

Swift and Messer (1971) evaluated six different forest treatments in North Carolina using regression techniques and found that water temperature increases following clearcutting were consistently higher than other treatments (Table I). They also noted that after eight years the vigorous coppice forest had provided enough shade for water temperatures to return to normal.

In West Virginia defoliation of the lower portion of watersheds increased the mean water temperatures by 1.1 C to 2.2 C. Defoliation of the upper half of watersheds did not contribute to a temperature increase (Patric and Reinhart, 1971).

Brown et al. (1971) evaluated stream temperatures above and below clearcuts on tributary streams of Steamboat Creek in Oregon. They observed how the heated water in the tributary streams affected the main streams in Steamboat Drainage and found that the water temperatures of both feeder and receiving streams plus the volumes of flow for both streams were important in determining the final temperature increase of the receiving stream. They also determined that buffer strips need not be a set width but should conform to the stream configuration.

Buffer strip evaluation performed by Swift and Baker (1973) in the North Carolina mountains indicated water temperature increased 7.2 C when buffer strips were not left along streams. Water temperatures were observed to cool approximately 2.2 C after the stream re-entered a shaded buffer strip. This temperature recovery was attributed to the influx of cool groundwater.

In the piedmont of Georgia maximum water temperatures within a buffer strip were 11.1 C higher than in an undisturbed stream. The input of heat was attributed to the inadequacy of the buffer strip and to the heating of shallow groundwater as it moved from the clearcut, through the buffer strip, and to the stream. The buffer strip had been gleaned of merchantable pine and had undergone some wind damage (Hewlett and Fortson, 1982).

Modeling Stream Temperatures

Excluding thermal springs, water emerges from the ground at low temperatures. As the water moves downstream, it is affected at the surface by the sun and wind, which raise the water temperature during the summer. The greater the temperature difference of air and water, the greater the surface area of the water, and the more slowly the water moves, the greater will be the heating of the water. This is the basis for applying the theory of mass-energy relationships to forest streams. The theory states that if a stream reach is at uniform temperature, Tw, at any given instant of time, t, then the system contains a mass of water, Mw, into which flows a mass of water, Mi, at temperature, Ti, and out of which flows a mass of water, Mi, at temperature, To. A change in heat content, H, also exists from the four energy fluxes operating across the stream surface area, A. Raphael (1962) stated the time rate of temperature change for fully mixed streams to be:

$$\frac{dTw}{dt} = \frac{H \cdot A + Mi\ (Ti - To)}{Mw} \qquad (3)$$

Raphael (1962) modeled the shallow areas in reservoirs on the Columbia River where mixing occurred using this principle. Delay and Seaders (1966) modeled the temperatures of the Umpqua River in Oregon, accounting for thermal stratification.

Brown's Model

Brown (1969) recorded the energy budgets of small, well-mixed stream sections in the Oregon mountains which were cleared of protective vegetation, accounting for the four energy fluxes: net radiation, condensation/evaporation, convection, and conduction. Using the theory of Equation 3, he predicted the temperature changes of three small streams to within 0.6 C. Equally as important, he established the net radiation flux as the principle driving force behind temperature changes in clearcuts.

Brown (1970) simplified his model on the premise that the change in heat content, H, could be closely approximated by using only the net radiative flux, NR. This eliminated the need to measure or predict the other three energy fluxes. The change in temperature, T, is computed from:

$$\Delta T = \frac{\text{Total heat added}}{\text{Total volume heated}} \tag{4}$$

Using Brown's assumptions, the total heat added is the product of the rate per unit area at which heat is received, H, the total area over which it is received, A, and the total amount of time the heat is added to the stream, t (Brown, 1980), or

$$\text{Total heat added} = H \cdot A \cdot t \tag{5}$$

The total volume heated is the product of the stream discharge, Q, and the time of exposure, or:

$$\text{Total volume heated} = Q \cdot t \tag{6}$$

thus the change in temperature is:

$$\Delta T = \frac{H \cdot A}{Q} \tag{7}$$

The dimensional relationship is:

$$\Delta T = \frac{H(\text{cal/cm}^2\text{min}) \cdot A(\text{cm}^2)}{Q(\text{cm}^3/\text{sec})} \tag{8}$$

Converting flow (cm^3/sec) to grams of water per minute gives:

$$\Delta T = \frac{H(\text{cal/cm}^2\text{min}) \cdot A(\text{cm}^2)}{60\ Q\ (\text{g/min})} \tag{9}$$

Since a degree Celcius is one calorie per gram of water, then:

$$\Delta T\ (C) = \frac{H \cdot A \cdot 0.0167}{Q} \tag{10}$$

Brown (1970) developed a nomograph for determining the absorbed solar radiation in a stream reach using the travel time of water through the clearing and the mid-day solar angle. The nomograph furnishes the solar radiation flux in English Units (BTU/ft^2 min) but this can be converted to SI units by the functional relationship:

$$BTU/ft^2\ min = 0.2712\ cal/cm^2\ min \tag{11}$$

Or, Equation 10 can be used where A is in meters squared, Q is in litres per second, H is in langleys per minute, T is in degrees Celsius, and the conversion constant is 0.1667.

Travel time of water in a stream reach can be determined from a variety of methods employing dye injection (Alvey, 1972; Hubbard et al., 1981; Wilson, 1968). The most frequently recommended procedure is to inject a flourescent dye at the upstream end of the clearcut and take dye concentration readings at the downstream end of the clearcut with a fluorometer. The time to the peak dye concentration corresponds to the amount of time it has taken for the principle water mass to move through the system. The mid-day solar angle is obtained from solar ephemeris tables available from the Smithsonian Institution (List, 1971).

Brown's Model has been consistently inaccurate in streams having bedrock channel substrates or a high pool-riffle ratio. Brown (1972) found that bedrock bottoms act as a heat sink and may decrease the net radiative flux to the water by 15 to 20 percent. He also concluded that only the portion of the pool that actually contains flowing water should be used in the determination of the effective surface area. The flowing portion was discerned by observing the dye cloud pass through the pool during the travel time study.

Brown's method provides a simple approach to stream temperature modeling in which the only field measurements required are the determination of the pool water travel time and the surface area of the stream reach. All other calculations can be done off site.

State of Washington, Department of Ecology Model

Wooldridge and Stern (1979) also recognized the situations where Brown's Model performed poorly. They noticed that the Brown Model worked well for smooth channels without large storage pools or protruding rocks. They hypothesized that the rock could be acting as a heat sink during the day. Also, channels with several protruding rocks were indicative of shallow reaches and areas of backwater, where flows were slow. In these areas water was heated longer, and slowly discharged and mixed with the normal streamflow, raising its temperature.

To overcome these problems Wooldridge and Stern (1979) developed a model that used the Manning coefficient to characterize channel roughness:

$$V = \frac{1}{n} \cdot R^{0.66} \cdot D^{0.5} \qquad (12)$$

where:

V is the velocity (m/sec).
R is the hydraulic radius (the cross sectional area of the stream reach divided by the linear length of the wetted perimeter in meters).
S is the channel slope (m/m).
n is the Manning coefficient for channel roughness.

Wooldridge and Stern (1979) recommended that the Brown Model not be applied to streams where Manning's n is greater than 0.04.

Additionally, Wooldridge and Stern (1979) developed a scheme for characterizing shade. The method uses a camera equipped with a 180 degree fisheye lens placed normal to the flat planar surface of the stream to take a photograph of the sky view factor. A polar graph is superimposed on the photographic print. A polar graph is a plot of the altitude and azimuth as a function of latitude, declination, and hour angle (Wooldridge and Stern, 1979; Currier and Hughes, 1980). The sun can be effectively tracked across the camera's view of the sky for any day of the year using the polar graph. Vegetation along side the stream appears on the image and the "effective sunrise" and "effective sunset" are determined from the superimposed solar path.

To evaluate the potential loss of shade by removal of the forest canopy, the fraction of potential solar radiation is computed for the stream with the vegetation intact:

$$FP = \frac{PS(t_2 - t_1)}{PS\ (daily)} \tag{13}$$

where: FP is the fraction of potential solar radiation received.
$PS(t_2 - t_1)$ is the solar radiation from effective sunrise to effective sunset.
PS(daily) is the potential solar radiation from sunrise to sunset if no vegetation existed.

Potential solar radiation for the time interval between effective sunrise and effective sunset is determined by:

$$PS = \frac{C}{R^2}((t_2 - t_1) \cdot \sin l \cdot \sin d + 3.8197 \cdot \cos l \cdot \cos d \cdot (\sin W_2 - \sin W_1)) \tag{14}$$

where: PS is the potential solar radiation during the time interval t_1 through t_2 (ly).

C is the solar constant (116.4 ly/hr).

t_2 and t_1 are the ending and initial times in hours and minutes before (-) or after (+) true solar noon.

W_2 and W_1 are the hour angles corresponding to the ending and starting times.

l is the latitude.

d is the declination.

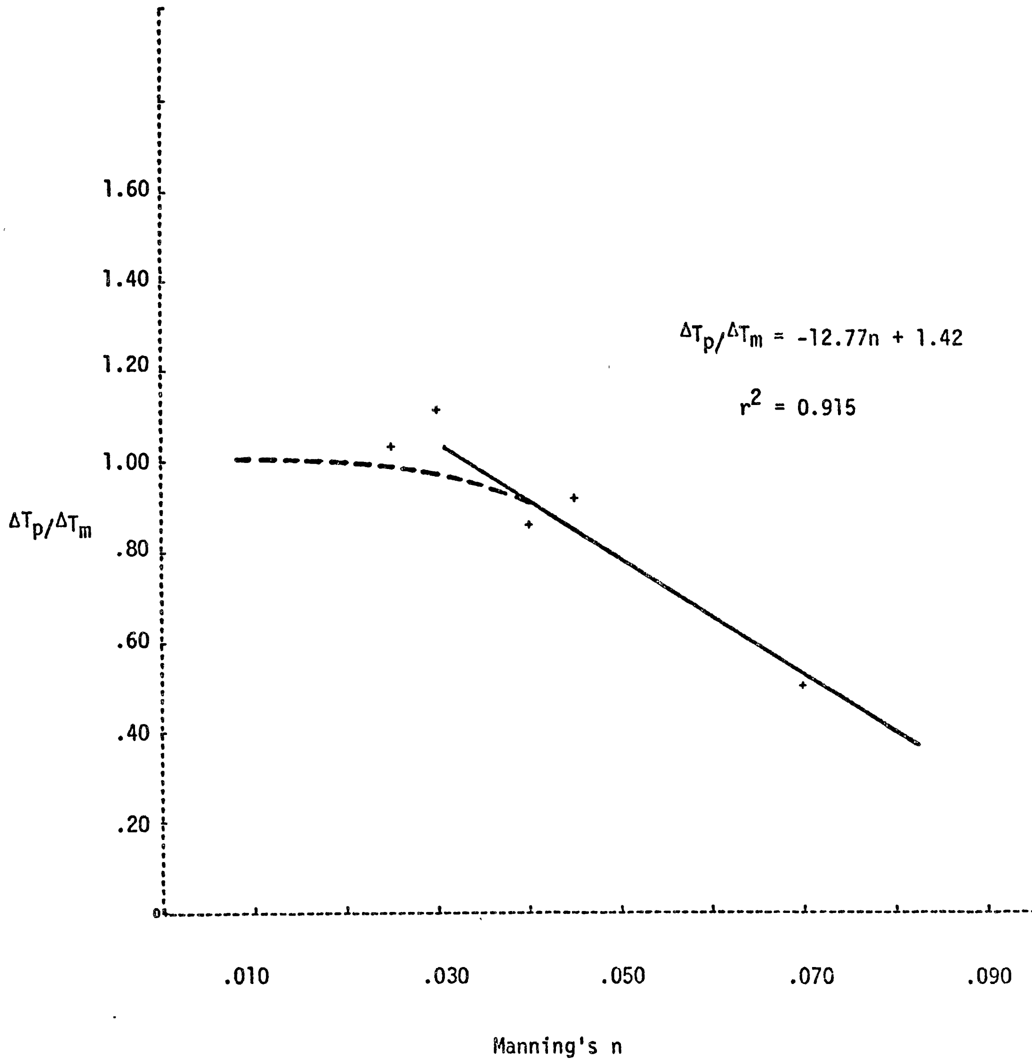
R is the radius vector of the earth-sun distance with respect to the length of the semi-major axis of the earth's orbit.

These equations calculate direct solar radiation at the edge of the atmosphere based on the solar constant. To find the actual radiation on a horizontal ground surface, the value obtained is multiplied by a correction factor based on latitude. The correction factor for southeastern Oklahoma is 0.825 (Moon, 1940).

The equations developed by Wooldridge and Stern are used as a modification of Brown's Model. By finding the added energy input (PS) caused by shade removal and multiplying by the regional correction factor (0.825), the values can be substituted into Brown's Model (Equation 10) to yield the temperature change. For streams having a Manning's n value of 0.04 or greater the ratio of predicted and measured temperatures is determined (Figure 1). This ratio is divided into the prediction obtained from using the model to obtain an adjusted temperature prediction.

Combined Model

A combined model can be used to predict stream temperature increases by obtaining estimates of the four energy fluxes from methods outlined by different researchers. The four energy fluxes are combined to arrive at a total energy flux from which the resultant temperature is determined.



Source: Wooldridge and Stern (1979).

Figure 1. The relationship of the ratio of predicted to measured stream temperatures and Manning's n coefficient

Net radiation is estimated by measuring shortwave radiation with a pyranometer. Shortwave radiation is accepted as meaning radiation of a wavelength from 0.1 to 4.0 microns (Reifsnyder and Lull, 1975). Comparability between shortwave radiation (S) and net radiation (NR, Equation 1) is achieved by accounting for radiation of all wavelengths:

$$NR = S - RS + LI - LO \tag{15}$$

where:

RS is the fraction of shortwave radiation reflected by the stream.
LI is the incoming longwave radiation.
LO is the outgoing longwave radiation.

The amount of shortwave radiation reflected from a stream has been expressed by Lee (1978) as:

$$RS = 0.09 \cdot ST \tag{16}$$

where ST is global radiation. Global radiation values are available in List (1971).

Empirical relationships for determining the longwave radiation component have been developed by DeWalle (1976) and are represented by the equation:

$$LO = es(Tw + 273.16)^4 \tag{17}$$

where:

LO is outgoing longwave radiation ($cal/cm^2 min$).
e is the emissivity of water = 0.97 (Anderson, 1954).
s is the Stefan-Boltzmann constant = $8.132 \cdot 10^{-11}$ $cal/cm^2 min\ K^4$.
Tw is the surface water temperature.

Unfortunately, the water temperature needs to be known to predict the longwave radiation. In the case of small openings, the temperature of water upstream of the opening is an acceptable approximation (Lee, 1978), but when the clearing is large and/or the exposure time of water is long, an iterative trial and error process is used (Edinger et al., 1968). This involves trying different values for the water temperature within the range established by the final prediction temperature. A "best fit" value is used for subsequent predictions on streams of similar characteristics in the region.

To determine the incoming longwave radiation, Lee (1978) used the formula:

$$LI = Fes(Ta + 273.16)^4 \qquad (18)$$

where: LI is incoming longwave radiation (cal/cm^2 min).
F is the view factor of the stream (Figure 2).
Ta is the air temperature (C).
e and s are as previously defined.

Net radiation can then be computed from Equation 14 by substituting the values obtained from Equations 16, 17, and 18.

The evaporative flux (E) can be determined from the equation of Brutsaert and Yu (1968):

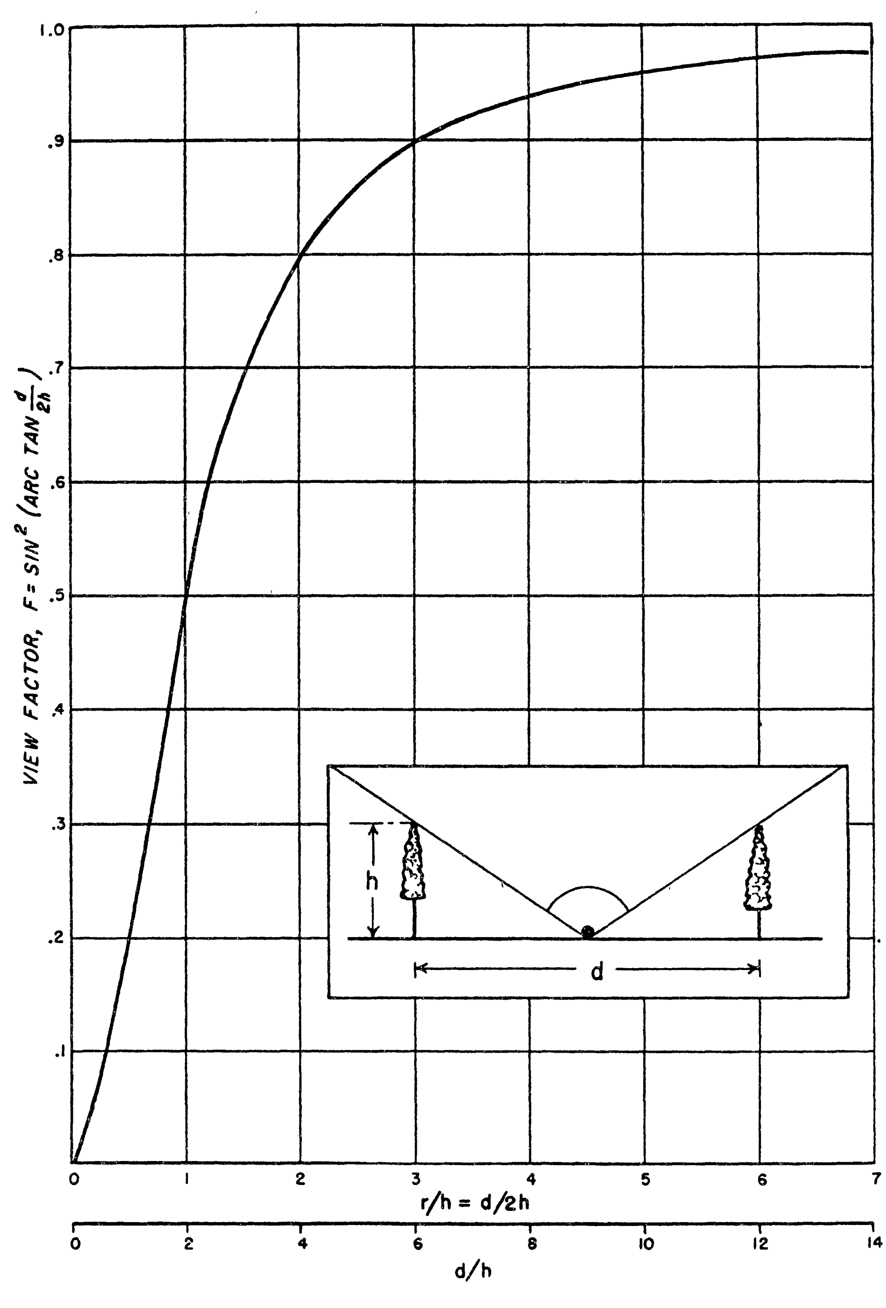
$$E = 2.7473 \cdot 10^{-4} U(A^{0.5})^{-0.132} (ew - ea) \qquad (19)$$

where:

U is the wind velocity (cm/sec).
A is the evaporating area of the water (cm^2).
ew is the saturation vapor pressure corresponding to the water temperature (mbar).
ea is the saturation vapor pressure corresponding to the air temperature (mbar).

As with the determination of outgoing longwave radiation, the solution for the evaporative flux involves the unknown water temperature. The same iterative process is used here to predict the water temperature to be used in the evaporative flux calculation.

The loss of heat through the convective flux (V) is found using



Source: Reifsnyder and Lull (1975).

Figure 2. View factor of differential area at center of forest opening to sky above

the Bowen ratio (R) (Bowen, 1926):

$$R = V/E = 0.47(Tw - Ta) / (ew - ea) \qquad (20)$$

where R and E are known. Again, water temperature must be known.

The conductive flux (C) is determined from the relationship given by Pluhowski (1972):

$$C = Kt \cdot \frac{dt}{dc} \qquad (21)$$

where:

K is the thermal conductivity for stream bed material (Clark, 1966) (cal/cm sec C).
$\frac{dt}{dz}$ is the temperature gradient in the bed material (C/cm).
t is the time (s).

Total heat input, H, is found by summing the model components:

$$H = S - RS + LI - LO + E + V + C \qquad (22)$$

The net temperature change is found using Equation 9.

Other Modeling Approaches

Collings (1969) and Tasker and Burns (1974) noted that fluctuations in stream temperature followed a sinusoidal curve both diurnally and annually. Using historical data, they predicted water temperatures for any time by:

$$T = M + A \cdot \sin \left[\frac{2\Pi}{T} \right] \cdot X + C \qquad (23)$$

where:

T is the predicted temperature.
M is the mean temperature.
A is the amplitude of the harmonic function.
X is the number of days since September 30 of each year.
C is the phase angle of the harmonic function in radians.
T is the period.

Song et al. (1973) separated the harmonic function into a deterministic and a stochastic part and obtained the deterministic coefficients by using standard curve fitting techniques.

Historical data limits the use of the equation for predicting stream temperatures in exposures because the environment changes after logging near the stream. The baseline data used to generate the original parameter values is then no longer applicable.

Morse (1978) evaluated the "dishonest method" of Keller (1962) to solve the stochastic differential equation obtained from the quasi-linear partial differential form of the thermal energy conservation principle. By recasting the stocastic differential equation as a random forcing function, the solution to the equation using random initial conditions was found. The solution compared favorably to values obtained by repetitively solving the partial differential equation as a random equation such as described by Edinger et al. (1968).

CHAPTER III

METHODS AND MATERIALS

Little River Drainage

The primary smallmouth bass fishery in southeastern Oklahoma is comprised of three main streams, the Little River, the Glover River, and the Mountain Fork of the Little River (Figures 3 and 4). The Glover River has received the most attention as a smallmouth bass sport fishery.

Physiography

The Little River drains approximately 5700 km^2 and is 240 km in length within the State of Oklahoma. The channel gradient is small, generally less than 2 m per kilometer, especially where the river enters the coastal plain. In the headwater areas of the Ouachita Mountains, channel gradients may exceed 40 m per kilometer.

Typically, the hills and mountains range from 230 m to 380 m above mean sea level. However, some peaks are as high as 460 m. The mountains are irregular resulting in a combination of trellis and dendritic types of drainages. Ridges can be high, narrow, and nearly parallel with each other. The slopes are steep, rugged, and covered with coarse float. Outcropping ledges of hard sandstone and flint occur frequently along the crests and around the edges of mountains (Honess, 1923).

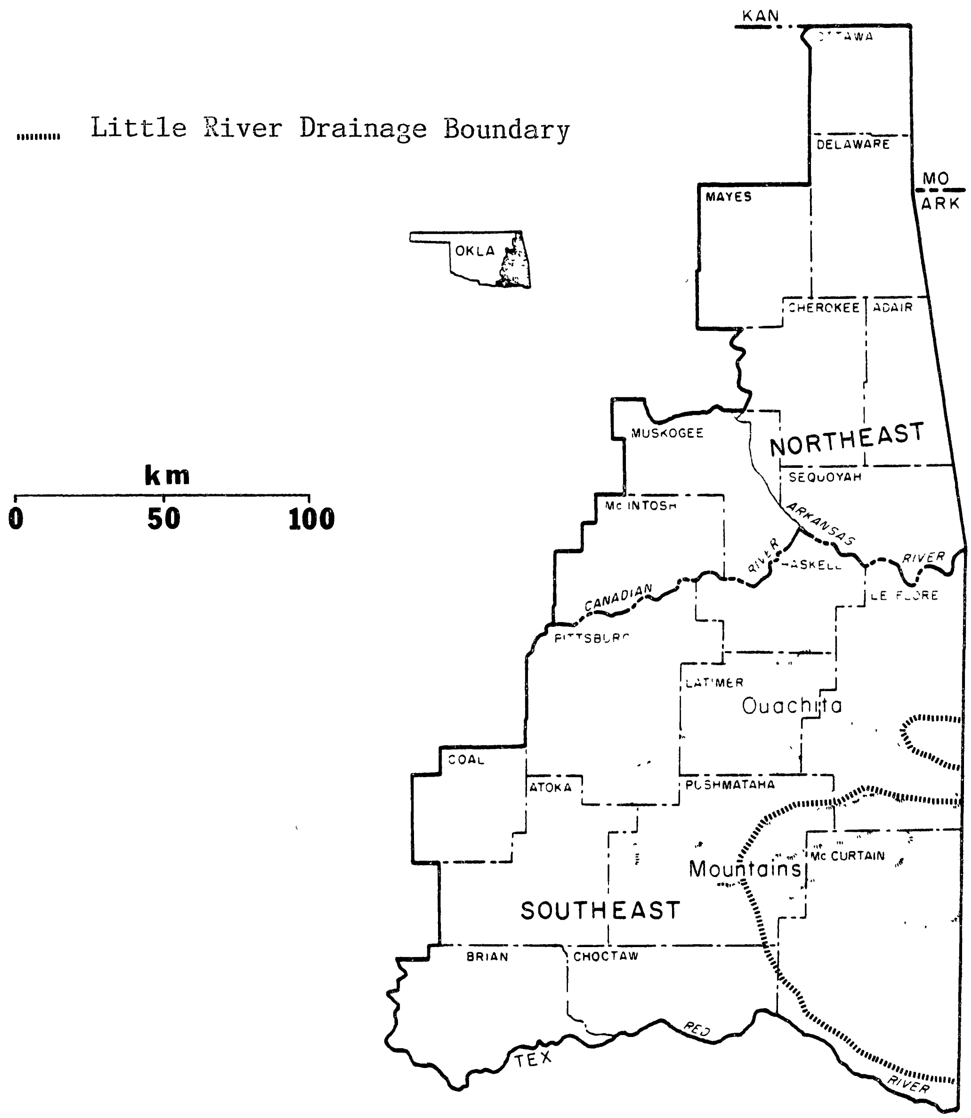
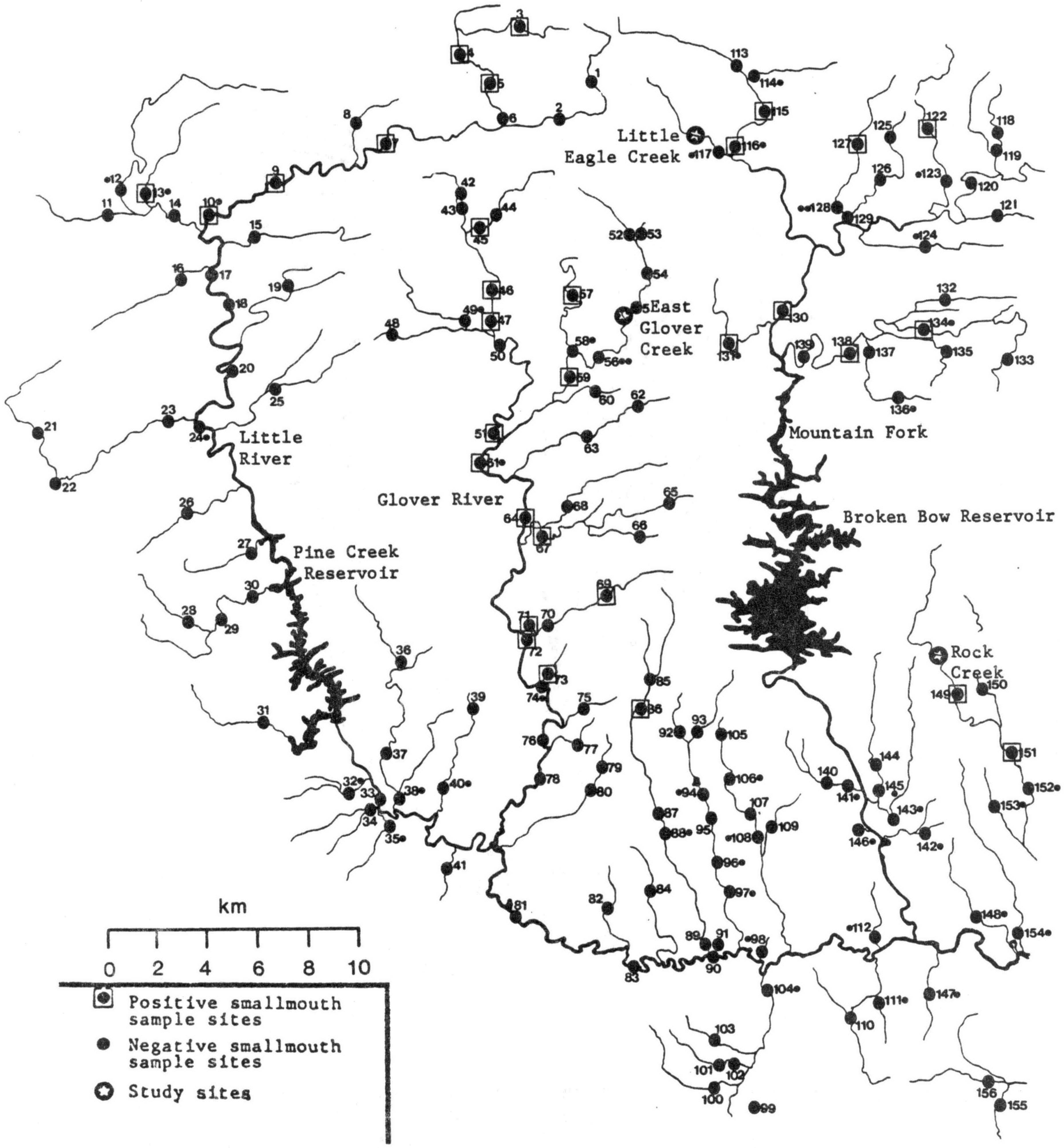


Figure 3. The Little River Drainage in Oklahoma



Source: A. Rutherford (1982).

Figure 4. The Little River Drainage showing the study sites and the results of an independent smallmouth bass distribution study

Geology and Soils

Ninety percent of the Little River drainage basin may be characterized as mountainous with steep, rocky, talus-covered slopes and projecting ledges of sandstone and cherts. The soils on the hills are residual and have been derived largely from sandstone and shales. These soils are loose, sandy loams ordinarily less than one foot thick which typically contain sandstone gravel one to two inches in diameter (Finnell et al., 1956).

Climate

The climate of the Little River drainage is humid and mesothermal. Air masses from the Gulf of Mexico play the dominant role in influencing weather. The highest air temperature recorded at Smithville in McCurtain County was 46 C on August 10, 1936. The lowest reading was -30 C on February 2, 1951. The number of freezing days averages 85 per year. Temperatures of 32 C or above occur on the average of 78 days per year (Reasoner, 1974).

Precipitation varies seasonally. Spring is the wettest period receiving 31 percent of the average yearly precipitation. Autumn is the driest season with 21 percent of the total yearly precipitation.

Vegetation

Aquatic vegetation in streams is sparse and represented principally by water willow weed (*Justicia americana*), cut grass (*Leersia oryzoides*), and buttonbush (*Cephalanthas occidentalis*). Bank vegetation consists of bald cypress (*Taxodium distichum*), sweet gum (*Liquidambar styraciflua*), sour gum (Nyssa sylvatica), white oak (Quercus alba), willow oak (Quercus phellow), water oak (Quercus nigra), black willow (Salix nigra), hazel alder (Alnus serrulata), red mulberry (Morus rubra), American holly (Ilex opaca), shortleaf pine (Pinus echinata), and black gum (Nyssa sylvatica). Frequent flooding and coarse soil inhibit the establishment of a permanent understory. Some grasses survive as do annual invading species. Vines such as greenbriar (Smilax spp.), poison ivy (Rhus radicans), and Virginia creeper (Parthenocissus quinquefolia) survive where they can cling to brush and trees (Finnell et al., 1956).

Stream Characteristics

None of the streams in the region have reached maturity. Many headwater channels are in a youthful condition characterized by steep gradients, rapids, boulder shoals, V-shaped rocky valleys, and, where in existence, narrow alluvial margins.

> The Mountain Fork is typically represented by riffles and pools, with many bank-to-bank barriers of rock which impound extensive stretches of stream. The bottom is bedrock with large boulders strewn about in the channel. Smaller gravel and rubble bottom materials occur only in isolated portions of the river and its tributaries. The river bed is 15 m to 25 m wide and 0.6 m to 1.5 m deep in the upper reaches (Finnell et al., 1956).

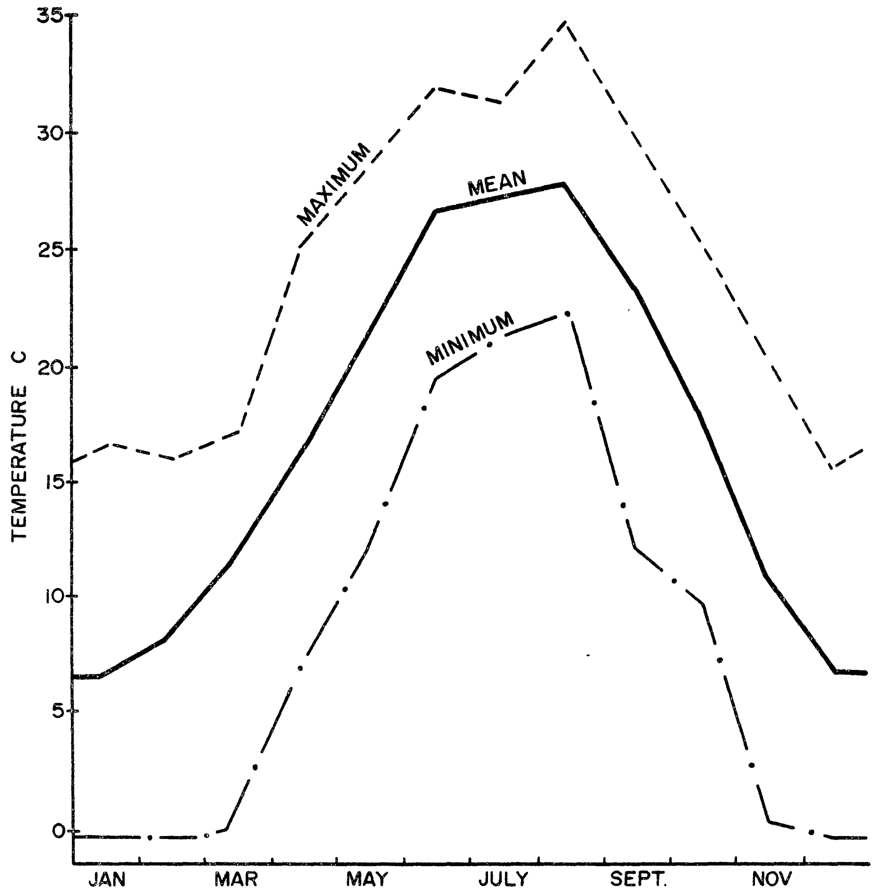
The upper sections of the Little River and the Glover River are similar to those on the Mountain Fork. All of the tributaries in the mountainous region are characterized by steep gradients and boulder-littered courses. Most of these streams contain little surface flow in the summer but disconnected pools up to one hectare in area can be found. These pools average 45 cm in depth but may be over 300 cm deep. The pools are fed primarily by subsurface channel flow and secondarily by subsurface flow moving to the channel from the alluvial flood plain (Finnell et al., 1956). Streams with extensive pool systems are the prime habitat of smallmouth bass (Maughan et al., 1980).

Stream flows are erratic in the spring and winter months. Convectional storms and physiographic conditions make streams flashy in nature during the spring. Frontal storms may produce high flows in both winter and spring. Most stream discharge occurs from January through May (Finnell et al., 1956).

Average temperatures of natural stream waters appear to range from 27.6 C to 28.9 C during the summer months (Pettyjohn et al., 1983). Maximum water temperatures average above 15.6 C throughout the year with temperatures above 32.2 C occurring in August (Finnell et al., 1956). Mean water temperatures are above 15.6 C from April to October with the highest mean temperatures generally occurring in August (Figure 5).

Stream Topographic Shading

Many stream sections in southeastern Oklahoma share similar morphological features, have similar topographic shading, and have similar potentials for temperature increases following vegetation removal. Because this study was limited to a small number of specific study sites in the Little River Drainage, a stream characterization scheme was developed to assess the physical features of streams containing smallmouth bass. Subsequently, the characteristics of the streams were summarized by stream order and used as an aid in locating specific study sites.



Source: Finnell et al., (1956).

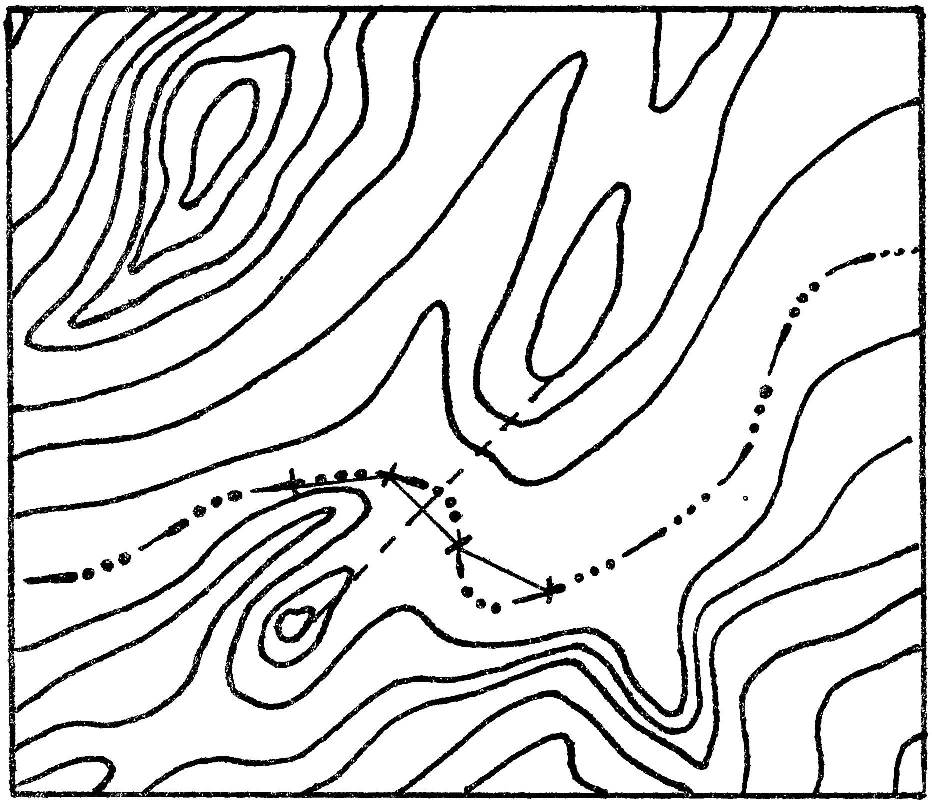
Figure 5. Mean, maximum, and minimum water temperatures of Little River near Idabel, 1947-1953

Characterization

Data from Rutherford (1982) were used to determine which stream reaches contained smallmouth bass (Figure 4). Only those locations where smallmouth bass had been verified were included in the characterization scheme.

At each location where smallmouth bass were verified, the stream size (order) was recorded and the stream was divided into 244 m (800 ft.) straight line segments (Figure 6). Stream segmentation proceeded upstream and downstream of the Rutherford (1982) sample point until a change in stream order was encountered, after which the data (Rutherford, 1982) were again consulted to determine if that stream order had verified smallmouth bass populations. If smallmouth bass occurance was not verified, the characterization procedure was terminated. If smallmouth bass were verified at the new location, stream characterization proceeded along the stream reach until occurance of smallmouth bass could not be verified or until the stream order changed again. This procedure was repeated until all locations with verified smallmouth bass populations had been segmented.

Next, each stream segment was perpendicularly bisected and the bisection lines extended to the topographic features that produced the greatest slope angles on both stream banks (Figure 6). Information gathered for each straight line segment included: stream order, orientation (azimuth), direction of flow, elevation, distance to the dominant topographic unit on the perpendicular bisect for both stream banks, elevation of the dominant topographic unit for both stream banks, number of stream channels, approximate channel width, presence of



Actual stream channel

243.8 m straight line stream segment

Perpendicular bisection of straight line stream segment

Figure 6. Straight line stream segments showing the perpendicular bisection lines extended to the dominant topographic feature

a dominant pool, and a legal description. All information was obtained from U.S. Geological Survey 15 and 7½ minute topographic quadrangles.

Stream segments were divided into groups based on stream order. Analysis of the stream sections in each group provided information regarding the degree of expected topographic shading for similar stream sections in each stream order.

Summary

Most of the streams where smallmouth bass were verified to occur were first, second, and third order streams (Table II). A large portion of these streams occur in headwater areas. Most of these streams in the smallmouth bass range occur in the Glover River and Mountain Fork basins. Rutherford (1982) sampled 13.8 percent of these streams and 60.9 percent of the streams sampled by Rutherford (1982) were characterized for this study.

Even though the majority of the streams containing smallmouth bass were low order streams, the characterization procedure showed that the greatest number of stream segments in which smallmouth bass occurred were in fifth order streams (Table III). These fifth order streams tended to be wider and have a higher pool-riffle ratio than the lower order streams. Fourth order streams contained the second greatest amount of confirmed smallmouth bass habitat. Fourth and fifth order streams contained over 67 percent of the total stream segments characterized. This is partly due to the low order streams being smaller in length because of their location within the drainage.

The direction of streamflow dictates the potential for shading from surrounding landforms and vegetation. Therefore, the

TABLE II

STREAMS OF THE LITTLE RIVER DRAINAGE SYSTEM WITHIN THE SMALLMOUTH BASS RANGE* ESTABLISHED BY RUTHERFORD (1982)

Drainage	N	% First Order	% Second Order	% Third Order	% Fourth Order	% Fifth Order	% Sixth Order	% positive Samples	% Streams Charact.	% Rutherford Sampled
Little R.	20	00.0	45.0	40.0	15.0	00.0	00.0	20.0	30.0	40.0
Glover R.	142	59.2	28.9	7.7	2.8	1.4	00.0	6.3	7.0	14.8
Lukfata Cr.	17	64.7	29.4	5.9	00.0	00.0	00.0	5.9	5.9	5.9
Mountain Fk.	185	43.8	36.8	13.5	3.8	1.6	0.5	5.4	7.0	10.3
Rock Cr.	6	00.0	33.3	50.0	16.7	00.0	00.0	16.7	16.7	33.3
Totals	370	47.6	33.8	13.0	4.0	1.3	0.3	6.8	8.4	13.8

* The smallmouth bass range is defined as those streams at or upstream of the points where Rutherford identified smallmouth bass. The range includes all streams shown as being perennial on the USGS topographic quadrangle maps.

TABLE III

SUMMARY OF STREAM SEGMENT CHARACTERISTICS IN THE LITTLE RIVER DRAINAGE WITHIN THE SMALLMOUTH BASS RANGE OF SOUTHEASTERN OKLAHOMA

Linear Distance (m) Characterized Within:	Stream Order 2	3	4	5	6
Little River	19751	11460	42428	36576	0
Glover River	18288	27310	23409	34869	0
Lukfata Creek	0	9022	0	0	0
Mountain Fork	6340	30724	27798	73883	4877
Rock Creek	0	0	21458	0	0
Total	44379	78516	115093	145328	4877

Percent of Stream Segments:	Stream Order 2	3	4	5	6
With pools	1.1	23.9	78.4	99.7	100.0
Without pools	98.9	76.1	21.6	0.3	0.0
Less than 10 m Wide	100.0	85.4	32.7	1.5	0.0
From 10 to 30 m Wide	0.0	14.6	60.3	54.0	0.0
Greater than 30 m Wide	0.0	0.0	7.0	44.5	100.0
With one stream Channel	96.2	93.6	93.2	92.9	70.0
With two stream Channels	3.8	4.5	6.1	6.4	30.0
With three stream Channels	0.0	1.9	0.7	0.7	0.0

stream segments within each stream order class were subdivided by flow directions and topographic features (Tables IV, V, VI, VII, VIII). Streams flowing north or south would show the greatest effect from vegetation removal in the morning and evening hours. Vegetation removal on the east streambank would expose the stream to solar radiation earlier in the morning, whereas vegetation removal on the west streambank would expose the stream to solar radiation later in the afternoon. Likewise, high ridges on the east or west banks modify morning and evening solar radiation inputs. Streams flowing east or west would experience increased exposure if vegetation on the southern streambank were removed. Vegetation removal on the northern bank would not significantly affect the radiation input unless the vegetation overhangs the water surface. These differences occur in the northern hemisphere because the angle of incidence of radiation is directed from the southern hemisphere of the sky. Landforms located on the southern bank would also influence shading. Streams flowing in other directions would show vegetative and topographic shading effects somewhere between the extremes defined above. Topographic features in southeastern Oklahoma generally did not create significant stream shade because their degree of influence was small (Tables IV, V, VI, VII, and VIII). A methodology for determining if a shadow from a landform will be cast across a stream is presented in Appendix A.

