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Relationship Between Water Temperatures and Air Temperatures for Central U.S. Streams

by

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ABSTRACT

An analysis of the relationship between air and stream water temperature records for 11 rivers located in the central United States was conducted. The reliability of commonly available water temperature records was shown to be of unequal quality. Simple linear relationships between air (T_a) and water (T_w) temperatures were developed for daily and weekly average temperatures and showed some level of accuracy, especially for weekly average temperatures and for small streams. The general equations $T_w = 5.0 + 0.75\ T_a$ and $T_w = 2.9 + 0.86\ T_a$ simulated the daily and weekly temperatures of the 11 streams studied with a standard deviation between measurements and prediction of 2.7°C and 2.1°C, respectively. Predictions were better for shallow streams than for deep streams. Better predictions were obtained with equations derived for each specific stream individually. Time lags between water and air temperatures ranged from hours to days. In first approximation, the lag time between water temperature response to air temperature changes is found to be proportional to average water depth. For a 2 ft deep stream, it is on the order of hours, for a 15 ft deep river it is on the order of days. Taking into account these time lags slightly improved daily water temperature predictions. Periods of ice cover were excluded from the analysis.

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A = Linear coefficient (°C) or surface area of a parcel of water (ft^2)
A_1,B_1 = Regression coefficients for daily data ignoring the time lag
A_2,B_2 = Regression coefficients for daily data considering a time lag
A_3,B_3 = Regression coefficients for weekly data
B = Linear coefficient
c_p = Calorific capacity of water ($Btu.lbm^{-1}.°F^{-1}$)
h = average depth of a river over width, length and time (ft)
k = Bulk heat transfer coefficient ($Btu.hr^{-1}.ft^{-2}.°F^{-1}$)
n = Number of pairs of data
Q = Average discharge (cfs)
r = Correlation coefficient
R = Goodness of fit coefficient
R_1,R_2 = Goodness of fit coefficient for daily data
R_3 = Goodness of fit coefficient for weekly data
t = Time (hr for hourly data; day for daily data)
T = Time period (24 hrs for hourly data; 265 days for daily data)
T_a = Air temperature at a location close to the stream (°C)
$\bar{T}_a$ = Average air temperature over the period April 1 – Oct. 31 (°C)
T_{a0},T_{a1} = Constants (°C)
T_w = Water temperature of stream (°C)
$\hat{T}_w$ = Estimated value of the water temperature (°C)
$\bar{T}_w$ = Average water temperature over the period April 1–Oct. 31(°C)
T^i_{wd} = Deterministic part of water temperature in Fourier analysis (°C)
T^i_{ws} = Stochastic part of the water temperature (°C)
T^m_w = Mean daily water temperature (°C)
T^r_w = Randomly generated daily water temperature generated from hourly data (°C)

T_{w_1}, T_{w_2} = Constants (°C)

V = Volume of water over a stream reach (ft^3)

X_i = Error committed between T_w^r and T_w^m (one value per day) (°C)

α = Thermal diffusivity coefficient

$\alpha_0, \beta_0, \gamma_0, \delta_0$ = Constants of regression equation

β, γ = Constants of regression equation

δ = Lag time between air and water temperatures

φ = Phase between air and water temperatures

φ_0 = Constant

μ_x = Average of X_i (°C)

ρ = Density of water (lbm ft^{-3})

σ_{T_a} = Standard deviation of T_a (°C)

σ_{T_w} = Standard deviation of T_w (°C)

σ_x = Standard deviation of X_i (°C)

$\sigma_1, \sigma_2, \sigma$ = Standard deviations (°C)

$\omega = \frac{2\pi}{T}$

Subscripts:

a = air

d = deterministic

s = stochastic

w = water

1 = daily data (with no time lag)

2 = daily data (with lag time)

3 = weekly data (with no time lag)

Superscript:

i = i^{th} day of the calendar year

m = mean

r = random

INTRODUCTION

I.1 Purpose of Study

Global climate change has become a major environmental issue during the last decade. Most of the concern has been focused on changes in the atmosphere and oceans and on land. However, there is also a need to study the effects of atmospheric warming on the temperatures of streams and lakes. The forecasting of future stream water temperatures will allow ecologists to predict how organisms, e.g. fish, might be affected. Fish and other aquatic organisms are highly dependent on seasonal water temperatures for reproduction, growth and survival in the long term.

Unfortunately, stream water temperature data are more scarce and more difficult to obtain than air temperatures and are rarely studied systematically. A common practice has been to use air temperature records, as a substitute for water temperature in biological and other studies of streams and lakes. Often, air and water temperatures are equated, which is only a rough approximation as will be shown in this report. Also, some existing water temperature records are of uncertain reliability, because they are based on random measurements. This question will also be addressed in this report.

The main purpose of this study is to develop a method to relate daily or weekly water temperatures of any stream to air temperatures recorded at a nearby location and to point out the magnitude of error associated with this procedure. Stream water temperatures depend on several meteorological parameters, not only air temperature, but sometimes water temperature estimates must be made without requiring a large quantity of data, since data may not be available, may be difficult to obtain, or may not be accurate.

The second purpose of this study is to examine the representativeness of random water temperature measurements in streams. These occur for example when stream temperatures are measured concurrently with stream biological or fisheries studies at random times of a day and on a random number of days. This study is limited to streams, i.e. well mixed water bodies in vertical and transverse direction of a cross–section, and to the time period when there is no ice cover.

I.2 Study Overview

(1) Existing measured air and stream temperature records, for a variety of streams and over several years, were assembled. Of the 28 records originally selected, only 11 proved to be useful for this study, because the others were incomplete. These records were for streams located in the north central and the south central United States.

2) Since the data records obtained varied considerably in their format and in their quality, a first analysis was performed to estimate the magnitude of error to be expected in the measured air and water data themselves (Chap. II).

(3) Serial correlation coefficients were calculated between air and water temperature records, for the 11 rivers studied over several years. The reason for this was to examine if water temperatures can be approximated as a linear function of air temperatures as expressed in eq. 1.1:

$$T_w(t) = A + B \cdot T_a(t) \qquad (1.1)$$

where $T_w(t)$ and $T_a(t)$ are, respectively, the stream and the air temperature at time t, and A and B are constants.

In Fig. 1.1, an example of both the hourly water temperatures of the Zumbro River, near Kellogg, in southern Minnesota and the air temperature recorded at Minneapolis/St.Paul International Airport are plotted versus time.

(4) The response of water temperature to air temperature is dampened and retarded by the thermal inertia of the water. Therefore, it was determined what time lag yields the best correlation between air and water temperatures (Chap. IV). In Fig. 1.2, the water temperature was shifted 7 hours to show that air and water temperature are in phase when taking a time lag into account. The predictability of this time lag as a function of stream parameters was also analyzed. (Chapt. II)

(5) Regression analysis was applied to determine to what extent air and water temperatures are linearly related, using hourly, daily and weekly records. Linear relationships were obtained for daily and weekly air and water temperature records for each of the 11 streams studied.

These relationships were then "averaged" to provide one general linear relationship for daily data, and another one for weekly data. The resulting two relationships were tested on the 11 records used in this study to give the magnitude of the standard deviation to be expected when using them (Chap. IV).

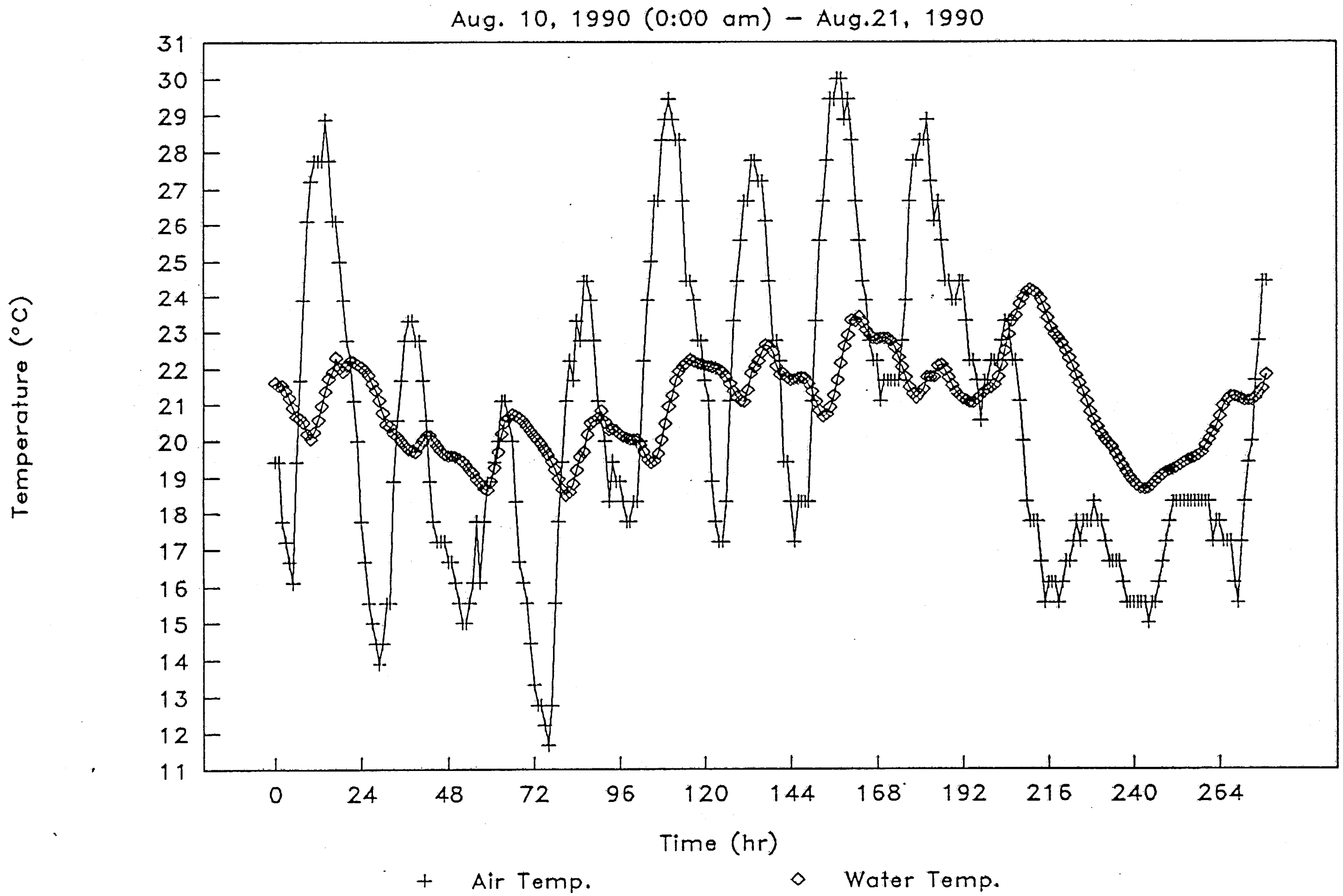

Fig. 1.1 Hourly water temperature of the Zumbro River near Kellogg, MN and hourly air temperature at Minneapolis/St–Paul.

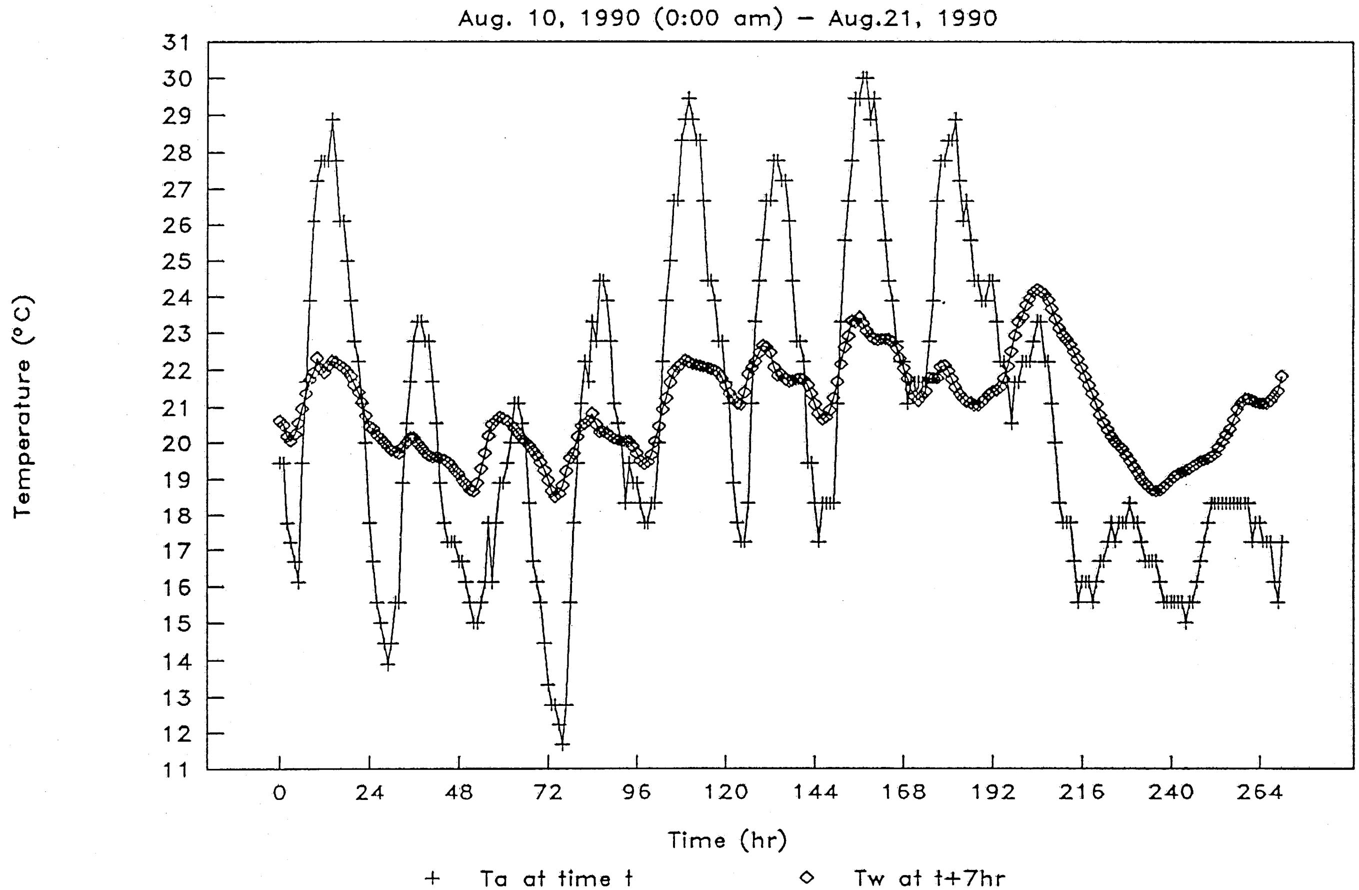

Fig. 1.2 Hourly water and air temperature for the Zumbro River. Water temperature shifted back 7 hours.

(6) Since the relationship between air and water temperatures is expected to be somewhat different from stream to stream, it is of interest to study streams with different climatological and morphometric characteristics and to determine the extent to which these characteristics influence the accuracy of the projected water temperatures.

(7) Water temperatures are often measured manually during daytime hours in biological field studies. A look at Fig. 1.1 shows that such measurements are biased, since the water temperatures might fluctuate by as much as 3 or 4° C during the day. A study of the possible errors was made.

The study was limited to the period from April 1 to October 31. During the winter, streams in the northern states of the United States are usually ice-covered. The frozen surface drastically alters the relationship between air and water temperature. Basically, during the iced-cover period, the temperature of the water is at, or slightly above, 0° C. This period was excluded from the study.

I.3 Literature Review

In the heat budget regulating the temperature of streams, air temperature is usually a very influential parameter. Therefore, an air-water temperature relationship may be considered as a first approach to predicting water temperature. The concept of using air temperature records as a surrogate for water temperatures was previously explored extensively from a stochastic perspective (see Cluis, 1972; Song et al., 1973; Gillett & Long, 1974; Tasker & Burns, 1974; Song & Chien, 1977; Chiu & Isu, 1978 and others. In these studies, the water temperature is broken down into two parts:

$$T_w^i = T_{wd}^i + T_{ws}^i \tag{1.2}$$

where T_{wd}^i is the deterministic part and T_{ws}^i the stochastic part of the daily water temperature on the i^{th} day of the year.

Values of T_{wd}^i consist of the daily water temperature averaged over several years of record. They can be approximated over 1 year by a sinusoidal function of the time of the year:

$$T_{wd}^i = \alpha_0 + \beta_0 . \sin\left(\frac{2\pi t}{365} - \varphi_0\right) \tag{1.3}$$

where α_0, β_0 and φ_0 are constants depending on the stream.

In these studies $T_{w_s}^i$ is considered to be a linear function of the air temperature on the same day i:

$$T_{w_s}^i = \gamma_0 . T_a^i + \delta_0 \tag{1.4}$$

where γ_0 and δ_0 are constants depending on the river and T_a^i is the air temperature of the i[th] day of the year.

However, air temperature is not the only parameter influencing the water temperature. Other parameters of influence are solar radiation, relative humidity, wind speed, water depth, groundwater inflow, thermal conductivity of the sediments, etc... Several numerical heat budget models of different complexities have been developed, taking these parameters into account, to predict stream water temperatures (see Brown, 1972; Novotny & Krenkel, 1973; Noble, 1979; Stefan et al., 1980; Morin et al., 1987 and others). Meteorological data required for such models are is not always available. Even if the data can be acquired, the effort necessary may be substantial.

Therefore, it would be beneficial to have an approximate relationship between air and water temperatures such as eq. 1.1 (as was proposed for rivers with monthly data in England by Smith, 1981). This might be accurate enough to predict daily or weekly average water temperatures, which would be sufficient e.g. for fish studies. It is worth noting that fish can endure peaks on the order of a few hours of higher temperature. Therefore, knowing daily or weekly mean temperatures can be sufficient e.g. to assess water temperature effects on fish.

II. AIR AND WATER TEMPERATURE DATA BASE

II.1 Data Availability

II.1.1 Air Temperature Records

Air temperatures are recorded in many locations and can be fairly easily obtained from agencies such as the U.S. National Weather Service, airports or even independent observers. Available air temperature records from the U.S. National Weather Service consists of two values per day: the daily maximum and minimum temperatures. In some records, the real daily mean is also included. Fig. 2.1 shows the locations of the principal climatological stations of the U.S. National Weather Service. This data is reliable and of good quality: no data is missing in the records, and data has been recorded over a long period of time, allowing statistical analysis.

II.1.2 Water Temperature Records

Obtaining usable water temperature records is not as easy, despite the fact that water temperature plays a determining role in most of the physical and chemical properties of the water, as well as in the ecology of rivers. Temperature records of many streams throughout the U.S. exist and are available from the U.S. Geological Survey. A major problem encountered is that stream temperature records frequently lack continuity. There are few complete records available for an entire year. This lack of continuity occurs for several reasons. One reason is that in summertime, the stream water level may drop below the temperature probes, which then record air temperature instead of water temperature. Damage to probes due to flow, ice, sediments or animals is another reason.

As in the case of air temperature, water temperature records can be found in several agencies, public or private.

Federal agencies likely to have stream water temperature records are:

- U.S. Geological Survey (USGS)
- U.S. Environmental Protection Agency
- U.S. Army Corps of Engineers
- U.S. Forest Service (Department of Agriculture)
- U.S. Bureau of Reclamation (Department of the Interior)
- U.S. Atomic Energy Commission
- Tennessee Valley Authority

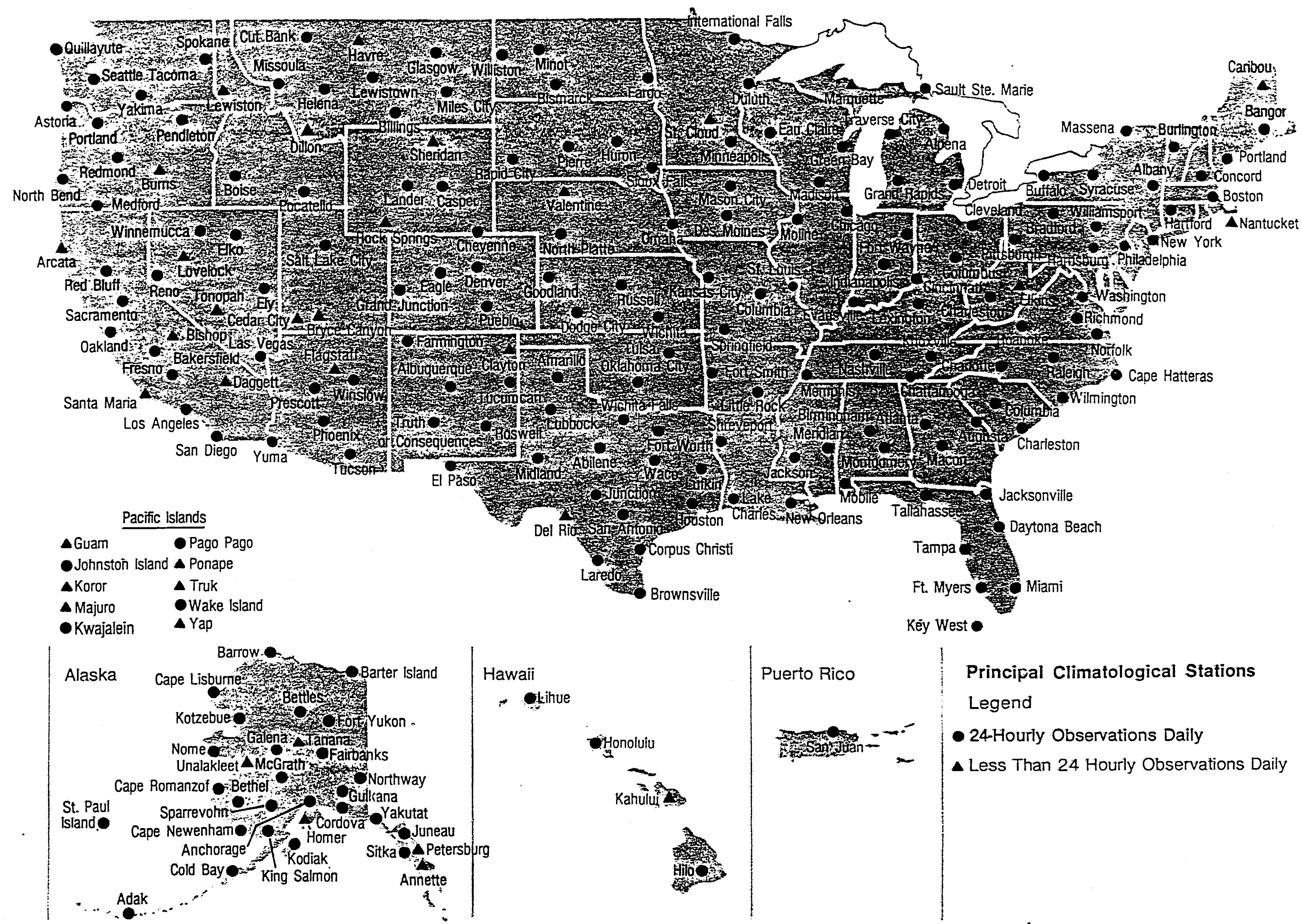

Fig. 2.1 Principal climatological stations in the United States.

Additional sources for such data are local agencies such as:

- Electric power companies
- Municipal water intakes
- Waste water treatment plants

In the context of this study, three characteristics of the records are of importance: the frequency of the measurements, the length of the record and the quality of the record. Since this study requires hourly, daily and weekly data, more than 60% of the water quality monitoring stations' data in the United States cannot be used (Pauszek, 1970). Most monitoring stations collect data on a monthly, quarterly or seasonal basis.

Another limitation is that the location of the stations is not uniform throughout the U.S. For example, out of 731 stations recording water temperature data continuously in the U.S., Pauszek (1970) found only 4 stations located in Minnesota; of 700 stations recording daily temperatures, only three were in Minnesota.

II.2 Data Compilation

To evaluate the linear relationship 1.1 between air and water temperatures and the time lag, existing data was used. The original intent of this study was to use a broad range of Minnesota streams, varying in such characteristics as flow rate, water depth, watershed area, geographical location, presence of an impoundment upstream, etc. Faced by the lack of usable data for Minnesota streams, the study was extended to streams located in the southern states of Louisiana, Arkansas and Texas. This provided a broader range of air and water temperatures, which was desirable.

The air temperatures used for this study were either taken at the same location as the stream temperature monitoring stations when available, or from a location nearby (Table 2.1 and Fig. 2.2 and 2.3). The correlation between daily air and water temperature (calculated with the help of the computer program CORRELATION COEFF, in Appendix A.1) starts to decrease when the 2 locations are more than 100 miles apart, especially if the 2 sites are not at the same latitude. Instead of being of the order of 0.8 or 0.9 (which is typical for sites where air and water temperatures are measured concurrently), the correlation coefficient becomes as low as 0.5 or 0.4. We arbitrarily disregarded such cases, where the correlation coefficient was below 0.7. One exception to this was the Roseau River, MN, which, despite of a distance of 144 miles between the water and the air stations, still showed a correlation of 0.92.

Because of the different formats used by various agencies to store the data on computer discs, a large amount of data manipulation was required to render these records uniform and usable. When 1 or 2 values were missing in a record, they were generated by interpolation. If the record was still not

Table 2.1 Water and air temperature monitoring stations.

RIVER STATION	DRAINAGE AREA (mi^2)	MEAN DISCHARGE (ft^3/s)	RIVER STATION LOCATION		AIR STATION	AIR STATION LOCATION		DISTANCE APART (mi)
			Lat	Long		Lat.	Long.	
1. STRAIGHT RIVER (near Park Rapids, MN)	53	45	465230	950356	same location	425230	950356	0
2. STRAIGHT RIVER (at C. Hwy 115 near Park Rapids, MN)	45	45	465245	950612	same location	465245	950612	0
3. VERMILLION RIVER (near Empire, MN)	110	55.2	444000	930317	Mpls Airport MN	445309	931312	17
4. ROSEAU RIVER (near Caribou, MN)	1570	286	485854	962746	International Falls, MN	483500	932410	144
5. MINNESOTA RIVER (near Jordan, MN)	16200	3776	444135	933830	Mpls Airport MN	445309	931312	25
6. MISSISSIPPI RIVER (at St-Paul, MN)	36800	11200	445640	930520	Mpls Airport MN	445309	931312	8
7. ARKANSAS RIVER (at Dardanelle, ARK)	153670	37080	351334	930858	Little Rock ARK	344448	921642	55
8. AMITE RIVER (at 4H camp near Denham Springs, LA)	1280	2076	302630	905820	New Orleans LA	295724	900348	55
9. PEARL RIVER (near Bogalusa, LA)	6573	9983	304735	894915	New Orleans LA	295724	900348	60
10.NORTH WICHITA RIVER (near Truscott, TX)	937	63.2	334914	994710	Wichita Falls TX	335412	982936	72
11.PLUM CREEK (near Luling, TX)	309	102	294158	973612	San Antonio TX	292524	982942	35
12.ZUMBRO RIVER (at Kellog, MN)	1400	886	441843	920014	Mpls Airport MN	445309	931312	72
13.MISSISSIPPI RIVER (at Minneapolis, MN)	19050	7954	445900	931508	same location	445900	931508	0

* Annual mean discharge over the years recorded by USGS

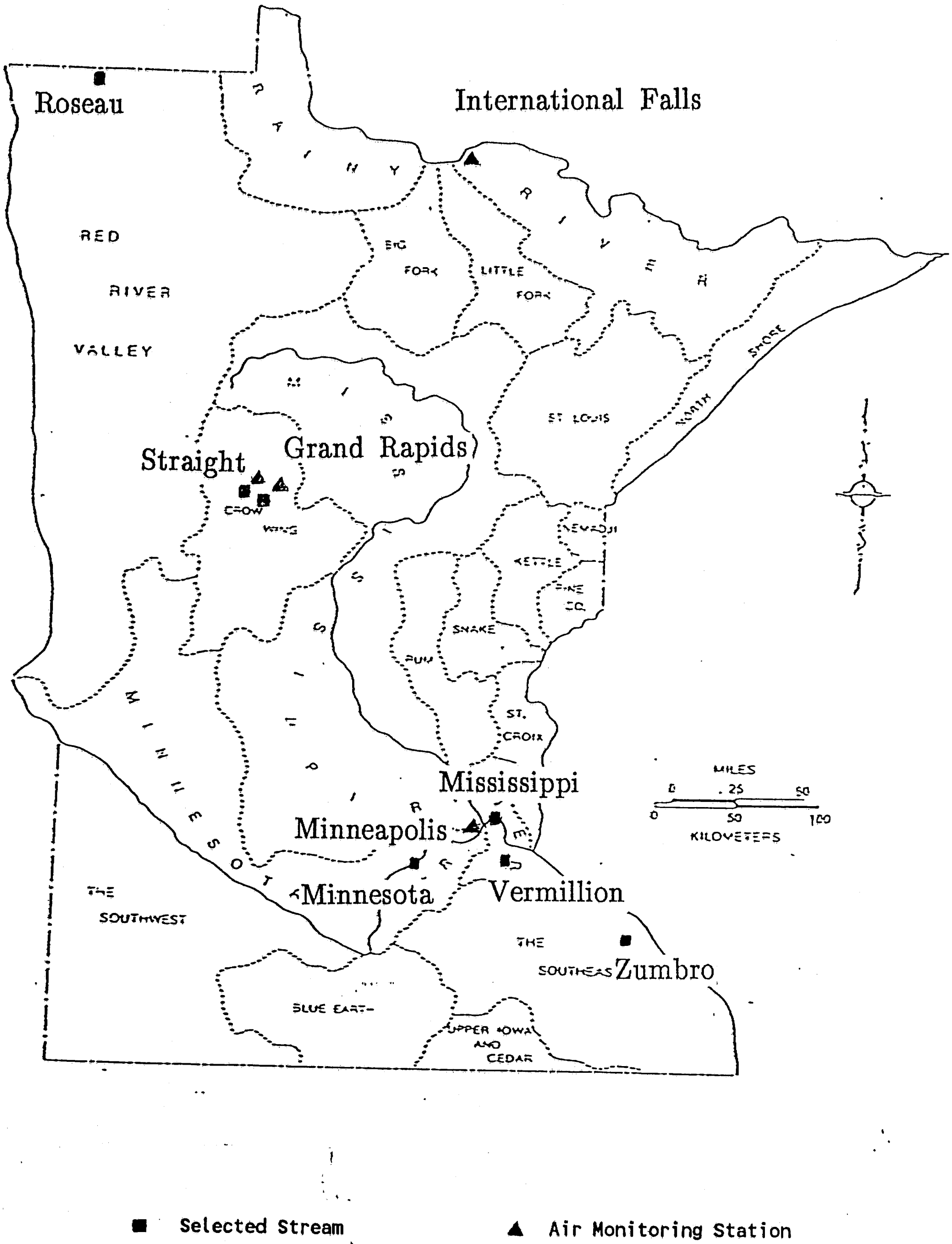

Fig. 2.2 Location of the selected streams and air temperature monitoring stations in Minnesota.

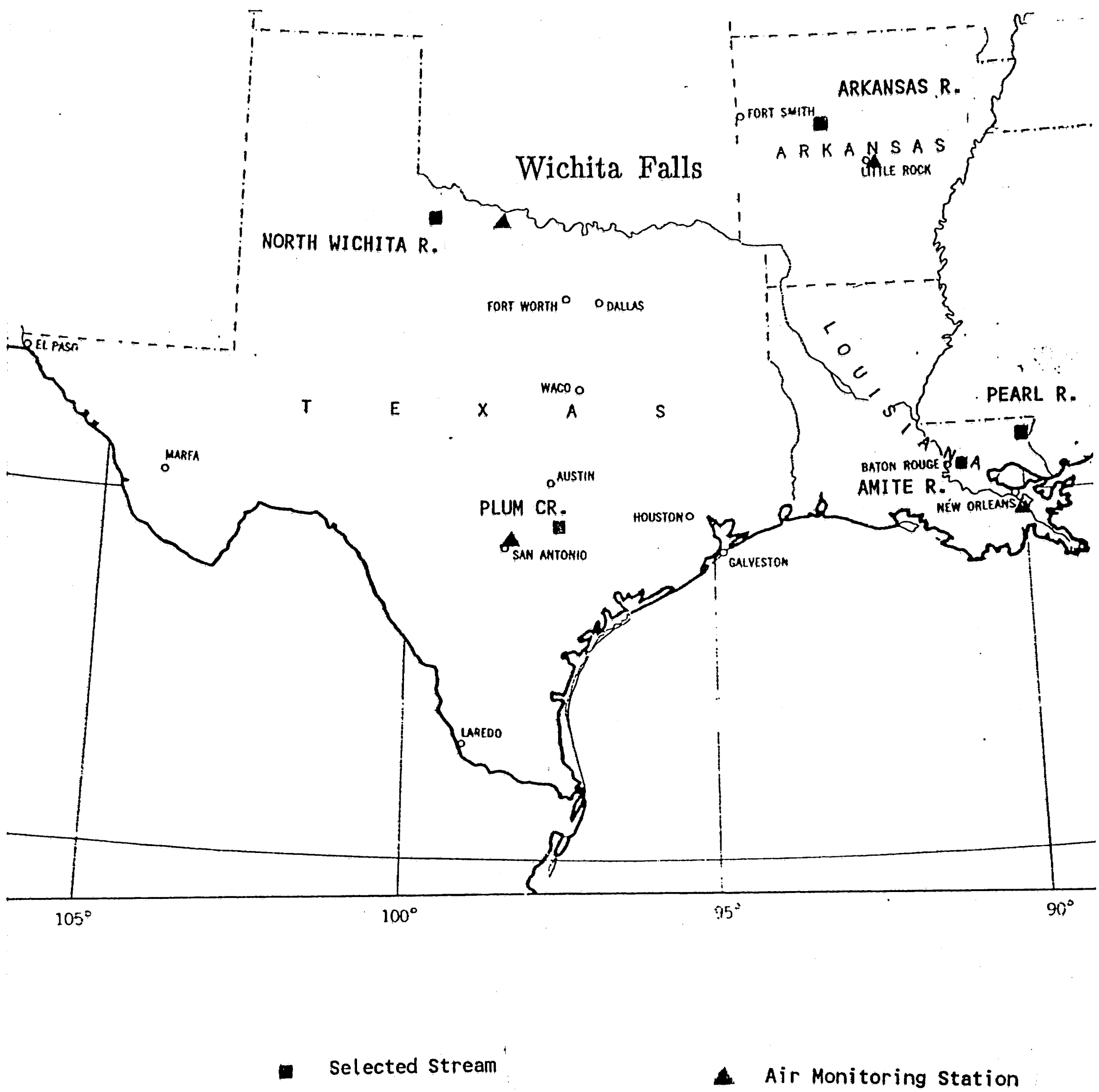

Fig. 2.3 Location of the selected streams and air temperature monitoring stations in the southern United States.

complete after interpolation for the period of April 1 through October 31, then the record was used for the shorter period for which there was no missing data. Also, when available, several years of data were used for the same river (Table 2.2).

Since the air temperature records provided by the weather service consist of the daily maximum and minimum temperatures, the daily air temperatures were obtained by averaging these two values. The other daily data obtained were daily mean values. The daily water and air temperature records are given in Appendix B and on the floppy discs.

For the Straight River, air and water temperatures measured every 2 hrs were provided by Stark (USGS). For the Mississippi River in Minneapolis and the Zumbro River, air and water temperatures measured every 20 minutes were provided , respectively, by Ellis and Stefan (St. Anthony Falls Hydraulic Laboratory). This data is not reported in Appendix B for being too voluminous, but is available on floppy discs.

Three sets of air and water temperature records are plotted in Figs. 2.4, 2.5, 2.6 and 2.7, corresponding to 3 rivers of different sizes. Daily data for the Mississippi River in St. Paul, MN are plotted in Fig. 2.4. This represents the largest river studied (drainage area = 36,800 square miles). The Pearl River in Louisiana (Fig. 2.5) illustrates a medium size river (drainage area = 6,673 square miles), and the Straight River in northern Minnesota (Figs. 2.6 and 2.7) represents a small river. For the Mississippi and the Pearl River, the stream and air temperature data available were daily averages, whereas air and water temperatures had been recorded every 2 hours (on a "two-hourly" basis) for the Straight River. Comparing these figures shows already that amplitudes of the diurnal stream temperature fluctuations are inversely correlated with the water depth.

The program AVERAGE (see Appendix A.2) was used to calculate the mean daily data from the records of temperature measured every 20 min or every 2 hrs, and the mean weekly data from the daily temperature records.

II.3 Errors related to Data Collection

II.3.1 Random Data Collection

One major source of stream water temperature data are agencies and organizations dealing with fisheries. Often water temperature data are collected on field trips. By compiling such data from different sources, over long periods of time, fisheries scientists develop temperature records for streams at various locations.

Some error is contained in these records, for the following reasons: temperatures may have been recorded at different times of the day; an observer may have recorded the temperature at 7:00 a.m. on one day and at 2:00 p.m. the next day. However, water temperatures fluctuate between

Table 2.2 Water and air temperature records.

RIVER STATION	WATER TEMPERATURE RECORD				AIR TEMPERATURE RECORD
	PERIOD	LENGTH	FORMAT	QUALITY	
1. STRAIGHT RIVER (near Park Rapids, MN)	1989	1 yr	2_hourly	-	2_hourly
2. STRAIGHT RIVER (at C. Hwy 115 near Park Rapids, MN)	1989	1 yr	2_hourly	-	2_hourly
3. VERMILLION RIVER (near Empire, MN)	1979-85	7 yrs	daily max, min, mean	5 years are incomplete	daily mean
4. ROSEAU RIVER (near Caribou, MN)	1981-83	3 yrs	daily max, min, mean	all years are incomplete	daily mean
5. MINNESOTA RIVER (near Jordan, MN)	1979,81, 1983-85	5 yrs	daily max, min, mean	all years are incomplete	daily mean
6. MISSISSIPPI RIVER (at St-Paul, MN)	1957-64	8 yrs	daily max, min	-	daily mean
7. ARKANSAS RIVER (at Dardanelle, ARK)	1983-88	6 yrs	daily max, min, mean	-	daily max, min
8. AMITE RIVER (at 4H camp near Denham Springs, LA)	1973-74	2 yrs	daily max, min, mean	-	daily max, min
9. PEARL RIVER (near Bogalusa, LA)	1976,79-80	3 yrs	daily max, min, mean	1 year is incomplete	daily max, min
10.NORTH WICHITA RIVER (near Truscott, TX)	1983,87-88	3 yrs	daily max, min, mean	-	daily max, min
11.PLUM CREEK (near Luling, TX)	1981-85	5 yrs	daily max, min, mean	2 years are incomplete	daily max, min
12.ZUMBRO RIVER (at Kellog, MN)	Jul.28-Aug.21 1990	3 wks	3 meas./hr	1 day of data is missing (Aug.9)	hourly
13.MISSISSIPPI RIVER (at Minneapolis, MN)	April-Aug. 1991	22 wks	3 meas./hr	temp. might be high by 1 or 2 C	3 meas./hr

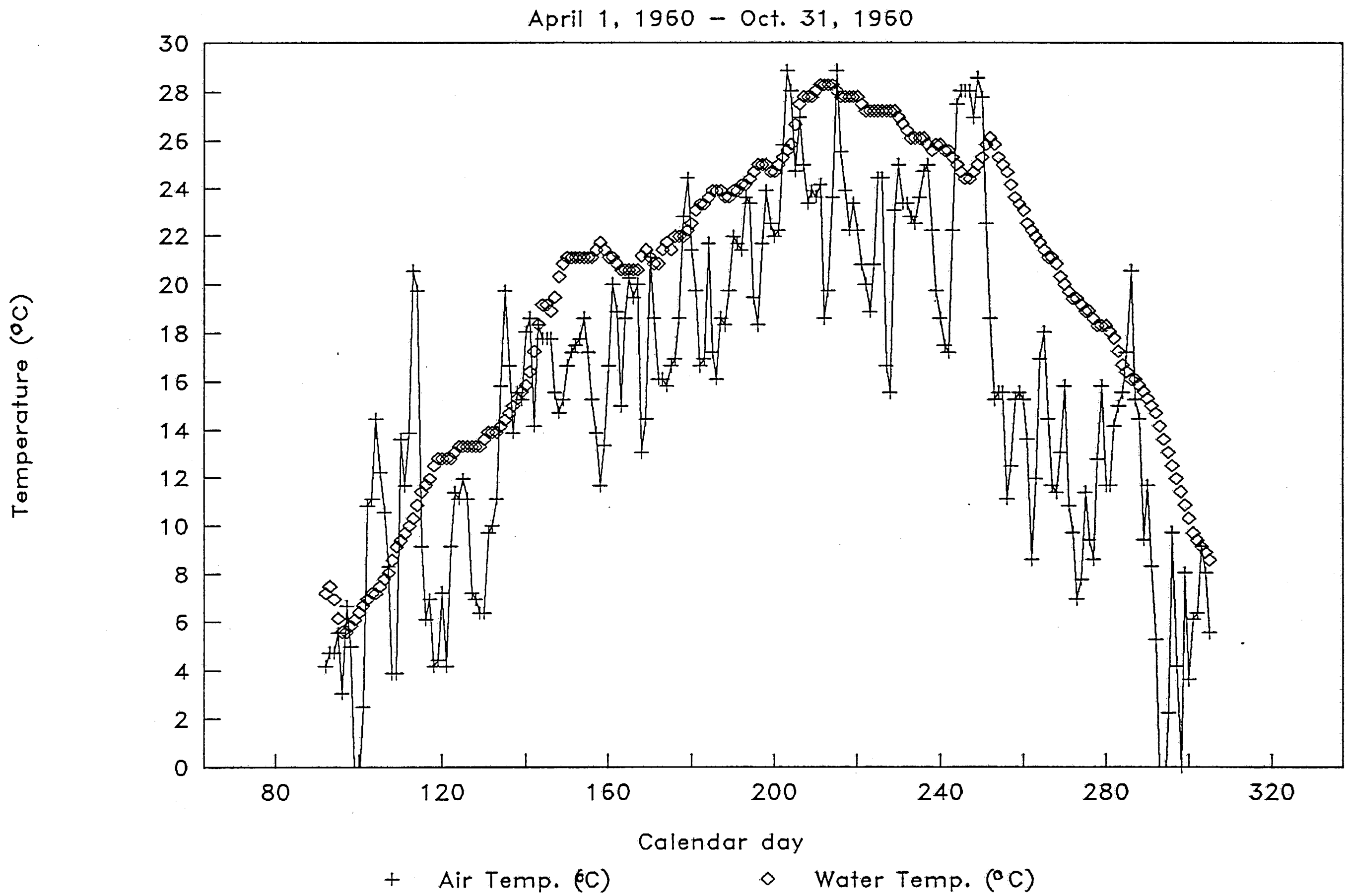

Fig. 2.4 Daily water temperature of the Mississippi River at St. Paul, MN and daily air temperature measured at the Minneapolis/ St. Paul International Airport.