Southerly and southwesterly flow patterns dominated the drainage directions of all stream orders except second order and fifth order streams which flow west (Tables IV, V, VI, VII, VIII). For streams flowing south, topographic shading from east and west banks would be important in the morning and evening hours respectively. For streams

TABLE IV

SLOPE CLASSES FOR SECOND ORDER STREAMS REPRESENTED BY FLOW DIRECTION FOR THE SMALLMOUTH BASS RANGE OF THE LITTLE RIVER DRAINAGE SYSTEM IN SOUTHEASTERN OKLAHOMA

	Stream Order	N	Flow Direction	Obser-vations	Right Bank Slope Angles <15%	15-30%	30-45%	45-60%	>60%	Left Bank Slope Angles <15%	15-30%	30-45%	45-60%	>60%
Percents	2	11.4	N	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			NW	1.1	0.5	0.5	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0
			W	36.8	17.0	17.0	2.2	0.5	0.0	10.4	20.9	5.5	0.0	0.0
			SW	31.3	17.0	12.1	1.6	0.0	0.5	13.7	13.7	3.8	0.0	0.0
			S	21.4	12.1	8.2	0.5	0.0	0.5	14.8	6.0	0.0	0.5	0.0
			SE	6.6	5.5	1.1	0.0	0.0	0.0	5.5	0.5	0.5	0.0	0.0
			E	2.8	1.1	1.1	0.5	0.0	0.0	2.8	0.0	0.0	0.0	0.0
			NE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Totals			100.0	53.3	40.1	5.0	0.5	1.1	48.4	41.2	9.9	0.5	0.0
Numerics	2	182	N	0	0	0	0	0	0	0	0	0	0	0
			NW	2	1	1	0	0	0	2	0	0	0	0
			W	67	31	31	4	1	0	19	38	10	0	0
			SW	57	31	22	3	0	1	25	25	7	0	0
			S	39	22	15	1	0	1	27	11	0	1	0
			SE	12	10	2	0	0	0	10	1	1	0	0
			E	5	2	2	1	0	0	5	0	0	0	0
			NE	0	0	0	0	0	0	0	0	0	0	0
	Totals			182	97	73	9	1	2	88	75	18	1	0

TABLE V

SLOPE CLASSES FOR THIRD ORDER STREAMS REPRESENTED BY FLOW DIRECTION FOR THE SMALLMOUTH BASS RANGE OF THE LITTLE RIVER DRAINAGE SYSTEM IN SOUTHEASTERN OKLAHOMA

Stream Order	N	Flow Direction	Observations	Right Bank Slope Angles <15%	15-30%	30-45%	45-60%	>60%	Left Bank Slope Angles <15%	15-30%	30-45%	45-60%	>60%
3	20.2	N	1.6	1.6	0.0	0.0	0.0	0.0	0.6	0.9	0.0	0.0	0.0
		NW	3.7	3.1	0.6	0.0	0.0	0.0	2.5	1.2	0.0	0.0	0.0
		W	20.5	11.5	6.5	1.6	0.9	0.0	9.3	9.6	1.6	0.0	0.0
Percents		SW	21.4	17.4	3.7	0.3	0.0	0.0	13.0	7.8	0.6	0.0	0.0
		S	33.6	28.6	4.3	0.3	0.3	0.0	29.8	3.1	0.3	0.3	0.0
		SE	15.2	10.2	4.0	0.6	0.3	0.0	13.7	1.2	0.3	0.0	0.0
		E	3.7	1.6	1.2	0.6	0.3	0.0	3.4	0.3	0.0	0.0	0.0
		NE	0.3	0.3	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
Totals			100.0	74.2	20.5	3.4	1.9	0.0	72.7	24.2	2.8	0.3	0.0
3	322	N	5	5	0	0	0	0	2	3	0	0	0
		NW	12	10	2	0	0	0	8	4	0	0	0
		W	66	37	21	5	3	0	30	31	5	0	0
Numerics		SW	69	56	12	1	0	0	42	25	2	0	0
		S	108	92	14	1	1	0	96	10	1	1	0
		SE	49	33	13	2	1	0	44	4	1	0	0
		E	12	5	4	2	1	0	11	1	0	0	0
		NE	1	1	0	0	0	0	1	0	0	0	0
Totals			322	239	66	11	6	0	234	78	9	1	0

TABLE VI

SLOPE CLASSES FOR FOURTH ORDER STREAMS REPRESENTED BY FLOW DIRECTION FOR THE SMALLMOUTH BASS RANGE OF THE LITTLE RIVER DRAINAGE SYSTEM IN SOUTHEASTERN OKLAHOMA

Stream Order	N	Flow Direction	Observations	Right Bank Slope Angles <15%	15-30%	30-45%	45-60%	>60%	Left Bank Slope Angles <15%	15-30%	30-45%	45-60%	>60%
4	29.7	N	2.3	1.9	0.4	0.0	0.0	0.0	1.9	0.4	0.0	0.0	0.0
		NW	3.6	3.6	0.0	0.0	0.0	0.0	3.2	0.4	0.0	0.0	0.0
		W	10.4	10.0	0.2	0.2	0.0	0.0	9.1	1.3	0.0	0.0	0.0
		SW	17.2	14.0	3.2	0.0	0.0	0.0	13.3	2.5	0.4	0.6	0.2
Percents		S	33.3	26.5	6.1	0.4	0.2	0.0	28.4	3.6	1.1	0.0	0.2
		SE	16.7	9.5	4.0	2.3	0.4	0.4	13.6	3.2	0.0	0.0	0.0
		E	12.3	6.8	3.4	1.3	0.8	0.0	10.6	1.5	0.2	0.0	0.0
		NE	4.2	3.2	0.8	0.0	0.2	0.0	3.6	0.6	0.0	0.0	0.0
Totals			100.0	75.4	18.2	4.3	1.7	0.4	83.7	13.6	1.7	0.6	0.4
4	472	N	11	9	2	0	0	0	9	2	0	0	0
		NW	17	17	0	0	0	0	15	2	0	0	0
		W	49	47	1	1	0	0	43	6	0	0	0
		SW	81	66	15	0	0	0	63	12	2	3	1
Numerics		S	157	125	29	2	1	0	134	17	5	0	1
		SE	79	45	19	11	2	2	64	15	0	0	0
		E	58	32	16	6	4	0	50	7	1	0	0
		NE	20	15	4	0	1	0	17	3	0	0	0
Totals			472	356	86	20	8	2	395	64	8	3	2

TABLE VII

SLOPE CLASSES FOR FIFTH ORDER STREAMS REPRESENTED BY FLOW DIRECTION FOR THE SMALLMOUTH BASS RANGE OF THE LITTLE RIVER DRAINAGE SYSTEM IN SOUTHEASTERN OKLAHOMA

Stream Order	N	Flow Direction	Obser- vations	Right Bank Slope Angles <15%	15-30%	30-45%	45-60%	>60%	Left Bank Slope Angles <15%	15-30%	30-45%	45-60%	>60%
5	37.4	N	3.2	3.0	0.0	0.2	0.0	0.0	2.7	0.5	0.0	0.0	0.0
		NW	11.9	10.2	1.7	0.0	0.0	0.0	9.6	1.7	0.5	0.2	0.0
		W	27.4	21.5	5.7	0.2	0.0	0.0	16.1	6.9	3.9	0.3	0.2
		SW	21.0	18.3	2.5	0.2	0.0	0.0	14.1	5.0	1.7	0.0	0.2
Percents		S	17.8	14.9	2.2	0.5	0.2	0.0	14.1	3.5	0.2	0.0	0.0
		SE	10.7	8.1	1.5	0.8	0.2	0.2	9.7	0.8	0.2	0.0	0.0
		E	6.5	3.2	2.7	0.5	0.2	0.0	5.4	0.8	0.3	0.0	0.0
		NE	1.5	0.7	0.8	0.0	0.0	0.0	1.0	0.2	0.2	0.2	0.0
Totals			100.0	79.9	17.1	2.3	0.5	0.2	72.6	19.5	6.9	0.7	0.3
5	596	N	19	18	0	1	0	0	16	3	0	0	0
		NW	71	61	10	0	0	0	57	10	3	1	0
		W	163	128	34	1	0	0	96	41	23	2	1
		SW	125	109	15	1	0	0	84	30	10	0	1
Numerics		S	106	89	13	3	1	0	84	21	1	0	0
		SE	64	48	9	5	1	1	58	5	1	0	0
		E	39	19	16	3	1	0	32	5	2	0	0
		NE	9	4	5	0	0	0	6	1	1	1	0
Totals			596	476	102	14	3	1	433	116	41	4	2

TABLE VIII

SLOPE CLASSES FOR SIXTH ORDER STREAMS REPRESENTED BY FLOW DIRECTION FOR THE SMALLMOUTH BASS RANGE OF THE LITTLE RIVER DRAINAGE SYSTEM IN SOUTHEASTERN OKLAHOMA

				Right Bank Slope Angles					Left Bank Slope Angles				
Stream Order	N	Flow Direction	Obser- vations	<15%	15-30%	30-45%	45-60%	>60%	<15%	15-30%	30-45%	45-60%	>60%
6	1.3	N	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		NW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		W	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Percents		SW	35.0	35.0	0.0	0.0	0.0	0.0	25.0	10.0	0.0	0.0	0.0
		S	60.0	55.0	0.0	5.0	0.0	0.0	60.0	0.0	0.0	0.0	0.0
		SE	5.0	5.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0
		E	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		NE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Totals			100.0	95.0	0.0	5.0	0.0	0.0	90.0	10.0	0.0	0.0	0.0
6	20	N	0	0	0	0	0	0	0	0	0	0	0
		NW	0	0	0	0	0	0	0	0	0	0	0
		W	0	0	0	0	0	0	0	0	0	0	0
Numerics		SW	7	7	0	0	0	0	5	2	0	0	0
		S	12	11	0	1	0	0	12	0	0	0	0
		SE	1	1	0	0	0	0	1	0	0	0	0
		E	0	0	0	0	0	0	0	0	0	0	0
		NE	0	0	0	0	0	0	0	0	0	0	0
Totals			20	19	0	1	0	0	18	2	0	0	0

flowing west, south bank topographic shading would be important. More than 94 percent of all bank slopes studied were less than 30 percent and more than 73 percent were less than 15 percent (Tables IV, V, VI, VII, VIII). These data suggest that topography plays a minor role in stream shading within the Little River Drainage.

Study Sites

Site selection was based on several factors. First, the stream had to be within the established range of smallmouth bass in the Little River Drainage and be representative of a significant topographic shading class. Second, equipment availability dictated that a maximum of three sites could be instrumented. Finally, each site would have to be accessible but without great potential for vandalism.

Potential sites were identified from areal photographs and topographic maps. Field reconnaissance was used to evaluate each potential site. Those sites that showed potential were viewed by the author along with Weyerhaeuser and Oklahoma State University personnel. The three sites chosen for this study were on Rock Creek, Little Eagle Creek, and the East Fork of the Glover River (Figure 4).

Rock Creek

The Rock Creek study site was located in Sections one and two of Township Five South, Range 26 East (Figure 7). The pool-riffle ratio for this stream section was 1.1.

The vegetation along the streambanks was two tiered. The upper tier was set back from the water's edge and dominated by water oak (40 percent) and shortleaf pine (*Pinus echinata*) (40 percent). The

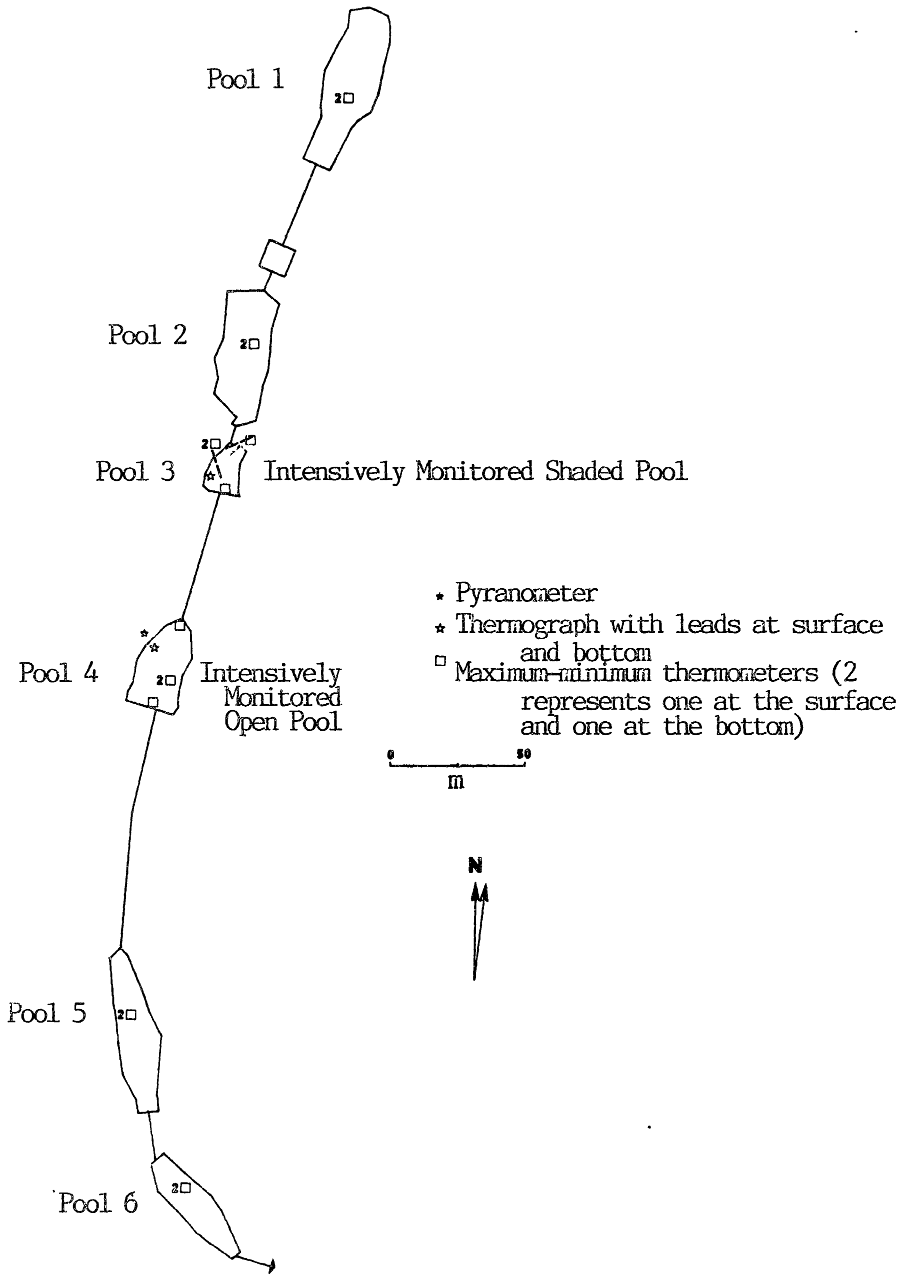


Figure 7. Stream Temperature Study Site on Rock Creek showing the placement of the recording instruments

remaining species of the upper tier included river birch (Betula nigra), sweetgum (Liquidambar styraciflua), red maple (Acer rubrum), redcedar (Juniperus virginiana), and hornbeam (Caprinus caroliniana).

The vegetation of the lower tier grew to the water's edge and often overhung the water surface. It was composed predominantly of hazel alder (60 percent) and hornbeam (30 percent). The remaining 10 percent was mostly eastern redcedar.

The Rock Creek study site was located on a fourth order stream which flowed in a southerly direction for most of its length. All left bank slope angles were less than 15 percent and the majority of right bank slope angles were also less than 15 percent. At the very downstream end of the study site, the stream turns southeast and here, the right bank slope angle was 25 percent. Characterization by flow direction showed that the stream section represented one third of all fourth order streams in areas occupied by smallmouth bass. Characterization based on left and right bank slope angles showed this stream section represented in excess of 26 percent of fourth order streams (Table VI).

A stream habitat classification system developed by Platts et al., (1983) was used to characterize the Rock Creek site. Results showed that pool diameters exceeded pool width and that the pools were 0.6 to 0.9 m feet in depth and lacked abundant fish cover. The streambank soil alteration rating indicated streambanks were being altered only slightly by water flows and/or animals. Streambank stability was good because the streambanks were covered with vegetation, rock, or other protective materials.

The dominant vegetation on the site was of shrub form. Vegetation overhang averaged 36 cm on transects taken along the stream reach. The streamside habitat rating, using the system of Platts et al. (1983), indicated that rubble or roots were the dominant armor protecting the streambank. Undercutting of banks occurred in localized areas and averaged only 7.4 cm over the entire stream section. Vegetation use by animals was light.

Channel substrate was composed largely of bedrock (61 percent) followed by small cobbles (17 percent), large and medium boulders (9 percent), large cobbles (8 percent), with the remainder being small cobbles, very coarse gravel, and coarse gravel. Particle size classes were based on sediment terminology of the American Geophysical Union as reported by Lane (1947). An embeddedness rating using the classification system of Platts et al. (1983) showed that gravel, rubble, and boulders had less than 5 percent of their surface covered by fine sediment.

Smallmouth bass up to 20 cm in length were observed in Pool 4 at the Rock Creek site (Figure 7), but no smallmouth bass were observed in Pools 2 and 3. Pool 1 had several bass, the largest seen being approximately 25 cm in length. Pools 5 and 6 each had small bass less than 20 cm in length.

Little Eagle Creek

The Little Eagle Creek site was located in Section 27 of Township 1N and Range 24E. This stream was characterized by long, deep pools, relatively short riffle sections and a pool-riffle ratio of 1.8 (Figure 8). The channel substrate was composed primarily of very coarse, coarse, and medium gravels (32 percent). A significant portion of the

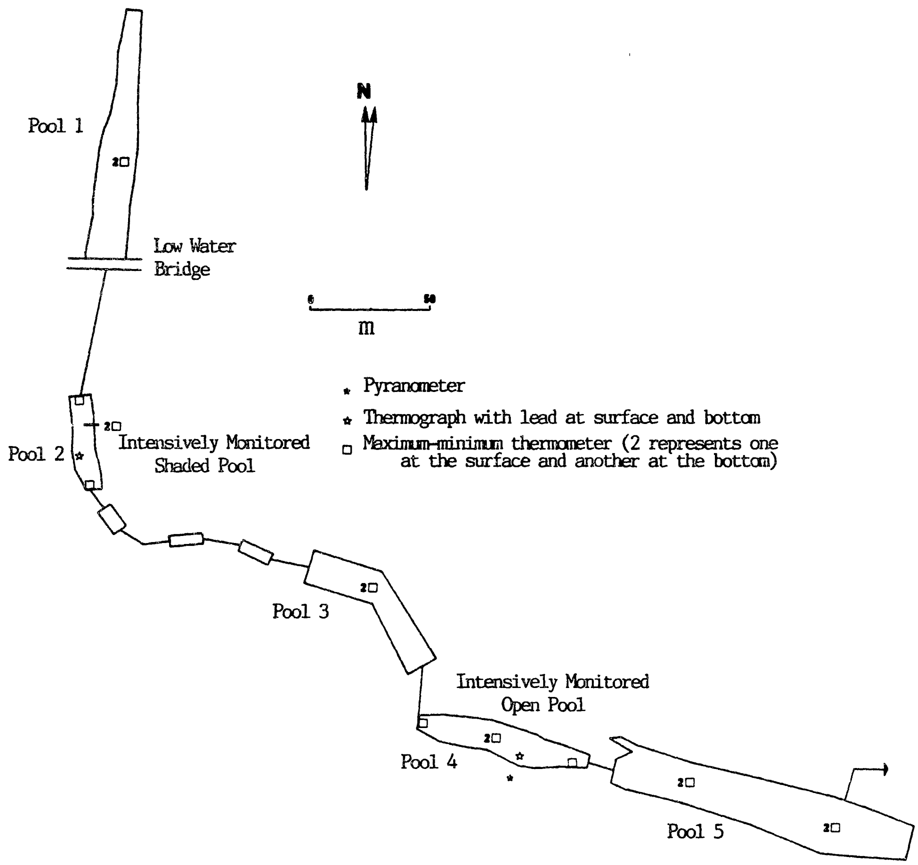


Figure 8. Stream Temperature Study Site on Little Eagle Creek showing the placement of the recording instruments

stream channel had been scoured to bedrock (25 percent). Small cobbles made up 17 percent of the channel bottom while large cobbles comprised 13 percent and small boulders 8 percent of the substrate. Fine gravels comprised 5 percent of the substrate and were mostly mixed with the other gravels.

Much of this study section was situated in a clearcut. A SMZ had been left after the removal of merchantable pine. The SMZ vegetation was two tiered. The upper tier was composed of water oak (50 percent) and river birch (40 percent). The remaining 20 percent was a mix of several species but was dominated by redcedar.

The lower tier overhanging the water surface was predominantly hazel alder (80 percent). The remaining 20 percent was composed principally of red maple and river birch.

The channel geometry of Little Eagle Creek was more complex than that of the other sites. Flows were essentially south and east and the main pools of the study site flowed in an easterly direction. Based on the characterization results for fourth order streams, this easterly flow represented over 12 percent of the fourth order streams where smallmouth bass occurred. Topographic slope angles were less than 15 percent for both the right and left banks. Characterization based on channel physiography showed this stream represented in excess of 6 percent of the characterized streams (Table VI).

According to the pool classification scheme of Platts et al. (1983), maximum pool diameters exceeded the average stream widths and the depths were in excess of 0.9 m and there was abundant fish cover. The streambank alteration rating indicated that approximately 25 percent of the streambank was undercut, broken down, or eroding. The streambank vegetative stability rating was good with 50 to 79 percent of the streambank surfaces covered by vegetation, gravel, or larger material. The vegetation use rating indicated roughly 30 percent of streambank vegetation had been altered by livestock. The embeddedness rating for channel materials indicated that gravel, rubble, and boulder had between 5 and 25 percent of their surface covered by fine sediments.

The dominant vegetation in the system were trees and the average vegetation overhang was 106 cm. The streamside habitat rating indicated the predominance of boulder, bedrock, and tree root bank cover (Platts et al., 1983). Bank undercutting was limited and averaged only 1.5 cm in the stream reach.

All pools in the Little Eagle Creek were observed to have smallmouth bass except Pool 3 which was an expansive shallow pool (Figure 8). Fishermen were observed taking smallmouth bass from Pool 1 and had reported taking smallmouth bass up to 1.4 kg from Pool 5. Smallmouth bass in excess of 25 cm were frequently seen in Pool 4 before shade removal.

The Little Eagle Creek site was located in a broad alluvial valley. The silty soils in the valley provided a source of cool water for the stream as they slowly released water held in storage by delayed drainage. Pool 2, the intensively-monitored, shaded pool (Figure 8), received the most groundwater influx. Groundwater which entered the pool was colder than the water in the stream and therefore sank to the bottom. The groundwater flux entering the pool became the factor controlling temperature at the bottom of Pool 2.

East Fork of the Glover River

The East Fork of the Glover River site was located in Section 7 of Township 2S, Range 24E. This stream section was characterized by well spaced, long, deep pools. The large pools were broken up by riffle sections containing small pools, some of which were quite deep (Figure 9). The pool-riffle ratio was 1.9. The channel substate was a diverse mixture of boulder, cobble, and gravel. Bedrock, the dominant feature, occupied 27 percent of the channel. Small boulders (24 percent) and medium boulders (15 percent) provided instream cover for fish. Large cobbles composed 18 percent of the channel substrate while small cobbles accounted for 8 percent. Gravels, where found, were usually deposited in bars along the stream margins. Very coarse gravel occurred more frequently (8 percent) than coarse gravel (3 percent). Fines were, for the most part, absent from the stream section.

East Glover River, a fourth order stream, flowed in a southeasterly direction through the study site. Characterization results showed that over 16 percent of fourth order streams flowed in this direction. Bank slopes, both right and left, were less than 15 percent along the stream reach. According to the characterization results these slope characteristics represented over 9 percent of all fourth order streams where smallmouth bass were verified.

The vegetation along East Glover River occurred in three distinct layers. The upper tier was composed of shortleaf pine (50 percent) with the remaining 50 percent equally distributed among white oak, red oak (Quercus falcata), sweet gum, and sycamore (Platanus occidentalis).

The middle tier was dominated by hornbeam and hophornbeam (Ostrya virginiana) which made up 50 percent of the tier. The remaining 50

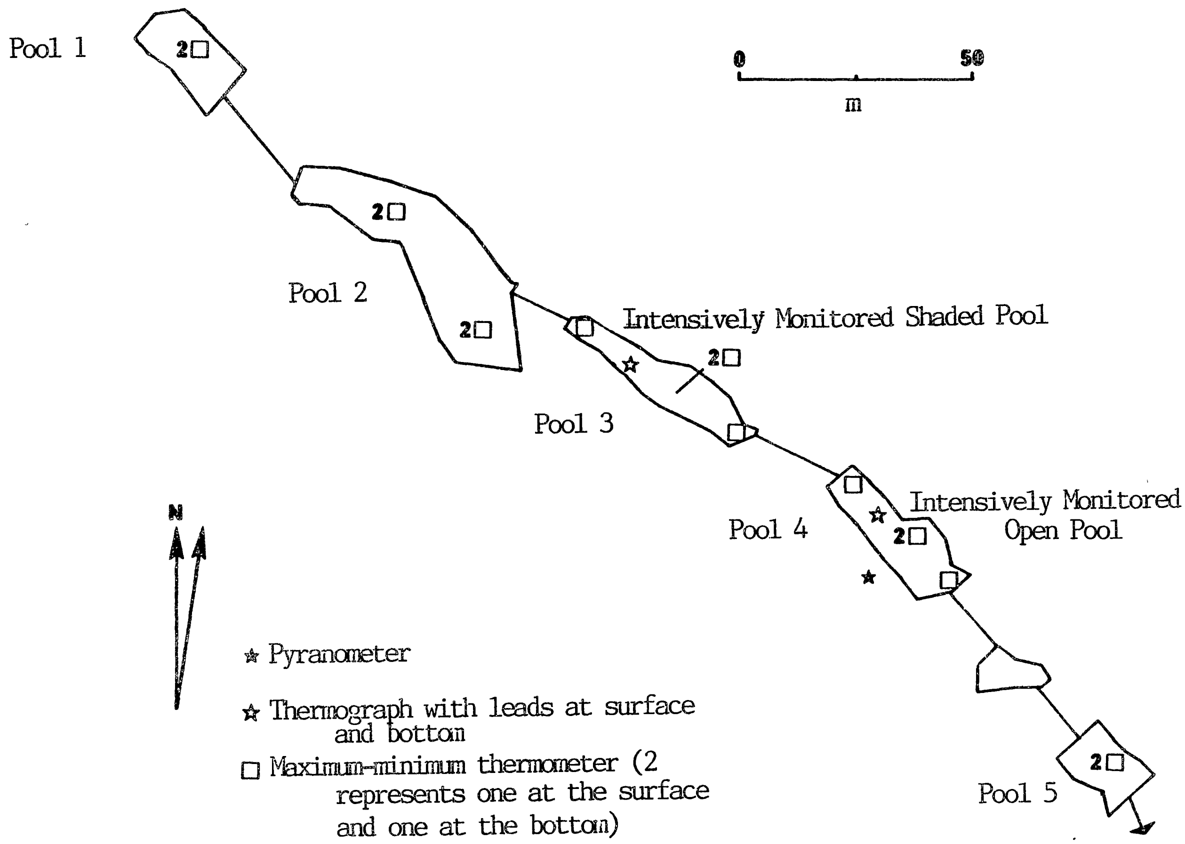


Figure 9. Stream Temperature Study Site on the East Fork of the Glover River showing the placement of the recording instruments

percent was composed of varying densities of southern sugar maple (Acer barbatum), river birch, hazel alder, sycamore, and red maple. The lower tier overhanging the water was mostly hazel alder (90 percent). The remaining 10 percent was predominantly red maple.

The quality of pools according to the classification system of Platts et al. (1983) indicated that pools were 0.6 to 0.9 m in depth and lacking abundant fish cover, although fish cover was present in some pools, exemplified by undercut banks averaging nearly 6 cm and vegetation overhang averaging 135 cm. The streamside cover rating indicated the dominant vegetation to be trees. The streamside habitat rating along the left bank was rubble which armored the channel and provided fish cover, and on the right bank, thick rooted masses entangled the shoreline which was littered with rubble.

Streambank soil alteration was very low, with approximately 3 percent of the streambank experiencing light stress from water and/or animals. The vegetative stability and vegetation use ratings supported this finding. The vegetative stability rating showed over 80 percent of the streambanks were well protected and the vegetation use rating showed only 5 percent of the vegetative cover had been altered by animals or man. These factors created an environment in which little sediment was transported. The embeddedness rating indicated that gravel, rubble, and boulder material had less than 5 percent of their surface covered by fine sediment.

Smallmouth bass were observed in Pools 2, 3, 4, and 5 of the East Glover Creek site (Figure 9). Pool 2 is a long, very deep pool and contained smallmouth bass over 25 cm in length. Bass observed in the other pools were no longer than 15 cm.

Instrumentation

Each site consisted of a series of five or six pools separated by riffle sections. The pools at each site differed by flow direction, volume, surface area, and channel characteristics. However, within each pool series, two adjacent pools, referred to as intensive pools, were identified that shared similar physical characteristics (Figures 7, 8, and 9). Of these adjacent pools, the downstream pool was exposed to direct solar radiation by vegetation removal. Temperatures of the upstream pool, left in its natural state, were compared with temperatures of the downstream exposed pool to determine if increased exposure to direct solar radiation increased stream temperatures. In the case of Little Eagle Creek, the two pools chosen for intensive temperature measurement were not adjacent. In this instance, the pools were chosen on the basis of their morphological similarities and not by their relative position.

Maximum-Minimum Recording Thermometers

Daily maximum and minimum water temperatures were recorded for pools upstream and downstream of the intensive measurement sites with maximum-minimum recording thermometers (Figures 7, 8, and 9). The thermometers in pools upstream of the intensive site allowed for the measurement of natural stream temperature fluctuations. Temperatures measured in pools downstream of the intensive site determined if temperature changes occurred once the water left the exposed pool and re-entered a shaded pool.

Maximum-minimum thermometers were deployed in pairs at the deepest location in all of the pools. One thermometer at each point was placed at the channel bottom; the other was placed at the surface. Single maximum-minimum thermometers were placed at the inlets and outlets of pools within the intensive sites to measure the water temperatures entering and leaving the exposed pool and the naturally shaded pool.

Recording Thermographs

To quantify temporal temperature variations within the intensively monitored stream sections, recording thermographs were placed in exposed and naturally shaded pools (Figures 7, 8, and 9). Thermograph leads recorded the temperature at the pool bottom and at the water surface in each pool.

Intensive Site Temperature Monitoring

The horizontal, longitudinal, and vertical temperature profiles of the two intensively monitored pools at each site were recorded every third day. To ensure that temperature readings could be repeated at the same points throughout the summer, a permanent grid system was established at the intensive measurement sites (Figures 10, 11, and 12). The grid system consisted of nylon string stretched horizontally across the pools and secured to each bank. The spacing of the sample points along these transects was two dimensional. The horizontal spacing of sample points along the principle axis of the pools was 6 m. The longitudinal placing of the horizontal nylon strings was distributed to give approximately ten sample points. At each sample point on the grid, temperatures were recorded at the water surface, at 23 cm depth

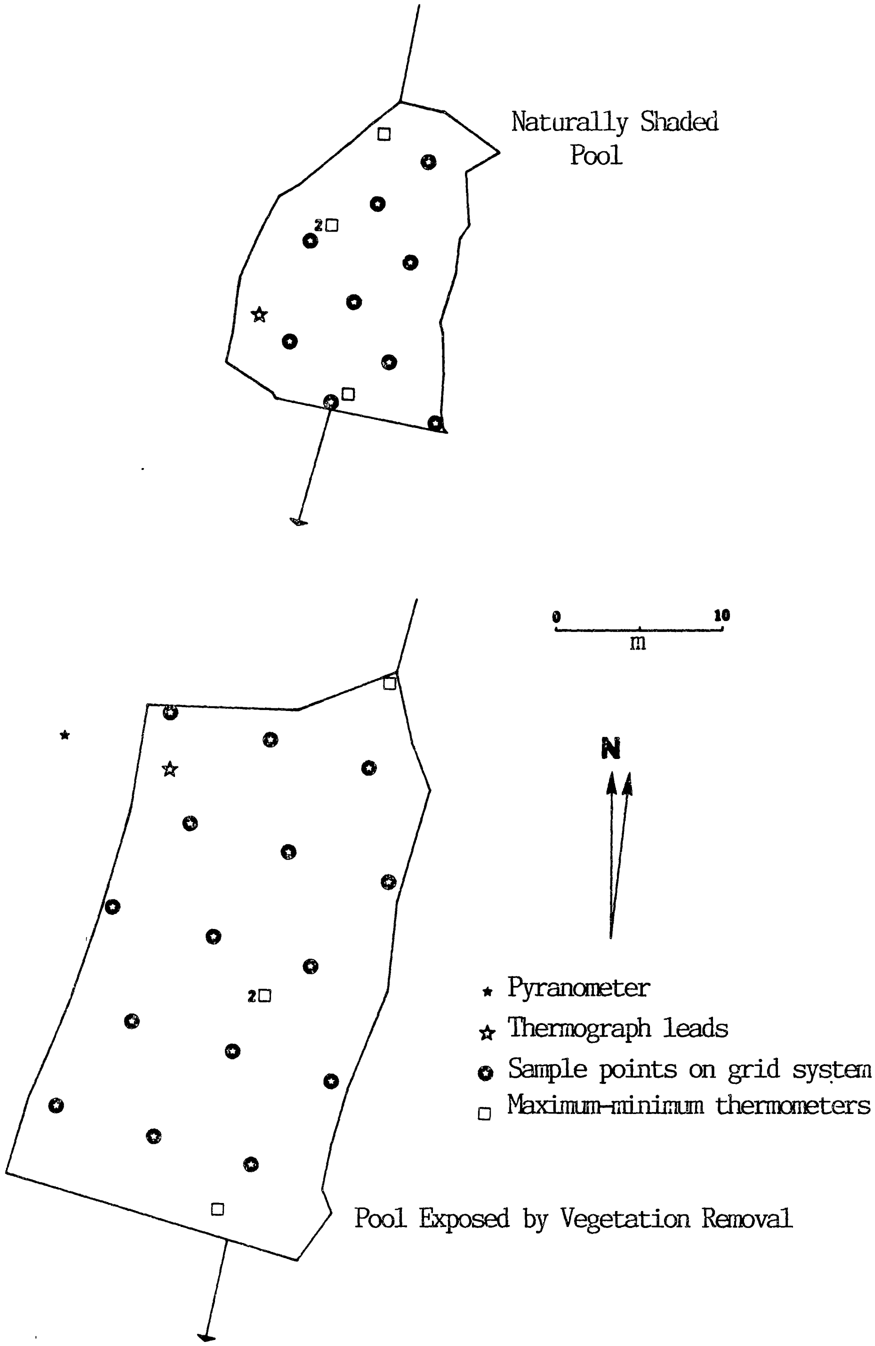


Figure 10. Location of sample points in the intensively monitored pools on the Rock Creek Stream Temperature Study Site.

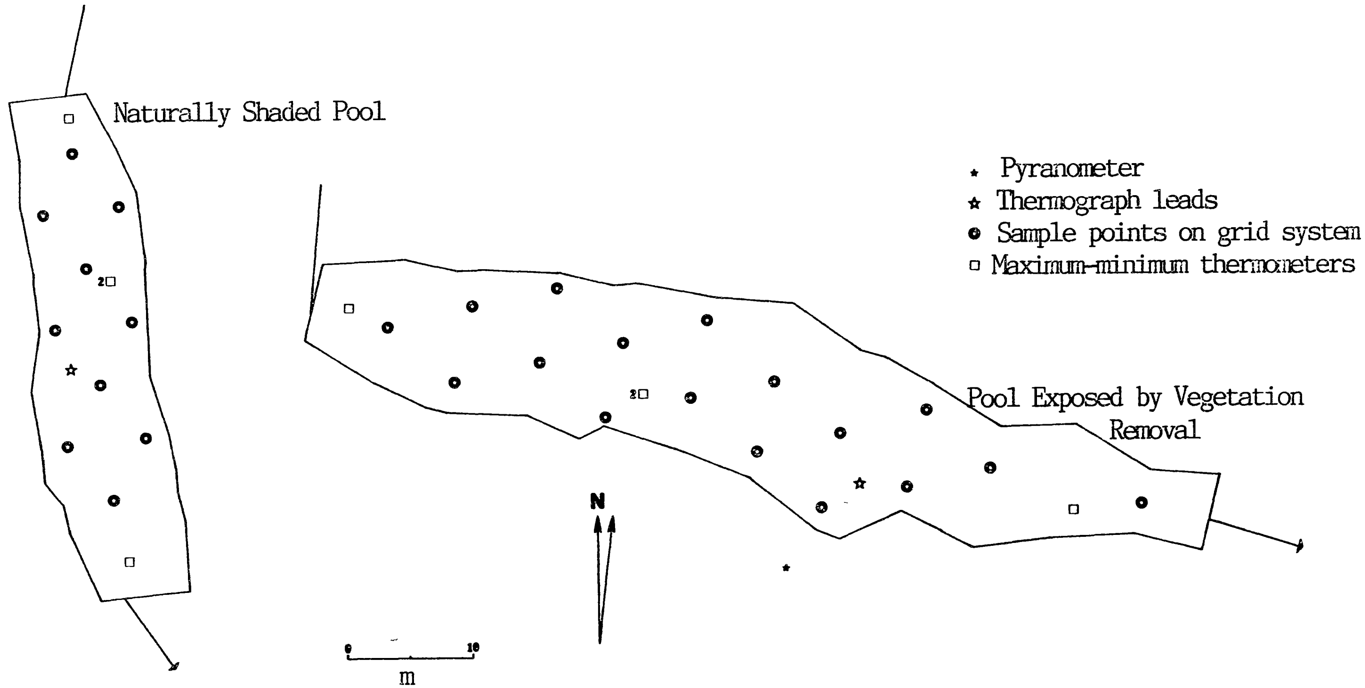


Figure 11. Location of sample points in the intensively monitored pools of the Little Eagle Creek Stream Temperatue Study Site

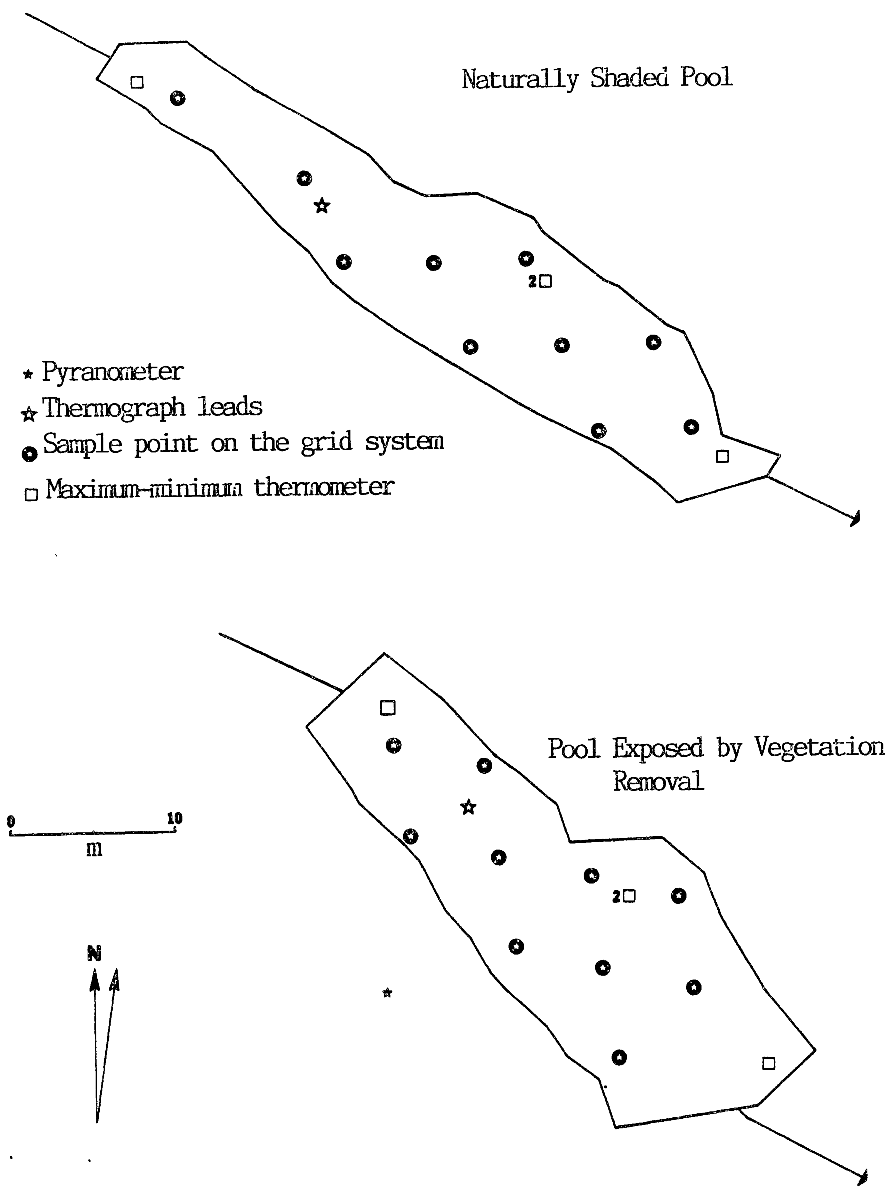


Figure 12. Location of sample points in the intensively monitored pools of the East Fork of the Glover River Stream Temperature Study Site

increments, and at the channel bottom.

All grid temperatures were measured using a Keithley Model 871 digital electronic thermometer. When taking temperature readings, field personnel began at the lowermost grid point on the downstream pool and worked their way upstream. The temperature lead from the digital thermometer was suspended 1.5 m in front of the person recording the temperatures on a boom made of bamboo. By carefully walking through the pools, readings were taken at each gridpoint 1.5 m ahead of the recorder without significantly mixing the water.

Climatic Data

An approximate measurement of solar radiation incident on the exposed pool was made by mounting a pyranmeter in the clearing at the edge of the exposed pool (Figures 7, 8, 9, 10, 11, and 12). A totalizing anemometer and a sling psychrometer were used to monitor wind speed and relative humidity on the days when temperatures at the intensive sites were measured.

Streamflow Data

On each study stream, a control section was identified where flow rates were measured weekly using a pygmy-type flow meter. Stage was monitored daily at each site. Stage, in this instance, represents the fluctuation of waterlevels from a zero datum established when the streams had reached a relative equilibrium after the spring high flows.

The amount of time that the water stayed in the exposed pool was determined using a dye injection technique (Hubbard et al., 1982; Alvey, 1972). A flourescent dye (Rhodamine WT) was injected at the upstream end of the pool and periodic water samples were taken to measure dye concentration at the pool outlet with a fluormeter (Wilson, 1968). Dye concentration was plotted against time to determine the time of peak dye movement through the pool. This time corresponded to the amount of time it took for the principal water mass to move through the system (Table IX).

Turbidity decreases the penetration efficiency of radiant light energy as it passes through water (List, 1951). By doing this, radiant energy, which ultimately becomes heat, is concentrated in the upper portion of the pool. Measurements of turbidity were an indicator of the temperature difference that could exist between the pool surfaces and pool bottoms. Turbidity was measured once a week using a turbidimeter.

Shade Approximation

The extent of vegetative and topographic shading were quantitatively evaluated at each study site by measuring the linear distance shadows extended along the transects established to mark the intensive site sample points. These measurements were made at three times during the day: early morning, noon, and late afternoon at the beginning and end of the summer data collection period to include temporal changes due to solar declination shift.

A second method applied to approximate shading over the entire stream reach at Rock Creek and Little Eagle Creek involved computing the direction of sunrise and sunset by knowing the latitude and declination. The stream reach was divided into 15.24 m (50 ft.) increments and a clinometer was used to determine the angle at which no shade would fall on the center of the stream, by reading the clinometer angle at each interval in the directions of sunrise and sunset. The amount of effective

TABLE IX

RESIDENCE TIMES OF WATER IN THE NATURALLY SHADED AND UNSHADED POOLS OF THE THREE TEMPERATURE STUDY SITES DETERMINED BY DYE TRACING

Site	Shaded Pool (hrs)	Unshaded Pool (hrs)	Date of Measurement	Stage (cm)
East Glover Creek	0.67	0.48	7-31	0.0
Rock Creek	0.07	0.17	8-1	+6.1
Little Eagle Creek	0.75	2.27	7-30	0.0

direct solar radiation for a day was then found using a solar emphemeris (Currier and Hughes, 1980). No readings were taken at East Glover Creek because the site was inaccessible during the measurement period.

The third method used a 35 mm SLR camera equipped with a 180 degree fisheye lens to photograph the sky view factor from the stream center 0.6 m above the water surface at each 15.24 m interval at Rock Creek and Little Eagle Creek. The polar graph of Currier and Hughes (1980) was superimposed on the photographic print and the sun arc traced across the sky. The time of effective sunrise and effective sunset were then determined and these measurements used to determine how much of each pool in the study site was shaded during the day.

Data Collection

Vegetation removal was accomplished by felling brush and trees in place and lopping off branches so they would not protrude in the air and provide shade. Any vegetation falling in the water was removed. Vegetation removal at East Glover Creek was completed on July 10, at Rock Creek on July 16, and at Little Eagle Creek on July 18.

Maximum-minimum thermometers were placed in the pool systems of Rock Creek and East Glover Creek on July 3 and in the pool system at Little Eagle Creek on July 4. Temperature leads for the thermographs in the shaded pool and the pool designated for shade removal at Rock Creek were set in place on June 28. Thermographs were operational in the naturally shaded pool and the pool designated for shade removal on June 29 at East Glover Creek. At Little Eagle Creek, the thermographs were installed at the naturally shaded pool on June 29 and at the pool designated for shade removal on July 11.

Data were collected Monday through Saturday and each site was visited every collection day. On each visit, the maximum-minimum thermometers were read and reset. All recording instruments were checked daily and charts were changed once a week.

Because the monitoring of temperatures at the grid points of the intensive pools required being at the site during the period of highest temperatures, only one site could be intensively monitored each day. The timing of this intensive monitoring coincided with the time of maximum water temperature indicated by the recording thermographs. A rotation scheme allowed each intensive site to be monitored once every three days (twice a week).

Data Analysis

Water temperatures recorded with the digital thermometer in shaded and exposed pools were statistically compared to determine if significant differences existed. Statistical models conformed to n-factor analysis of variance (ANOVA) designs. Factors analyzed included: shade, depth, and date. Depth refers to the water depth at which temperatures were recorded, date refers to the date of measurement, and shade refers to the presence or absence of a natural forest canopy. In cases where two factors (shade and depth) ANOVA's were used, the significance of the shade factor was determined by blocking with depth and the significance of the depth factor was determined by blocking by the shade factor. In cases where these factors (shade, depth, and date) ANOVA's were used, the individual dates or measurements served as blocks.

Analyses of variance were performed using two-tailed F tests because it was impossible to be certain that all treatment deviations from the sample mean would be either positive or negative. Certain days, such as cloudy or rainy days, had temperatures in the open pool which were near the means of temperatures in the shaded pool. A two tailed test was appropriate given these conditions. All analyses of variance were performed using the general linear models procedure available on SAS (Statistical Analysis System, 1979).

Nonparametric statistics were used because not all data conformed to normal distributions (Table X). This procedure involved ranking the observed temperatures from lowest value to highest (Conover and Iman, 1981). ANOVA procedures were performed on the temperature ranks to determine if significant differences existed. By hypothesis, water temperatures in the shaded pool should be cooler and thus have lower ranks than those in the exposed pool.

General comparisons were made between solar radiation observations and water temperatures using data from pyranometers and thermographs. Solar radiation characteristics and air temperatures were also compared by graphical representations. The time of maximum solar radiation was compared with the time of maximum water temperature, both at the surface and at the bottom of the pools. Additionally, maximum air temperature was compared with the maximum water temperature at the pool surfaces and bottoms.

An empirical temperature prediction model was constructed by multiple regression and used as a test for the existing temperature prediction models. Spearman Correlations for several environmental parameters were used to determine which variables had the greatest association with open pool temperatures (Table XI). A Stepwise

TABLE X

EXISTENCE OF NORMALLY DISTRIBUTED TEMPERATURE DATA BY STUDY SITE*

	Naturally Shaded Pool		Unshaded Pool	
	Normal	Non-normal	Normal	Non-normal
Little Eagle Creek	5	6	9	2
East Glover Creek	10	5	8	7
Rock Creek	9	4	12	1

* The normality analysis was performed using the Shapiro-Wilk W test on the data gathered with the electronic thermometer. Each number represents the number of days observed temperatures conformed to the indicated distribution.

TABLE XI

SPEARMAN CORRELATIONS FOR THE ENVIRONMENTAL PARAMETERS AND EXPOSED POOL TEMPERATURES AT EAST GLOVER CREEK

Variable	Open Pool Temperature Coefficient	Pr > R	Variable	Open Pool Temperature Coefficient	Pr > R
Turbidity of Shaded Pool	-0.3708	.0001	Stage	-0.5113	.0001
			Wind Speed	0.1767	.0001
Turbidity of Unshaded Pool	-0.3725	.0001	Daily Rad.	-0.0028	.9568
Surface Temp. of Shaded Pool	0.7247	.0001	Peak Rad.	-0.3944	.0001
Temp. at 23 cm in Shaded Pool	0.7313	.0001	Maximum Air Temp.	0.4632	.0001
Temp. at 46 cm in Shaded Pool	0.6858	.0001	Minimum Air Temp.	0.2952	.0001
Temp. at 69 cm in Shaded Pool	0.4082	.0059	Average Air Temp.	0.4609	.0001
Depth of Temp. Measurement in Unshaded Pool	-0.4935	.0001			

regression procedure was used to construct the regression equation using the parameters which had absolute values of the Spearman correlation coefficients greater than 0.4.

A major problem with regression analysis was that temperatures observed on any particular day were not completely independent of water temperatures observed on the preceding day. This autocorrelated data could have underestimated both the mean square error and the standard deviation of the estimated regression coefficient. Also, confidence intervals using the t and F distributions were no longer strictly applicable (Neter and Wasserman, 1977).

A Durbin-Watson test for the significance of autocorrelation of the residual errors showed that temperature observations made at the water surface and at 46 cm were autocorrelated using a one factor ANOVA model with shade as the factor. Temperature observations made at other depths (23 cm, 69 cm, and 91 cm) showed no significant autocorrelation. After lumping all temperature observations together by treating depth as a factor in a two factor ANOVA, the Durbin-Watson test showed the entire time series temperature data set was autocorrelated.

CHAPTER IV

RESULTS AND DISCUSSION

Seasonal climatic conditions in southeastern Oklahoma can vary drastically from year to year. For a single season, the magnitude and significance of research results must be examined in the context of the specific conditions encountered.

Generally, the summer of the study was cooler than normal. Mornings were often cloudy with cloud cover remaining in several afternoons. Average July temperatures were 1.2 C below the 20 year norm and mean maximum temperatures were 1.6 C below normal for the month. August average temperatures were 1.3 C below normal and mean maximum temperatures were 2.2 C below the 20 year norm. The cooler weather persisted into September with average temperatures 1.8 C below the norm and mean maximum temperatures 2.5 C below normal (National Oceanic and Atmospheric Administration, 1964-1984). Smoke from prescribed burns in nearby clearcuts frequently reduced the amount of solar radiation reaching the streams.

The summer of 1984 was also wetter than the 20 year norm. July precipitation was 1.32 cm above normal, August precipitation was 6.40 cm below normal and September precipitation was 12.65 cm above normal.

Natural Stream Temperature Variability

Water temperatures in forest streams fluctuate along a stream reach partly because the forest canopies do not provide continuous and complete shade from incident solar radiation. Also, groundwater and subsurface flow reaching the stream channel may have different temperatures than the receiving stream. These factors often produce a mottled temperature regime in streams (Lee and Samuel, 1976; Rishel et al., 1982; Collings, 1969; Meehan, 1970).

The natural variation in maximum and minimum stream temperatures were measured at the three study sites in pools upstream of the exposed pools (Figures 7-9). Temporal and spatial variability of the maximum and minimum water temperatures are represented with box plots (Figure 13).

Daily Maximum Temperatures

Daily maximum water temperature values were grouped and presented by month (Figures 14-22). The variation of daily maximum water temperatures for each month was represented by the difference between the highest and lowest maximum temperatures recorded at each point in the pool systems.

The largest variation in daily maximum temperatures at East Glover Creek at the water surface was from 23.3 C to 31.8 C while the largest variation in pool bottom maximum temperatures was from 21.1 C to 27.8 C, both occurring in September (Figures 14-16). The highest maximum temperatures recorded upstream of the exposed pool at East Glover Creek were 32.8 C at the water surface and 31.2 C at the pool bottoms, both in August. At Rock Creek, the largest variation in daily maximum temperatures at the water surface was from 26.1 C to 34.5 C in August while the largest daily maximum temperature variation at the pool bottoms was

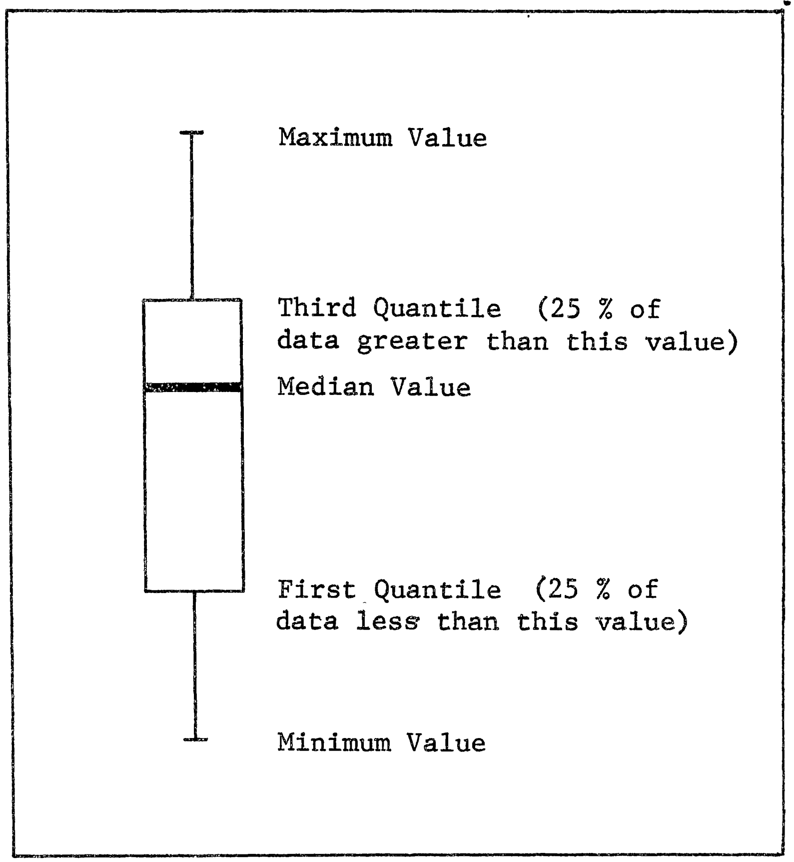


Figure 13. Box Plot Interpretation

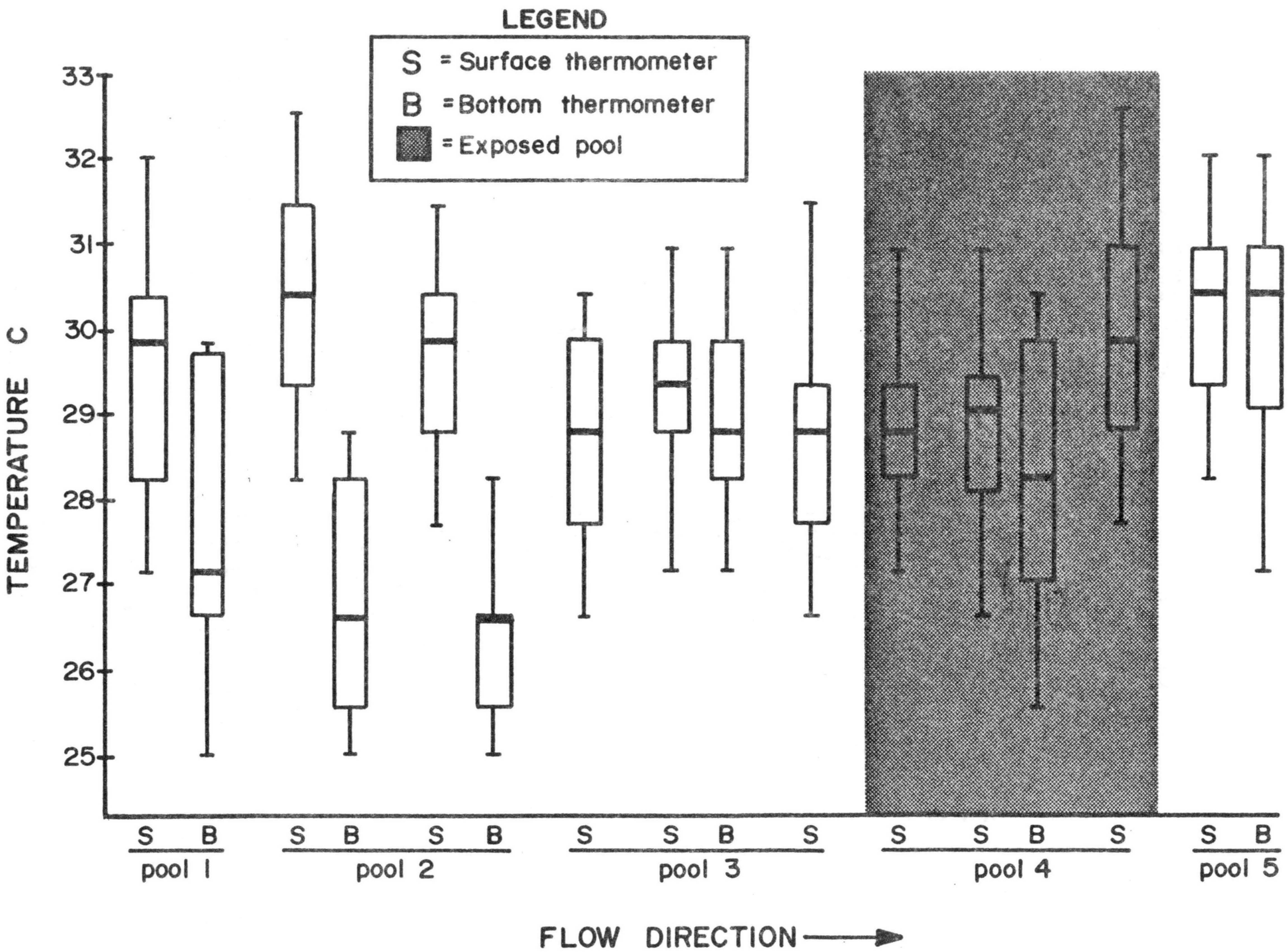


Figure 14. July maximum temperatures at East Glover Creek

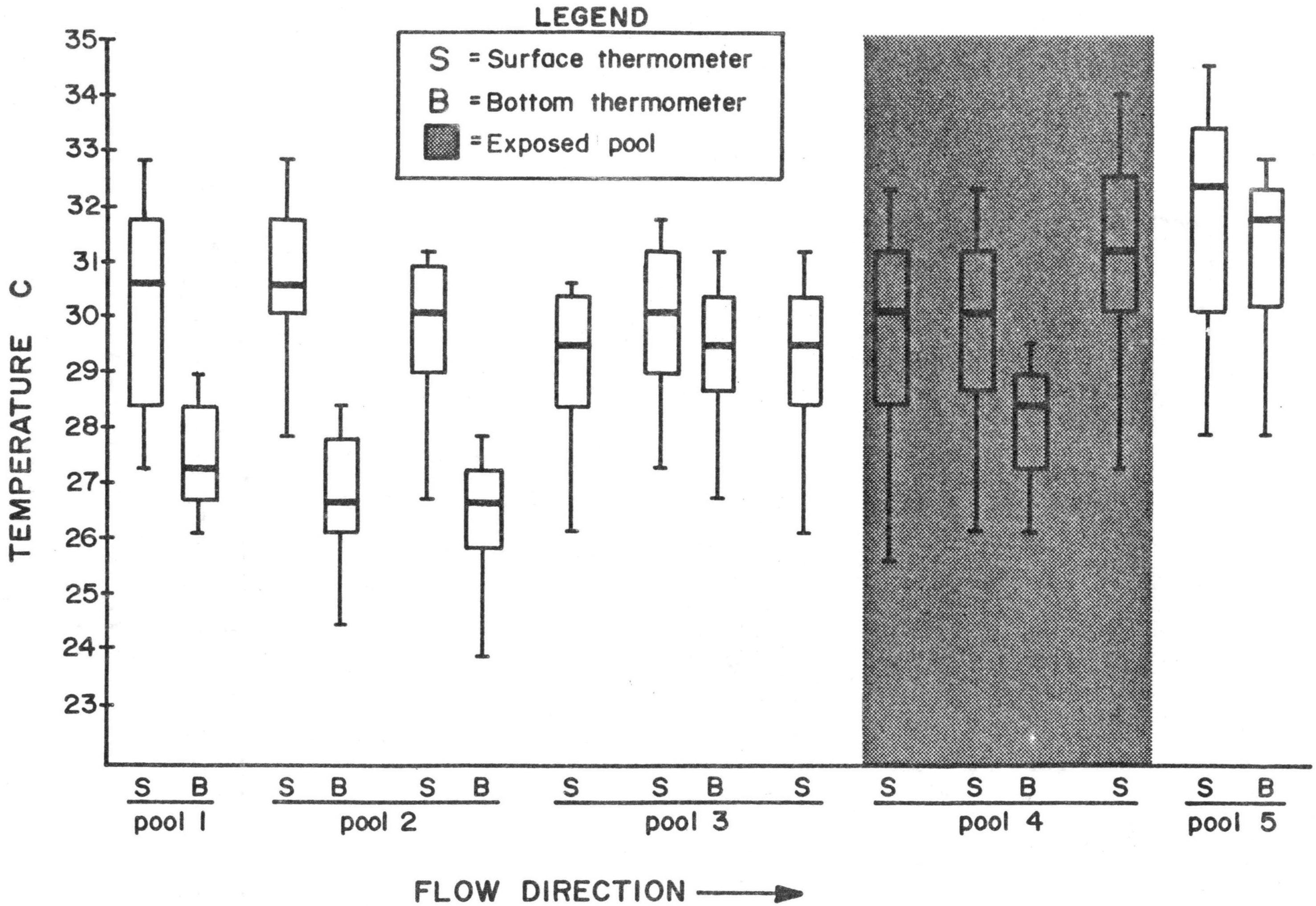


Figure 15. August maximum temperatures at East Glover Creek

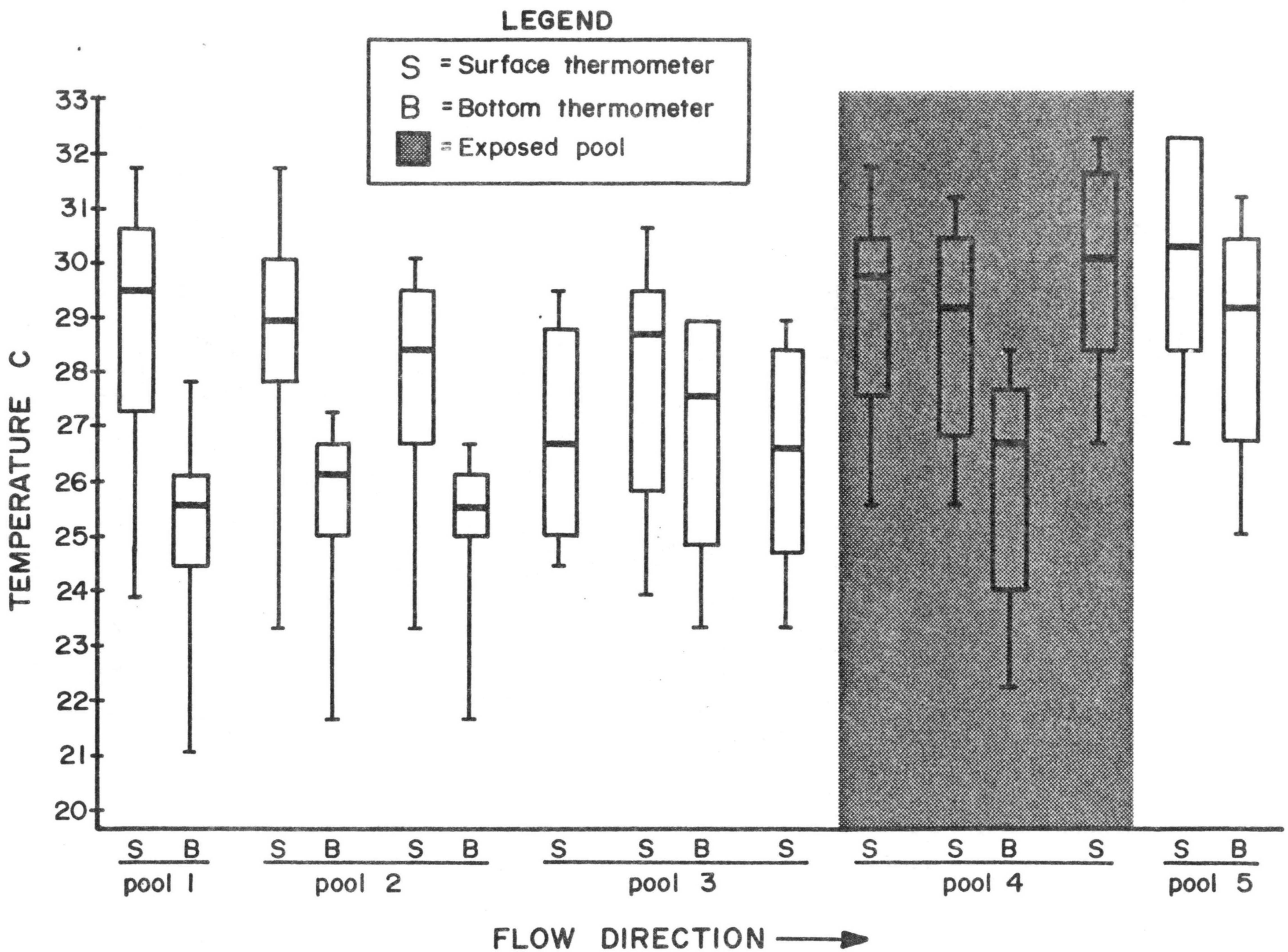


Figure 16. September maximum temperatures at East Glover Creek

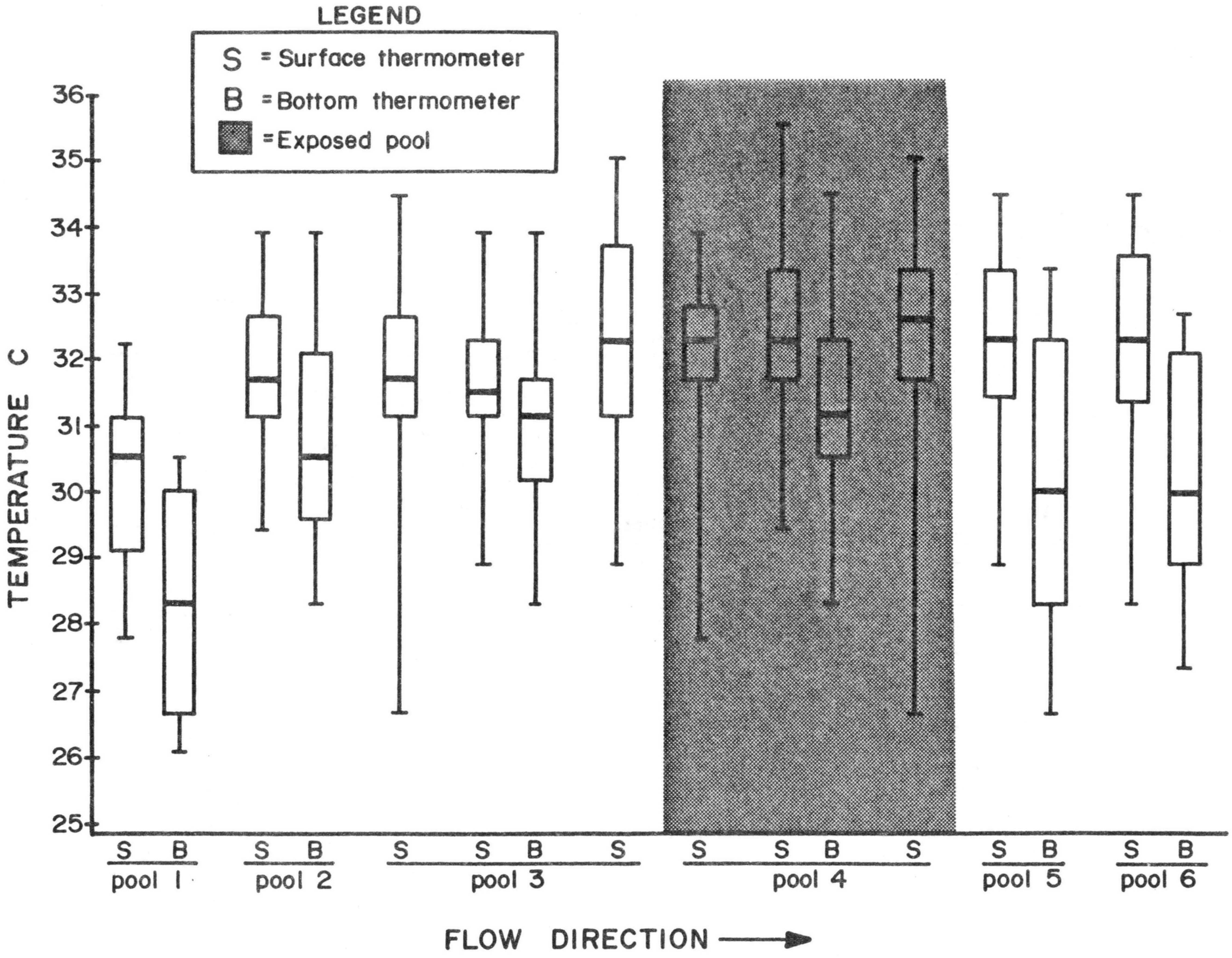


Figure 17. July maximum temperatures at Rock Creek

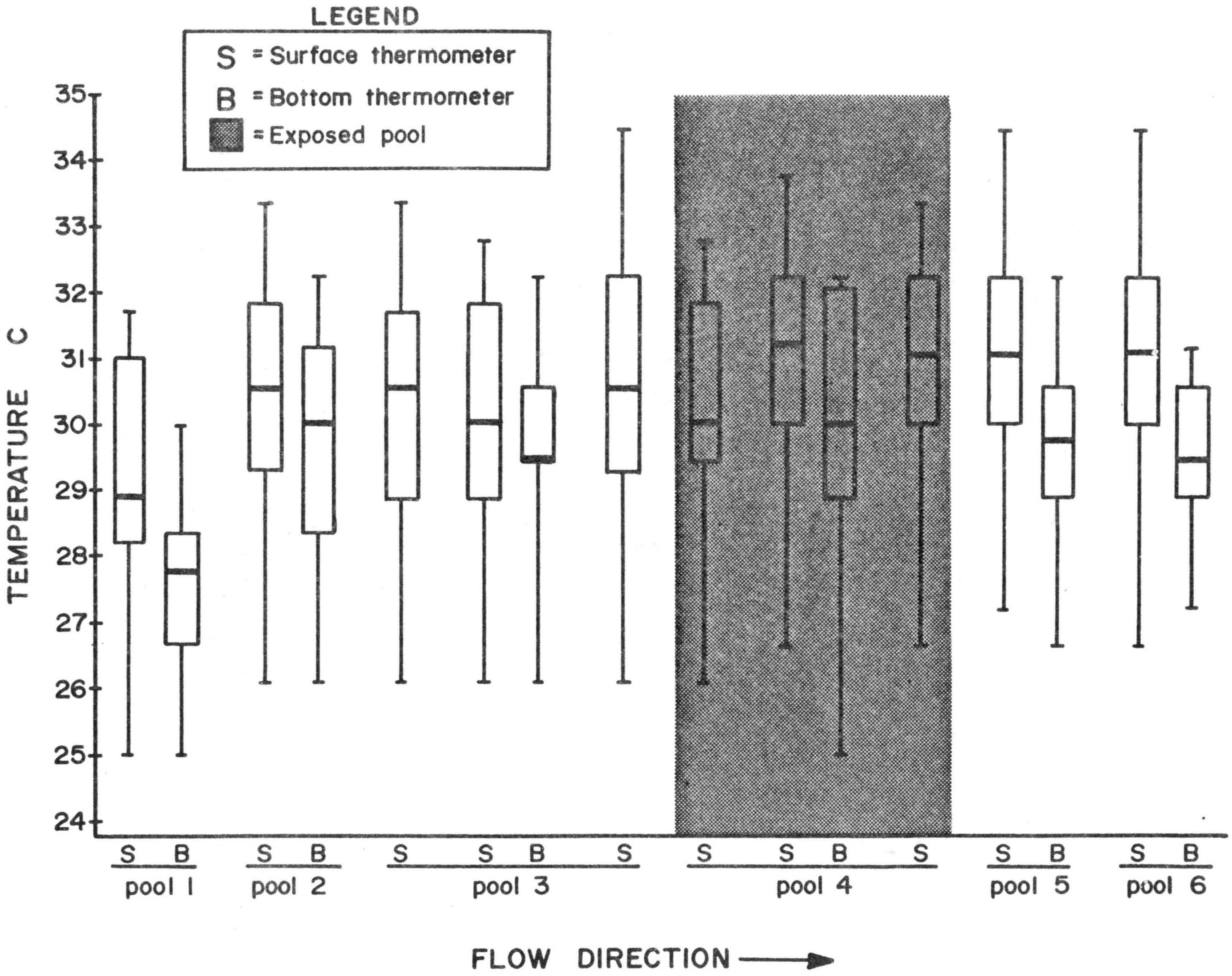


Figure 18. August maximum temperatures at Rock Creek

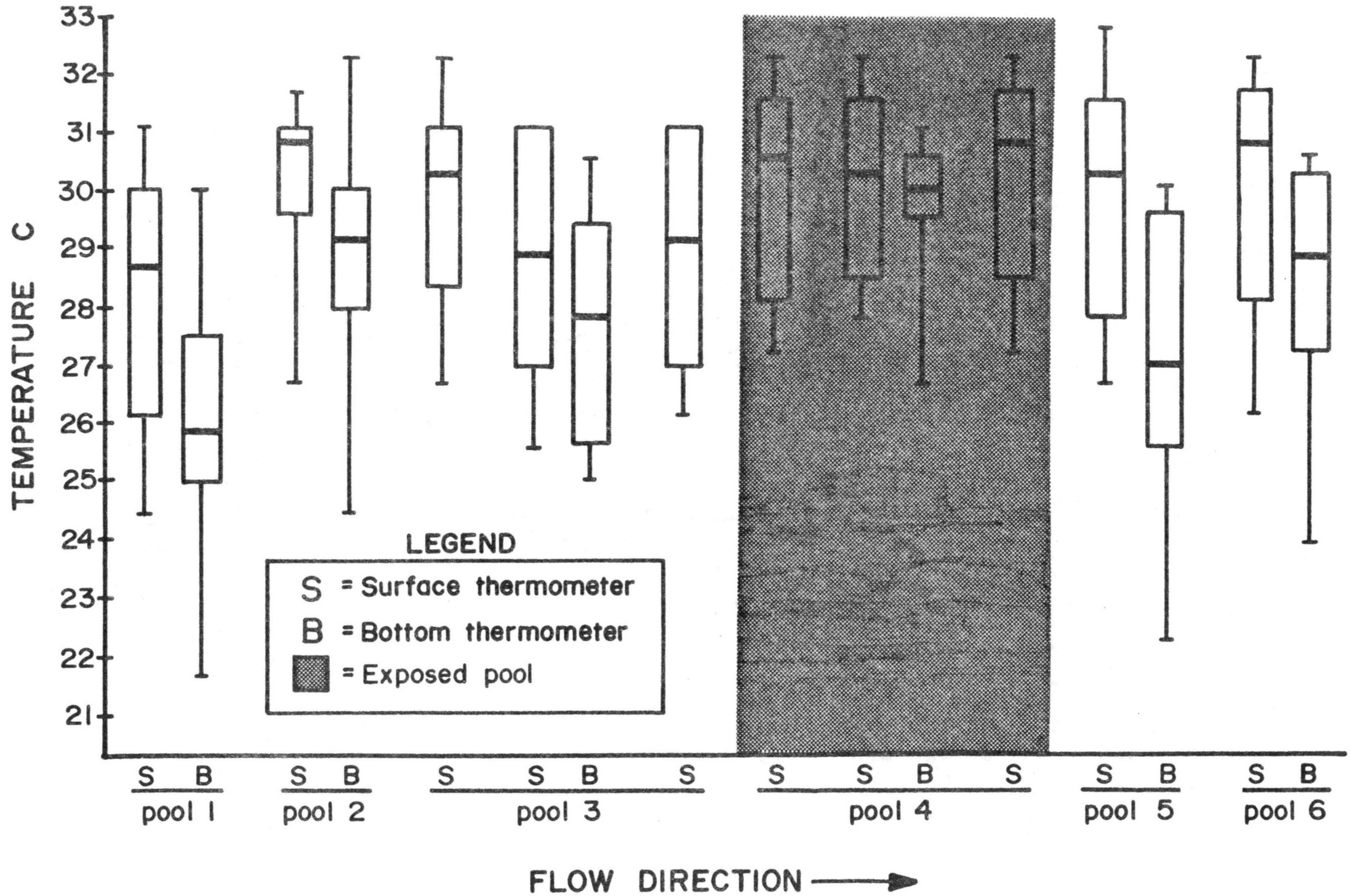


Figure 19. September maximum temperatures at Rock Creek

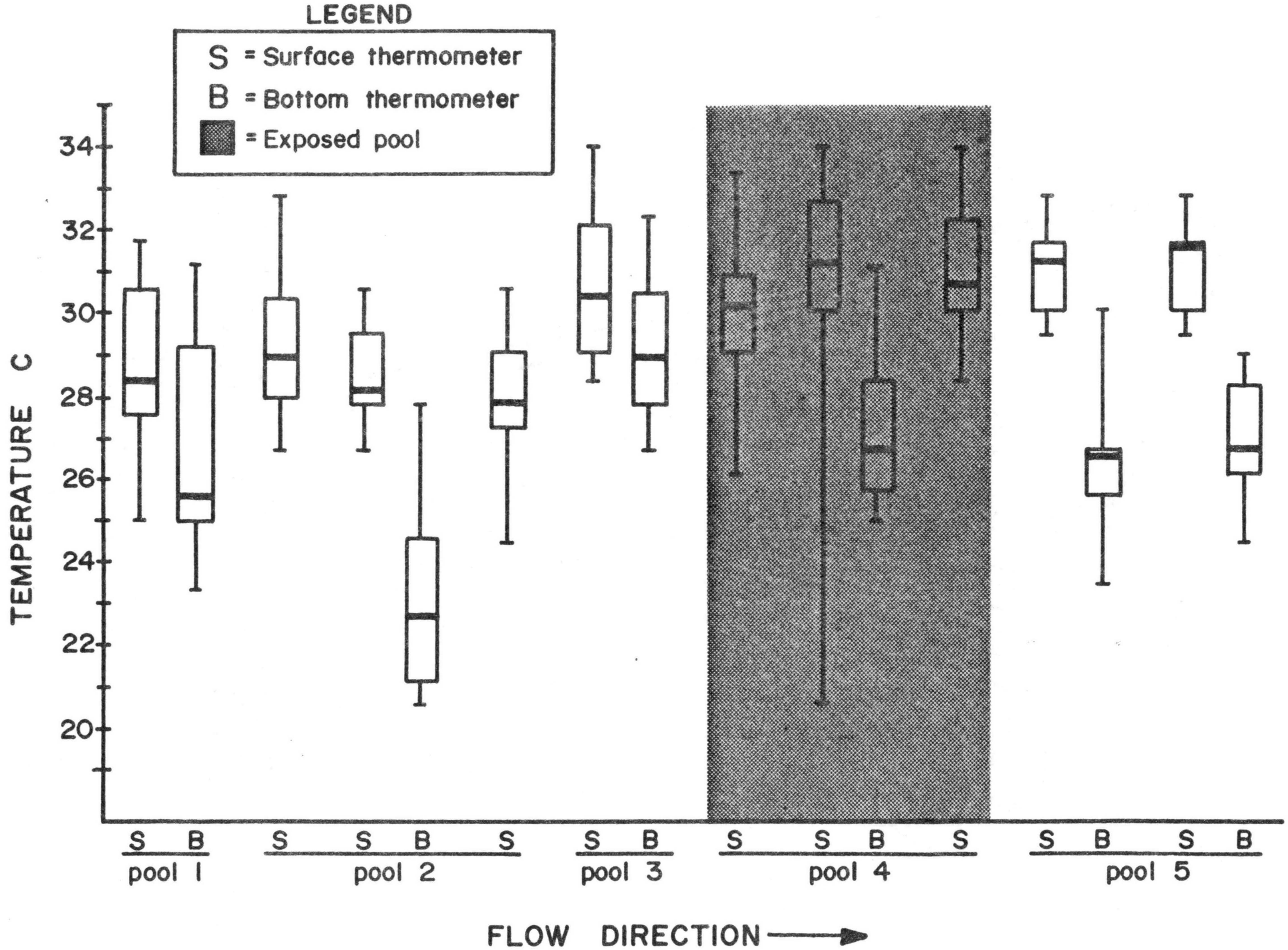


Figure 20. July maximum temperatures at Little Eagle Creek

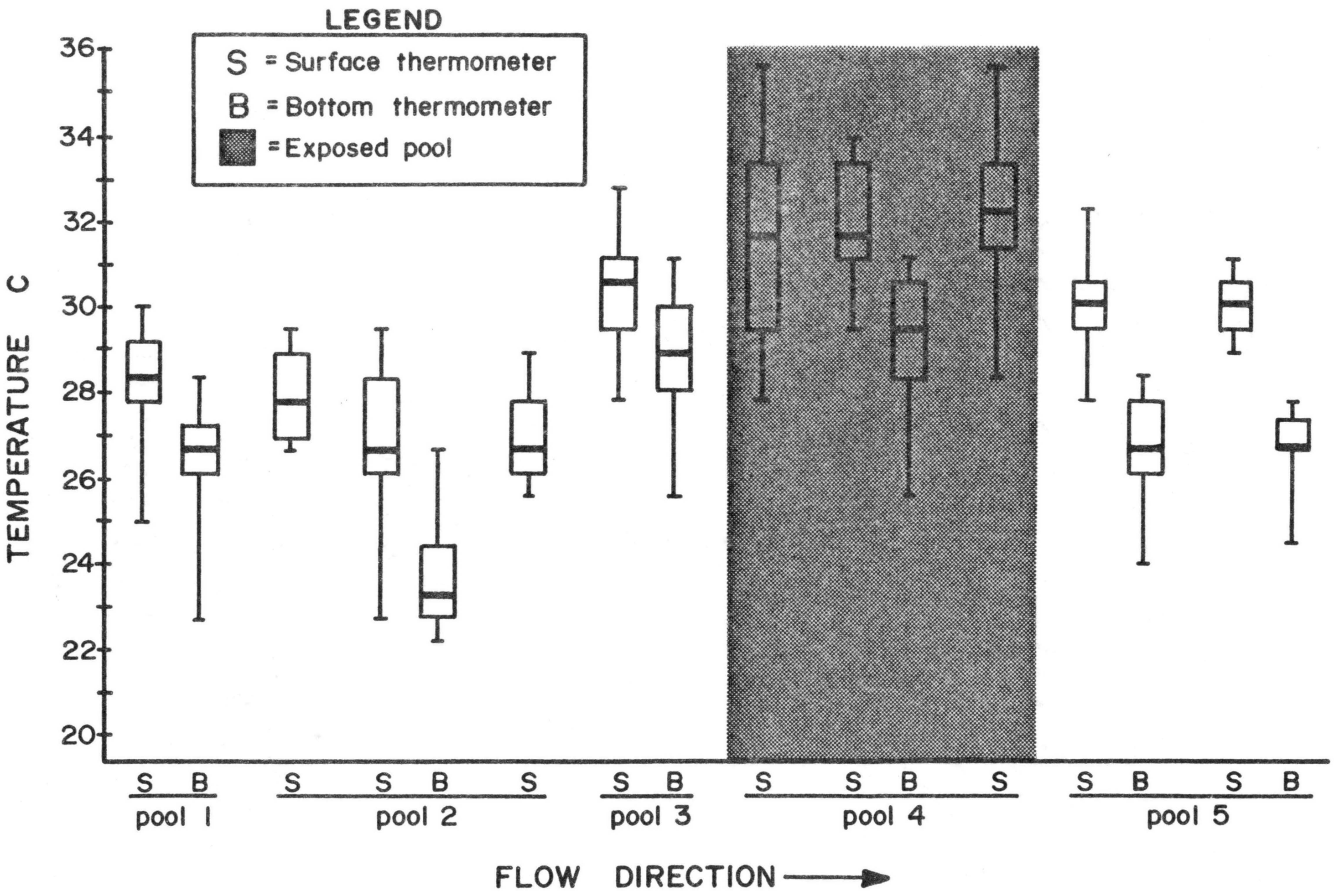


Figure 21. August maximum temperatures at Little Eagle Creek

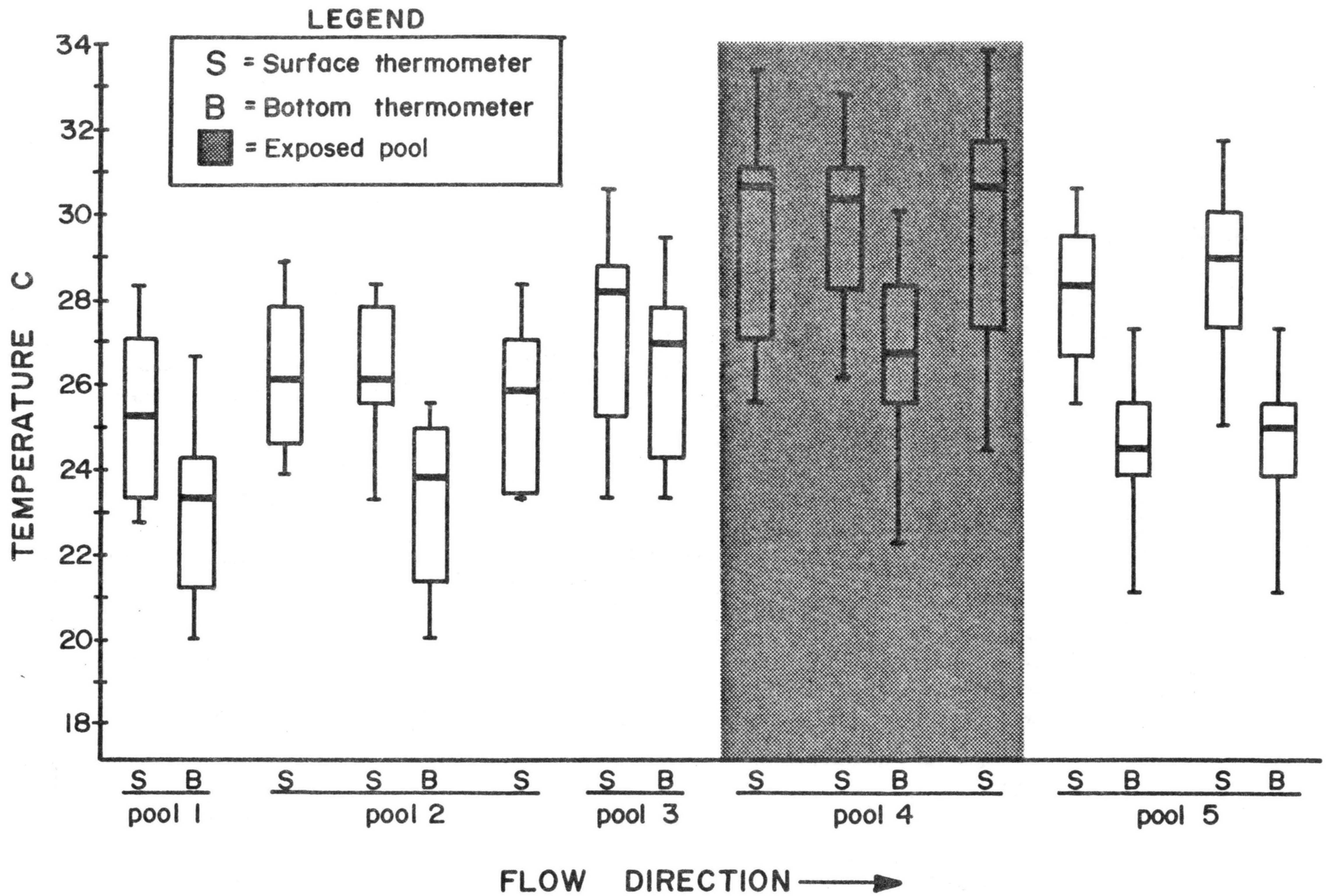


Figure 22. September maximum temperatures at Little Eagle Creek

from 21.7 C to 30.0 C in September (Figures 17-19). The highest maximum temperatures upstream of the exposed pool were 35.0 at the water surface in July and 33.9 C at the pool bottoms, also in July. The largest variation in daily maximum temperatures at Little Eagle Creek at the water surface was from 23.4 C to 30.6 C in September and the largest daily variation in pool bottom maximum temperatures was from 23.3 C to 31.2 C in July (Figures 20-22). The highest maximum temperatures upstream of the exposed pool at the water surface was 34.0 in July and the highest maximum temperature at the pool bottom was 32.1 C also in July.

Pool surface natural daily variations of maximum temperatures were from 0.1 C to 1.8 C greater than pool bottom daily variations at Rock Creek and East Glover Creek. The largest maximum temperature variation occurs at the water surface because it is the zone where solar radiation directly heats water during the day and the zone where heat is directly lost from during the night when air temperatures drop below water temperatures (Velz and Gannon, 1960). However, at Little Eagle Creek, daily pool bottom maximum temperature variability was greater than surface variability. Greater daily variation in the bottom maximum temperatures at Little Eagle Creek was most likely due to the groundwater influx. After rains, a significant amount of groundwater input was observed entering Pool 1 but during dry periods, groundwater inputs were not detected. The groundwater flux difference probably accounted for the 7.9 C temperature variability at the pool bottom. Daily maximum temperature variation could have reflected the transition between moist and dry weather experienced during July.

At the East Glover Creek and Little Eagle Creek sites, the largest maximum temperature variations recorded at the water surface were in

September. This was probably due to the seasonal transition from hot, dry summer weather to the cool, moist autumn weather which occurred in September. The largest daily maximum temperature variation at Rock Creek pool surfaces observed in August was probably a result of the channel physiography and hydrologic response. Rock Creek is a steep gradient, small-pooled stream when compared to East Glover Creek and Little Eagle Creek. During summer convectional storms, Rock Creek probably transported runoff more quickly than Little Eagle Creek or East Glover Creek. High maximum water temperature variability in August could reflect the difference between measurements taken shortly after rains and those taken during dry periods.

The largest daily pool bottom maximum temperatures variations at East Glover Creek and Rock Creek also occurred in September, but the largest daily maximum temperature variation at the pool bottoms at Little Eagle Creek was in July. Again, the reduction of groundwater inputs which most likely occurred as a result of the transition from moist to dry weather in July was probably the reason for the large July maximum temperature variations at Little Eagle Creek.

Daily Minimum Temperatures

Daily minimum water temperature values were grouped by month and the natural daily minimum temperature variations were represented by the difference between the highest and lowest minimum temperatures at each point upstream of the exposed pools. The largest variation in daily minimum temperatures at East Glover Creek at the water surface was from 17.8 C to 25.0 C while the largest variation in daily minimum temperatures at the pool bottoms was from 18.3 C to 26.1 C (Table XII).

TABLE XII

MONTHLY MEDIAN AND MINIMUM TEMPERATURES AND DAILY MINIMUM TEMPERATURE VARIATION AT EAST GLOVER CREEK

		Pool Surface			Pool Bottom		
		Median Temp (C)	Minimum Temp (C)	Variation (C)	Median Temp (C)	Minimum Temp (C)	Variation (C)
July	Pool 1	25.0	21.7	5.0	24.4	22.2	5.0
	Pool 2	25.0	21.7	5.6	25.5	23.3	3.9
		25.0	21.7	5.0	24.4	23.3	3.3
	Pool 3	25.6	23.9	3.9			
		25.0	22.8	3.9	26.1	23.9	4.4
		25.3	23.3	3.9			
	Pool 4	25.0	22.8	5.6			
		23.9	18.9	7.2	25.6	22.8	4.4
		25.6	22.8	5.0			
	Pool 5	25.6	22.8	5.0	25.0	22.0	5.6
August	Pool 1	24.4	21.7	4.4	25.0	22.2	4.4
	Pool 2	25.6	21.7	5.0	25.6	22.8	4.4
		25.0	21.7	5.0	25.0	22.2	4.4
	Pool 3	25.6	22.8	4.4			
		25.0	21.7	6.1	25.6	22.2	4.4
		25.0	22.2	6.1			
	Pool 4	24.4	21.7	8.9			
		23.3	20.6	9.4	25.0	22.2	4.4
		25.6	22.2	8.9			
	Pool 5	25.6	22.2	4.4	25.0	22.2	5.0
September	Pool 1	21.7	16.7	7.2	23.3	18.9	5.6
	Pool 2	23.9	19.4	6.1	23.9	18.9	7.2
		23.3	17.8	7.2	23.9	18.3	7.8
	Pool 3	22.5	20.0	5.0			
		20.6	17.8	6.1	22.2	18.9	6.7
		21.9	18.3	6.1			
	Pool 4	21.9	17.8	6.1			
		21.7	17.8	10.0	23.3	17.8	7.2
		21.7	18.3	6.1			
	Pool 5	22.2	18.3	6.7	23.3	18.9	6.1

temperatures in pools upstream of the exposed pools occurred at the water surface (Table XV). Surface water temperature ranges were 2.2 C to 4.4 C higher than bottom temperature ranges at the three sites.

Effects of Shade Removal

The data obtained from the intensively monitored pools at each site were used to statistically compare water temperature in exposed and shaded stream reaches. Comparisons were made only for data gathered with the hand held electronic thermometer because these were the only temperature measurements that conformed to the n-factor experimental design.

Pretreatment Pool Similarity

East Glover Creek mean maximum pretreatment temperatures in the designated shaded (reference) pool were 29.7 C at the surface and 29.2 C at the bottom while the designated exposed (treatment) pool pretreatment mean maximum temperatures were 29.1 C at the surface and 28.9 C at the bottom (Table XVI). At Rock Creek, pretreatment mean maximum temperatures in the designated shaded pool were 32.5 C at the surface and 31.5 C at the bottom and the designated exposed pool mean maximum temperatures were 32.0 C at the surface and 30.3 C at the bottom. Maximum designated shaded pool temperatures were higher than maximum designated exposed pool temperatures for all days of measurement at East Glover Creek and for 14 of the 17 days of measurement at Rock Creek (Table XVI).

Little Eagle Creek mean maximum pretreatment temperatures in the designated exposed pool were 31.0 C at the surface and 27.7 C at the bottom which was warmer than the designated shaded pool mean maximum

TABLE XVI

AVERAGE DAILY PRETREATMENT MAXIMUM AND MINIMUM TEMPERATURES IN THE INTENSIVELY MONITORED POOLS AT THE THREE STUDY SITES

		Designated Shaded Pool				Designated Exposed Pool			
		Surface		Bottom		Surface		Bottom	
	Date	Max (C)	Min (C)	Max (C)	Min (C)	Max (C)	Min (C)	Max (C)	Min (C)
East Glover Creek	6-29	30.0	----	29.4	----	----	----	30.0	----
	6-30	29.4	25.6	28.3	25.0	----	----	28.9	26.1
	7-1	28.9	25.0	27.8	23.9	----	----	28.3	25.0
	7-2	29.4	25.0	28.9	24.4	----	----	28.9	25.0
	7-3	29.1	25.9	28.9	26.3	28.1	26.1	25.8	25.6
	7-4	28.7	25.5	27.8	25.6	28.5	25.1	28.3	26.7
	7-5	28.5	25.3	28.3	26.4	28.3	26.4	28.3	25.8
	7-6	30.1	26.6	30.0	26.7	29.9	26.1	30.3	26.4
	7-7	31.1	26.7	30.6	26.7	----	26.7	----	27.2
	7-8	30.8	25.9	30.0	26.1	29.4	26.5	----	----
	7-9	30.6	27.0	30.3	27.2	30.1	26.5	30.3	27.2
	Averages	29.7	26.0	29.2	26.0	29.1	26.1	28.9	26.2
Rock Creek	6-29	31.7	26.7	30.6	26.7	30.0	27.2	28.9	26.7
	6-30	31.1	26.7	30.0	26.7	29.4	26.7	28.3	26.7
	7-1	32.2	26.7	30.6	26.7	30.0	26.7	28.9	26.7
	7-2	32.2	26.1	30.0	26.1	30.0	26.7	28.9	26.1
	7-3	33.9	26.7	31.7	26.7	30.6	26.7	29.4	26.7
	7-4	32.8	25.3	30.6	27.2	32.8	26.0	29.7	26.7
	7-5	29.4	26.0	29.7	26.4	30.6	26.2	30.0	26.9
	7-6	31.1	26.3	31.1	26.7	30.9	26.2	28.9	26.7
	7-7	32.8	27.8	32.2	27.8	30.0	27.8	30.0	27.2
	7-8	33.1	27.2	31.9	27.8	32.7	27.4	31.9	27.2
	7-9	33.2	27.8	32.8	27.8	32.6	27.8	30.0	27.2
	7-10	33.6	27.6	32.8	28.1	32.8	28.7	30.0	27.2
	7-11	33.8	27.5	32.5	28.1	33.3	27.4	31.7	27.5
	7-12	31.4	27.5	30.8	28.1	31.5	27.0	30.3	27.2
	7-13	32.1	27.6	31.4	28.1	32.2	27.6	30.8	27.8
	7-14	34.4	28.3	32.2	28.3	31.1	27.8	30.6	27.2
	7-15	34.2	27.5	33.1	27.8	33.8	27.7	32.5	27.8
	Averages	32.5	27.0	31.5	27.4	32.0	27.1	30.3	27.1
Little Eagle Creek	7-4	28.0	22.4	21.1	19.7	29.6	23.5	26.7	26.7
	7-5	26.6	22.6	19.4	18.6	28.1	24.4	25.0	25.0
	7-6	28.9	22.4	21.1	19.4	30.6	25.3	27.2	24.4
	7-7	30.0	22.2	19.4	----	----	----	----	----
	7-8	30.8	19.7	20.6	19.4	31.9	24.5	30.0	28.3
	7-9	31.2	23.3	22.8	20.0	32.3	26.1	30.0	26.7
	7-10	30.8	23.4	26.4	19.7	32.7	27.1	30.6	26.7
	7-11	31.3	22.7	27.2	20.6	33.7	24.2	31.1	24.4
	7-12	27.2	24.2	25.0	21.1	28.5	24.4	27.2	25.0
	7-13	29.9	24.8	22.2	21.1	31.5	24.9	26.7	24.7
	7-14	31.7	23.9	20.6	20.0	33.3	26.1	27.8	25.6
	7-15	30.9	24.4	22.2	20.0	33.0	25.6	28.3	25.6
	7-16	27.0	23.5	23.6	19.4	27.6	24.1	26.9	24.4
	7-17	29.4	23.0	23.9	19.7	30.9	23.4	26.4	23.6
	Averages	29.4	23.0	22.7	19.9	31.0	24.8	27.7	25.2

temperatures of 29.4 C at the surface and 22.7 C at the bottom (Table XVI). Higher designated exposed pool temperatures were probably the result of the designated shaded pool having extensive cool groundwater inputs. By the time the water had flowed from the designated shaded pool to the designated exposed pool, it had warmed considerably (Table XVI).