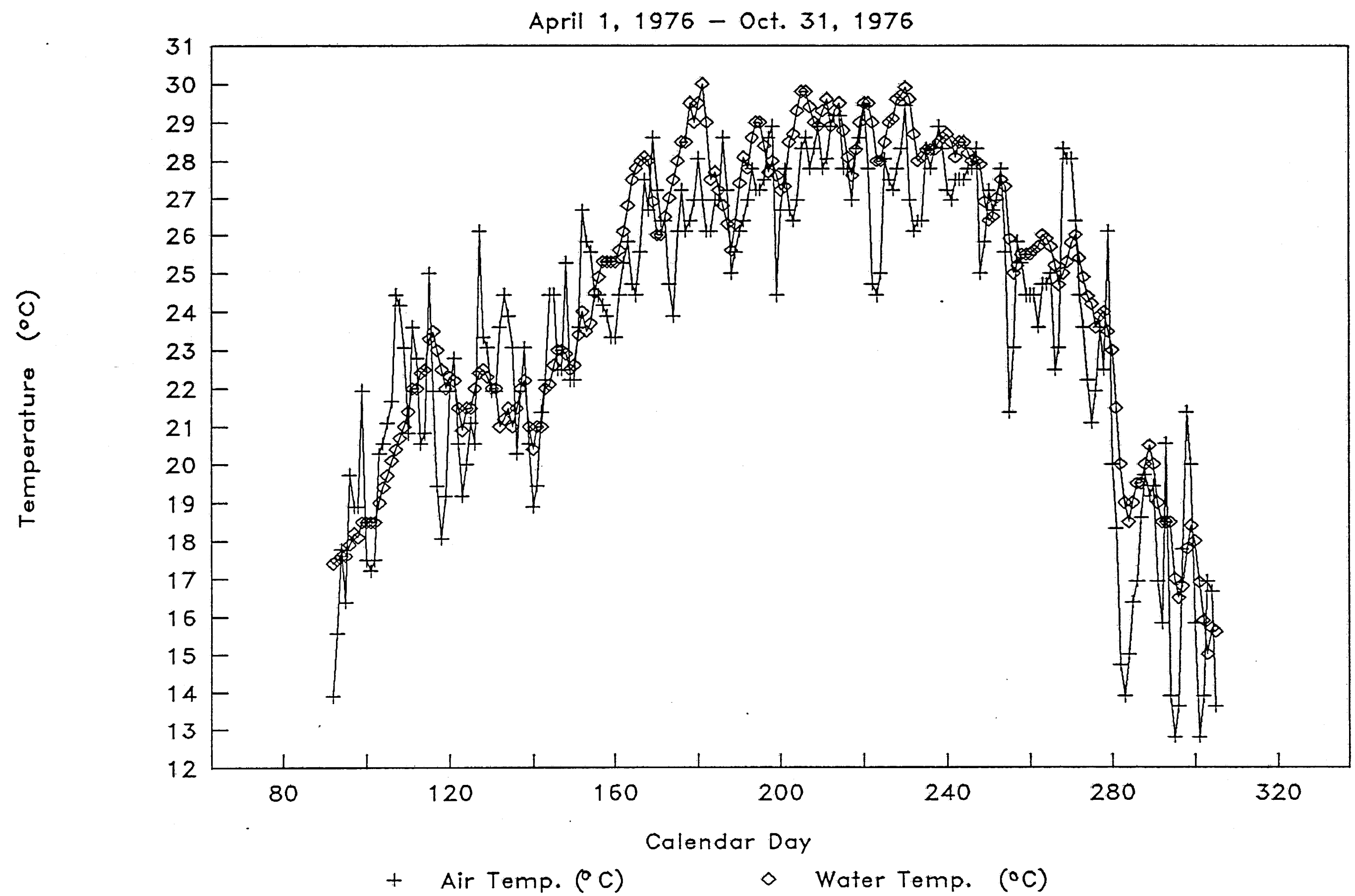

Fig. 2.5 Daily water temperature of the Pearl River near Bogalusa, LA and daily air temperature measured in New Orleans.

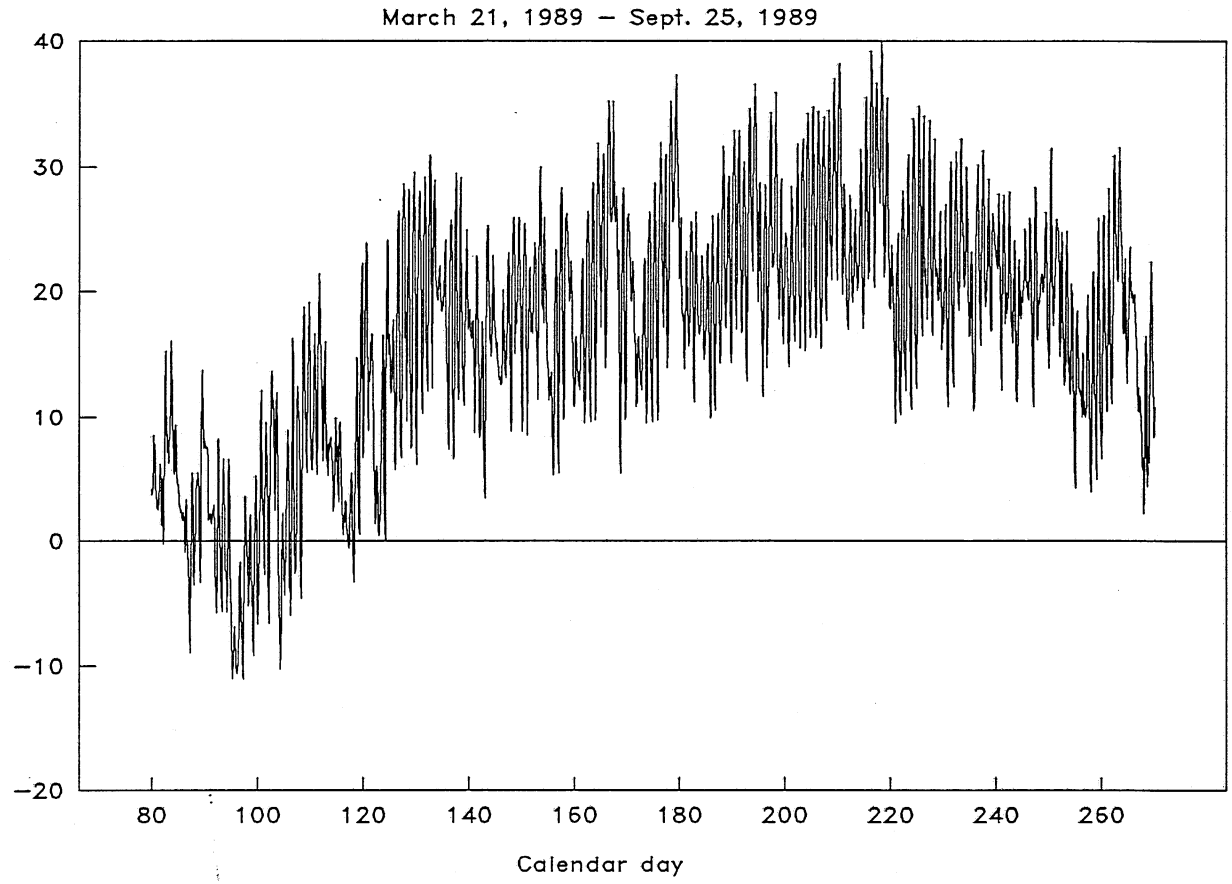

Fig. 2.6 Air temperatures measured at 2 hours intervals near the Straight River (at County Highway 115, near Park Rapids, MN).

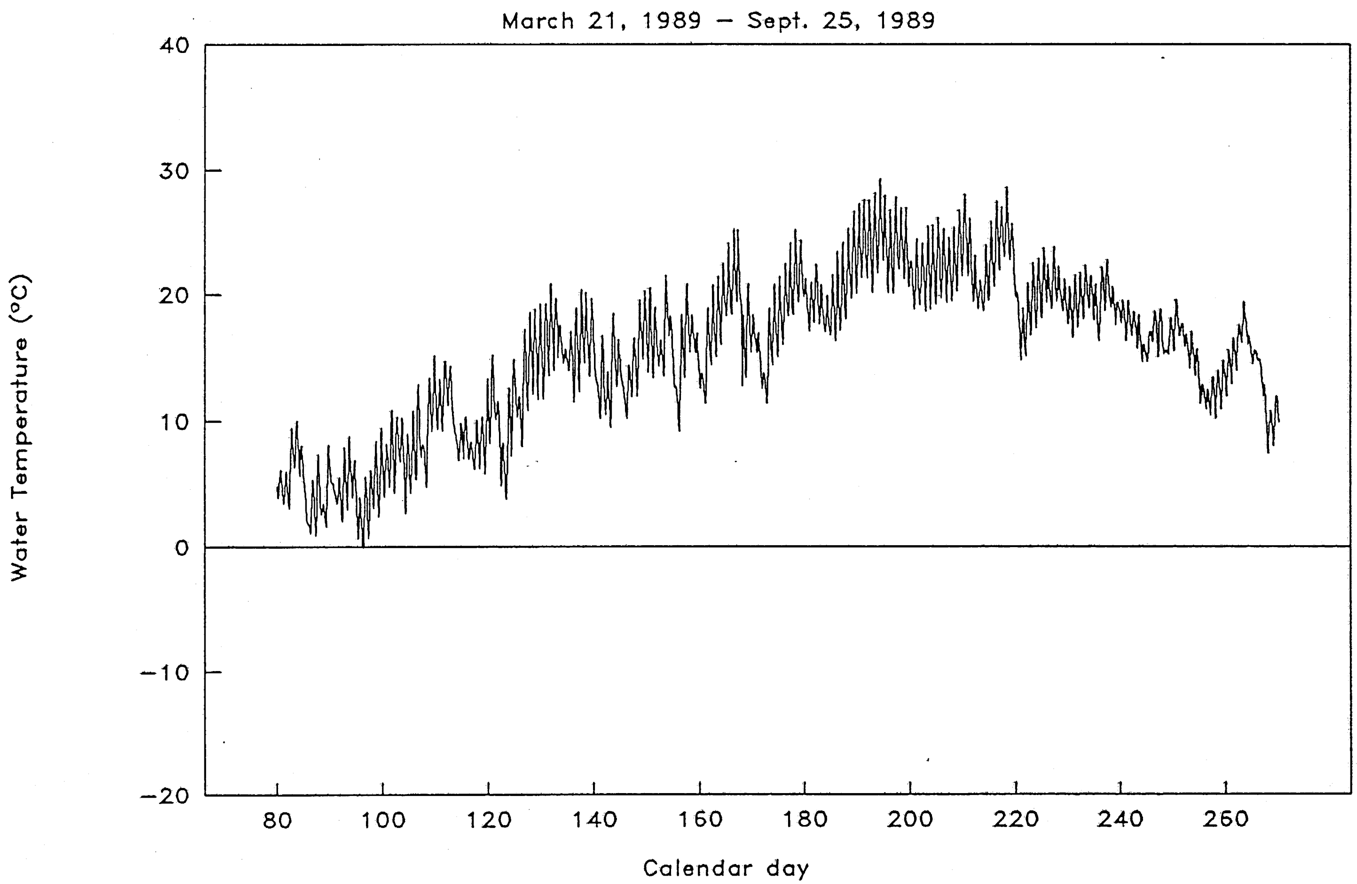

Fig. 2.7 Water temperature measured at 2–hour intervals in the Straight River at County highway 115, near Park Rapids, MN.

morning and afternoon, especially if the river is shallow. In the Zumbro River, for example, water temperatures shown in Fig. 1.1 fluctuate by as much as 3 °C during the day. Thus, equating an instantaneous temperature with a daily temperature might prove to be erroneous. An illustration of this is shown in Fig. 2.8 for the Straight River, near Park Rapids, MN; measured two-hourly water temperatures are plotted, along with the daily average temperature. This figure can be used to show how imprecise a "random" temperature sampling might be. It is also of interest to note that for this river, the average stream temperatures occur around noon in the winter and around 1:00 p.m. in the summer (which in both cases correspond to the time of the day when the sun is at its zenith).

In order to have an idea of the error likely to result from substituting random instantaneous measurements for true daily averages, several scenarios were constructed. The scenarios assumed that water temperatures were collected randomly (with a uniform probability) during different periods of each day. In this way, a time series of artificial "measurements" of stream temperatures were made by randomly selecting from available hourly or two-hourly temperature records. The Mississippi River in Minneapolis and the Straight River (at two different locations) near Park Rapids, Minnesota were selected as examples. One is a very large river, the other a small one.

The four sampling periods studied are:

Case 1 :	6:00 am – 6:00 pm	
Case 2 :	8:00 am – 4:00 pm	
Case 3 :	6:00 am – 12:00 pm	(morning)
Case 4 :	12:00 pm – 8:00 pm	(afternoon)

In each of these cases, the computer program RANDOM TEMP (see Appendix A) generated one water temperature per day, picked at random from the existing hourly records. Then, this set of daily data over a period of several months was compared with the actual calculated daily average temperature set, and statistics were computed. The statistical variables used are:

$$X_i = T_w^r - T_w^m \tag{2.1}$$

$$\mu_x = \frac{\Sigma X_i}{n} \tag{2.2}$$

$$\sigma_x = \left(\frac{\Sigma(X_i - \mu_x)^2}{n-1}\right)^{1/2} \tag{2.3}$$

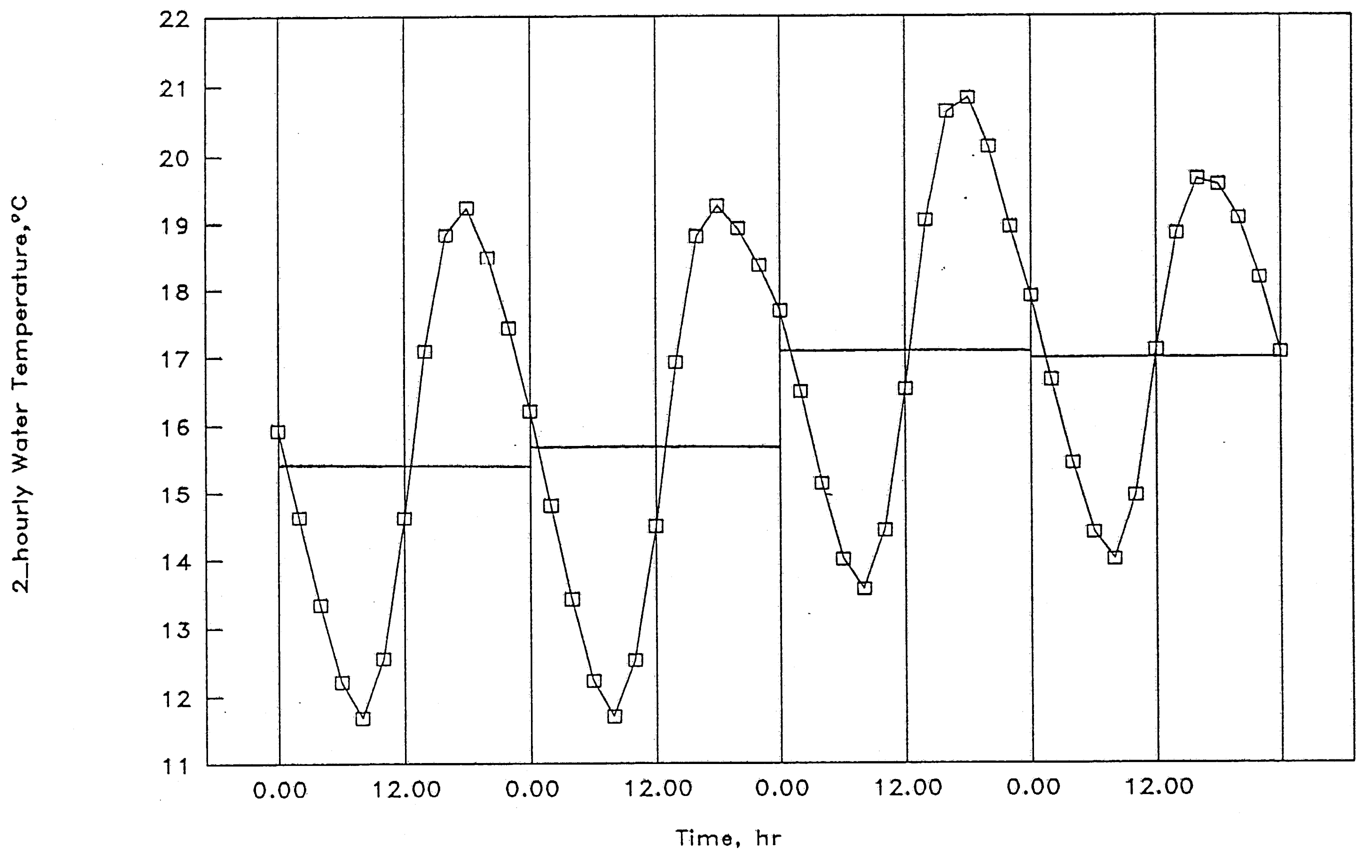

Fig. 2.8 Two–hour measured water temperature and daily average water temperature of the Straight River near Park Rapids, MN.

where: T_w^r is a randomly generated daily water temperature, T_w^m is the true daily mean temperature calculated from the records, X_i is the difference between T_w^r and T_w^m (giving one value of X_i per day of record), μ_x is the average of X_i over several months of record, n is the number of days of the record, and σ_x is the standard deviation of X_i.

Regression lines between the sets of values T_w^r and T_w^m were computed, as shown in Fig. 2.9, providing the coefficients β and γ of the linear relationship:

$$T_w^m = \beta + \gamma . T_w^r \qquad (2.4)$$

Results of the error analysis are presented in Table 2.3, where σ represents the standard deviation of the data from the regression line, and R^2 is the coefficient of regression. The error is much smaller for the deep river than for the shallow river. This is expected since the variations of the water temperature during the day are larger for shallow rivers than for deep rivers.

For the Mississippi River in Minneapolis, Minnesota (Table 2.3), the maximum expected error is only 0.2 to 0.3°C, for whatever period of the day the water temperatures are measured. In contrast, for the Straight River, the error can be as large as 1.5°C. If most of the measurements are made in the morning, the records will underestimate the daily average, if they are made mostly in the late afternoon, the average will be overestimated.

Comparing the results for the four different periods of sampling (Table 2.3), the measurements made between 6:00 a.m. and 6:00 p.m. give the best results (off by only ± 0.5°C on average). The worst case occurs when measurements are made in the early morning only.

II.3.2 Daily Temperature averaging

Another source of data error results from the way air and water temperatures are recorded. Some records provide only the daily minimum and maximum temperatures instead of the true daily mean temperature. Air and water temperature records in this study (Table 2.2) had various formats:

- temperatures recorded every 20 min, 1 or 2 hrs
- daily minimum and maximum temperatures recorded
- daily minimum and maximum, and daily mean temperatures recorded.

It was therefore of interest to study if daily averages and the averages of the daily minimum and maximum temperatures agree statistically. Using the records from the Straight River, which consist of hourly water and air temperature data, the mean temperatures calculated from the hourly data (using the computer program AVERAGE, in Appendix A) was compared with the average of the daily minimum and maximum of the hourly temperatures (calculated with the computer program MINMAX, in Appendix A).

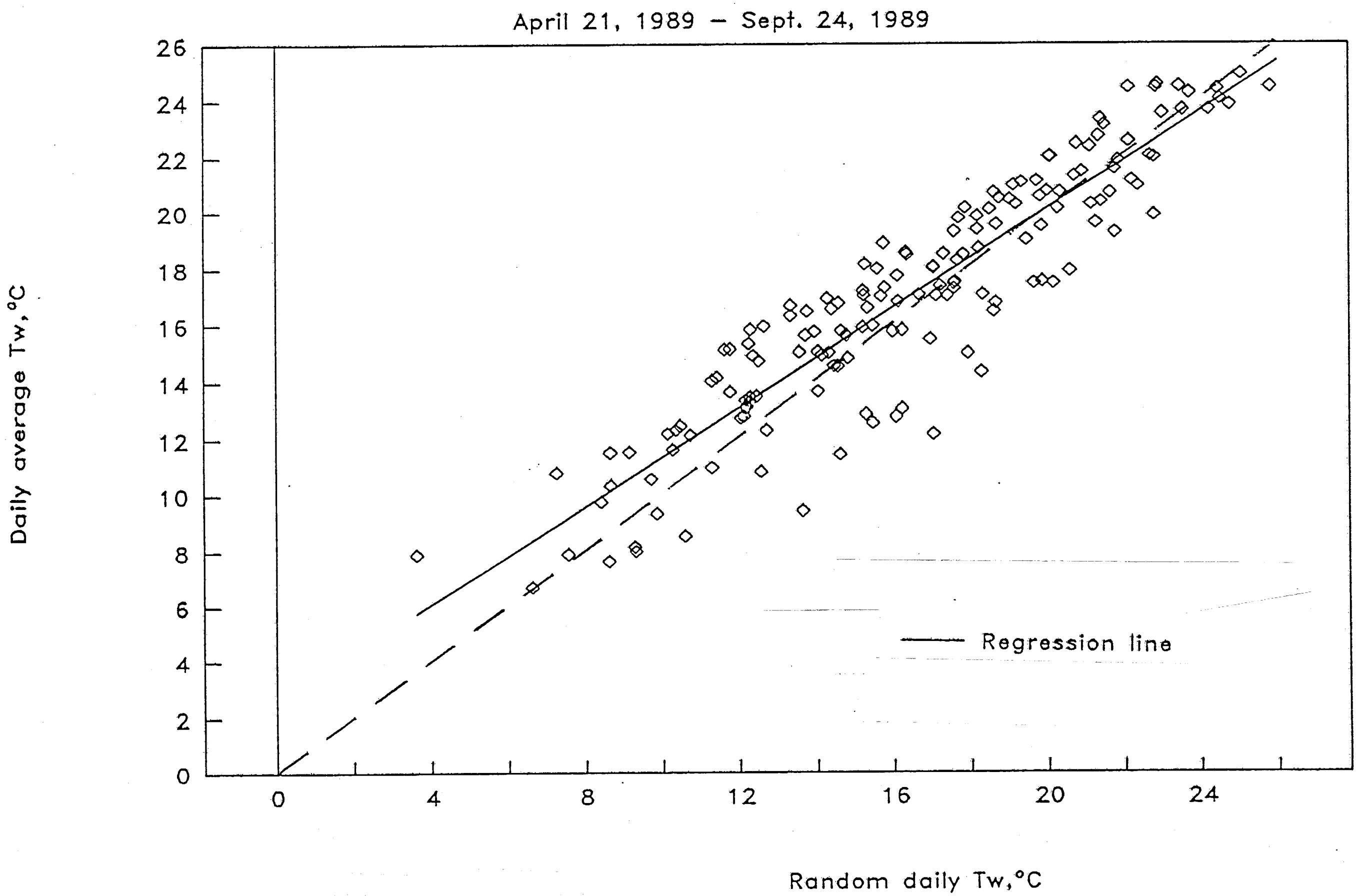

Fig. 2.9 Daily average water temperature vs. random water temperature. Random temperatures picked between 6:00 a.m. and 6:00 p.m. from temperatures measured at 2–hour intervals in the Straight River near Park Rapids, MN.

Table 2.3 Comparison of average and randomly selected daily water temperatures.

RIVER STATION	YEAR	PERIOD OF MEASUREMENT	β (°C)	γ	σ (°C)	R^2	μ_x (°C)	σ_x (°C)
1. STRAIGHT RIVER (near Park Rapids, MN)	1989	6:00am-6:00pm	2.48	0.890	1.6	0.87	-0.68	1.6
		8:00am-4:00pm	2.89	0.885	1.4	0.89	-1.04	1.5
		6:00am-12:00am	2.23	0.956	1.0	0.95	-1.56	1.0
		12:00am-8:00pm	2.44	0.838	1.8	0.82	0.39	2.0
2. STRAIGHT RIVER (at C. Hwy 115 near Park Rapids, MN)	1989	6:00am-6:00pm	3.25	0.796	1.5	0.87	0.36	1.8
		8:00am-4:00pm	3.50	0.766	1.1	0.92	0.72	1.7
		6:00am-12:00am	4.62	0.751	1.3	0.90	-0.40	1.9
		12:00am-8:00pm	1.65	0.855	1.3	0.90	1.00	1.5
13.MISSISSIPPI RIVER (at Minneapolis, MN)	1991	6:00am-6:00pm	0.08	1.00	0.43	0.99	-0.13	0.43
		8:00am-4:00pm	0.11	1.00	0.35	0.99	-0.13	0.35
		6:00am-12:00am	0.14	1.01	0.33	0.99	-0.35	0.34
		12:00am-8:00pm	0.27	0.983	0.39	0.99	-0.13	0.41

In Fig. 2.10 and 2.11, the true daily mean temperatures for air and water, respectively, are plotted against the averages of daily minimum and maximum temperatures. By regression analysis, it was determined that the two can be equated without much error. The standard deviation of daily mean temperatures from the average of daily minimum and maximum temperatures was higher for the air temperatures ($\sigma = 0.89^\circ C$) than for the water temperatures ($\sigma = 0.23^\circ C$) as can be seen in the figures. It is expected that for a river deeper than the Straight River, which is only 1 to 3 feet deep, the standard deviation for the water data will be even lower due to the smaller daily temperature variations in deeper rivers.

In summary, equating true daily mean temperatures and temperatures obtained by simply averaging daily maximum and minimum temperature values appears acceptable in the case of water temperature. It is more questionable for air temperatures.

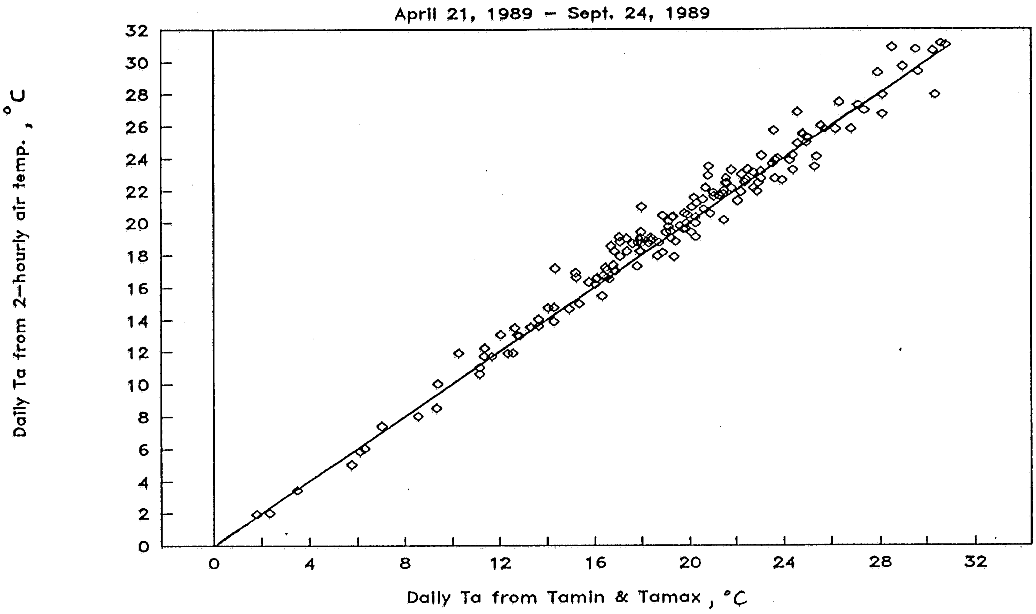

Fig. 2.10 Daily average air temperature vs. the average of daily T_{min} and T_{max}, near Park Rapids, MN.

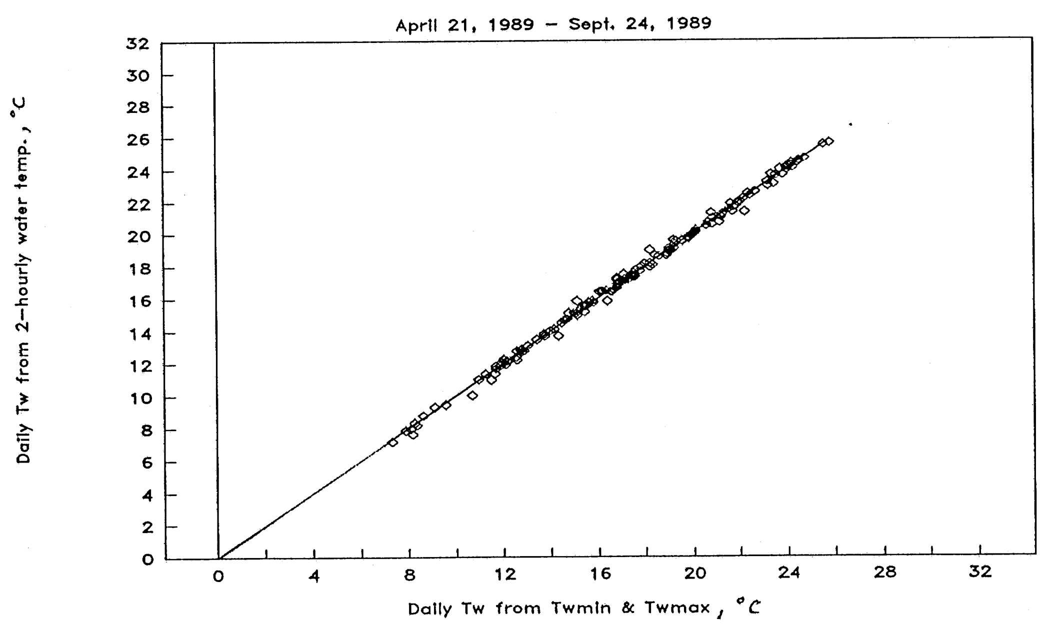

Fig. 2.11 Daily average water temperature vs. the average of daily T_{min} and T_{max} of the Straight River, near Park Rapids, MN.

III. TIME LAG BETWEEN AIR AND WATER TEMPERATURES

III.1 Definition of Time Lag

Annual records of daily average water and air temperatures averaged over several years follow approximately a sinusoidal pattern. This can be explained by the sinusoidal pattern of solar irradiance, the length of daylight and the angle of the sun. Similarly, daily records of hourly temperatures show a sinusoidal trend associated with the daily rotation of the earth.

By fitting daily average air and water temperature records of a stream with Fourier series, Kothandaraman (1971) found that the first harmonic accounts for about 80% and 95% of the total seasonal variance, respectively, for air and water temperatures. Also, it was observed that the air temperature follows the sinusoidal inclination angle of the earth with a lag time of several weeks. In the case of the air temperature record used for the Illinois River by Kothandaraman (1971), the maximum of the first harmonic occurs towards the end of July, showing a lag time of more than 1 month with the solstice of June.

Comparing the hourly air and water temperature records of a stream (Fig. 1.1), a time lag is observed between these two records. The time lag can be defined as shown in Fig. 3.1, in the case of two sinusoidal functions for air temperature and water temperature, respectively.

III.2 Derivation of Time Lag

Assuming that rivers are well mixed and that the only source of heat exchange with the atmosphere is by convection, the governing equation for water temperature is:

$$V \rho c_p \frac{dT_w}{dt} = k (T_a - T_w) A \tag{3.1}$$

where V and A are the volume and the surface area of a parcel of water, ρ and c_p are the density and the specific heat of water, T_w and T_a are the water and air temperatures, k is a bulk heat exchange coefficient, t is the travel time.

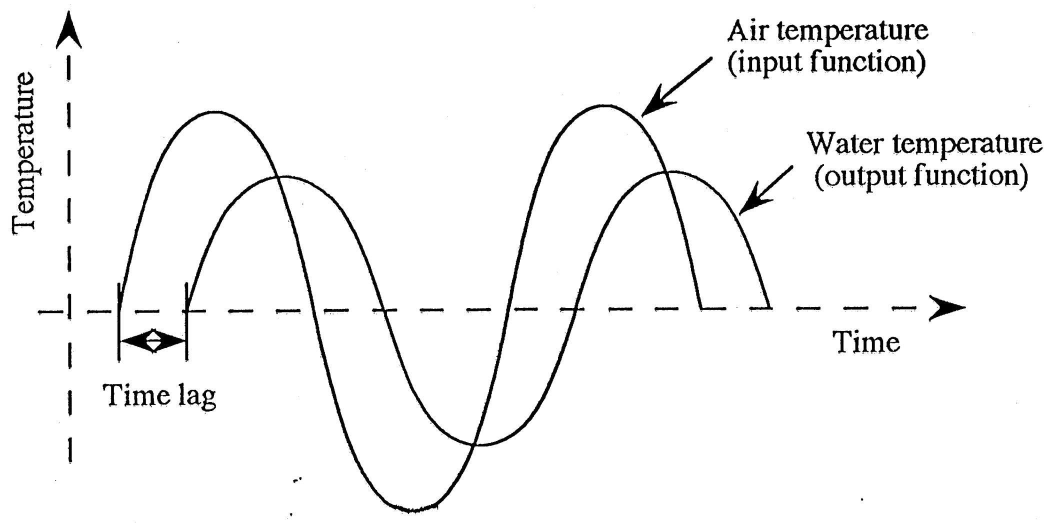

Fig. 3.1 Approximate water temperature response to a sinusoidal air temperature variation.

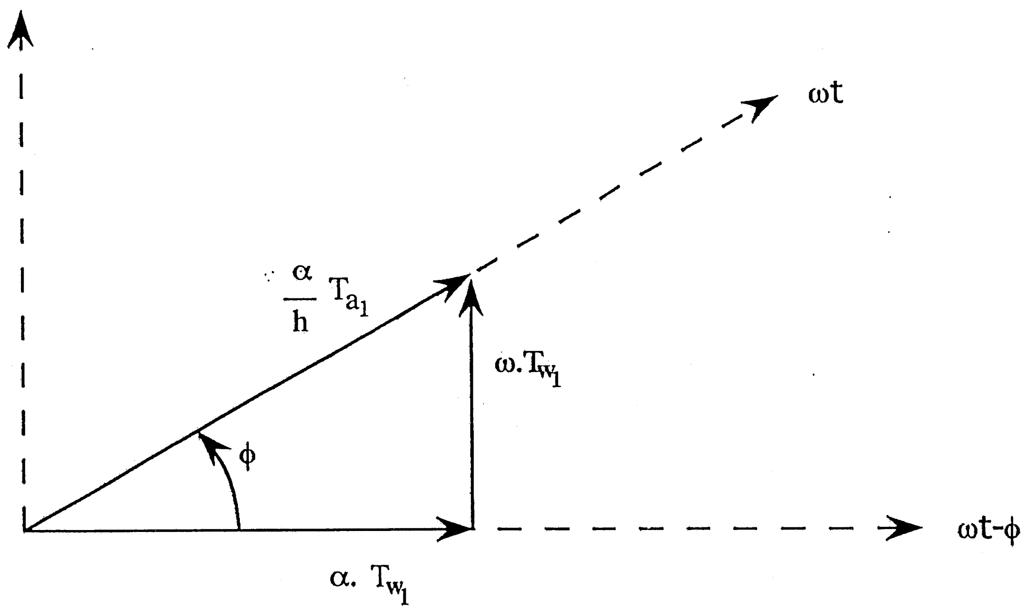

Fig. 3.2 Fresnel diagram representation of daily and weekly water and air temperatures approximated by sine functions.

Using the definition of the thermal diffusivity coefficient:

$$\alpha = \frac{k}{\rho c_p} \tag{3.2}$$

and describing the water parcel by:

$$V = A.h \tag{3.3}$$

where h is the average depth of the river over the width and the length of a reach investigated, eq. 3.1 can be rewritten as:

$$\frac{dT_w}{dt} + \frac{\alpha}{h} T_w = \frac{\alpha}{h} T_a \tag{3.4}$$

Using hourly temperature data over a period of a few days or daily data over a period of several months, the air temperature can be in both cases given by a sinusoidal function of time in first approximation. The periods of the sine functions will be a day or a year, respectively.

The daily temperature case has been studied by Kathandaraman (1972). The origin of time t may be chosen such as to obtain:

$$T_a = T_{a0} + T_{a1} \sin\frac{2\pi t}{T} \tag{3.5}$$

where T_{a0} and T_{a1} are constants, T = 24 hr for hourly temperatures and T = 365 days for daily average temperature. Here, t is no longer the travel time, but the absolute time at a fixed location of the river (also called Eulerian time). The switch is possible because at any Eulerian time, the air and water temperatures and other conditions are similar in time along a reach of several miles of the river. In other words, the river is assumed to be a uniform, freely flowing river, unaffected by reservoirs, groundwater or tributaries.

We assume α to be constant (k being the factor in eq. 3.1 that varies the most, with air temperature and wind speed). In order to solve the differential equation 3.4, the water temperature has to be of the form:

$$T_w(t) = T_{a0} + T_{w1} \sin(\frac{2\pi t}{T} - \varphi) + T_{w2} \exp(-\frac{\alpha}{h}t) \tag{3.6}$$

where φ represents the phase between the air and water temperatures, and T_{w1} and T_{w2} are constants.

Substituting eq. 3.6 into eq. 3.4 yields:

$$T_{w1}\frac{2\pi}{T}\cos(\frac{2\pi t}{T} - \varphi) + \frac{\alpha}{h}T_{w1}\sin(\frac{2\pi t}{T} - \varphi) = \frac{\alpha}{h}T_{a1}\sin(\frac{2\pi t}{T}) \quad (3.7)$$

or:

$$T_{w1}\frac{2\pi}{T}\sin(\frac{2\pi t}{T} - \varphi + \frac{\pi}{2}) + \frac{\alpha}{h}T_{w1}\sin(\frac{2\pi t}{T} - \varphi) = \frac{\alpha}{h}T_{a1}\sin(\frac{2\pi t}{T}) \quad (3.8)$$

φ can be calculated by representing the sinusoidal function by vectors in a rotating Fresnel Diagram (Fig. 3.2), with

$$\omega = \frac{2\pi}{T} \quad (3.9)$$

The phase φ is

$$\varphi = \mathrm{Arctan}(\frac{\omega}{\alpha}h) = \mathrm{Arctan}(\frac{2\pi h}{T\alpha}) \quad (3.10)$$

The time lag between air and water temperature is then defined (both for hourly and daily data) as:

$$\delta = \frac{T\varphi}{2\pi} = \frac{T}{2\pi}\mathrm{Arctan}(\frac{2\pi h}{T\alpha}) \quad (3.11)$$

In the case of daily data, since $\frac{2\pi h}{T\alpha}$ is small (below 0.2), the term $\mathrm{Arctan}(\frac{2\pi h}{T\alpha})$ is fairly well approximated by $\frac{2\pi h}{T\alpha}$. Therefore, for daily temperatures:

$$\delta = \frac{h}{\alpha} \quad (3.12)$$

According to this result, the lag time, in the case of daily temperatures, varies linearly with the depth of the river.

From the Fresnel Diagram (Fig. 3.2), it can also be derived that

$$\varphi = \mathrm{Arccos}\frac{T_{w1}}{T_{a1}} \quad (3.13)$$

Therefore, given the air and water temperatures versus the time records, φ can also be estimated from the ratio of the average amplitude of the water and air oscillations.

III.3 Estimation of Time Lag

For the water of rivers, we assume

$$\rho = 62.3 \text{ lbm.ft}^{-3}$$
$$c_p = 0.999 \text{ Btu.lbm}^{-1}.{}^\circ\text{F}^{-1}$$
$$k = 2 \text{ to } 10 \text{ Btu.hr}^{-1}.\text{ft}^{-2}.{}^\circ\text{F}^{-1}$$

The value of k increases with the wind speed, other weather parameters and the water temperature (Thomann and Mueller, 1987).

Using an average value $k = 6.0$ Btu.hr^{-1}.ft^{-2}.°F^{-1}, which corresponds to an average wind speed of 5 m/s and an average temperature of 15°C according to Edinger et al. (1974), the time lag can be expressed as a function of the average depth of the river, in both cases of hourly temperature and daily average temperature records. Unfortunately, the average depth of rivers is not as commonly recorded as their discharge. Therefore, it is more convenient to express δ as a function of the discharge.

An empirical relationship was proposed by Leopold and Maddock (1953), under the general form

$$h = aQ^b \tag{3.14}$$

where a and b have different values for different river basins or geographical areas in the United States.

The empirical equation

$$h = 0.074\ Q^{0.55} \tag{3.15}$$

where Q is the average discharge (in cfs) and h is in feet, was obtained by MacDonald, Parker & Leuthe (1991) for Minnesota Rivers. Coefficients for other rivers are also available (Thomann & Mueller, 1987, Leopold & Maddock, 1953, see Appendix C)

Substituting eq. 3.14 into eq. 3.12, we obtain for daily temperatures in Minnesota

$$\delta = \frac{0.074 \rho c_p Q^{0.55}}{k} \tag{3.16}$$

With the numerical values previously given, we obtain for Minnesota rivers

$$\delta = 0.768\ Q^{0.55} \tag{3.17}$$

where the lag time δ is in hours and the discharge Q in cfs.

For the southern central U.S. rivers, the empirical equation 3.18 was used. It is based on the values given in Appendix C and the consideration that the Republican–Kansas River is the most representative river for the southern region.

$$h = 0.138\ Q^{0.43} \tag{3.18}$$

The lag time for southern central U.S. rivers therefore is:

$$\delta = 1.5\ Q^{0.43} \tag{3.19}$$

It should be noted that the values of a and b of eq. 3.14 are extremely variable from one river to another (see Appendix C) and therefore, using individual values for a and b could improve the accuracy of the estimated value of the lag time.

III.4 Regression Analysis with Variable Time Lags

In order to estimate the accuracy of a linear relationship between air and water temperatures according to eq. 1.1, the correlation coefficient was computed with different lag times δ between the time series of measured air and water temperatures for the 11 rivers studied. The lag time which yielded the best correlation for each river (Table 3.1) was thus determined. The sinusoidal daily and seasonal trends were not removed from the temperature data to calculate the correlation coefficient. They were conserved in the regression analysis (see Chap. IV).