Pool Temperature Differences Following Shade Removal

Exposed pool maximum temperatures were found to be significantly greater ($P > 0.0001$) than shaded pool maximum temperatures for all days of measurement at Little Eagle Creek using a two factor ANOVA with shade and depth of measurement as factors (Table XVII). Little Eagle Creek exposed pool mean maximum temperatures were from 0.5 C to 8.4 C greater than shaded pool mean maximum temperatures. The shade factor from the two factor ANOVA showed significantly greater exposed pool temperatures at Rock Creek ($P>0.001$) for all days of measurement (Table XVIII) and at East Glover Creek ($P >0.001$) for all days but one (Table XIX). Mean maximum exposed pool temperatures were from 0.1 C lower to 1.7 C higher than shaded pool mean maximum temperatures at Rock Creek and mean maximum exposed pool temperatures at East Glover Creek were from 0.2 C higher to 2.9 C higher than shaded pool mean maximum temperatures. Three factor (shade, depth, and date) ANOVA results showed summer mean maximum exposed pool temperatures were significantly greater ($P> 0.0001$) than the mean summer shaded pool maximum temperatures at all three sites (Table XX). Maximum-minimum thermometer data also indicated that exposed pool water temperatures were greater than shaded pool

TABLE XVII

TWO FACTOR ANALYSIS OF VARIANCE RESULTS FOR SHADED AND CLEARED POOLS AT LITTLE EAGLE CREEK USING MAXIMUM TEMPERATURE RANKS

Date	Shading	N	Mean Temp at all Depths (C)	P > F for the Shade Factor	P > F for the Depth Factor	P > F for the Interaction
7-30	E	64	26.9	0.0001	0.0001	0.0001
	S	41	22.4			
8-6	E	64	29.2	0.0001	0.0001	0.0001
	S	41	23.9			
8-13	E	64	29.8	0.0001	0.0001	0.0015
	S	41	23.7			
8-16	E	66	29.7	0.0001	0.0001	0.0008
	S	40	23.9			
8-20	E	65	28.3	0.0001	0.0001	0.3930
	S	40	23.6			
8-23	E	65	32.4	0.0001	0.0001	0.0071
	S	41	25.4			
8-27	E	63	30.9	0.0001	0.0001	0.0048
	S	40	23.9			
8-30	E	59	31.5	0.0001	0.0001	0.0485
	S	39	23.1			
9-6	E	64	29.6	0.0001	0.0001	0.0001
	S	39	23.1			
9-10	E	64	26.6	0.0001	0.0001	0.0001
	S	42	26.1			
9-13	E	47	28.1	0.0001	0.0001	0.0129
	S	39	26.1			

E = Exposed Pool and S = Shaded Pool

TABLE XVIII

TWO FACTOR ANALYSIS OF VARIANCE RESULTS FOR SHADED AND EXPOSED POOLS AT ROCK CREEK USING MAXIMUM TEMPERATURE RANKS

Date	Shading	N	Mean Temp at all Depths (C)	P > F for the Shade Factor	P > F for the Depth Factor	P > F for the Interaction
8-1	E	50	27.3	0.0001	0.0001	0.2118
	S	27	26.8			
8-4	E	50	29.1	0.0001	0.0001	0.0414
	S	28	28.3			
8-8	E	49	31.2	0.0001	0.0001	0.9002
	S	28	30.2			
8-11	E	55	28.2	0.0006	0.0001	0.9525
	S	29	28.3			
8-15	E	51	30.2	0.0001	0.0001	0.0090
	S	28	29.5			
8-18	E	50	33.4	0.0001	0.0001	0.2601
	S	28	32.8			
8-22	E	48	31.4	0.0001	0.0001	0.6238
	S	28	30.9			
8-25	E	48	30.4	0.0001	0.0001	0.9602
	S	28	30.1			
8-29	E	47	33.4	0.0001	0.0001	0.1730
	S	22	32.6			
9-1	E	41	32.1	0.0001	0.0177	0.7039
	S	21	31.3			
9-5	E	38	30.5	0.0001	0.0001	0.1235
	S	22	28.8			
9-8	E	37	28.3	0.0001	0.0001	0.6934
	S	21	27.2			
9-12	E	43	31.4	0.0001	0.0001	0.1244
	S	24	30.6			

E = Exposed Pool and S = Shaded Pool

TABLE XIX

TWO FACTOR ANALYSIS OF VARIANCE RESULTS FOR SHADED AND EXPOSED POOLS AT EAST GLOVER CREEK USING MAXIMUM TEMPERATURE RANKS

Date	Shading	N	Mean Temp at all Depths (C)	P > F for the Shade Factor	P > F for the Depth Factor	P > F for the Interaction
7-24	E	28	28.9	0.0001	0.0001	0.0001
	S	27	28.3			
7-27	E	29	27.5	0.0001	0.0001	0.0184
	S	28	27.3			
7-31	E	26	27.8	0.0001	0.0001	0.0001
	S	26	26.7			
8-3	E	31	26.1	0.0888	0.0001	0.5933
	S	31	25.9			
8-7	E	31	28.8	0.0001	0.0001	0.1039
	S	28	27.9			
8-10	E	31	27.9	0.0001	0.0001	0.0885
	S	27	27.3			
8-14	E	31	29.7	0.0001	0.0001	0.0170
	S	28	28.9			
8-17	E	31	31.2	0.0001	0.0001	0.1102
	S	28	30.1			
8-21	E	30	31.6	0.0001	0.0001	0.0300
	S	26	30.1			
8-24	E	30	30.9	0.0001	0.0001	0.0552
	S	27	29.0			
8-28	E	26	31.6	0.0001	0.0001	0.1138
	S	24	29.9			
8-31	E	27	31.4	0.0001	0.0001	0.2082
	S	26	29.1			
9-4	E	25	29.2	0.0001	0.0001	0.0211
	S	24	26.3			
9-7	E	26	28.2	0.0001	0.0001	0.3549
	S	25	25.4			
9-11	E	25	29.9	0.0001	0.0001	0.0616
	S	24	28.2			

E = Exposed Pool and S = Shaded Pool

TABLE XX

THREE FACTOR ANALYSIS OF VARIANCE RESULTS BETWEEN SHADED AND EXPOSED POOL MAXIMUM TEMPERATURE RANKS FOR THE SUMMER OF 1984

	East Glover Creek				Rock Creek				Little Eagle Creek			
	Shaded		Exposed		Shaded		Exposed		Shaded		Exposed	
Depth (cm)	N	Mean Temp (C)	N	Mean Temp (C)	N	Mean Temp (C)	N	Mean Temp (C)	N	Mean Temp (C)	N	Mean Temp (C)
0	150	28.1	148	29.9	115	29.8	195	30.6	120	27.1	180	30.4
23	147	28.1	142	29.6	110	29.9	195	30.6	120	24.6	180	30.1
46	85	27.9	102	29.0	75	29.7	165	30.5	108	23.1	178	29.2
69	17	26.9	35	27.4	34	29.2	52	29.8	102	22.4	101	27.8
91	0	----	30	26.7	1	28.2	2	28.9	32	21.6	46	26.8

ANOVA Factors	P > F	DF	P > F	DF	P > F	DF
Shade	.0001	1	.0001	1	.0001	1
Depth	.0001	4	.0001	4	.0001	4
Date	.0001	14	.0001	12	.0001	11
Shade by Depth Interaction	.0001	3	.0001	4	.0001	4
Shade by Date Interaction	.0001	14	.0001	12	.0001	10
Depth by Date Interaction	.0001	56	.0001	37	.0001	44
Shade by Depth by Date Interaction	.0001	42	.0005	36	.0001	40

temperatures at all three sites except for Rock Creek during August (Figures 14-22).

Because shading effects cannot be separated from other differences between pools, the ANOVA results do not strictly indicate shade removal to be the cause of the increase in maximum temperatures. However, examination of the increased duration of exposure coupled with knowledge of energy and heat exchange relationships indicates that the duration of exposure was probably the principle cause of the temperature increase (Figure 23 and Table XXI).

Two factor (shade and depth) ANOVA results also indicate that significant differences in maximum temperatures existed with depth of measurement in the shaded and exposed pools at each site. East Glover Creek and Little Eagle Creek had significantly different maximum temperatures ($P > 0.0001$) monitored at each 23 cm depth increment in the shaded and open pools for all days of measurement (Tables XIX and XVII). Rock Creek maximum temperatures were significantly different ($P > 0.0001$) for the 23 cm depth increments for all days of measurement except one (Table XVIII). Three factor (shade, depth, and date) ANOVA results show that the pool surface maximum temperatues were significantly greater than pool bottom temperatures in the shaded and exposed pools at the three sites (Table XX). Exposed pool maximum surface temperatures were as much as 4.5 C, 7.8 C, and 1.7 C greater than bottom temperatures and shaded pool maximum surface temperatures were as much as 3.0 C, 7.8 C, and 1.9 C greater than bottom temperatures at East Glover Creek, Little Eagle Creek, and Rock Creek, respectively.

Two factor (shade and depth) ANOVA results for Little Eagle Creek showed a significant shade by depth interaction ($P > 0.05$) for all days

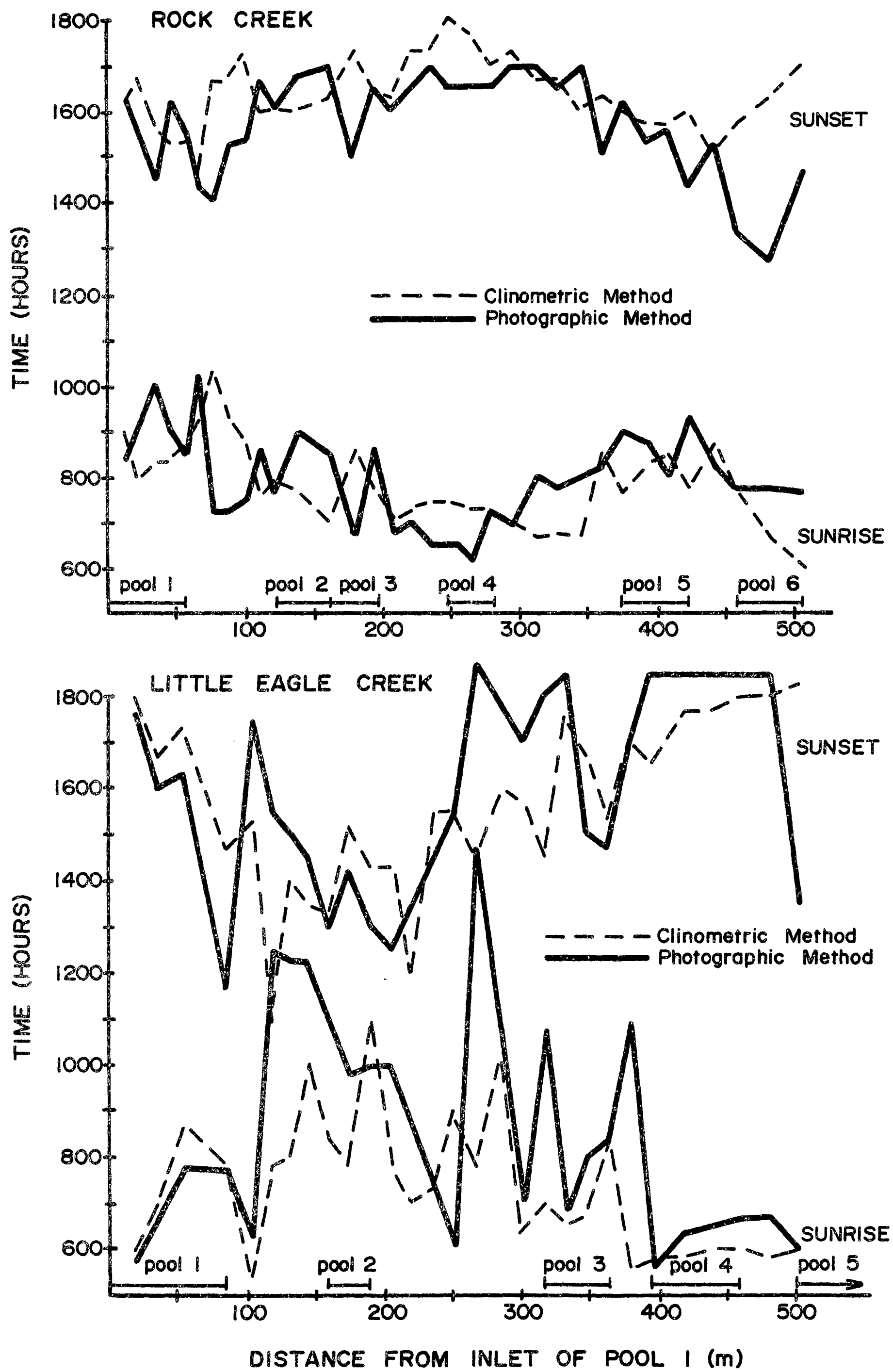


Figure 23. Times of sunrise and sunset for the pool systems at Rock Creek and Little Eagle Creek determined by photographic and clinometric methods

TABLE XXI

AVERAGE TIMES OF SUNRISE AND SUNSET FOR ROCK CREEK AND LITTLE EAGLE CREEK USING THE CLINOMETRIC AND PHOTOGRAPHIC METHODS OF MEASUREMENT

Date: September 22

Location	Time of Sunrise		Time of Sunset		Duration of Exposure	
	Photo.	Clino.	Photo.	Clino.	Photo.	Clino.
Rock Creek:						
Upstream of Open Pool	0805	0815	1550	1618	7.75	8.05
Open Pool	0635	0713	1630	1733	9.92	10.33
Downstream of Open Pool	0807	0728	1522	1610	7.25	8.70
Little Eagle Cr.						
Upstream of Open Pool	0913	0742	1534	1508	6.35	7.43
Open Pool	0615	0553	1830	1728	12.25	11.58
Downstream of Open Pool	0620	0553	1600	1808	9.67	12.25

of measurement except one (Table XVII). The significant interaction indicates the maximum temperature gradients with depth were different in the shaded and open pools. At Little Eagle Creek, unequal daily temperature gradients with depth could have been a result of shade removal, but were more likely a result of the springwater in the shaded pool influencing the maximum temperature gradient while the exposed pool did not have a significant springwater influence. Neither Rock Creek nor East Glover Creek consistently had a significant daily shade by depth interaction using the two factor ANOVA (Tables XVIII and XIX).

Although significant shade by depth interactions were not consistently shown for individual days of measurement using two factor ANOVA at two of the sites, a different pattern emerged when maximum temperatures for the entire summer were grouped. Noticeable differences in maximum temperatures existed at the water surface between the shaded and exposed pools for all three sites but the differences became smaller with depth (Figures 24-26). Three factor (shade, depth, and date) ANOVA results indicate that the shade by depth interaction was significant ($P > 0.0001$) for the summer at all sites, (Table XX) indicating the gradients of maximum temperatures with depth were different in the shaded and exposed pools.

It is unclear why Rock Creek and East Glover Creek failed to have a consistent daily maximum temperature gradient difference between shaded and unshaded pools (Tables XVIII and XIX) while a significant maximum temperature gradient difference was found using maximum temperature data pooled for the summer (Table XX). The inclusion of more data in the three factor (shade, depth, and date) ANOVA obviously provided more observations at the lower depths (Table XX) and increased the degrees of

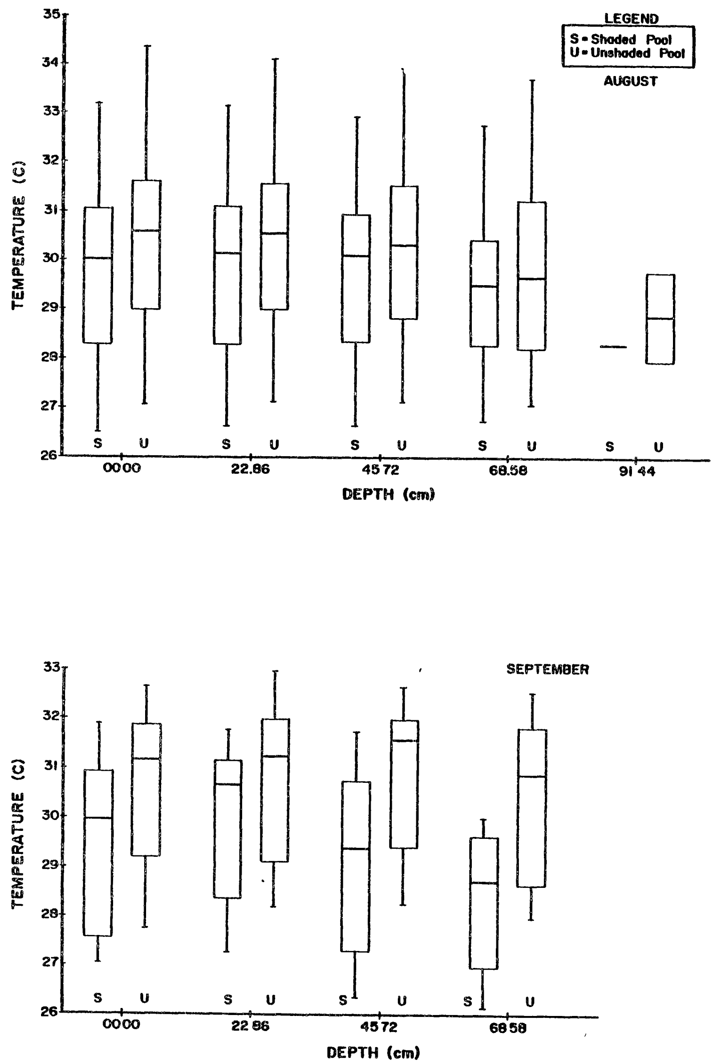


Figure 24. Relationship between maximum water temperature and pool depth for the shaded and exposed pools at Rock Creek

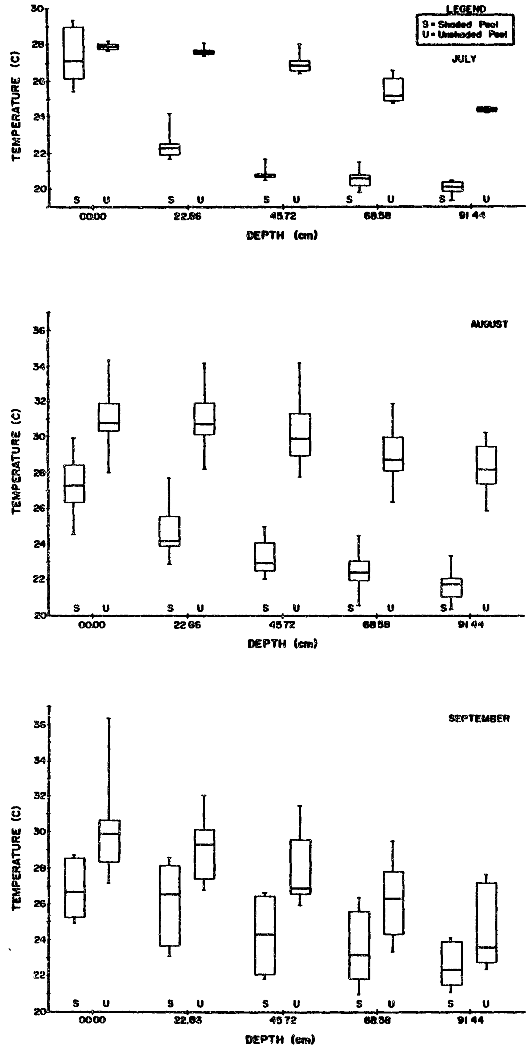


Figure 25. Relationship between maximum water temperature and pool depth for the shaded and exposed pools at Little Eagle Creek

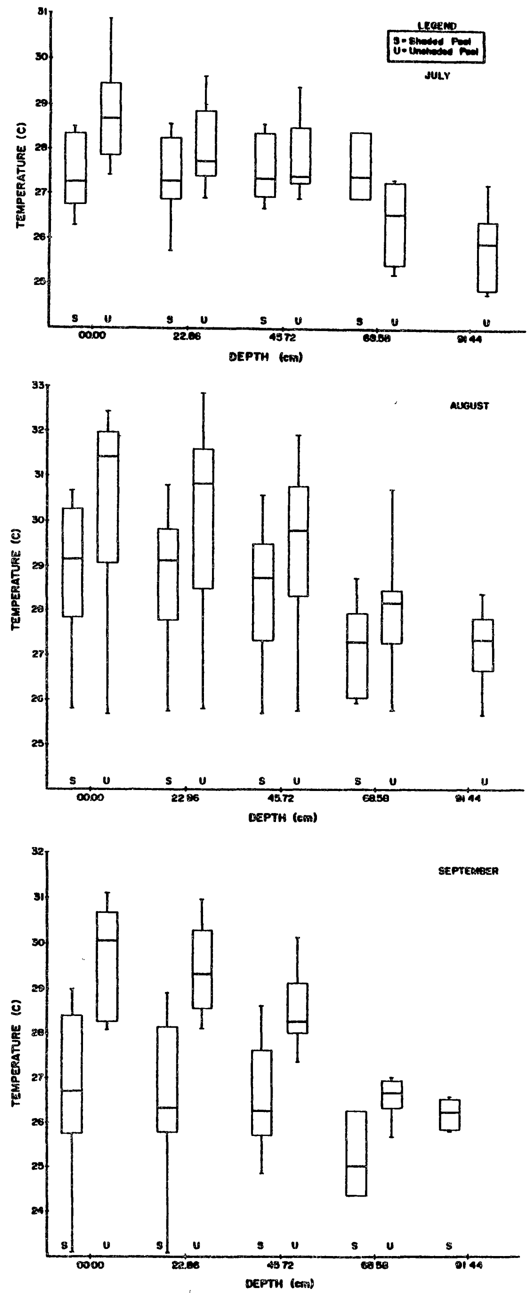


Figure 26. Relationship between maximum water temperature and pool depth for the shaded and exposed pools at East Glover Creek

freedom. However, the two factor (shade and depth) ANOVA did not show a significant daily maximum temperature gradient difference given ample degrees of freedom ($DF > 40$). A distinct difference between daily maximum temperature gradients and seasonal maximum temperature gradients in the shaded and exposed pools probably existed. The absence of consistent daily maximum temperature gradient differences between shaded and exposed pools may have been due to small treatment differences and several cloudy and rainy days during the summer. The difference in duration of exposure to solar radiation between shaded and exposed pools would have been offset by the lack of sunshine or the input of cool rainwater on these days. The significant differences between maximum temperature gradients in the shaded and exposed pools for the summer (Table XX) were probably due to the seasonal weather patterns which included days of complete sunshine.

One factor (shade) ANOVA results comparing shaded pool and exposed pool maximum temperatures for each depth of measurement showed that at Little Eagle Creek, maximum temperatures in the exposed pool were significantly greater ($P > 0.0001$) than maximum temperatures in the shaded pool at depths less than or equal to 23 cm (Table XXII). For water depths of 46 and 69 cm, exposed pool maximum temperatures were also significantly greater ($P > 0.0001$) than shaded pool maximum temperatures for all days of measurement except one using the one factor ANOVA. Even maximum temperatures at 91 cm were significantly greater at ($P > 0.05$) in the exposed pool than in the shaded pool for all days of measurement except two. Exposed pool maximum temperatures at the water surface or 23 cm depths were from 1.1 C to 7.7 C greater than shaded pool maximum temperatures at the same depths while exposed pool maximum temperatures

TABLE XXII

ONE FACTOR ANALYSIS OF VARIANCE RESULTS FOR SHADED POOL AND EXPOSED POOL MAXIMUM WATER TEMPERATURE RANKS BY DEPTH FOR LITTLE EAGLE CREEK

Date	Depth (cm)	Exposed Pool N	Exposed Pool Mean Temp (C)	Shaded Pool N	Shaded Pool Mean Temp (C)	P > F for the Shade Factor
7-30	0	17	27.8	10	25.9	.0001
	23	17	27.6	10	22.2	.0001
	46	17	26.8	9	20.9	.0001
	69	9	25.4	9	20.7	.0001
	91	4	24.3	3	19.9	.0117
8-6	0	17	30.6	10	28.7	.0001
	23	17	30.0	10	23.7	.0001
	46	17	28.6	9	22.2	.0001
	69	9	27.3	9	21.6	.0001
	91	4	26.2	3	20.9	.0117
8-13	0	17	30.7	10	26.6	.0001
	23	17	30.7	10	23.9	.0001
	46	17	29.4	9	22.5	.0001
	69	9	28.1	9	22.1	.0001
	91	4	27.3	3	21.4	.0117
8-16	0	17	30.3	10	26.6	.0001
	23	17	30.3	10	24.0	.0001
	46	17	29.7	9	22.9	.0001
	69	10	28.7	9	22.4	.0001
	91	5	28.2	3	22.1	.0316
8-20	0	17	28.3	10	24.8	.0001
	23	17	28.4	10	24.4	.0001
	46	17	28.4	9	23.1	.0001
	69	10	28.2	8	22.4	.0001
	91	4	28.0	3	21.3	.0101
8-23	0	17	33.4	10	29.1	.0001
	23	17	33.3	10	26.1	.0001
	46	17	32.5	9	24.1	.0001
	69	9	30.7	9	23.1	.0001
	91	5	29.6	3	21.9	.0075
8-27	0	17	31.9	10	27.1	.0001
	23	17	31.8	10	24.3	.0001
	46	16	30.7	9	22.6	.0001
	69	9	29.3	8	22.2	.0001
	91	4	28.4	3	21.4	.0117

TABLE XXII (continued)

Date	Depth (cm)	Exposed Pool N	Exposed Pool Mean Temp (C)	Shaded Pool N	Shaded Pool Mean Temp (C)	P > F for the Shade Factor
8-30	0	16	31.9	10	27.4	.0001
	23	16	31.8	10	25.8	.0001
	46	16	31.5	9	24.7	.0001
	69	8	30.4	8	23.7	.0001
	91	3	30.0	2	23.2	.0577
9-6	0	17	30.1	10	25.3	.0001
	23	17	30.3	10	23.6	.0001
	46	16	29.8	9	21.9	.0001
	69	10	28.3	8	21.4	.0001
	91	4	27.3	2	21.2	.0418
9-10	0	16	28.1	10	26.6	.0001
	23	16	27.2	10	26.6	.0001
	46	16	26.6	9	26.4	.0588
	69	11	25.2	9	25.6	.8259
	91	5	22.7	4	23.4	.2443
9-13	0	12	31.4	10	28.6	.0001
	23	12	29.3	10	28.2	.0001
	46	12	27.0	9	24.3	.0001
	69	7	24.5	8	23.1	.0001
	91	4	23.6	2	22.3	.0363

at 46 cm and 69 cm were from 0.4 C less than to 8.4 C greater than shaded pool temperatures at similar depths (Table XXII).

Rock Creek one factor (shade) ANOVA results comparing shaded and exposed pool maximum temperatures by depth indicated that maximum temperatures were significantly greater (P 0.0001) in the exposed pool than in the shaded pool for depths less than or equal to 23 cm for all days except one, but maximum temperatures at 69 cm were not consistently different in the shaded and exposed pools using the one factor ANOVA (Table XXIII). Exposed pool mean maximum temperatures at the water surface and 23 cm depths were from 0.1 C less than to 1.5 C greater than shaded pool mean maximum temperatures at the same depths. Exposed pool maximum temperatures at 46 cm were from 0.1 C less than to 2.1 C greater than shaded pool maximum temperatures at 23 cm.

East Glover Creek also had significantly greater maximum temperatures (P 0.001) in the exposed pool than in the shaded pool at depths less than or equal to 23 cm using one factor (shade) ANOVA, but maximum temperature differences at depths greater than 23 cm were not consistently significant (P 0.05) between the shaded and exposed pools (Table XXIV). Exposed pool mean maximum temperatures at the water surface were from 0.3 C to 3.5 C higher than shaded pool mean maximum surface temperatures while exposed pool mean maximum temperatures at 23 cm were from 0.2 C to 3.1 C higher than shaded pool mean maximum temperatures at 23 cm. The lack of statistically significant maximum temperature differences at or near the pool bottoms at Rock Creek and East Glover Creek may be due to a reduction in temperature differences between shaded and exposed pools at deeper pool depths (Figures 24 and 26). However, these non significant maximum temperature differences near the pool bottoms may

TABLE XXIII

ONE FACTOR ANALYSIS OF VARIANCE RESULTS FOR SHADED POOL AND EXPOSED POOL MAXIMUM WATER TEMPERATURE RANKS BY DEPTH FOR ROCK CREEK

Date	Depth (cm)	Exposed Pool N	Exposed Pool Mean Temp (C)	Shaded Pool N	Shaded Pool Mean Temp (C)	P > F for the Shade Factor
8-1	0	15	27.3	9	26.7	.0001
	23	15	27.3	9	26.8	.0001
	46	15	27.3	6	26.7	.0001
	69	5	27.2	3	26.8	.0068
8-4	0	15	29.3	9	28.3	.0001
	23	15	29.1	9	28.3	.0001
	46	15	29.1	7	28.3	.0001
	69	5	28.9	3	28.2	.0075
8-8	0	15	31.2	9	30.1	.0001
	23	15	31.2	9	30.3	.0001
	46	15	31.1	7	30.2	.0003
	69	4	31.1	3	30.2	.0117
8-11	0	15	28.2	9	28.2	.0002
	23	15	28.2	9	28.3	.0761
	46	15	28.2	7	28.3	.0937
	69	10	28.1	4	28.3	.0068
8-15	0	15	30.4	9	29.4	.0001
	23	15	30.2	9	29.5	.0001
	46	15	30.1	7	29.5	.0001
	69	6	29.9	3	29.5	.1230
8-18	0	15	33.5	9	32.8	.0001
	23	15	33.4	9	32.8	.0001
	46	15	33.3	7	32.8	.0003
	69	5	32.9	3	32.3	.3336
8-22	0	15	31.5	9	31.0	.0001
	23	15	31.4	9	31.1	.0001
	46	15	31.3	7	31.0	.0051
	69	4	31.2	3	30.6	.1747
8-25	0	15	30.6	9	30.2	.0003
	23	15	30.6	9	30.3	.0001
	46	14	30.5	7	30.2	.0431
	69	4	29.9	3	29.0	.1747

TABLE XXIII (continued)

Date	Depth (cm)	Exposed Pool N	Exposed Pool Mean Temp (C)	Shaded Pool N	Shaded Pool Mean Temp (C)	P > F for the Shade Factor
8-29	0	15	33.6	8	32.8	.0001
	23	15	33.7	8	32.9	.0001
	46	14	33.3	4	31.9	.0062
	69	3	32.0	2	31.1	.6376
9-1	0	15	32.1	8	31.6	.0001
	23	15	32.2	7	31.6	.0001
	46	9	32.1	4	31.0	.0059
	69	2	31.9	2	29.8	.1056
9-5	0	15	30.5	9	29.1	.0001
	23	15	30.7	7	29.2	.0001
	46	7	30.2	4	28.1	.0049
	69	1	28.8	2	27.4	.3333
9-8	0	15	28.2	9	27.3	.0001
	23	15	28.4	7	27.4	.0001
	46	6	28.3	4	26.8	.0015
	69	1	27.9	1	26.1	-----
9-12	0	15	31.5	9	30.7	.0001
	23	15	31.6	9	30.8	.0001
	46	11	31.4	4	30.2	.0117
	69	2	30.8	2	28.8	.1056

TABLE XXIV

ONE FACTOR ANALYSIS OF VARIANCE RESULTS FOR SHADED POOL AND EXPOSED POOL MAXIMUM WATER TEMPERATURE RANKS BY DEPTH FOR EAST GLOVER CREEK

Depth	Depth (cm)	Exposed Pool		Shaded Pool		P > F for the Shade Factor
		N	Mean Temp (C)	N	Mean Temp (C)	
7-24	0	10	29.6	10	28.3	.0001
	23	9	29.1	10	28.3	.0001
	26	7	28.8	6	28.4	.0687
	69	2	26.6	1	28.4	.3333
7-27	0	10	27.7	10	27.3	.0001
	23	10	27.5	10	27.2	.0159
	46	7	27.3	7	27.3	.4546
	69	2	27.3	1	27.4	.3333
7-31	0	10	28.9	10	26.7	.0001
	23	8	27.6	10	26.6	.0001
	46	6	27.3	5	26.8	.0304
	69	2	25.4	1	26.9	.3333
8-3	0	10	26.2	10	25.9	.0660
	23	10	26.1	10	25.9	.3148
	46	7	25.9	8	26.0	.2036
	69	4	25.9	3	26.0	.3270
8-7	0	10	29.2	10	27.9	.0001
	23	10	28.7	10	27.9	.0001
	46	8	28.5	7	27.9	.0001
	69	3	28.3	1	27.9	.2254
8-10	0	10	28.4	10	27.3	.0001
	23	10	27.8	10	27.2	.0005
	46	8	27.6	6	27.3	.0144
	69	3	27.3	1	27.3	.6667
8-14	0	10	30.1	10	28.8	.0001
	23	10	29.9	10	28.8	.0001
	46	9	29.6	7	29.1	.0005
	69	2	27.6	1	28.7	.3333
8-17	0	10	31.7	10	30.3	.0001
	23	10	31.4	10	30.2	.0001
	46	9	30.9	7	30.1	.0090
	69	2	28.3	1	27.8	.3333
8-21	0	10	32.2	10	30.3	.0001
	23	10	31.8	10	30.2	.0001
	46	8	31.1	5	29.9	.0149
	69	2	28.8	1	27.9	.3333

TABLE XXIV (continued)

Date	Depth (cm)	Exposed Pool N	Exposed Pool Mean Temp (C)	Shaded Pool N	Shaded Pool Mean Temp (C)	P > F for the Shade Factor
8-24	0	10	31.7	10	29.2	.0001
	23	10	31.2	10	29.1	.0001
	46	8	30.4	6	28.9	.0008
	69	2	28.3	1	27.0	.3333
8-28	0	10	32.2	10	30.3	.0001
	23	9	31.8	9	30.1	.0001
	46	5	31.1	4	29.3	.0386
	69	2	28.4	1	27.3	.3333
8-31	0	10	32.3	10	29.3	.0001
	23	9	31.7	10	29.2	.0001
	46	5	30.6	5	28.8	.0010
	69	3	29.1	1	26.9	.2254
9-4	0	9	29.9	10	26.4	.0001
	23	9	29.5	9	26.4	.0001
	46	5	28.4	4	26.1	.0025
	69	2	26.1	1	25.0	.3333
9-7	0	10	28.2	10	25.3	.0001
	23	9	28.5	10	25.4	.0001
	46	5	28.2	4	25.6	.0021
	69	2	26.7	1	24.3	.3333
9-11	0	9	30.8	10	28.5	.0001
	23	9	30.3	9	28.4	.0001
	46	5	28.8	4	27.8	.3611
	69	2	27.0	1	26.2	.3333

also be due to the small number of observations (Tables XXIII and XXIV).

Temporal Maximum Temperature Differences
Between Shaded and Exposed Pools

The magnitude and time of occurrance of peak water temperatures in the shaded and exposed pools were monitored with thermographs at the three sites. On two typical sunny days, peak surface water temperatures were seen to occur from one to two hours after the time of peak solar radiation at the different sites (Figure 27). However, maximum pool bottom temperature were not recorded until four to 12 hours after the time of peak solar radiation at the three sites.

Maximum water surface temperatures occurred at relatively the same time of day at the three sites for two typical sunny days but the time of occurrance of maximum pool bottom temperatures differed by up to eight hours (Figure 27). Differences in the time of temperature peaks at pool bottoms was probably due to the slow transfer of heat by conductive energy exchange between water molecules. Heat conduction between point contacts of water molecules is a slow process complicated by water movements and dynamic radiation flux densities. At the water surface, all three sites experienced relatively the same radiation fluxes and all three sites responded similarly. At the pool bottoms, water currents, groundwater contributions, and varied longwave radiation fluxes from the terrestrial environment created a situation where water temperature magnitude and time of occurrance were site specific. At Rock Creek, weekly shaded pool minimum temperatures occurred around 0830 hours in late June but occurred as late as 1230 hours by mid September while exposed pool weekly minimum temperatures also appeared

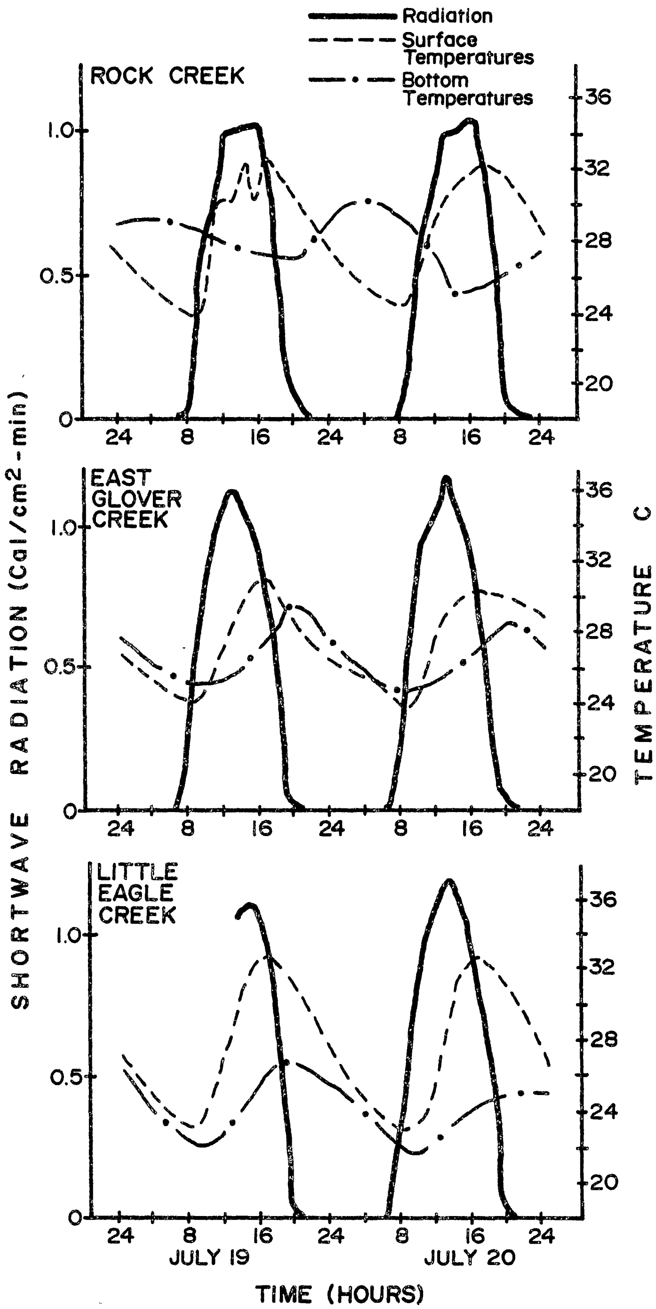


Figure 27. Relationship between pool water temperatures and solar radiation inputs at the three study sites for two selected dates

to occur from one to three hours later in September than in June. (Table XXV). This later occurrance of weekly minimum temperatures may have been due to the shorter day lengths or it may have been due to the increased amount of shade that both the shaded and exposed pools experienced later in the summer (Table XXVIII).

Weekly Rock Creek exposed pool maximum temperatures generally occurred between 1700 hours and 1900 hours at the water surface and weekly exposed pool bottom temperatures generally occurred between 1600 hours and 1000 hours (Table XXV). Shaded pool weekly maximum temperatures generally occurred around two hours earlier than exposed pool weekly maximum temperatures, especially at the water surface. Weekly maximum temperatures at the water surface occurred from one to four hours after the time of peak radiation and generally from three to six hours after the time of maximum air temperature in the shaded and exposed pools but several weeks existed where this was not true. Pool bottom maximum temperatures occurring in the early morning hours, such as the case with Rock Creek on July 20 (Figure 27), were the reason that some weeks had average times of pool bottom maximum temperatures occurring earlier in the day than surface temperatures. Weeks in which the peak pool bottom temperatures occurred earlier in the day than pool surface temperatures had temperatures which occurred in the early moring hours (Figure 27) averaged into the weekly figure.

At Little Eagle Creek, the weekly minimum temperatures at the surface of the shaded pool generally occurred around 0800 hours in late June but began occurring up to four hours later by mid September (Table XXVI). Weekly minimum shaded pool bottom temperatures also generally occurred later as the season progressed probably because the shaded pool

TABLE XXV

WEEKLY AVERAGE TIMES OF MAXIMUM AND MINIMUM AIR TEMPERATURES, MAXIMUM AND MINIMUM POOL SURFACE AND BOTTOM TEMPERATURES, AND PEAK SOLAR RADIATION VALUES AT ROCK CREEK

	Shaded Pool				Exposed Pool						
Week	Surface		Bottom		Surface		Bottom		Air		Rad
Beginning	Max Temp	Min Temp	Max Temp	Min Temp	Max Temp	Min Temp	Max Temp	Min Temp	Max Temp	Min Temp	
6-28	1526	0821	1641	0838	1934	1130	1821	1053	----	----	----
7-5	1655	0845	1650	0812	1727	1004	1604	0912	----	----	----
7-12	1430	0855	1722	1005	1510	0938	1520	0937	----	----	1410
7-19	1522	0802	1934	0741	1715	0845	1505	0850	----	----	1402
7-26	1620	0915	1702	0807	1820	1024	1605	0954	----	----	1315
8-2	1702	0908	1812	1137	1735	1114	2038	1114	1226	1026	1337
8-9	1519	1035	1657	1219	1749	1241	1912	1255	----	----	1430
8-16	1745	0921	1719	1002	1802	1214	2145	1305	1312	0607	1430
8-23	1738	0951	2055	1037	1827	1031	2012	1110	1230	0645	1419
8-30	1508	1135	2200	1041	1834	1232	1922	1002	1700	----	1420
9-6	1717	1110	1616	1102	1937	1208	1709	1212	1300	0745	1514
9-13	1512	1237	1257	1233	1706	1145	1739	1238	1145	----	1435
9-20	1620	0926	1212	1015	1730	1010	1905	1020	----	----	1315

TABLE XXVI

WEEKLY AVERAGE TIMES OF MAXIMUM AND MINIMUM AIR TEMPERATURES, MAXIMUM AND MINIMUM POOL SURFACE AND BOTTOM TEMPERATURES, AND PEAK SOLAR RADIATION VALUES AT LITTLE EAGLE CREEK

Week	Shaded Pool				Exposed Pool				Rad
	Surface		Bottom		Surface		Bottom		
Beginning	Max Temp	Min Temp	Max Temp	Min Temp	Max Temp	Min Temp	Max Temp	Min Temp	
6-28	1631	0809	1630	----	----	----	----	----	----
7-5	1533	0926	1318	1226	1645	----	----	----	----
7-12	1430	0808	1200	1210	1730	1047	1615	1221	1215
7-19	1618	0805	1450	0754	1608	0800	1346	0926	1334
7-26	1630	1044	1328	1053	1610	0809	0714	0919	1330
8-2	1528	0817	1417	0804	1545	0802	1622	0942	1305
8-9	1532	0804	1522	0743	1605	0940	1457	1120	1315
8-16	1525	0817	1554	0808	1538	0735	1023	0844	1357
8-23	1512	0833	0838	1021	1630	0828	1734	0920	1329
8-30	1526	0917	1104	1120	1616	0845	1119	0942	1241
9-6	1616	0858	1105	1225	1633	0910	1337	0922	1306
9-13	1743	1202	0933	1022	1610	0815	1019	1158	1325
9-20	1815	1007	0512	1312	1515	0800	0107	1012	1300

did not receive as much radiation toward the end of the season (Table XXVIII). The exposed pool weekly minimum temperatures generally occurred around 0800 hours at the water surfaces and 0930 hours at the pool bottom and did not appreciably change as the season progressed. This relative consistency was probably due to the constant lack of shade throughout the summer (Table XXVIII).

In the shaded pool at Little Eagle Creek, maximum weekly water temperatures at the pool surface occurred around 1530 hours or about two hours after the time of peak solar radiation (Table XXVI). Pool bottom maximum weekly temperatures in the shaded pool occurred around 1300 hours at the first of July but occurred as much as four hours earlier as the season progressed and were probably controlled by seasonal groundwater input differences.

Weekly exposed pool maximum temperatures were essentially unchanged in their time of occurrance of around 1600 hours on the water surface while the maximum temperatures shifted from appearing at around 1600 hours in mid July to 1000 hours or earlier by mid September (Table XXVI). This earlier occurrance of exposed pool bottom maximum temperatures as the season progressed was also observed in the shaded pool and also may have been related to the groundwater flux influence from the shaded pool.

At East Glover Creek, the time of occurrance of weekly minimum temperatures did not change noticeably during the study at the shaded and exposed pool surfaces and bottoms (Table XXVII) even though the shaded pool received more shade and the exposed pool received less shade as the summer progressed (Table XXVIII). Shaded and exposed pool weekly minimum temperatures generally occurred between 0800 hours and 1000

TABLE XXVII

WEEKLY AVERAGE TIMES OF MAXIMUM AND MINIMUM AIR TEMPERATURES, MAXIMUM AND MINIMUM POOL SURFACE AND BOTTOM TEMPERATURES, AND PEAK SOLAR RADIATION VALUES AT EAST GLOVER CREEK

	Shaded Pool				Exposed Pool						
Week	Surface		Bottom		Surface		Bottom		Air		Rad
Beginning	Max Temp	Min Temp	Max Temp	Min Temp	Max Temp	Min Temp	Max Temp	Min Temp	Max Temp	Min Temp	
6-28	1836	0930	1811	0926	1722	0815	1807	0838	1548	0532	----
7-5	1742	0935	1615	0816	1707	0841	1535	0912	1604	0638	1315
7-12	1523	1058	1750	0930	1431	1012	1533	1037	1710	0901	1413
7-19	1627	0814	1409	0722	1508	0742	2037	0840	1550	0710	1330
7-26	1639	0844	1841	0902	1518	0822	1917	0845	1532	0700	1336
8-2	1609	0907	1732	0950	1533	0816	1825	0831	1538	0823	1350
8-9	1106	0912	1505	0944	1358	1010	1711	1015	1432	0632	1412
8-16	1415	0633	1934	0809	1626	0800	1931	0817	1555	0501	1418
8-23	1430	0723	1841	0822	1641	0912	1835	0833	1645	0947	1315
8-30	1428	0817	1608	0932	1650	0921	1837	0937	1810	0838	1323
9-6	1525	0754	1900	0928	1620	0917	1622	0913	1900	0901	1313
9-13	1290	1322	1622	1139	1347	1112	1639	1118	1904	1086	1348
9-20	1427	0905	2100	0927	1400	0815	1945	0912	1720	1030	----

TABLE XXVIII

PERCENT SHADE RECORDED ON THE GRID TRANSECTS IN THE SHADED AND EXPOSED POOLS AT THE THREE STUDY SITES AT THE BEGINNING AND END OF THE STUDY PERIOD

	Shaded Pool			Exposed Pool		
Site	0800 Hours	1200 Hours	1700 Hours	0800 Hours	1200 Hours	1700 Hours
Date: July 18						
East Glover Cr.	34	36	76	64	0	26
Rock Cr.	66	8	80	40	0	0
Little Eagle Cr.	58	29	89	6	0	13
Date: September 20						
East Glover Cr.	31	60	89	43	3	18
Rock Cr.	100	9	96	100	0	5
Little Eagle Cr.	92	52	93	18	0	19

hours. Weekly maximum temperatures in the shaded and exposed pools occurred between 1700 hours and 1800 hours at the water surface at the beginning of the study but occurred up to four hours earlier in the day as the season progressed, probably owing to the shorter day lengths and lower flow volume (lower velocity). Lower flow velocities would decrease the convectional and turbulent transport of heat energy from the water surface to the pool bottoms. Weekly maximum bottom temperatures in the shaded and exposed pools were essentially unchanged from their time of occurrance between 1600 hours and 1900 hours throughout the season.

Temperature Ranges in Exposed and Shaded Pools

The summer temperature ranges (the difference between maximum and minimum temperatures) at the water surface were generally greater in the exposed pools than in the shaded pools at East Glover Creek and Little Eagle Creek. Surface temperature ranges in the exposed pool at East Glover Creek averaged 13.7 C over the summer while shaded pool temperature ranges averaged 12.4 C (Table XXIX). Little Eagle creek exposed pool surface temperature ranges averaged 16.5 C while shaded pool temperature ranges averaged 15.0 C. Rock Creek had a larger water surface average temperature range of 15.2 C in the shaded pool than the average range of 12.8 C in the exposed pool. Average summer pool bottom temperature ranges were from 0.0 C to 1.3 C greater in the shaded pools than in the exposed pools at the three sites with the largest shaded pool bottom average temperature range of 12.4 C occurring at Little Eagle Creek.

The recording thermographs placed in the shaded and exposed pools at each site showed that average weekly temperature ranges were generally

TABLE XXIX

TEMPERATURE RANGES RECORDED WITH MAXIMUM-MINIMUM THERMOMETERS IN THE POOL SYSTEMS AT THE THREE STUDY SITES

		Upstream of Exposed Pool Temperature (C)			Exposed Pool Temperature (C)			Downstream of Exposed Pool Temperature (C)		
		Jul.	Aug.	Sept.	Jul.	Aug.	Sept.	Jul.	Aug.	Sept.
East Glover Creek										
Surface	Max	32.8	32.8	31.7	32.8	33.9	31.7	32.8	34.4	32.2
	Min	21.7	21.7	15.0	18.9	20.6	17.8	22.8	22.2	18.3
	Range	11.1	11.1	15.0	13.9	13.3	13.9	10.0	12.2	13.9
Bottom	Max	30.5	28.9	28.8	31.3	29.4	28.3	32.2	32.8	31.1
	Min	22.2	22.2	18.3	23.9	22.2	18.9	22.0	22.2	17.8
	Range	8.3	6.7	10.5	7.4	7.2	9.4	10.2	10.6	13.3
Rock Creek										
Surface	Max	35.0	34.4	32.2	35.6	33.9	32.2	34.4	34.4	32.8
	Min	17.8	22.2	16.1	22.2	22.8	18.3	21.7	22.2	17.8
	Range	17.2	12.2	16.1	13.4	11.1	13.9	12.7	12.2	15.0
Bottom	Max	33.9	32.2	32.2	34.4	32.2	31.1	33.3	32.2	30.6
	Min	22.8	23.3	18.3	23.3	22.8	17.8	22.2	22.2	17.8
	Range	11.1	8.9	13.9	11.1	9.4	13.3	11.1	10.0	12.8
Little Eagle Creek										
Surface	Max	33.9	32.8	30.6	33.9	35.6	33.9	32.8	32.2	31.7
	Min	18.3	16.7	17.2	19.4	17.8	16.7	23.3	22.8	18.3
	Range	15.6	16.1	13.4	14.5	17.8	17.2	9.5	9.4	13.4
Bottom	Max	32.2	31.1	29.4	31.1	31.1	30.0	30.0	28.3	27.2
	Min	19.4	18.9	29.4	31.1	31.1	30.0	30.0	28.3	27.2
	Range	12.8	12.2	12.2	10.0	11.1	12.2	5.6	6.1	10.0

1.0 C to 5.0 C greater at the water surface than at pool bottoms (Figures 28-33). Additionally, weekly water temperature ranges were almost invariably 0.5 C to 2.5 C greater in the exposed pools than in the shaded pools at all three sites. Weeks where the temperature ranges were greater in the shaded pools generally coincided with weeks where the solar radiation input was lower due to cloud cover (Table XXX). Lee and Samuel (1976), Rishel et al. (1982), and Meehan et al. (1969) all noted that shade removal increased water temperature ranges. The increased exposure to solar radiation during the day and the loss of the insulating cover of vegetation at night was the probable cause of the increased temperature ranges in the exposed pools.

Natural Water Temperature Variation and Exposed Pool Temperatures

All three study sites had significantly higher maximum temperatures in the exposed pool at water depths less than 46 cm when compared to shaded pool maximum temperatures. Exposed pool surface temperatures were as much as 4.8 C higher than the shaded pool surface temperatures (Figure 25) which indicates that vegetation removal can result in significantly higher maximum temperatures in this depth interval. Given the short lengths of exposures created on the streams (35 m, 35 m, and 78 m for Rock Creek, East Glover Creek, and Little Eagle Creek, respectively), the potential for substantial temperature increases in large exposures is evident.

Maximum temperature increases at the water surface in exposed pools at East Glover Creek and Little Eagle Creek averaged from 0.6 C to 0.7 C greater than the natural maximum temperature variation established with

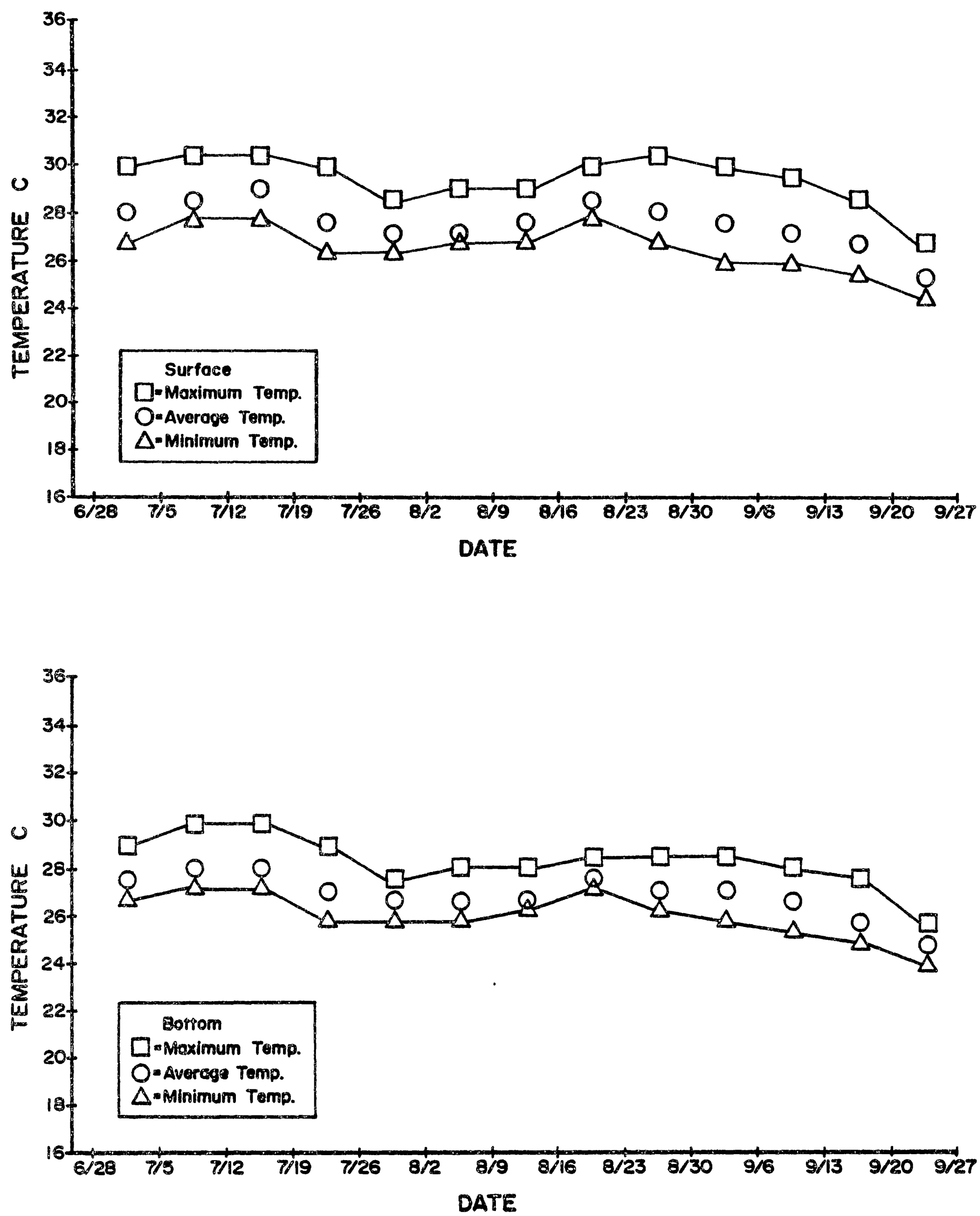


Figure 28. Maximum, minimum, and average temperatures in the shaded pool at Rock Creek for the study period

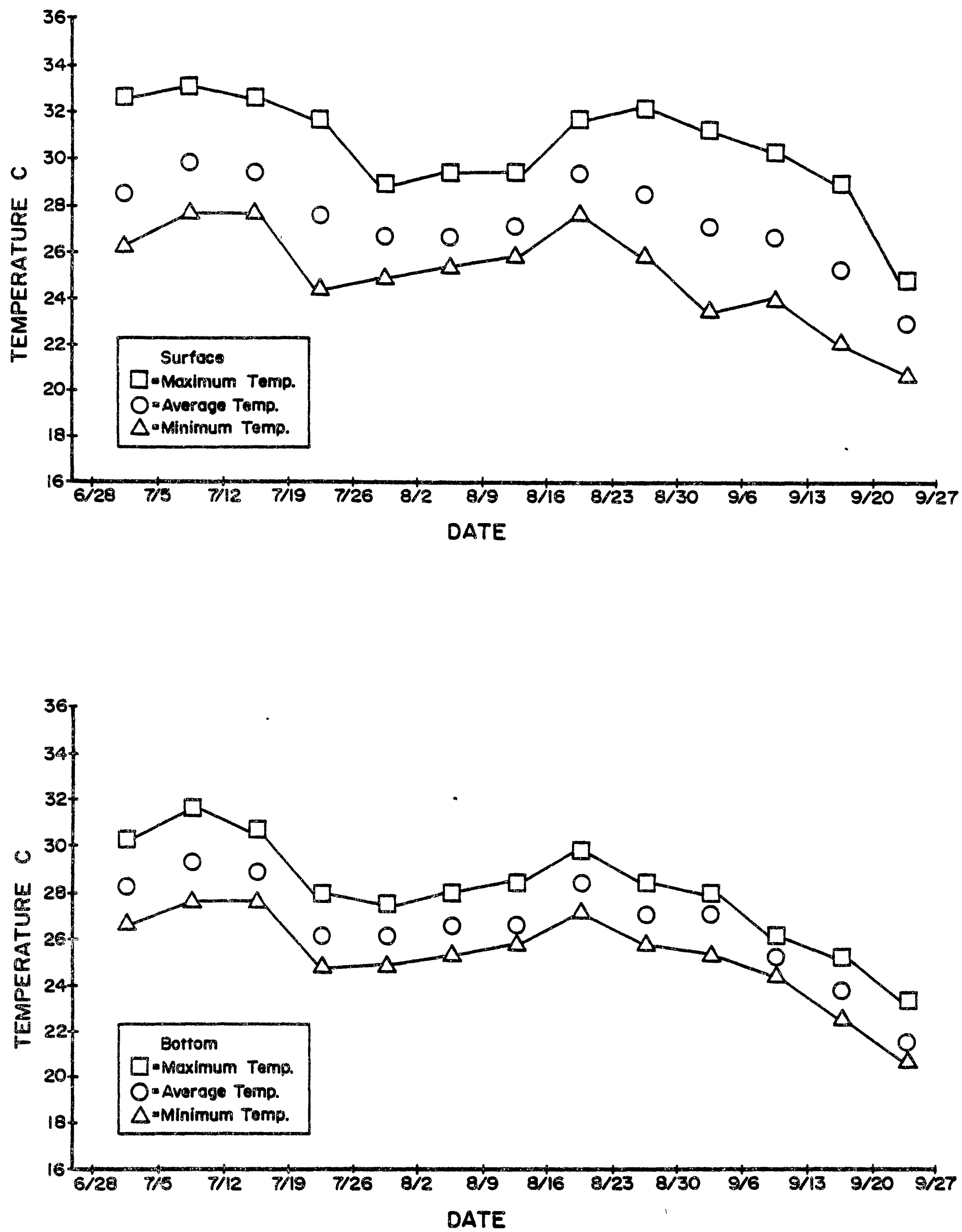


Figure 29. Maximum, minimum, and average temperatures in the exposed pool at Rock Creek for the study period

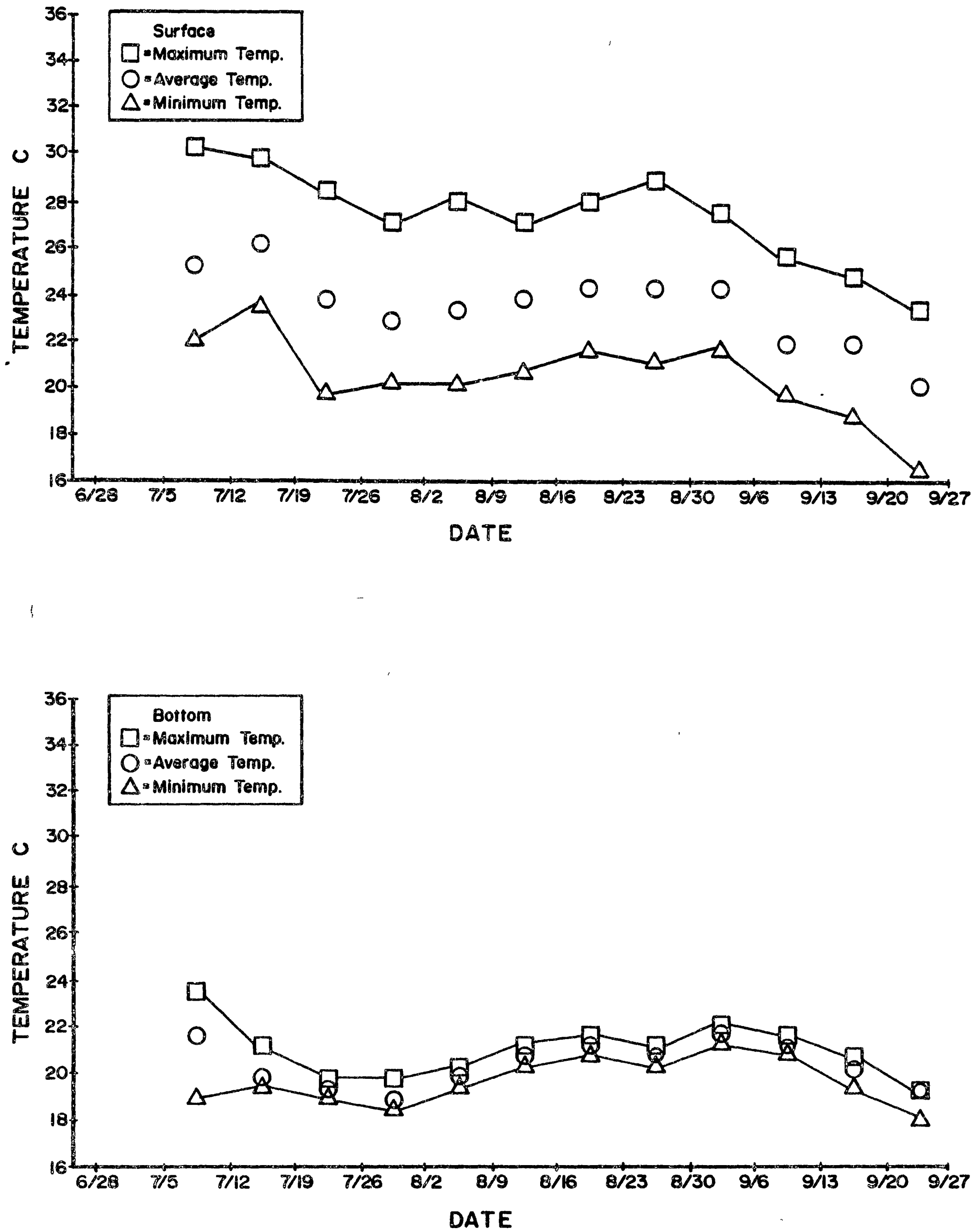


Figure 30. Maximum, minimum, and average temperatures in the shaded pool at Little Eagle Creek for the study period

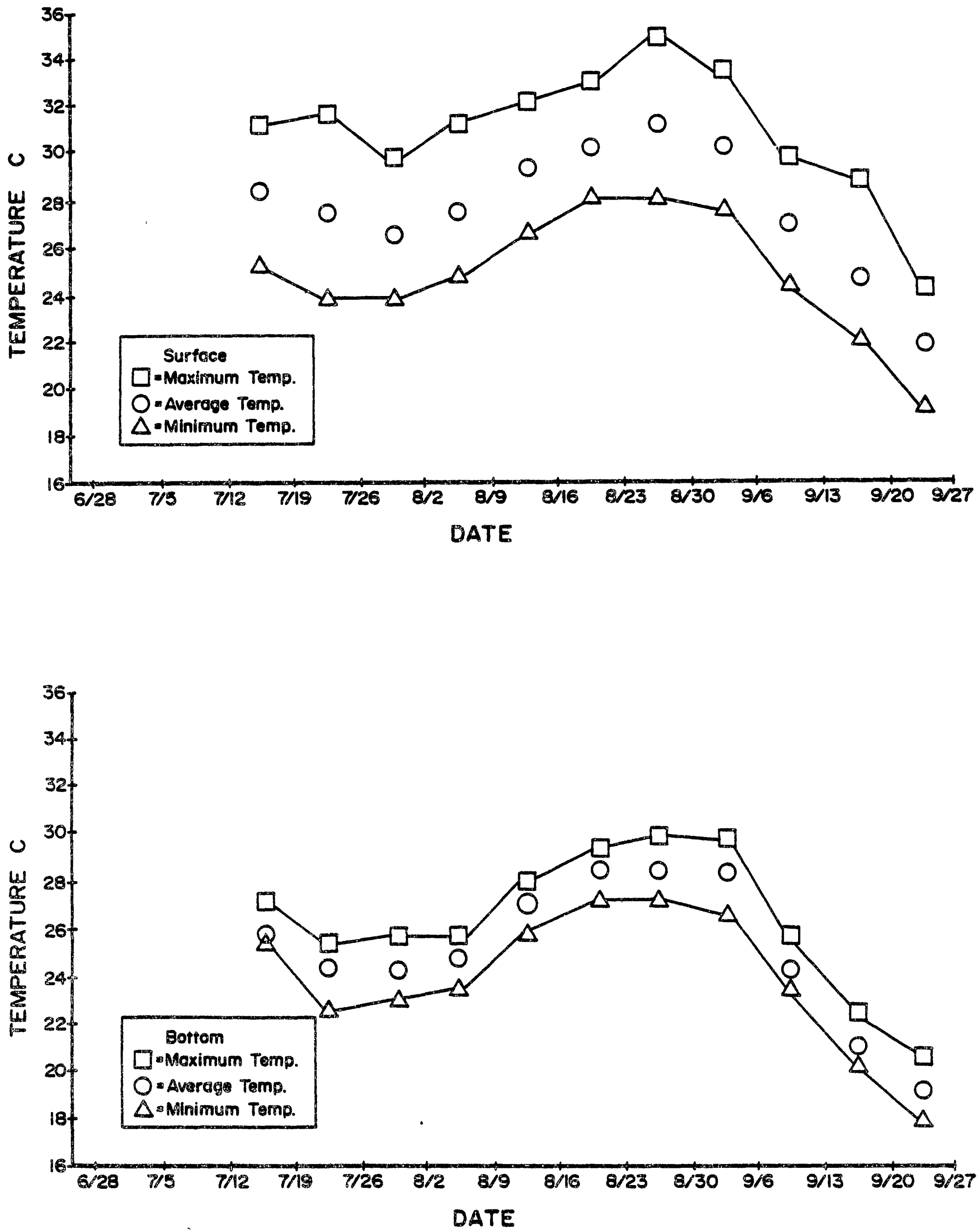
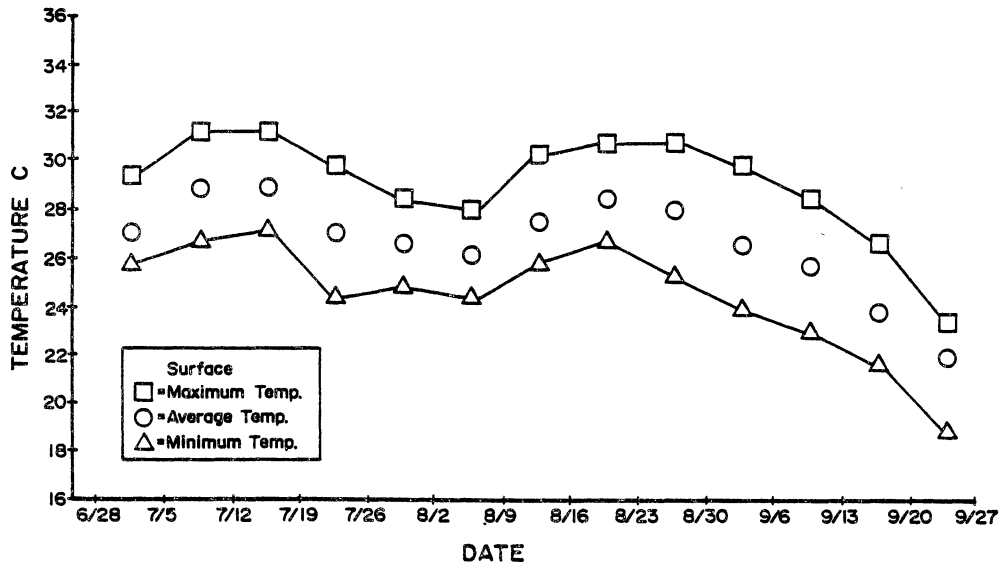


Figure 31. Maximum, minimum, and average temperatures in the exposed pool at Little Eagle Creek for the study period



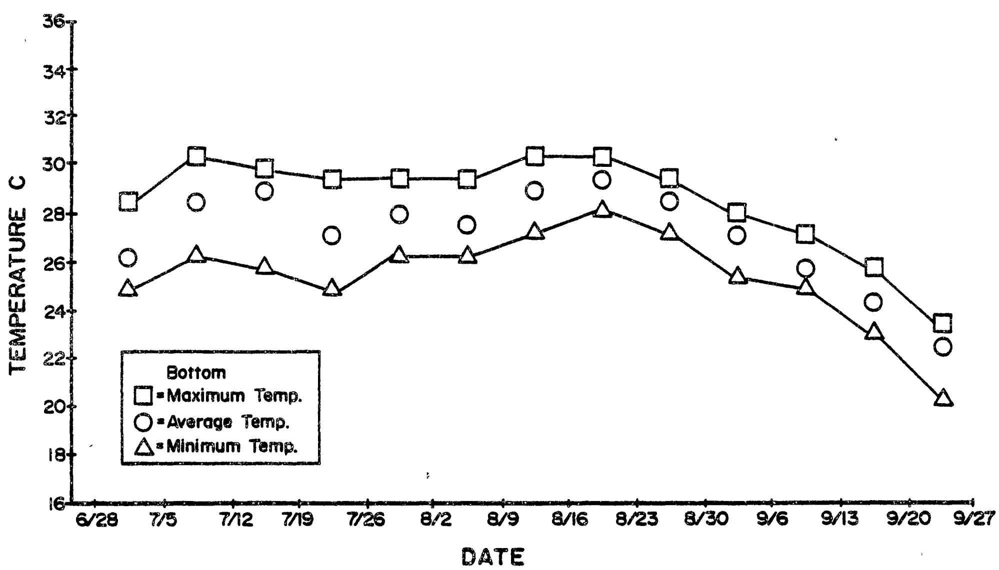


Figure 32. Maximum, minimum, and average temperatures in the shaded pool at East Glover Creek for the study period

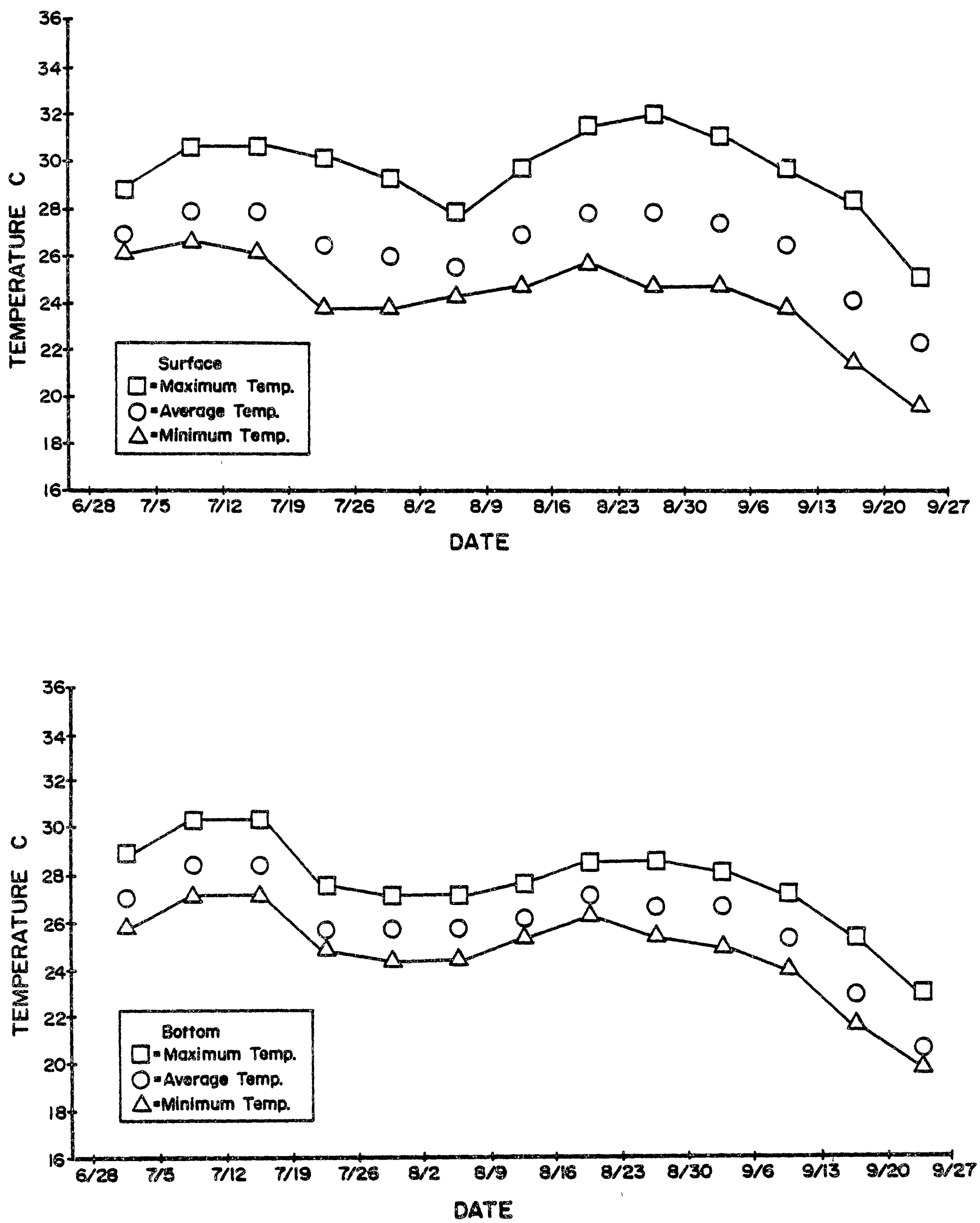


Figure 33. Maximum, minimum, and average temperatures in the exposed pool at East Glover Creek for the study period

TABLE XXX

AVERAGE WEEKLY PEAK RADIATION, DAILY RADIATION, AND MAXIMUM AND MINIMUM AIR TEMPERATURE VALUES AT THE THREE STUDY SITES

	East Glover Creek				Rock Creek				Little Eagle Creek	
Week Beginning	Peak Rad (cal/cm^2 min)	Daily Rad (cal/cm^2)	Max Temp (C)	Min Temp (C)	Peak Rad (cal/cm^2 min)	Daily Rad (cal/cm^2)	Max Temp (C)	Min Temp (C)	Peak Rad (cal/cm^2 min)	Daily Rad (cal/cm^2)
6-28	----	---	37.2	20.6	----	---	----	----	----	---
7-5	1.10	949	35.6	20.5	----	---	----	----	----	---
7-12	1.09	889	36.8	15.9	0.93	808	----	----	0.89	653
7-19	1.13	897	34.6	17.1	1.04	832	31.7	17.8	1.07	820
7-26	1.13	565	34.2	18.2	1.09	826	35.4	18.2	0.87	750
8-2	1.08	821	34.2	18.2	1.11	783	34.1	17.1	1.08	743
8-9	0.99	779	35.6	19.1	0.98	712	34.4	18.6	0.98	753
8-16	1.06	743	38.9	21.1	0.97	721	37.3	20.2	1.03	624
8-23	1.06	842	38.7	18.2	1.00	852	37.1	17.1	1.04	887
8-30	1.06	816	38.0	16.9	1.03	829	36.9	14.4	1.06	806
9-6	0.98	683	34.9	17.6	1.00	684	35.4	14.3	0.97	597
9-13	0.98	632	33.6	13.0	0.98	735	33.5	12.2	0.95	541
9-20	----	---	30.3	10.8	0.83	548	29.4	14.7	0.96	---

maximum-minimum thermometers (Table XXXI). At Little Eagle Creek, pool bottom maximum temperature increases in the exposed pool averaged 0.5 C greater than the natural maximum temperature variation. Observed maximum temperature increases at Rock Creek between the shaded and exposed pools did not exceed the natural maximum temperature variations (Table XXXI). It appears that vegetation removal at Rock Creek did not significantly alter maximum water temperatures. Even though pretreatment shaded pool maximum temperatures and maximum bottom temperatures were normally 1.2 C higher (Table XVI), natural maximum temperature variation still accounted for the maximum temperatures observed in the exposed pool at Rock Creek (Table XXXI).

At East Glover Creek, pretreatment maximum temperatures in the shaded pool averaged 2.8 C higher at the water surface and 0.3 C higher at the pool bottom than those in the exposed pool (Table XVI). After treatment, maximum temperatures in the shaded pool averaged 1.8 C lower at the water surface and 0.4 C lower at the pool bottom than those of the exposed pool (Table XXXI). These data represented a 4.6 average maximum temperature increase at the water surface and a 0.7 C average maximum temperature increase at the pool bottom in the exposed pool. The 4.6 C average maximum temperature increase at the water surface exceeded the natural maximum temperature variability established with the maximum-minimum thermometers by 3.5 C (Table XXXI).

It was expected that exposed pool maximum temperatures at Little Eagle Creek would be greater than shaded pool maximum temperatures because pretreatment exposed pool average maximum temperatures were 1.6 C higher at the water surface and 5.0 C higher at the pool bottom (Table XVI). These large maximum temperature differences were

TABLE XXXI

COMPARISON OF AVERAGE TEMPERATURE INCREASES BETWEEN SHADED AND EXPOSED POOLS WITH NATURAL TEMPERATURE VARIATION AT THE THREE STUDY SITES

Site	Date	Mean Temperature Increase*		Natural Temperature Variation	
		Pool Surface (C)	Pool Bottom (C)	Pool Surface (C)	Pool Bottom (C)
East Glover Creek	7-24	+1.3	-1.8	0.6	1.3
	7-27	+0.4	-0.1	0.3	1.8
	7-31	+2.2	-1.5	1.4	2.4
	8-3	+0.3	-0.1	0.9	2.1
	8-7	+1.3	+0.4	1.1	2.1
	8-10	+1.1	0.0	0.6	3.5
	8-14	+1.3	-1.1	0.5	1.8
	8-17	+1.4	+0.5	1.4	2.9
	8-21	+1.9	+0.9	0.9	1.8
	8-24	+2.5	+1.3	0.4	1.9
	8-28	+1.9	+1.1	1.0	3.5
	8-31	+3.0	+2.2	1.4	2.6
	9-4	+3.5	+1.1	2.0	0.8
	9-7	+2.9	+2.4	0.5	0.7
	9-11	+2.3	+0.8	3.1	2.6
	Averages	+1.8	+0.4	1.1	2.1
Rock Creek	8-1	+0.6	+0.4	1.4	1.9
	8-4	+1.0	+0.7	1.9	2.5
	8-8	+1.1	+0.9	1.9	1.4
	8-11	0.0	-0.2	1.4	1.9
	8-15	+1.0	+0.4	0.8	1.9
	8-18	+0.7	+0.6	1.9	2.5
	8-22	+0.5	+0.6	1.4	2.5
	8-25	+0.4	+0.9	0.8	4.2
	8-29	+0.8	+0.9	3.1	2.8
	9-1	+0.5	+2.1	1.4	4.2
	9-5	+1.4	+1.4	3.1	3.1
	9-8	+0.9	+1.8	2.5	1.4
	9-12	+0.8	+2.0	1.9	3.1
	Averages	+0.7	+1.0	1.8	2.6
Little Eagle Creek	7-30	+1.9	+4.4	2.2	3.3
	8-6	+1.9	+5.3	2.3	4.4
	8-13	+4.1	+5.9	1.4	5.0
	8-16	+3.7	+6.1	3.2	4.4
	8-20	+3.5	+6.7	3.4	5.6
	8-23	+4.3	+6.7	2.9	6.1
	8-27	+4.8	+7.0	3.1	5.0
	8-30	+4.5	+6.8	3.3	3.9
	9-6	+4.8	+6.1	3.9	5.0
	9-10	+1.5	-0.7	3.6	4.2
	9-13	+2.8	+1.3	1.7	3.6
	Averages	+3.4	+5.1	2.8	4.6

*A negative number indicates the unshaded pool temperature was cooler than the shaded pool temperature.

responsible for the high natural maximum temperature variations at the Little Eagle Creek site (Table XXXI). However, after treatment, exposed pool average surface maximum temperatures exceeded natural maximum temperature variations by 0.6 C at the water surface and 0.5 C at the pool bottom (Table XXXI).

Water Temperatures After Re-entry into Shade

Water temperatures may be increased by removing vegetation but water temperatures can also be reduced after re-entering shaded stream channels. Burton and Likens (1973) found that water temperatures rose as much as 5.5 C each time a stream entered a strip clearcut. After the stream entered a shaded strip, the water temperatures were reduced to near pretreatment levels. A similar cooling effect was observed by Rishel et al. (1982) and Greene (195)). Brown et al. (1971) and Levno and Rothacher (1967) attributed temperature decreases after shade re-entry to two factors: reduction of the heat input by shade and the influx of cool groundwater from subsurface flows or bank storage. Hewlett and Fortson (1982) hypothesized that vegetation removal near streams maintain the benefits of shade but can result in heating subsurface water in the exposure which migrates to the stream, raising stream water temperatures.

At East Glover Creek, daily water temperature maximums downstream of the exposed pool were higher than water temperature maximums in the exposed pool for all three months of measurement (Figures 14-16). In July, pool surface daily maximum temperatures downstream of the exposed pool were 1.1 C higher than exposed pool surface daily maximum temperatures. Downstream pool surface daily maximum temperatures were

0.6 C higher than exposed pool surface daily maximum temperatures in both August and September. These higher downstream daily maximum temperatures were most likely due to three factors. The first factor was a lag time for the increased radiant energy input from the exposure to manifest itself as a temperature increase in the vertical profile. This probably happened because heat conduction by point to point contacts between water molecules can be slow. Because the lag time existed, the water may have already moved through the exposed pool before a temperature increase below the air-water interface occurred. The second factor was the sparse vegetation downstream of the exposed pool which maintained a relatively high solar radiation flux. The third factor was the small groundwater inflow through the bedrock channel bottom.

At Rock Creek, daily maximum water temperatures downstream of the exposed pool were relatively equal to exposed pool daily maximum temperatures. Maximum water surface temperatures downstream of the exposed pool were 1.1 C lower than daily surface maximum temperatures in the exposed pool during July, but August daily downstream maximum surface temperatures were 0.6 C higher than exposed pool daily surface maximum temperatures. In September, downstream daily maximum water surface temperatures were 0.6 C lower than exposed pool surface daily maximum temperatures (Figures 17-19). These data also suggest the three factors which probably caused higher downstream water temperatures at East Glover Creek may have been influencing downstream temperatures at Rock Creek. However, the slightly reduced maximum surface water temperatures downstream of the exposed pool were probably a result of the water entering a well shaded channel as it left the exposure.

At Little Eagle Creek, both water surface and pool bottom daily maximum temperatures declined after leaving the exposed pool (Figures 20-22). In July, daily maximum water temperatures dropped 1.1 C at the surface and 2.2 C at the pool bottom after leaving the exposed pool. In August, surface temperatures dropped 4.4 C and bottom temperatures 3.3 C after leaving the exposed pool. September maximum daily pool surface and bottom temperatures were both 2.8 C lower downstream of the exposed pool than in the exposed pool. Pool 5 downstream of the exposure (Figure 8), was a long, deep, well shaded pool which received substantial groundwater inputs. The conditions in this pool reduced the temperature of the water leaving the exposed pool.

Significance of Results

The maximum daily temperature observed in the exposed pool at East Glover Creek was 32.9 C at a 23 cm depth in August while the shaded pool maximum daily temperture was 30.8 C for the same month and depth (Figure 24). At Rock Creek, the maximum daily exposed pool temperature was 34.4 C at the water surface in August and the maximum daily temperature for the same month and depth was 33.2 C in the shaded pool (Figure 25). At Little Eagle Creek, the maximum daily exposed pool temperature was 36.4 C in September at the water surface and the maximum daily shaded pool temperature for the same month and the depth was 28.7 C (Figure 26). These open pool daily maximum temperatures represented increases of 2.1 C at East Glover Creek, 1.2 C at Rock Creek, and 7.7 C at Little Eagle Creek above shaded pool daily maximum temperatures.

However, surface temperatures of 32.8 C, 34.5 C, and 30.6 C were recorded in pools upstream of the exposed pool at East Glover Creek, Rock Creek, and Little Eagle Creek, respectively. In this context, maximum daily exposed pool temperatures were only 0.1 C and 5.9 C higher than daily maximum shaded stream temperatures at East Glover Creek and Little Eagle Creek and daily maximum temperatures in the exposed pool at Rock Creek were actually 0.1 C lower than the daily maximum shaded stream temperatures.

Increased temperatures in the exposed pool were probably not detrimental to smallmouth bass. Smallmouth bass embryo, which are most susceptible to high water temperatures, appear in the streams in early spring, after the spawn when flow volumes are high and water temperatures in small exposed pools would probably not be significantly higher than shaded pool temperatures (Maughan et al., 1980). Likewise, smallmouth bass fry would probably not be significantly affected either. However, according to a rating curve of Maughan et al. (1980), juvenile smallmouth bass begin to show declines in growth rates at temperatures above 30.0 C. Natural maximum stream temperatures above 30.0 were recorded at all three study sites as early as July, therefore any increase above natural stream temperatures may further reduce growth rates. However, the temperatures greater than 30.0 C were all recorded at the water surface. Daily maximum pool bottom temperatures never exceeded 30.0 C in the shaded pools and 30.2 C in the exposed pools at any of the sites (Figures 24-26). The occurrance of low temperatures in shaded and exposed pool bottoms means that juvenile smallmouth bass can escape high surface water temperatures. Adult smallmouth bass show declines in growth rates at temperatures greater than 31.5 C (Maughan et al., 1980). Natural mean maximum stream temperatures above 31.5 C were recorded at East Glover Creek and Rock Creek but not at Little Eagle Creek. Temperatures above 31.5 C were not recorded on pool bottoms at any of the sites, however. Based on these findings, it is probable that temperature changes caused by small vegetation clearings on the three streams studied in southeastern Oklahoma did not significantly impact smallmouth bass.

The variability of natural temperature maximums and exposed pool temperature maximums and increases among sites was great. Natural median maximum surface temperatures differed by as much as 6.5 C in the pool systems at the three sites (Figures 14-22) and maximum temperature increases in exposed pools differed by 5.9 C (Figures 24-26). These temperature differences indicate that application of these data to other sites in the region may not accurately approximate the natural temperature conditions and responses at those sites.

Model Testing

Three stream temperature models were examined to establish if they were suitable for predicting stream temperatures in southeastern Oklahoma. The models tested were developed in other regions of the United States on completely mixed streams. Because the streams examined in this study developed thermal gradients from the surface to the bottom, the assumption of well mixed conditions was not met. Therefore, the models were compared with a regression model developed from data obtained at East Glover Creek to determine their applicability in southeastern Oklahoma.

The regression model was developed for the East Glover Creek site because this site had the most complete data set and had hydrologic characteristics in between the faster flowing Rock Creek and the slow, meandering Little Eagle Creek. A stepwise regression procedure was performed on the significant variables identified by the Spearman correlations (Table XI) and the resulting regression model developed for East Glover Creek was:

$$P = 39.514 - 34.188(G) + 0.483(RK) - 14.253(D) \qquad (24)$$

where:

P is the rank of the rank of the open pool temperature.
G is the stage (ft.).
RK is the rank of the water surface temperature in the shaded channel.
D is the desired depth in the open pool (ft.).

and R^2 is 0.86 and the mean square error is 98.2. RK is linearly interpolated from Table XXXII and the actual predicted temperature is determined from linear interpolation between the computed exposed pool temperature ranks (Table XXXIII).

The regression model predicted water temperatures within an average of 0.4 C at all depths for the 15 days to which it was applied at East Glover Creek (Table XXXIV). Tests of the regression model using data from the other sites showed that temperature predictions were within an average of 1.8 C at Little Eagle Creek and within an average of 2.7 C at Rock Creek (Table XXXIV). The larger prediction errors using Little Eagle Creek and Rock Creek data indicate that caution should be used when applying site specific equations on a region wide basis.

One source of error for the regression model could have been in the use of autocorrelated data. Pindyck and Rubinfeld (1976) have outlined several procedures designed to correct for serial correlation.

TABLE XXXII

TEMPERATURE RANKS VERSUS ACTUAL SURFACE TEMPERATURES IN THE SHADED POOL AT EAST GLOVER CREEK

Shaded Pool Temperature Rank (RK)	Actual Surface Water Temperature (C)
3.5	25.31
9.5	25.96
15.5	26.59
21.5	26.66
27.5	27.26
33.5	27.31
39.5	27.96
45.5	28.33
51.5	28.51
57.5	28.82
63.5	29.15
69.5	29.34
75.5	30.33
84.5	30.34

TABLE XXXIII

TEMPERATURE RANKS VERSUS ACTUAL TEMPERATURES
IN THE EXPOSED POOL AT EAST GLOVER CREEK

Exposed Pool Temperature Rank (P)	Actual Water Temperature (C)	Temperature Rank (P)	Actual Water Temperature (C)
1.0	24.47	46.0	27.78
2.5	24.83	47.0	27.97
4.0	25.36	48.0	28.08
5.0	25.47	49.0	28.11
6.5	25.78	50.0	28.20
8.0	25.89	51.0	28.24
9.0	25.92	52.0	28.26
10.0	25.93	53.0	28.28
11.5	25.94	54.0	28.33
13.0	26.00	55.5	28.39
14.0	26.07	57.0	28.47
15.0	26.08	58.5	28.49
16.0	26.11	60.0	28.72
17.0	26.17	61.0	28.77
18.0	26.23	62.5	28.81
19.0	26.36	64.0	28.88
20.0	26.38	65.0	29.04
21.0	26.50	66.0	29.13
22.5	26.53	67.0	29.24
24.0	26.56	68.0	29.48
25.0	26.67	69.0	29.58
26.0	26.69	70.0	29.63
27.0	26.72	71.0	29.94
28.0	26.78	72.0	29.96
29.0	26.92	73.0	30.07
30.0	26.97	74.0	30.36
31.0	27.00	75.0	30.40
32.0	27.27	76.0	30.60
33.0	27.28	77.0	30.83
34.0	27.34	78.0	30.90
35.0	27.35	79.0	31.04
36.0	27.44	80.0	31.05
37.0	27.50	81.0	31.23
38.0	27.51	82.0	31.39
39.0	27.54	83.0	31.66
40.0	27.56	84.5	31.72
41.0	27.58	86.0	31.83
42.0	27.61	87.0	31.85
43.0	27.71	88.0	32.17
44.5	27.72	89.0	32.23

TABLE XXXIV

ACCURACY OF MODEL PREDICTIONS AT THE THREE RESEARCH SITES SHOWING AVERAGE DEVIATIONS FROM ACTUAL TEMPERATURES

Model	Surface		23 cm		46 cm		69 cm		91 cm		114 cm	
	Diff. (C)	Ave % Error	Diff. (C)	Ave % Error	Diff. (C)	Ave % Error	Diff. (C)	Ave % Error	Diff. (C)	Ave % Error	Diff. (C)	Ave % Error
Regression	+0.2	2.3	-0.2	2.2	-0.4	2.0	+0.3	2.5	+0.2	2.2	-0.2	1.8
Brown's	-1.7	5.8	-1.3	4.4	-0.8	2.7	+0.8	3.7	+1.4	6.0	+1.5	7.4
Washington	-1.8	6.0	-1.4	4.7	-0.8	2.8	+0.7	3.5	+1.4	5.7	+1.8	7.1
Combined	-1.2	4.9	-0.8	4.5	-0.2	3.2	+1.6	5.6	+2.0	8.0	+2.4	9.4
Regression	+0.2	2.3	-0.8	2.6	-1.4	4.6	-1.8	6.0	-2.7	9.3	----	---
Brown's	-0.4	1.7	-0.5	1.7	-0.3	1.4	+0.2	1.8	0.0	1.2	----	---
Washington	-0.6	2.0	-0.6	2.1	-0.5	1.6	0.0	1.4	0.0	1.1	----	---
Combined	+1.1	7.2	+1.4	14.4	+1.9	7.2	+2.3	8.4	+0.2	1.0	----	---
Regression	-1.3	4.5	-1.8	6.0	-1.7	6.6	-1.2	7.0	-1.1	8.2	-1.6	9.0
Brown's	-2.7	8.9	-2.4	7.9	-1.5	7.0	-0.2	6.8	+0.8	7.9	+1.0	8.1
Washington	-3.6	11.8	-3.3	10.7	-2.4	8.8	-1.1	8.4	0.0	9.2	+0.1	9.1
Combined	+5.4	17.5	+5.7	18.8	+6.6	22.4	+7.9	28.4	+8.9	33.5	+9.1	34.2

Application of one of these correction methods may improve the estimate of the standard error and confidence intervals about the predictions.

Brown's Model was consistently better at predicting temperature increases than the other models tested (Table XXXIV). The Brown Model predicted temperatures to within 2.7 C at all three sites at all depths. The combined model proved to be the least accurate.

All models, including the regression model, performed poorly at Little Eagle Creek. Stream flow gains and losses to and from groundwater and channel bank storage were substantial and were not accounted for in the models. However, the models tended to underpredict the water temperatures in the exposed pool at Little Eagle Creek. This underprediction was an indication that the subsurface water entering the exposed pool was at a temperature higher than water in the shaded pool. Hewlett and Fortson (1982) experienced similar underpredictions in the piedmont of Georgia.

The combined model may have failed because the evaporation, convection, and conduction components were derived for small, rapidly moving, turbulent streams. Both the evaporation (Equation 19) and convection (Equation 20) equations contain a water surface area term. Since the surface area of a pool is greater than that of a normal stream channel, higher energy flux values and higher predicted temperatures resulted from the use of these equations. The conduction term (Equation 21) incorporates the travel time of water through the stream reach. Since pool travel time is much longer than riffle travel time, the conduction term may also have contributed to overprediction of temperature increases.

A closer look at Brown's Model and the State of Washington adaptation to the Brown Model indicates that at depths between 46 and 69 cm, the models switched from underpredicting to overpredicting temperatures (Table XXXIV). Since the Brown and State of Washington Models predict only one temperature for the entire vertical temperature profile, the 46 cm to 69 m depth interval represents the intersection of the actual temperature gradient with the single value prediction.

Without the addition of a depth variable, the application of the Brown and State of Washington Models to southeastern Oklahoma is limited to predicting the value of the intersection with the exposed pool temperature gradient. If this point were fixed, the models could be used to predict temperatures at that point. However, there is no evidence that the point of intersection would always occur between 46 cm and 69 cm in all streams in the region. Therefore, caution should be used if the models are to be applied in southeastern Oklahoma.

CHAPTER V

SUMMARY AND CONCLUSIONS

The streams of the Little River Drainage in southeastern Oklahoma are unique in that surface flows in the channels become almost negligible in the summer dry season, isolating large pools which are maintained primarily by groundwater inputs. The aquatic communities in these pools, which include smallmouth bass, must adapt to any environmental changes because of their limited mobility.

The increase in timber harvesting in southeastern Oklahoma has raised concern about possible detrimental effects on water quality. One concern is the effect that streamside vegetation removal has on water temperatures of the isolated pools and the subsequent impact on smallmouth bass. Water temperature changes can affect smallmouth bass both directly and indirectly. Direct influences could include reduced growth, abnormal spawning characteristics, and increased susceptability to disease. Indirect influences could involve pertubations of the food chain, such as the changing of the dominant species present, the species diversity, or the total biomass.

Streams of the Little River Drainage containing smallmouth bass are generally small first, second, or third order streams. However, fourth and fifth order streams have the greatest total distance of smallmouth bass habitat. Three stream temperature study sites were located on fourth order streams which represented over 41 percent of the possible channel configurations for streams of this order within the drainage.

Natural stream temperature regimes were highly variable, probably because of the uneven distribution of shade along streams. Surface temperature maximums in excess of 32.0 were found in the open portions of naturally shaded pools in mid summer, but well shaded portions of the same pools had surface water temperature maximums as much as 5.5 C cooler. The largest daily variation of maximum temperatures among pools was 2.8 C at the water surface and 4.4 C at the pool bottoms. Average monthly maximum temperature gradients from shaded pool surfaces to bottoms ranged from 0.0 C to 3.9 C. The maximum temperature recorded in any shaded pool was 35.0 C.

Streamside vegetation (shade) removal had a significant impact on pool surface temperatures. Monthly mean maximum water temperatures increased as much as 4.8 C at the water surface after shade removal and daily maximum surface temperatures increased as much as 7.7 C to a maximum of 36.4 C. However, at two of the study sites, the largest daily maximum temperature increase at the pool bottoms was only 2.4 C and generally there was little or no change in water temperatures between shaded and exposed pools at the channel bottom. The third site, Little Eagle Creek, had significant temperature increases at all depths after shade removal. This was attributed to the difference in cool groundwater inputs between the pools because the shaded pool received relatively large groundwater inputs whereas the exposed pool received only small groundwater inputs. This groundwater flux difference magnified the temperature differences between the two pools.

Average monthly maximum temperature gradients from pool surfaces to bottoms for the exposed pools were generally from 0.6 C to 2.8 C greater than shaded pool temperature gradients. The larger exposed pool temperature gradients were the result of significantly higher surface maximum temperatures in the exposed pools than in the shaded pools and exposed pool maximum bottom temperatures that were similar to shaded pool maximum bottom temperatures.

Maximum surface water temperature increases in the exposed pools averaged only 0.6 C to 0.7 C greater than shaded pool maximum temperature variation during the summer at East Glover Creek and Little Eagle Creek. At Rock Creek, surface water temperatures in the exposed pool did not exceed natural surface water temperature variation measured upstream of the exposed pool. Rock Creek and East Glover Creek also had bottom temperatures in the exposed pools that did not exceed shaded pool bottom temperatures variation. Summer average bottom temperatures in the exposed pool at Little Eagle Creek were 0.5 C greater than shaded pool average bottom temperature variation, but this was probably a result of cool groundwater entering the shaded pool.

The fact that removal of shading vegetation had minimal effects on pool bottom temperatures is important. Smallmouth bass can avoid areas of higher temperature by seeking cooler, deeper water during mid afternoon peak surface water temperatures. Pool areas with temperatures suitable for smallmouth bass were observed in all exposed pools on all days of measurement. However, some reduction in available habitat may occur in exposed pools because of the potential for higher water temperatures near the pool surfaces. Floating aquatic organisms restricted to the water surface will not be able to escape the temperature increases and could conceivably be subjected to severe temperature stress.

Surface water temperatures can be expected to return to near normal after entering shade downstream of clearcuts, provided that cool groundwater inputs are present. This is most likely to occur in broad valleys that have a significant alluvial plain. Steep, rock valleys probably deliver a substantial portion of their water to streams quickly, and thus sustained baseflow from stream margins is less. In streams like these, the temperature effects from clearcuts may be observable farther downstream.

The removal of shading vegetation along the isolated pools found in the Little River Drainage should be avoided. However, when stream-side vegetation removal is necessary, the size of the openings along pools should be minimized. Establishment of fast rooting shrubs could help create a more favorable water temperature in the pools affected by vegetation removal. Establishment of brush species, especially the fast growing alder, in openings may lessen the effect of shade removal after just one or two summers.

From a resource management perspective, the ability to foresee or predict potential temperature increases is important. Several models have been developed in other parts of the country for other types of stream systems. Application of these models to southeastern Oklahoma streams showed the Brown Stream Temperature Model to be the most accurate at predicting water temperatures over the range of conditions encountered at the three study sites; however, errors up to 2.7 C were found. The foremost problem with using existing stream temperature models is that the models assume completely mixed streams and constant temperatures with depth. Because temperature gradients from pool surfaces to bottoms exist in southeastern Oklahoma streams, single value predictions do not accurately approximate the range of temperatures encountered with depth. Potential exists for the addition of a depth factor to Brown's Model to reduce error. A regression model developed from data at one of the study sites predicted temperatures to within 0. C at that site. However, when the regression equation was applied to the other two sites, errors equal to those of the Brown Model were found. These large errors indicate that caution should be used when applying temperature prediction equations to southeastern Oklahoma streams.

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APPENDIXES

APPENDIX A

DETERMINATION OF LANDFORM SHADOW LENGTHS

Lee (1978) introduced a formula for determining landform shadow lengths:

$$L = h * \cos(B) * \cot(I) \qquad (25)$$

where:

L is the horizontal length of the shadow cast.
h is the height of the landform above the stream.
B is the acute angle between the stream axis and the sun.
I is the solar altitude.

The factor B is determined by:

$$90 + \text{latitude} - \text{declination} - \text{stream azimuth} \qquad (26)$$

where latitude and declination are in degrees and stream azimuth is in degrees corrected for the eastern hemisphere. The correction for the eastern sky hemisphere is applicable for morning sun. If the stream azimuth is from 0 to 180 degrees, the correction factor is zero. If the stream azimuth is from 181 to 359 degrees, then 180 is subtracted from the azimuth to give the stream azimuth corrected for the eastern sky hemisphere.