The correlation coefficient r between water temperature T_w and air temperature T_a is calculated as follows:

$$r = \frac{1}{n-1} \sum_{i=1}^{n} \left(\frac{T_w(t_i+\delta)-\overline{T}_w}{\sigma_{T_w}}\right)\left(\frac{T_a(t_i)-\overline{T}_a}{\sigma_{T_a}}\right) \tag{3.20}$$

where δ is the time lag, $T_a(t_i)$ is the air temperature at time t_i, $T_w(t_i+\delta)$ is the water temperature at time $t_i+\delta$, $\overline{T}_a$ and $\overline{T}_w$ are, respectively, the average air and water temperature over the entire record, σ_{T_a} is the standard deviation of T_a, σ_{T_w} is the standard deviation of T_w and n is the number of compared data. By definition, r always falls in the range $-1 \leq r \leq 1$. r near 0 means the data is not correlated. The data is strongly correlated when r is near 1 or –1. In the case of this study, the correlation coefficients are expected to be positive, meaning that an increase in air temperature results in an increase of stream temperature and vice versa.

Table 3.1 Correlation between daily air and water temperatures for different lag times obtained from the regression analysis.

RIVER \ LAG TIME (days)	CORRELATION COEFFICIENT (over the whole record)								
	0	1	2	3	4	5	6	7	8
1. STRAIGHT RIVER (near Park Rapids, MN)	0.911	0.858	0.732	0.670	0.633	0.573	0.551	0.543	0.553
2. STRAIGHT RIVER (at C. Hwy 115 near Park Rapids, MN)	0.947	0.886	0.761	0.704	0.665	0.617	0.579	0.572	0.589
3. VERMILLION RIVER (near Empire, MN)	0.911	0.903	0.833	0.769	0.723	0.694	0.671	0.651	0.636
4. ROSEAU RIVER (near Caribou, MN)	0.865	0.864	0.819	0.781	0.749	0.723	0.709	0.707	0.704
5. MINNESOTA RIVER (near Jordan, MN)	0.867	0.886	0.881	0.864	0.837	0.809	0.783	0.762	0.749
6. MISSISSIPPI RIVER (at St-Paul, MN)	0.775	0.786	0.798	0.809	0.819	0.825	0.827	0.826	0.823
7. ARKANSAS RIVER (at Dardanelle, ARK)	0.847	0.865	0.876	0.882	0.883	0.882	0.879	0.875	0.870
8. AMITE RIVER (at 4H camp near Denham Springs, LA)	0.829	0.834	0.793	0.744	0.702	0.668	0.645	0.637	0.639
9. PEARL RIVER (near Bogalusa, LA)	0.872	0.886	0.875	0.855	0.837	0.822	0.808	0.797	0.788
10. NORTH WICHITA RIVER (near Truscott, TX)	0.939	0.893	0.817	0.771	0.750	0.744	0.739	0.729	0.716
11. PLUM CREEK (near Luling, TX)	0.885	0.930	0.887	0.816	0.750	0.698	0.656	0.620	0.605

Optimum correlation is underlined

Fig. 1.1 shows that for the 5 ft deep Zumbro River, the water temperature can vary by as much as 3°C between day and night. This figure also shows that hourly water temperatures are strongly influenced by the hourly air temperature variations. On the other hand, the response for the 15 ft deep Mississippi River at St. Paul (see Fig. 2.4), shows much more inertia. Therefore, it is expected that the time lag for a shallow river will be on the order of a few hours and can be reduced to 0 if daily data are used. However, it can be on the order of several days for deeper rivers and cannot be ignored with daily data (Table 3.2). In that case, diurnal fluctuations also become less influential on the water temperature response.

Time lags predicted by eqs. 3.17 or 3.19 and time lags obtained by regression analysis using daily air and water temperature data (Table 3.3) are plotted in Fig. 3.3. The trends are similar, but there is much scatter. For the Arkansas River, AK, in particular (annual mean discharge Q = 37080 cfs, recorded over the last 53 years), eq. 3.14 overestimates the depth of water, and therefore, overestimates the time lag. Most of the time, the Arkansas River carries much less than the annual average flow (average annual extreme flows are on the order of 50 cfs and 250,000 cfs). There are also many underestimations. It is likely that eq. 3.14 is not a good universal equation because the coefficients in the Q vs. h equation are not universal, as reported by Thomann & Mueller (1987).

Fig. 3.4 gives an example of the correlation coefficient versus the time lag δ for the shallow Straight River, MN (average depth about 3 ft), using two–hourly data. The best correlation r is obtained for $\delta = 4$ hr. The fact that the correlation coefficient versus the lag time oscillates (with a 24 hr period) and does not decrease rapidly is due to the high autocorrelation of the air temperature with itself when lagged by a multiple of 24 hours, as illustrated by Fig. 3.5, where the coefficient of autocorrelation was calculated for hourly air temperatures for various lag times.

The correlation coefficient between hourly air and water temperatures would decrease more quickly if the deterministic part (approximately sinusoidal, with a period of 1 year) of the air and water temperature records was removed. In a second step, the two–hourly air and water temperature data for the Straight River were averaged into daily mean temperatures. The lag time found with this daily data was 0 days. As shown in Fig. 3.6, the best lag time corresponds to a correlation coefficient as high as 0.92.

Fig. 3.7 shows the results of the same analysis for the Mississippi River in St. Paul, MN, which is a deeper river (average depth about 15 ft). For this river, the observed lag time is 6 days, which is larger than for a smaller stream, as expected. The correlation coefficient is only 0.83.

Table 3.2 Predicted lag times and lag times obtained from the regression analyses.

RIVER STATION	YEAR	ANNUAL MEAN DISCHARGE (cfs)	PREDICTED LAG TIME (days)	LAG TIME OF DAILY DATA BY REGRESSION (days)
1. STRAIGHT RIVER (near Park Rapids, MN)	1989	45	0.3	0
2. STRAIGHT RIVER (at C. Hwy 115 near Park Rapids, MN)	1989	45	0.3	0
3. VERMILLION RIVER (near Empire, MN)	1979	59.1	0.3	1
	1980	47.0	0.3	0
	1981	34.3	0.2	0
	1982	53.9	0.3	1
	1983	94.4	0.4	1
	1984	87.4	0.4	0
4. ROSEAU RIVER (near Caribou, MN)	1981	147	0.5	0
	1982	315	0.8	0
	1983	319	0.8	0
5. MINNESOTA RIVER (near Jordan, MN)	1979	8146	4.5	1
	1981	2659	2.4	1
	1983	8448	4.6	2
	1984	9646	5.0	2
6. MISSISSIPPI RIVER (at St-Paul, MN)	1957	12710	5.8	6
	1958	7369	4.3	6
	1959	4677	3.3	5
	1960	9616	5.0	7
	1961	5524	3.7	5
	1962	30810	9.4	8
	1963	9178	4.8	6
	1964	7460	4.3	8
7. ARKANSAS RIVER (at Dardanelle, ARK)	1983	38170	4.9	3
	1984	40220	5.0	3
	1985	73070	6.6	3
	1986	57080	5.9	3
	1987	53000	5.7	5
8. AMITE RIVER (at 4H camp near Denham Springs, LA)	1974	*1280	1.1	1
9. PEARL RIVER (near Bogalusa, LA)	1976	*9983	2.7	1
10. NORTH WICHITA RIVER (near Truscott, TX)	1983	121	0.4	0
	1987	107	0.4	0
	1988	31	0.2	0
11. PLUM CREEK (near Luling, TX)	1981	124	0.4	1
	1983	77	0.3	1
	1984	14	0.2	1

* Average over the period 1938-90

Table 3.3 Correlation between daily air and water temperatures for different lag times obtained by regression analysis for the Mississippi River in St. Paul, MN, for each year of record.

YEAR \ LAG TIME (days)	CORRELATION COEFFICIENT												
	0	1	2	3	4	5	6	7	8	9	10	11	12
1957	0.828	0.837	0.846	0.854	0.864	0.869	0.870	0.870	0.867	0.859	0.853	0.844	0.829
1958	0.730	0.743	0.755	0.766	0.776	0.783	0.783	0.778	0.771	0.760	0.747	0.736	0.732
1959	0.827	0.835	0.846	0.856	0.861	0.860	0.854	0.844	0.834	0.825	0.819	0.810	0.799
1960	0.795	0.805	0.818	0.832	0.841	0.847	0.849	0.850	0.847	0.840	0.833	0.822	0.810
1961	0.840	0.843	0.846	0.852	0.858	0.860	0.857	0.851	0.844	0.836	0.829	0.817	0.802
1962	0.708	0.725	0.743	0.759	0.774	0.786	0.797	0.807	0.811	0.807	0.797	0.784	0.772
1963	0.714	0.726	0.740	0.755	0.766	0.772	0.774	0.773	0.772	0.771	0.768	0.765	0.761
1964	0.763	0.775	0.788	0.802	0.814	0.825	0.831	0.836	0.836	0.834	0.832	0.829	0.823
AVERAGE	0.775	0.786	0.798	0.809	0.819	0.825	0.827	0.826	0.823	0.817	0.810	0.801	0.791

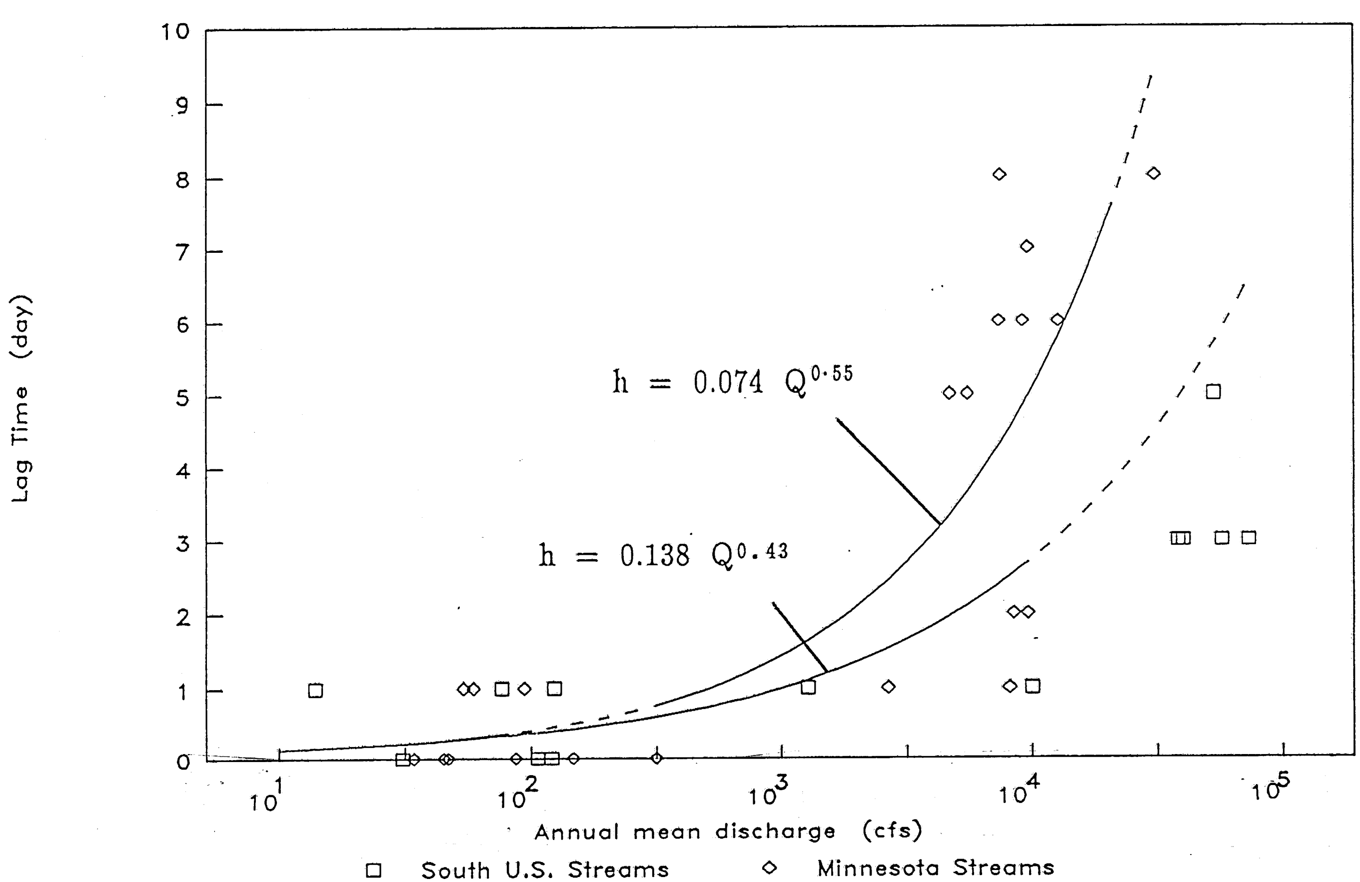

Fig. 3.3 Theoretical lag times and lag times obtained from the regression analyses vs. the annual mean discharge for the 11 records, year by year.

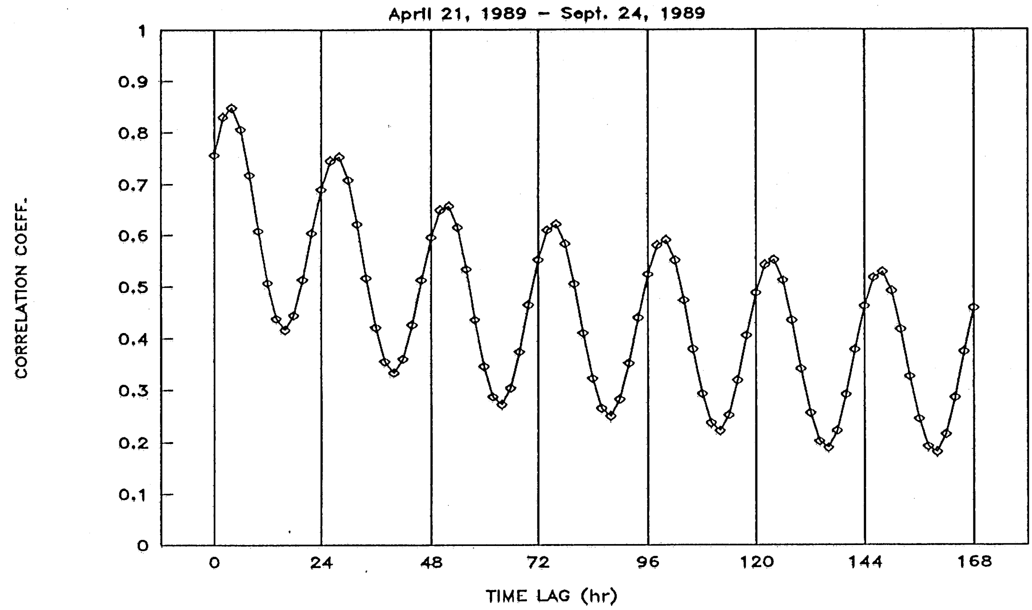

Fig. 3.4 Correlation between water and air temperatures measured at 2–hour intervals, for different lag times, for the Straight River, near Park Rapids, MN.

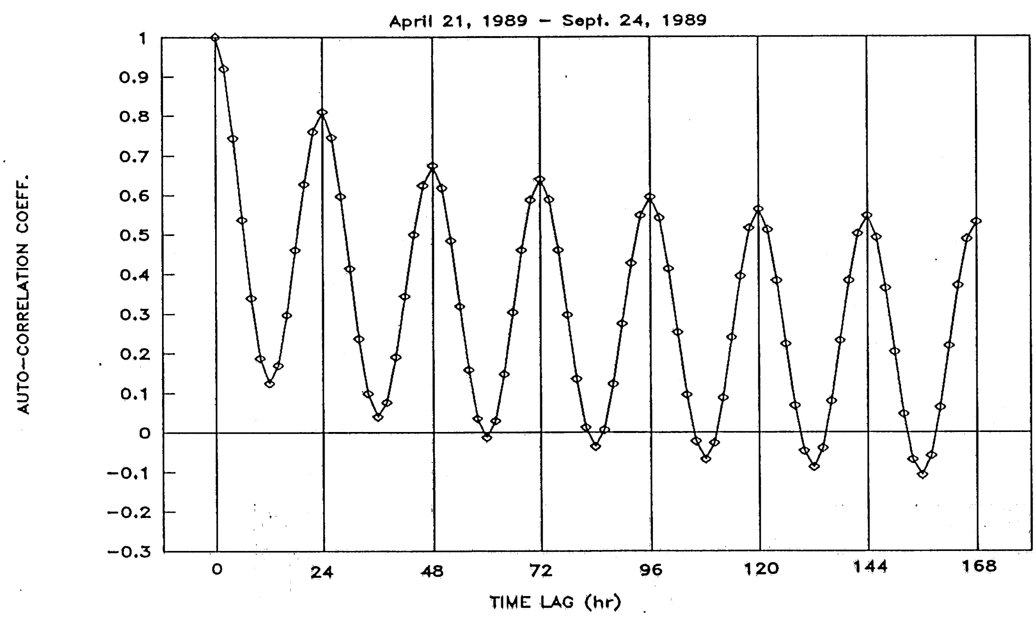

Fig. 3.5 Autocorrelation of air temperatures, measured at 2–hour intervals, for different lag times, at the Straight River, near Park Rapids, MN.

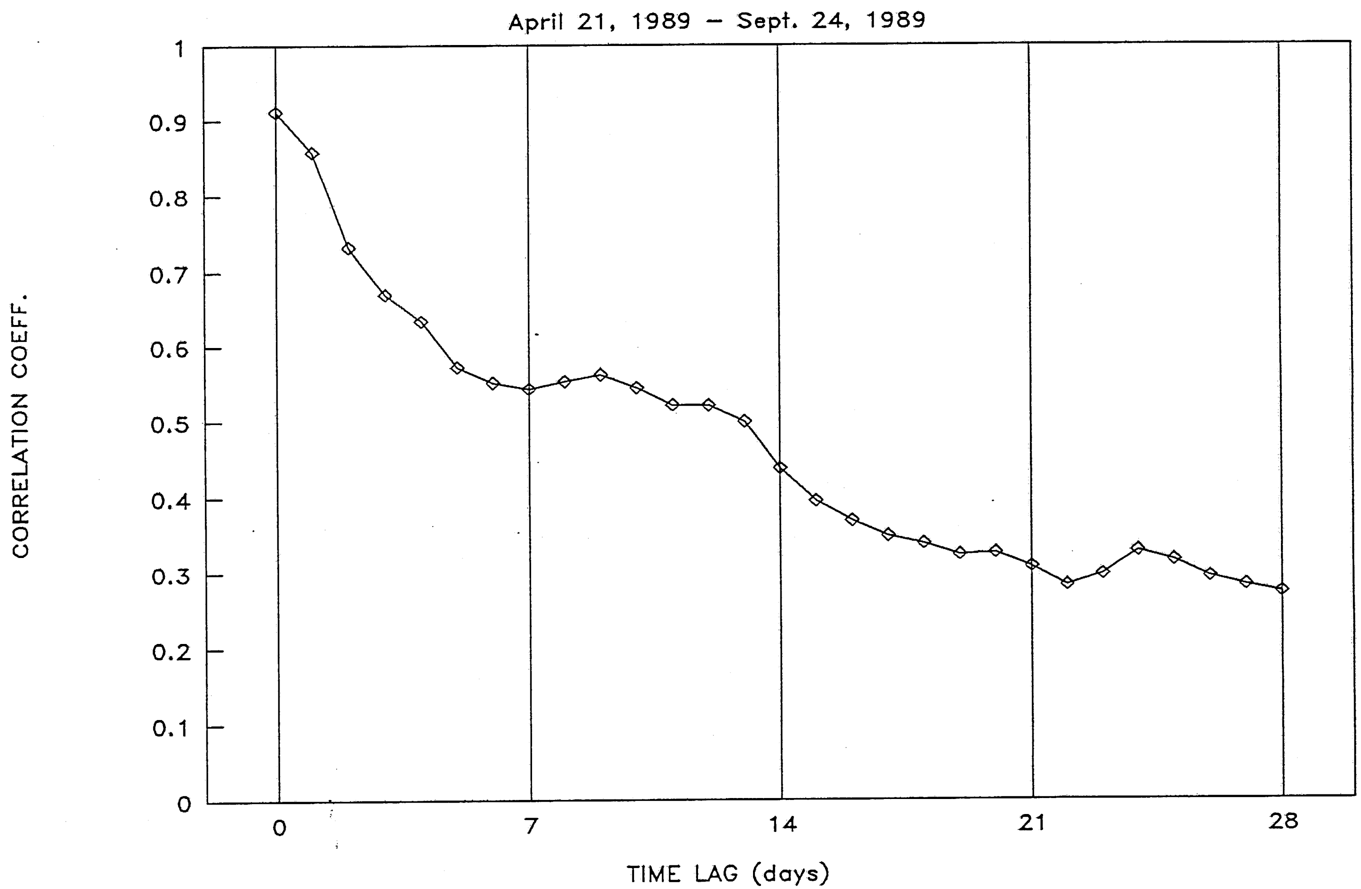

Fig. 3.6 Correlation between daily water and air temperatures, for different lag times, for the Straight River, near Park Rapids, MN.

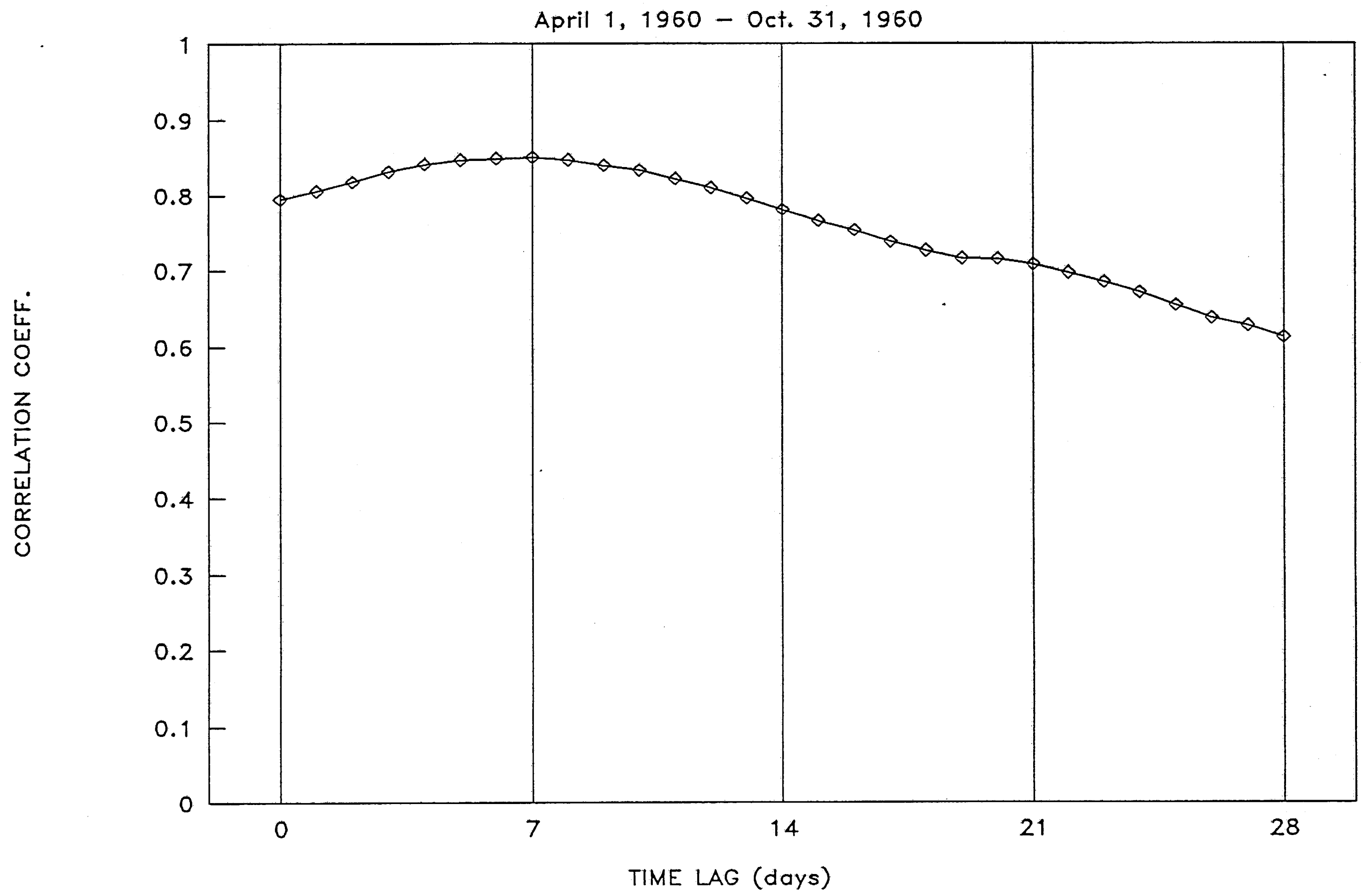

Fig. 3.7 Correlation between daily water and air temperatures for different lag times for the Mississippi River in St. Paul, MN.

IV. STOCHASTIC RELATIONSHIPS BETWEEN AIR AND WATER TEMPERATURES

IV.1 Introduction: A Case Study

The concept of a linear relationship between air and stream water temperatures (eq. 1.1) is based on the simplifying statement that the net rate of change in heat storage in a river can be related to the ambient air temperature (eq. 3.1). Several methods, more or less sophisticated, have been used by Cluis (1972), Song & Chien (1972) and others to correlate air and water temperatures,.

Air and water temperatures recorded at the Straight River, near Park Rapids, Minnesota, over the entire year of 1989, allowed us to demonstrate that a linear approximation gives useful results, at least when the temperature data is averaged over 1 day or 1 week. Smith (1981) studied similar relationships based on monthly averaged temperatures in England, and considered them successful.

The simple plotting of the hourly water temperature T_w against the hourly air temperature T_a in Fig. 4.1 shows much scatter around the regression line, as indicated by a standard deviation $\sigma = 3.05°C$ and a coefficient of regression squared $R^2 = 0.57$. R^2 is defined as

$$R^2 = 1 - \Sigma(T_w(t_i)-\hat{T}_w(t_i))^2/\Sigma(T_w(t_i)-\overline{T}_w)^2 \tag{4.1}$$

where $\hat{T}_w(t_i)$ is the estimated value (calculated using the regression coefficients) of the water temperature at the time t_i and $\overline{T}_w$, as previously defined, is the average air temperature over the whole record.

The data cover the period from April 21 to Sept. 24 of 1989. This period was chosen in order to avoid low daily air temperatures. Over this period, the hourly air temperatures cover a range from –4°C in springtime to 40°C in summertime.

A decrease in standard deviation σ was obtained by introducing a lag time of 4 hrs (Fig. 4.2). This value corresponds to the best correlation between the air and the water temperatures ($r = 0.91$) found in Chapter III. The standard deviation is reduced to 2.59°C but this is still large.

From this two–hourly set of data, daily averages were computed, and in the same manner, the sets of T_w versus T_a were plotted on Fig. 4.3.

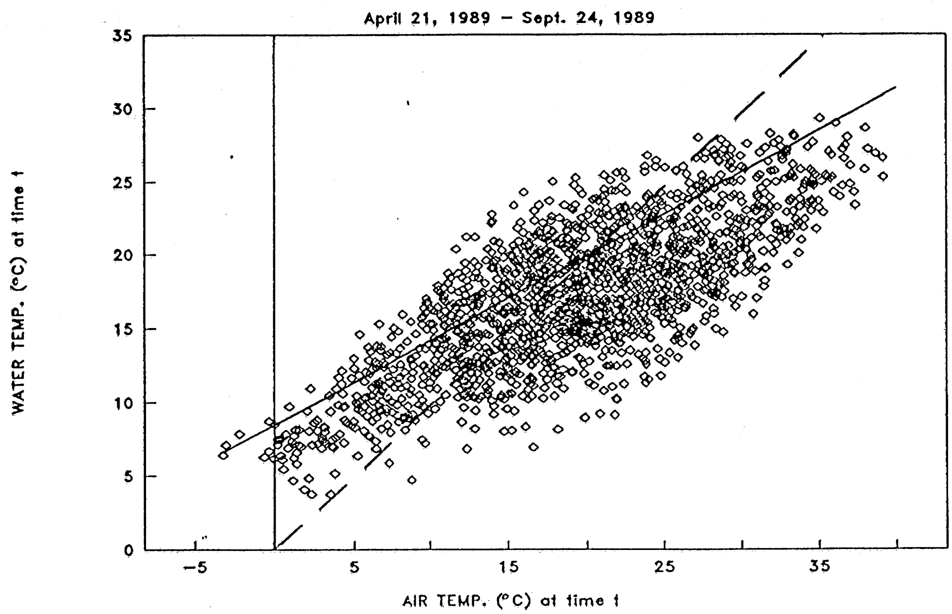

Fig. 4.1 Water temperature vs. air temperature measured at 2–hour intervals, without lag time, for the Straight River, near Park Rapids, MN.

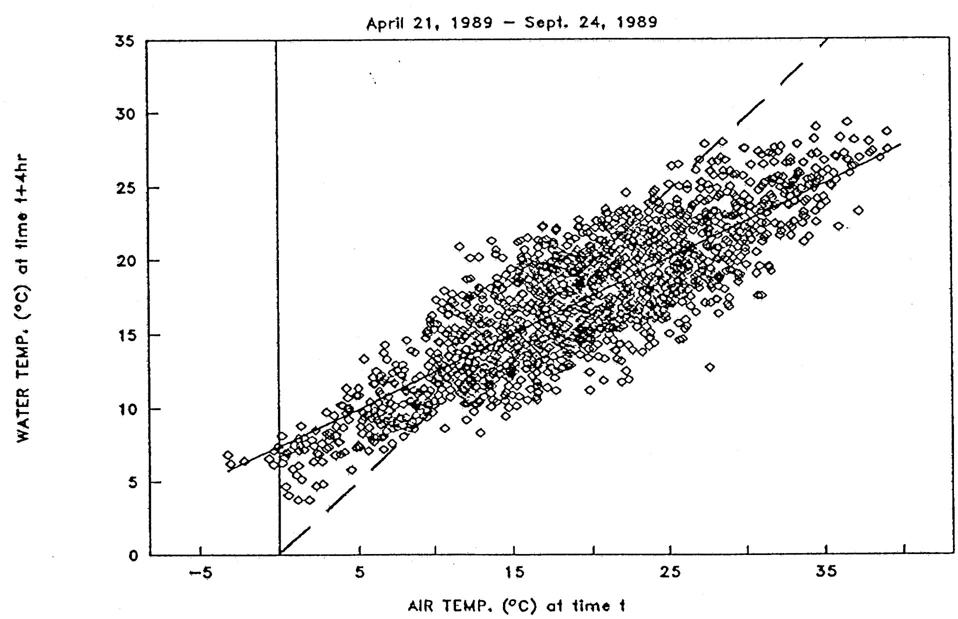

Fig. 4.2 Water temperature vs. air temperature measured at 2–hour intervals, with a 4 hour lag time, for the Straight River near Park Rapids, MN.

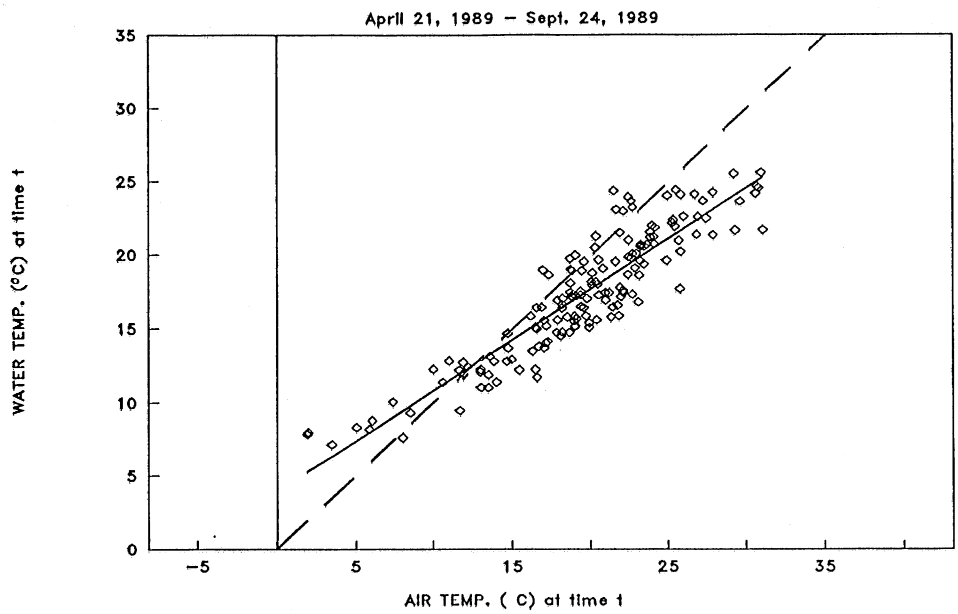

Fig. 4.3 Daily water temperature vs. air temperature, with no lag time, for the Straight River, near Park Rapids, MN.

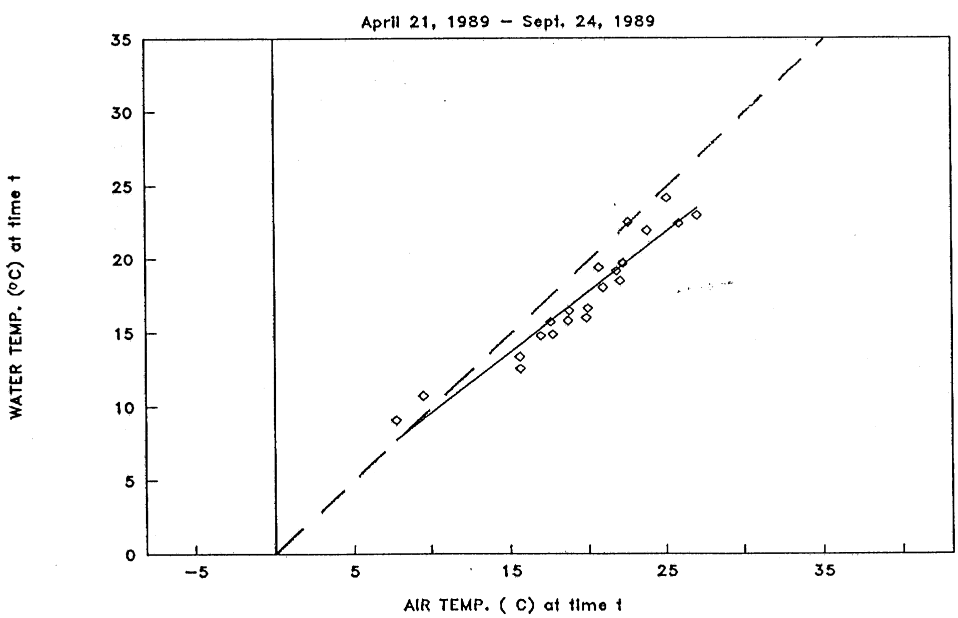

Fig. 4.4 Weekly water temperature vs. air temperature, with no lag time, for the Straight River, near Park Rapids, MN.

The standard deviation was thus reduced to 1.77°C and the regression coefficient squared increased to 0.83. Although a lag time of 4 hrs was used with hourly data, this lag time can be ignored when the time step is 1 day.

An even better standard deviation is obtained when regressing weekly data (Fig. 4.4) obtained by averaging daily data. The standard deviation is decreased to 1.21°C. The advantage of averaging the data over a larger time unit (such as a day or a week) therefore is obvious. By using a longer timescale, the large scatter found with hourly data (see Fig. 4.1) is eliminated.

The linear relationships between the air and the water temperature of the Straight River are not the same when data averaged over 1 day or 1 week are used. The constant A in eq. 1.1 is lowered from 6.04°C for hourly data to 3.96°C for daily data and 1.40°C for weekly data, whereas the linear coefficient B increases from 0.562 for hourly data to 0.684 for daily data and 0.816 for weekly data. The same trend was observed at the second location of measurements on the Straight River as well as with the other rivers' data. This means that daily or weekly averaging of data brings the linear relationships between air and water temperatures closer to the "ultimate" approximation $T_w(t) = T_a(t)$.

It is interesting to note that for the ensemble of rivers studied in this analysis, the ensemble average water and air temperatures over the period April 1 – Oct. 31 are almost identical, with a standard deviation of 2.3°C between them.

IV.2 Regression Analysis

IV.2.1 Derivation of Relationship for Daily Data:

Regression analysis was performed using the available sets of values of daily average water and air temperatures over several years. Using the lag times obtained from the data as described in chapter III.4, the analysis was performed both with a lag time and without a lag time, when the lag time was found to be 1 day or more.

The notations used for the linear relationship when ignoring the lag time were

$$T_w(t) = A_1 + B_1 . T_a(t) \tag{4.2}$$

and when the lag time was taken into account:

$$T_w(t) = A_2 + B_2 . T_a(t-\delta) \tag{4.3}$$

where t represents the time and δ the time lag both in units of days, and A_1, A_2, B_1 and B_2 are constant coefficients obtained from linear regression analysis. These regressions were computed with the help of the Lotus 123 software. An example (1960) is given for the Mississippi River in St. Paul, MN, in Fig. 4.5. Water temperatures are plotted versus air temperatures. The large scatter for this example is reflected by a large standard deviation ($\sigma = 3.25°C$).

The results of the regression analyses are presented in Table 4.1, along with the standard deviations σ_1 and σ_2 of T_w from the regression equations 4.2 and 4.3, respectively. Among the 11 rivers studied, the highest standard deviation was found to be 4.07°C for the Mississippi River, and the lowest was 1.41°C for the Straight River, when no time lag was considered. The values were smaller when a time lag was considered. The regression relationships with lag time (eq. 4.3), obtained for each of the 11 rivers are plotted in Fig. 4.6. Despite major differences of characteristics (size, location, climate, etc) between the 11 rivers studied, the 11 relationships were found to be relatively close to each other.

The coefficients A_1 and A_2 were found to be positive for the 11 rivers studied. They vary from one river to another, i.e. from 3.39 °C for the Pearl River to 7.44°C for the Mississippi River. The average value was 5.08°C for A_1, with a standard deviation of 1.25°C, and 5.02°C for A_2, with a standard deviation of 1.2°C.

The coefficients B_1 and B_2 are relatively close to each other. Each was found to be smaller than 1, from 0.604 for the Vermilion River (the release of warm water from a power plant upstream might be the reason for this low value...) to 0.887 for the Pearl River. The average was found to be 0.752 for B_1 with a standard deviation as small as 0.088 and 0.756 for B_2 with a standard deviation of 0.086.

As a first approach, the daily water temperature can therefore be simulated by using daily air temperatures and a time lag as described in chapter III.3. The "averaged" relationship is

$$T_w(t) = 5.0 + 0.75.T_a(t-\delta) \tag{4.4}$$

where the time t and the time lag δ are in units of days, and temperatures are in °C.

This "geographic" average relationship indicates that when the daily air temperature is close to 0°C, the daily water temperature is warmer than the air temperature by approximately 5°C. The water will be warmer in the average than the air as long as the daily air temperature is below 20°C; if the daily air temperature is above 20°C, the water will be colder than the air. Individual lines in Fig. 4.6 indicate that water temperature equals air temperature in the range from 14°C to 22°C, depending on the river. This reflects that air temperature is not the only climate parameter influencing the water temperature. Other parameters such as solar radiation, wind speed, relative humidity, etc. as well as other processes such as heat exchange with the sediments and inflow of groundwater tend to affect water temperatures and water temperature variations.

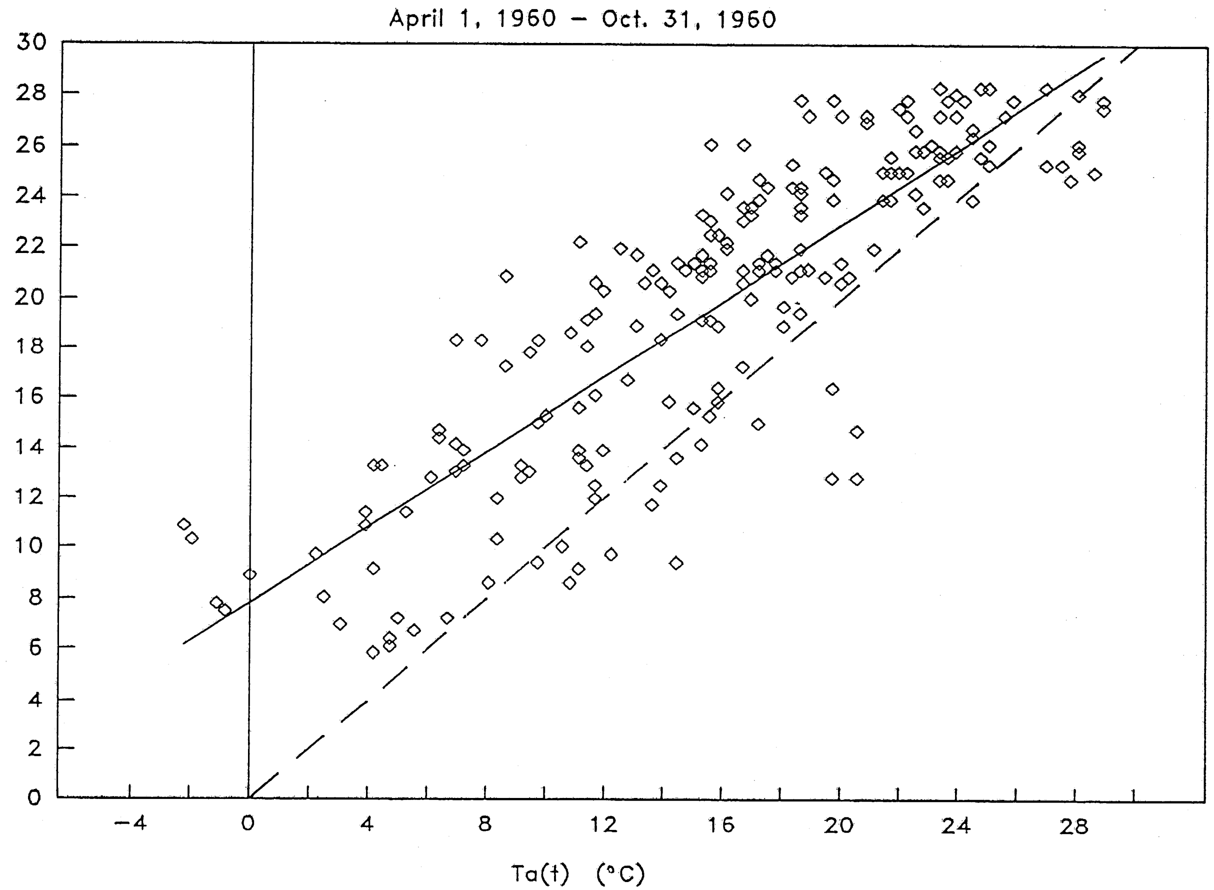

Fig. 4.5 Daily water temperature vs. air temperature, with a 6–day lag time, for the Mississippi River in St. Paul, MN over 1 year.