To determine shade angles for evening sun, the factor B is found from:

$$270 + \text{latitude} - \text{declination} - \text{stream azimuth} \qquad (27)$$

where the stream azimuth is now corrected for the western sky hemisphere by adding 180 degrees if the original azimuth was from 0 to 180 degrees. If the original stream azimuth is from 181 to 359 degrees, no correction is made.

APPENDIX B

STREAM TEMPERATURES DATA FOR THE THREE STUDY SITES

TEMPERATURES RECORDED WITH MAXIMUM-MINIMUM THERMOMETERS AT
EAST GLOVER CREEK, P=POOL NUMBER, S=POOL SURFACE, B=POOL BOTTOM

OBS	DATE	MAXP1S	MAXP1B	MAXP2S	MAXP2B	MAXSP2	MAXBP2	MAXP3S	MAXSP3	MAXP3B	MAX3PS	MAXP4S	MAXSP4	MAXP4B	MAX4PS	MAXP5S	MAXP5B	STAGE
1	185	85		87	78	85	80	84	85	84	82	81	.	78	82	83	81	0.0
2	186	84	80	86	80	86	80	82	84	82	83	83	82	82	84	85	82	0 1
3	187	83		89	80	87	79	83	84	83	82	83	82	83	84	84	84	0 0
4	188	85	86	89	82	87	82	86	86	86	85	85	85	86	86	86	86	0.0
5	190	87		91	81	88	80	87	87	84	86	85	85	.	85	86	88	0 0
6	191	88	86	89	83	87	81	86	87	86	86	86	85	86	87	88	88	0.0
7	192	89	86	90	82	87	81	86	88	87	89	87	87	87	89	90	89	-0 1
8	193	89	85	90	84	89	83	87	88	87	89	88	88	87	90	90	90	0.1
9	194	87	86	88	81	87	80	85	86	86	85	84	84	86	86	87	.	0.0
10	195	86	85	89	80	86	80	85	86	85	85	85	85	86	86	87	87	0.0
11	197	90	86	91	80	89	80	87	88	88	87	88	88	87	89	90	90	0 0
12	198	81	80	85	80	82	80	80	81	81	80	81	80	81	83	83	82	0 0
13	199	87	83	85	79	86	79	85	85	84	84	84	85	84	87	87	87	-0.1
11	200	88	82	87	82	87	80	86	86	86	85	85	86	84	88	89	88	-0.2
15	201	87	80	87	78	86	79	85	86	86	84	84	82	83	91	88	87	-0 2
16	202	85	81	86	78	84	79	84	85	84	84	83	84	82	89	88	88	-0.2
17	204	87	79	86	78	85	78	84	86	84	83	84	86	80	88	88	88	-0 2
18	205	86	80	85	78	83	78	83	85	84	83	83	85	80	86	87	87	-0.3
19	206	82	80	83	78	83	78	82	84		82	82	83	80	86	86	86	-0.3
20	207	81	77	83	77	82	77	80	84	85	81	81	82	78	83	83	82	-0 2
21	208	83	80	84	77	84	78	82	83	83	82	83	83	81	86	86	85	0.0
22	209	83	80	83	78	82	79	81	84	82	82	83	83	83	84	85	.	-0.1
23	212	85	81	85	79	84	78	82	85	82	83	85	84	83	86	87	86	-0.2
24	213	.		.	.	.		.		.	.	.	.		.		.	.
25	215	83	78	82	76	80	75	80	81	80	80	78	82	79	85	86	85	0.0
26	216	81	79	83	76	80	76	79	81	80	79	79	79	80	81	82	82	-0.1
27	218	83	78	85	76	84	76	82	82	82	81	82	82	81	84	85	84	0.0
28	219	83	80	86	78	84	77	82	83	83	83	82	83	82	85	85	87	-0.1
29	220	83	80	86	80	83	78	83	83	83	81	83	82	83	86	86	85	-0.1
30	222	83	79	86	79	84	79	83	84	83	83	83	84	82	86	87	87	-0.2
31	223	83	80	84	79	85	78	83	84	85	83	83	83	81	86	86	84	-0 2
32	225	86	81	87	79	85	79	86	86	86	84	86	86	81	88	89	88	-0.3
33	226	87	82	87	80	86	79	85	87	84	85	86	86	82	89	90	89	-0 3
34	227	86	81	86	81	85	80	84	86	84	85	85	86	82	88	89	89	-0 3
35	228	86	80	86	79	85	80	84	86	85	85	85	86	81	88	89	88	-0 3
36	229	90	83	90	80	88	80	87	89	88	86	86	89	85	92	92	89	-0 3
37	230	90	83	88	82	88	81	87	88	87	87	87	88	84	90	92	90	-0 3
38	232	90	82	88	82	88	81	87	88	87	87	88	89	84	93	94		-0.4
39	233	91	84	90	81	87	81	87	88	87	87	88	88	84	92	92	91	-0 4
40	234	87	84	89	83	88	82	87	87	86	86	88	87	84	90	91	90	-0.4
41	235	87	82	86	82	86	82	85	88	86	87	87	87	82	90	89	86	-0 4
42	236	87	83	87	80	86	80	85	88	86	87	88	87	85	92	92	90	-0.4
43	237	85	81	87	82	84	82	85	84	85	85	87	86	84	88	91	90	-0 5
44	239	88	77	87	81	86	80	84	84	85	84	86	86	80	88	86	90	-0 4
45	240	89	81	89	82	86	80	86	87	85	85	88	87	83	90	91	88	-0.4
46	241	89	81	89	82	88	79	86	89	87	86	89	88	84	91	90	90	-0.5
47	242	91	84	91	81	88	82	87	89	88	88	90	90	84	92	94	91	-0.5
48	243	88	84	89	80	86	80	86	87	86	86	90	89	83	90	92	89	-0.5
49	244	87	81	88	82	84	80	84	85	86	84	87	88	83	88	91	89	-0.5
50	246	87	82	89	81	85	80	84	87	84	84	88	87	83	88	90	88	-0.4
51	247	83	82	83	80	82	80	84	86	84	84	86	87	83	90	90	88	-0.4
52	248	82	78	83	79	84	80	80	80	80	79	84	84	79	85	87	85	-0.5
53	249	86	76	84	77	84	78	80	83	81	80	86	85	79	86	86	83	-0 5
54	250	85	78	84	80	82	78	80	83	80	80	85	83	81	86	86	84	-0 5
55	251	81	78	82	78	80	77	77	85	79	78	85	82	82	83	84	83	-0.5

TEMPERATURES RECORDED WITH MAXIMUM-MINIMUM THERMOMETERS AT
EAST GLOVER CREEK, P=POOL NUMBER, S=POOL SURFACE, B=POOL BOTTOM

OBS	DATE	MAXP1S	MAXP1B	MAXP2S	MAXP2B	MAXSP2	MAXBP2	MAXP3S	MAXSP3	MAXP3B	MAX3PS	MAXP4S	MAXSP4	MAXP4B	MAX4PS	MAXP5S	MAXP5B	STAGE
56	253	85	77	83	77	80	78	80	83	82	80	83	81	79	84	82	80	-0.4
57	254	87	78	86	78	83	78	83	84	83	82	86	86	80	88	89	86	-0.4
58	255	89	79	85	80	83	78	82	85	84	83	86	85	80	87	88	85	-0 4
59	256	88	79	86	79	85	79	83	85	84	83	88	87	81	89	90	87	-0 4
60	257	87	79	86	80	86	79	85	86	84	84	89	88	81	90	90	86	-0.4
61	260	85	80	87	80	85	79	84	85	84	83	87	86	82	90	90	88	-0.4
62	261	75	70	74	71	74	73	76	75	75	74	78	78	73	80	80	77	-0.4
63	262	79	70	78	72	76	72	77	78	76	76	81	80	74	82	83	80	-0 4
64	263	77	71	78	72	76	71	76	77	75	75	81	80	73	83	83	79	-0.4
65	264					.		76	78	74	74	80	80	72	81	83	79	-0.4

MAXIMUM-MINIMUM THERMOMETER READINGS AT EAST GLOVER CREEK
P=POOL NUMBER, S=POOL SURFACE, B=POOL BOTTOM

OBS	DATE	MINP1S	MINP1B	MINP2S	MINP2B	MINSP2	MINBP2	MINP3S	MINSP3	MINP3B	MIN3PS	MINP4S	MINSP4	MINP4B	MIN4PS	MINP5S	MINP5B
1	185	77	.	77	78	76	78	78	77	81	81	80	.	78	78	.	81
2	186	77	79	77	78	76	76	78	77	78	78	77	75	80	78	78	80
3	187	78		77	78	77	76	78	77	83	78	83	76	78	80	80	78
4	188	80	80	79	80	78	78	82	79	80	80	80	77	80	80	80	80
5	190	79	.	79	81	75	79	82	73	79	80	80	77	.	82	80	79
6	191	79	80	79	80	80	78	82	80	82	80	79	78	81	82	81	80
7	192	80	81	80	80	79	78	79	80	80	75	81	75	78	82	82	81
8	193	79	80	79	81	79	80	80	79	80	.	78	77	80	81	80	80
9	194	79	80	79	81	80	80	80	79	80	.	80	78	80	81	80	.
10	195	80		80	80	80	80	80	79	82	.	80	78	80	82	81	80
11	197	79	80	81	80	80	80	81	80	81	81	80	79	80	82	82	81
12	198	77	78	77	80	77	80	78	77	79	79	77	75	78	79	78	77
13	199	76	76	76	78	77	78	78	77	79	78	77	74	77	77	77	77
14	200	73	74	75	76	77	76	77	76	76	77	77	70	76	76	76	75
15	201	72	74	71	75	73	75	75	75	76	76	75	66	74	74	75	75
16	202	73	74	75	76	73	75	76	76	76	76	75	72	75	74	76	75
17	204	73	75	76	77	73	76	77	76	77	77	75	73	76	76	75	76
18	205	72	74	75	76	71	75	76	75	75	76	74	72	75	75	74	75
19	206	73	76	76	77	76	76	77	76	.	77	76	73	76	77	76	75
20	207	73	74	75	76	75	75	76	75	76	77	74	72	75	75	75	74
21	208	75	76	76	77	76	76	76	76	77	77	76	74	76	76	76	75
22	209	77	78	76	78	78	76	78	77	80	78	77	76	78	79	79	.
23	212	71	72	74	74	74	74	75	74	75	74	73	70	73	73	73	72
24	215	71	72	71	73	71	75	73	71	72	72	71	69	72	72	72	72
25	216	73	71	74	73	74	72	75	74	76	76	75	72	74	74	75	74
26	218	75	76	77	75	76	73	77	76	77	77	74	74	77	77	77	76
27	219	76	77	77	77	77	75	77	77	78	77	76	74	77	78	78	78
28	220	77	78	78	78	77	75	80	77	79	79	77	75	77	78	78	78
29	222	75	77	76	77	76	76	77	76	78	77	76	73	76	77	76	76
30	223	76	77	77	78	77	76	81	77	78	77	76	74	77	78	77	76
31	225	76	76	77	77	77	77	77	76	78	75	75	74	76	77	76	77
32	226	76	76	77	78	77	76	78	77	79	77	75	74	77	77	77	77
33	227	75	76	77	78	77	77	78	76	78	76	76	74	77	77	77	76
34	228	76	77	77	78	78	78	79	77	78	77	76	74	77	78	78	77
35	229	76	78	78	79	78	77	79	77	78	78	78	75	77	78	78	77
36	230	78	78	78	80	79	78	80	82	80	79	78	86	78	79	79	78
37	232	77	78	79	80	79	79	80	77	79	79	77	75	78	79	79	.
38	233	77	79	79	80	79	79	80	78	79	79	78	76	78	79	79	78
39	234	79	79	80	81	80	80	81	79	80	80	79	77	80	80	80	80
40	235	78	80	79	80	79	79	80	79	80	80	79	76	79	80	80	81
41	236	75	76	79	77	79	77	79	75	76	76	75	72	76	76	76	76
42	237	74	75	77	78	78	79	78	73	76	75	74	74	76	76	76	75
43	239	71	74	77	76	76	76	76	72	74	73	71	71	73	72	74	73
44	240	77	78	79	79	78	78	79	77	78	83	87	76	78	88	80	80
45	241	77	78	79	79	78	79	75	77	78	78	76	76	78	79	79	79
46	242	77	78	79	80	78	80	81	77	78	79	78	77	79	78	80	80
47	243	75	75	78	79	76	79	78	74	75	76	74	74	77	77	77	77
48	244	75	76	78	79	76	79	78	74	76	77	76	75	77	77	78	78
49	246	75	76	78	79	72	79	77	74	78	76	75	75	76	74	76	76
50	247	69	71	75	76	75	74	73	69	71	70	71	70	74	71	71	72
51	248	67	69	74	74	64	74	72	68	70	70	70	82	72	70	70	72
52	249	69	71	74	74	75	75	72	69	71	71	71	70	72	68	71	72
53	250	70	72	75	75	74	75	72	70	73	72	72	71	74	71	73	74
54	251	73	74	75	77	74	76	74	69	74	74	73	73	76	75	75	76
55	253	71	74	74	75	74	76	73	73	74	74	73	71	74	74	74	74

MAXIMUM-MINIMUM THERMOMETER READINGS AT EAST GLOVER CREEK
P=POOL NUMBER, S=POOL SURFACE, B=POOL BOTTOM

OBS	DATE	MINP1S	MINP1B	MINP2S	MINP2B	MINSP2	MINBP2	MINP3S	MINSP3	MINP3B	MIN3PS	MINP4S	MINSP4	MINP4B	MIN4PS	MINP5S	MINP5B
56	254	73	74	75	76	75	75	75	74	74	75	74	73	75	75	75	75
57	255	73	74	76	77	76	77	76	73	75	75	75	73	76	76	76	76
58	256	74	74	77	77	77	77	76	74	76	75	74	74	76	76	77	77
59	257	74	75	77	78	77	77	77	74	76	76	75	74	77	76	77	77
60	260	73	75	69	70	70	70	68	64	66	65	64	66	65	65	65	66
61	261	62	67	67	66	67	65	69	65	67	67	66	64	64	68	68	69
62	262	65	66	69	70	69	69	69	65	67	66	67	65	67	68	67	.
63	263	65	66	68	69	68	69	68	65	66	66	65	64	67	66	67	
64	264					.	.	68	66	68	67	67	64	68	68	68	

THERMOGRAPH DATA AT EAST GLOVER CREEK, OP-OPEN POOL, SH=SHADED POOL, S=SURFACE MEASUREMENT, B=BOTTOM MEASUREMENT

OBS	DATE	OPMAXS	OPTIMAXS	OPMINS	OPTIMINS	OPAVES	OPBOTDEP	OPMAXB	OPTIMAXB	OPMINB	OPTIMINB	OPAVEB	SHMAXS	SHTIMAXS	SHMINS	SHTIMINS	SHAVES	SHBOTDEP	SHMAXB	SHTIMAXB	SHMINB	SHTIMINB	SHAVEB
1	181	.	.	.			4.1	86	1745		.	.	86	1730	.	.	.	2 2	85	1730	.	.	.
2	182			.	.		4.1	84	1745	79	900	81.0	85	1700	78	915	80 9	2.2	83	1800	77	900	79.8
3	183	.					4.1	83	1800	77	830	79.6	84	1730	77	900	80.0	2.2	82	1800	75	815	78 9
4	184	.	.	.	.	.	4.1	84	1900	77	800	80.0	85	2015	77	845	80 8	2.2	84	1915	76	915	79.1
5	185	85	1830	.			4.1		.	79	745	81 4	86	2100	79	945	82.2	2 2	84	.	78	915	.
6	186	84	1615	79	815	80.8	4.1	84	1645	80	915	81.9	85	1745	79	1045	82.3			.	.	.	.
7	187	83	1915	77	1015	79 2	4.2	83	1915	79	930	80 6	84	2130	78	1145	80.6	2.3	83	.	76	.	.
8	188	87	1630	79	830	81 7	4 1	87	1800	79	800	81 7	87	1830	79	815	83.1	2.2	86	1645	.	.	.
9	189	.	.	80	815		4.1			81	900	.	88	1645	80	1000	84 2	2.2	87	1515	80	815	83.1
10	190	.		.	.		4.1	.		.	.		89	1830	80	745	84.6	2.2	88	1700	79	700	83.4
11	191	87	1630				4.1	87	600	.	.	.	89	1600	81	730	85.5	2.2	87	1600	80	815	83.8
12	192	90	1530	81	815	84 8	4 0	89	1645	82	830	84 9	90	1645	82	1015	85.5	2 1	88	.	80	.	.
13	193	90	1630	81	730	84 3	4 2	89	1715	82	900	84 6	91	1515	82	815	85.5	2 3	88	.	79	.	.
14	194	86	1830	79	800	81 9	4.1	86	1800	80	745	82 9	87	2145	81	1015	84 2	2.2	86	.	78	.	.
15	195	.	.	80	815	83.0	4.1	87	1815	81	815	84 0	87	1700	82	800	86.0	2.2	86	1700	.	.	.
16	196	89	1630	81	800	84.2	4 1	88	1730	82	815	85.0	90	1545	82	745	85.7	2 2	88	1800	80	930	84.0
17	197	90	1630	81	815	85.0	4.1	89	1745	81	845	84 6	90	1600	82	745	86.5	2.2	89	.	81	930	.
18	198	85	15	80	2345	81 5	4 0	86	15	81	2345	82.2	88	15	81	2345	83 2	2.1	83	.	79	.	.
19	199	87	1630	78	800	81 4	3 9	86	1815	79	800	81.8	87	1930	79	930	82 6	2.0	85	.	77	.	.
20	200	88	1615	77	715	81 8	3 9	86	1815	79	900	81 4	88	1730	79	830	83.1	2.0	86	.	76	.	.
21	201	87	1430	75	800	80 4	3.9	85	1915	77	845	79 9	86	1800	76	915	81.1	2 0	85	1715	77	.	.
22	202	88	1700	75	715	80 3	3.9	83	2015	76	900	79 6	87	1615	74	715	80.8	2.0	85	1600	75	630	82.3
23	203	89	1615	75	745	80 8	3.9	83	2100	77	830	78 8	87	1530	76	700	81.2	2.0	84	1715	75	730	79.4
24	204	88	1600	75	745	80 7	3.9	82	2215	77	830	78 5	87	1600	77	715	81.8	2 0	85	1800	76	730	80.3
25	205	86	1400	76	730	79 2	3 8	81	1900	77	830	78 2	85	1515	77	730	80.8	1 9	84	.	77	.	.
26	206	88	1600	74	730	80 0	3 8	81	2200	76	815	77.9	85	1730	76	800	80 3	1 9	88	.	.	.	.
27	207	82	1215	75	730	77 5	3.9	79	1915	77	830	77 8	81	1600	77	845	79 1	2.0	84	15	80	800	82.0
28	208	85	1430	74	730	78.6	4.1	80	2115	76	815	77 5	84	1645	75	845	79.2	2 2	85	1800	79	900	81.7
29	209	83	1430	75	800	78 6	4.0	83	1745	77	845	79.0	83	1800	77	1000	80 5	2 1	86	1830	80	1015	83 8
30	210	86	1515	78	915	81.0	3 9	84	1745	79	1000	80.7	85	1545	79	930	81.4	2 0	87	1815	82	1015	84.2
31	211	86	1500	76	845	80.0	3 9	82	1930	77	815	78.8	85	1530	77	745	80 6	2 0	87	1815	80	900	83.2
32	212	86	1615	74	730	79 2	3.9	81	2015	75	815	77.4	83	1700	76	745	79 4	2.0	85	1915	78	830	82.2
33	213	86	1530	73	745	78 7	4 1	80	1930	74	800	76.9	82	1530	75	815	78.3	2.2	84	1915	77	830	81.1
34	214	81	1330	74	715	76 7	4.1	78	1945	75	830	76 4	81	1445	75	830	77.7	2 2	82	1800	78	830	80.3
35	215	80	1130	73	715	74.3	4.1	76	1815	74	800	75 1	80	1315	74	1445	75 7	2 2	81	1300	77	845	78.2
36	216	80	1715	72	715	75 1	4 0	80	1830	73	830	75 8	80	1915	72	845	76 6	2 1	84	1745	74	1015	78.6
37	217	83	1630	75	800	78.0	4 1	82	1815	76	830	78.1	83	1715	75	700	79.5	2 2	85	1900	78	915	82 0
38	218	84	1415	76	800	79 0	4.1	81	1730	77	830	78.3	84	1400	77	700	80 5	2 2	86	1600	80	915	83.4
39	219	82	1630	77	815	78 5	4 0	81	1745	77	815	78 8	82	1645	78	745	79 8	2.1	85	1830	80	945	82 6
40	220	85	1600	78	845	80 0	4 0	83	1900	78	815	79.4	85	1630	78	1015	81 2	2.1	88	1630	81	1100	83.8
41	221	86	1615	78	745	80 7	3 9	83	1945	78	900	80.0	85	1645	79	900	82.3	2.0	88	1845	82	915	84 9
42	222	80	15	77	2345	77.8	3 9	81	15	78	2345	79 2	83	15	79	2345	80 3	2 0	85	15	81	2345	82.6
43	223	83	1630	76	700	78 6	3 9	83	1745	77	730	79 0	89	1300	77	800	80 5	2.0	85	1615	80	845	83.2
44	224	85	1645	77	730	80 5	3.8	82	2000	78	745	79.4	85	1215	78	545	81.7	1 9	87	1700	81	645	83.8
45	225	88	1615	76	745	81 1	3.8	81	2130	77	815	79 0	87	1415	78	530	82.2	1.9	88	1730	80	645	84.8
46	226	89	1545	76	800	81 9	3.8	82	2330	77	830	79 0	87	1200	78	545	82.9	1.9	88	1830	81	700	84.8
47	227	90	1445	77	730	81 9	3 8	82	1945	77	830	79.7	87	1300	78	700	82 3	1.9	88	1745	81	730	84.6
48	228	88	1615	76	745	81 2	3.8	82	1815	77	815	79 2	86	1300	78	645	81.7	1.9	87	1900	81	700	84.0

THERMOGRAPH DATA AT EAST GLOVER CREEK, OP=OPEN POOL, SH=SHADED POOL, S=SURFACE MEASUREMENT, B=BOTTOM MEASUREMENT

OBS	DATE	OPMAXS	OPTIMAXS	OPMINS	OPTIMINS	OPAVES	OPBOTDEP	OPMAXB	OPTIMAXB	OPMINB	OPTIMINB	OPAVEB	SHMAXS	SHTIMAXS	SHMINS	SHTIMINS	SHAVES	SHBOTDEP	SHMAXB	SHTIMAXB	SHMINB	SHTIMINB	SHAVEB
49	229	89	1600	77	700	81 7	3.8	82	2045	78	800	79 7	86	1800	78	730	83.9	1.9	87	1915	81	745	86.0
50	230	91	1615	77	730		3 8	83	1845	79	815	80.4	89	1400	79	745	83 8	1.9	87	2100	82	630	85.2
51	231	93	1600	78	800	.	3.7	85	1845	79	830	81 5	90	1130	80	515	84.5	1.8	87	1815	82	800	84.8
52	232	90	1515	78	815	83 2	3 7	83	1815	79	830	80 3	89	1315	80	515	84.0	1.8	85	2000	82	815	84 3
53	233	85	1730	79	830	81.4	3 7	82	1915	79	845	80.4	84	1400	81	615	81.7	1.8	85	1500	83	915	83.8
54	234	91	1530	79	630	84 0	3 7	85	1845	79	700	81.5	90	1345	80	600	84.5	1.8	87	1930	82	830	84.3
55	235	87	1515	80	815	82.9	3 7	83	1930	80	900	81.7	87	1515	81	715	83 4	1 8	86	2000	83	930	84.9
56	236	92	1615	79	815	83.9	3.7	86	1815	80	900	81.9	87	1400	80	700	84.2	1.8	87	1615	83	1000	86.3
57	237	90	1645	76	830	82.5	3.6	84	1600	77	845	81.4	87	1300	77	530	82.5	1.7	86	1830	80	830	83.4
58	238	89	1700	76	915	81 0	3.7	82	1915	76	615	79 0	85	1430	77	715	80.0	1.8	84	1815	80	830	82.2
59	239	89	1645	73	900	80.0	3.7	81	1900	74	845	77.4	86	1330	75	730	79.8	1.8	83	1930	78	830	80 6
60	240	.	.	75	815		3.7	81	1900	75	830	78.3	88	1400	76	730	81.7	1.8	84	1900	79	845	81.7
61	241			79	900	.	3 6	85	1615	79	900	81.5	89	1430	78	815	83.4	1.7	86	1800	82	900	83.7
62	242	92	1600	78	930	84.8	3 6	85	1900	79	900	82.1	91	1445	78	845	83.7	1.7	85	2000	81	945	83.5
63	243	86	1800	79	1000	82.1	3.6	83	1845	80	930	81.5	85	1800	78	900	82.0	1.7	85	15	82	1215	84.8
64	244	92	1515	77	845	83 2	3.6	84	1900	77	915	80 7	90	1330	75	745	82.0	1.7	85	1800	79	845	82.3
65	245	89	1700	78	915	83.5	3.7	84	1845	78	845	81.3	88	1415	77	800	81.7	1.8	84	1900	80	815	82.3
66	246	88	1645	78	930	82.2	3 7	83	1800	77	900	80.1	86	1445	75	800	80.5	1.8	82	1815	78	930	80.8
67	247	89	1645	79	900	82 8	3.7	84	1800	78	845	80 7	84	1515	78	815	80.0	1 8	83	1915	80	945	81.7
68	248	87	1615	74	945	79 6	3.6	81	1830	73	915	77 2	82	1500	71	915	76.2	1.7	80	1900	74	930	77.4
69	249	87	1630	72	915	78.6	3 6	79	1845	73	930	76 3	83	1415	69	745	75.7	1.7	78	1915	72	845	76 0
70	250	86	1630	73	900	78 9	3 6	80	1930	73	930	76 8	85	1430	69	815	77.4	1 7	79	2015	73	915	76.6
71	251			74	945		3 6	82	1800	75	845	78.2	83	1245	71	645	76.3	1.7	80	1800	75	745	78.0
72	252	81	1600	.	.		3.6	79	1930	76	930	77 5	80	1615	74	830	76 5	1 7	80	1915	77	1015	78 2
73	253	80	1745	74	1100	76.4	3.7	79	15	75	1130	75.6	79	1745	75	400	76.8	1.8	79	1815	77	800	78.2
74	254	89	1615	75	730	80 5	3 7	80	1830	75	815	77.2	85	1615	75	745	80.0	1.8	81	1815	78	830	79.5
75	255	88	1530	76	900	81 4	3 6	81	1745	76	900	78.1	85	1500	75	915	80.0	1.7	82	1945	78	915	80.3
76	256	90	1600	76	930	82 1	3 6	82	1830	76	845	78.5	87	1530	75	930	79 8	1.7	82	2000	77	1000	80.3
77	257	89	1600	77	830	82 2	3.7	82	1830	76	900	79.3	87	1630	75	1015	81 8	1 8	82	1915	78	1030	80 8
78	258	91	1530	77	900	82 9	3.7	83	1830	77	845	80.3	87	1415	76	815	80.9	1.8	83	1700	79	830	81 5
79	259	82	15	73	2345	77 5	3.7	82	15	73	2345	76.9	80	15	71	2345	76.2	1.8	82	15	75	2345	78.9
80	260	80	1600	68	915	71 7	3.7	75	1845	68	900	71 5	77	1345	70	2345	73.1	1.8	77	1845	73	900	74.8
81	261	80	1600	66	845	71 0	3.7	73	1930	66	900	68.6	76	1700	67	745	70.9	1.8	75	1830	69	830	72.3
82	262	82	1545	68	830	72.9	3 7	74	1915	68	830	69 8	77	1430	67	815	72.2	1.8	75	1830	70	845	72.9
83	263	82	1545	68	845	72 5	3 6	74	1830	67	830	69.4	77	1500	67	900	71.4	1.7	74	1945	69	915	72.0
84	264	82	1500	67	830	72 1	3.6	73	1945	67	900	69 4	76	1545	66	1000	72 0	1.7	74	2100	68	945	72.2
85	265	73	1300	68	800		3.6	.	.	68	845	.	73	1230	66	730	.	1.7	.	.	69	830	.

EAST GLOVER CREEK INTENSIVELY MONITORED POOL TEMPERATURES
POOL. SH=SHADED POOL. UN=UNSHADED POOL. (N)CM=MEASUREMENT DEPTH

OBS	DATE	GRIDPOIN	UNOCM	UN23CM	UN46CM	UN69CM	UN91CM	UN114CM	SHOCM	SH23CM	SH46CM	SH69CM
1	206	1	87.6	.		.	.	.	83.1	83.2	83.2	.
2	206	2	85 6	85.3	84 9	.		.	83 3	83.4	.	.
3	206	3	84 9	84 6			.	.	83 2	82 8	.	.
4	206	4	85.6	85 2	84.9	.	.		83.3	83.2	82.7	.
5	206	5	84 7	83.9	83.6	.	.		83.3	83.4	83.4	.
6	206	6	85.1	84.2	83.1	79.7	78.6	77.6	82.0	81 9	.	.
7	206	7	85 1	84 1	83.0	79.9	78.7	78.1	83.0	83.1	83.1	.
8	206	8	85.0	83.8	83.7	.	.	.	82.7	82 6	.	.
9	206	9	85 0	84.0	.	.	.	.	83 1	83.1	83.1	83.1
10	206	10	83 9	83.4	83.3	.	.	.	83.0	83.0	83.0	.
11	209	1	82 3	82 8	.		.	.	80.9	80 9	80.8	.
12	209	2	81.8	81.6	81 6	.	.	.	81.0	81.0	81.0	.
13	209	3	82.1	81.5	.	.	.	.	80.8	80.7	.	.
14	209	4	82.1	82 1	.	.	.	.	81.0	81.1	80.9	.
15	209	5	81 5	81 2	81 2	.	.	.	81.1	81.2	81.2	.
16	209	6	81 8	81.4	81.2	81.2	79.0	78.5	80.9	80.2	.	.
17	209	7	82.2	81 3	81.1	81.0	81.0	81.0	81.2	81.2	81.2	.
18	209	8	82.1	81.3	81.3	.	.	.	81.1	81.1	.	.
19	209	9	81.4	81.1	81 3	.	.	.	81 2	81.3	81.3	81.3
20	209	10	81 5	80.8	80.8	.	.	.	81.4	81.4	81.3	.
21	213	1	86.9	.	.	.	.	.	80.2	80.1	80.1	.
22	213	2	84.4	83.2	82 8	.	.	.	80.0	79 9	.	.
23	213	3	84 7		.		.	.	79.8	79.7	.	.
24	213	4	83 4	82.1		.	.	.	80.0	80.1	80.0	.
25	213	5	83 2	81 3	81 0	.	.	.	80.0	80.4	80.5	.
26	213	6	83.5	81 3	80 4	77.4	76.6	.	79.3	78.3	.	.
27	213	7	83 7	81.8	80 6	77.9	76.8	76.7	80.1	80.4	80.4	.
28	213	8	83 4	81.6	81.3	.	.	.	79 9	79 6	.	.
29	213	9	83.8	81.9				.	80.2	80 4	80.4	80.4
30	213	10	82.9	80 4	80 4	.	.	.	80 4	80 5	.	.
31	216	1	80 2	79.7	.	.	.	.	78 6	78.7	78.7	78.7
32	216	2	79.5	79.3	79.3	79 2	.	.	78.6	78.8	78.7	.
33	216	3	79 6	79 1	.	.	.		78.5	78.5	.	.
34	216	4	79 2	79.2	.	.	.	.	78.5	78 7	78.7	.
35	216	5	78 6	78.6	78.6	78.4	.	.	79.3	78.8	78.8	.
36	216	6	79 5	78.8	78 7	78 5	78 2	73.6	78 5	78 4	.	.
37	216	7	79 3	78.6	78 6	78 6	78.6	78.5	78 7	78.9	78 8	78.7
38	216	8	79 4	78.8	78.7	.	.		78 7	78.5	78.3	.
39	216	9	78 5	78 6	78 6	.	.	.	78 8	78 8	78.9	78.9
40	216	10	78 3	78.5	78.4	.		.	79.0	79 1	79.1	.
41	220	1	85 5	85 7		.	.	.	82.5	82 5	82.5	.
42	220	2	85.1	84.2	83.9			.	82 6	82 6	82.5	.
43	220	3	84 6	83.4	.		.	.	82 4	82 4	.	.
44	220	4	85.2	84.1	83.8	.	.		82 4	82.4	82.4	.
45	220	5	84 4	83 2	83 0	83 0	80.0		82 6	82.6	82.5	.
46	220	6	84 2	83 4	83.2	82.9	80.0	78.7	82.1	81.1	.	.
47	220	7	84 7	83.4	83 0	82 7	80.3	79.2	82 2	82.3	82.1	.
48	220	8	84.3	83 5	83 2	.	.		82 1	82 0	.	.
49	220	9	84 0	83.2	83 4	.	.		82.3	82.3	82.3	82.3
50	220	10	84 3	82 8	82 7	.	.	.	82 1	82.1	82.1	.
51	223	1	84 6	84.3		.	.		81.2	81.3	81.2	.
52	223	2	84 2	83.0	82.4	.	.		81.3	81.3	.	.
53	223	3	83 8	81 9		.		.	81.1	80.8	.	.
54	223	4	83 9	82 3	82 1	.			81.2	81 3	80.7	.
55	223	5	82 8	81 5	81 4	81 5			81 3	81 5	81.4	.

EAST GLOVER CREEK INTENSIVELY MONITORED POOL TEMPERATURES
POOL, SH-SHADED POOL, UN=UNSHADED POOL, (N)CM=MEASUREMENT DEPTH

OBS	DATE	GRIDPOIN	UNOCM	UN23CM	UN46CM	UN69CM	UN91CM	UN114CM	SHOCM	SH23CM	SH46CM	SH69CM
56	223	6	83.4	81 6	81 4	81.1	78.7	78.1	81.3	80 4	.	.
57	223	7	82 8	81.5	81 3	81.1	80 8	78 7	81 0	81.2	81.2	.
58	223	8	82 2	81 6	81.6	.	.	.	81.0	80 4		.
59	223	9	81 5	81 3	81.4	.	.	.	81 2	81.2	81.2	81.1
60	223	10	81.8	81 1	81 0	.	.	.	80.9	80.9	80.9	.
61	227	1	86.3	87.2	.	.	.		84.6	84.6	84.5	.
62	227	2	87 2	86 9	86.5	.	.	.	83 1	84.6	84.9	.
63	227	3	85 7	85 6	85 5	.	.	.	84.3	84.2	.	.
64	227	4	87 0	86 7	86 3		.	.	84.3	84.4	84 5	.
65	227	5	86 3	85 5	84 7	.	.		84 1	84 4	84 4	.
66	227	6	85 9	85.6	84.9	81 3	80.1	79.1	83.1	82.1	.	.
67	227	7	85 6	85.9	84 6	81.9	80.8	79.8	84 0	84 1	83.9	.
68	227	8	85 6	85 6	85 4		.	.	83 7	83.0	.	.
69	227	9	85 9	85.5	85 5	.	.	.	83 8	84.0	84.0	83.7
70	227	10	85 8	84.7	84 6	.		.	83.7	83.8	83.7	.
71	230	1	88 6	89 1	.	.	.	.	87.3	87.5	85.9	.
72	230	2	89.3	89.7	89.1	.	.	.	87.2	87 2	87.1	.
73	230	3	88 9	88.0	88 1	.	.	.	87.0	86 3	.	.
74	230	4	90 0	89 6	89.5	.	.	.	87.0	87.0	86.3	.
75	230	5	89 4	88.2	86.2	.	.	.	87.0	86.9	86.7	.
76	230	6	89 0	88.3	86 1	82.9	81.2	80.2	86 0	84 5	.	
77	230	7	89 0	88 3	86 4	83 1	82.1	81.0	86.5	86.5	86 1	.
78	230	8	88 9	88.2	87 5	.	.		86.4	85.0	.	.
79	230	9	89 0	88.4	88.5	.	.	.	86.0	86 0	84.9	82.1
80	230	10	88 8	87 3	87 2	.	.	.	85.8	85.8	85.7	.
81	234	1	90 7	91 4	.	.	.	.	87.0	87 3	86.4	.
82	234	2	89.9	90 1	89.7	.	.	.	86.7	87.3	.	.
83	234	3	89.9	88.6	88.4	.	.	.	86 8	86 7	.	.
84	234	4	90.1	90.2	89.1	.	.	.	86.5	87.1	86.8	.
85	234	5	89 9	89 0	86 8	.	.	.	87 1	87.2	87.0	.
86	234	6	89 6	88 5	86 9	83.8	82 0	81.6	85 6	84.8	.	
87	234	7	89.8	89 2	86.5	83.9	83.1	82.2	86 6	86.7	85 7	.
88	234	8	89 8	89.3	88 3	.	.	.	86.5	84.6	.	.
89	234	9	89.8	89.3	.		.	.	86.7	86.6	83.3	82.3
90	234	10	89 5	87.3	87.4		.	.	86 5	85.3	.	.
91	237	1	89 5	89.3	.	.	.	.	84 3	85 2	83.7	.
92	237	2	89 0	88 3	88 9		.	.	85.0	85.3	.	.
93	237	3	89 4	88 1	87.6	.	.	.	84 8	84 4	.	.
94	237	4	89 2	89.2	87 3	.	.	.	84.8	84.9	84.9	.
95	237	5	89 0	88.1	86 7	.	.	.	85 0	85 1	84.9	.
96	237	6	88 5	87.6	84.8	83.6	81 5	79.9	82 8	82.0	.	.
97	237	7	88 8	88 9	85 6	82.2	81.3	80 5	84 8	84 6	84.4	.
98	237	8	88 8	88 1	87.1	.	.	.	84.4	82.8		.
99	237	9	88 9	88.7			.	.	84.4	84 4	82.5	80.6
100	237	10	88 7	85 8	85 7	.	.	.	84.4	84 0	83.8	.
101	241	1	89 5	.		.	.	.	86.9	86.4	85.3	.
102	241	2	89 8	89.6	89.4	.	.	.	87.2	87 1	.	.
103	241	3	90 4	89 4			.		86 9	86.6	.	.
104	241	4	90.3	90 2	89.6	.	.	.	86 9	86 7	86.6	.
105	241	5	89 8	88.6	87 7	.			87.2	86.8	.	.
106	241	6	89 8	88 8	86 2	82.7	82 1		85 0	.	.	.
107	241	7	89 7	89 7	86 5	83 5	82 6	82 6	86 6	86 5	85.1	.
108	241	8	90 1	89 4		.		.	86 7	85 5	.	.
109	241	9	90 5	90 3	.		.		86 6	85.9	82.0	81.1
110	241	10	90 2	88.0	.		.		86.2	84 3		.

EAST GLOVER CREEK INTENSIVELY MONITORED POOL TEMPERATURES
POOL, SH=SHADED POOL, UN=UNSHADED POOL, (N)CM=MEASUREMENT DEPTH

OBS	DATE	GRIDPOIN	UN0CM	UN23CM	UN46CM	UN69CM	UN91CM	UN114CM	SH0CM	SH23CM	SH46CM	SH69CM
111	244	1	90 4	.	.		.	.	85 6	84.9	84.8	.
112	244	2	89 9	89 8	89 4	.	.	.	85 4	85 1	.	.
113	244	3	90 5	88 7	.	.	.	.	85 3	85.1	.	.
114	244	4	90 4	89 6	87.9	87 3	.		85 2	85.5	85.2	.
115	244	5	89 9	89.1	87 1		.		84 5	85.2	85.0	.
116	244	6	89.7	88 8	85 5	82 8	81.4	80 9	82 6	82 5	.	.
117	244	7	89 9	89 1	85 5	83 2	82.4	82.1	84 8	84.5	83.2	.
118	244	8	89 7	89 2		.		.	84.7	84.6		.
119	244	9	90 4	90.1		.	.	.	84.9	84 6	80.8	80.5
120	244	10	89 8	87 4	.	.	.	.	85.1	84.4	.	.
121	248	1			.		.	.	80 2	80 1	79.7	.
122	248	2	85.5	84.7	84 6		.	.	80.7	80.8	.	.
123	248	3	86 3	86 1	.	.	.	.	80.2	79 7	.	.
124	248	4	85 9	84.6	84.4	.	.		80.1	80 0	79 8	.
125	248	5	85 7	85 0	83 7	.	.		79 9	79.8	.	.
126	248	6	85 8	84 8	82 4	78.2	.	.	79 6	.	.	.
127	248	7	85.9	85.3	81 1	79 8	78.6	78.7	79.2	79.2	78.9	.
128	248	8	85 4	84.5	.	.	.	.	79.2	78.7	.	.
129	248	9	86 3	86 0	.	.	.	.	79.3	79 0	77.2	77.0
130	248	10	86.2	84.5		.	.	.	80 3	79 2	.	.
131	251	1	82.5		.	.	.		77 6	78.4	78.2	.
132	251	2	82 6	82 6	82 6	.	.	.	78.7	78 9	.	.
133	251	3	83 7	83.7	.	.	.	.	78 7	78 3	.	.
134	251	4	83.1	83 0	82 7	.	.	.	78.3	78.8	78.9	.
135	251	5	82 7	83.1	82 8	.		.	77.9	78.6	.	.
136	251	6	82.6	83 4	82 8	79.8	78.5	78 1	73 6	73.6	.	.
137	251	7	82 5	83 4	82.9	80.3	79.7	79.5	77 9	78 2	78.2	.
138	251	8	82 6	82 8	.	.	.	.	78 0	77 9	.	.
139	251	9	83.4	84.2	.	.	.	.	78 2	78 4	76.6	75.8
140	251	10	82 7	83.3	.	.	.	.	76.6	77 1	.	.
141	255	1	.	.	.		.		83.5	83.3	82.5	.
142	255	2	86 9	86.5	86 2	.	.	.	84 2	84.1	.	.
143	255	3	88 0	87.7	.	.		.	83 7	83 4	.	.
144	255	4	87 3	86 6	84.3	.	.	.	83.7	83.6	83.5	.
145	255	5	87 3	86.5	84.5			.	83 8	83 5	.	.
146	255	6	87 5	87.2	82.1	80.6	79.2	.	81.7	.	.	.
147	255	7	87 1	86 5	82 2	80 5	79.8	79.7	83.1	83 0	82.3	.
148	255	8	87.5	85 2	.	.	.	.	83 1	82 2	.	.
149	255	9	88 1	87 8		.	.	.	83 5	82.9	79 5	79.2
150	255	10	87 7	85 8		.	.	.	82 9	81.6	.	.

AIR TEMPERATURES RECORDED WITH THERMOGRAPHS AND SOLAR RADIATION DATA RECORDED WITH PYRANOMETER AT EAST GLOVER CREEK

OBS	DATE	MAXAIRT	TIMMAX	MINAIRT	TIMMIN	AVEAIRT	TIMMAXR	PEAKRAD	DAILYRAD	WIND
1	181	99	1600	.	.			.	.	.
2	182	97	1530	65	500	72 8		.		
3	183	96	1530	63	500	71 6			.	.
4	184	97	1600	66	400	74 6				.
5	185	98	1530	68	530	76 4	.		.	.
6	186	98	1500	68	530	72 8		.		.
7	187	96	1600	69	400	71.6				.
8	188	101	1600	69	600	77.0			.	.
9	189	102	1600	69	600	76.4		.	.	.
10	190	100	1600	68	630	77.0	.	.		.
11	191	96	1600	69	630	77 6	.	.	.	.
12	192	98	1600	69	630	78.2	1300	1 13		.
13	193	100	1630	70	700	76.4	1330	1 06	948 5	
14	194	96	1630	71	700	74 6	1315	1 17	893.8	.
15	195	97	1630	70	500	76.4	1330	1.15	875.5	.
16	196	98	1630	70	700	77 0	1345	1.05	1057.9	.
17	197	99	1600	69	700	77 6	1430	1 07	1130.9	.
18	198	82	1700	72	400	75 0	1730	0.78	182.4	.
19	199	101	1700	69	2300	75 2	1400	1.26	1003 2	.
20	200	99	1800	61	730	73 4	1345	1 12	1076 2	.
21	201	98	1600	62	700	71 0	1315	1 13	1057 9	.
22	202	100	1630	55	630	70 4	1245	1.16	1112.6	.
23	203	101	1630	59	500	73 4	1315	1 13	1076.2	.
24	204	102	1530	60	630	72 8	1315	1 15	1003 2	.
25	205	96	1430	63	800	69 8	1400	1 00	711.4	.
26	206	99	1700	61	630	72 8	1245	1.09	.	0.71
27	207	92	1330	64	800	69 2	1200	1 22	419.5	.
28	208	96	1530	64	830	69 8	1330	1 16	.	
29	209	99	1630	69	930	73.4			.	0.21
30	210	94	1500	70	1030	73 4		.	.	.
31	211	94	1530	61	500	70.4		.		.
32	212	94	1500	56	530	68 6	.			.
33	213	95	1530	57	600	69 8	1315	1 14		0.06
34	214	88	1230	62	200	69 8	1245	1.10	565 4	.
35	215	86	1130	61	2345	67 4	1545	1 07	583 7	.
36	216	94	1600	61	530	69 2	1400	1 08	857.3	0.13
37	217	95	1530	64	600	72.2	1215	1 08	985 0	.
38	218	91	1500	65	630	70 4	1215	1 12	.	.
39	219	96	1530	68	630	74 6	1430	1.05		.
40	220	97	1600	67	430	75 8	1315	1 14	820 8	0.31
41	221	96	1600	67	600	74.0	1330	1.05	857.3	.
42	222	78	900	71	730	72 5	1530	0.53	237.1	
43	223	99	1700	69	400	75 2	1500	1 10	766 1	0.23
44	224	99	1300	68	530	75 8	1300	1.09	820 8	.
45	225	103	1500	63	630	75.2	1315	1.16	1003 2	.
46	226	100	1500	65	600	74 0	1400	1 01	893.8	.
47	227	96	1530	64	630	72 8	1430	1.00	857 3	0.23
48	228	97	1600	64	630	73 4	1415	1 01	875 5	.
49	229	99	1500	67	300	75 8	1300	1.00	747 8	.
50	230	103	1500	68	530	76 4	1245	1 00	893 8	0 20
51	231	109	1500	68	630	79.4	1430	1.02	930.2	.
52	232	108	1430	68	630	79 4	1315	1 12	693 1	.
53	233	91	1600	74	500	75 8	1515	1 15	620.2	.
54	234	102	1630	74	15	80 0	1345	1.02	747.8	0.13
55	235	102	1730	71	630	76 4	1500	1 10	565 4	
56	236	103	1630	69	2345	77 0	1230	1 17	820.8	.
57	237	96	1600	62	700	72 2	1300	1.05	985 0	0 45
58	238	99	1630	61	730	72 8	1315	1 04	802 6	.
59	239	100	1600	59	700	70 4	1300	1 03	820 8	.
60	240	103	1600	64	700	75.2	1315	1.09	802 6	.
61	241	102	1730	71	730	78 8	1430	1 04	766.1	0.60
62	242	108	1730	67	730	80.6	1315	1 02	893.8	.
63	243	102	1630	69	700	75.8	1345	1.03	547 2	.
64	244	105	1830	61	730	78 2	1330	1 01	893 8	0 50
65	245	100	1730	65	800	77.0	1245	1 07	857.3	.
66	246	98	1800	63	700	72.2	1315	1.12	674 9	.
67	247	99	1800	63	830	73.4	1330	1.16	766.1	.
68	248	98	1800	52	900	66 8	1400	1 05	1021 4	0.60
69	249	101	1800	54	930	69 2	1300	0 99	948 5	
70	250	98	1830	56	830	70 4	1300	0.98	893 8	.
71	251	93	1830	59	1000	72 8	1315	1 00	893 8	0 87
72	252	91	1800	73	800	74 6	1230	0 83	456 0	.
73	253	94	1900	66	600	71 0	1345	1.00	383 0	.
74	254	96	1830	63	800	74 6	1430	1 01	766.1	.
75	255	95	1900	64	1000	73 4	1330	1 02	638 4	0.57
76	256	97	1930	64	1000	72 8	1245	1 05	747 8	.
77	257	98	1900	65	1000	74 6	1300	0 97	693 1	.
78	258	101	1800	66	1030	74 6	1300	1 02	693 1	
79	259	86	1830	56	2345	66 8	1445	0 94	510 7	.
80	260	87	1830	50	430	61 4	.	.		.
81	261	91	1830	48	900	62.6	.		.	.
82	262	92	1930	52	1000	66.2			.	.
83	263	92	1930	51	900	65 0	.		.	.
84	264	92	1930	49	1030	63 8				.
85	265	81	1430	54	1030	62 6				.

TEMPERATURES RECORDED WITH MAXIMUM-MINIMUM THERMOMETERS AT ROCK CREEK
P=POOL NUMBER, S=POOL SURFACE, B=POOL BOTTOM

OBS	DATE	MAXP1S	MAXP1B	MAXP2S	MAXP2B	MAXP3S	MAXSP3	MAXP3B	MAX3PS	MAXP4S	MAXSP4	MAXP4B	MAX4PS	MAXP5S	MAXP5B	MAXP6S	MAXP6B	STAGE
1	185	.				.							.	92	86	90	89	0.0
2	186	88	80	92	88	90	90	87	90	91	96	87	91	89	88	90	84	0.0
3	187	82	82	85	85	80	87	85	86	89	88	88	87	87	84	87	86	0 1
4	188	87	83	87	87	88	88	88	88	88	88	.	89	89	87	89	86	0.1
5	190	89	.	90	.	91	90	89	92	92	92	92	93	92	92	93	91	0.0
6	191	88	87	90	90	91	91	92	92	90	93	.	92	92	90	93	91	0.0
7	192	88	87	92		93	91	92	93	93	92	.	92	92	90	93	.	-0 2
8	193	89	87	93	91	92	92	91	93	93	93	92	93	93	90	93	90	0.0
9	194	86	85	89		88	88	88	88	89	90	88	89	89	88	88	87	0.0
10	195	87	86	89	89	89	89	89	90	90	91	89	91	89	90	91	88	0 0
11	197	90	87	93	93	94	93	93	93	93	95	94	95	94	90	94	89	0 0
12	198	83	83	85	85	84	84	85	84	84	85	84	80	84	85	85	85	0.0
13	199	85	83	88	87	88	88	88	89	89	89	88	89	89	86	90	86	0.0
14	200	87	83	90	88	90	90	89	91	91	92	90	92	92	86	92	86	-0 2
15	201	84	84	88		89	88	89	89	90	90	89	91	88	86	90	85	-0.2
16	202	86	80	89	86	89	88	87	95	89	90	88	90	90	83	90	83	-0.3
17	204	88	81	91	87	90	88	88	93	91	90	90	91	92	83	92	85	-0.3
18	205	84	79	86	83	85	85	83	85	86	85	83	86	87	80	83	81	-0.3
19	207	85	79	89	86	89	88	86	89	89	90	87	90	90	82	88	83	-0 2
20	208	88	81	90	88	90	89	88	90	90	90	87	91	91	83	91	83	-0.1
21	213	84	80	88	85	87	87	86	87	82	.	87	88	88	83	89	84	0 2
22	214	78	77	80	80	80	79	81	80	80	82	80	81	81	81	82	83	0.2
23	215	77	77	79	79	79	79	79	79	79	80	79	80	81	80	80	81	0.1
24	216	80	79	83	83	83	82	82	83	83	85	84	85	84	85	85	84	0.0
25	218	82	80	85	84	84	84	85	84	85	86	85	86	86	85	87	83	0 0
26	219	83	80	86	85	86	85	86	85	86	87	86	88	87	86	87	84	0.0
27	220	84	82	87	87	88	86	86	87	87	88	77	88	88	86	89	85	0 0
28	222	84	83	87	86	87	85	85	87	86	89	87	89	88	87	89	85	0.3
29	223	82	80	84	83	84	83	84	84	83	84	83	85	84	84	85	85	0.2
30	225	82	81	84	83	84	83	85	84	84	85	84	85	85	85	86	86	0 2
31	226	83	80	86	85	86	85	85	86	86	88	87	87	87	87	88	88	0.2
32	227	84	82	85	85	85	85	85	85	86	87	86	87	87	87	87	87	0.2
33	228	83	81	84	83	84	84	85	85	85	86	86	87	86	87	87	88	0 1
34	229	84	82	87	86	87	86	87	87	87	88	87	88	88	89	89	87	0 0
35	230	88	86	90	90	91	90	90	90	91	93	90	92	92	90	92	88	0.0
36	232	88	85	91	89	91	89	90	90	90	92	90	92	92	90	92	88	-0.1
37	233	84	82	86	85	85	85	85	85	85	87	86	87	86	85	86	84	-0.1
38	234	88	83	89	88	88	88	88	88	89	90	88	90	90	86	91	87	-0.2
39	235	86	82	88	87	87	86	87	88	88	89	88	89	88	86	88	85	-0.2
40	236	88	84	90	90	89	89	89	89	90	90	89	90	90	88	90	86	-0 2
41	237	86	80	89	88	89	88	87	89	89	90	89	90	88	84	90	85	-0.2
42	239	87	80	88	88	88	86	85	92	86	88	86	89	88	82	89	81	-0.3
43	240	86	80	88	86	87	87	85	94	88	88	84	89	89	81	90	82	-0.3
44	241	89	83	92	90	92	91	88	91	91	91	90	91	94	86	94	87	-0 3
45	242	87	83	92	82	90	90	87	91	90	90	.	81	93	85	94	88	-0.3
46	243	85	82	87	87	88	86	84	87	86	88	87	87	88	84	86	85	-0.4
47	244	88	82	91	88	91	90	87	90	91	92	89	91	92	84	82	85	-0 4
48	246	86	82	88	90	88	88	87	88	90	90	88	89	88	86	89	87	-0 4
49	247	86	82	89	88	90	88	87	88	90	90	88	86	88	86	88	87	-0 4
50	248	82	78	86	82	87	85	81	85	87	88	85	88	86	79	87	82	-0 5
51	249	81	77	86	83	86	83	82	84	86	87	85	87	85	78	86	81	-0.5
52	250	82	76	86	83	86	83	82	84	87	88	86	88	87	79	88	81	-0 5
53	251	81	77	85	84	86	82	82	84	86	86	85	85	82	78	87	81	-0.5
54	253	80	77	84	80	83	83	79	82	84	84	82	84	82	86	84	87	-0 3
55	254	88	86	88	85	88	88	83	88	88	88	86	89	90	80	89	81	-0 4

TEMPERATURES RECORDED WITH MAXIMUM-MINIMUM THERMOMETERS AT ROCK CREEK
P=POOL NUMBER, S=POOL SURFACE, B=POOL BOTTOM

OBS	DATE	MAXP1S	MAXP1B	MAXP2S	MAXP2B	MAXP3S	MAXSP3	MAXP3B	MAX3PS	MAXP4S	MAXSP4	MAXP4B	MAX4PS	MAXP5S	MAXP5B	MAXP6S	MAXP6B	STAGE
56	255	86	79	88	85	88	87	84	87	88	85	86	89	90	81	90	85	-0 3
57	256	85	80	88	86	88	86	85	87	88	85	86	89	89	83	89	84	-0.3
58	257	86	80	89	85	89	88	85	88	89	90	87	90	91	82	90	85	-0 4
59	260	88	86	87	86	88	88	85	88	89	89	88	89	87	86	88	87	-0 4
60	261	86	78	88	86	80	78	77	80	81	82	86	81	80	81	82	85	-0 5
61	262	82	79	89	84	83	80	78	79	82	83	87	83	83	74	81	84	-0.4
62	263	76	71	80	78	82	80	77	80	82	82	80	82	80	74	79	77	-0 4
63	264	78	71	80	76	82	80	78	80	82	82	80	82	82	72	81	75	-0.4

MAXIMUM-MINIMUM THERMOMETER READINGS AT ROCK CREEK
P=POOL NUMBER, S=POOL SURFACE, B=POOL BOTTOM

OBS	DATE	MINP1S	MINP1B	MINP2S	MINP2B	MINP3S	MINSP3	MINP3B	MIN3PS	MINP4S	MINSP4	MINP4B	MIN4PS	MINP5S	MINP5B	MINP6S	MINP6B
1	185			.				.	.	.	.	.		78	80	78	77
2	186	78	80	78	80	79	76	81	78	80	77	80	78	78	78	76	80
3	187	.	80	78	80	80	77	80	79	80	79	82	78	76	79	77	79
4	188	80	82	80	80	79	78	80	80	80	79		77	79	83	80	81
5	190	80		81		82	79	82	81	80	82	82	81	82	80	80	82
6	191	76	82	83	84	83	80	81	82	85	82	.	80	81	81	83	81
7	192	79	82	83	.	82	80	82	82	82	82	.	81	80	82	81	.
8	193	80	82	82	83	82	80	82	81	82	82	82	80	80	81	85	80
9	194	80	81	82	.	82	80	82	81	81	81	81	79	80	81	80	79
10	195	81	81	83	84	83	80	83	82	82	82	83	81	80	84	82	81
11	197	82	82	82	82	82	80	81	81	83	82	82	81	80	82	82	80
12	198	78	80	80	80	80	79	79	80	80	80	80	83	78	79	79	77
13	199	76	77	78	78	78	76	77	77	77	77	77	76	76	77	76	75
14	200	76	76	76	77	76	74	76	75	76	76	76	75	74	75	74	74
15	201	73	74			74	73	74	74	74	74	74	73	71	74	74	72
16	202	74	75	76	76	75	73	75	64	75	75	75	74	72	74	74	74
17	204	74	75	75	76	75	73	75	75	76	75	75	75	74	75	76	74
18	205	73	73	74	74	74	73	74	74	74	74	74	72	73	73	73	73
19	207	74	75	76	78	76	75	76	75	76	76	75	74	75	74	75	74
20	208	77	77	78	78	78	77	78	77	79	78	78	76	78	77	78	74
21	213	73	74	74	74	74	73	75	74	74		74	73	73	74	74	73
22	214	74	76	76	76	76	74	75	75	76	76	75	74	74	75	75	74
23	215	72	74	74	74	74	72	74	73	74	74	73	73	72	73	73	72
24	216	74	74	76	76	76	75	76	75	76	75	75	75	75	74	76	73
25	218	76	78	78	79	78	76	77	77	77	77	76	75	76	76	77	77
26	219	77	78	80	80	79	78	79	79	79	79	79	77	78	78	78	78
27	220	78	79	79	79	79	77	79	78	80	79	79	78	77	78	78	77
28	222	74	75	76	76	75	74	76	75	77	75	75	73	74	75	75	75
29	223	75	77	77	78	77	76	77	76	78	77	77	75	76	77	77	76
30	225	76	77	78	78	78	76	77	76	78	78	77	76	76	77	77	76
31	226	77	78	79	78	79	77	79	78	80	78	78	77	78	79	78	77
32	227	76	79	80	79	79	77	80	79	79	79	79	77	78	78	79	79
33	228	79	80	81	81	80	79	80	80	81	82	80	79	79	79	80	78
34	229	80	80	80	80	80	78	79	79	80	80	79	78	79	78	80	78
35	230	80	81	81	82	81	79	81	81	81	81	81	79	80	80	80	79
36	232	82	81	82	82	81	80	80	80	82	81	81	79	80	80	80	79
37	233	78	80	80	81	80	79	80	80	81	80	80	79	79	80	80	79
38	234	80	80	81	81	81	86	81	80	81	81	81	79	80	80	80	79
39	235	80	79	82	82	82	80	82	82	82	81	82	81	81	80	81	79
40	236	77	77	78	78	78	76	77	77	78	77	78	76	76	77	76	76
41	237	76	77	77	77	76	85	77	76	76	76	76	75	76	75	76	74
42	239	75	75	75	76	77	76	78	74	76	79	78	78	78	77	75	75
43	240	74	74	78	78	78	78	79	74	79	79	79	79	76	76	74	73
44	241	78	79	79	79	79	77	80	78	80	77	79	78	78	79	79	78
45	242	80	80	80	80	80	78	81	79	82	78	.	90	79	80	79	80
46	243	76	77	76	78	76	75	78	76	78	77	77	76	75	76	74	76
47	244	76	77	77	78	77	75	78	78	78	79	79	77	76	76	78	78
48	246	77	77	76	76	77	74	77	78	78	78	78	75	73	77	78	77
49	247	70	73	70	71	72	71	73	70	72	74	74	71	71	71	71	71
50	248	70	72	70	71	71	69	72	67	71	72	72	71	70	70	68	69
51	249	70	73	71	71	71	70	72	71	71	73	74	71	70	70	72	70
52	250	72	74	71	72	72	69	73	72	73	73	73	72	70	71	73	70
53	251	72	73	72	73	73	72	74	73	75	76	75	75	71	72	75	71
54	253	74	75	74	75	74	72	75	73	75	76	77	75	73	74	74	73
55	254	75	75	75	75	75	74	76	75	76	76	76	75	74	76	76	75

MAXIMUM-MINIMUM THERMOMETER READINGS AT ROCK CREEK
P=POOL NUMBER, S=POOL SURFACE, B=POOL BOTTOM

OBS	DATE	MINP1S	MINP1B	MINP2S	MINP2B	MINP3S	MINSP3	MINP3B	MIN3PS	MINP4S	MINSP4	MINP4B	MIN4PS	MINP5S	MINP5B	MINP6S	MINP6B
56	255	75	75	75	75	75	73	73	75	75	75	75	75	75	76	76	75
57	256	76	77	76	76	76	74	76	75	76	76	76	76	75	76	76	75
58	257	76	77	76	77	77	75	77	77	77	78	78	78	76	77	78	76
59	260	65	66	64	65	66	64	66	65	66	66	65	66	66	66	64	64
60	261	65	67	76	67	67	68	68	66	68	65	64	68	64	66	66	65
61	262	68	68	65	66	67	66	68	66	68	65	67	68	67	67	67	67
62	263	67	67	66	67	66	66	67	66	67	68	68	68	66	67	68	67
63	264	61	67	64	65	66	65	68	66	66	67	67	67	64	65	67	66

THERMOGRAPH DATA AT ROCK CREEK, OP=OPEN POOL, SH=SHADED POOL, S=SURFACE MEASUREMENT, B=BOTTOM MEASUREMENT

OBS	DATE	OPMAXS	OPTIMAXS	OPMINS	OPTIMINS	OPAVES	OPBOTDEP	OPMAXB	OPTIMAXB	OPMINB	OPTIMINB	OPAVEB	SHMAXS	SHTIMAXS	SHMINS	SHTIMINS	SHAVES	SHBOTDEP	SHMAXB	SHTIMAXB	SHMINB	SHTIMINB	SHAVEB
1	180	85	1900	.	.		2.3	83	1730	.	.				.	.	.	.	.	.	.	.	.
2	181	86	1830	81	1200	82.1	2.3	84	1800	80	1100	81.5	89	1600	80	900	83 5	2 5	87	1530	80	930	82.7
3	182	85	2000	80	1030	82.7	2.3	83	1830	80	1030	80.9	88	1630	80	800	83.5	2.5	86	1630	80	730	82.1
4	183	86	1800	80	1100	82 1	2.3	84	1830	80	1030	80 9	90	1600	80	830	84.1	2.5	87	1730	80	800	22 7
5	184	86	2000	80	1030	82 7	2.3	84	1930	79	1030	81.5	90	1600	79	730	83.5	2.5	86	1830	79	730	82.1
6	185	87	1930	80	1100	82 7	2.3	85	1930	80	1100	82 1	93	1430	80	800	84 7	2 5	89	1630	80	800	83.9
7	186	86	1800	81	1100	82 7	2.3	84	1700	80	1030	81 5	94	1300	77	630	82 9	2.5	87	1500	81	800	83.3
8	187	84	1930	80	1330	81 5	2 4	84	1900	79	1130	81 5	87	1530	79	830	81 8	2 6	86	1500	79	830	81.5
9	188	85	1800	81	1130	83 3	2 4	84	1500	80	1100	82 7	88	1800	80	900	82 5	2 6	88	1730	80	830	83.9
10	189	86	1600	82	900	83 3	2 3	86	1500	81	900	82.7	91	1700	82	900	86 5	2 5	90	1600	82	900	85.8
11	190	87	1600	82	830	83.9	2 3	86	1530	81	800	82 7	93	1630	82	830	87 1	2 5	90	1630	82	800	85 8
12	191	87	1700	82	830	84 5	2.3	86	1600	81	800	82 7	93	1700	83	830	87.6	2.5	90	1730	83	800	85.8
13	192	87	1730	82	900	84.5	2 1	86	1600	81	830	83 3	93	1630	83	830	87.1	2.3	90	1730	83	800	85.8
14	193	88	1730	82	830	84 5	2.3	86	1600	81	830	83 3	94	1600	83	800	87 1	2 5	90	1630	83	730	85.2
15	194	86	1800	82	900	84 5	2.3	85	1800	81	930	82.7	90	1730	83	930	84.1	2.5	87	1700	83	800	84 5
16	195	87	1730	82	900	83 3	2 3	86	1700	81	830	82 7	91	1700	82	900	85.9	2.5	88	1530	82	800	83.9
17	196	88	1800	82	900	85 1	2.3	87	1730	81	900	83.9	94	1630	83	830	87.6	2.5	90	1800	83	730	85 8
18	197	88	1830	82	900	85 7	2 3	87	1800	82	930	83.3	94	1630	83	900	87.6	2.5	90	1700	83	800	86.4
19	198	85	15	82	930	83 9	2.3	84	15	82	930	82.7	87	15	83	800	83 5	2.5	85	1600	83	2345	83 9
20	199	86	1600	81	930	82 7	2.3	85	1800	81	930	81 5	90	1430	80	900	84 1	2.5	86	1830	81	830	83.3
21	200	87	1800	80	830	82.7	2 1	86	1800	80	830	82.1	91	1600	79	730	84.1	2.3	86	1900	79	730	82.1
22	201	87	1800	79	830	82 7	2 1	86	1800	79	900	81 5	91	1630	75	800	82.4	2 3	86	1600	77	800	80.3
23	202	86	1800	79	830	81.5	2 0	85	1830	78	830	80 9	90	1600	75	830	81 8	2.2	83	2000	75	730	79.1
24	203	87	1800	79	830	82.1	2.0	85	1830	78	830	81 5	90	1700	75	830	82.4	2.2	83	2030	76	730	80.3
25	204	87	1730	79	830	82 7	2 0	86	1830	78	830	80 9	92	1600	76	830	83 5	2.2	83	2100	76	800	79 7
26	205	85	1400	80	800	82 1	2 0	83	15	79	830	80.9	87	1300	77	730	80.6	2.2	81	1730	77	730	78.5
27	206	86	1800	78	900	81 5	2.1	84	1900	78	830	80.3	90	1600	75	800	80 6	2.3	82	2100	75	700	78.5
28	207	84	1400	80	900	80 9	2 1	82	1330	80	900	81 9	85	1230	78	800	80.0	2.3	81	1700	78	700	79.7
29	208	87	1600	80	830	82 1	2 2	84	1630	79	830	80 9	91	1500	77	700	82 9	2.4	84	1900	77	630	80.3
30	209	85	1830	81	1000	82 1	3 2	84	1830	80	1030	82 1	89	1630	80	930	82 9	3.5	84	1930	79	930	80 9
31	210	82	1830	79	1100	80 3	2.5	82	15	79	1030	80 0	81	1700	77	1000	78 8	2 7	80	1630	77	930	79.7
32	211	82	1900	79	1030	80 3	2.5	81	1900	78	930	79.1	83	1700	75	900	78 8	2.7	82	1630	75	830	77.3
33	212	82	1900	78	1000	80 9	2 5	81	2000	78	930	79 1	82	1700	75	900	78 2	2.7	81	1630	75	800	77.9
34	213	82	1900	78	1000	79 7	2 5	81	1930	78	1000	79 1	82	1600	75	900	78 2	2 7	81	1600	75	800	78.5
35	214	83	1500	79	930	79 7	2.5	81	1930	78	930	79 1	82	1230	76	800	78 2	2 7	81	1600	76	730	78.5
36	215	81	1430	79	1000	80 3	2.4	80	1730	78	1000	79.1	81	1200	76	800	77.6	2 6	79	1200	76	2345	77 3
37	216	84	1400	78	1030	79 7	2.3	82	2030	77	1000	79.1	84	1630	75	730	77.6	2.5	81	1700	75	800	77 9
38	217	84	1400	79	1030	80 9	2.3	82	2100	78	1030	79.1	84	1800	77	800	79 4	2.5	82	2000	77	730	79 1
39	218	84	1830	80	1100	80 9	2 3	82	1900	79	1030	79.7	86	1630	78	930	80 6	2 5	83	1830	77	1000	79.1
40	219	85	2030	81	1200	81.5	2 3	83	2030	80	1230	80.9	87	1930	80	1200	81 2	2.5	84	1830	79	1130	83.3
41	220	85	2030	81	1030	82 1	2 3	83	2100	80	1100	80 3	87	1900	80	900	82.4	2 5	84	2100	79	930	80.9
42	221	85	2030	80	1130	82.7	2 6	83	2100	79	1130	80.9	88	1830	79	1000	82 9	2.8	84	2030	79	1030	80 9
43	222	84	15	80	1500	80 9	2 6	83	15	79	1500	79.7	84	15	79	1230	79.4	2 8	83	15	79	2345	79.1
44	223	82	2100	79	1130	80 3	2 5	80	2330	78	1130	79.1	80	1830	76	930	77 6	2 7	80	2030	76	930	77.3
45	224	83	1900	80	1130	80 9	2.5	82	1900	79	1130	80.3	85	1600	77	930	80 6	2 7	84	1630	77	1000	80 3
46	225	84	2130	80	1200	81 5	2.5	82	2230	79	1200	81 5	85	1930	78	1030	81.2	2.7	84	2100	78	1030	80.3
47	226	85	2100	80	1230	82 1	2 5	83	2200	80	1300	80 9	87	1730	79	1000	81 8	2 7	85	1930	79	1100	81.5
48	227	85	2000	81	1300	82 7	2 4	83	2230	80	1300	80 3	86	1730	79	1100	82.4	2 6	85	2000	79	1100	82.1

THERMOGRAPH DATA AT ROCK CREEK, OP=OPEN POOL, SH=SHADED

POOL, S=SURFACE MEASUREMENT, B=BOTTOM MEASUREMENT

OBS	DATE	OPMAXS	OPTIMAXS	OPMINS	OPTIMINS	OPAVES	OPBOTDEP	OPMAXB	OPTIMAXB	OPMINB	OPTIMINB	OPAVEB	SHMAXS	SHTIMAXS	SHMINS	SHTIMINS	SHAVES	SHBOTDEP	SHMAXB	SHTIMAXB	SHMINB	SHTIMINB	SHAVEB
49	228	85	2000	81	1200	82 1	2.3	83	2200	80	1230	80.9	87	1800	80	1030	83.5	2.5	84	1900	79	1030	82.1
50	229	85	2000	81	1200	82 7	2.3	83	2130	80	1300	81.5	88	1530	81	930	84.7	2 5	85	2030	80	1000	82.1
51	230	87	2100	81	1200	83.3	2 2	84	2130	80	1300	81 5	91	1700	81	930	84.7	2.4	86	2030	80	930	82.8
52	231	88	2030	82	1130	83 3	2.2	84	2130	81	1300	82.1	93	1630	82	930	85.9	2.4	88	2030	81	1000	84.5
53	232	86	2130	82	1130	83.3	2.2	84	2200	81	1230	82.1	90	1900	82	900	84.7	2.4	86	2100	81	930	82.7
54	233	85	15	82	1300	82.7	2.1	83	2200	81	1330	82.1	86	1930	82	900	83.5	2.3	85	15	82	1130	82.7
55	234	86	2030	81	1130	83 3	2.1	84	2200	81	1200	81.5	90	1730	81	930	84.1	2.3	86	1730	81	1030	83.3
56	235	86	2030	81	1130	83 3	2 1	83	2030	81	1200	82.1	89	1800	82	930	85.3	2.3	85	2100	81	1000	83.9
57	236	86	1900	82	1200	83 9	2.1	84	2230	81	1200	82 1	91	1630	83	930	85.3	2 3	86	2030	82	1030	83.9
58	237	86	2030	80	1130	81.5	2 0	84	2200	79	1130	80.3	90	1800	78	1000	82.4	2 2	84	2100	78	1030	81 5
59	238	85	1800	79	1130	81 5	2.0	82	1930	79	1200	82.4	88	1630	77	1000	80.6	2 2	83	1900	77	1030	80.9
60	239	85	1730	78	930	81 5	2.0	82	2000	78	1000	79 1	88	1730	75	1000	81 2	2 2	81	2100	75	930	78.8
61	240	86	1730	79	930	82.1	2 0	82	2030	78	930	80.3	89	1700	77	900	82 4	2 2	82	2200	77	930	79.1
62	241	88	1800	80	900	83.3	2.0	84	1900	80	1030	80.9	92	1700	80	830	85 3	2.2	85	2030	80	1000	82.1
63	242	88	1800	80	1000	83 3	2 0	84	1800	80	1000	82 1	93	1700	80	1000	85.9	2.2	85	2030	79	1030	82.1
64	243	85	1700	81	900	82 7	1 9	83	1900	80	930	81 5	88	1730	'81	830	84.7	2.1	84	2100	81	1030	82.7
65	244	88	1800	79	1000	83 3	1 9	84	1800	79	1030	80.9	91	1500	77	930	84.1	2 1	84	2130	78	1000	80.9
66	245	86	1700	80	1000	82 7	1 9	84	1900	79	1000	81 5	90	1500	78	930	83.5	2.1	84	2130	79	1000	82.1
67	246	86	1800	79	1000	82 1	1.9	84	1830	79	1000	81.5	89	1500	76	900	81.8	2.1	83	2200	78	1030	80.9
68	247	85	1700	80	2345	80 9	1.9	84	1900	80	1000	82.1	88	1400	76	2345	80 6	2 1	84	2030	80	1030	81.5
69	248	84	1930	75	1000	79 7	1.8	82	2000	77	1030	79.7	86	1500	68	830	75.9	2.0	80	2230	75	1100	79.1
70	249	85	1930	77	1100	79 7	1.8	83	2130	76	1030	79.1	89	1430	65	900	77 1	2.0	79	2300	73	1100	76.7
71	250	85	1900	77	1100	80 9	1.8	83	1930	77	1100	80.3	86	1630	73	1000	80.0	2 0	79	2030	74	1100	76.7
72	251	85	1900	77	1130	80.9	1 8	83	1930	77	1130	79.4	85	1800	73	1030	78.8	2.0	79	2230	74	1100	77.9
73	252	83	1830	79	1130	80 3	1 8	81	2030	78	1100	78.5	83	1800	76	1000	78.2	2.0	79	15	76	1000	77.3
74	253	83	2000	79	1430	80.9	2.0	81	15	78	1530	77.9	84	1730	76	1300	78.8	2.2	78	15	76	1430	76.7
75	254	86	1930	79	1130	81 5	1.9	83	2000	78	1200	79 7	89	1630	76	1030	81 8	2.1	80	2300	76	1030	78.5
76	255	85	2000	79	1130	81.5	2.0	83	2030	78	1230	80.9	88	1700	76	1030	81 8	2 2	80	2245	77	1030	78.5
77	256	86	2000	79	1130	82 1	2 0	83	2030	78	1200	80.9	89	1730	76	1100	81 8	2.2	81	2200	76	1030	79.1
78	257	86	2000	79	1130	82 7	1 9	84	2030	78	1200	80 3	90	1800	77	1100	82 4	2.1	82	2300	77	1100	79.7
79	258	86	2000	80	1130	82.7	1 9	84	2000	79	1200	81 5	90	1800	78	1100	83.5	2.1	82	2130	78	1100	80.3
80	259	84	15	80	1330	81 5	1 9	83	15	79	1330	80.9	84	15	76	2345	78 8	2.1	82	15	76	2345	79.1
81	260	81	2000	75	1130	77 9	1.9	80	2100	74	1200	76.1	80	1730	68	1030	73.4	2 1	76	15	69	1030	71.5
82	261	82	2000	75	1100	77 3	1 8	80	2030	74	1200	76 1	80	1700	67	1030	73.4	2.0	74	15	68	1030	69.7
83	262	82	2000	76	1100	79 5	1 9	80	2000	75	1130	77 3	82	1630	69	1030	75.3	2.1	74	2130	69	1000	70.9
84	263	82	1930	75	1100	78 5	1 9	80	2000	75	1130	77.3	82	1630	68	1030	75.3	2 1	74	2200	69	1030	70.9
85	264	82	1930	75	1100	78 5	1 9	80	2000	74	1130	76 7	81	1730	68	1030	74 1	2 1	74	2330	68	1030	70.3
86	265	78	1530	76	1000	76.1	1 9	77	1730	75	1030	76 7	73	1430	69	930	72 4	2 1	74	15	70	1000	71.7
87	266	.		76	930		1 9			75	900		.	.	71	700		2.1	.		.	.	.

ROCK CREEK INTENSIVELY MONITORED POOL TEMPERATURES
S=SHADED POOL, U=UNSHADED POOL, DEP=DEPTH OF MEASUREMENT

OBS	SHADE	DATE	GRIDPOIN	DEPOCM	DEP23CM	DEP36CM	DEP69CM	DEP91CM
1	.	214	1	81.8	81 5	81 5		
2		214	2	80 9	81 1	81 1		
3	.	214	3	81 3	81 3	81 4		
4	.	214	4	81 6	81 3	81.2		
5	.	214	5	81 2	81.4	81 0	81 1	
6		214	6	80.8	81 0	81 3		
7	.	214	7	80 9	81 0	81 0	80 7	
8	.	214	8	81 0	81 3	80 9	80 8	
9	.	214	9	81.3	81 5	81.2	81 1	
10	.	214	10	81 2	81 2	81 2	.	
11	.	214	11	81 1	81 3	81 2		
12	.	214	12	80 7	80 8	80 8	80 8	
13		214	13	81 0	81 1	81 3		
14		214	14	80.9	80.8	80 8		
15		214	15	81 1	81 1	81 6		
16		214	1	80 2	80 2			
17	.	214	2	80.4	80 5			
18		214	3	80 3	80 3		.	
19		214	4	80.1	80 2	80 2	80 3	.
20	.	214	5	80 0	80 1	80 1	80 1	
21	.	214	6	80 4	80 4	80 3		
22	.	214	7	80.1	80 2	80 2	80 2	
23		214	8	79 9	79 9	79 9		
24	.	214	9	79 7	80 0	80.1		.
25		217	1	85 6	84 8	84 6		.
26		217	2	84 5	84 7	85 2		
27	.	217	3	84 5	84.4	84 6		
28	.	217	4	85 3	84 3	84 4		
29		217	5	84 9	84 7	84 3	84 5	
30		217	6	84 2	84 2	84 5		
31	.	217	7	84 0	84 1	83 8	83 2	
32	.	217	8	84 6	84 5	84 1	84 1	.
33		217	9	85 0	84 6	84 4	84 2	
34		217	10	85 3	84 7	84 7		
35		217	11	84 7	84 5	84.3		.
36	.	217	12	84.0	84 0	83 8	84 0	
37	.	217	13	84 4	84 2	84 0		
38	.	217	14	84.2	84 2	83 7		.
39	.	217	15	84 8	84 2	84 4		
40	.	217	1	82 9	82 9		.	
41	.	217	2	83.3	83 4			
42	.	217	3	83 3	83 1	83 2		.
43		217	4	82 9	82 9	82 9	82 7	
44	.	217	5	82 8	82 8	82 8	82 8	
45		217	6	83.4	83 2	83 0		
46	.	217	7	82.6	82 9	83 0	82 8	
47	.	217	8	82 7	82 6	82 6		
48	.	217	9	82 6	82 7	82 7		
49		221	1	89 4	88 8	88 2		
50		221	2	87 8	88 0	88 4		
51	.	221	3	88 5	88 8	88 8		
52	.	221	4	88 7	88 5	89 5		
53		221	5	88 5	88 5	88 3	88 5	
54	.	221	6	88.0	88 2	88 3	.	
55		221	7	87 8	87 7	85 4		
56	.	221	8	88 0	88 1	87 8	87 8	
57		221	9	88 3	88 3	88 2	88.3	
58		221	10	88 7	88 1	88 6		
59		221	11	88 0	88 1	87 9		
60	.	221	12	87.7	87 6	87 4	87 5	
61		221	13	87.8	87.8	87 7		
62	.	221	14	87 6	87 8	87 3	.	.
63	.	221	15	87 8	87 6	87 7	.	.
64	.	221	1	86 2	86 5			
65	.	221	2	86 5	86.8	.		.
66	.	221	3	86 5	86 7	86 7		
67		221	4	86 3	86 4	86 4	86 1	
68		221	5	86 0	86.4	86 4	86 4	
69	.	221	6	86 5	86 6	86 6		
70		221	7	85 9	86 3	86 3	86 3	
71	.	221	8	86 1	86 2	86 2		
72	.	221	9	86 2	86 3	86 4		.
73	.	224	1	82 7	82 9	82 5		
74	.	224	2	82 9	83 0	83 0	82 7	.
75	.	224	3	82 7	83 0	83 0	82.2	
76	.	224	4	82 7	82 9	82 9		
77	.	224	5	82 7	82 9	82 9	82 8	
78		224	6	82 6	82 9	82 8	82 8	
79		224	7	82 7	82 8	82 9	82 5	
80		224	8	82 6	82 9	82 9	82 9	82 3
81		224	9	82 8	82 9	82 9	82 7	
82		224	10	82 7	82 8	82 9		.
83		224	11	82 7	82 7	82 7	82 9	
84		224	12	82 6	82 6	82 7	82.0	.
85		224	13	82 5	82 6	82 3		
86	.	224	14	82 5	82 7	82 7	82.7	
87	.	224	15	82 7	82 8	83.1		
88	.	224	1	82 8	82 9			
89		224	2	82 9	82 9			
90		224	3	82.7	82 9	83 0		
91	.	224	4	82 8	82 9	82 9	82 9	
92	.	224	5	82 9	83 0	83 0	83 0	
93	.	224	6	82 8	82 9	82 9	82 9	

ROCK CREEK INTENSIVELY MONITORED POOL TEMPERATURES
S=SHADED POOL, U=UNSHADED POOL, DEP=DEPTH OF MEASUREMENT

OBS	SHADE	DATE	GRIDPOIN	DEPOCM	DEP23CM	DEP36CM	DEP69CM	DEP91CM
94	.	224	7	82 8	82 9	82 9	82 9	82.8
95	.	224	8	82.9	82 9	83 0		
96	.	224	9	82 9	82 9	82 9		
97	.	228	1	88 0	87.4	86 1		.
98	.	228	2	86.5	86 4	86 1		
99		228	3	87 0	86 5	86 4		.
100		228	4	87 1	86.5	86 6		
101	.	228	5	87.0	86 5	86 2	86 7	
102	.	228	6	86.0	86 0	86 3		
103	.	228	7	85.8	85.8	85 8	85 0	
104	.	228	8	86 6	86 4	86 0	85 8	85 6
105	.	228	9	86.5	86 4	86 2	86 1	
106		228	10	87 2	86 3	86 5		.
107	.	228	11	86 8	86 4	86 6		
108		228	12	85.8	85 8	85 7	85 8	
109	.	228	13	86 4	86 2	86 0	86 2	
110	.	228	14	86.4	85.7	85.9	.	.
111	.	228	15	86.8	86 1	86 4		
112		228	1	85 0	85.1			
113		228	2	85 3	85 3			
114	.	228	3	85 1	85 2	85 3		
115	.	228	4	85 0	85 1	85 1	85 1	.
116	.	228	5	84 8	84 9	85 0	85 1	
117		228	6	85 3	85 3	85 2		
118	.	228	7	85 0	85 2	85 2	85.2	
119	.	228	8	84 9	84 9	84 9		
120		228	9	84 9	84 9	85 1		.
121	.	231	1	93 9	91 6	90 0		
122	.	231	2	91 3	92 8	91 8		.
123		231	3	92 6	92 7	92 7		
124	.	231	4	92 8	91 5	91 3		
125	.	231	5	92 7	92 4	92 3	92 7	
126		231	6	91.7	92 2	92 2		
127	.	231	7	91 8	91 8	91 7	89 0	
128	.	231	8	92 4	92 3	92 0	90 5	
129	.	231	9	92 2	92 6	92 3	92 0	
130	.	231	10	92 8	92 6	92 7		
131	.	231	11	92.3	92 5	92.1		
132	.	231	12	91.7	91 9	91 7	91 9	
133	.	231	13	91 8	92 1	92 1		
134	.	231	14	92.1	92 0	91 9		
135	.	231	15	92.4	92 1	92 4		
136	.	231	1	90 8	91 0			
137	.	231	2	91.2	91 3			
138		231	3	91 3	91 3	91 3		
139	.	231	4	91 8	91 7	90 9	90 2	
140	.	231	5	90 6	91 0	91 0	91 0	
141	.	231	6	91 2	91 2	91 1		
142		231	7	90 9	90 9	90 9	89 5	
143		231	8	90 7	90 7	90 8		
144	.	231	9	90 7	91 0	91 0		
145		235	1	89 9	87 6			
146	.	235	2	88 7	88 6	87 3	.	
147		235	3	87 9	88 7	88 4		
148	.	235	4	88 6	88.7	88.8		
149	.	235	5	88 6	88 6	88 5	88 3	
150	.	235	6	88 5	88 5	88 5		
151	.	235	7	88 1	88 3	86 1		
152	.	235	8	88 5	88 6	88 3	87 3	
153	.	235	9	88 8	88 7	88 4	88 1	
154	.	235	10	89 0	88 9	88 6		
155	.	235	11	88 9	88 8	88 9		
156	.	235	12	88 4	88 5	88 4	88 5	
157		235	13	88 8	88 6	88 1		
158	.	235	14	88 9	88 5	88 6		
159		235	15	88 6	88 8	89 4		
160	.	235	1	87 8	87 8			
161		235	2	88 0	88 0			
162	.	235	3	88 1	88 1	87 8		
163	.	235	4	87 6	87 8	87.7	87 5	
164	.	235	5	87 5	87 9	87 9	87 7	
165		235	6	88.0	88.0	87 8		
166		235	7	87 6	87 8	87 7	85 9	
167		235	8	87 7	87 7	87 7		
168		235	9	87 8	88 0	87 7		
169		238	1	87 6	86 7			
170		238	2	86 7	86 9	85 6		
171	.	238	3	87.0	87.2	87 2		
172		238	4	87.3	87 1	87.2		
173	.	238	5	86 8	87 0	86.8	87 0	
174	.	238	6	86 6	86 8	87 0		
175		238	7	86 4	86.6	86 0	.	
176		238	8	86 5	86 9	86 5	84 7	
177	.	238	9	87 0	87 1	86 8	86 6	
178		238	10	87 6	87 5	88 1		
179	.	238	11	87 2	87 2	87 3		
180	.	238	12	86 5	86 7	86 5	84 8	
181		238	13	86.9	86 8	86 2		
182		238	14	86.7	86 9	86 8		
183	.	238	15	87 5	87 3	88 0		
184		238	1	86 0	86 1			
185		238	2	85 9	86 2			
186		238	3	86 6	86 8	86 5		

POLK CREEK INTENSIVELY MONITORED POOL TEMPERATURES
S-SHADED POOL, U-UNSHADED POOL, DEP=DEPTH OF MEASUREMENT

OBS	SHADE	DATE	GRIDPOIN	DEPOCM	DEP23CM	DEP36CM	DEP69CM	DEP91CM
187		238	4	86 2	86.4	85 5	83 4	
188		238	5	86 5	86 6	86 5	85 6	
189		238	6	86 8	86 8	86 8		
190		238	7	86 3	86 4	85 5	83 5	
191	.	238	8	86 4	86 4	86 4		
192	.	238	9	86 4	86 6	86 6		
193		242	1	92 6	92 1			
194	.	242	2	92.6	92 4	89 9	.	
195		242	3	92 5	92 7	92 7		
196		242	4	92 8	92 8	92 8		
197	.	242	5	92.5	92 5	92 2		
198	.	242	6	92 5	92 6	92 4		
199	.	242	7	91 8	92 2	88 7		
200	.	242	8	92 0	92 6	92 1	88.2	
201	.	242	9	92 2	92 8	92 1	92 0	
202	.	242	10	93 0	93 4	92 8		
203	.	242	11	92.2	93 0	93 1		
204	.	242	12	92 2	92 6	91 8	88 7	
205	.	242	13	92 3	92 7	92 3		
206		242	14	92 9	92 7	92 6		
207		242	15	93 2	92 4	93 0	.	
208	.	242	1	91 0	91 2			.
209	.	242	2					.
210		242	3	91 5	91 3			
211	.	242	4	91 2	91 2	88 8		.
212	.	242	5	91.3	91 5	89 6	89 1	
213		242	6	91 2	91 6	90 9		
214	.	242	7	91 0	91 2	88 6	86 8	
215	.	242	8	90 8	90 9			
216	.	242	9	90 6	90 9			
217	.	245	1	89 3	89 2			
218	.	245	2	89 9	90 0			
219		245	3	90.0	89 8	.		
220		245	4	89.8	90.0			
221	.	245	5	89 1	89 9	90 0		
222	.	245	6	89 7	89 9	89 9		
223		245	7	89 4	89 4	87 6		
224		245	8	89 7	89 9	89 9	88 6	
225		245	9	89 4	90.1	90 0	90 4	
226		245	10	90.1	91 1			.
227	.	245	11	90 1	90 4	90 5		
228	.	245	12	89 9	90 0	90 1		
229		245	13	89 5	90 1	90 1		
230	.	245	14	88 8	90 3	90 3		
231	.	245	15	90 7	90 2			.
232	.	245	1	88 8				
233	.	245	2					
234	.	245	3	88.6	88 3			
235	.	245	4	88 8	89 0	87 3	85 9	
236	.	245	5	89 0	89 1	88 0		
237		245	6	89.3	89 1	89 0		
238		245	7	88 8	88 9	86 9	85 3	
239	.	245	8	88 8	88 7	.		.
240	.	245	9	89 1	89.0			
241	.	249	1	87 2	87 6	.		
242	.	249	2	86 7	87 1			
243	.	249	3	86.8	87 2			
244	.	249	4	86 7	87 4			
245	.	249	5	86 8	87 0	87 4		
246	.	249	6	87 0	87 6			
247		249	7	86 4	86 3	83 0		
248	.	249	8	86 6	86 9	86 9	83 9	
249	.	249	9	85 8	87 1	87 0		
250		249	10	87 6	88 0			
251	.	249	11	87 3	87 5	87 8		
252		249	12	87.0	87 0	84 8		
253	.	249	13	87 1	87.1			.
254	.	249	14	87 2	87 6	87 6		
255	.	249	15	87 8	88 1			
256	.	249	1	82 2				
257		249	2	84 7				
258	.	249	3	83.7	83 4			
259	.	249	4	84 4	84 2	80 9		
260	.	249	5	84 8	84 2	82 8	82 2	
261		249	6	84 6	84 4	84 3		
262		249	7	84 6	84 4	81 9	80 5	.
263	.	249	8	85 2	84 7			
264	.	249	9	85 8	85 9			
265		252	1	84 0	83 2		.	
266		252	2	82 8	83 6			
267		252	3	82 7	83 0			
268	.	252	4	81 9	83 0			
269	.	252	5	82.6	82.8	83.1		
270	.	252	6	82.7	83.1			.
271	.	252	7	82 7	82.6	81.9	.	
272	.	252	8	82 4	82 9	82.8	82 2	
273	.	252	9	82.1	82 8	82 8		
274	.	252	10	82 6	82.8			
275	.	252	11	82.6	83.0			

ROCK CREEK INTENSIVELY MONITORED POOL TEMPERATURES
S=SHADED POOL, U=UNSHADED POOL, DEP=DEPTH OF MEASUREMENT

OBS	SHADE	DATE	GRIDPOIN	DEPOCM	DEP23CM	DEP36CM	DEP69CM	DEP91CM
276	.	252	12	82 7	83.1	83 1		
277	.	252	13	83 2	83 4			
278		252	14	83 0	83 4	83 6		
279		252	15	82 6	83.4	.		
280		252	1	81 2		.	.	
281	.	252	2	80 6				
282	.	252	3	80 9	81 3			
283	.	252	4	80 9	81.0	79 5		
284		252	5	81 0	81.2	80 5		
285		252	6	81.1	81 4	81 5		
286	.	252	7	81.5	81 5	79.4	79 0	
287	.	252	8	81 3	81.8			
288	.	252	9	81 5	81 9			
289	.	256	1	88 3	87.9	.		
290	.	256	2	88.6	88 9			
291	.	256	3	88.6	89 0			
292	.	256	4	88 6	89 3			
293	.	256	5	88 6	88 7	89 0		
294	.	256	6	88 5	88 7	88 7		.
295		256	7	88.6	88 6	85 0		
296	.	256	8	88 2	89 0	88 7	86 9	
297	.	256	9	88.5	88 8	88 7	87 9	
298	.	256	10	89 0	89 3	88 8		
299	.	256	11	89.0	89 3	89 2		
300	.	256	12	88 6	88 9	88 5		
301	.	256	13	88 6	88.9	88 9		
302	.	256	14	88 7	89 1	89 0		
303	.	256	15	89 4	89.0	89.1		
304	.	256	1	86.9	87 1	.		
305	.	256	2	87.1	87 9			
306	.	256	3	87.3	87.2			
307	.	256	4	87 6	87.7	85 6	83 6	
308	.	256	5	87 6	87 8	86 4		
309	.	256	6	87 3	87 6	87 8		
310		256	7	87.2	87 7	85 4	84 1	
311	.	256	8	87 4	87 6			
312	.	256	9	87 4	87 6		.	

AIR TEMPERATURES RECORDED WITH THERMOGRAPHS AND SOLAR RADIATION

DATA RECORDED WITH PYRANOMETER AT ROCK CREEK

OBS	DATE	TIMMAXR	PEAKRAD	DAILYRAD	MAXAIRT	TIMMAX	MINAIRT	TIMMIN	AVEAIRT	WIND
1	196	1530	0 96	.		.			.	.
2	197	1445	1 02	897 4				.	.	.
3	198	1045	0.49	458 7		.		.	.	
4	199	1500	1 12	757 8		.	.			.
5	200	1530	1 05	1116.7		.	.	.		.
6	201	1530	1.05	1096 8	.	.		.		.
7	202	1545	1.03	897.4	.	.	.	.	.	.
8	203	1345	1 10	897 4		.	.	.		.
9	204	1115	1 05	1037 0	.	.	.			.
10	205	1245	0 99	478.6		.	.		.	
11	206	1445	0 97	937 3		.	.	.		.
12	207	1315	1.10	478 6	89	.	64			.
13	208	1245	1.04	837 6	100		69	.	.	.
14	209	1215	1 08	618 2	93		70	.	.	.
15	210	1300	1.10	837 6	94		55	.	.	.
16	211	1400	1 10	957.2	.	.	.	.		.
17	212	1315	1 14	977.2	.	.	.			.
18	213	1400	1 11	817 6	.	.	.		.	
19	214	1330	1 04	737 9	.			.		0.14
20	215	1245	1 00	558.4	94	1115	59	2345	71.7	.
21	216	1530	1 16	877.4	90		59	15	.	.
22	217	1515	1 05	1156 6	91		65	.	.	0.21
23	218	1230	1 10	698 0	96		62	.		.
24	219	1300	1 21	737.9	92	.	63	.	.	
25	220	1300	1 23	638 1	96	1245	66	.		.
26	221	1245	1 05	817 6	95	1200	65	600	.	0.97
27	222	1445	0 64	319 1	79		67		.	.
28	223	1200	1 16	737 9	91	.	69			.
29	224	1515	1 05	478 6	.	.	.	.	.	0.34
30	225	1330	1 10	877 4	100	.	68		.	.
31	226	1415	1 01	937 2	102		64	.	.	.
32	227	1430	0 94	877 4	95		62	.	75 8	.
33	228	1400	0 95	757 8	97	.	63	.	79.2	0.04
34	229	1430	0 95	678.0	97	1230	67	500	79.1	.
35	230	1500	0.97	897 4	99		67	.		.
36	231	1445	0 96	777 7	101		69	.	.	0 12
37	232	1415	1 08	737 9	104	.	67	.		.
38	233	1345	0 92	498 6		.	68	.		.
39	234	1445	0 93	817 6	99		72	.	.	.
40	235	1430	0.96	638 1	95	1315	69	715		0.02
41	236	1430	1 10	737 9	95		73	.	.	
42	237	1530	1 01	977.2	95	1230	60	645	.	.
43	238	1500	1 06	877 4	93	.	59			0 08
44	239	1415	0 97	897 4	98	.	57		.	.
45	240	1145	0 93	777 7	107		65	.		.
46	241	1415	1 01	757.8					.	.
47	242	1500	0 95	937 3	104	.	.		.	0.13
48	243	1400	1 12	698 0	99	.	68	.		.
49	244	1500	0 96	817 6	105	.	61	.		
50	245	1515	1 02	693 0	101	.	62	.	.	0.12
51	246	1300	1 06	837 6	97	.	49	.	.	.
52	247	1200	1 06	897 4	97	.	50			.
53	248	1500	1 01	957 2		.		.		.
54	249	1530	0 96	897 4	92	1700				0 11
55	250	1600	0 95	877 4	100	1300	52	745		.
56	251	1615	0 97	877 4	95	.	53	.	.	.
57	252	1545	0 98	538 4	89	.	60		.	0.16
58	253	1430	0 99	219 4	99	.	64			.
59	254	1515	1 03	757 8			60	.		.
60	255	1300	1 08	757.8	.	.	.		.	
61	256	1315	0.97	757 8		.	.	.		0.08
62	257	1445	0 97	777 7	101	1145	62		.	
63	258	1530	0 95	698 0	103		64			
64	259	1330	1 00	398 8	83		61		.	.
65	260	1400	0 95	817 6	91	.	45		.	.
66	261	1415	0 94	897 4	86	.	50	.	.	.
67	262	1315	0 99	817 6	90	.	48	.		.
68	263	1330	1.03	737 9	92	.	48			.
69	264	1430	0 95	777 7	85	.	52			.
70	265	1200	0 70	319 1			65	.		.