Table 4.1 Data analysis for daily water and air temperature data with no lag time and with a lag time (calculated by eq. 3.16).

RIVER STATION	YEAR	TIME LAG (days)	WITHOUT LAG TIME				WITH LAG TIME			
			A_1 (C)	B_1	σ_1 (°C)	R_1	A_2(C)	B_2	σ_2(°C)	R_2^2
1. STRAIGHT RIVER (near Park Rapids, MN)	1989	0	3.96	0.684	1.77	0.83	-	-	-	-
2. STRAIGHT RIVER (at C. Hwy 115 near Park Rapids, MN)	1989	0	4.22	0.728	1.41	0.90	-	-	-	-
3. VERMILLION RIVER (near Empire, MN)	1979-85	0	5.02	0.604	1.78	0.84	-	-	-	-
4. ROSEAU RIVER (near Caribou, MN)	1981-83	0	4.10	0.874	2.86	0.80	-	-	-	-
5. MINNESOTA RIVER (near Jordan, MN)	1979,81 1983-85	2	4.70	0.803	2.97	0.76	4.81	0.803	2.74	0.79
6. MISSISSIPPI RIVER (at St-Paul, MN)	1957-64	6	7.37	0.706	4.07	0.60	7.44	0.716	3.44	0.67
7. ARKANSAS RIVER (at Dardanelle, ARK)	1983	3	4.37	0.827	2.68	0.81	4.60	0.822	2.37	0.84
8. AMITE RIVER (at 4H camp near Denham Springs, LA)	1973	0	5.13	0.779	1.83	0.73	-	-	-	-
9. PEARL RIVER (near Bogalusa, LA)	1976	1	3.69	0.875	1.73	0.81	3.39	0.887	1.67	0.82
10. NORTH WICHITA RIVER (near Truscott, TX)	1983	0	6.39	0.737	1.68	0.89	-	-	-	-
11. PLUM CREEK (near Luling, TX)	1981-85	1	6.93	0.658	1.45	0.79	6.25	0.684	1.20	0.86
AVERAGE			5.08	0.752	2.20		5.02	0.756	2.07	
STD DEVIATION			1.26	0.088			1.21	0.086		

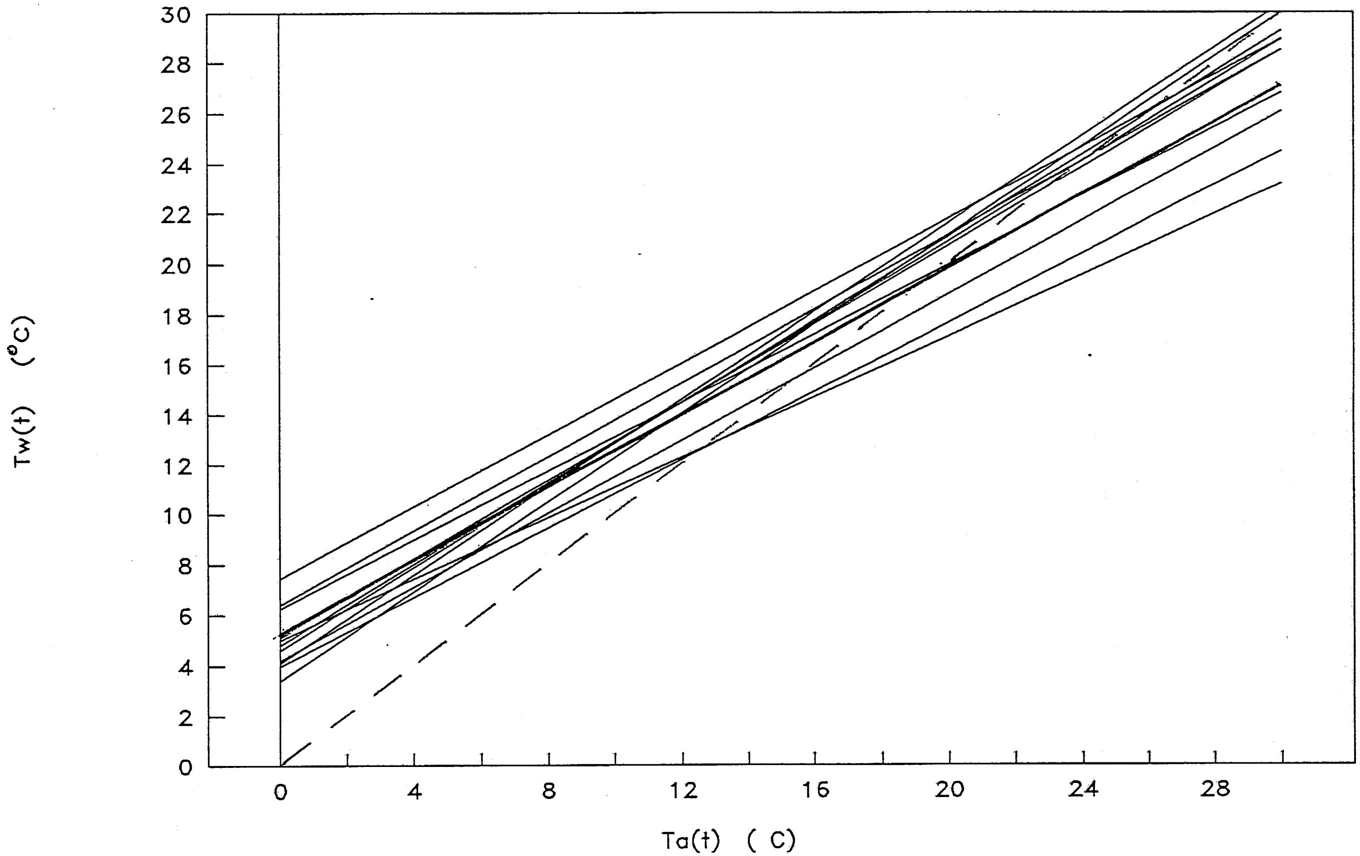

Fig. 4.6 Relationship obtained from the regression analyses between the daily water and air temperatures, for the 11 rivers studied.

IV.2.2 Application of Relationship for daily data

In order to test the relationship 4.4, it was used on the 11 rivers' records (over all the years of records available), calculating the daily water temperatures from the measured air temperatures. The results are reported in Table 4.2. The daily water temperatures were calculated in three different ways:

- with eq. 4.4 using a lag time calculated with eq. 3.16 using annual average discharges,
- with eq. 4.4 with no lag time,
- by equating the water temperature T_w with the air temperature T_a as is commonly done.

The average standard deviation is 3.08°C when using $T_w = T_a$ over the 11 temperature records. The standard deviation is reduced to 2.73°C when using equation 4.3 with no lag time and 2.69°C with a calculated lag time. This compares with an average standard deviation of 2.07°C for the 11 rivers when for each river its own regression equation 4.2 or 4.3 is used with the coefficients from Table 4.1. It is therefore advantageous, to develop an equation for each river being studied from existing air and water temperature records or to use a relationship established for a similar river in a similar environment (in terms of discharge, drainage area, average depth, climate, etc.) instead of eq. 4.4. Parameters that might have an influence on the linear relationship will be studied in section IV.3 and IV.4 separately.

To illustrate these results, the daily water temperatures predicted using eq. 4.4 were plotted along with the measured daily water temperatures for three rivers of different sizes:

- Mississippi River in St. Paul in Fig. 4.7,
- North Wichita River in Texas in Fig. 4.8,
- Straight River in Minnesota in Fig. 4.9.

As already indicated by the standard deviations between measured and simulated water temperatures in Table 4.2, the results are worst for the Mississippi River, better for the North Wichita River and best for the Straight River. For a large river the relationship 4.4 seems to underestimate water temperature in summer. This probably is the effect of solar radiation: larger rivers are more exposed to solar radiation (less shading). Air temperatures account mainly for heat input by convection. The effect of river impoundment is another possible reason for the discrepancy. Water temperatures may stratify during the day and water temperatures may be measured near the surface.

Table 4.2 Standard deviations between measured and predicted water temperatures over all years of record.

RIVER STATION	DAILY DATA				WEEKLY DATA	
	LAG TIME (PREDICTED) (days)	σ_{d_1} (WITH LAG TIME) (C)	σ_{d_2} (NO LAG TIME) (C)	σ_{d_3} (Tw=Ta) (C)	σ_{w_1} (NO LAG TIME) (C)	σ_{w_2} (Tw=Ta) (C)
1. STRAIGHT RIVER (near Park Rapids, MN)	0	-	2.96	3.37	2.70	2.70
2. STRAIGHT RIVER (at C. Hwy 115 near Park Rapids, MN)	0	-	1.83	2.17	1.24	1.19
3. VERMILLION RIVER (near Empire, MN)	0	-	3.06	3.34	2.72	2.87
4. ROSEAU RIVER (near Caribou, MN)	1	3.00	3.05	3.86	2.46	3.05
5. MINNESOTA RIVER (near Jordan, MN)	3	2.98	3.07	3.34	2.25	2.52
6. MISSISSIPPI RIVER (at St-Paul, MN)	5	3.96	4.42	5.28	3.77	4.20
7. ARKANSAS RIVER (at Dardanelle, ARK)	10	2.98	3.11	3.06	2.36	2.33
8. AMITE RIVER (at 4H camp near Denham Springs, LA)	2	2.72	2.60	2.24	1.89	1.67
9. PEARL RIVER (near Bogalusa, LA)	5	2.50	2.35	2.22	1.58	1.50
10.NORTH WACHITA RIVER (near Truscott, TX)	0	-	1.99	2.23	1.33	1.58
11.PLUM CREEK (near Luling, TX)	0	-	1.58	2.73	1.46	2.12
AVERAGE		2.69	2.73	3.08	2.16	2.34

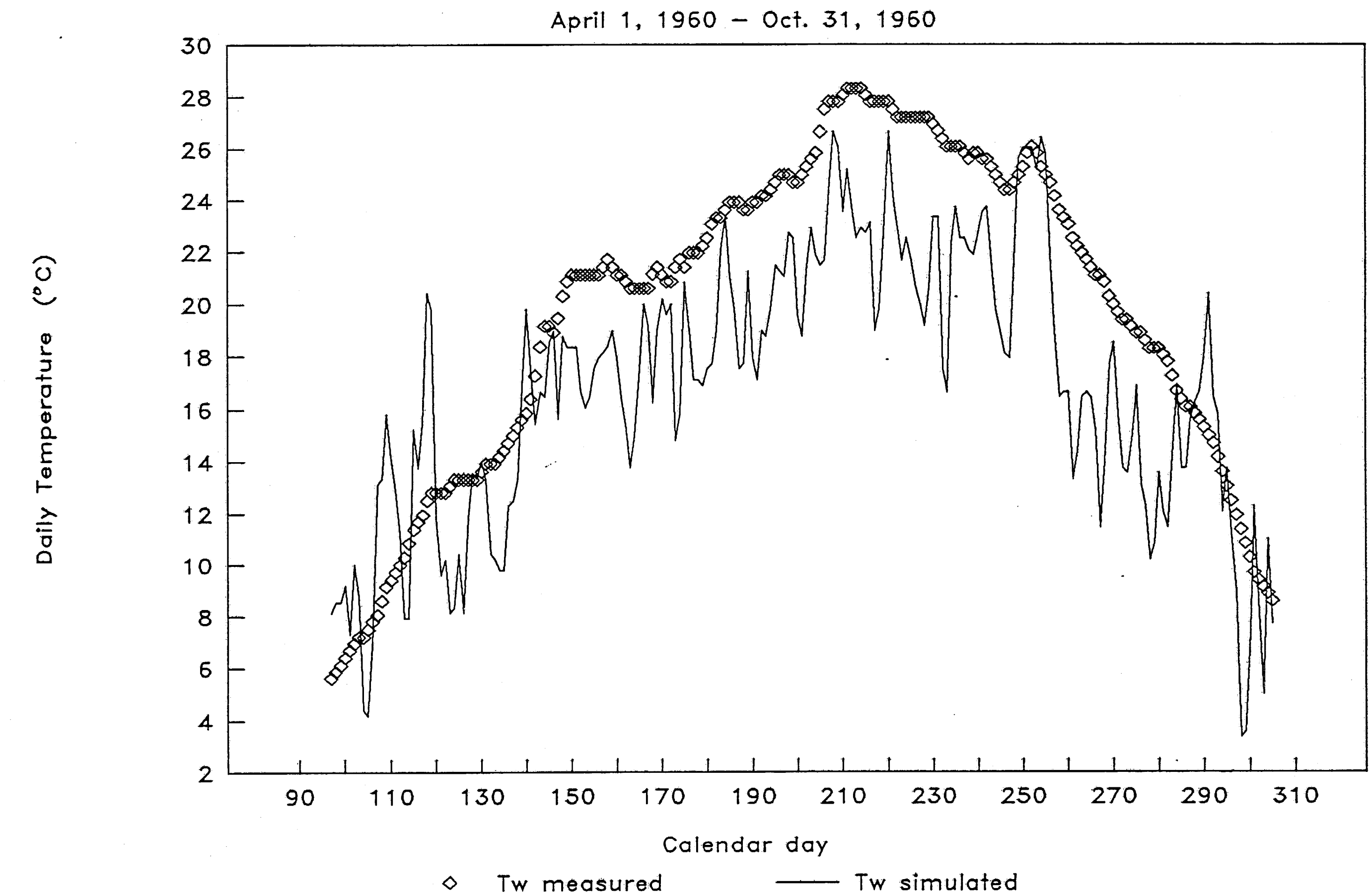

Fig. 4.7 Simulated and measured daily water temperatures, over 1 year, for the Mississippi River at St. Paul, MN.

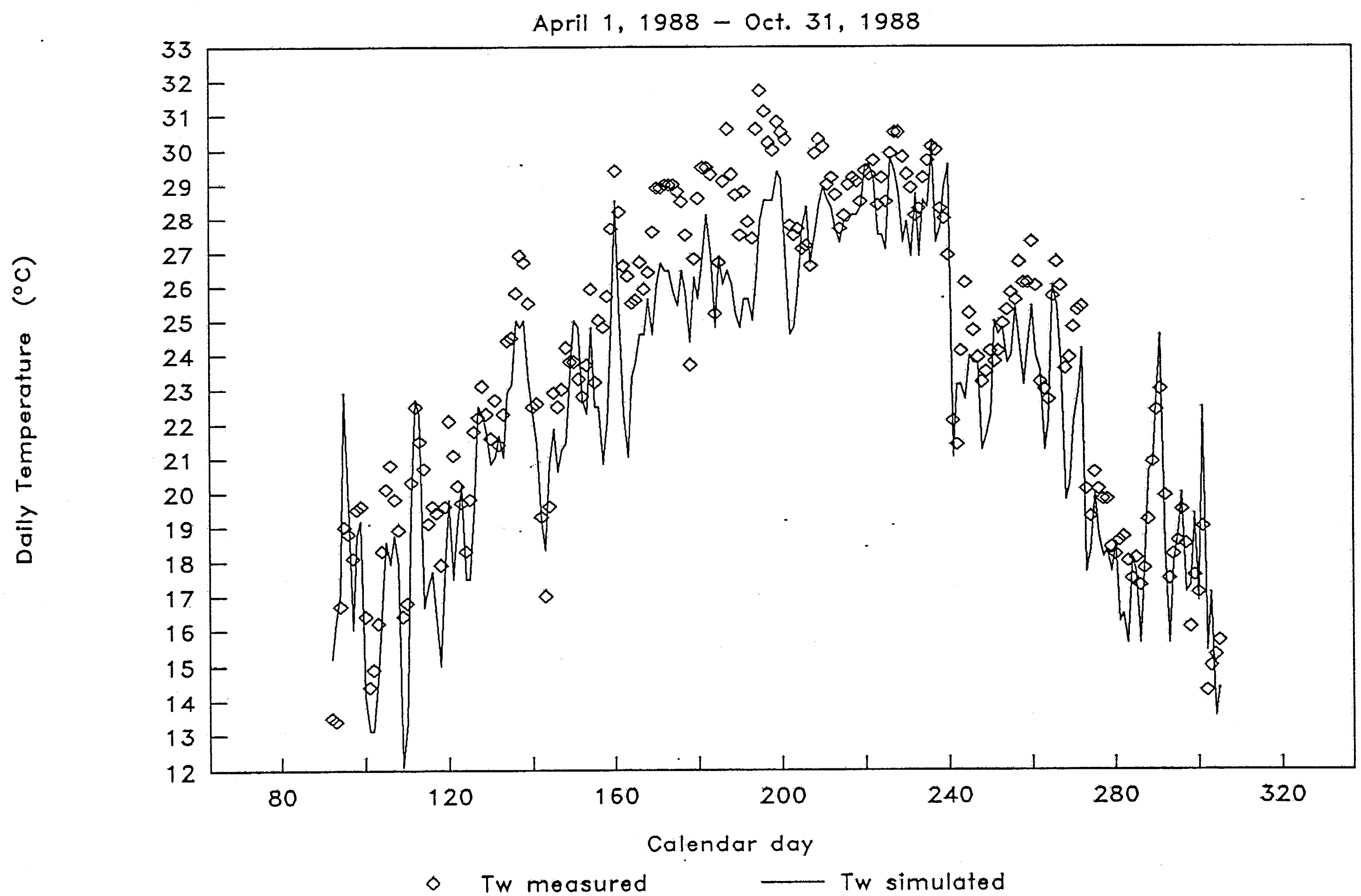

Fig. 4.8 Simulated and measured daily water temperatures, over 1 year, for the North Wichita River, near Truscott, TX.

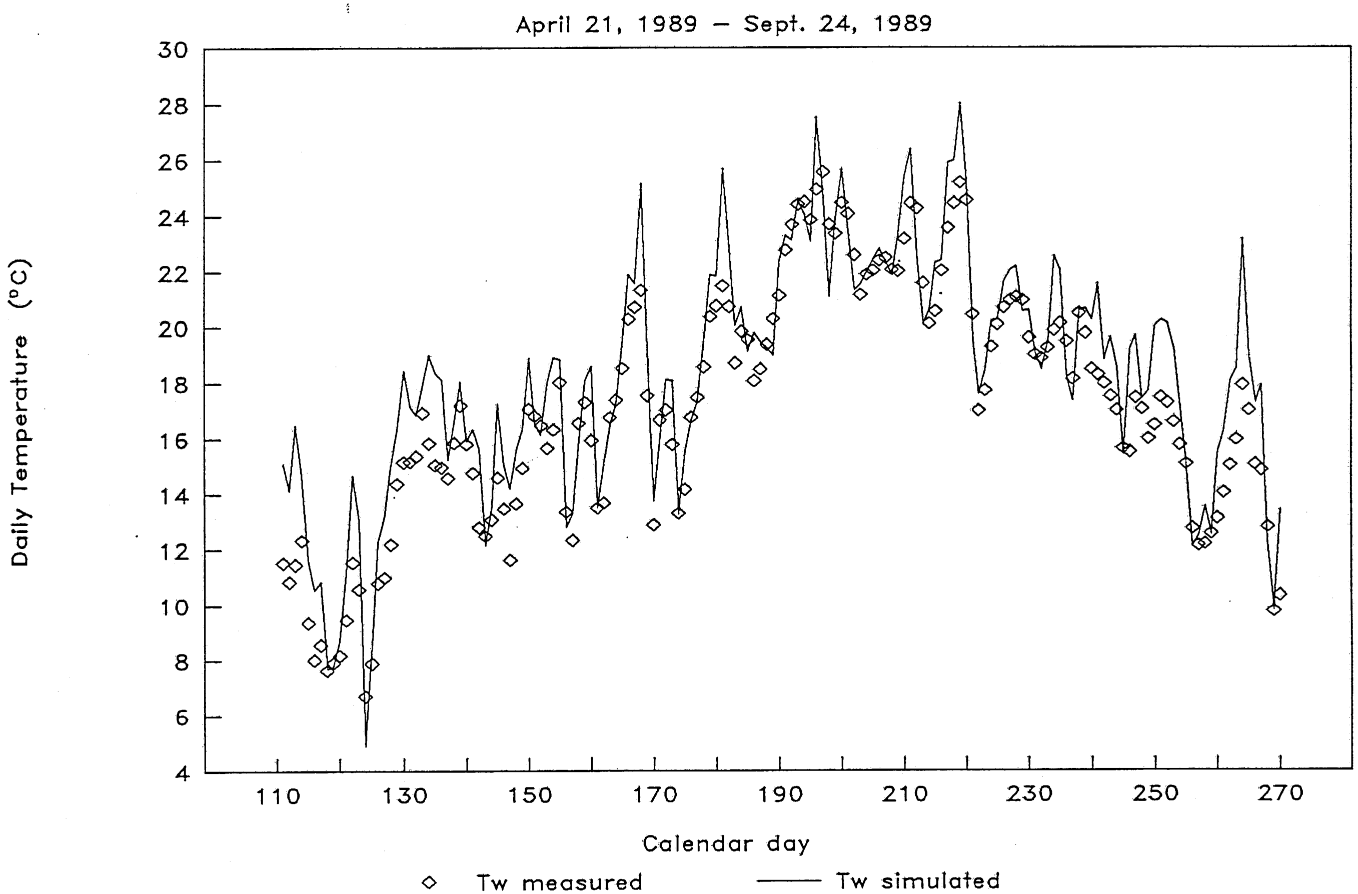

Fig. 4.9 Simulated and measured daily water temperatures, over 1 year, for the Straight River, near Park Rapids, MN.

IV.2.3 Derivation of Relationship for Weekly Data

Except for large rivers such as the Mississippi River in St. Paul, with a large flow rate and depth (annual mean discharge: 36,800 cfs), the time lag is normally below 2 or 3 days as shown in Table 3.2. An example is the Minnesota River in St. Paul (average flow: 3,776 cfs). Therefore, when using weekly averaged data, the lag time becomes 0 and need not be considered.

The relationship used for the weekly data is:

$$T_w(t) = A_3 + B_3.T_a(t) \tag{4.5}$$

where t is the time in unit of weeks, A_3 and B_3 are constants obtained from the linear regressions. As with daily data, a regression analysis was conducted for the 11 sets of data. The results are presented in Table 4.3. An example of a regression equation for the Mississippi River for the year 1960 is given in Fig. 4.10.

The standard deviations σ_3 of T_W from the linear regression equations were also calculated, and were found to be 1.45°C in the average. An apparent advantage of using weekly temperatures instead of daily temperatures is to reduce the standard deviation of the water temperatures from the regression linear equations in average from 2.07°C to 1.45°C.

The relationships obtained for the 11 rivers studied are plotted in Fig. 4.11.

The coefficients A_3 are still positive and still differ from one river to another, varying from 0.43°C for the Pearl River in Louisiana, up to 5.41°C for the North Wichita River in Texas. The average value was found to be 2.91°C with a standard deviation of 1.43°C.

The coefficient B_3 was again smaller than 1 except for the Roseau River, MN and for the Pearl River, LA. For both, B_3 is only slightly above 1 (1.03 and 1.01 respectively). The average value of B_3 for the 11 rivers studied is 0.804 with a standard deviation of 0.108.

The weekly water temperatures could therefore be approximated by using a record of weekly air temperatures and applying the relationship:

$$T_w(t) = 2.9 + 0.86\ T_a(t) \tag{4.6}$$

where t is the time in units of weeks, and temperatures are in °C.

The mean weekly water temperature is larger than the weekly air temperature when T_a is below 20.5°C, which is similar to the result found in chapter IV.2.1 for daily temperatures.

Table 4.3 Data analysis for weekly water and air temperature data.

RIVER STATION	YEAR	WITHOUT LAG TIME			
		A_3 (°C)	B_3	σ_3 (°C)	R_3^2
1. STRAIGHT RIVER (near Park Rapids, MN)	1989	1.59	0.804	0.70	0.93
2. STRAIGHT RIVER (at C. Hwy 115 near Park Rapids, MN)	1989	2.63	0.820	0.65	0.97
3. VERMILLION RIVER (near Empire, MN)	1979-85	3.98	0.669	1.23	0.92
4. ROSEAU RIVER (near Caribou, MN)	1981-83	2.10	1.026	1.81	0.92
5. MINNESOTA RIVER (near Jordan, MN)	1979,81 1983-85	2.53	0.934	2.03	0.88
6. MISSISSIPPI RIVER (at St-Paul, MN)	1957-64	4.49	0.887	3.17	0.75
7. ARKANSAS RIVER (at Dardanelle, ARK)	1983	2.60	0.907	1.97	0.89
8. AMITE RIVER (at 4H camp near Denham Springs, LA)	1973	2.26	0.896	1.33	0.82
9. PEARL RIVER (near Bogalusa, LA)	1976	0.43	1.011	1.07	0.91
10. NORTH WICHITA RIVER (near Truscott, TX)	1983	5.41	0.781	1.09	0.94
11. PLUM CREEK (near Luling, TX)	1981-85	3.99	0.770	0.882	0.91
AVERAGE		2.91	0.864	1.45	0.89
STD DEVIATION		1.43	0.108		

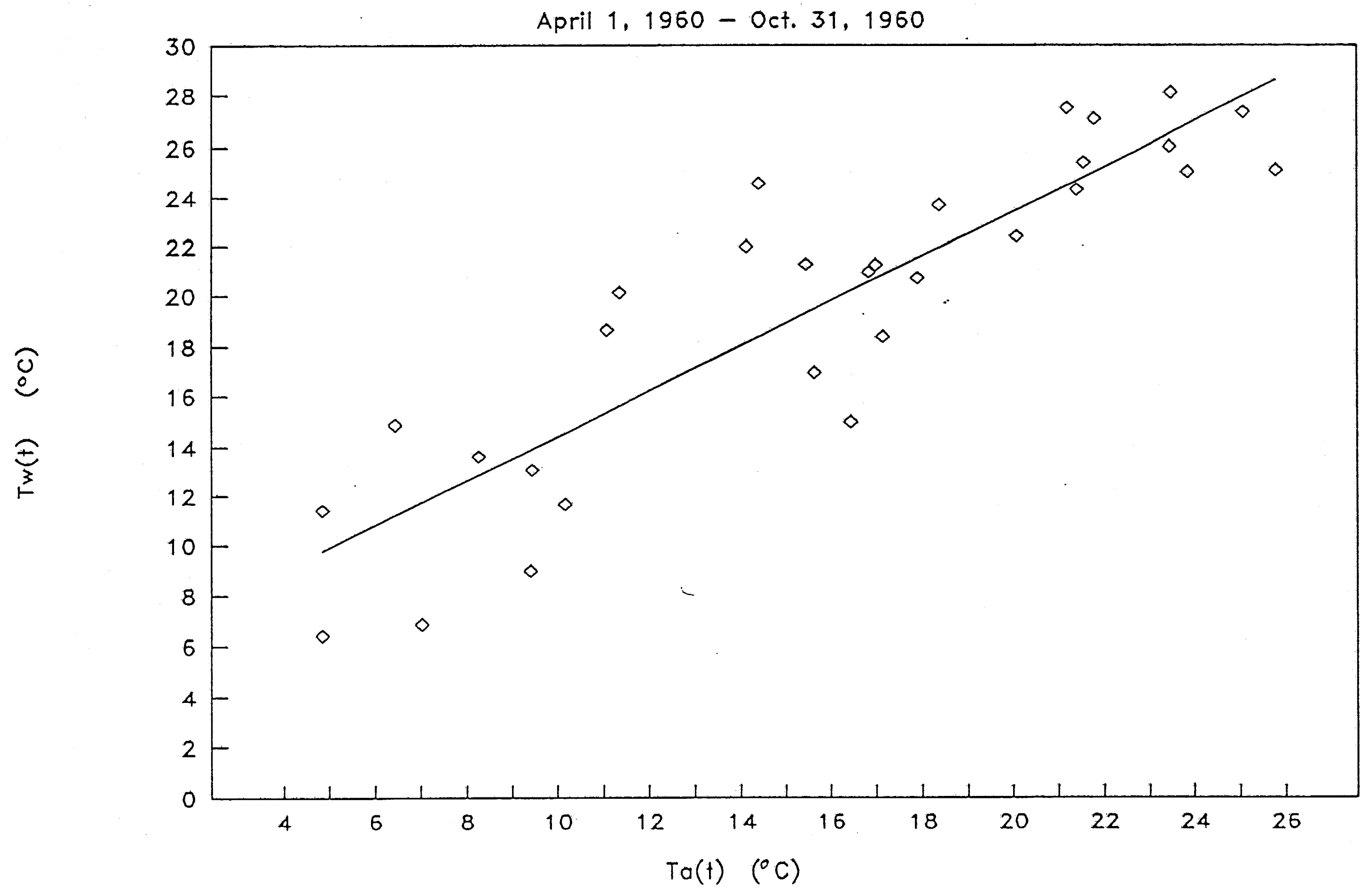

Fig. 4.10 Weekly water temperature vs. air temperature, with no lag time, for the Mississippi River in St. Paul, MN over 1 year.

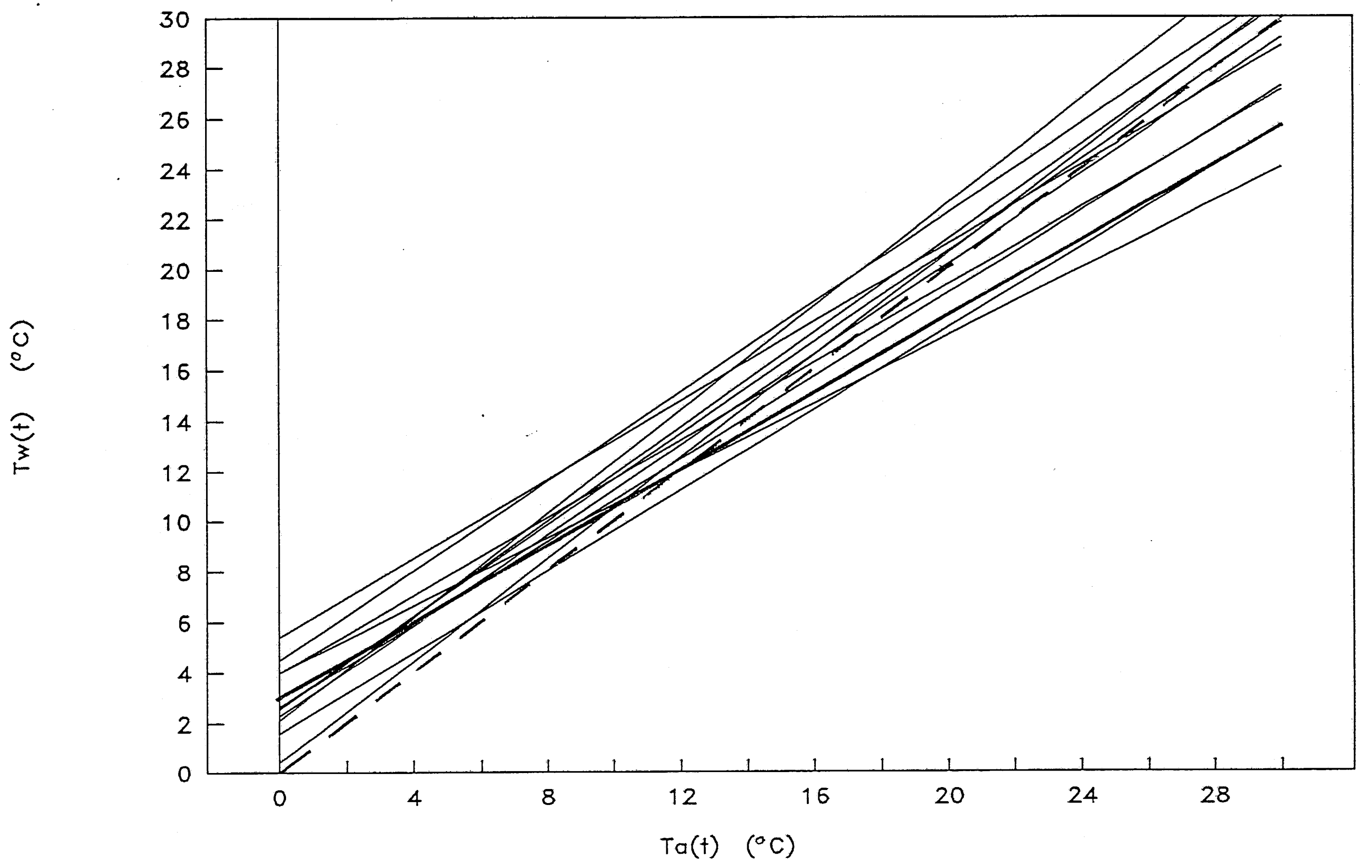

Fig. 4.11 Relationship obtained from the regression analyses between the weekly water and air temperatures for the 11 rivers studied.

IV.2.4 Application of Relationship for Weekly Data

As for daily temperatures, the "average" relationship 4.5 was tested with the 11 records available of weekly air temperatures. The projected weekly water temperatures obtained this way were compared to the actual measured weekly values of the water temperatures. The average standard deviation between the calculated and the measured weekly average water temperatures over the 11 records, when using $T_w = T_a$, is 2.34°C. It is reduced to 2.16°C when using eq. 4.6. This compares with an average standard deviation of 1.45°C for the 11 rivers when using individual regression equations for each river. It has been concluded that, instead of applying eq. 4.6, it is better to use eq. 4.5 with coefficients for each individual river given in Table 4.3 or a relationship established for a similar river in a similar environment. Graphs representing the simulated and measured weekly water temperatures were plotted for the Mississippi River in St. Paul, MN, (Fig. 4.12), the North Wichita River in Texas (Fig. 4.13) and the Straight River in Minnesota (Fig. 4.14).

Again, much better results are obtained for the smaller rivers. The standard deviation between simulated and measured weekly water temperatures is as low as 1.24°C for the Straight River and 1.30°C for the North Wichita River, whereas it is still as high as 4.35°C for the Mississippi River.

For the Mississippi River in St. Paul, including a lag time of 1 week increased the correlation coefficient between weekly air and water temperatures from 0.87 to 0.92 (average over 8 years of data, from 1957 to 1964). This corresponds to a reduction of the standard deviation σ_3 of T_w from 3.2°C to 2.4°C.

IV.3 Dependence of Air–Water Temperature Relationships on Weather Parameters

Since the coefficients A_1, A_2, A_3 and B_1, B_2, B_3 seem to fluctuate substantially from one river to another, or for the same river from one year to another (see Table 4.4), it is useful to examine briefly the major factors influencing these coefficients, at least qualitatively.

In Table 4.4 the regression constants A_3 and B_3 for each river and each year of record are assembled, along with the average air temperature, water temperature and solar radiation calculated from April 1 to Oct. 31, which is the period of the year studied in this report. Since the rivers studied are located in the north central and south central United States, the range of average air and water temperatures is large, as shown in table 4.4. Water temperatures go from 12.0°C for the Mississippi River in St. Paul, MN, in 1982 to 25.8°C for Plum Creek in Texas in 1981.

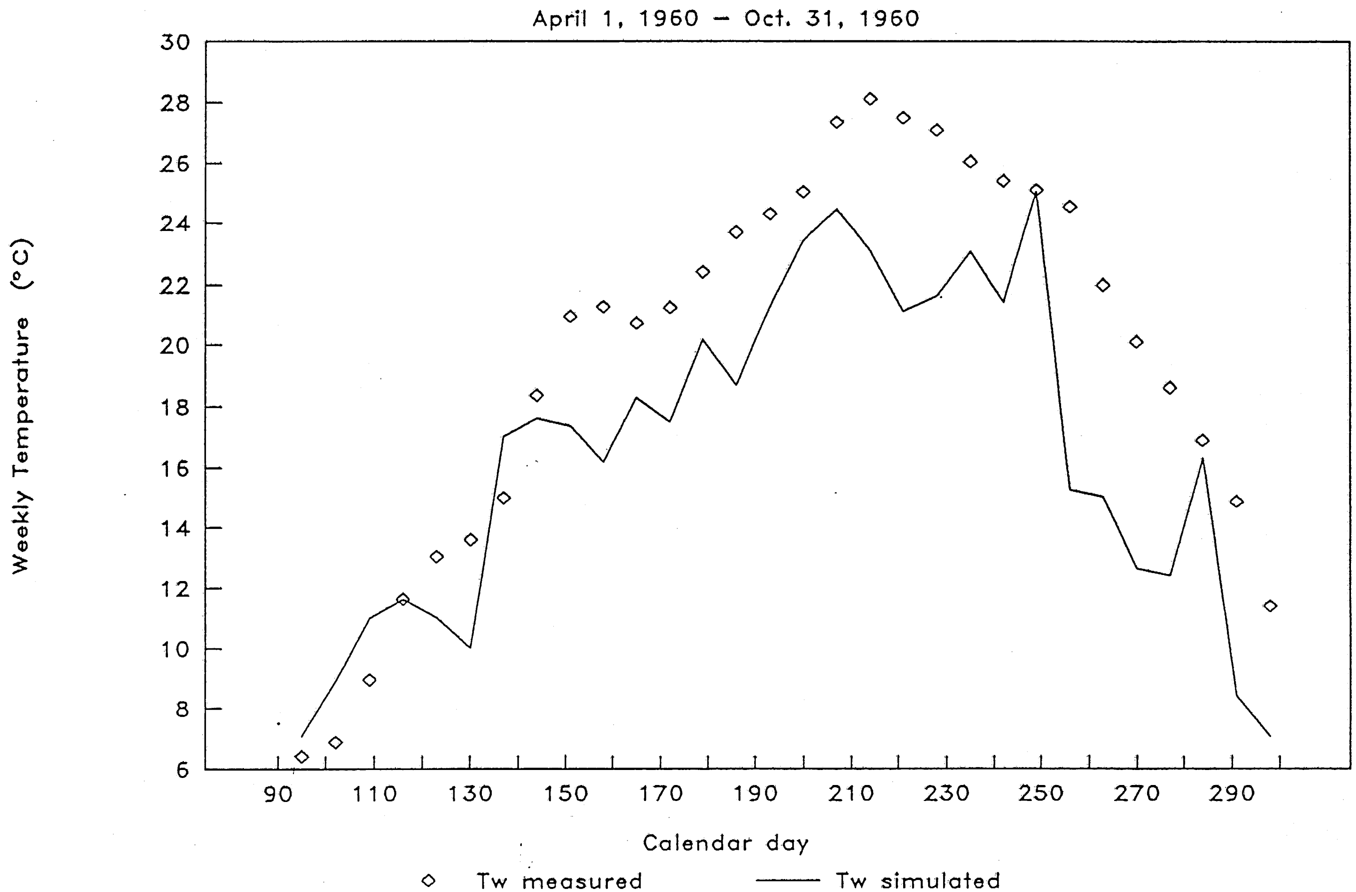

Fig. 4.12 Simulated and measured weekly water temperatures, over 1 year, for the Mississippi River at St. Paul, MN.

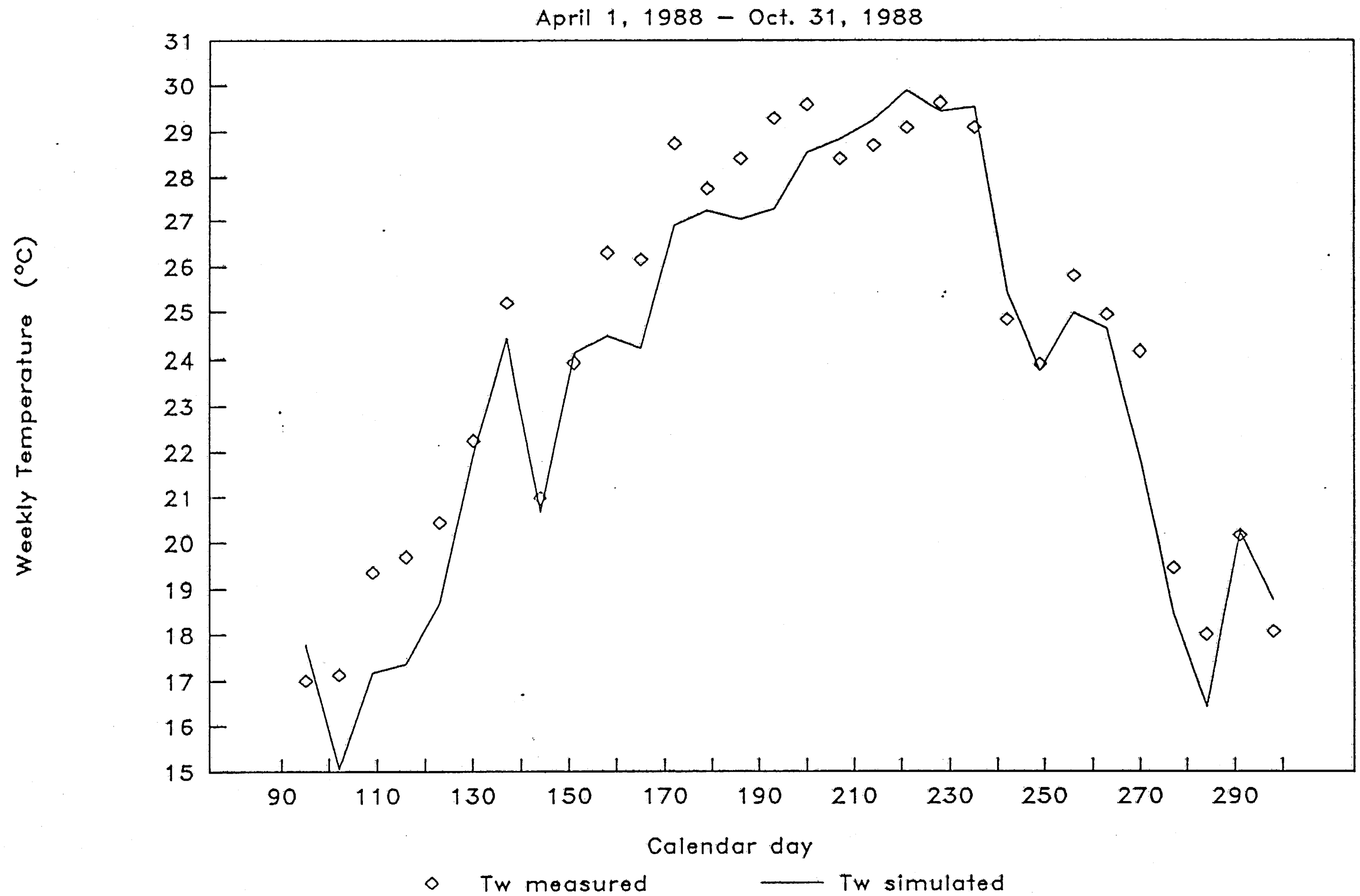

Fig. 4.13 Simulated and measured weekly water temperatures, over 1 year, for the North Wichita River near Truscott, TX.

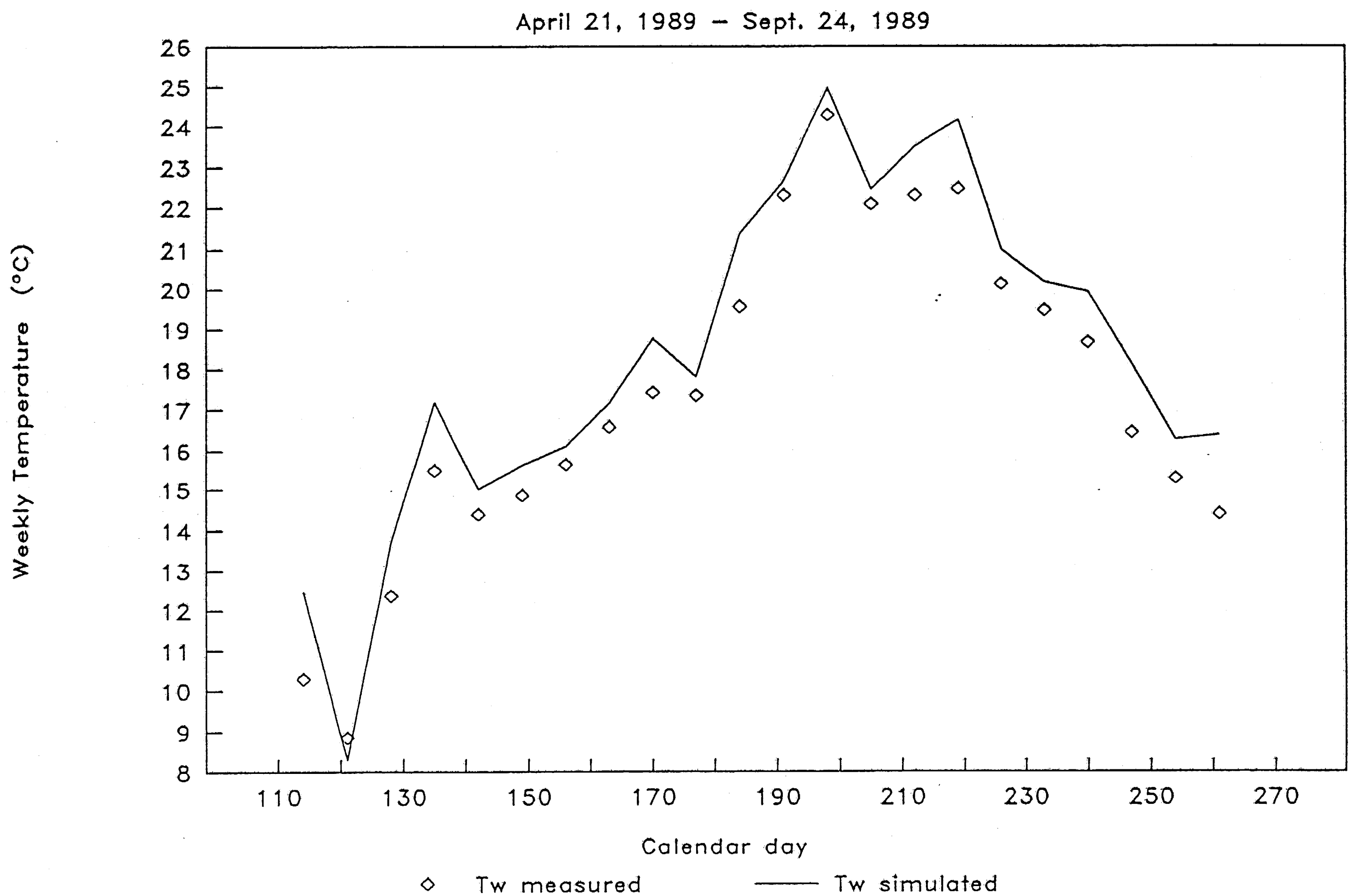

Fig. 4.14 Simulated and measured weekly water temperatures, over 1 year, for the Straight River, at County Hwy 115, near Park Rapids, MN.

Table 4.4 Climatological data and data analysis for weekly data, for each year of record.

RIVER STATION	YEAR	AVERAGE Tw* (°C)	AVERAGE Ta* (°C)	AVERAGE SOLAR RAD. (kcal/m /day)	ANNUAL AVERAGE FLOW (cfs)	A_3 (°C)	B_3	σ_3 (°C)	R_3^2
1. STRAIGHT RIVER (near Park Rapids, MN)	1989	-	-	-	45	1.40	0.816	1.21	0.91
2. STRAIGHT RIVER (at C. Hwy 115 near Park Rapids, MN)	1989	-	-	-	45	2.63	0.820	0.65	0.97
3. VERMILLION RIVER (near Empire, MN)	1979	-	15.6	-	59.1	3.57	0.73	1.03	0.96
	1980	15.1	16.3	-	47.0	4.52	0.65	1.31	0.92
	1981	14.8	15.5	-	34.3	4.33	0.68	0.87	0.95
	1982	-	16.3	-	53.9	4.47	0.63	0.73	0.97
	1983	-	16.4	-	94.4	4.84	0.58	1.32	0.84
	1984	-	16.2	-	87.4	2.93	0.72	1.41	0.91
4. ROSEAU RIVER (near Caribou, MN)	1981	-	12.9	-	147	4.13	0.89	1.52	0.94
	1982	-	12.0	-	315	-0.93	1.22	2.02	0.89
	1983	-	12.7	-	319	1.75	1.05	1.55	0.95
5. MINNESOTA RIVER (near Jordan, MN)	1979	-	15.6	-	8146	2.13	0.97	2.00	0.91
	1981	-	15.5	-	2659	3.06	0.97	1.47	0.91
	1983	-	16.4	-	8448	3.45	0.90	1.82	0.93
	1984	-	16.2	-	9646	1.39	0.91	1.57	0.92
6. MISSISSIPPI RIVER (at St-Paul, MN)	1957	17.3	16.2	450.0	12710	2.93	0.89	2.15	0.88
	1958	19.1	16.4	457.3	7369	1.88	1.05	2.54	0.81
	1959	19.8	17.0	497.9	4677	3.74	0.88	2.14	0.88
	1960	19.6	15.7	461.7	9616	5.08	0.92	2.09	0.88
	1961	18.7	15.2	450.3	5524	6.61	0.81	1.96	0.89
	1962	18.2	15.0	432.8	30810	5.99	0.82	2.58	0.78
	1963	19.1	16.9	430.6	9178	3.38	0.95	2.36	0.82
	1964	19.5	16.3	422.7	7460	5.13	0.90	2.25	0.87
7. ARKANSAS RIVER (at Dardanelle, ARK)	1983	23.0	22.5	-	38170	2.60	0.91	1.97	0.89
8. AMITE RIVER (at 4H camp near Denham Springs, LA)	1973	23.8	24.0	-	*1280	2.26	0.90	1.33	0.82
9. PEARL RIVER (near Bogalusa, LA)	1976	24.5	23.8	-	*9983	0.43	1.01	1.07	0.91
10. NORTH WICHITA RIVER (near Truscott, TX)	1983	23.5	23.2	-	121	5.41	0.78	1.08	0.94
11. PLUM CREEK (near Luling, TX)	1981	23.9	25.8	-	124	4.70	0.74	1.02	0.86
	1983	23.0	24.7	-	77	4.07	0.77	0.76	0.94
	1984	23.8	25.7	-	14	3.20	0.80	0.84	0.92

* averaged over the period of the year : April 1 - Oct. 31

Even for a given river, there is a wide variation in values of A_3 and B_3 from year to year. To study this variability, the coefficients A_3 and B_3, respectively, are plotted versus the average air temperature over the period of the year April 1 – Oct. 31 in Figs. 4.15 and 4.16. These two graphs show clearly that A_3 and B_3 are not directly dependent on the average air temperature. Even for the same river such as the Mississippi River for which 8 years of data were available, whether a year is warm or cold does not seem to influence distinctly the constants A_3 and B_3.

The average solar radiation over the period April 1 to Oct. 31 near the Mississippi River for 8 years are also reported in Table 4.4. Again, plotting the regression constants A_3 and B_3 versus the average solar radiation, respectively in Figs. 4.17 and 4.18, shows clearly that A_3 and B_3 are not directly dependent on variations of the average solar radiation alone from year to year. Calling upon individual weather parameters cannot resolve the variability of the regression equation coefficients A and B, because weather parameters and water temperatures are related in a non–linear way, as can be shown by a complete heat budget analysis (see e.g. Stefan et al., 1980).

IV.4 Dependence of Air–Water Temperature Relationships on Stream Characteristics

Some streams characteristics are easily available, such as the average flow rate, the drainage area, the presence of impoundments upstream, which might influence the coefficients A_1, A_2, A_3 and B_1, B_2, B_3. Other parameters which might be influential are the shading created by trees or cliffs on the banks of the river.

IV.4.1 Flow Rate, Drainage Area and Depth

Average flow rate, drainage area and average depth of the river are correlated as shown by MacDonald & Parker (1991) and Murdock & Gulliver (1991), and might all three influence the parameters A_1, A_2, A_3 and B_1, B_2, B_3. Using the numbers from Table 4.4, A_3 and B_3 were plotted versus the logarithm of the annual average discharge in Figs. 4.19 and 4.20, respectively. No significant correlation between A_3 and logQ is apparent.

By regression analysis, it is found that:

$$B_3 = 0.638 + 0.0739 \log Q \qquad (4.7)$$

The standard deviation of B_3 from the linear regression eq. 4.7 is 0.12 and the regression coefficient squared is only 0.30. This shows that any physical meaning of eq. 4.7 must be put in question.

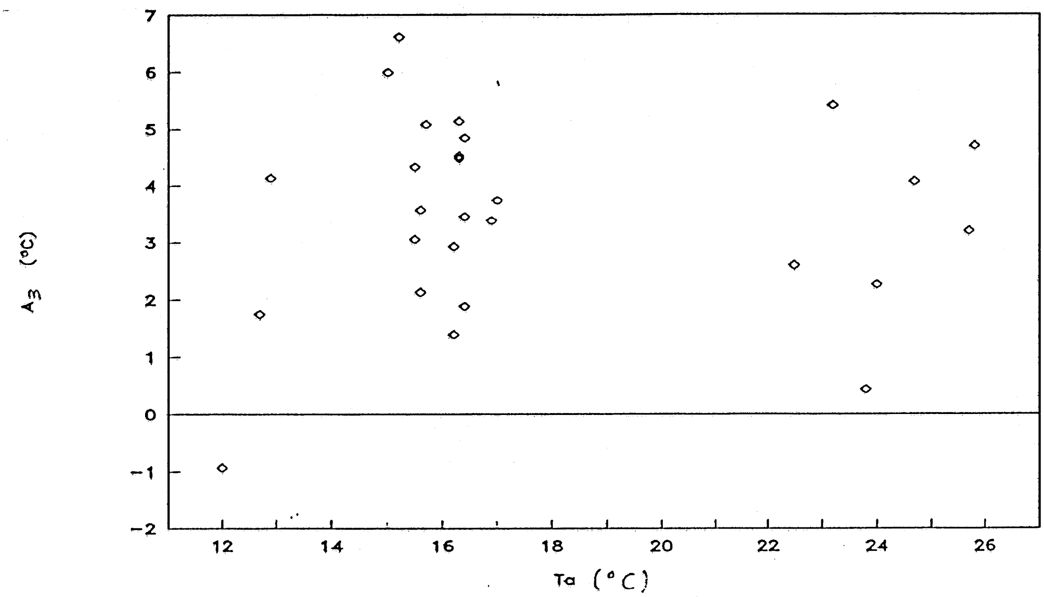

Fig. 4.15 Coefficient A_3 for eq. 4.6 vs. the average air temperature $\overline{T_a}$ over the periods April 1 – Oct. 31, for each river and each year of data.

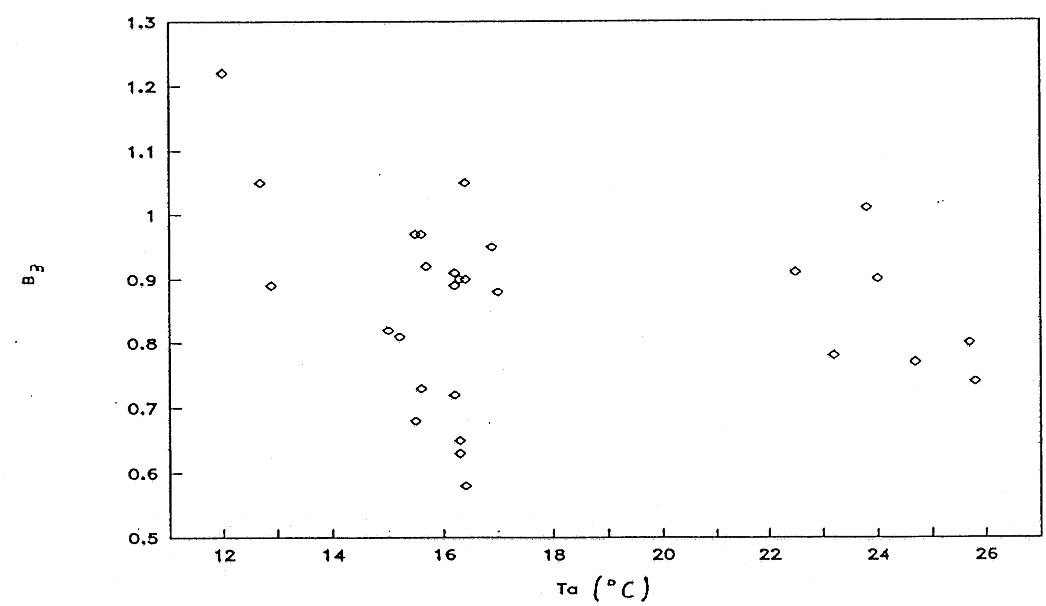

Fig. 4.16 Coefficient B_3 for eq. 4.6 vs. the average air temperature $\overline{T_a}$ over the periods April 1 – Oct. 31, for each river and each year of data.

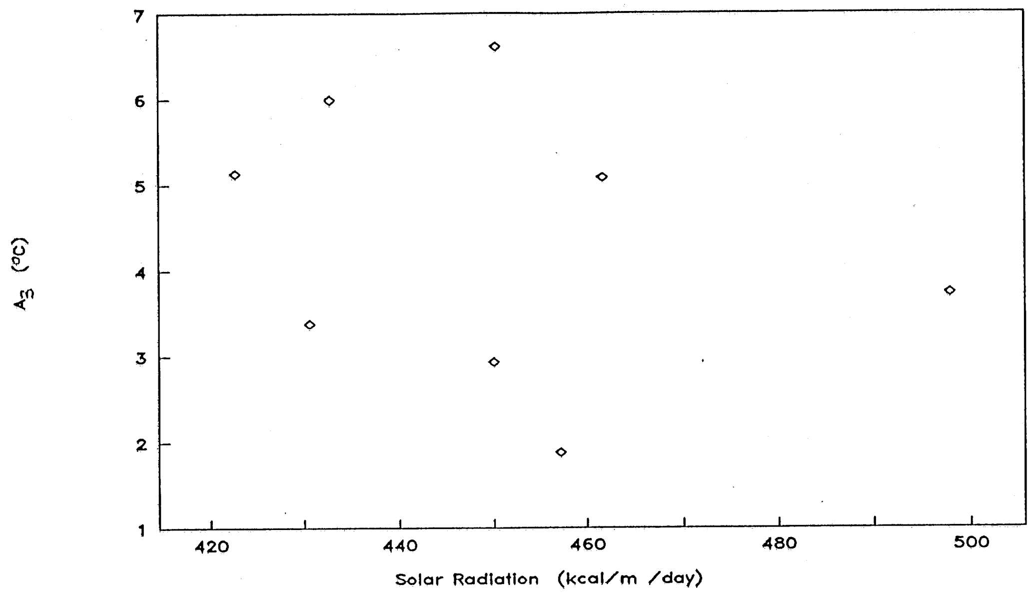

Fig. 4.17 Coefficient A_3 for eq. 4.6 vs. the average solar radiation over the periods April 1 – Oct. 31, for each river and each year of data.

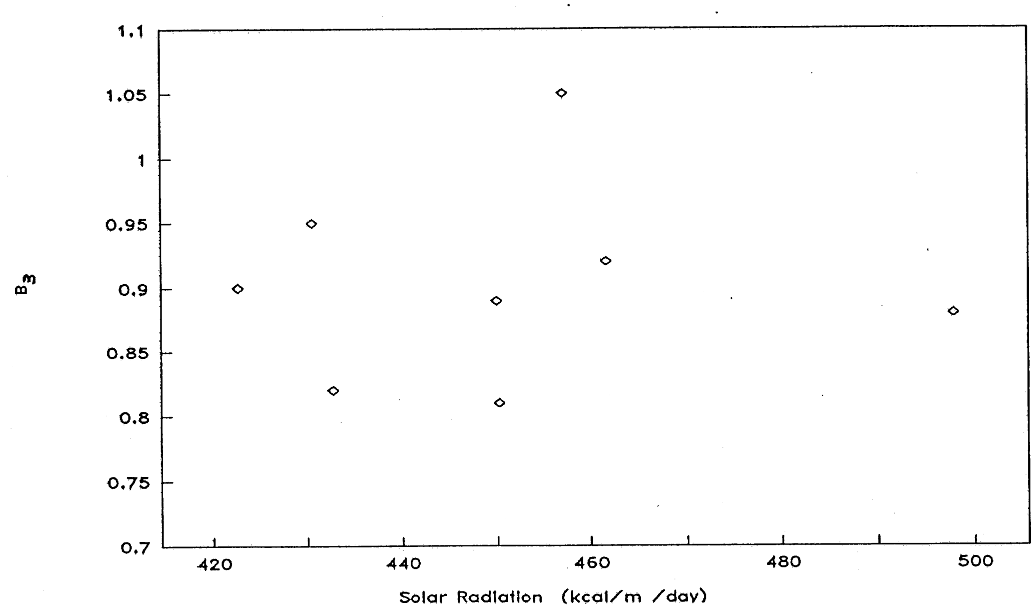

Fig. 4.18 Coefficient B_3 for eq. 4.6 vs. the average solar radiation over the periods April 1 – Oct. 31, for each river and each year of data.

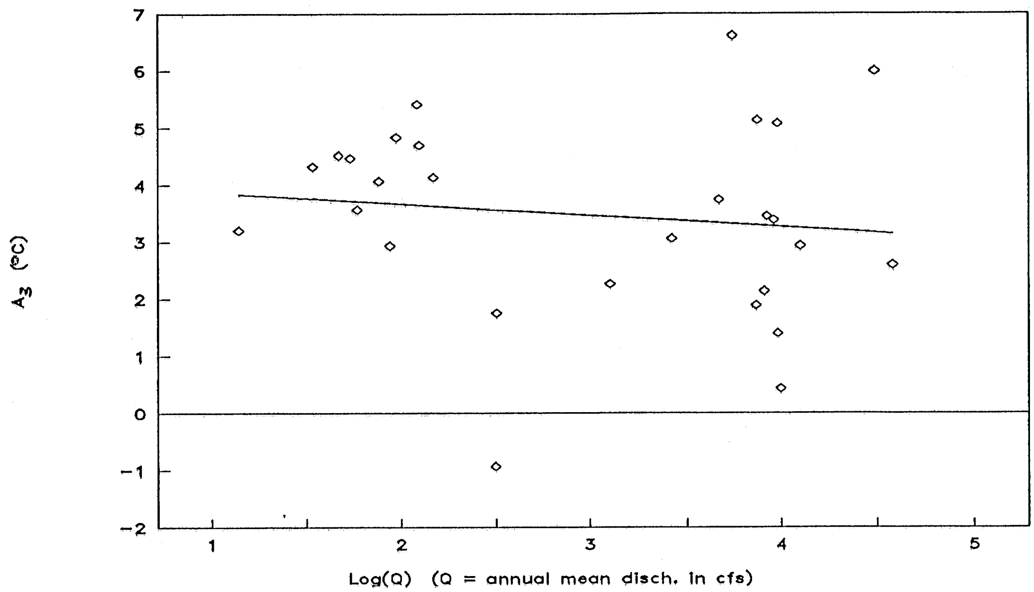

Fig. 4.19 Coefficient A_3 for eq. 4.6 vs. the annual average discharge, for each river and each year of data.

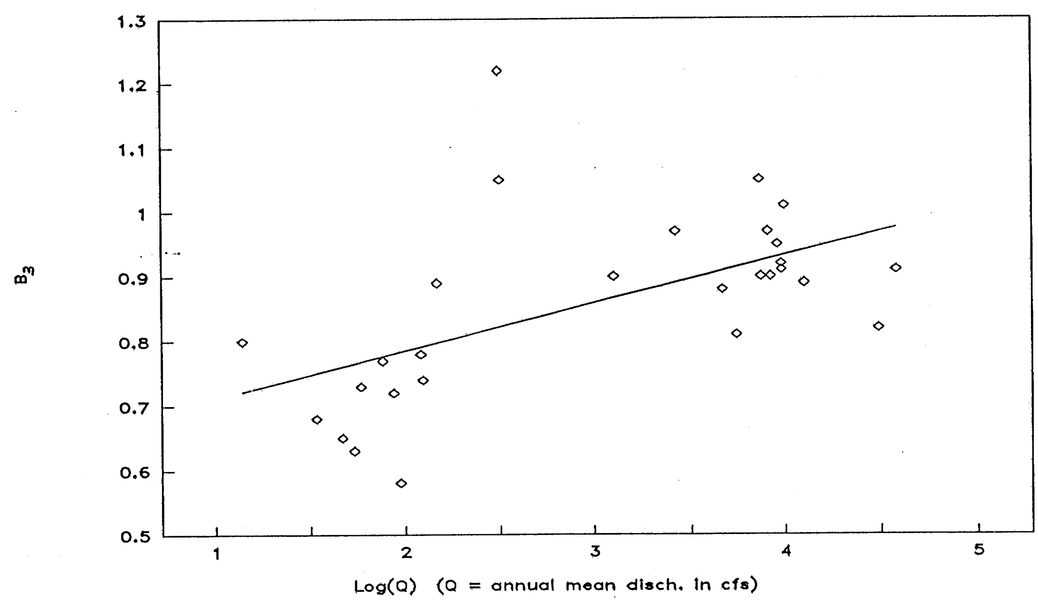

Fig. 4.20 Coefficient B_3 for eq. 4.6 vs. the annual average discharge, for each river and each year of data.

IV.4.2 Groundwater and Impoundments

Groundwater provides the stream with water of relatively uniform temperature during the day and the year, and might have a large effect, especially when flows are low in summer on small streams, as shown by Stevens, Fick & Smoot (1975), Smith (1975) and Meisner, Rosenfeld & Regier (1988). Groundwater temperatures at depth of 10–20 m in the United States are approximately 1.1°C to 1.7°C greater than the mean annual air temperature and variations throughout the year are generally less than 0.5°C , according to Collins (1925).

Impoundments also have a major effect on the water temperature downstream. Palmer & O'Keeffe (1989) found that, on the Buffalo River in South Africa, surface release impoundments were reducing the normal water temperature 15 km downstream, by as much as 8°C and effects were most visible in summertime, especially on the upper reach of the river where the discharge is smaller. Bottom releases from impoundments can be 16°C cooler than pre–impoundment temperatures.

Similarly, lakes, wetlands and marshes alter natural stream temperature regimes by providing water surface exposure to solar radiation and the potential for water temperature stratification. This is of importance e.g. in Minnesota. Water temperature stratification has implications for water temperature measurements. Therefore, the depth a which a water temperature sensor is located in a river as well as the distance from an impoundment or lake can influence a water temperature record significantly.

Therefore, the presence of groundwater inflow and impoundments are likely to influence the coefficients A_1, A_2, A_3 and B_1, B_2, B_3 downstream over at least 10 miles for rivers with small flows: the coefficients A_1, A_2, A_3 are expected to be increased and the coefficients B_1, B_2, B_3 to be decreased to represent less variations in water temperature.

IV.4.3 Shading

Rishel et al. (1982) and Brown (1969)showed that shading has a major effect on the water temperature of small headwater streams. By studying the change of water temperature after forest cover was removed along a stream exposing it to direct solar radiation, it was shown that average monthly maximum stream temperature increased by as much as 4.4°C, especially during the summer.

The effect of shading should therefore be noted in summer (when trees are covered with leaves) on small streams. Shading will probably increase the B_i constants. Large rivers will probably not be affected much by shading since most of the width of the river is exposed to direct solar radiation during most of daylight hours.

V. SUMMARY AND CONCLUSIONS

The purpose of this study was twofold: (1) to examine with which accuracy stream water temperatures can be estimated from air temperatures and (2) to estimate the representativeness of random stream temperature sampling. Data from eleven streams in the Mississippi River basin were analyzed to find answers. A summary of the findings is as follows:

(1) Some existing stream water temperature records are not giving representative daily average values, especially when only one measurement per day is made, at a "random" time. In shallow streams with a depth on the order of 3 ft or less, the standard deviation between the measurements and the real daily mean temperature can be as high as 2°C, i.e. errors larger than 4°C will occur 5% of the time, assuming that the error distribution is Gaussian. In a deep river, with a depth on the order of 10 ft, the standard deviation of the randomly measured water temperature from the actual mean water temperature is expected to be only 0.3 to 0.4°C.

Morning water temperature measurements will underestimate the daily mean water temperature, whereas afternoon measurements will overestimate it. In a case study of a shallow stream, the average error was as much as –1.5°C for morning measurements, and as much as +1°C for afternoon measurements.

(2) Water temperature was shown to respond to air temperature with a time lag, ranging from 4 hrs for shallow rivers less than 2 ft deep, when using hourly temperature data, up to 7 days for rivers 15 ft deep, when using daily data. Using a time lag improved daily water temperature estimates from air temperatures.

(3) Daily and weekly stream temperatures can be easily estimated by a linear relationship with air temperature records. For the ensemble of 11 streams used in this study, weekly average water temperature estimates as regressed linear functions of air temperature, had a standard deviation from the measured values of T_w on the order of 1°C for small shaded streams, and on the order of 2°C for large, wide streams. Also, better results were obtained for weekly data than for daily data, with standard deviations on the average of 1.4°C and 2.1°C, respectively.

(4) For immediate daily average water temperature estimates, the general linear relationship 4.4 between daily air and water temperatures can be used, with an expected standard deviation of the calculated T_w from the real daily average water temperature on the order of 2.7°C. For weekly data, the general relationship 4.6 between air and water temperatures can be used, with an expected standard deviation on the order of 2.1°C. In order to improve the water temperature estimates, it is advisable to derive the coefficients A_i and B_i of eqs. 4.4 and 4.6 by using data from a similar stream in a similar climatological and geographical environment.

(5) The above standard deviations are on the same order as random measurements in shallow streams. Therefore, using available daily air temperature data to calculate daily water temperatures of small streams proves to be almost as accurate as taking "random" measurements. Better results are obtained for smaller streams, which are more responsive to air temperature, because they have smaller thermal inertia. For larger streams, the stochastic approach developed by Song, Pabst & Bowers (1973), which takes into account the seasonal sinusoidal trend of air and water temperatures, is better, but requires more complex computations and parameters.

(6) The dependence of regression coefficients on stream characteristics and weather parameters other than air temperature is evident in the results but difficult to quantify without resort to more complex heat budget models. The objective of this study was to estimate stream water temperatures from air temperatures alone.

If more accurate hourly or daily water temperatures are needed, the use of complete heat budget models is recommended. Such models can give stream temperatures with a standard deviation of 1°C or less (Stefan et al., 1980, Sinokrot & Stefan, 1992). More input data will be required. The relationships found in this study can be used to obtain rough estimates of stream water temperatures.

(7) Diurnal and daily air temperature fluctuations are reflected in smaller water temperature changes. The damping effect is due to the thermal inertia of a water body and is more pronounced when the water depth is increased. This effect is not included in simple water temperature predictions from air temperature, which leads to larger discrepancies in deeper water bodies. The damping effect is included in stochastic prediction methods.

REFERENCES

Brown, G. W. (1969). "Predicting temperatures of small streams." Water Resources Research. Vol. 5, No. 1.

Brown, G. W. (1972). "An improved temperature prediction model for small streams." Oregon Water Resources Research Institute, Corvallis, *Completion Report*, 20 pp

Chiu, C. L. and Isu, E. O. (1978). "Stream temperature estimation using Kalman filter." *Journal of the Hydraulics Division*, American Society of Engineers, Vol. 104, No. HY9, Proceedings Paper 13991, 1257–1268.

Cluis, D. A. (1972). "Relationship between stream water temperature and ambient air temperature." *Nordic Hydrology*, Vol.3, No.2, 65–71.

Collins, W. D. (1925). "Temperature of water available for industrial use in the United States." United States Geological Survey Water Supply Paper 520–F.

Edinger et al. (1974). Heat exchange and transport in the environment. Report EA–74–049–00–3.

Ellis, C. (1991). SAFHL (St. Anthony Falls Hydraulic Laboratory). Water and air temperatures of the Mississippi River in Minneapolis, MN.

Gillett, B. E. and Long, L. L. (1974). "Statistical analysis of water temperature residuals." *Water Resources Research*, Vol. 10, No. 6, 1127–1132.

Huntsberger, D.V. and Billinger P. (1973). *Elements of statistical inference.* Allyn and Bacon, inc, Boston. pp. 218–232.

Incropera, F. P. and De Witt D.P. (1990). *Introduction to heat transfer.* New York. John Wiley and Sons.

Kothandaraman, V. (1971). "Analysis of water temperature variations in large river." *Journal of Sanitary Engineering Division,* ASCE, Vol. 97, No. SA1, Proc. Paper 7908, Feb. 1971, pp. 19–31.

Kothandaraman, V. (1973). "Air–water temperature relationship in Illinois River." *Water Resources Bulletin,* American Water Resources Association, Vol. 8, No 1, Feb 1972.

Leopold, L.B. and Maddock, Thomas Jr. (1953). "The hydraulic geometry of stream channels and some physiographic implications." U.S. Geological Survey Professional Paper 252, pp. 1–16.

MacDonald, T. E., Parker, G. and Leuthe, D. P. (1991). "Inventory and analysis of streams meander problems in Minnesota." St. Anthony Falls Hydraulic Laboratory, University of Minnesota.

Meisner, J. D., Rosenfeld, J. S. and Regier, H. A. (1988). "Role of groundwater in the impact of climate warming on stream salmonines." *Fisheries*, Vol. 13, No. 3, 2–8.

Morin, G., Couillard, D., Cluis, D., Jones, H. G. and Gauthier, J.–M. (1987). "Prediction of temperatures in rivers using a conceptual model (prevision des temperatures de l'eau en riviere a l'aide d'un modele conceptuel)." *Hydrological Sciences Journal* HSJODN, Vol. 32, No. 1, 31–41.

Noble, R. D. (1979). "Analytical prediction of natural temperatures in rivers." *Journal of the Environmental Engineering Division*, American Society of Civil Engineers, Vol. 105, No EE5, Technical Note, 1014–1018.

Novotny, V. and Krenkel, P. A. (1973). "Simplified mathematical model of temperature changes in rivers." *Journal of Water Pollution Control Federation*, Vol. 45, No.2, 239–248.

Palmer, R. W. and O'Keeffe, J. H. (1989). "Temperature characteristics of an impounded river." *Archiv fuer Hydrobiologie* AHYBA4, Vol. 116, No. 4, 471–485.

Pauszek, F. H. (1972). 'Water–temperature data acquisition activities in the United States." *Geological Survey Water–Resources Investigations* 2–72.

Rishel, G. B., Lynch, J. A. and Corbett, E. S. (1982). "Seasonal stream temperature changes following forest harvesting." *Journal of Environmental Quality*, Vol. 11, No. 1, 112–116.

Sinokrot, B. , A and Stefan, H. G. (1992). "Stream temperature dynamics: Measurements and Predictions." Submitted to *Water Resources Research, AGU*, August, 1992.

Smith, K. (1975). "Water temperature variations within a major river system." *Nordic Hydrology*, Vol.6, No. 3, 155–169.

Smith, K. (1981). "The prediction of river water temperature." *Hydrological Science Bulletin*, Vol. 26, N0.1, 19–32.

Song, C. C. S. and Chien, C–Y. (1977). "Stochastic properties of daily temperature in rivers." *Journal of the Environmental Engineering Division*, American Society of Civil Engineers, Vol. 103, No. EE2, Proceedings Paper 12858, 217–231.

Song, C. C. S.,Pabst, A. F. and Bowers, C. E. (1973). Stochastic analysis of air and water temperatures. *Journal of the Environmental Engineering division*, ASCE, Vol. 99, No. EE6, proc. paper 10209, Dec. 1973

Stark, J. (1988). USGS (United States Geological Survey). Air and water temperature records for the Straight River (obtained by written communication)

Stefan, H.G. (1990). SAFHL (St. Anthony Falls Hydraulic Laboratory). Air and Water temperature data for the Zumbro River.

Stefan, H.G., Gulliver J., Hahn M.G. and Fu A.Y. (1980). "Water temperature dynamics in experimental field channels: Analysis and modeling". St Anthony Falls Hydraulic Laboratory (SAFHL). Report No 193.

Stefan, H. G., Hondzo M. and Sinokrot B. (1990). "Global climate change impacts on lake and stream environmental conditions and fishery resources." St Anthony Falls Hydraulic Laboratory. University of Minnesota. *Memorandum No M*–224.

Stevens, H. H., Ficke, J. F. and Smoot, G. F. (1975). "Water temperature–influential factors, field measurement, and data presentation." *Techniques of Water–Resources Investigations of the United States Geological Survey*, Book 1, Chapter D1, 65 pp.

Tasker, G. D. and Burns, A. W. (1974). "Mathematical generalization of stream temperature in central New England." *Water Resources Bulletin*, Vol. 10, No. 6, 1133–1142.

Thomann, R. V. and Mueller J. A. (1987). *Principles of surface water quality modeling and control.* New York. Harper and Row. pp. 599–615.

USGS (United States Geological Survey). Water temperature records for Minnesota, Arkansas, Texas and Louisiana streams.

U.S. National Weather Service. Air temperature records for Arkansas, Louisiana and Texas.

APPENDIX A

COMPUTER PROGRAMS

```
program CORRELATION;

(*   PROGRAM CALCULATES THE CORRELATION COEFFICIENT   *)
(*   BETWEEN 2 SETS OF DATA, FOR DIFFERENT LAG TIMES  *)

VAR
   fichier:  TEXT;
   filename: STRING[30];
   temp: ARRAY[1..5000,1..2] OF REAL;
   datanumber,i,last,lagmax,delta: INTEGER;
   oput: TEXT;
   oputname: STRING[30];
   product,sumair,sumwat,squarewat: REAL;
   squareair,correlationcoef: REAL;

BEGIN

   (*   ASKS FOR INPUT FILE NAME.                     *)
   (*   THE INPUT FILE  NEEDS TO BE ON 2 COLUMNS,     *)
   (*   THE FIRST ONE BEING THE WATER TEMP., THE      *)
   (*   SECOND ONE THE AIR TEMP., MEASURED AT         *)
   (*   THE SAME TIME.                                *)

   WRITE('file name:');
   READLN(filename);
   ASSIGN(fichier,filename);
   RESET(fichier);

   (*   WILL PUT THE CORRELATION COEFF. IN OUTPUT FILE   *)

   WRITE('output file name:');
   READLN(oputname);
   ASSIGN(oput,oputname);
   REWRITE(oput);

   (*   ASKS FOR THE EXACT NUMBER OF PAIRS OF    *)
   (*   VALUES IN THE RECORD.                    *)

   WRITE('Number of measurements (5000 maximum) :');
   READLN(datanumber);

   (*   ASKS FOR RANGE OF LAG, BY WHICH THE DATA      *)
   (*   WILL BE SHIFTED                               *)

   WRITE('Lag from 0 to how much:');
   READLN(lagmax);
```

```
(*  READS THE TEMP. INPUT FILE    *)

FOR i:=1 TO datanumber DO
   BEGIN
      READ(fichier,temp[i,1]);
      READ(fichier,temp[i,2]);
   END;

   WRITELN(oput,'delta  r');
WRITELN;
FOR delta:=0 TO lagmax DO
   BEGIN

      (*  CALCULATES THE CORREL. COEFF. BETWEEN              *)
      (*  THE AIR AND WATER TEMPERATURES RECORDS,            *)
      (*  THE WATER TEMPERATURE RECORD BEING SHIFTED         *)
      (*  DOWN BY A NUMBER DELTA OF ROWS.                    *)

      product:=0;
      sumair:=0; sumwat:=0;
      squarewat:=0; squareair:=0;
      last:=datanumber-delta;

      FOR i:=1 TO last DO
         BEGIN
            product:=product+temp[i+delta,1]*temp[i,2];
            sumwat:=sumwat+temp[i+delta,1];
            sumair:=sumair+temp[i,2];
            squarewat:=squarewat+sqr(temp[i+delta,1]);
            squareair:=squareair+sqr(temp[i,2]);
         END;

      correlationcoef:=(product-sumwat*sumair/last)
                       /sqrt((squarewat-sqr(sumwat)/last)
                       *(squareair-sqr(sumair)/last));

      (*   PUTS THE CORREL. COEFF. IN THE OUTPUT FILE   *)

      WRITELN(oput,delta:4,'   ',correlationcoef:4:5);
   END;
CLOSE(oput);

END.
```

```
program RANDOMTEMP;

(*    PROGRAM PICKS AT RANDOM ONE VALUE FROM A WATER        *)
(*    TEMP. RECORD INPUT FILE FOR EACH DAY OF DATA,         *)
(*    DURING A GIVEN PERIOD OF THE DAY.                     *)
(*    CALCULATES ALSO THE ACTUAL DAILY AVERAGE AIR          *)
(*    AND WATER TEMPERATURES.                               *)

VAR
   fichier: TEXT;
   filename: STRING[30];
   temp: ARRAY[1..5000,1..2] OF REAL;
   datanumber, day, i, j: INTEGER;
   dataperday ,starting, ending: INTEGER;
   oput: TEXT;
   oputname: STRING[30];
   wattemp, randtemp, airtemp: REAL;

BEGIN

   (*  ASKS FOR INPUT FILE NAME.                          *)
   (*  THE INPUT FILE NEEDS TO BE ON 2 COLUMNS,           *)
   (*  THE FIRST ONE BEING THE WATER TEMP., THE           *)
   (*  SECOND ONE THE AIR TEMP.                           *)

   WRITE('file name:');
   READLN(filename);
   ASSIGN(fichier,filename);
   RESET(fichier);

   (*  WILL PUT THE TEMPERATURES IN OUTPUT FILE            *)
   (*  ON 3 COLUMS: DAILY AVERAGE WATER TEMP., RANDOM      *)
   (*  WATER TEMP. AND DAILY AVERAGE AIR TEMPERATURE       *)

   WRITE('output file name:');
   READLN(oputname);
   ASSIGN(oput,oputname);
   REWRITE(oput);

   (*  ASKS FOR THE EXACT NUMBER OF PAIRS OF VALUES     *)
   (*  IN THE INPUT RECORD.                             *)

   WRITE('Number of measurements (5000 maximum) :');
   READLN(datanumber);

   WRITE('Number of values per day?');
   READLN(dataperday);

   (*  ASKS FOR THE PERIOD OF THE DAY FOR WHICH          *)
   (*  RANDOM MEASUREMENTS ARE SIMULATED.                *)

   WRITELN('Starting time (in hrs) of random pick');
   WRITE ('for example: 16 for 4 p.m.):');
   READLN(starting);
```

```
   WRITE('Ending time of random pick');
   READLN(ending);

   (*  READS THE TEMP. INPUT FILE    *)

   FOR i:=1 TO datanumber DO
      BEGIN
         READ(fichier,temp[i,1]);
         READ(fichier,temp[i,2]);
      END;


   RANDOMIZE;

   FOR day:=0 TO TRUNC(datanumber/dataperday)-1 DO
      BEGIN
         wattemp:=0;
         airtemp:=0;

         FOR j:=1 TO dataperday DO
            BEGIN
               wattemp:=wattemp+temp[day*dataperday+j,1];
               airtemp:=airtemp+temp[day*dataperday+j,2];
            END;

         (*  CALCULATES DAILY AVERAGE WATER AND AIR TEMP. *)

         wattemp:=wattemp/dataperday;
         airtemp:=airtemp/dataperday;

         (*  PICKS ONE VALUE AT RANDOM PER DAY     *)
         (*  FROM THE WATER TEMPERATURE RECORD.    *)

         j:=1+TRUNC(starting*dataperday/24)
             +RANDOM(1+TRUNC((ending-starting)
                             *dataperday/24));
         randtemp:=temp[day*dataperday+j,1];

         (*  PUTS THE 3 COLUMNS OF RESULT       *)
         (*  IN THE OUTPUT FILE.                *)

         WRITELN(oput,wattemp:4:2,'   ',
                 randtemp:4:2,'   ',airtemp:4:2);
      END;
   CLOSE(oput);

END.
```

APPENDIX A.3 AVERAGE

```
program AVERAGE;

(*   TRANSFORMS HOURLY DATA INTO DAILY DATA          *)
(*   OR DAILY DATA INTO WEEKLY DATA, BY              *)
(*   AVERAGING.                                      *)

VAR
   fichier: TEXT;
   filename: STRING[30];
   temp: ARRAY[1..5000,1..2] OF REAL;
   datanumber, i, j, ratio: INTEGER;
   oput: TEXT;
   oputname: STRING[30];
   value1, value2 : REAL;

BEGIN

    (*   ASKS FOR INPUT FILE NAME.                         *)
    (*   THE INPUT FILE NEEDS TO BE ON 2 COLUMNS,          *)
    (*   THE FIRST ONE BEING THE WATER TEMP.,              *)
    (*   THE SECOND ONE THE AIR TEMPERATURE.               *)

   WRITE('file name:');
   READLN(filename);
   ASSIGN(fichier,filename);
   RESET(fichier);

   (*   WILL PUT THE AVERAGE DATA IN OUTPUT FILE   *)

   WRITE('output file name:');
   READLN(oputname);
   ASSIGN(oput,oputname);
   REWRITE(oput);

   (*   ASKS FOR THE EXACT NUMBER OF PAIRS OF VALUES   *)
   (*   IN THE RECORD.                                 *)

   WRITE('Number of measurements (5000 maximum) :');
   READLN(datanumber);

   (*   ASKS FOR THE NUMBER OF VALUES TO BE AVERAGED   *)
   (*   TO GET 1 VALUE                                 *)

   WRITE('Average out of how many values?');
   READLN(ratio);
```

```
(*   READS THE TEMP. INPUT FILE    *)

FOR i:=1 TO datanumber DO
   BEGIN
      READ(fichier,temp[i,1]);
      READ(fichier,temp[i,2]);
   END;

(*   CALCULATES THE AVERAGE VALUES    *)

FOR i:=0 TO trunc(datanumber/ratio)-1 DO
   BEGIN
      value1:=0; value2:=0;
      FOR j:=1 TO ratio DO
         BEGIN
            value1:=value1+temp[ratio*i+j,1];
            value2:=value2+temp[ratio*i+j,2];
         END;
      value1:=value1/ratio;
      value2:=value2/ratio;

      (*  PUTS THE AVERAGE VALUES IN THE OUTPUT FILE  *)

      WRITELN(oput,value1:4:2,'   ',value2:4:2);
   END;
CLOSE(oput);

END.
```