TEMPERATURES RECORDED WITH MAXIMUM-MINIMUM THERMOMETERS AT LITTLE EAGLE CREEK, P=POOL NUMBER, S=POOL SURFACE, B=POOL BOTTOM

OBS	DATE	MAXP1S	MAXP1B	MAXP2S	MAXSP2	MAXP2B	MAX2PS	MAXP3S	MAXP3B	MAXP4S	MAXSP4	MAXP4B	MAX4PS	MAXP5S	MAXP5B	MAXSP5	MAXBP5	P1STAGE	STAGE
1	185			84	82	70	82	.		.			.	.		.	.	0.0	0.0
2	186	84	78	81	82	70	82	86	83	85	86	80		.	.	.	.	0 0	0.0
3	187	85	78	82	80	70	76	84	80	79	84	77	85	86	74	85	80	0 0	0.0
4	188	87	86	84	83	70	84	89	84	86	88	81	88	88	78	89	80	-0.2	0 0
5	190	87	88	88	86	69	87	90	85	88	91	83	90	89	81	89	83	-0.3	0.0
6	191	87	81	90	87	73	86	91	89	89	92	86	90	90	83	89	84	-0.5	0.0
7	192	89	82	90	87	76	83	91	89	91	91	87	91	90	86	90	84	-0 6	0.0
8	193	89	84	91	86	81	87	93	90	92	93	88	93	90	84	91	84	0.2	0.1
9	194	81	76	83	82	77	76	84	82	82	84	80	83	85	78	86	80	0.1	0.0
10	195	83	78	86	85	74	85	89	87	86	90	81	89	88	78	89	79	0.1	0.0
11	197	87	80	88	85	75	87	92	89	90	93	84	91	91	80	91	80	0 1	0.0
12	198	77	78	82	80	76	80	83	82	81	84	79	83		80	86	83	0.2	0 1
13	199	83	78	85	84	78	84	87	86	86	88	80	87	88	80	89	82	0 1	0 1
14	200	82	77	85	83	78	83	87	85	86	88	83	88	88	80	89	80	0.0	0.0
15	201	81	85	84	82	73	81	86	84	86	88	78	86	87	80	87	78	0 0	0 0
16	202	79	74	83	82	70	82	86	84	86	69	78	87	87	76	87	76	0.0	0.0
17	205	82	76	85	82	70	81	87	84	86	88	78	86	88	78	87	80	-0.2	-0 1
18	206	82	85	83	82	72	80	85	82	85	87	78	84	86	79	86	79	-0 3	-0.1
19	207	85	76	85	83	71	82			.		.	.	86	78	86	78	-0 4	-0.1
20	208	84	88	80	83	73	82	86	82	86	89	80	89	88	80	89	78	-0.3	0 0
21	209	82	77	82	80	74	81	84	82	84	87	79	87	86	79	90	79	-0.3	0.0
22	211	81	78	84	82	82	81	84	82	84	86	80	86	85	78	85	79	-0 3	0.0
23	215	78	76	80	78	72	79	82	78	82	85	78	83	84	78	84	79	-0 5	0.0
24	216	80	73	80	79	73	79	83	80	83	86	87	86	85	75	84	76	-0 6	0 0
25	218	81	78	85	80	73	79	85	82	87	88	81	87	85	78	85	78	-0 9	-0 1
26	219	84	79	83	80	76	79	85	84	88	88	82	87	86	78	86	80	-1.0	-0 1
27	220	84	79	81	81	74	82	87	85	89	90	83	89	87	79	87	79	-1 1	-0.1
28	222	84	80	83	80	73	82	87	85	88	89	84	89	86	79	86	80	-1.1	-0.1
29	223	82	78	80	77	72	78	83	81	84	86	82	88	85	80	85	79	-1.1	-0.1
30	225	85	80	82	79	73	80	84	82	85	88	82	89	84	80	86	80	-1 2	-0 1
31	226	82	79	82	80	74	79	85	83	.	89	83	88	83	80	85	80	-1.2	-0.2
32	227	82	80	81	81	74	79	85	84	88	89	85	90	82	80	85	81	-1 2	-0.2
33	228	84	80	80	73	80	79	86	85	.	90	84	92	87	80	87	80	-1.2	-0.2
34	229	83	80	80	77	74	80	85	82		87	84	89	86	80	86	81	-1 2	-0 2
35	230	83	80	80	79	75	80	85	83	.	88	84	89	85	80	86	80	-1 2	-0.2
36	232	86	81	82	80	73	83	88	86	91	92	86	93	87	81	88	81	-1 2	-0 2
37	233	82	80	83	82	76	80	88	86	92	89	85	92	87	80	87	80	-1.2	-0.2
38	234	86	82	83	83	76	83	88	87	92	92	86	92	87	82	87	82	-1.2	-0.2
39	235	85	82	85	85	75	84	89	86	92	92	87	92	87	82	87	81	-1.2	-0 2
40	236	84	82	84	85	76	82	89	87	92	92	88	93	87	81	87	82	-1 2	-0.2
41	237	82	81	82	83	73	80	87	84	.	90	86	92	86	82	87	82	-1.2	-0.2
42	239	77	74	81	80	73	80	87	83		90	84	90	86	79	87	80	-1 2	-0.3
43	240	84	80	84	78	75	79	86	84	83	89	85	92	86	80	86	81	-1 2	-0 2
44	241	85	81	85	83	77	80	89	87	94	93	87	94	88	82	87	81	-1.2	-0 3
45	242	86	83	85	84	76	84	91	88	96	93	88	96	90	82	88	82	-1 2	-0.3
46	243	82	82	85	82	79	80	88	86	93	91	87	92	88	83	85	82	-1.2	-0 3
47	244	83	81	84	83	73	79	89	87	93	93	87	94	88	82	88	82	-1.4	-0.4
48	246	83	80	84	82	75	80	87	85	92	91	80	93	85	81	86	81	-1 4	-0 4
49	247	81	80	79	79	76	80	85	85	88	88	86	93	83	80	85	81	-1 4	-0 4

TEMPERATURES RECORDED WITH MAXIMUM-MINIMUM THERMOMETERS AT LITTLE EAGLE CREEK, P=POOL NUMBER, S=POOL SURFACE, B=POOL BOTTOM

OBS	DATE	MAXP1S	MAXP1B	MAXP2S	MAXSP2	MAXP2B	MAX2PS	MAXP3S	MAXP3B	MAXP4S	MAXSP4	MAXP4B	MAX4PS	MAXP5S	MAXP5B	MAXSP5	MAXBP5	P1STAGE	STAGE
50	248	78	75	78	78	72	75	82	81	88	87	83	89	84	79	84	79	-1.5	-0.3
51	249	80	75	80	80	70	79	82	80	89	88	83	90	83	78	84	78	-1.5	-0 3
52	250	76	75	77	78	72	75	83	81	87	87	83	89	82	78	83	78	-1.2	-0.2
53	251	74	75	77	78	73	74	81	80	87	85	83	88	80	78	82	78	-1.2	-0.2
54	253	76	76	79	79	77	78	79	78	83	82	80	84	80	76	81	77	0.1	0.1
55	254	77	74	80	80	78	80	83	82	87	88	84	87	80	78	81	78	-0.3	0 0
56	255	79	75	82	82	77	81	83	82	87	86	79	84	85	76	85	77	-0.4	0.0
57	256	81	75	82	82	75	83	84	82	88	89	78	88	87	75	86	75	-0.4	0.0
58	257	81	76	83	83	77	82	84	83	88	87	80	86	87	76	86	76	-0 4	-0.1
59	260	80	75	84	82	75	82	83	80	88	86	78	87	86	75	89	77	-0.4	-0 1
60	261	74	68	75	74	78	74	76	74	78	85	78	77	78	76	79	75	-0.5	-0.1
61	262	74	69	76	76	68	75	77	74	80	80	72	80	79	70	78	70	-0.4	-0.1
62	263	73	69	76	78	69	74	74	75	80	80	72	78	78	70	77	70	-0.2	0.0
63	264	73	69	75	74	70	74	75	74	78	79	72	76		.		.	-0.2	0.0

MAXIMUM-MINIMUM THERMOMETER READINGS AT LITTLE EAGLE CREEK
P=POOL NUMBER, S=POOL SURFACE, B=POOL BOTTOM

OBS	DATE	MINP1S	MINP1B	MINP2S	MINSP2	MINP2B	MIN2PS	MINP3S	MINP3B	MINP4S	MINSP4	MINP4B	MIN4PS	MINP5S	MINP5B	MINSP5	MINBP5
1	185		.	80	72	70	74	.		.						.	.
2	186	75		72	73	70	72	72	74	72	76	80				.	.
3	187	74	76	75	72	68	72	71	74	77	76	77	77		77	77	
4	188	75		74	73	67	73	72	74	75	78	76	79		78	79	.
5	190	69		65	63	69	72	72	74	73	78	86	77	.	78	79	
6	191	76		78	74	68	73	75	74	75	81	80	81		80	82	.
7	192	73		76	74	69	74	76	77	78	82	80	82	.	83	83	
8	193	75	.	75	73	68	72	75	76	72	77	76	77		78	80	
9	194	76		77	76	70	76	75	75	72	77	76	77		78	79	
10	195	75		78	77	70	77	76	76	76	77	76	77		78	80	.
11	197	76	79	77	77	69	75	75	76	74	82	77	76		79	81	.
12	198	74	77	75	74	68	74	74	77	71	76	74	76	81	77	79	.
13	199	74	75	75	73	69	73	72	72	70	74	73	76	.	77	78	78
14	200	72	73	74	71	68	71	69	69	67	73	70	73	77	76	77	77
15	201	71	72	71	70	67	70	67	67	68	71	70	72	77	76	77	76
16	202	70	70	72	70	67	70	68	68	67	72	70	71	74	76	77	76
17	205	68	71	72	70	67	69	68	68	67	73	70	74	74	76	74	78
18	206	73	74	73	70	67	70	69	70	70	75	73	76	78	78	78	78
19	207	73	75	73	71	67	70			.	.	.	.	78	77	77	77
20	208	75	76	73	75	67	72	70	70	70	74	73	75	79	78	79	77
21	209	75	76	77	75	67	72	73	73	73	77	76	77	80	79	79	77
22	211	71	72	70	69	68	68	67	67	68	73	71	74	78	76	77	76
23	215	62	69	69	68	67	67	66	66	64	69	68	70	74	72	73	75
24	216	70	73	71	70	68	70	69	69	69	74	72	74	76	74	75	75
25	218	72	74	74	72	69	71	71	71	72	76	75	77	77	76	77	75
26	219	72	76	75	73	70	72	74	72	73	78	76	78	79	77	79	78
27	220	75	78	73	72	70	72	73	72	74	79	77	80	79	78	79	77
28	222	74	76	74	73	70	73	73	73	74	78	76	78	79	78	79	79
29	223	75	77	74	72	70	72	73	73	74	69	77	78	78	79	79	79
30	225	64	75	70	70	70	70	71	70	75	77	76	76	76	78	79	78
31	226	74	76	72	71	70	70	72	72	.	78	76	78	74	79	79	78
32	227	74	76	72	71	70	70	73	72	79	78	76	78	74	79	79	79
33	228	73	76	72	70	73	72	74	73	81	80	78	78	80	79	80	79
34	229	75	77	72	72	70	72	74	73	80	79	78	78	80	80	79	79
35	230	75	77	73	72	70	71	74	74	82	80	78	78	80	80	80	79
36	232	76	78	74	73	72	73	75	75	80	80	80	79	81	80	80	80
37	233	75	77	76	74	71	74	75	75	78	78	78	79	81	80	79	79
38	234	75	79	76	74	73	74	77	77	80	81	81	80	82	80	81	80
39	235	76	79	75	74	72	74	75	76	78	81	79	81	81	81	81	80
40	236	74	76	72	72	71	72	73	72	77	78	78	77	80	80	80	79
41	237	73	75	71	71	70	70	73	72	.	78	77	77	80	80	79	79
42	239	73	69	69	69	69	70	70	69	.	76	76	74	79	78	77	78
43	240	75	78	74	74	71	71	76	76	79	80	80	80	84	79	79	78
44	241	75	78	74	74	73	73	76	76	79	82	81	79	84	80	79	79
45	242	76	78	83	74	74	82	77	78	80	81	82	80	82	80	78	79
46	243	74	74	74	73	74	73	75	75	78	79	80	78	80	80	77	79
47	244	74	76	74	73	72	73	75	75	78	80	80	78	80	80	80	80
48	246	74	76	75	74	75	74	75	76	79	80	77	78	81	76	80	80
49	247	79	70	68	70	70	79	69	69	72	76	75	72	74	71	79	77
50	248	67	69	68	68	69	68	67	68	71	74	73	71	76	76	76	74
51	249	68	70	68	68	69	68	68	69	72	75	74	72	76	76	75	74
52	250	69	70	70	69	70	66	70	71	72	76	75	73	77	76	75	74
53	251	68	72	72	71	72	71	71	72	74	76	76	75	76	77	75	74
54	253	69	71	72	70	72	70	69	70	70	70	71	72	71	71	70	72
55	254	71	72	74	72	72	73	70	71	75	74	75	76	74	72	71	73

MAXIMUM-MINIMUM THERMOMETER READINGS AT LITTLE EAGLE CREEK
P=POOL NUMBER, S=POOL SURFACE, B=POOL BOTTOM

OBS	DATE	MINP1S	MINP1B	MINP2S	MINSP2	MINP2B	MIN2PS	MINP3S	MINP3B	MINP4S	MINSP4	MINP4B	MIN4PS	MINP5S	MINP5B	MINSP5	MINBP5
56	255	71	73	73	72	73	72	71	71	70	73	73	74	72	72	73	71
57	256	71	73	73	72	72	72	71	72	71	74	72	74	76	72	75	72
58	257	71	73	74	72	73	73	72	72	72	74	74	75	76	73	76	72
59	260	63	65	65	64	65	65	63	64	62	70	72	65	70	68	69	75
60	261	65	66	66	65	65	66	64	63	63	64	64	67	67	64	65	63
61	262	64	65	66	65	66	65	64	65	64	66	65	67	70	68	69	.
62	263	64	65	65	65	64	65	63	64	63	65	64	66	70	67	69	.
63	264	64	66	66	65	65	65	64	64	63	65	65	66	.	.	.	.

THERMOGRAPH DATA AT LITTLE EAGLE CREEK, OP=OPEN POOL, SH=SHADED POOL, S=SURFACE MEASUREMENT, B=BOTTOM MEASUREMENT

OBS	DATE	OPMAXS	OPTIMAXS	OPMINS	OPTIMINS	OPAVES	OPBOTDEP	OPMAXB	OPTIMAXB	OPMINB	OPTIMINB	OPAVEB	SHMAXS	SHTIMAXS	SHMINS	SHTIMINS	SHAVES	SHBOTDEP	SHMAXB	SHTIMAXB	SHMINB	SHTIMINB	SHAVEB
1	181		.	.	.		.	.	.	.	.	.	82	1700	.	.	.	3.6	.	.	.	.	
2	182	.	.		.	.	.		.	.		.	82	1715	72	745	76.1	3.6	.	.	.	.	.
3	183		.	.	.	.				.	.	.	82	1315	69	800	74.8	3.6	.	.	.	.	
4	184		.	.	.	.	.	.	.	.	.	.	83	1545	70	800	75.5	3.6	.		.	.	.
5	185		.		.			.			.	.	85	1630	71	800	77.0	3.6	.	.		.	.
6	186	.	.	.		.	.	.		.	.	.	84	1645	73	900	77.5	3.6	65	1630	.	.	.
7	187	.		.		.	.	.		.	.	.	81	1830	72	1015	75.5	3.6	64	1700	63	800	.
8	188			.	.	.	.	.	.		.	.	84	1500	70	700	79.2	3.6	.	.	.	.	.
9	189	.		.				.	.		.	.	86	1430	72	630	77.5	3.6	67	1430	.	.	.
10	190	.	.			.	.	.	.		.	.	88	1430	70	715	78.0	3.6	.	.	65	800	.
11	191	.	.	.	.			.	.	.	.	.	89	1500	71	730	78.9	3.6	.	.	.	.	.
12	192		.	.	.	.	.			.	.	.	89	1500	73	915	78.6	3.6	83	2130	66	800	70.2
13	193	93	1645	.	.	.	4.2	.	.	.	.	.	89	1545	72	800	77.7	3.7	81	15	70	2345	72.2
14	194	85	1800	77	800	80.6	4.1	82	15	78	1130	79.4	82	1715	74	915	78.4	3.6	.	.	.	.	.
15	195	90	1800	77	845	82.9	4.1	79	2345	77	1030	78.4	87	1515	75	715	81.1	3.6	70	1500	.	.	.
16	196	92	1700	79	900	85.5	4.1	82	2145	78	1115	79.4	89	1545	75	700	80.8	3.6	69	1500	68	1000	68.0
17	197	92	1700	80	815	86.1	4.1	82	1930	79	1000	80.6	90	1530	75	815	80.9	3.6	69	1530	67	930	67.8
18	198	79	1715	78	2345	80.3	4.2	82	15	78	2345	79.0	80	15	75	800	77.0	3.7	73	615	66	2345	67.5
19	199	90	1615	76	800	81.6	4.2	79	2345	76	930	77.4	86	1715	73	800	78.1	3.7	72	545	66	530	66.7
20	200	92	1500	76	830	83.9	4.1	81	2230	76	1000	76.8	86	1700	72	915	77.2	3.6	68	1515	66	1045	66.4
21	201	91	1645	74	745	82.3	4.1	78	2345	72	900	76.1	84	1745	68	930	75.6	3.6	68	1600	66	1045	66.4
22	202	91	1715	73	800	81.3	4.1	78	15	71	900	74.5	85	1500	67	815	76.1	3.6	68	1415	66	800	67.3
23	203	91	1630	74	745	81.3	4.0	77	2345	72	900	75.2	85	1515	67	715	74.8	3.5	67	1400	66	700	66.3
24	204	90	1730	76	745	81.9	4.0	78	2345	73	915	75.8	84	1530	68	730	74.8	3.5	67	1545	66	645	66.3
25	205	89	1400	77	745	80.6	4.0	78	15	74	830	76.5	81	1630	68	745	73.6	3.5	67	1430	66	645	66.0
26	206	90	1630	75	730	81.0	4.0	78	2345	73	845	76.1	84	1613	68	900	74.5	3.5	67	1415	65	630	65.9
27	207	85	1230	78	815	80.6	4.0	78	15	73	915	76.5	79	1515	68	800	72.8	3.5	67	1345	66	815	66.0
28	208	90	1515	76	700	81.3	4.1	78	2345	74	830	76.5	85	1715	68	815	74.5	3.6	71	1900	65	600	66.9
29	209	88	1630	76	830	82.6	4.1	78	15	75	1000	76.8	82	1500	72	845	77.8	3.6	68	15	66	1230	66.6
30	210	88	1700	78	915	82.3	4.1	80	2300	76	930	77.7	84	1400	72	2345	76.7	3.6	67	1330	65	1000	65.5
31	211	88	1600	75	745	80.6	4.1	79	15	73	900	76.1	82	1530	67	745	73.6	3.6	67	1400	65	700	65.6
32	212	86	1600	74	745	80.0	4.1	78	15	72	915	75.2	80	1600	66	830	72.7	3.6	67	1330	65	700	66.1
33	213	86	1630	74	715	79.4	4.1	77	15	71	845	73.9	79	1645	65	900	70.9	3.6	66	1430	65	800	65.6
34	214	77	1600	74	1015	76.5	4.1	76	15	72	1015	73.5	72	1745	66	830	69.2	3.6	66	1615	65	2345	65.2
35	215	78	1215	72	745	74.2	4.1	73	15	70	845	71.0	74	1330	64	915	68.1	3.6	67	1600	65	730	65.6
36	216	88	1715	70	815	77.7	4.1	73	2345	68	915	71.0	82	1500	65	800	72.2	3.6	67	1430	66	1215	66.7
37	217	88	1715	75	730	81.6	4.0	77	2345	72	945	74.2	85	1400	68	745	75.5	3.5	68	1330	66	645	67.0
38	218	86	1415	77	800	80.6	4.0	77	15	76	930	76.5	80	1430	70	730	74.5	3.5	68	1415	66	645	67.2
39	219	91	1600	78	715	83.2	4.0	81	2015	76	1000	78.4	85	1615	70	800	76.6	3.5	69	1400	67	615	67.8
40	220	93	1615	80	1000	85.2	4.0	83	2345	78	1015	80.6	85	1600	71	900	77.2	3.5	70	1400	68	900	68.3
41	221	92	1545	82	815	89.0	4.0	84	2000	80	945	84.2	85	1545	71	830	76.9	3.5	70	1345	68	600	68.8
42	222	84	1600	81	2345	83.1	4.0	83	15	80	2345	81.0	76	1915	72	815	74.1	3.5	69	1700	68	730	68.6
43	223	90	1700	79	700	83.2	4.0	81	2300	78	915	79.7	80	1545	71	630	76.3	3.5	69	1500	68	630	68.3
44	224	91	1630	80	730	85.2	4.0	82	1945	78	800	80.3	82	1300	70	700	75.3	3.5	70	1400	68	700	68.8
45	225	90	1400	80	700	84.5	4.0	82	15	78	915	80.0	81	1345	69	730	74.2	3.5	70	1400	68	715	68.8
46	226	91	1600	79	645	84.5	3.9	82	2115	77	845	79.7	80	1400	68	800	73.6	3.4	70	1445	68	730	68.8
47	227	93	1430	80	730	86.1	3.9	84	2015	79	845	81.3	83	1445	69	830	74.4	3.4	71	1430	68	800	69.4
48	228	93	1600	82	730	88.1	3.9	84	1800	80	900	82.9	82	1500	68	845	74.2	3.4	71	1500	69	900	69.4

THERMOGRAPH DATA AT LITTLE EAGLE CREEK, OP=OPEN POOL, SH=SHADED

POOL, S=SURFACE MEASUREMENT, B=BOTTOM MEASUREMENT

OBS	DATE	OPMAXS	OPTIMAXS	OPMINS	OPTIMINS	OPAVES	OPBOTDEP	OPMAXB	OPTIMAXB	OPMINB	OPTIMINB	OPAVEB	SHMAXS	SHTIMAXS	SHMINS	SHTIMINS	SHAVES	SHBOTDEP	SHMAXB	SHTIMAXB	SHMINB	SHTIMINB	SHAVEB
49	229	90	1545	82	700	86 1	3 9	84	15	81	845	82 6	80	1500	70	915	76.1	3.4	70	1730	69	900	70 6
50	230	91	1330	81	715	86 1	3.9	84	1730	80	845	82.3	83	1400	70	730	75.0	3.4	71	1415	69	715	70.6
51	231	94	1530	81	745	87.4	3.9	86	1745	80	830	83.5	87	1400	70	715	76 7	3.4	72	1345	69	700	70.0
52	232	93	1545	83	715	86 8	3.9	85	15	81	845	82 9	83	1630	70	830	75.8	3.4	71	1415	70	745	70.0
53	233	88	1745	83	945	84.8	3 9	85	15	82	945	82 9	77	1445	71	800	74.4	3.4	70	1645	69	845	69.5
54	234	95	1430	82	700	88 4	3 9	86	2000	80	700	83 5	86	1500	70	815	77.7	3.4	72	1530	69	730	70.3
55	235	92	1645	85	630	88 1	3.9	86	1645	83	900	84.5	83	1800	73	915	77 3	3.4	71	1800	70	745	70.9
56	236	95	1615	83	815	88 4	3 9	86	1900	81	845	83 5	87	1630	73	945	79.8	3.4	73	600	70	545	72.2
57	237	94	1600	82	815	87.7	3.9	86	15	80	930	83.2	86	1415	70	830	76.7	3.4	71	15	69	1700	70.2
58	238	93	1615	81	800	86.1	3 8	85	2000	79	945	82.6	81	1600	68	800	73.4	3 3	69	100	68	1600	68.9
59	239	93	1600	80	800	86.5	3.8	84	2030	78	915	81.3	82	1500	67	800	73 1	3.3	68	300	68	1145	68.3
60	240	94	1500	82	745	87.7	3 9	85	1800	79	915	82 3	84	1400	68	745	75.0	3.4	69	1830	68	715	68.0
61	241	97	1600	85	730	90.6	3.8	88	2100	83	945	85 5	84	1545	72	815	77 2	3.3	70	1230	68	730	69.1
62	242	97	1600	86	815	90.6	3 8	88	2015	84	945	84.2	86	1500	72	900	78.3	3.3	71	1515	69	715	70.0
63	243	92	1400	85	900	88.7	3.8	88	15	84	1015	85 8	84	1600	72	1100	79.2	3.3	72	1800	68	715	71.9
64	244	96	1630	83	830	89 4	3.7	87	1930	81	845	84 2	85	1400	72	730	77.5	3 2	73	1345	71	1200	71.7
65	245	93	1630	83	830	88 4	3 7	86	15	81	945	84 2	82	1500	72	745	76 4	3 2	72	1415	71	1200	72 0
66	246	93	1500	83	930	87.1	3.7	86	1930	81	915	84 0	83	'1500	73	745	77 0	3.2	73	1430	71	1200	72.0
67	247	92	1615	82	830	87.1	3.7	86	1930	81	1000	83 2	82	1330	73	845	76.4	3 2	72	1430	72	1215	72.0
68	248	90	1645	78	800	83.9	3.8	84	15	77	930	80 3	78	1630	68	945	72.3	3.3	72	15	69	1230	70.6
69	249	91	1615	78	800	82.6	3.8	82	2000	76	945	79.4	80	1445	65	1030	71.7	3.3	70	15	68	800	68.4
70	250	90	1600	78	815	83 5	3 8	82	2000	76	1000	79.7	79	1530	66	1030	72 0	3.3	69	2000	68	830	69.5
71	251	88	1615	78	800	82 9	3 8	82	2030	77	1000	79.7	75	1445	67	800	70 8	3.3	72	1045	68	715	69.5
72	252	86	1730	78	900	81.9	3 8	81	15	77	900	79.0	77	1645	69	745	72.5	3.3	70	1630	69	1115	69.7
73	253	74	2000	72	1315	74 5	4.2	80	30	70	1330	72 6	.	.	.		.	3.7	71	615	69	1315	70.0
74	254	85	1545	73	700	79 1	4.4	73	2345	71	730	72 3		.	.	.	.	3.9	71	15	70	1215	70.3
75	255	90	1515	76	745	81.9	4 1	75	2345	73	15	73.9	.	.	.	.	.	3.6	70	1530	70	2345	70.5
76	256	90	1430	77	815	83 2	4.1	75	600	73	1200	74.5	83	1845	.	.	.	3.6	70	900	70	1045	70.2
77	257	90	1630	76	745	82 3	4 0	75	2345	73	1030	74 2	83	1900	70	1115	77.8	3.5	70	945	70	1130	70.8
78	258	89	1600	76	745	81 6	4 1	76	2200	73	945	74 2	82	1630	71	900	77.2	3.6	71	1500	70	600	70.6
79	259	81	1545	74	1130	77.1	4.1	75	15	71	2345	73.2	74	1700	69	2345	72.7	3.6	71	1000	70	600	70.3
80	260	80	1545	68	800	73 2	4 1	71	15	66	945	67.4	74	1700	64	930	68.4	3.6	70	15	66	1200	67.5
81	261	81	1445	67	745	72 9	4.1	69	15	64	930	66.5	74	1715	62	900	67.3	3.6	68	230	64	1200	65.8
82	262	84	1630	69	745	75 5	4.1	70	2345	66	915	68.4	75	1745	63	945	68 6	3.6	67	2345	64	1200	65.9
83	263	82	1600	70	800	75 2	4.1	70	200	67	1000	68.1	74	1815	63	1000	68.3	3.6	67	500	65	1230	66.1
84	264	81	1600	67	800	73 5	4.1	69	15	64	945	66.8	74	1815	62	1115	68.4	3.6	67	500	64	1345	66.6
85	265	71	1430	67	800	70 3	4.1	69	200	64	1000	65 8	.	.	62	900	.	3.6	67	445	65	1200	.

LITTLE EAGLE CREEK INTENSIVELY MONITORED POOL TEMPERATURES
S=SHADED POOL, U=UNSHADED POOL, DEP=DEPTH OF MEASUREMENT

OBS	SHADE	DATE	GRIDPOIN	DEPOCM	DEP23CM	DEP36CM	DEP69CM	DEP91CM	DEP114CM
1	.	208	1	82 4	72 1	70 0	.		
2	.	208	2	84 4	71.4	69 6	69.5		
3		208	3	83 8	71.3	69.5	68.4	.	.
4		208	4	84 5	72 6	69 6	68.6	68 3	
5		208	5	84 2	72 5	71 0	70 9	.	.
6	.	208	6	83 7	72 1	69 4	67.9	.	.
7	.	208	7	84 3	71 5	69 6	69.0	68.8	.
8		208	8	84 1	72.2	69 6	69.2	.	.
9	.	208	9	83.7	75 6		.	.	.
10		208	10	84.6	73 5	69.5	69 4		.
11		212	1	82.4	82 3	82 3			.
12	.	212	2	82 1	81 3	80 5		.	.
13	.	212	3	82 3	81 4	80.4	.	.	.
14		212	4	82 5	81.0	80 7		.	
15		212	5	82 5	81 6	79 6	76 5	75 5	75.4
16		212	6	82 1	81 7	80.6	77 3		
17		212	7	82 2	81 8	79 6	76 5	75.9	.
18		212	8	82 2	81.7	79 4	76.7	76.0	.
19		212	9	82 1	81 7	79 8	78 5	.	
20	.	212	10	82.0	81 9	80 0	77 1	75 7	75 7
21		212	11	81 8	81 7	80 3	.		
22	.	212	12	82 1	81 7	79.7	77.8		.
23		212	13	82 0	81.5	80 5		.	.
24		212	14	81 8	81 3	79.8	79.1		.
25		212	15	81.5	81.4	80 1		.	.
26	.	212	16	81.8	81 6	79 9	.	.	.
27	.	212	17	81.6	81 4	79.6	79.5	.	.
28	.	212	1	77 7	72 2	69.7	69 6		.
29		212	2	77.8	71 7	69 6	70.0		
30		212	3	78 0	71 5	69 4	68 3	67 1	.
31		212	4	78 8	70.9	69 2	68.1	67.8	
32	.	212	5	78 9	71 9	69 8	70 2		.
33	.	212	6	78 4	72.1	69 8	68 9	.	
34	.	212	7	79 2	72 0	69 7	68 8	68.7	
35	.	212	8	79.3	71 9	69.7	69.2	.	.
36		212	9	79.3	73 3	.	.	.	.
37		212	10	79.3	71 4	69 5	69 4		.
38		219	1	87.3	86 9	86 8		.	.
39	.	219	2	86.9	85.3	85.1	.	.	.
40		219	3	86 8	85 5	82 0	.		.
41	.	219	4	86 8	85 2	84 1		.	
42		219	5	86.9	85 7	82 9	81.4	78 5	78 4
43		219	6	86.7	86 2	82 7	80 2	.	
44	.	219	7	87 0	85 1	82 3	79 4	79.3	
45		219	8	86 8	85.8	82 4	79 6	79 5	.
46	.	219	9	86.6	85 8	82 3	81 5		
47		219	10	86 9	85 3	82 5	80 0	78 9	78 6
48		219	11	87 0	86.6	84.1			
49	.	219	12	87 1	84 7	82 6	81 8	.	.
50	.	219	13	87 8	86 5	85 0	.		.
51		219	14	87 0	86 1	83.0	82.5		
52		219	15	87.1	87 0	84 1	.	.	.
53	.	219	16	87 4	86.4	84 0		.	
54		219	17	87.2	87 2	83 6	83.6	.	
55		219	1	83 9	73 3	72 2	71 5		
56		219	2	83 6	73 2	71 9	72 2	.	
57		219	3	83 5	74 3	71 9	69 3	68.7	
58		219	4	83 4	75 2	72 0	70 0	69 9	
59		219	5	83 7	75 0	71 8	72.3		.
60		219	6	83 0	75 2	71.9	70 3		
61	.	219	7	83.6	74 8	71 9	70 4	70 3	
62		219	8	84.0	73 4	71.7	71 0		
63		219	9	83 5	77 5	.	.		.
64		219	10	84 5	73.8	71 7	71.2	.	
65	.	226	1	88 6	88 4	88 4			.
66		226	2	87 4	86 5	85 6		.	
67		226	3	87.4	86 8	84 1		.	
68		226	4	87 5	86 2	85 5			
69		226	5	87.4	86 9	84.3	81.8	80 7	80 6
70		226	6	87 1	87 1	84 6	81 9		
71		226	7	87.2	87 3	84 3	81 6	81 2	
72		226	8	87 3	87 2	83.8	81 6	81 3	.
73		226	9	87 4	87.6	84.1	83.3		
74		226	10	87 2	87 4	84.6	81 9	81 0	80 9
75		226	11	87 3	87 0	85.6			
76		226	12	87 0	86 5	83.8	83 4		.
77		226	13	87 7	87.3	86 6		.	.
78		226	14	86 8	87 4	84 5	84 0		
79		226	15	87 2	87 3	85 0			
80		226	16	87 2	87 6	85 2			
81	.	226	17	86 9	87.2	85.0	84.0	.	.
82		226	1	78 8	74.0	72 9	73.0		.
83		226	2	78 7	74 9	72 5	73 3	.	.
84		226	3	79 2	75 1	72 6	69 0	68.8	.
85		226	4	79 0	74 3	72 8	71 3	71.2	.
86	.	226	5	80 0	74 5	72 6	72 9		.
87		226	6	79 8	75 2	72 6	71 6	.	
88	.	226	7	79 8	74 5	72 5	71 7	71 7	
89	.	226	8	81 1	76.0	71 8	71.9		
90		226	9	80 5	76 8			. .	
91		226	10	81 9	74 3	72 5	71.6	.	.

LITTLE EAGLE CREEK INTENSIVELY MONITORED POOL TEMPERATURES
S=SHADED POOL, U=UNSHADED POOL, DEP=DEPTH OF MEASUREMENT

OBS	SHADE	DATE	GRIDPOIN	DEP0CM	DEP23CM	DEP36CM	DEP69CM	DEP91CM	DEP114CM
92		229	1	88 0	88 0	88 1			.
93		229	2	86 8	86 3	85 8		.	
94		229	3	86 7	86 2	84 5	84 4		
95		229	4	86 6	86 1	85 8			.
96		229	5	86.6	86 1	84 2	82 8	82.3	82.4
97		229	6	86 4	86 2	84.6	82 6	82 7	
98		229	7	86.3	86.6	84.9	83 0	82.8	.
99		229	8	86 5	86.6	84 8	83 0	82 9	
100		229	9	86 7	86 7	84 8	84 4	.	
101		229	10	86 5	86 6	85.2	83 0	82.8	82.6
102		229	11	86 3	86 5	86 1			
103		229	12	86 4	86.6	84 7	84 1		
104		229	13	86 7	86 7	86 1		.	.
105		229	14	86 4	86 7	85 2	84.6	.	.
106		229	15	86 6	86 5	86 1	.		
107		229	16	86 3	86 6	85 9			.
108		229	17	86 5	86 6	85 9	84 8		
109		229	1	79 8	74 5	73 3	73.5		.
110		229	2	79 4	75 3	73 1	73 4		.
111		229	3	79 4	75 3	73 0	71 1		.
112		229	4	79 6	75 2	73 5	71.5	71 1	
113		229	5	80 4	75 1	73 5	73 0		
114		229	6	79.0	75 4	72.9	71 6	.	
115	.	229	7	79 8	75 4	73.3	71 9	72.2	.
116		229	8	79 8	75.1	73 1	72.3		.
117		229	9	80 7	75 6	.	.	.	
118		229	10	80 5	74 7	73 3	73.0	.	.
119		233	1	83 9	84.1	84 4		.	
120		233	2	83 1	82 9	83.2	.		
121		233	3	82 4	82 8	82 8	82 8	.	.
122		233	4	83 0	82.9	83.1	.		.
123		233	5	82 9	82 9	82 9	82 6	82.2	82 2
124		233	6	82 8	82.9	82 8	82.8	.	
125	.	233	7	82 8	82 8	82 9	82 5	82.5	.
126		233	8	82 7	82 9	82 9	82.6	82.5	.
127	.	233	9	82 6	82 9	83.0	83 0	.	.
128	.	233	10	82 5	82 9	83 0	82.5	82 4	82.4
129	.	233	11	83 0	83 2	83 5	.	.	.
130		233	12	83 0	83 1	83.0	83.2	.	
131	.	233	13	83 3	83 4	83.0	.	.	.
132		233	14	83 1	83 2	83 2	83.5		
133		233	15	83 3	83 3	83 5	.	.	
134		233	16	83.1	83 3	83 5	.		
135	.	233	17	83 0	83 2	82.8	82.5	.	
136		233	1	76 4	75 2	74.1	.	.	.
137		233	2	76.2	75.4	73.4	73 6	.	.
138		233	3	76.6	75 5	73 7	70 6	68.6	
139	.	233	4	76 7	75 5	73.6	71.3	71 1	
140		233	5	76.8	75 9	73 9	74 0		.
141		233	6	76.5	76 3	74 0	72 2		.
142		233	7	77.0	76.3	73.0	71.7	71.6	.
143		233	8	77 0	76.4	73 4	72 6		.
144		233	9	76 7	76 5			.	
145		233	10	77 0	76 6	73 5	73 3	.	.
146		236	1	93 7	93 4	93 5			.
147		236	2	92.4	91 3	90 9		.	
148		236	3	92 2	91 4	89 7	.		.
149		236	4	92.1	91.4	91.1		.	.
150		236	5	91 8	91 9	89 5	85 8	84 8	84 7
151	.	236	6	91 6	90 5	89.4	86.3	85 3	.
152		236	7	91 5	91 6	89 5	85.8	85 3	.
153		236	8	92 0	91.9	90 0	86.4	85.6	.
154		236	9	92.2	91 9	89 1	88 5	.	
155		236	10	91.9	92 1	90 0	86.5	85 4	85 2
156	.	236	11	91 8	91 8	91 5	.		
157		236	12	92.2	92 1	89.6	88 4		
158		236	13	92 4	92 3	92 2			
159		236	14	92.3	92 3	89 9	89.4		.
160	.	236	15	92 3	92 0	91 5	.		
161		236	16	92 3	92.1	90 7			
162		236	17	91 8	92 2	89 8	87 7		
163		236	1	83.3	78 1	75 4	74.6		.
164		236	2	82 9	78 6	75 6	74 1		.
165		236	3	84 2	79 6	75 5	72 8	70 5	
166		236	4	84 7	80 8	75 3	72 7	71.6	
167		236	5	83 1	79 8	75 7	74 7	.	.
168		236	6	84.4	78 4	76.0	74 0	.	.
169		236	7	85 1	78.3	74 8	72.7	72.2	.
170		236	8	85.5	76.5	75 6	73 4	.	.
171		236	9	84.9	81 9	.	.	.	
172		236	10	85 9	77 5	74.9	73.7	.	.
173		240	1	91.1	90.9	90 6	.	.	.
174		240	2	89 3	88.2	87 8		.	.
175	.	240	3	89.4	89 0	87 6	.	.	
176		240	4	89 2	88 0	87.3	.	.	
177		240	5	89.2	88.6	86 1	83 6	82.5	82 5
178		240	6	89 2	88 7	86 8	84.4	.	
179		240	7	89.2	89 0	86.2	83 9	83.0	
180	.	240	8	89 3	89 4	86 2	84 0	83 8	.
181		240	9	89 5	89 5	86.0	85.7	.	.

LITTLE EAGLE CREEK INTENSIVELY MONITORED POOL TEMPERATURES
S=SHADED POOL, U=UNSHADED POOL, DEP=DEPTH OF MEASUREMENT

OBS	SHADE	DATE	GRIDPOIN	DEP0CM	DEP23CM	DEP36CM	DEP69CM	DEP91CM	DEP114CM
182		240	10	89.3	89.2	86.6	83.8	82.9	83.0
183		240	11	89.6	88.8	88.3	.		.
184		240	12	89.2	89.2	85.7	85.4		.
185	.	240	13	89.4	89.4	86.7	86.7		
186	.	240	14	89.5	89.6		.		
187	.	240	15	89.4	89.4	87.3	.		.
188		240	16	89.5	89.5	88.7	.	.	.
189		240	17	89.4	89.4	87.5	85.9	.	.
190	.	240	1	80.6	74.8	72.4	.	.	.
191		240	2	82.0	78.7	72.4	72.1		.
192		240	3	79.7	75.0	72.9	71.1	69.9	.
193		240	4	76.3	75.5	72.5	71.4	70.6	.
194		240	5	81.6	74.1	73.3	72.7	.	.
195		240	6	81.4	75.8	73.1	71.7		
196		240	7	81.5	75.1	72.4	71.4	71.4	.
197	.	240	8	81.1	75.5	72.5	72.1	.	.
198		240	9	80.8	76.5	.	.		.
199		240	10	81.8	75.7	72.7	72.9	.	
200	.	243	1	90.5	90.6	90.4	.	.	.
201	.	243	2	89.4	88.6	88.9			.
202	.	243	3	89.3	88.9	88.3	.	.	
203		243	4	89.4	89.0	88.8		.	.
204	.	243	5	88.9	89.3	88.0	86.3	85.5	85.5
205	.	243	6	88.9	88.9	88.1	86.3	.	
206		243	7	88.7	89.0	87.9	86.1	86.2	
207		243	8	89.0	89.2	88.0	86.2	86.4	.
208		243	9	89.9	89.4	88.2	88.0		
209		243	10	89.4	89.5	88.4	87.3		.
210		243	11	89.3	89.4	89.7			.
211		243	12	89.2	89.5	88.7	88.5	.	.
212		243	13					.	
213		243	14	90.3	89.7	89.5	.	.	.
214		243	15	89.7	89.5	89.1			
215		243	16	89.2	89.3	89.3	.	.	.
216		243	17	89.0	89.3	87.9	85.2	.	.
217		243	1	80.6	77.8	76.1			
218		243	2	80.7	78.1	76.2	75.4		
219	.	243	3	81.2	78.2	76.5	71.6		
220		243	4	81.3	78.3	76.7	74.4	73.4	
221		243	5	82.0	78.8	76.7	75.8	.	.
222	.	243	6	81.3	78.5	77.0	74.9	.	.
223		243	7	81.6	78.5	76.4	74.1	74.0	.
224		243	8	81.8	78.5	75.9	74.5		
225	.	243	9	81.5	80.5		.	.	
226	.	243	10	81.9	77.9	76.5	76.0	.	.
227		250	1	88.9	89.6	88.6	.	.	.
228		250	2	86.1	86.0	85.6	.	.	.
229		250	3	86.2	86.1	85.3	84.0	.	.
230	.	250	4	86.2	86.2	86.3	.	.	.
231	.	250	5	86.0	86.1	85.2	81.4	80.8	80.5
232		250	6	86.0	86.1	84.8	82.0	.	
233		250	7	85.6	86.1	85.1	81.6	81.2	.
234		250	8	85.4	86.3	85.5	82.1	81.7	.
235		250	9	86.1	86.3	85.2	84.1	.	.
236		250	10	85.8	86.2	84.5	81.9	81.0	80.7
237		250	11	85.2	86.5	86.5	.		.
238		250	12	86.3	86.6	84.9	83.5	.	.
239		250	13	86.5	86.7		.	.	.
240		250	14	85.6	86.7	86.0	84.2		.
241	.	250	15	85.2	86.5	86.4	.		.
242		250	16	86.3	86.6	86.6	.		.
243		250	17	85.6	86.2	85.2	85.1	.	.
244		250	1	76.8	74.3	71.6		.	
245	.	250	2	78.1	74.2	71.7	71.2	.	
246		250	3	76.9	74.5	71.7	69.6		
247	.	250	4	77.8	74.5	71.8	70.0	69.8	.
248		250	5	77.9	73.7	71.4	71.2	.	
249		250	6	77.3	74.0	71.5	71.0		.
250		250	7	77.4	74.6	71.6	70.4	70.3	
251	.	250	8	77.9	74.0	71.1	70.3	.	.
252		250	9	77.7	77.3			.	.
253		250	10	77.7	73.5	71.4	71.1		
254	.	254	1	80.9	80.5	80.3	.	.	
255	.	254	2	81.9	80.1	79.1	79.2	.	
256		254	3	82.4	80.4	79.3	79.4		
257		254	4	82.5	80.5	79.3	.	.	.
258		254	5	82.0	80.9	79.8	77.5	72.2	72.0
259		254	6	82.9	82.2	79.7	74.0	73.9	.
260		254	7	82.9	80.8	79.9	74.4	72.6	.
261		254	8	82.7	80.8	79.8	75.6	73.1	.
262		254	9	83.2	81.2	80.0	77.4		.
263		254	10	83.0	81.7	79.4	75.3	72.4	72.8
264	.	254	11	83.0	81.2	80.1			.
265		254	12	82.9	80.7	79.6	79.4	.	.
266		254	13	83.6	81.5	79.9	.		
267		254	14	83.2	80.5	80.2	79.7	.	
268		254	15	82.7	81.6	80.2			.
269		254	16		.	.			.
270		254	17	81.2	80.5	80.1	79.7		
271		254	1	79.8	79.7	79.5	79.1	.	.
272		254	2	79.9	79.7	79.6	78.4		.
273		254	3	80.0	79.8	79.5	79.0	75.2	.
274		254	4	79.9	79.7	79.6	79.4	71.5	71.4
275		254	5	79.8	79.7	79.7	79.4		

LITTLE EAGLE CREEK INTENSIVELY MONITORED POOL TEMPERATURES
S=SHADED POOL, U=UNSHADED POOL, DEP=DEPTH OF MEASUREMENT

OBS	SHADE	DATE	GRIDPOIN	DEPOCM	DEP23CM	DEP36CM	DEP69CM	DEP91CM	DEP114CM
276		254	6	79.9	79 8	79 6	74 4	.	
277		254	7	79 8	79.7	79 5	77 7	74.4	
278		254	8	80 3	79.7	79.2	76.5	75.3	.
279		254	9	79 9	79 9	.	.	.	.
280		254	10	79.9	79 9	79.8	79.3	.	
281		257	1	86.5	85.8	84 5	.	.	
282		257	2	87.1	84 0	79.8	.	.	.
283		257	3	87.5	84 1	79.1	77.1		
284		257	4	88.0	85 2	83.1	.	.	
285		257	5	87 8	84 5	79 4	75.7	74.2	73.8
286		257	6	97 4	85.4	78 6	75 7		
287	.	257	7	87 9	84 5	79.0	75 5	74.4	
288		257	8	88.2	84 9	81 0	75 6	75.0	.
289		257	9	88 8	85 0	79 0	77.0	.	.
290		257	10	88 5	84 4	79.9	75.9	74.4	74 5
291	.	257	11	87 3	84 7	82.5			
292		257	12	88 6	83 6	80 8	.		.
293		257	13	.	.	.	.	.	
294		257	14			.	.	.	
295	.	257	15	.	.	.		.	
296	.	257	16				.	.	.
297	.	257	17			.	.	.	.
298		257	1	83.7	82 6	75.7	.	.	.
299		257	2	83 6	82.7	75 8	74 2	.	
300	.	257	3	83.3	82 8	75 4	72.2	.	.
301		257	4	83 4	82.6	76.9	72 9	71 8	
302		257	5	83 0	82 6	75.7	75.0	.	.
303	.	257	6	83 1	83.0	75.4	73.3	.	.
304		257	7	83 4	82 8	75 4	73.0	72 5	.
305	.	257	8	83.6	83.4	75 2	73.6	.	.
306		257	9	83 5	82.9				
307		257	10	83 6	82.4	75.7	74.5	.	.

AIR TEMPERATURES RECORDED WITH THERMOGRAPHS AND SOLAR RADIATION DATA RECORDED WITH A PYRANOMETER AT LITTLE EAGLE CREEK

OBS	DATE	TIMMAXR	PEAKRAD	DAILYRAD	WIND
1	202	1315	1.11	1045 20	.
2	203	1315	0.99	1023.40	.
3	204	1300	1.07	849 20	.
4	205	1345	0.93	653 20	
5	206	1415	1 14	892 80	.
6	207	1315	1 17	457 30	.
7	208	1400	1.05	805 70	.
8	209	1215	0.98	740.30	.
9	210	1330	0 97	827 40	
10	211	1345	0.96	892 80	.
11	212	1045	0 75	740.30	0 67
12	213	1400	0 90	849 20	.
13	214	1300	0 48	391 90	
14	215	1630	0 95	544.40	
15	216	1300	1 15	979 90	
16	217	1200	1 05	892 80	.
17	218	1200	0.99	544.40	.
18	219	1245	1 21	740 30	0 25
19	220	1230	1 16	696 80	.
20	221	1330	1.07	805.70	.
21	222	1630	0 90	435 50	
22	223	1030	0.94	653 20	
23	224	1300	1 07	827 40	.
24	225	1200	1.07	827 40	.
25	226	1245	0 96	892 80	0 18
26	227	1400	0 97	805 70	.
27	228	1400	0.96	827.40	
28	229	1215	0.89	653 20	0 17
29	230	1300	1 08	740.30	.
30	231	1300	1.02	805.70	.
31	232	1330	1.12	609.70	.
32	233	1400	0.88	391 90	0.26
33	234	1400	0.99	740 30	
34	235	1415	1.06	457 30	
35	236	1300	1 13	740 30	0 18
36	237	1330	1.02	958 08	
37	238	1400	1.06	958 10	.
38	239	1300	0.97	914 50	
39	240	1430	1.02	827 40	0 38
40	241	1345	1.05	892 80	.
41	242	1200	1 05	914 50	.
42	243	1245	1 15	587 90	0 27
43	244	1315	0.99	892 80	.
44	245	1200	1 05	805 70	
45	246	1200	1 10	740 30	
46	247	1200	1 15	805.70	.
47	248	1230	1.01	892 80	.
48	249	1300	1.00	914 50	.
49	250	1245	0.99	762 10	0 30
50	251	1300	1 01	696.80	
51	252	1130	1.04	500 80	.
52	253	1515	0 63	348 40	.
53	254	1245	1.00	522 60	0 45
54	255	1215	1 10	696 80	.
55	256	1215	0.99	653 20	.
56	257	1245	0 97	609 7	0 21
57	258	1230	0 86	609.7	
58	259	1345	0.98	370 2	.
59	260	1300	1 01	587 9	
60	261	1230	0 86	544 4	
61	262	1330	0 98	544 4	
62	263	1315	1 00	522 6	.
63	264	1300	0 96	.	

VITA

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Candidate for the Degree of

Master of Science

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