APPENDIX A.4 MINMAX

```
program MINMAX;

(*   PROGRAM CALCULATES THE MIN. AND MAX. VALUES               *)
(*   FOR EACH DAY OF TEMP. DATA AND PUTS THE AVERAGES          *)
(*   OF THESE 2 VALUES IN THE OUTPUT FILE.                     *)

VAR
   fichier: TEXT;
   filename: STRING[30];
   temp: ARRAY[1..5000,1..2] OF REAL;
   datanumber, i, j, ratio: INTEGER;
   oput: TEXT;
   oputname: STRING[30];
   value1,value2: REAL;
   value1max,value1min,value2max,value2min: REAL;

BEGIN

   (*   ASKS FOR INPUT FILE NAME.                              *)
   (*   THE INPUT FILE NEEDS TO BE ON 2 COLUMNS                *)
   (*   THE FIRST ONE BEING THE WATER TEMP.,  THE              *)
   (*   SECOND ONE THE AIR TEMP.                               *)

   WRITE('file name:');
   READLN(filename);
   ASSIGN(fichier,filename);
   RESET(fichier);

   (*   WILL PUT THE AVERAGE VALUE IN OUTPUT FILE      *)

   WRITE('output file name:');
   READLN(oputname);
   ASSIGN(oput,oputname);
   REWRITE(oput);

   (*   ASKS FOR THE EXACT NUMBER OF PAIRS      *)
   (*   OF VALUES IN THE RECORD.                *)

   WRITE('Number of measurements (5000 maximum) :');
   READLN(datanumber);

   (*   ASKS FOR THE NUMBER OF VALUES PER DAY      *)
   (*   OF THE THE RECORD.                         *)

   WRITE('Average out of how many values?');
   READLN(ratio);
```

```
(*   READS THE TEMP. INPUT FILE   *)

FOR i:=1 TO datanumber DO
   BEGIN
      READ(fichier,temp[i,1]);
      READ(fichier,temp[i,2]);
   END;


FOR i:=0 TO trunc(datanumber/ratio)-1 DO
   BEGIN
      value1max:=0;
      value1min:=1000;
      value2max:=0;
      value2min:=1000;

      (*   CALCULATES FOR EACH  DAY OF DATA THE MAX.    *)
      (*   AND MIN. VALUES OF THE INPUT FILE.           *)

      FOR j:=1 TO ratio DO
         BEGIN
            value1:=temp[ratio*i+j,1];
            value2:=temp[ratio*i+j,2];
            IF value1max<value1 THEN value1max:=value1;
            IF value1min>value1 THEN value1min:=value1;
            IF value2max<value2 THEN value2max:=value2;
            IF value2min>value2 THEN value2min:=value2;
         END;

      (*   CALCULATES THE AVERAGE OF THE DAILY MIN.    *)
      (*   AND MAX. TEMPERATURES.                      *)

      value1:=(value1min+value1max)/2;
      value2:=(value2min+value2max)/2;

      (*   PUTS THE DAILY DATA IN THE OUTPUT FILE    *)
      (*   ON ONE COLUMN.                            *)

      WRITELN(oput,value1:4:2,'   ',value2:4:2);
   END;
CLOSE(oput);

END.
```

APPENDIX B

DAILY WATER AND AIR TEMPERATURE RECORDS

APPENDIX B.1 STRAIGHT RIVER

2-HOURLY WATER (Tw) AND AIR (Ta) TEMPERATURE DATA OBTAINED BY WRITTEN COMMUNICATION FROM STARK (USGS) FOR THE YEAR 1989, AVERAGED INTO DAILY DATA

STATION 05243725 STRAIGHT RIVER NEAR PARK RAPIDS, MN

Lat 465230, Long 950356

Calendar Day	Tw	Ta	Calendar Day	Tw	Ta	Calendar Day	Tw	Ta	Calendar Day	Tw	Ta
111	11.95	11.89	151	17.45	20.98	191	22.97	22.14	231	19.68	20.55
112	11.35	10.62	152	17.19	18.84	192	24.00	24.97	232	18.94	19.48
113	11.87	13.53	153	16.45	16.91	193	24.40	25.54	233	19.09	20.84
114	12.81	11.03	154	15.39	19.96	194	23.94	22.47	234	19.58	23.25
115	10.06	7.40	155	17.42	22.16	195	24.23	27.93	235	20.22	25.83
116	8.19	5.86	156	17.27	19.41	196	25.51	29.29	236	20.08	22.74
117	8.78	6.04	157	12.71	11.92	197	24.36	21.54	237	18.97	17.00
118	7.84	1.94	158	13.68	14.74	198	23.07	21.69	238	19.35	23.47
119	7.97	2.01	159	17.05	18.26	199	24.13	26.75	239	20.71	23.65
120	8.32	5.05	160	16.93	21.00	200	24.08	25.83	240	19.79	22.64
121	9.46	11.72	161	15.78	18.56	201	23.65	22.66	241	18.66	22.45
122	11.69	16.62	162	13.12	13.60	202	21.28	20.39	242	18.60	23.19
123	10.99	13.50	163	14.98	16.60	203	21.53	21.91	243	17.99	20.50
124	7.15	3.45	164	17.32	18.94	204	21.55	23.87	244	17.76	21.94
125	7.61	8.03	165	17.95	20.13	205	21.99	23.98	245	17.10	18.90
126	11.02	13.06	166	19.11	22.90	206	22.16	25.29	246	15.56	17.08
127	11.37	14.02	167	20.72	24.15	207	22.60	26.02	247	15.76	21.35
128	12.23	16.52	168	21.38	26.87	208	22.36	25.34	248	17.42	21.22
129	14.73	18.71	169	21.35	27.93	209	21.93	25.46	249	17.05	19.81
130	15.57	20.44	170	16.42	16.60	210	22.49	27.48	250	15.85	19.76
131	15.50	19.00	171	17.51	19.41	211	23.62	29.67	251	16.56	21.78
132	15.64	19.13	172	16.79	23.12	212	24.66	30.74	252	17.59	22.15
133	17.28	20.57	173	15.10	16.52	213	23.22	22.75	253	17.30	22.74
134	17.15	21.99	174	12.79	13.87	214	21.02	22.49	254	16.41	19.60
135	16.45	21.45	175	15.84	16.20	215	19.86	22.47	255	15.58	17.94
136	15.07	19.96	176	17.47	18.77	216	21.21	23.87	256	14.67	14.73
137	15.19	19.08	177	18.17	20.37	217	22.57	26.97	257	12.40	12.23
138	15.20	17.22	178	19.61	24.93	218	24.16	30.66	258	11.84	11.91
139	16.48	19.42	179	20.71	23.29	219	24.54	30.85	259	12.07	12.99
140	17.17	19.13	180	21.66	29.37	220	25.60	31.03	260	12.23	13.02
141	16.40	18.23	181	21.70	31.12	221	23.67	27.28	261	12.90	14.99
142	13.70	17.07	182	19.54	19.62	222	19.00	18.78	262	13.80	16.73
143	13.48	16.32	183	18.93	18.86	223	16.93	17.92	263	14.73	17.88
144	12.17	11.68	184	19.99	19.09	224	18.16	20.09	264	15.85	21.86
145	14.02	17.18	185	18.78	20.16	225	19.54	21.64	265	17.70	25.80
146	14.51	18.15	186	18.09	18.76	226	20.09	22.99	266	16.64	18.25
147	12.78	14.66	187	18.64	17.38	227	20.98	25.72	267	15.11	19.05
148	12.20	15.48	188	19.76	18.74	228	20.58	23.48	268	14.75	18.24
149	14.13	17.30	189	20.50	20.35	229	21.23	24.11			
150	15.84	19.04	190	21.86	24.19	230	20.57	23.27			

APPENDIX B.2 STRAIGHT RIVER

2-HOURLY WATER (Tw) AND AIR (Ta) TEMPERATURE DATA OBTAINED BY WRITTEN COMMUNICATION FROM STARK (USGS) FOR THE YEAR 1989, AVERAGED INTO DAILY DATA

STATION 05243725 STRAIGHT RIVER AT COUNTY HIGHWAY NEAR PARK RAPIDS, MN

Lat 465245, Long 950612

Calendar Day	Tw	Ta	Calendar Day	Tw	Ta	Calendar Day	Tw	Ta	Calendar Day	Tw	Ta
111	11.51	13.46	151	16.82	15.46	191	22.77	24.40	231	19.01	18.77
112	10.84	12.15	152	16.47	14.85	192	23.68	24.14	232	18.88	17.96
113	11.46	15.31	153	15.65	17.36	193	24.41	26.09	233	19.26	19.28
114	12.31	12.92	154	16.33	18.52	194	24.50	25.36	234	19.90	23.43
115	9.35	8.85	155	18.01	18.46	195	23.85	24.09	235	20.14	22.75
116	8.01	7.39	156	13.35	10.39	196	24.94	30.03	236	19.49	17.67
117	8.56	7.79	157	12.32	11.07	197	25.57	26.56	237	18.14	16.49
118	7.65	3.63	158	16.56	14.27	198	23.69	21.48	238	20.50	20.84
119	7.91	3.66	159	17.31	17.43	199	23.35	25.17	239	19.78	20.91
120	8.17	4.95	160	15.92	18.13	200	24.47	27.58	240	18.49	20.36
121	9.46	8.22	161	13.50	11.34	201	24.07	24.58	241	18.29	22.09
122	11.53	12.89	162	13.68	13.44	202	22.59	21.77	242	17.98	18.43
123	10.58	10.72	163	16.76	15.31	203	21.16	22.06	243	17.53	19.53
124	6.71	-0.11	164	17.38	16.31	204	21.89	22.62	244	17.03	18.05
125	7.89	4.73	165	18.52	19.11	205	22.03	23.27	245	15.64	13.91
126	10.79	9.71	166	20.28	22.51	206	22.40	23.77	246	15.51	18.93
127	10.98	10.89	167	20.70	22.07	207	22.49	23.13	247	17.47	19.62
128	12.18	13.27	168	21.32	26.91	208	22.08	22.48	248	17.08	16.56
129	14.37	15.15	169	17.54	18.89	209	22.01	24.43	249	15.99	16.95
130	15.15	17.91	170	12.88	11.69	210	23.16	27.24	250	16.48	20.04
131	15.16	16.22	171	16.68	14.51	211	24.45	28.52	251	17.49	20.35
132	15.35	15.81	172	17.04	17.50	212	24.27	23.45	252	17.30	20.19
133	16.92	17.20	173	15.78	17.48	213	21.59	20.15	253	16.60	18.98
134	15.82	18.67	174	13.31	11.05	214	20.13	20.86	254	15.76	16.44
135	15.05	17.78	175	14.16	14.04	215	20.57	23.08	255	15.08	13.49
136	14.95	17.49	176	16.78	15.56	216	22.03	23.20	256	12.75	9.47
137	14.57	13.67	177	17.49	16.41	217	23.56	27.89	257	12.13	10.00
138	15.84	15.55	178	18.58	19.32	218	24.45	27.98	258	12.19	11.42
139	17.20	17.39	179	20.38	22.51	219	25.20	30.72	259	12.57	10.02
140	15.80	14.55	180	20.77	22.45	220	24.58	26.98	260	13.12	13.90
141	14.75	15.11	181	21.48	27.60	221	20.46	19.42	261	14.04	15.00
142	12.80	14.16	182	20.74	23.74	222	17.01	16.79	262	15.03	17.39
143	12.47	9.52	183	18.70	20.05	223	17.74	17.91	263	15.95	18.00
144	13.07	11.45	184	19.86	20.96	224	19.29	20.31	264	17.92	24.21
145	14.59	16.33	185	19.54	18.82	225	20.10	20.38	265	17.03	18.59
146	13.47	13.42	186	18.07	19.74	226	20.70	22.19	266	15.06	16.40
147	11.62	12.26	187	18.49	19.27	227	20.99	22.77	267	14.85	17.25
148	13.64	14.10	188	19.37	19.02	228	21.09	22.95	268	12.81	9.67
149	14.93	15.15	189	20.30	18.65	229	20.97	20.76			
150	17.08	18.51	190	21.13	23.12	230	19.62	20.85			

APPENDIX B.3 VERMILLION RIVER

DAILY MEAN WATER TEMPERATURE DATA Tw COMPILED FROM USGS RECORDS (YEARS 1979-1985)
STATION 05345000 VERMILLION RIVER NEAR EMPIRE, MN
Lat 444000, Long 0930317
DAILY MEAN AIR TEMPERATURE DATA Ta COMPILED FROM MINNEAPOLIS/ST. PAUL INTERNATIONAL AIRPORT RECORDS
Lat 445309, Long 931312

Calendar	1979		1980		1981		1982		1983		1984		1985	
Day	Tw	Ta	Tw	Ta	Tw	Ta	Tw	Ta	Tw	Ta	Tw	Ta	Tw	Ta
91	2.90	1.94			8.30	6.94	5.00	4.16					3.00	1.66
92	3.80	1.66	5.20	5.55	9.60	13.80	5.00	10.80			6.70	3.88	5.50	6.11
93	4.10	-0.80	6.10	6.66	10.00	8.88	4.00	1.66			6.30	5.00	7.00	8.33
94	5.00	1.11	4.70	4.44	7.00	1.38	2.00	-5.20			6.50	6.66	7.00	4.44
95	3.90	-4.40	5.30	5.55	7.00	2.77	2.00	-3.80			7.50	6.66	6.00	2.77
96	2.30	-6.10	6.70	7.77	8.50	6.66	2.50	-4.40			8.10	6.66	6.50	5.00
97	3.60	2.50	8.10	12.20	9.50	11.90	3.50	-2.20			7.50	6.11	7.00	3.88
98	4.30	1.94	8.00	9.44	10.00	11.30	3.50	-1.90			7.00	7.77	6.50	0.00
99	4.60	1.66	5.70	2.77	10.00	10.80	4.00	-1.60			6.90	8.88	7.00	1.66
100	5.90	2.50	3.20	-1.10	11.50	14.40	4.50	0.55			7.60	10.00	9.50	11.60
101	5.40	5.83	4.10	-0.20	10.00	9.16	5.00	1.66			7.20	10.50	11.00	11.60
102	6.30	10.20	5.80	1.38	11.00	12.20	6.00	8.05			6.50	8.88	13.00	18.30
103	6.60	5.27	6.30	3.05	11.80	8.61	7.50	9.44			6.90	6.66	11.50	9.44
104	5.80	5.27	5.00	0.55	9.20	3.33	8.50	10.80			6.80	7.22	9.00	7.22
105	7.40	7.77	5.30	3.88	9.80	7.77	9.00	14.40			8.10	8.33	10.50	12.20
106	9.80	9.16	7.70	8.61	9.80	11.30	10.00	11.30			9.30	11.10	10.50	10.00
107	10.60	11.60	8.40	8.88	10.80	13.80	9.50	8.88			9.20	11.10	10.50	17.70
108	11.40	14.70	10.30	13.00	11.00	8.05	8.50	10.80			8.90	8.33	15.00	19.40
109	10.90	13.30	11.30	15.20	11.00	9.44	7.50	5.00			9.70	7.77	17.50	25.00
110	10.80	10.20	12.10	18.30	10.10	5.00	6.00	2.77			10.10	8.33	17.00	21.10
111	10.90	11.10	12.40	17.70	8.30	6.38	7.50	4.72			9.80	10.00	17.00	20.00
112	11.80	13.00	13.80	23.00	9.60	10.00	8.50	7.22			7.20	11.60	16.00	17.70
113	12.80	16.60	14.80	21.90	7.90	5.55	10.00	15.20			7.90	10.00	15.50	12.70
114	13.60	16.10	12.80	11.60	9.60	9.16	11.50	17.50			10.00	11.10	13.50	11.60
115	11.90	11.10	10.80	7.50	10.60	9.44	12.00	16.10			10.10	11.10	12.50	11.10
116	10.60	8.88	10.40	9.44	13.20	14.10	11.00	9.72			12.00	10.00	11.50	8.33
117	10.30	7.77	9.70	11.30	13.90	16.90	10.50	8.88			14.00	17.70	10.50	10.50
118	10.10	5.83	11.10	14.40	11.10	10.50	10.50	10.50			8.70	11.10	12.50	13.30
119	9.10	6.38	11.80	12.20	11.70	11.90	10.50	12.20			7.00	5.55	15.00	17.20
120	8.80	6.94	11.50	13.60	12.00	11.60	10.00	13.60			3.60	3.88	15.50	17.70
121	8.30	6.11	12.60	17.70	12.60	9.44	11.00	13.30			6.30	2.77	14.50	15.50
122	8.90	9.16	13.80	17.50	13.80	14.70	12.00	15.80			9.20	6.11	15.00	15.00
123	9.40	7.22	14.20	18.00	13.30	18.80	13.00	18.80			11.50	7.77	15.50	19.40
124	9.80	6.94	14.50	19.40	12.20	14.10	14.00	23.80			12.50	11.60	16.00	22.20
125	11.10	12.50	14.70	21.60	12.60	13.60	12.50	13.00			12.40	10.50	15.50	16.60
126	12.60	16.60	14.40	17.20	12.80	9.44	9.50	8.61			13.70	11.60	15.00	14.40
127	14.50	16.60	12.40	10.80	12.50	10.00	10.00	10.00			13.40	14.40	16.00	15.50
128	12.60	12.20	9.80	6.38	11.70	13.00	11.00	13.60			13.00	8.33	16.00	18.30
129	10.10	7.50	9.80	10.20	10.10	7.22	12.50	17.20			12.00	6.11	18.50	23.30
130	9.70	8.33	11.80	11.90	11.50	6.11	14.50	23.30			12.50	10.50	19.50	24.40

131	9.30	5.55	11.90	12.50	11.50	8.61	15.00	17.20	13.50	15.00	18.50	20.50
132	10.20	9.44	11.30	9.44	12.50	9.72	12.50	14.70	13.00	15.00	16.50	12.70
133	13.00	12.70	11.80	11.10	13.70	11.30	13.00	19.10	12.50	11.60	13.50	12.70
134	13.70	12.20	11.20	9.72	14.00	12.70	15.00	20.80	12.30	10.50	13.00	16.10
135	13.90	11.60	11.10	10.00	13.90	14.10	15.50	19.40	14.40	11.60	12.50	14.40
136	14.50	16.90	12.10	8.88	12.80	16.90	15.50	20.80	12.90	13.80	12.00	12.20
137	16.40	23.80	12.20	13.60	13.00	13.00	15.50	18.30	13.90	13.30	12.50	14.40
138	17.40	16.90	11.20	12.70	14.00	12.70	15.50	18.00	16.10	20.00	14.50	17.70
139	16.30	14.40	11.20	12.70	15.10	13.00	16.00	17.20	17.10	17.70	16.00	17.20
140	14.40	10.20	13.20	15.50	15.70	16.60	15.50	14.10	16.70	18.30	14.50	12.70
141	13.60	9.44	15.50	18.00	16.00	18.80	13.00	14.10	16.60	16.60	14.00	12.70
142	14.70	15.00	16.10	20.00	15.50	20.20	12.00	16.10	16.30	20.50	14.50	16.60
143	14.60	12.50	16.90	21.90	13.30	19.10	12.50	13.80	15.50	17.20	14.00	15.50
144	15.20	14.40	17.10	21.90	12.80	13.60	13.00	16.10	15.20	15.00	15.00	17.20
145	15.60	12.50	17.20	21.60	13.70	12.70	13.50	16.60	14.70	18.30	16.00	22.20
146	16.00	15.00	17.80	23.80	15.20	15.50	13.00	16.30	13.50	13.80	15.00	15.50
147	15.80	15.50	17.80	24.40	15.20	17.20	13.00	19.10	12.30	11.10	14.50	15.50
148	16.80	18.60	17.50	24.40	16.50	17.50	14.00	20.20	12.70	11.60	14.50	17.70
149	18.60	21.60	18.20	25.20	15.60	19.10	15.50	20.80	13.40	11.10	14.00	18.80
150	19.00	18.30	17.40	21.60	16.30	15.00	16.00	18.60	14.20	11.60	16.00	19.40
151	16.10	13.60	16.30	17.20	16.20	15.80	16.00	14.10	16.00	14.40	16.00	16.10
152	14.90	13.80	16.20	17.70	15.80	21.60	14.50	14.10	17.50	21.60	13.50	13.30
153	15.70	16.60	16.30	18.30	17.00	18.80	13.50	11.30	17.20	22.70	11.00	9.44
154	17.10	21.90	15.10	16.30	18.20	18.30	13.50	13.80	16.70	20.00	13.50	10.50
155	17.90	21.10	13.80	18.60	17.70	17.50	14.00	15.00	15.50	19.40	14.00	15.00
156	18.30	18.60	17.50	21.60	17.80	21.90	13.50	16.90	17.60	18.80	15.00	14.40
157	18.90	27.20	17.00	20.80	17.10	20.00	13.50	17.20	20.20	23.80	16.50	19.40
158	19.40	20.80	18.00	20.80	17.00	23.60	14.50	17.50	19.80	26.60	18.00	23.80
159	16.50	15.80	17.60	17.20	16.50	17.70	15.00	18.00	19.40	23.30	20.50	28.30
160	14.00	15.20	16.40	14.40	15.40	18.00	14.50	16.30	19.10	20.50	19.00	19.40
161	14.60	17.50	16.60	19.70	16.80	19.40	13.50	16.60	18.10	20.00	15.50	15.00
162	16.70	17.70	16.70	15.80	16.30	19.70	14.00	16.30	17.40	16.60	14.00	12.70
163	17.40	19.70	16.60	18.80	16.50	21.10	14.50	16.30	22.30	16.10	15.00	13.30
164	18.20	21.60	16.00	20.80	17.80	23.30	14.50	18.60	24.00	22.70	16.50	15.00
165	20.50	26.30	17.30	22.20	18.40	23.00	14.00	17.70	21.00	20.00	15.50	15.50
166	20.20	25.00	19.10	22.50	17.90	18.30	14.00	18.00	18.00	18.30	16.00	18.30
167	17.70	18.00	17.70	15.50	16.70	17.50	14.50	18.80	16.50	20.50	17.00	20.00
168	16.10	16.10	16.40	15.20	16.80	20.80	15.00	18.80	16.50	18.80	16.50	16.10
169	17.20	18.30	16.80	20.20	16.80	16.90	14.00	15.80	19.10	23.30	16.00	17.20
170	17.90	21.10	17.60	19.10	14.90	15.20	13.50	14.10	18.10	21.10	16.50	16.10
171	18.10	20.00	17.30	16.30	16.00	16.90	13.00	16.60	17.40	19.40	17.00	19.40
172	18.40	20.00	16.80	17.50	14.50	15.00	14.00	16.90	17.40	22.70	18.50	21.10
173	17.10	15.00	17.50	22.70	14.50	15.50	15.00	16.60	17.30	22.70		
174	15.90	14.70	18.60	24.10	14.40	15.50	16.00	21.90	17.30	22.70		
175	17.00	18.60	19.10	24.70	16.50	20.50	15.50	21.60	17.00	20.50		
176	18.30	20.00	18.60	22.70	17.40	19.70	15.00	18.80	17.00	20.00		
177	18.80	21.90	19.20	25.50	18.00	20.50	16.00	17.70	18.20	21.10		
178	19.30	20.50	21.10	26.60	17.80	22.20	17.50	23.30	17.40	25.50		
179	18.10	20.20	18.70	19.10	17.60	23.00	18.00	23.60	17.10	22.20		
180	18.60	21.30	17.80	20.50	19.00	20.80	16.50	19.10	16.40	21.10		
181	19.50	22.20	16.80	15.80	19.30	20.50	16.00	19.10	16.50	20.00		
182	19.70	22.70	16.70	18.60	19.50	20.50	16.00	20.00	16.70	20.50		
183	20.00	24.10	18.90	21.30	19.60	20.80	16.00	21.60	17.90	21.60		
184	19.60	21.60	18.60	18.60	19.40	23.00	17.00	26.30	18.00	26.10		
185	19.40	21.30	18.70	21.30	19.50	23.60	18.50	27.50	17.90	25.00		

186	19.10	19.70	19.40	24.40	20.40	23.00	20.00	31.60	17.50	23.30
187	18.20	19.40	20.10	21.90	21.10	24.70	17.50	24.70	16.20	21.60
188	18.10	21.30	20.20	23.00	21.80	26.60	18.00	21.30	14.50	17.20
189	18.30	22.70	21.90	29.40	22.40	24.70	17.50	21.30	16.50	16.60
190	19.70	24.70	20.80	22.70	20.80	19.70	18.00	25.00	15.00	21.10
191	20.70	25.80	20.90	25.50	20.20	22.70	16.50	18.60	16.50	24.40
192	20.80	25.20	21.70	28.00	20.60	24.40	16.00	22.20	18.90	20.50
193	21.20	26.60	22.30	30.00	21.50	23.80	18.00	23.60	21.80	21.60
194	20.60	24.70	22.50	26.90	20.30	25.00	18.50	23.80	26.30	25.00
195	21.90	24.40	21.20	26.10	19.30	20.50	19.00	26.10	25.70	26.60
196	21.80	23.30	22.50	31.60	17.90	17.70	18.00	24.10	22.20	23.80
197	19.90	18.60	22.00	26.90	18.40	20.00	19.00	26.60	20.10	21.10
198	18.70	19.40	22.00	23.80	20.30	23.80	20.50	25.20		
199	19.00	21.10	21.20	24.40	20.80	22.50	19.50	23.60		
200	19.40	22.50	21.30	24.10	21.00	24.10	18.00	23.60		
201	20.00	24.10	20.60	24.40	20.60	23.00	19.30	26.10		
202	20.50	24.40	19.40	22.50	19.10	18.60	18.60	24.70		
203	21.40	26.90	19.70	22.20	18.30	19.10	19.10	25.80		
204	20.30	23.80	19.60	19.70	18.40	21.10	19.80	25.00		
205	20.30	25.20	19.40	20.50	18.40	21.10	19.40	26.30		
206	21.60	25.20	20.50	24.40	18.60	19.40	19.40	25.80		
207	20.60	22.50	20.80	23.60	17.70	18.00	18.60	22.20		
208	19.60	21.90	20.00	19.70	16.40	15.20	18.70	23.60		
209	19.30	20.50	19.60	20.80	17.30	16.60	19.00	23.60		
210	19.20	23.30	19.70	23.80	17.90	16.90	19.00	24.10		
211	20.50	25.20	20.10	21.60	19.40	23.00	18.50	22.50		
212	20.00	22.70	20.60	25.50	20.40	24.10	18.30	23.30		
213	20.00	23.60	21.00	23.30	20.00	21.10	19.20	25.20		
214	20.70	24.10	21.00	24.10	19.80	23.00	20.20	26.10		
215	20.80	23.60	20.90	23.00	20.30	23.60	21.10	30.00		
216	21.90	25.20	20.50	21.60	21.00	23.30	20.50	28.30		
217	22.30	25.00	20.00	21.60	20.50	22.70	20.10	27.70		
218	23.20	27.20	19.90	22.20	20.50	21.30	19.60	24.70		
219	24.70	27.20	21.00	23.80	20.50	20.20	19.40	25.50		
220	22.50	22.50	21.30	25.50	20.50	20.00	18.40	21.30		
221	20.60	21.90	20.60	23.00	20.50	19.40	15.70	17.50		
222	20.20	19.40	18.90	19.10	20.00	17.70	15.20	16.60		
223	19.60	18.30	18.10	21.60	20.10	20.80	16.40	18.00		
224	18.80	18.80	18.60	21.10	20.60	24.40	16.10	18.30		
225	19.20	18.00	18.80	19.70	20.50	24.10	16.00	19.70		
226	18.60	16.10	18.60	21.30	20.00	21.60	15.40	23.30		
227	17.80	14.70	18.60	20.00	19.50	20.50	17.00	23.60		
228	16.60	14.70	18.80	20.20	18.00	17.20	18.50	25.00		
229	17.90	21.90	16.60	16.10	17.50	15.80	18.90	25.20		
230	19.90	22.50	16.30	19.40	17.50	16.60	19.50	25.80		
231	19.60	20.50	18.30	21.30	17.50	17.70	19.60	26.90		
232	19.60	21.60	20.00	25.00	17.50	18.30	19.00	22.70		
233	19.70	21.60	20.40	24.40	17.50	20.20	18.20	21.90		
234	20.00	22.70	19.60	21.30	17.50	22.20	18.40	21.30		
235	20.00	17.70	19.00	20.50	18.50	23.80	18.00	21.30		
236	18.60	15.00	18.80	23.00	19.00	23.00	16.50	19.70		
237	18.20	17.70	18.80	23.80	17.50	21.10	16.50	20.20		
238	18.30	18.00	20.00	26.30	17.50	20.20	17.00	20.00		
239	18.90	19.40	18.60	18.60	17.00	19.70	16.00	14.10		
240	18.40	18.80	16.90	17.20	16.00	18.30	15.00	16.60		

241	19.80	22.50	17.40	20.00	16.50	19.70	15.00	18.00		
242	21.60	22.50	19.30	25.20	17.00	21.10	15.50	18.80		
243			19.40	19.40	18.50	22.70	15.50	19.70		
244			16.60	14.70	17.20	15.50	16.50	22.70		
245			17.20	18.80	15.90	15.50	16.80	18.00		
246			17.50	18.00	15.80	16.60	15.90	16.90		
247			18.60	24.40	16.00	15.80	15.90	19.70		
248			18.60	18.30	15.10	16.60	16.40	18.00		
249			17.60	18.60	15.70	20.00	15.30	15.20		
250			17.40	19.10	17.00	18.60	14.60	15.50		
251			19.20	22.70	16.10	18.00	15.10	19.40		
252			19.80	26.60	16.30	20.50	16.60	23.30		
253			18.40	16.10	17.40	22.20	17.70	23.60		
254			16.30	15.20	17.70	21.30	18.20	24.70		
255			14.80	13.00	16.80	18.80	18.10	20.80	15.10	14.40
256			15.00	17.50	16.50	21.60	15.70	14.70	14.00	13.60
257			16.20	17.50	16.50	16.90	13.60	12.50	13.10	13.00
258			14.90	13.80	15.20	13.80	12.50	10.80	12.60	12.20
259			15.00	17.50	13.70	11.10	12.50	11.90	12.80	14.10
260			14.60	10.50	12.90	10.20	13.50	15.00	13.50	15.00
261			12.90	9.72	12.70	13.30	13.30	13.30	14.90	14.70
262			13.20	11.90	13.80	15.20	13.10	13.00	12.60	10.80
263			14.30	17.70	13.90	13.80	12.20	9.44	11.10	8.88
264			15.10	15.20	14.10	14.40	11.70	10.00	10.00	8.05
265			14.50	13.60	13.00	11.90	12.20	12.70	9.70	6.11
266			14.50	11.30	11.80	10.20	13.60	18.00	9.90	7.22
267			12.80	7.77	12.70	16.10	13.40	12.20	11.40	14.40
268			13.40	14.70	13.90	16.90	12.10	10.80	13.30	16.60
269			13.00	7.77	14.20	16.60	12.20	12.70	14.40	19.70
270			11.50	6.94	12.30	9.44	12.60	13.00	15.50	21.30
271			12.30	10.80	11.50	8.61	13.60	18.30	16.20	21.60
272			12.60	11.90	12.60	14.40	15.20	20.50	15.90	18.00
273			13.60	14.70	13.10	11.30	14.90	13.80	16.30	21.30
274			14.30	15.20	10.80	5.00	13.50	12.50	16.50	20.50
275			14.30	14.10	9.90	6.66	13.10	11.30	16.70	20.20
276			11.90	8.33	9.60	7.77	12.40	13.00	16.00	13.60
277			11.20	5.55	10.40	10.80	11.70	16.10	13.70	12.70
278			11.20	6.94	11.50	12.20			13.40	12.50
279			10.80	8.33	11.30	8.05			12.10	8.61
280			12.40	13.80	10.50	7.77			12.10	11.60
281			13.30	18.60	10.70	11.10			12.00	7.77
282			13.70	15.80	10.30	8.33			10.70	7.50
283			13.20	15.00	11.10	12.20			10.70	10.00
284			12.80	11.10	11.10	10.50			11.60	8.61
285			10.30	5.00	11.80	14.40			9.40	2.22
286			9.80	2.50	12.30	15.80			8.30	2.77
287			9.70	4.72	13.10	13.30			8.50	6.94
288			9.80	5.83	12.10	9.72			8.50	9.44
289			10.50	8.61	11.00	10.50			9.00	9.16
290			11.10	12.70	11.60	11.10			8.50	6.66
291			10.70	9.72	9.50	3.61			9.00	10.50
292			9.20	3.33	8.30	7.50			7.00	8.61
293			9.10	5.55	9.60	7.77			7.30	8.05
294			11.00	10.20	9.00	2.50			7.50	8.05
295			10.90	6.94	7.50	0.27			7.90	9.16

296	9.40	4.44	5.80	-2.70	6.70	4.72
297	9.80	7.22	5.00	-1.60	7.70	6.94
298	9.30	3.61	6.40	1.11	8.40	6.11
299	7.60	1.38	6.40	3.05	8.60	9.44
300	7.60	0.55	7.70	8.88	9.30	12.50
301	7.80	0.55	8.50	9.16	10.00	7.50
302	7.60	-0.20	9.40	12.50	8.10	4.16
303	7.40	0.00	10.40	14.40	7.50	6.94
304	8.30	7.77	10.60	9.72	8.40	8.05
305	8.70	6.94				

APPENDIX B.4 ROSEAU RIVER

DAILY MEAN WATER TEMPERATURE DATA Tw COMPILED FROM USGS RECORDS (YEARS 1975-1983)
STATION 05112000 ROSEAU RIVER BELOW STATE DITCH 51 NEAR CARIBOU, MN
Lat 485854, Long 962746
DAILY MEAN AIR TEMPERATURE DATA Ta COMPILED FROM THE U.S. NATIONAL WEATHER SERVICE
AT INTERNATIONAL FALLS, MN (AVERAGE OF DAILY MIN. AND MAX. AIR TEMPERATURES)
Lat 483500, Long 932410

Calendar	1981		1982		1983	
Day	Tw	Ta	Tw	Ta	Tw	Ta
91	1.50	1.94				
92	3.50	8.05				
93	4.50	3.33				
94	4.50	1.38				
95	5.00	1.11				
96	5.50	5.00			0.40	2.50
97	6.50	7.77			1.40	2.77
98	7.00	4.72			2.00	2.50
99	7.50	7.22			3.20	1.38
100	9.00	7.77			3.90	5.55
101	6.50	0.83	0.50	-2.50	4.50	5.55
102	5.50	4.44	1.00	2.50	4.80	3.33
103	6.50	1.94	1.00	4.72	3.80	0.83
104	5.50	-3.60	1.00	7.22	3.10	-3.30
105	7.00	7.22	1.50	12.20	2.80	-1.90
106	10.50	13.30	5.00	6.66	3.20	-3.60
107	10.00	4.72	6.00	1.38	4.00	-2.50
108	7.50	5.00	7.00	3.33	4.50	0.83
109	8.50	3.05	6.50	1.38	4.70	2.77
110	9.00	2.22	5.50	0.00	6.00	6.11
111	8.00	2.50	5.50	4.16	7.60	10.00
112	7.00	5.55	7.00	7.77	8.60	5.83
113	6.50	3.61	9.00	15.50	9.30	5.83
114	8.00	2.77	11.00	19.40	10.30	10.00
115	9.00	4.44	11.00	8.05	10.90	12.70
116	10.50	10.00	9.00	4.44	11.20	12.70
117	12.50	6.66	9.50	7.50	9.80	3.88
118	13.00	10.20	10.00	11.30	8.20	1.94
119	14.00	9.72	10.50	10.80	6.70	0.55
120	13.00	5.27	10.50	12.70	7.00	3.33
121	12.00	6.11	12.00	10.50	8.30	6.94
122	13.00	9.44	14.00	16.10	9.60	9.72
123	14.00	14.10	15.50	17.70	10.70	8.88
124	13.50	10.00	16.50	16.60	10.30	4.16
125	13.00	7.77	14.00	10.00	10.90	6.66
126	14.00	7.77	12.50	10.50	11.80	8.33
127	15.00	10.50	10.00	5.27	11.70	6.66
128	14.00	9.16	10.00	5.00	12.00	7.22
129	12.00	1.94	10.50	12.70	11.80	10.00

130	11.00	3.33	9.50	15.20	11.30	16.10
131	12.50	8.05	10.00	10.00	10.60	12.20
132	14.50	9.72	11.50	10.50	9.10	15.00
133	15.50	13.00	11.50	10.50	8.60	8.05
134	16.50	12.70	12.00	12.20	7.50	2.50
135	17.50	13.30	12.50	17.20	7.90	2.50
136	16.00	10.20	13.00	11.90	8.60	3.05
137	16.00	11.60	13.00	15.50	9.60	8.61
138	17.00	10.80	14.00	14.70	10.50	13.80
139	18.50	14.40	14.00	9.16	12.00	11.90
140	19.30	18.00	14.00	10.50	12.00	10.50
141	19.50	19.10	15.00	10.80	13.00	13.30
142	20.50	19.70	15.50	13.30	13.50	7.77
143	19.30	18.00	16.50	14.10	14.50	10.20
144	16.90	15.20	17.50	15.80	15.00	6.66
145	14.70	11.90	18.50	16.30	14.50	5.83
146	14.60	13.30	19.00	17.70	15.00	9.72
147	15.90	13.00	20.50	18.00	15.50	15.50
148	16.80	16.60	22.00	18.60	16.00	13.60
149	17.00	15.20	22.00	16.60	15.00	10.50
150	16.10	9.72	20.00	13.60	14.00	12.70
151	17.20	12.20	17.50	12.20	14.50	13.00
152	17.10	13.00	15.00	7.50	15.00	10.50
153	16.10	13.30	15.00	7.50	15.50	15.00
154	17.30	18.60	16.50	11.30	16.50	13.80
155	18.40	18.80	16.50	16.10	16.00	12.20
156	18.70	18.60	16.50	16.90	14.50	11.30
157	19.30	17.50	16.00	16.60	15.00	12.20
158	20.50	18.00	15.00	12.50	15.50	9.16
159	19.60	15.80	13.50	11.60	16.50	13.00
160	19.00	15.50	13.00	12.50	16.50	11.30
161	19.20	13.80	13.50	12.70		
162	19.40	16.10	16.00	14.10		
163	20.50	15.80	16.50	12.20		
164	20.20	17.20	16.50	17.20		
165	18.80	19.10	18.00	17.20		
166	18.20	16.90	18.50	11.30		
167	17.90	16.10	18.50	12.50		
168	18.00	18.30	18.50	12.20		
169	15.90	11.90	18.00	12.50		
170	16.30	12.70	17.00	10.20		
171	17.60	15.80	16.50	13.00		
172	17.90	14.70	17.50	12.70		
173	17.80	15.80	18.50	14.40		
174	17.80	12.20	20.00	17.20		
175	17.90	17.20	20.00	13.30		
176	18.70	15.50	18.50	12.50		
177	19.40	18.30	20.00	15.80		
178	19.70	17.70	21.50	17.70		
179	20.00	20.50	21.00	13.00		
180	20.60	17.50	19.50	13.80		
181	20.20	17.70	20.00	14.10		
182	20.50	20.00	21.00	16.30		
183	21.20	19.70	21.00	18.80		
184	21.70	22.50	21.50	19.40		

185	22.80	21.90	22.50	21.90		
186	23.80	23.30	21.50	23.60		
187	24.80	26.90	21.50	23.60		
188	25.50	27.20	21.50	16.30		
189	24.90	23.00	20.50	18.30		
190	23.60	21.10	20.70	15.20		
191	23.50	22.20	20.80	18.60		
192	23.10	22.70	21.60	20.00		
193	24.40	24.40	22.80	20.20		
194	25.10	22.20	22.50	18.30		
195	24.60	22.20	21.60	21.30		
196	22.60	18.00	22.50	21.60		
197	22.30	19.10	23.00	23.00		
198	23.40	20.80	22.70	21.10		
199	24.20	20.50	20.80	15.80		
200	25.30	21.10	21.50	15.20		
201	24.00	19.70	23.00	21.90		
202	22.50	16.60	24.20	20.00		
203	22.50	15.80	23.30	19.10		
204	22.00	15.20	22.90	21.30		
205			24.00	21.60		
206			23.80	19.40		
207			23.80	18.80		
208			23.90	18.00		
209			23.40	19.40		
210			21.60	17.70		
211			21.90	19.70		
212			22.00	20.80		
213			21.30	16.90		
214			21.20	18.00		
215			21.20	20.50	26.00	22.20
216			21.20	21.10	28.00	23.60
217			21.20	21.90	28.50	25.50
218			21.20	19.70	26.50	20.80
219			21.20	21.90	26.50	26.30
220			21.20	15.00	25.50	19.70
221			21.20	13.00	24.00	18.80
222			21.20	11.30	23.50	19.40
223			21.20	13.30	23.50	18.00
224			21.20	16.10	24.00	19.10
225			21.20	19.70	24.50	21.90
226			21.20	19.70	23.50	19.10
227			21.20	22.70	24.50	21.90
228			21.30	18.80	22.00	15.80
229			21.40	17.70	21.50	21.10
230					23.50	25.00
231					23.50	17.50
232					20.00	13.80
233					19.50	14.70
234					20.00	16.10
235					21.00	19.70
236					22.00	20.50
237					23.50	25.00
238					24.00	21.90
239					24.00	21.90

240	23.50	20.80
241	23.00	19.70
242	22.50	18.60
243	22.50	19.70
244	24.00	24.10
245	24.50	23.60
246	23.50	20.50
247	21.50	16.60
248	20.50	18.80
249	17.50	13.30
250	17.00	14.10
251	18.00	20.50
252	17.00	17.70
253	17.00	13.80
254	14.00	10.80
255	13.50	10.00
256	12.50	8.88
257	12.00	7.77
258	12.50	9.72
259	12.00	10.50
260	12.00	11.30
261	11.00	9.44
262	9.50	7.50
263	8.50	5.83
264	8.00	5.27
265	7.00	3.05
266	6.50	5.55
267	9.00	11.90
268	11.50	13.60
269	12.50	13.80
270	13.50	16.30
271	15.00	17.20
272	12.50	9.72
273	10.50	12.70
274	11.10	12.50
275	10.80	8.33
276	10.90	8.61
277	10.90	7.22

APPENDIX B.5 MINNESOTA RIVER

DAILY MEAN WATER TEMPERATURE DATA Tw COMPILED FROM USGS RECORDS (YEARS 1972-1985)
STATION 05330000 MINNESOTA RIVER NEAR JORDAN, MN
Lat 444135, Long 093830
DAILY MEAN AIR TEMPERATURE DATA Ta COMPILED FROM MINNEAPOLIS/ST. PAUL INTERNATION
Lat 445309, Long 931312

Calendar	1979		1981		1983		1984		1985	
Day	Tw	Ta	Tw	Ta	Tw	Ta	Tw	Ta	Tw	Ta
91	1.40	1.94	10.00	6.94	3.60	5.27			2.75	1.66
92	1.95	1.66	14.40	13.80	4.35	5.83			3.50	6.11
93	2.25	-0.80	13.00	8.88	4.85	3.61			4.75	8.33
94	2.80	1.11	10.00	1.38	4.95	4.16			6.00	4.44
95	2.65	-4.40	9.55	2.77	5.05	4.16			6.25	2.77
96	1.95	-6.10	10.20	6.66	4.70	1.66			6.50	5.00
97	2.50	2.50	10.80	11.90	4.25	1.38	7.15	6.11	6.75	3.88
98	2.95	1.94	11.50	11.30	4.45	3.88	7.55	7.77	6.50	0.00
99	3.25	1.66	11.30	10.80	4.70	3.05	7.70	8.88	6.00	1.66
100	3.75	2.50	11.90	14.40	4.40	5.00	7.65	10.00	7.00	11.60
101	3.80	5.83	11.30	9.16	5.00	6.94	7.80	10.50	7.75	11.60
102	4.40	10.20	11.50	12.20	5.55	4.44	7.95	8.88	9.50	18.30
103	5.20	5.27	11.60	8.61	5.10	4.16	6.85	6.66	10.70	9.44
104	5.30	5.27	11.00	3.33	4.70	0.27	6.05	7.22	10.70	7.22
105	5.75	7.77	11.10	7.77	3.70	0.55	6.15	8.33	11.00	12.20
106	6.85	9.16	11.10	11.30	4.30	0.00	6.60	11.10	10.70	10.00
107	8.00	11.60	11.50	13.80	4.40	-1.90	7.50	11.10	11.20	17.70
108	9.40	14.70	11.60	8.05	4.65	-0.50	8.05	8.33	12.70	19.40
109	10.30	13.30	12.20	9.44	5.25	0.83	8.40	7.77	14.50	25.00
110	10.70	10.20	12.10	5.00	6.00	4.72	9.05	8.33	16.20	21.10
111	11.00	11.10	11.60	6.38	7.00	8.05	9.80	10.00	17.20	20.00
112	11.50	13.00	10.60	10.00	8.20	12.20	10.10	11.60	17.70	17.70
113	12.30	16.60	9.95	5.55	9.30	9.72	9.30	10.00	16.50	12.70
114	12.50	16.10	10.80	9.16	10.40	9.72	8.75	11.10	14.50	11.60
115	13.10	11.10	11.80	9.44	11.60	13.80	9.25	11.10	13.50	11.10
116	12.60	8.88	13.70	14.10	12.50	16.90	9.70	10.00	12.50	8.33
117	12.50	7.77	15.80	16.90	12.80	11.90	10.60	17.70	11.70	10.50
118	12.20	5.83	16.00	10.50	13.00	11.90	10.40	11.10	12.20	13.30
119	12.00	6.38	16.00	11.90	12.80	7.50	8.25	5.55	13.70	17.20
120	11.40	6.94	16.50	11.60	13.10	11.10	10.20	3.88	14.50	17.70
121	10.90	6.11	16.50	9.44	13.50	10.80	8.75	2.77	15.00	15.50
122	10.50	9.16	16.40	14.70	12.70	11.10	8.00	6.11	15.70	15.00
123	10.40	7.22	16.50	18.80	13.00	12.20	8.25	7.77	16.70	19.40
124	10.60	6.94	15.70	14.10	13.20	9.16	9.95	11.60	17.00	22.20
125	11.00	12.50	15.70	13.60	13.40	13.80	10.50	10.50	17.20	16.60
126	12.00	16.60	15.70	9.44	14.00	11.60	11.10	11.60	17.20	14.40
127	13.70	16.60	14.50	10.00	13.70	10.20	12.10	14.40	17.20	15.50
128	14.60	12.20	14.50	13.00	13.60	8.61	12.20	8.33	17.70	18.30
129	14.30	7.50	13.50	7.22	13.90	10.80	11.60	6.11	18.50	23.30
130	13.40	8.33	12.50	6.11	14.40	16.30	11.70	10.50	19.50	24.40

131	12.30	5.55	12.20	8.61	15.20	17.70	11.80	15.00	20.20	20.50
132	11.30	9.44	12.20	9.72	16.10	16.30	12.80	15.00	20.00	12.70
133	11.60	12.70	12.50	11.30	16.20	11.90	13.20	11.60	19.20	12.70
134	12.60	12.20	14.20	12.70	15.80	9.44	13.50	10.50	18.50	16.10
135	13.60	11.60	15.20	14.10	14.80	8.61	14.00	11.60	17.50	14.40
136	15.00	16.90	16.50	16.90	14.80	10.00	14.90	13.80	16.50	12.20
137	16.50	23.80	16.10	13.00	14.90	12.50	15.00	13.30	16.00	14.40
138	17.80	16.90	16.10	12.70	14.50	11.30	15.30	20.00	16.20	17.70
139	18.20	14.40	16.70	13.00	14.00	11.30	16.10	17.70	17.20	17.20
140	18.60	10.20	17.80	16.60	13.60	12.70	17.00	18.30	17.70	12.70
141	17.50	9.44	18.40	18.80	14.10	14.10	17.70	16.60	18.00	12.70
142	18.20	15.00	18.90	20.20	15.10	14.70	18.20	20.50	18.50	16.60
143	18.10	12.50	19.20	19.10	15.60	13.60	18.30	17.20	19.20	15.50
144	18.60	14.40	18.30	13.60	16.50	17.50	18.20	15.00	20.00	17.20
145	18.90	12.50	17.00	12.70	16.90	11.30	18.00	18.30	20.50	22.20
146	19.10	15.00	16.70	15.50	17.10	12.70	17.50	13.80	20.70	15.50
147	19.50	15.50	17.50	17.20	17.50	17.20	17.00	11.10	20.70	15.50
148	20.40	18.60	18.40	17.50	17.70	13.80	16.20	11.60	21.20	17.70
149	21.20	21.60	19.60	19.10	17.40	11.10	15.60	11.10	21.20	18.80
150	21.70	18.30	20.00	15.00	16.70	11.60	15.30	11.60	21.20	19.40
151	20.60	13.60	20.30	15.80	16.10	14.10	15.60	14.40	21.20	16.10
152	19.40	13.80	20.50	21.60	16.20	14.70	15.70	21.60	20.70	13.30
153	18.90	16.60	20.50	18.80	16.90	16.30	17.10	22.70	19.20	9.44
154	19.30	21.90	20.50	18.30	17.70	16.60	17.80	20.00	19.20	10.50
155	20.00	21.10	21.10	17.50	18.00	15.20	18.60	19.40	18.20	15.00
156	20.40	18.60	22.40	21.90	18.10	13.80	18.80	18.80	18.20	14.40
157	21.20	27.20	22.90	20.00	17.90	13.80	19.10	23.80	18.70	19.40
158	20.50	20.80	23.50	23.60	18.30	17.20	19.80	26.60	19.50	23.80
159	20.20	15.80	22.70	17.70	18.80	19.10	20.60	23.30	21.20	28.30
160	19.80	15.20	21.50	18.00	19.60	18.30	20.80	20.50	22.00	19.40
161	20.30	17.50	20.90	19.40	20.60	23.30	20.50	20.00	21.50	15.00
162	20.90	17.70	20.20	19.70	21.70	24.40	20.00	16.60	20.50	12.70
163	21.50	19.70	19.20	21.10	22.20	25.20	19.00	16.10	20.00	13.30
164	21.00	21.60	19.70	23.30	22.20	23.30	18.20	22.70	20.70	15.00
165	20.50	26.30	19.70	23.00	21.80	18.80	18.50	20.00	20.20	15.50
166	19.70	25.00	19.50	18.30	21.20	17.20	18.80	18.30	20.00	18.30
167	19.00	18.00	18.70	17.50	20.50	15.00	18.90	20.50	20.20	20.00
168	18.70	16.10	19.00	20.80	20.00	15.20	19.20	18.80	20.70	16.10
169	19.00	18.30	20.00	16.90	19.90	17.70	19.50	23.30	20.20	17.20
170	19.70	21.10	21.20	15.20	19.90	21.90	20.30	21.10	20.50	16.10
171	20.20	20.00	22.00	16.90	20.50	22.70	20.60	19.40	20.70	19.40
172	20.20	20.00	20.50	15.00	21.20	23.80	20.90	22.70	21.50	21.10
173	20.20	15.00	21.90	15.50	22.20	25.80	21.00	22.70	21.70	21.10
174	20.00	14.70	21.00	15.50	23.80	23.00	20.70	22.70	22.00	17.70
175	20.20	18.60	21.00	20.50	24.10	23.60	20.70	20.50	22.20	18.80
176	21.00	20.00	21.70	19.70	24.40	25.80	20.40	20.00	23.50	26.60
177	21.50	21.90	20.10	20.50	25.00	26.60	20.60	21.10	24.70	23.30
178	22.50	20.50	21.00	22.20	24.60	19.10	21.20	25.50	23.70	17.20
179	22.70	20.20	21.30	23.00	23.40	18.00	21.10	22.20	22.20	16.60
180	23.00	21.30	21.80	20.80	22.00	18.00	21.30	21.10	22.70	18.30
181	23.50	22.20	22.50	20.50	21.40	24.40	21.40	20.00	22.00	21.10
182	23.70	22.70	23.10	20.50	21.60	23.60	21.70	20.50	22.00	23.30
183	24.20	24.10	23.80	20.80	22.30	24.40	21.90	21.60	22.20	22.70
184	24.00	21.60	24.30	23.00	23.20	23.00	22.30	26.10	23.00	23.30
185	25.00	21.30	25.60	23.60	22.80	19.40	22.80	25.00	24.00	22.70

186	25.00	19.70	25.70	23.00	22.60	17.20	23.00	23.30	24.20	23.80
187	24.90	19.40	26.80	24.70	22.60	20.20	22.90	21.60	24.70	25.50
188	24.60	21.30	27.20	26.60	23.20	25.20	22.30	17.20	26.20	30.00
189	24.10	22.70	28.00	24.70	24.10	28.30	21.30	16.60		
190	24.10	24.70	26.70	19.70	25.20	28.00	21.10	21.10		
191	24.60	25.80	26.90	22.70	26.20	27.50	21.00	24.40		
192	25.00	25.20	26.40	24.40	26.60	23.30	21.10	20.50		
193	25.60	26.60	26.50	23.80	26.50	23.60	21.00	21.60		
194	25.40	24.70	26.30	25.00	26.60	27.50	22.00	25.00		
195	25.80	24.40	26.40	20.50	26.70	29.70	22.80	26.60		
196	26.00	23.30	25.90	17.70	26.90	27.70	23.10	23.80		
197	24.00	18.60	26.20	20.00	26.70	25.80	22.80	21.10		
198	25.10	19.40	27.10	23.80	26.80	25.00	22.40	21.10		
199	25.00	21.10	27.10	22.50	26.20	23.60	21.70	18.80		
200	24.90	22.50	27.40	24.10	26.50	26.90	21.40	18.80		
201	25.00	24.10	27.10	23.00	26.70	25.50	21.40	22.70		
202	25.20	24.40	25.90	18.60	28.10	30.50	21.80	23.30		
203	25.50	26.90	25.00	19.10	29.00	27.70	22.40	24.40		
204	25.60	23.80	24.40	21.10	29.20	25.80	23.10	30.00		
205	25.30	25.20	24.10	21.10	28.70	22.70	23.70	22.70		
206	25.80	25.20	23.00	19.40	27.90	22.70	23.70	23.80		
207	25.70	22.50	22.50	18.00	27.10	24.10	23.80	23.80		
208	25.20	21.90	21.80	15.20	26.40	23.60	23.30	21.60		
209	24.90	20.50	21.00	16.60	25.70	25.20	22.90	20.50		
210	24.50	23.30	20.60	16.90	26.20	28.30	22.80	20.00		
211	24.30	25.20	22.00	23.00	26.60	26.90	22.70	21.60		
212	24.20	22.70	22.70	24.10	26.50	24.10	22.70	22.70		
213	23.70	23.60	23.20	21.10	26.50	23.00	22.70	24.40		
214	24.10	24.10	23.80	23.00	26.60	25.50	22.80	25.50		
215	25.00	23.60	24.90	23.60	27.40	28.80	23.10	25.00		
216	25.00	25.20	25.90	23.30	28.00	26.30	23.30	25.00		
217	25.50	25.00	26.60	22.70	28.20	25.50	23.40	25.50		
218	25.70	27.20	26.00	21.30	28.50	28.60	23.90	26.60		
219	25.50	27.20	25.20	20.20	28.60	27.20	24.40	27.70		
220	24.70	22.50	24.70	20.00	28.50	25.50	24.40	25.50		
221	24.20	21.90	23.70	19.40	27.60	22.20	24.20	25.00		
222	23.50	19.40	23.80	17.70	26.80	25.50	24.00	21.10		
223	22.20	18.30	24.40	20.80	26.00	21.10	23.30	21.60		
224	21.70	18.80	24.80	24.40	24.80	21.10	23.20	20.50		
225	22.20	18.00	25.90	24.10	24.80	23.30	23.20	23.30		
226	20.00	16.10	25.40	21.60	25.10	24.40	23.60	25.50		
227	19.70	14.70	24.40	20.50	25.70	26.30	24.00	25.00		
228	19.70	14.70	23.30	17.20	26.00	27.20	24.40	26.60		
229	19.00	21.90	22.80	15.80	25.80	23.80	24.10	24.40		
230	19.70	22.50	21.20	16.60	25.60	25.20	24.10	25.00		
231	20.20	20.50	21.20	17.70	26.20	25.80	23.80	23.80		
232	20.70	21.60	23.50	18.30	25.80	22.50	23.40	22.20		
233	21.20	21.60	23.60	20.20	25.30	22.70	22.80	21.60		
234	21.50	22.70	23.70	22.20	25.30	22.70	22.20	23.30		
235	20.70	17.70	23.80	23.80	24.80	22.20	21.70	16.10		
236	20.20	15.00	24.10	23.00	24.70	23.80	20.30	16.60		
237	20.00	17.70	23.80	21.10	24.30	25.80	19.90	18.30		
238	20.50	18.00	22.20	20.20	24.80	26.90	19.60	21.60		
239	20.00	19.40	20.80	19.70	26.20	27.20	19.80	24.40		
240	20.00	18.80	20.20	18.30	26.30	26.10	21.10	26.60		

241	20.00	22.50	20.00	19.70	26.40	26.60	24.80	27.20
242	22.70	22.50	20.50	21.10	25.60	24.40	25.10	21.60
243	22.20	27.50	21.20	22.70	25.00	21.60	22.20	16.60
244	21.70	24.10	20.90	15.50	25.00	23.30	21.10	17.20
245	23.20	19.10	20.50	15.50	25.50	26.90	19.70	17.70
246	23.20	17.70	20.30	16.60	25.30	24.10	18.30	15.50
247	23.70	25.20	20.10	15.80	24.80	22.20	17.40	16.60
248	23.20	21.90	20.20	16.60	24.00	21.10	17.70	16.10
249	22.70	15.50	22.30	20.00	23.50	18.00	17.50	14.40
250	22.00	11.60	23.30	18.60	22.20	18.00	17.50	15.50
251	24.20	16.30	21.70	18.00	22.80	25.50	16.70	20.50
252	25.00	22.50	23.70	20.50	23.70	25.20	16.70	16.60
253	24.20	20.50	24.00	22.20	23.70	20.00	16.30	12.70
254	22.50	18.60	22.20	21.30	22.30	14.10	15.80	15.50
255	20.70	15.80	20.50	18.80	20.80	14.40	15.70	13.80
256	20.50	13.30	20.50	21.60	19.60	13.60	16.00	20.50
257	17.70	12.50	20.00	16.90	18.50	13.00	16.80	16.10
258	20.00	15.80	18.70	13.80	17.20	12.20	16.40	10.50
259	21.70	18.60	17.20	11.10	16.60	14.10	15.20	10.00
260	21.70	22.50	16.10	10.20	16.50	15.00	14.80	12.70
261			15.40	13.30	17.40	14.70	14.80	16.10
262			15.40	15.20	16.40	10.80	15.50	21.10
263			15.60	13.80	14.90	8.88	16.40	22.20
264			16.10	14.40	13.50	8.05	16.90	17.20
265			15.80	11.90	12.10	6.11	16.80	20.50
266			15.20	10.20	12.00	7.22	16.70	17.70
267			14.90	16.10	12.50	14.40	15.70	12.20
268			15.40	16.90	13.60	16.60	14.40	10.50
269			15.80	16.60	15.00	19.70	12.40	5.00
270			14.70	9.44	16.60	21.30	10.50	4.44
271			13.60	8.61	18.00	21.60	10.40	8.33
272			15.30	14.40	18.80	18.00	10.20	6.11
273			15.40	11.30	19.30	21.30	9.80	7.22
274					19.80	20.50	9.65	9.44
275					20.20	20.20	9.25	11.10
276					19.70	13.60	10.00	14.40
277					19.60	12.70	10.20	12.70
278					21.50	12.50	10.50	13.80
279					18.70	8.61	10.70	15.00
280					16.40	11.60	11.20	15.00
281					16.30	7.77	11.70	15.50
282					15.50	7.50	12.00	15.00
283					15.00	10.00	11.70	16.10
284					13.60	8.61	12.20	17.70
285					12.00	2.22	12.70	17.70
286					10.90	2.77	13.50	17.20
287					10.40	6.94	14.00	17.70
288					10.30	9.44	14.20	14.40
289					10.20	9.16	14.00	10.50
290					10.50	6.66	12.50	5.55
291					11.00	10.50	10.70	8.33
292					11.00	8.61	10.70	10.00
293					13.40	8.05	10.70	8.33
294							9.75	6.66
295							9.25	5.00

296	8.25	3.88
297	8.25	5.55
298	8.25	7.22
299	5.50	7.77
300	5.75	12.20
301	6.50	11.60
302	6.25	1.11
303	5.75	5.00
304	5.50	2.77
305	4.25	1.11

APPENDIX B.6 MISSISSIPPI RIVER

DAILY MEAN WATER TEMPERATURE DATA Ta COMPILED FROM USGS RECORDS (YEARS 1957-1964)
STATION 05331000 MISSISSIPPI RIVER AT ST. PAUL, MN
Lat 445640, Long 930520
DAILY MEAN AIR TEMPERATURE DATA Tw COMPILED FROM MINNEAPOLIS/ST. PAUL INTERNATIONAL AIR
Lat 445309, Long 931312

Calendar	1957		1958		1959		1960	
Day	Tw	Ta	Tw	Ta	Tw	Ta	Tw	Ta
91	0.60	6.11	5.00	8.33	6.40	7.50		
92	0.85	1.67	5.30	7.22	6.70	6.94	7.20	4.17
93	1.40	3.33	5.85	10.56	6.95	5.56	7.50	4.72
94	1.95	-1.11	6.10	7.22	7.20	10.00	6.95	4.72
95	2.20	0.28	6.40	5.00	7.20	8.33	6.15	5.56
96	2.20	1.94	6.70	2.22	7.50	8.89	5.60	3.06
97	2.50	1.67	6.70	4.44	7.80	9.17	5.60	6.67
98	3.05	1.11	6.70	7.22	8.05	1.11	5.85	5.00
99	3.30	-1.11	6.95	7.22	8.30	3.61	6.10	-0.83
100	3.30	-0.56	7.20	6.67	8.30	3.89	6.40	-1.11
101	3.60	-5.56	7.20	8.33	8.30	4.17	6.70	2.50
102	4.45	-4.17	7.50	7.78	8.60	5.56	6.95	10.83
103	5.00	-0.28	7.80	8.33	8.90	6.67	7.20	11.11
104	5.00	3.33	8.05	12.78	9.15	11.94	7.20	14.44
105	5.30	5.00	8.60	15.00	9.40	16.11	7.50	12.22
106	5.30	13.61	8.90	18.33	9.70	13.06	7.80	10.56
107	5.60	10.00	9.15	17.22	10.30	6.67	8.05	8.33
108	5.85	13.61	9.70	16.11	10.60	5.00	8.60	3.89
109	6.10	19.72	10.30	15.00	10.85	5.28	9.15	3.89
110	6.40	13.33	10.85	13.89	11.10	6.94	9.40	13.61
111	6.95	13.33	11.40	10.00	11.40	8.61	9.70	11.67
112	7.25	17.22	11.95	6.11	11.70	11.39	10.00	13.89
113	8.35	17.50	12.20	6.67	11.70	8.61	10.30	20.56
114	9.15	18.61	12.50	6.67	11.70	12.78	10.85	19.72
115	9.70	18.06	12.80	5.00	11.70	8.33	11.40	9.17
116	10.55	13.06	12.80	6.67	11.95	7.22	11.70	6.11
117	11.65	13.61	12.80	8.33	12.20	8.06	11.95	6.94
118	12.50	15.83	12.80	3.89	12.20	10.83	12.50	4.17
119	13.05	18.61	13.05	3.33	12.20	14.17	12.80	4.44
120	13.30	20.83	13.05	12.78	12.20	14.72	12.80	7.22
121	13.60	23.06	13.30	5.83	12.50	23.06	12.80	4.17
122	14.15	13.33	13.30	8.89	13.05	26.94	12.80	9.17
123	14.70	8.33	13.30	13.33	13.60	24.17	13.05	11.39
124	15.00	8.06	13.30	8.89	14.15	24.17	13.30	11.11
125	15.00	11.94	13.30	10.56	15.00	18.61	13.30	11.94
126	15.00	16.94	13.30	11.94	16.40	8.61	13.30	11.11
127	15.00	20.28	13.30	14.72	17.20	8.61	13.30	7.22
128	15.00	18.61	13.60	13.06	17.20	11.67	13.30	6.94
129	15.00	11.67	13.90	15.28	17.20	14.44	13.30	6.39
130	15.30	15.56	14.15	23.06	16.95	18.06	13.60	6.39

131	15.60	15.28	14.70	18.89	16.70	12.78	13.90	9.72
132	15.60	15.00	15.30	22.22	16.70	14.17	13.90	10.00
133	15.60	16.11	15.60	22.22	16.70	8.33	13.90	11.11
134	15.60	8.61	15.85	20.00	16.70	5.28	14.15	15.83
135	15.85	9.44	16.40	17.78	16.40	8.06	14.40	19.72
136	16.10	10.28	16.95	19.72	16.10	13.33	14.70	16.67
137	16.10	7.78	17.50	19.17	16.10	19.17	15.00	13.89
138	15.85	7.50	18.05	15.83	16.10	19.72	15.30	15.56
139	15.60	8.61	18.60	14.17	16.10	18.89	15.60	15.28
140	15.60	11.39	18.90	13.89	16.10	14.72	15.85	18.06
141	15.30	17.50	18.90	16.94	16.10	12.50	16.40	18.61
142	15.00	10.83	18.90	14.17	16.10	11.39	17.25	14.17
143	15.00	11.11	18.90	13.89	16.10	12.78	18.35	18.33
144	15.00	14.72	18.90	18.89	16.10	16.11	19.15	17.78
145	15.00	15.56	18.90	16.39	16.40	21.11	19.15	17.78
146	15.00	11.67	18.90	19.72	16.70	20.00	18.90	17.78
147	15.00	14.17	18.90	13.89	16.70	15.28	19.45	15.56
148	15.00	17.22	19.15	14.17	16.95	19.72	20.30	14.72
149	15.30	18.61	19.40	21.67	17.20	18.89	20.85	15.28
150	15.60	20.28	19.70	20.83	17.50	18.33	21.10	16.67
151	16.15	21.11	20.00	16.11	17.80	14.17	21.10	17.22
152	16.95	15.56	20.00	10.83	17.80	16.11	21.10	17.50
153	17.20	15.00	20.00	11.94	18.05	19.44	21.10	17.78
154	17.50	21.11	20.00	16.11	18.60	21.67	21.10	18.61
155	17.80	21.11	20.00	22.50	18.90	24.72	21.10	17.22
156	18.05	22.22	19.70	16.67	19.45	24.72	21.10	15.28
157	18.30	20.83	19.40	15.83	20.30	26.94	21.40	13.89
158	18.60	17.50	19.40	18.06	20.85	26.94	21.70	11.67
159	18.90	17.50	19.40	18.06	21.40	27.22	21.40	13.33
160	19.15	20.83	19.40	16.67	21.70	28.61	21.10	16.67
161	19.40	24.17	19.40	16.39	21.95	25.28	21.10	20.00
162	19.70	18.89	19.40	12.22	22.20	22.78	20.85	18.89
163	20.00	17.22	19.40	16.39	22.50	17.78	20.60	15.00
164	20.30	21.39	19.40	17.22	22.50	17.50	20.60	18.61
165	20.60	20.28	19.40	14.44	22.20	18.06	20.60	20.28
166	20.85	19.17	19.40	15.28	22.20	24.44	20.60	19.44
167	21.10	22.22	19.70	15.28	22.50	25.28	20.60	20.00
168	21.40	23.06	20.00	16.67	22.80	22.50	21.15	13.06
169	21.70	17.78	20.00	17.22	22.80	19.72	21.40	14.44
170	21.70	20.83	20.00	20.00	22.80	21.11	21.10	21.11
171	21.95	25.28	20.00	15.56	22.50	20.00	20.85	18.61
172	22.50	24.72	20.00	17.78	22.20	18.33	20.85	16.11
173	22.80	18.06	20.30	17.50	22.20	16.94	21.40	16.11
174	23.05	15.00	20.60	16.11	22.20	19.72	21.70	15.83
175	23.60	15.28	20.60	14.44	22.20	21.67	21.40	16.67
176	23.90	15.83	20.60	13.06	22.20	21.11	21.95	16.94
177	23.60	17.22	20.85	18.33	22.50	25.28	21.95	18.61
178	23.30	18.33	21.10	19.17	22.80	25.83	21.95	22.78
179	23.30	19.44	21.10	23.89	23.05	20.83	22.20	24.44
180	23.30	20.83	21.40	28.33	23.30	13.89	22.50	21.39
181	23.30	21.67	21.95	29.17	23.30	11.67	23.05	19.72
182	23.60	23.33	22.50	28.06	23.30	16.11	23.30	16.67
183	23.90	26.67	23.05	26.39	23.30	19.72	23.30	16.94
184	23.90	24.44	23.85	24.72	23.05	22.50	23.60	21.67
185	24.15	21.39	24.70	20.00	22.80	24.17	23.90	17.22

186	24.40	21.39	25.30	19.44	23.05	19.44	23.90	16.11
187	24.40	25.00	25.30	19.44	23.30	21.11	23.90	18.61
188	24.70	27.50	25.00	15.83	23.60	24.72	23.60	18.33
189	25.00	24.17	24.70	15.28	23.85	21.67	23.60	19.72
190	25.00	22.78	24.15	20.00	24.15	20.28	23.90	21.94
191	25.00	25.28	24.15	18.06	23.90	20.56	23.90	21.67
192	25.00	28.61	23.60	19.44	23.90	17.78	24.15	21.39
193	25.00	26.11	23.30	22.50	23.90	19.72	24.15	23.61
194	25.00	25.56	23.30	23.61	23.90	24.17	24.40	23.33
195	25.30	26.11	23.30	20.00	24.15	25.00	24.70	19.44
196	25.85	24.44	23.60	17.22	24.40	25.28	25.00	18.33
197	26.10	22.78	23.90	17.50	24.40	25.00	25.00	21.67
198	26.10	25.28	23.90	18.33	24.70	26.39	25.00	23.89
199	26.10	29.44	23.90	21.39	25.30	23.33	24.70	22.50
200	26.10	28.61	23.90	20.83	25.60	23.33	24.70	21.94
201	26.40	24.44	23.90	21.11	25.60	24.17	25.00	22.22
202	26.70	24.44	23.90	21.94	25.60	27.50	25.30	25.83
203	26.95	24.72	24.15	22.78	25.60	26.67	25.60	28.89
204	27.20	21.39	24.40	24.17	25.85	25.56	25.85	28.06
205	27.20	21.67	24.70	23.89	26.40	21.67	26.65	24.72
206	26.95	21.11	25.30	22.22	26.95	22.22	27.50	26.94
207	26.70	21.67	25.60	24.72	27.20	26.94	27.80	25.00
208	26.40	25.83	25.85	22.22	27.20	28.06	27.80	23.33
209	26.10	25.00	26.10	21.67	27.20	27.78	27.80	23.89
210	26.10	26.67	26.10	21.11	27.50	29.17	28.05	23.61
211	26.10	24.44	26.10	22.22	27.80	24.44	28.30	24.17
212	26.10	26.11	26.10	23.33	28.05	26.11	28.30	18.61
213	26.10	26.94	26.40	23.06	28.60	25.28	28.30	19.72
214	26.10	26.11	26.70	26.67	28.90	23.89	28.30	23.61
215	26.40	20.28	26.95	25.56	28.90	25.28	28.05	28.89
216	26.70	18.06	27.50	23.89	28.90	27.22	27.80	25.56
217	26.40	19.17	27.50	25.00	28.90	29.17	27.80	23.89
218	26.10	20.83	27.80	25.83	28.60	22.78	27.80	22.22
219	25.85	24.44	27.80	24.72	28.30	17.22	27.80	23.33
220	25.30	23.61	28.05	24.72	28.05	17.22	27.80	22.22
221	24.70	23.06	28.30	28.61	27.80	20.83	27.50	20.83
222	24.40	24.17	28.60	24.72	27.50	23.89	27.20	20.00
223	24.40	25.28	28.90	26.94	27.20	24.72	27.20	18.89
224	24.15	22.78	28.90	23.89	26.95	22.22	27.20	20.83
225	23.90	22.22	29.15	22.22	26.70	21.67	27.20	24.44
226	24.15	23.89	29.40	24.44	26.70	20.28	27.20	24.44
227	24.40	22.50	29.40	20.56	26.40	22.78	27.20	16.67
228	24.15	21.94	29.40	19.44	26.10	19.72	27.20	15.56
229	23.90	20.28	29.40	22.78	26.10	21.67	27.20	23.06
230	23.90	21.11	29.15	21.94	26.10	25.00	26.95	25.00
231	23.60	19.44	28.90	26.67	25.85	28.89	26.70	23.33
232	23.05	20.56	28.60	21.39	25.60	28.33	26.40	23.33
233	22.80	23.61	28.30	18.61	25.60	27.22	26.10	22.78
234	22.80	23.06	28.05	17.50	25.85	23.33	26.10	22.50
235	22.80	21.67	27.80	17.78	26.40	26.39	26.10	23.61
236	22.50	20.56	27.50	15.00	26.70	24.72	26.10	24.72
237	22.20	22.50	26.95	11.67	26.70	27.22	25.85	25.00
238	22.20	18.06	26.40	16.11	26.70	22.50	25.60	22.22
239	21.95	15.56	26.10	20.28	26.70	26.39	25.85	19.72
240	21.70	14.72	25.85	22.50	26.70	26.67	25.85	18.61

241	21.40	17.22	25.30	26.11	26.70	26.94	25.60	17.50
242	20.85	19.44	25.00	16.39	26.70	22.78	25.60	17.22
243	20.30	26.39	25.00	12.78	26.70	21.67	25.30	22.22
244	20.00	26.39	24.70	15.28	26.10	19.44	25.00	27.50
245	20.00	20.00	24.40	21.39	25.85	16.11	24.70	28.06
246	19.70	16.94	24.15	21.11	25.30	16.94	24.40	28.06
247	19.40	15.28	23.60	17.50	24.70	20.83	24.40	28.06
248	19.40	14.72	23.30	17.78	24.15	25.56	24.70	26.94
249	19.40	16.94	23.05	16.94	23.60	27.50	25.00	28.61
250	19.15	16.67	22.80	16.94	23.05	26.11	25.30	27.78
251	18.90	17.78	22.50	16.94	22.80	28.33	25.85	22.50
252	18.60	16.67	22.20	18.89	22.50	18.61	26.10	18.61
253	18.30	17.78	21.95	13.06	22.20	12.78	25.85	15.28
254	18.30	18.61	21.70	16.94	22.20	15.56	25.30	15.56
255	18.30	15.83	21.70	20.00	21.65	19.44	25.00	15.56
256	18.30	13.89	21.40	21.11	21.10	20.28	24.70	11.11
257	18.30	13.33	21.10	18.61	20.85	20.83	24.15	12.50
258	18.05	13.61	20.85	17.50	20.30	10.00	23.60	15.28
259	17.80	12.50	20.60	11.39	19.70	8.61	23.30	15.56
260	17.50	17.78	20.60	13.33	19.70	11.39	23.05	15.28
261	16.95	19.72	20.60	16.39	19.40	11.11	22.50	13.61
262	16.70	14.17	20.30	20.00	19.15	15.56	22.20	8.61
263	16.70	8.33	19.70	19.44	18.60	22.22	21.95	11.94
264	16.40	13.33	19.40	16.39	18.05	22.78	21.70	16.94
265	16.10	12.22	19.15	20.56	17.50	20.28	21.40	18.06
266	15.85	9.17	18.90	24.44	17.20	15.56	21.10	14.44
267	15.60	15.00	18.90	21.11	16.95	16.39	21.10	11.67
268	15.60	12.22	18.90	14.72	16.70	16.39	20.85	11.39
269	15.30	8.61	18.60	15.56	16.40	15.28	20.30	13.06
270	14.70	10.56	18.30	11.39	16.10	15.00	20.00	15.83
271	14.40	12.78	18.30	13.61	15.85	12.22	19.70	10.83
272	14.40	16.94	18.30	16.11	15.30	8.33	19.40	9.72
273	14.15	18.61	18.05	6.67	15.00	8.33	19.40	6.94
274	13.90	15.56	17.50	5.83	14.70	7.50	19.15	7.78
275	13.90	17.78	16.95	10.00	14.15	8.89	18.90	11.39
276	13.60	16.11	16.70	17.22	13.60	11.94	18.90	9.44
277	13.30	13.89	16.40	13.61	13.30	12.22	18.60	8.61
278	13.30	15.00	15.85	9.72	13.05	13.33	18.30	12.78
279	13.30	13.89	15.60	17.78	12.50	13.06	18.30	15.83
280	13.30	15.83	15.30	16.67	12.20	10.83	18.30	11.67
281	13.05	10.83	15.00	13.06	11.95	6.67	18.05	11.67
282	12.80	6.67	15.00	10.00	11.40	4.72	17.80	14.17
283	12.80	4.72	14.70	4.44	11.10	7.22	17.25	15.00
284	12.50	5.83	14.40	5.56	10.85	2.22	16.70	15.56
285	12.20	10.00	14.15	15.00	10.60	1.11	16.40	17.22
286	11.95	11.67	13.90	20.28	10.30	2.50	16.10	20.56
287	11.70	12.50	13.90	20.00	9.70	5.56	16.10	15.28
288	11.70	15.00	13.60	18.06	9.15	9.72	15.85	14.44
289	11.40	11.94	13.30	13.06	8.90	6.39	15.60	9.44
290	11.10	8.61	13.30	11.11	9.15	4.44	15.30	11.67
291	10.85	5.83	13.05	12.22	9.70	8.61	15.00	8.33
292	10.60	6.67	12.80	17.50	10.00	11.11	14.70	5.28
293	10.60	5.28	12.80	19.17	10.00	6.67	14.15	-2.22
294	10.60	8.89	12.80	13.61	10.00	6.39	13.60	-1.94
295	10.30	10.83	12.80	8.89	9.70	12.78	13.05	2.22

296	12.50	8.06	12.50	8.06	9.15	8.89	12.50	9.72
297	9.40	1.67	12.20	8.06	8.60	6.67	11.95	4.17
298	9.15	-1.67	11.95	5.83	8.30	1.67	11.40	0.00
299	8.90	1.67	11.70	6.67	8.30	1.67	10.85	8.06
300	8.60	3.06	11.70	6.94	8.05	1.11	10.30	3.61
301	8.30	7.22	11.70	7.50	7.50	3.06	9.70	6.11
302	8.05	6.94	11.70	8.06	7.20	5.56	9.40	6.39
303	7.50	6.67	11.40	8.33	6.95	7.22	9.15	9.17
304	6.95	9.72	11.10	10.83	6.40	3.33	8.90	8.06
305							8.60	5.56

Calendar Day	1961 Tw	1961 Ta	1962 Tw	1962 Ta	1963 Tw	1963 Ta	1964 Tw	1964 Ta
91	4.70	-5.00	5.85	-0.28	2.80	17.22		
92	5.00	-1.67	5.00	-1.11	3.05	20.00	2.80	3.61
93	5.00	1.11	4.15	0.28	3.60	8.89	3.05	4.72
94	5.00	1.39	3.60	3.06	4.15	3.89	3.30	1.11
95	5.00	1.11	3.30	4.17	4.40	10.00	3.60	-0.28
96	5.30	0.56	3.30	1.11	4.70	7.78	3.90	1.67
97	5.60	1.39	3.30	0.83	5.30	7.78	4.15	1.94
98	5.85	1.39	3.30	1.94	5.60	3.89	4.40	-0.28
99	6.40	2.22	3.30	-1.11	6.15	2.78	4.70	1.11
100	6.70	3.33	3.30	-1.39	6.70	2.22	5.00	5.28
101	6.95	5.28	3.60	3.06	6.70	5.56	5.30	7.22
102	7.50	3.89	4.15	-4.72	7.25	8.33	5.60	14.72
103	7.80	2.50	4.40	-6.67	7.80	7.22	5.85	11.11
104	7.80	5.00	4.40	-2.78	7.80	10.00	6.40	6.39
105	7.80	-1.67	4.70	0.00	7.80	15.00	6.95	4.72
106	8.05	-2.50	5.30	2.22	8.05	16.67	7.20	9.17
107	8.60	2.22	5.85	7.22	8.60	5.56	7.50	19.72
108	8.90	5.56	6.10	6.94	9.15	3.89	8.05	13.33
109	8.90	10.00	6.40	6.94	9.70	7.22	8.60	6.67
110	8.90	10.00	6.70	7.78	10.00	6.11	8.90	8.33
111	8.90	9.72	6.95	15.00	10.00	5.56	9.15	8.89
112	8.90	11.11	7.50	11.39	10.30	3.89	9.40	9.72
113	9.45	8.33	8.05	8.33	10.85	2.78	9.70	9.44
114	10.00	6.94	8.60	18.33	11.10	6.67	10.00	11.11
115	10.00	3.06	8.85	22.78	11.10	12.78	10.00	11.39
116	10.00	4.72	9.70	21.11	11.10	12.22	10.00	12.50
117	10.30	4.44	10.30	12.50	11.10	16.11	10.30	15.83
118	10.85	3.33	11.15	9.17	11.40	14.44	10.85	17.50
119	11.10	6.39	11.95	10.28	11.95	8.33	11.40	12.22
120	11.10	4.72	12.50	12.50	12.20	6.67	11.70	6.11
121	11.40	5.56	12.50	13.06	12.20	9.17	11.70	10.56
122	11.70	4.44	12.20	12.22	12.20	13.33	11.95	11.39
123	11.70	8.06	12.50	18.06	12.20	13.61	12.50	11.94
124	11.70	11.67	12.80	20.28	12.20	11.11	12.80	20.28
125	11.95	12.50	12.80	16.94	12.20	11.11	13.05	19.72
126	12.50	9.72	12.80	10.56	12.50	14.17	13.60	17.50
127	12.80	12.50	12.80	6.67	12.80	23.89	14.15	17.78
128	13.05	8.06	12.80	9.17	12.80	21.11	14.70	17.22
129	13.30	6.67	12.80	9.44	13.05	19.72	15.30	13.89
130	13.60	16.11	13.05	10.56	13.60	8.89	16.40	11.67
131	13.90	21.67	13.30	10.28	14.15	5.83	17.20	13.61
132	14.15	22.78	13.05	18.06	14.40	7.78	17.20	17.50
133	14.70	17.22	12.80	21.94	14.40	12.22	17.50	11.39
134	15.30	11.94	12.80	22.22	14.15	7.78	18.05	11.94
135	15.85	10.56	13.35	23.89	13.90	11.11	18.60	14.17
136	16.40	10.28	13.90	25.00	13.60	14.72	18.90	16.67
137	16.70	8.61	14.15	24.44	13.30	17.78	18.90	16.39
138	16.95	7.50	14.70	23.06	13.30	11.94	19.15	14.17
139	17.20	6.94	15.85	19.17	13.60	6.11	19.70	23.06
140	17.50	11.39	16.95	13.61	13.90	8.61	20.00	18.06

141	17.80	14.44	17.50	11.39	13.90	6.94	20.30	16.11
142	17.80	13.61	17.50	19.44	13.90	6.39	20.85	23.89
143	17.80	13.61	17.20	13.89	13.90	8.33	21.10	28.06
144	18.05	16.94	17.50	13.61	13.90	15.83	21.10	22.50
145	18.60	11.67	18.05	11.94	13.90	15.56	21.10	18.33
146	18.90	9.17	18.30	12.78	13.90	15.83	21.10	18.33
147	18.90	13.89	18.05	15.56	13.90	16.11	21.10	16.94
148	19.15	18.61	17.80	15.83	14.15	12.22	21.10	13.89
149	19.70	15.00	17.80	20.83	14.40	13.61	21.40	12.78
150	20.00	16.67	17.80	16.94	15.00	18.33	21.70	12.78
151	20.00	21.94	17.80	10.83	15.60	23.61	21.40	13.33
152	19.70	17.78	18.05	10.00	16.15	21.94	21.10	11.67
153	19.70	15.56	18.30	11.94	16.95	21.94	21.10	11.67
154	20.55	15.56	18.60	12.78	17.50	24.72	21.10	13.61
155	21.10	18.33	18.90	14.72	18.35	25.83	21.10	13.89
156	20.85	20.83	18.90	18.89	19.45	23.33	20.85	15.00
157	20.85	21.11	18.90	16.11	20.30	25.00	20.60	18.89
158	21.40	18.06	18.90	20.28	20.85	22.22	20.60	20.56
159	21.70	22.50	18.90	18.89	21.65	23.89	20.60	21.39
160	21.70	23.61	19.15	21.67	22.50	19.17	20.85	25.83
161	21.95	22.22	19.70	18.61	22.80	12.22	21.10	18.61
162	22.50	22.50	20.00	17.22	22.80	11.11	21.10	17.78
163	22.80	24.17	20.30	14.72	22.80	13.61	21.40	15.28
164	22.80	20.83	20.60	16.11	23.05	20.28	21.70	22.78
165	22.80	17.50	20.85	18.89	23.05	16.67	21.70	20.28
166	22.80	13.61	21.40	22.22	22.80	17.78	21.70	21.11
167	22.80	15.28	21.70	24.72	22.80	17.50	21.95	17.50
168	22.80	18.33	21.70	23.33	22.80	19.17	22.20	13.61
169	22.80	23.89	21.95	15.00	22.80	21.94	22.20	19.17
170	22.80	15.28	22.50	17.22	22.80	19.72	22.20	24.17
171	22.80	15.83	22.80	16.94	22.50	15.28	22.20	22.50
172	23.05	16.94	23.05	18.89	22.20	15.83	22.20	20.28
173	23.30	18.06	23.30	20.28	22.20	18.06	22.20	20.56
174	23.30	15.83	23.60	20.56	21.95	21.39	22.50	20.28
175	23.05	17.50	24.15	20.28	21.70	25.56	23.05	19.44
176	22.80	16.94	24.40	22.22	21.70	27.78	23.30	19.72
177	22.80	20.56	24.40	21.67	21.70	22.50	23.30	26.67
178	22.80	25.56	24.40	23.89	21.70	24.17	23.30	28.06
179	22.80	29.72	24.40	27.22	21.95	23.61	23.60	25.56
180	23.05	28.89	24.40	23.33	22.50	27.78	24.15	25.28
181	23.60	28.06	24.40	20.56	23.05	29.72	24.70	26.11
182	24.45	21.67	24.40	20.28	23.60	22.78	25.00	25.56
183	25.30	19.72	24.40	20.83	24.15	20.28	25.30	23.33
184	25.85	18.33	24.40	21.94	24.40	18.06	25.60	25.00
185	26.10	18.89	24.40	20.00	24.40	20.28	25.60	23.06
186	26.10	21.11	24.40	21.94	24.40	21.94	25.85	19.44
187	26.10	21.67	24.15	23.89	25.00	23.33	26.40	23.06
188	26.10	21.11	24.40	25.83	25.60	23.33	26.10	24.72
189	25.85	18.61	24.40	20.00	25.60	21.94	26.10	25.56
190	25.60	19.44	24.70	19.17	25.85	21.11	26.10	24.44
191	25.85	22.50	24.70	23.89	26.10	22.78	26.10	23.33
192	26.10	21.67	24.70	21.39	26.10	24.72	26.40	23.06
193	25.85	20.83	25.00	20.56	26.10	21.67	26.70	22.50
194	25.60	21.11	24.70	17.50	25.85	24.72	26.70	19.17
195	25.60	19.44	24.15	18.61	25.60	20.83	26.70	20.28

196	25.60	19.17	23.90	15.56	25.60	17.78	26.70	22.50
197	25.60	20.00	23.60	17.22	25.60	21.11	26.70	25.28
198	25.60	21.67	23.05	18.61	25.60	23.33	26.70	29.17
199	25.60	24.17	22.80	18.89	25.60	24.17	26.95	30.00
200	25.30	21.11	22.80	22.50	25.60	23.61	27.50	29.72
201	25.00	22.22	22.50	23.06	25.85	23.89	28.05	29.44
202	25.00	21.67	21.95	19.72	26.40	25.83	28.60	25.83
203	25.00	21.94	21.70	19.72	26.70	27.50	29.15	27.78
204	25.00	20.28	21.70	15.83	26.70	27.22	29.40	26.39
205	25.00	21.39	21.70	21.94	26.70	25.56	29.70	28.33
206	24.70	23.06	21.95	16.67	26.70	27.78	30.30	23.89
207	24.40	24.44	22.50	15.28	26.70	27.50	30.60	23.06
208	24.70	24.72	22.80	16.39	26.70	23.06	30.60	22.78
209	24.70	24.72	22.80	18.89	26.70	21.11	30.60	26.67
210	24.40	25.28	22.80	20.28	26.70	21.94	30.30	25.56
211	24.40	25.00	22.50	16.11	26.70	22.22	30.00	20.83
212	24.70	20.83	22.20	18.61	26.70	23.33	29.45	18.89
213	25.00	23.89	22.20	17.22	26.40	22.78	29.40	24.44
214	25.00	23.89	22.20	19.72	25.85	24.44	29.40	31.11
215	25.30	24.17	22.50	18.06	25.60	22.50	29.15	30.56
216	25.60	23.61	22.80	20.83	25.60	23.06	28.60	28.61
217	25.60	19.17	22.80	24.44	25.60	23.61	28.30	27.22
218	25.60	17.78	22.80	22.50	25.30	26.94	28.60	28.06
219	25.60	21.94	22.80	22.50	25.00	26.39	28.90	25.00
220	25.60	24.72	22.80	19.72	25.00	25.28	28.90	20.28
221	25.30	21.11	23.05	18.06	25.00	22.22	28.60	18.33
222	24.70	21.67	23.60	20.83	25.00	20.56	28.05	15.83
223	24.40	18.61	23.90	21.94	25.00	22.50	27.80	23.06
224	24.40	15.83	23.90	18.89	25.00	23.06	27.50	14.72
225	24.40	21.11	23.90	18.61	25.00	16.39	26.95	13.06
226	24.40	23.61	23.90	19.44	24.70	15.83	26.40	15.00
227	24.40	25.28	23.90	23.33	24.40	17.78	25.85	15.56
228	24.40	24.44	23.90	16.39	24.15	20.28	25.30	18.61
229	24.40	24.72	23.90	15.83	23.90	14.44	24.70	22.22
230	24.70	19.44	23.90	20.00	23.60	15.83	24.40	20.83
231	25.00	16.94	23.90	23.33	23.30	16.94	24.15	21.94
232	25.00	16.94	23.90	21.94	23.30	22.78	23.90	22.78
233	24.70	18.33	23.90	23.61	23.30	23.06	23.60	22.50
234	24.40	17.50	23.90	21.67	23.30	23.33	23.30	20.83
235	24.40	20.83	23.90	24.44	23.30	19.72	23.30	16.11
236	24.15	20.56	23.60	16.39	23.30	15.56	23.30	16.11
237	23.90	22.50	23.30	18.06	23.30	17.78	23.30	14.17
238	23.90	19.72	23.30	20.00	23.30	19.44	23.05	14.72
239	23.90	20.83	23.30	23.33	23.30	19.44	22.50	15.56
240	23.90	23.33	23.60	20.28	23.30	21.67	22.20	23.61
241	23.90	26.39	23.90	19.17	23.30	18.06	22.20	20.00
242	23.90	28.33	23.60	18.06	23.30	16.67	21.95	20.28
243	23.90	28.89	23.05	16.67	23.30	16.94	21.70	16.39
244	23.90	24.17	22.80	18.61	23.30	20.28	21.70	15.83
245	23.90	25.56	22.80	20.28	23.30	19.44	21.70	20.56
246	23.90	14.44	22.80	17.78	23.30	18.33	21.40	25.28
247	23.90	15.56	22.80	10.83	23.30	17.50	21.10	21.67
248	23.90	19.17	22.50	10.28	23.30	16.39	21.10	16.39
249	23.60	18.06	21.95	12.22	23.30	18.89	21.10	15.56
250	23.30	19.44	21.70	17.22	23.05	19.17	21.10	20.28

251	23.30	21.94	21.40	19.72	22.80	20.56	21.10	20.83
252	23.30	26.39	21.10	14.44	22.80	20.00	20.85	21.39
253	23.05	22.50	21.10	9.17	22.80	19.44	20.60	23.89
254	22.80	13.61	20.85	14.17	22.80	23.61	20.60	17.78
255	22.50	12.78	20.60	20.28	22.80	12.22	20.60	8.89
256	21.95	10.28	20.00	16.94	22.80	9.44	20.60	10.56
257	21.70	10.56	19.40	14.44	22.80	13.89	20.60	13.61
258	21.40	13.33	19.40	17.50	22.80	18.61	20.30	10.83
259	20.85	13.33	19.40	17.50	22.50	21.11	20.00	8.89
260	20.60	17.78	19.40	12.50	21.95	23.33	19.15	15.28
261	20.30	20.83	19.40	13.61	21.70	21.39	19.40	18.61
262	20.00	19.17	19.40	7.78	21.70	15.00	19.40	16.94
263	19.70	19.72	19.40	6.67	21.70	15.83	19.15	16.94
264	19.15	18.06	19.40	12.78	21.70	13.06	19.40	13.33
265	18.60	8.89	19.40	11.11	21.70	10.83	19.40	14.44
266	18.30	6.67	19.15	12.78	21.70	12.50	19.40	14.17
267	18.05	9.44	19.15	13.06	21.40	16.39	19.15	9.72
268	17.80	8.06	19.40	9.44	20.85	18.61	18.90	10.00
269	17.50	13.06	19.15	11.11	20.60	16.94	18.90	11.67
270	17.20	7.50	18.90	10.00	20.60	16.94	18.90	12.50
271	17.20	4.72	18.90	10.28	20.60	9.44	18.60	6.94
272	16.95	8.89	18.90	11.67	20.30	8.89	18.30	9.44
273	16.70	6.39	18.90	12.50	19.70	13.89	18.60	10.56
274	16.40	5.00	18.30	13.61	19.40	16.94	18.05	11.39
275	15.85	7.22	18.30	12.78	19.40	16.67	17.80	17.78
276	15.30	11.39	18.30	12.50	19.40	12.22	17.80	12.22
277	15.00	12.22	18.30	13.89	19.40	16.39	17.80	13.33
278	15.00	16.39	18.05	11.11	19.15	19.72	17.50	6.67
279	14.70	20.28	17.80	11.11	18.90	20.28	17.20	6.94
280	14.40	19.44	18.05	12.78	18.90	14.72	17.20	3.61
281	14.40	18.33	18.30	13.61	18.90	13.06	16.95	12.22
282	14.15	13.06	18.30	13.61	18.90	15.28	16.40	4.44
283	13.90	16.11	18.30	18.61	18.60	16.39	16.10	2.22
284	13.90	13.33	18.30	19.17	18.30	15.56	15.85	3.61
285	13.90	15.56	18.30	12.78	18.30	13.06	15.60	5.56
286	13.90	9.44	18.30	17.50	18.30	15.28	15.60	8.06
287	13.90	6.39	18.30	22.22	18.30	17.50	15.60	11.39
288	13.90	15.56	18.60	16.67	18.30	19.17	15.30	13.33
289	13.90	16.94	18.90	7.78	18.30	18.89	15.00	15.28
290	13.60	17.50	18.90	10.56	18.30	15.83	14.70	17.22
291	13.05	7.78	18.90	11.11	18.05	13.06	14.40	10.00
292	12.80	5.28	18.60	10.28	17.80	15.83	14.40	5.83
293	12.80	5.56	18.30	6.94	17.80	16.39	14.40	1.67
294	12.80	9.17	18.30	7.22	17.50	16.39	14.40	7.78
295	12.80	9.72	18.05	5.83	16.95	17.22	14.40	5.83
296	12.50	7.22	17.50	2.50	16.70	19.44	14.15	2.50
297	12.20	9.72	16.65	0.28	16.70	16.39	13.90	3.61
298	11.95	7.22	15.55	-2.78	16.40	12.50	13.90	9.72
299	11.40	4.44	14.70	-0.28	15.85	11.94	13.60	16.67
300	10.85	10.00	14.15	8.06	15.60	8.33	13.05	13.33
301	10.60	12.50	13.90	6.94	15.30	6.11	12.80	14.44
302	10.60	10.00	13.60	6.94	14.70	3.89	12.80	5.83
303	10.60	6.39	13.05	8.06	14.15	8.33	12.80	3.33
304	10.30	8.61	12.50	1.39	13.60	6.39	12.80	9.72
305							12.80	14.17

APPENDIX B.7 ARKANSAS RIVER

DAILY MEAN WATER TEMPERATURE DATA Tw COMPILED FROM USGS RECORDS (YEARS 1983-1988)
STATION 07258000 ARKANSAS RIVER AT DARDANELLE, ARK
Lat 351334, Long 930858
DAILY MEAN AIR TEMPERATURE DATA Ta COMPILED FROM THE U.S. NATIONAL WEATHER SERVICE RECORDS
AT LITTLE ROCK, ARK (AVERAGE OF DAILY MIN AND MAX AIR TEMPERATURES)
Lat 344448, Long 921642

Calendar	1983		1984		1985		1986		1987		1988	
Day	Tw	Ta	Tw	Ta	Tw	Ta	Tw	Ta	Tw	Ta	Tw	Ta
91	10.00	13.06			14.00	11.11	15.00	19.44	10.50	11.94		
92	10.00	8.33	9.50	7.78	14.00	11.39	15.50	18.61	10.50	9.44	14.00	18.89
93	10.00	9.17	9.50	9.72	14.00	19.17	16.00	19.72	10.00	6.39	14.50	17.78
94	10.00	11.94	9.50	18.06	14.00	20.56	16.50	19.44	10.50	6.11	14.50	18.33
95	10.00	14.17	9.50	10.28	14.50	14.44	17.00	20.00	10.50	8.61	14.50	19.17
96	10.00	9.44	9.50	12.78	14.50	11.39	17.50	21.11	11.50	12.50	15.00	20.56
97	10.00	10.00	10.00	13.06	14.50	12.78	17.00	23.33	11.50	12.78	15.00	15.56
98	10.00	8.06	10.50	15.28	14.50	11.11	17.50	19.44	12.00	15.83	15.00	15.83
99	10.00	10.00	10.50	13.33	14.50	8.33	17.50	14.72	12.50	17.50	15.00	15.56
100	10.00	11.94	10.50	13.89	14.50	15.56	17.50	14.17	13.50	16.94	15.50	15.28
101	10.00	12.22	11.00	14.17	14.50	18.61	17.50	16.67	14.00	16.11	15.50	10.28
102	10.00	17.22	11.50	16.11	15.00	19.17	17.50	18.61	14.00	20.83	14.50	8.33
103	11.00	16.11	12.00	18.06	15.50	18.06	18.00	19.44	14.50	17.78	13.50	17.50
104	11.00	7.22	12.50	16.39	15.50	17.50	18.50	15.56	15.00	12.22	13.50	17.50
105	11.00	8.06	12.50	13.61	16.00	17.50	17.50	12.50	15.00	13.33	13.50	18.33
106	12.00	11.11	12.50	11.67	16.50	15.56	17.00	12.22	15.00	16.67	14.00	14.17
107	12.00	12.50	12.50	13.06	16.50	17.50	17.00	12.78	15.50	20.28	14.00	13.33
108	12.50	6.94	12.50	12.50	17.50	19.44	17.00	16.67	16.00	20.00	14.00	15.00
109	12.50	2.50	12.50	12.50	18.00	20.28	17.00	19.44	16.50	22.50	14.50	18.06
110	12.00	7.78	12.50	15.28	18.50	21.11	16.50	15.28	17.50	23.89	14.50	11.94
111	12.00	9.44	13.00	15.00	19.00	19.17	16.00	14.44	19.00	23.33	14.50	15.56
112	12.00	13.89	13.00	21.11	19.00	19.44	16.00	10.56	19.50	18.06	15.00	20.56
113	12.00	14.17	13.50	14.17	19.00	20.28	15.50	12.50	19.50	18.33	15.50	22.22
114	12.50	13.61	13.00	12.78	19.50	17.78	15.50	18.61	19.50	17.22	15.50	21.11
115	13.00	12.50	13.50	16.39	19.50	16.94	16.50	21.39	19.50	17.78	16.50	13.61
116	13.50	17.22	14.00	20.83	19.50	20.56	17.00	20.28	20.00	20.83	17.00	15.28
117	14.50	18.89	14.50	21.39	20.00	19.72	17.50	19.72	20.50	24.17	17.00	16.94
118	15.50	20.56	15.00	24.44	20.00	19.17	17.50	18.06	21.00	20.00	17.50	14.44
119	16.00	22.50	15.50	19.17	20.50	19.72	18.00	19.72	21.50	21.11	17.50	15.56
120	17.00	22.78	16.00	23.06	20.50	22.50	18.00	22.22	22.00	24.17	17.50	16.11
121	17.50	23.61	16.50	14.44	20.50	22.22	18.50	18.61	22.00	22.78	17.50	18.61
122	18.00	20.83	17.00	15.28	20.50	17.78	19.00	17.50	22.00	22.50	17.00	16.94
123	18.00	15.56	17.50	18.06	20.00	16.94	19.00	16.11	22.00	23.89	17.00	17.78
124	17.50	16.67	17.50	18.89	20.50	15.56	19.50	17.50	22.00	23.06	17.50	19.72
125	17.50	18.61	17.50	16.11	20.50	18.33	19.50	20.28	22.50	21.94	17.50	18.06
126	18.00	21.11	17.50	18.61	21.00	22.22	19.50	23.89	23.00	21.39	18.00	17.78
127	18.50	21.11	17.50	24.17	21.00	23.06	20.00	24.17	23.00	23.06	18.00	20.00
128	18.50	14.17	17.50	21.39	21.00	21.39	20.50	25.28	23.50	22.22	18.00	21.39
129	18.50	13.61	17.00	16.11	21.00	19.17	21.00	25.00	23.50	21.67	18.50	22.78
130	19.00	18.06	17.50	16.94	21.50	19.17	21.50	24.72	23.50	23.33	19.50	23.33

131	19.00	20.56	18.00	19.17	21.50	21.67	20.00	21.94	23.50	23.06	20.50	21.67
132	19.50	22.22	18.50	21.39	21.50	24.44	22.50	23.06	24.00	25.00	20.50	21.94
133	19.50	22.78	19.00	23.06	21.50	25.00	22.50	23.89	24.50	25.28	21.00	23.06
134	19.50	23.61	20.00	23.89	22.00	21.39	22.50	24.44	24.50	24.72	21.00	22.78
135	19.50	17.22	21.50	21.67	22.00	19.44	22.50	23.89	24.50	26.39	21.50	23.61
136	19.00	16.39	21.50	18.61	22.00	21.67	23.50	24.44	25.00	25.56	22.00	23.33
137	19.00	15.56	21.50	18.33	22.00	19.44	24.00	21.11	25.00	24.44	20.00	24.72
138	18.50	19.44	21.50	18.61	22.00	18.33	23.00	18.61	25.00	26.11	22.50	21.94
139	18.50	21.39	21.50	19.72	22.00	19.17	22.50	18.89	25.00	26.67	23.00	21.39
140	19.00	20.56	21.50	23.06	22.00	20.56	22.00	18.33	25.00	27.50	23.00	22.50
141	19.00	19.17	22.00	21.39	22.00	19.44	21.50	17.78	25.00	26.67	23.00	23.33
142	19.00	21.94	22.00	22.50	22.00	18.61	21.00	21.39	25.50	26.94	23.00	23.33
143	19.50	18.89	22.00	22.78	22.00	18.33	21.00	22.50	26.50	26.11	23.00	18.89
144	20.00	18.61	22.00	20.83	22.50	19.44	21.00	21.94	26.50	23.33	23.00	18.06
145	20.00	21.39	23.00	20.28	22.50	22.50	21.00	22.78	26.00	24.72	23.00	20.83
146	20.50	22.78	23.00	24.17	22.50	24.17	21.00	22.22	26.00	25.00	23.00	18.89
147	21.00	22.22	23.00	20.00	23.00	23.06	21.50	20.83	26.00	25.28	24.00	18.06
148	21.50	25.00	23.00	23.33	23.50	24.44	21.50	23.33	26.00	26.94	23.00	19.44
149	22.00	22.50	23.00	21.39	23.50	23.89	22.50	23.33	26.00	26.94	23.00	21.94
150	22.00	18.89	22.50	16.67	23.50	24.17	23.00	24.44	25.50	25.28	23.50	23.06
151	21.50	18.89	22.00	16.67	24.50	28.33	23.50	25.28	25.00	25.56	23.50	23.61
152	21.50	19.72	22.00	16.39	25.00	28.33	24.00	24.44	24.50	25.28	24.00	25.56
153	22.50	23.61	22.00	19.44	25.00	26.94	24.00	23.61	24.00	26.94	23.00	25.56
154	22.50	24.72	22.00	21.67	25.00	26.94	23.50	22.50	24.50	24.17	23.50	25.28
155	22.50	23.89	22.50	22.78	25.50	28.33	23.50	23.61	24.00	23.06	24.50	23.89
156	23.00	23.89	22.50	22.78	26.50	28.06	24.00	26.11	24.50	23.06	24.50	21.67
157	23.00	22.78	23.00	25.83	26.50	27.50	24.00	26.67	25.00	23.06	24.50	20.83
158	23.00	21.11	22.50	24.17	27.00	26.11	24.00	27.78	24.50	25.00	25.00	22.50
159	23.00	21.94	23.00	24.72	27.50	24.72	24.50	26.39	24.50	25.28	25.00	24.72
160	23.00	23.06	23.50	26.39	27.50	26.94	25.00	25.56	25.00	27.22	26.00	25.83
161	23.00	24.17	23.50	26.11	27.00	27.50	25.50	26.67	25.00	26.39	25.00	24.17
162	23.00	25.28	24.50	26.39	27.00	25.83	25.50	25.56	25.00	27.78	25.00	20.56
163	23.50	27.22	24.50	26.94	26.00	21.94	25.50	25.00	25.00	26.94	24.50	19.17
164	24.00	27.22	25.00	26.94	25.00	18.61	26.00	25.00	25.50	29.17	24.50	22.78
165	24.00	26.67	25.50	28.61	25.00	20.83	26.00	25.56	26.00	29.44	24.50	24.17
166	25.00	26.39	26.50	28.06	25.00	24.17	26.00	26.11	27.00	26.94	24.50	25.83
167	25.00	25.83	27.00	28.06	25.00	27.22	26.50	27.50	27.00	27.50	26.00	25.56
168	25.00	26.67	27.00	27.50	25.50	28.33	27.00	28.61	27.00	26.67	25.50	25.83
169	25.00	26.39	27.00	27.50	25.50	24.72	27.00	24.72	27.00	26.94	27.00	26.67
170	25.00	26.67	27.50	28.33	25.50	23.06	27.50	24.72	27.50	27.78	26.00	26.94
171	25.50	27.78	28.00	28.33	25.00	22.78	27.50	27.22	28.00	26.67	27.00	27.22
172	26.00	28.33	28.50	28.06	25.00	24.17	27.50	29.17	28.00	28.06	27.50	27.22
173	26.50	26.94	28.50	28.61	25.00	25.28	27.50	29.17	28.00	28.89	27.50	28.33
174	26.50	25.00	29.00	31.11	25.50	27.78	28.00	29.72	28.00	28.06	27.50	29.72
175	27.00	25.28	29.50	30.28	26.50	27.50	28.50	28.33	28.50	26.94	27.50	30.00
176	27.00	25.83	30.00	28.61	27.00	28.06	28.50	28.33	28.50	28.61	27.50	29.72
177	27.00	25.28	30.00	25.83	27.00	28.06	28.50	28.33	29.00	26.94	26.00	29.72
178	27.00	26.94	30.00	23.33	27.00	27.50	28.50	25.56	29.00	24.72	28.00	30.56
179	27.00	26.39	30.00	28.89	27.50	23.89	28.50	26.67	28.50	26.39	28.50	29.17
180	27.00	24.17	30.00	28.06	27.00	24.44	28.50	27.22	29.00	26.39	27.50	27.78
181	27.00	27.78	30.00	26.67	26.50	23.06	28.50	28.89	29.00	27.22	28.00	31.39
182	27.00	26.39	30.00	25.56	26.50	24.72	28.50	28.33	28.50	26.67	29.50	27.50
183	27.00	24.72	29.50	23.89	26.50	24.72	28.50	27.78	28.50	26.67	29.00	28.33
184	27.00	28.06	29.50	25.56	26.50	23.89	29.00	27.50	28.00	26.67	28.50	24.44
185	27.00	27.78	29.00	28.61	26.50	25.28	29.00	28.06	28.00	27.50	27.50	26.11

186	27.50	26.39	29.00	29.72	26.50	26.67	28.50	28.06	28.00	28.33	28.00	28.33
187	27.50	24.72	29.50	26.39	26.50	24.72	28.50	29.17	28.50	29.17	29.00	28.06
188	28.00	22.50	29.50	28.89	26.50	25.83	29.00	29.17	29.00	26.67	28.00	26.39
189	28.00	23.61	30.00	28.06	26.50	27.22	29.00	28.61	29.00	26.67	28.00	26.67
190	28.00	27.22	29.50	29.44	27.00	28.89	29.50	30.56	29.00	26.11	28.00	27.22
191	28.00	26.39	29.00	29.72	27.00	29.44	29.00	30.28	29.00	26.94	28.00	28.61
192	28.00	27.50	28.50	29.44	27.50	28.61	29.50	29.72	29.00	29.44	28.50	28.61
193	28.00	28.06	29.00	28.61	27.50	29.17	29.50	29.72	29.00	29.72	29.00	28.06
194	28.50	28.61	29.00	26.67	28.00	29.17	29.50	30.28	29.50	25.56	28.00	23.89
195	28.50	26.67	29.00	28.06	28.00	29.44	29.50	29.72	29.00	23.61	28.00	28.33
196	28.50	26.94	29.00	28.06	28.00	29.44	29.50	30.56	29.00	24.44	28.00	29.44
197	28.00	27.22	29.00	29.72	28.50	26.94	29.50	29.17	28.50	25.83	28.00	29.72
198	28.00	27.78	29.00	25.56	28.00	25.83	29.50	29.44	28.50	26.94	28.00	29.72
199	28.00	28.61	29.00	26.11	28.00	25.28	29.50	30.00	28.50	28.89	28.50	30.83
200	28.00	28.89	29.00	24.17	28.00	27.78	30.50	31.39	28.50	28.06	28.50	30.00
201	28.00	29.44	29.00	22.78	28.00	29.72	31.00	32.22	29.00	27.50	29.50	28.89
202	28.00	30.56	28.50	23.33	28.00	28.06	31.00	29.17	29.00	28.61	29.00	27.50
203	28.00	30.56	28.00	24.44	28.00	25.00	30.50	29.17	29.00	27.22	28.50	26.11
204	29.00	30.56	28.50	26.39	28.00	27.22	30.00	28.33	29.00	27.50	29.00	25.00
205	29.00	30.56	28.50	26.11	28.00	28.33	30.00	29.44	29.00	26.94	29.50	24.44
206	29.50	31.11	28.00	26.11	28.50	28.89	29.50	30.56	29.00	29.44	29.00	26.94
207	29.00	27.78	28.50	27.22	28.50	28.33	30.00	31.39	29.50	29.17	29.50	26.67
208	29.00	30.83	28.50	27.22	28.50	26.67	30.00	30.56	30.00	29.72	29.00	27.22
209	29.50	30.83	29.00	24.72	28.50	26.11	30.50	33.33	30.00	30.56	29.00	25.28
210	29.50	30.00	29.00	24.17	28.50	26.67	31.00	33.61	30.00	31.11	29.00	27.22
211	30.00	29.72	28.50	23.89	28.50	28.89	31.00	33.61	30.50	31.67	29.00	28.61
212	30.00	29.17	28.00	24.17	28.50	30.00	31.50	35.28	30.50	31.11	29.00	28.89
213	30.00	29.72	27.50	23.61	28.50	31.39	31.00	29.72	30.50	32.22	28.50	29.72
214	30.00	28.61	27.50	24.72	28.50	25.28	31.00	26.11	31.00	31.94	28.50	29.72
215	30.00	27.78	27.50	24.17	28.00	25.28	31.00	26.67	31.50	33.06	28.50	28.06
216	30.00	29.17	27.50	22.50	28.00	26.67	30.50	23.06	32.00	31.94	29.00	29.72
217	30.00	30.83	27.00	24.17	27.50	25.28	30.50	25.56	32.00	28.61	29.50	29.44
218	30.00	30.00	27.50	25.28	27.50	25.56	29.00	25.83	32.00	28.89	29.00	29.44
219	30.00	27.50	27.00	25.83	27.50	27.50	29.00	26.94	31.50	29.44	30.50	30.56
220	30.00	28.33	27.00	26.39	27.00	27.78	28.50	23.61	31.50	30.56	31.00	30.00
221	30.00	28.89	26.50	26.11	27.50	29.17	28.00	26.67	31.50	31.94	31.00	28.61
222	30.00	30.28	26.50	25.56	27.50	30.28	28.00	25.56	31.50	29.44	30.50	28.33
223	30.00	31.11	26.50	25.83	27.50	28.61	27.50	26.11	31.00	29.44	29.50	28.33
224	30.50	29.72	26.50	27.50	28.00	29.17	27.00	23.61	31.00	30.28	29.50	26.94
225	30.00	28.33	27.00	26.11	28.00	28.61	26.50	24.17	30.50	30.00	29.00	28.33
226	30.00	28.06	27.00	25.56	28.50	28.33	27.00	25.83	31.00	30.28	29.00	28.33
227	29.50	27.50	27.00	25.28	28.50	26.94	27.00	27.50	30.50	30.56	31.50	29.44
228	29.50	29.44	27.00	26.39	28.50	26.94	27.00	26.67	30.50	30.83	30.00	30.28
229	29.50	30.28	27.00	26.39	29.00	26.94	28.00	29.17	30.50	29.44	30.00	30.56
230	29.50	30.00	27.00	28.06	28.50	27.22	27.50	27.50	30.00	26.94	30.00	30.28
231	29.00	30.00	27.00	27.22	28.50	27.22	27.50	27.22	30.50	27.50	29.50	28.33
232	29.50	31.11	27.50	25.56	28.50	25.00	28.00	26.39	30.00	28.61	29.50	28.06
233	29.50	31.11	27.50	26.39	28.00	24.72	28.00	25.83	29.50	30.28	29.50	28.33
234	29.50	31.67	27.50	26.39	28.00	26.39	28.00	26.94	30.00	31.39	30.00	28.06
235	30.00	32.22	27.50	25.56	27.50	29.17	28.00	27.22	30.00	27.22	29.50	28.61
236	30.00	32.78	28.00	26.94	27.50	28.06	28.00	27.78	30.00	25.83	29.50	30.00
237	30.00	32.78	28.00	22.22	27.00	25.28	28.00	28.33	29.00	28.06	30.00	28.33
238	30.00	31.94	28.00	23.06	27.00	23.61	28.50	29.17	29.00	29.72	29.50	27.50
239	30.00	30.56	28.00	24.17	27.00	24.17	29.00	27.78	29.00	27.50	29.50	28.33
240	30.00	31.94	28.00	25.28	26.50	25.28	28.50	18.06	28.50	24.44	29.50	28.06

241	30.00	31.94	28.00	26.67	27.00	26.94	28.00	17.78	28.50	23.61	29.00	24.17
242	30.00	30.83	28.00	27.78	27.00	28.06	27.50	20.28	28.00	24.72	28.50	20.28
243	30.00	26.39	28.00	24.17	27.50	29.44	27.00	20.28	27.50	26.94	28.00	21.11
244	30.00	28.61	28.00	26.39	28.00	28.61	26.00	22.50	27.50	24.17	27.00	21.94
245	30.00	28.89	28.00	26.39	28.00	25.56	26.00	25.28	27.00	24.17	26.50	24.72
246	29.50	27.22	28.00	25.28	27.50	24.72	26.00	27.22	27.00	26.39	27.00	26.94
247	29.00	26.94	28.00	21.67	27.50	25.83	26.00	27.22	27.00	25.83	26.50	23.33
248	29.00	28.61	27.50	20.28	27.50	27.78	26.50	21.94	26.50	26.39	26.00	23.89
249	29.00	28.89	27.00	21.94	27.50	27.50	25.50	23.33	26.50	27.22	26.00	23.06
250	28.50	29.44	27.00	23.61	27.50	28.33	25.00	21.94	27.00	27.50	25.50	19.17
251	28.50	29.44	26.50	22.78	27.50	29.17	25.00	20.00	27.00	26.94	25.50	17.50
252	28.50	28.89	26.50	24.17	27.50	27.22	25.00	23.61	27.00	27.50	25.50	19.72
253	28.50	28.89	26.00	22.50	27.50	26.11	25.00	26.39	27.00	22.78	24.50	22.78
254	29.00	28.61	26.00	26.94	27.50	25.00	25.50	25.28	27.00	23.06	24.50	24.72
255	28.50	26.94	26.00	26.94	27.50	24.17	24.50	22.78	27.00	24.17	24.50	23.61
256	28.00	26.39	26.00	26.94	27.00	21.67	25.00	21.67	26.50	23.61	25.00	27.22
257	27.50	23.89	25.50	28.33	26.00	17.50	25.00	21.67	26.50	26.39	24.50	26.94
258	27.00	23.33	25.50	28.06	25.00	20.28	25.00	24.72	26.00	26.67	25.00	26.94
259	26.50	26.94	26.00	18.33	24.50	19.72	24.00	24.72	26.00	26.39	25.00	27.22
260	27.00	27.50	25.50	17.22	24.00	23.33	24.00	26.39	26.00	28.06	25.00	25.56
261	27.00	27.50	24.50	18.06	23.50	24.17	24.50	27.78	26.00	21.67	25.00	26.11
262	27.00	25.00	25.00	21.11	23.50	23.33	24.50	27.78	26.00	21.94	25.00	28.61
263	26.00	19.72	25.00	20.83	23.50	23.06	24.50	26.11	26.00	21.67	25.00	26.94
264	24.50	14.44	24.50	20.28	23.50	24.17	24.50	24.17	25.50	19.72	25.00	24.44
265	24.50	16.11	24.00	21.94	23.50	24.72	24.50	25.83	25.00	19.44	25.00	26.39
266	24.50	15.83	24.00	24.44	23.00	20.00	25.50	26.39	24.00	19.72	25.00	27.22
267	24.00	16.11	24.50	26.67	23.00	16.39	25.50	26.67	25.00	20.00	26.00	27.50
268	24.00	20.00	24.50	25.83	22.50	14.72	25.50	28.33	24.00	22.22	26.00	25.28
269	24.00	22.50	24.00	21.94	22.00	14.72	25.50	27.50	23.50	21.67	26.00	21.11
270	24.00	21.67	24.00	12.50	21.00	14.72	26.00	28.06	23.50	22.78	25.50	21.11
271	24.50	20.83	23.00	15.28	20.50	16.39	26.00	28.33	23.50	23.06	25.50	21.11
272	24.50	21.39	23.00	15.56	20.00	21.11	26.00	28.33	23.00	22.22	25.50	22.50
273	23.00	21.94	22.00	12.78	19.50	14.72	26.00	27.50	23.00	20.28	25.50	25.56
274	22.00	21.11	21.50	11.39	19.00	11.39	25.50	23.89	22.50	19.17	25.00	21.94
275	22.00	21.11	21.00	11.39	18.50	12.78	25.00	24.72	22.00	18.33	25.00	21.94
276	22.00	24.44	20.50	13.06	18.00	16.39	24.50	28.06	21.50	12.50	24.50	21.67
277	21.50	23.89	20.50	16.67	18.00	16.67	23.00	25.00	21.00	13.33	24.00	18.33
278	21.50	19.44	20.50	18.33	17.50	13.33	21.50	19.72	21.00	16.11	23.50	17.50
279	22.00	19.17	20.00	15.56	17.00	13.06	21.00	16.67	20.50	16.39	23.00	11.94
280	22.00	20.83	20.00	19.44	17.00	15.00	21.00	17.50	20.00	14.17	22.50	13.89
281	21.50	20.56	19.50	21.67	16.50	21.11	20.50	14.72	20.00	13.61	22.00	15.28
282	22.00	20.56	19.50	21.39	16.50	21.39	20.50	19.72	19.50	19.44	21.00	15.83
283	22.00	20.00	20.00	19.17	16.50	21.94	20.50	19.44	20.00	18.89	21.00	16.11
284	22.00	18.06	19.50	20.00	17.00	25.56	20.50	19.72	19.50	10.56	20.50	16.11
285	22.00	15.28	19.00	21.94	17.50	23.89	20.50	15.56	19.00	11.67	20.00	16.94
286	21.50	11.94	19.00	20.00	17.50	24.44	19.00	8.89	18.50	11.94	20.00	13.89
287	20.50	14.44	19.00	22.22	18.50	21.11	17.50	11.39	18.00	14.17	20.00	13.61
288	20.50	14.72	19.50	20.28	18.50	17.50	17.00	12.78	18.50	15.56	19.50	16.39
289	21.00	14.72	19.50	21.94	18.50	18.89	17.00	13.89	18.50	16.67	19.50	16.67
290.	20.50	18.89	20.00	22.22	18.50	21.11	17.00	15.83	18.50	16.67	19.00	20.28
291	20.00	18.61	20.00	15.83	18.50	23.61	17.50	17.78	19.00	16.39	19.00	22.50
292	20.00	19.44	20.00	20.28	18.50	22.22	17.00	18.06	18.50	16.67	18.50	17.22
293	20.00	21.94	19.50	16.94	18.50	22.50	18.00	17.22	18.00	13.33	18.50	14.17
294	20.00	18.89	19.00	16.39	19.00	22.22	18.00	16.67	17.50	9.17	18.50	12.22
295	20.00	15.00	18.00	14.72	19.00	21.39	18.00	16.94	17.00	12.78	18.50	17.22

296	19.50	15.28	16.50	12.22	19.00	23.61	18.00	16.11	17.00	13.06	18.00	15.56
297	19.00	14.44	15.50	11.11	19.00	24.17	17.00	15.00	16.50	14.17	18.00	15.00
298	18.50	14.72	15.00	12.22	19.50	19.72	17.50	16.94	16.50	14.17	18.00	14.72
299	18.00	14.44	14.50	17.22	19.50	16.11	17.50	14.72	16.50	18.61	17.50	17.50
300	18.00	13.61	14.00	21.39	18.50	17.50	17.00	14.17	16.00	13.61	17.50	11.94
301	17.50	16.11	14.00	20.83	18.50	17.50	17.00	15.28	16.00	12.50	17.00	15.28
302	17.50	15.56	14.50	20.83	18.00	17.50	17.00	17.50	16.00	16.11	17.00	13.89
303	17.50	15.56	15.00	19.44	17.50	12.50	17.00	16.39	16.00	18.89	16.50	12.22
304	17.00	17.78	15.50	20.56	17.00	11.67	17.00	15.83	16.50	18.61	16.00	9.44
305			15.50	22.50							16.00	12.22

APPENDIX B.8 AMITE RIVER

DAILY MEAN WATER TEMPERATURE DATA Tw COMPILED FROM USGS RECORDS (YEARS 1973-1974)
STATION 07378510 AMITE RIVER AT 4H CAMP NEAR DENHAM SPRINGS, LA
Lat 302630, Long 905820
DAILY MEAN AIR TEMPERATURE DATA Ta COMPILED FROM THE U.S. NATIONAL WEATHER SERVICE RECORDS
AT NEW ORLEANS, LA (AVERAGE OF DAILY MIN. AND MAX. AIR TEMPERATURES)
Lat 295724, Long 900348

Calendar	1973		1974	
Day	Tw	Ta	Tw	Ta
91	16.94	18.89	22.30	24.72
92	21.39	17.78	21.60	23.33
93	10.56	18.33	23.30	26.67
94	11.94	19.17	23.80	19.72
95	13.61	20.56	21.50	16.11
96	15.28	15.56	20.40	15.83
97	18.60	15.28	20.50	18.33
98	17.80	18.61	21.40	21.94
99	18.40	23.06	21.60	16.11
100	19.10	20.56	20.80	18.33
101	19.00	17.78	21.10	21.94
102	18.80	13.89	22.20	23.89
103	18.20	13.89	20.80	22.22
104	15.10	17.78	20.70	23.61
105	15.30	15.56	20.50	17.50
106	16.10	16.11	19.90	18.89
107	17.40	18.33	19.60	18.61
108	19.80	24.72	19.50	19.72
109	21.70	21.67	20.10	19.72
110	20.20	18.61	20.70	21.11
111	18.90	17.78	21.60	23.89
112	19.30	19.72	22.20	23.33
113	20.40	21.94	22.00	19.72
114	22.00	25.28	22.50	20.83
115	23.70	25.83	22.50	16.94
116	25.30	24.44	22.50	17.50
117	25.90	24.44	23.00	19.72
118	26.00	25.00	23.50	20.83
119	23.90	26.39	23.70	22.22
120	22.50	22.22	24.30	23.33
121	19.70	21.11	24.60	22.78
122	20.00	21.94	24.70	25.28
123	20.10	23.61	24.90	25.00
124	20.40	23.33	25.40	23.89
125	21.40	25.83	25.10	22.22
126	21.70	26.67	23.90	21.39
127	22.10	26.67	24.20	20.83
128	21.50	22.22	24.80	21.11
129	20.80	24.17	25.60	23.61
130	20.90	24.44	25.80	24.17

131	21.20	23.61	25.10	24.17
132	22.00	24.44	25.40	22.78
133	22.50	22.78	25.80	21.94
134	22.80	23.33	26.10	24.44
135	22.60	23.06	26.70	27.22
136	23.00	21.94	27.00	27.50
137	23.00	21.94	27.40	26.94
138	23.30	21.94	27.80	25.28
139	24.50	23.33	27.60	24.44
140	25.50	23.61	26.80	25.00
141	25.90	25.56	25.80	23.89
142	26.60	23.89	24.70	25.83
143	27.10	25.00	25.00	24.17
144	27.40	25.56	25.50	25.28
145	26.80	26.39	25.00	25.83
146	27.20	25.28	25.50	21.94
147	27.30	26.94	25.00	22.50
148	26.40	24.72	25.50	23.06
149	25.60	23.33	26.50	26.67
150	23.60	21.94	27.40	27.78
151	22.90	23.89	26.90	28.06
152	23.90	23.89	26.20	26.67
153	25.20	25.00	26.20	25.00
154	26.10	25.56	26.30	25.56
155	25.90	25.56	27.00	25.83
156	26.70	28.33	27.50	26.94
157	26.70	28.06	27.80	28.06
158	26.60	27.22	27.50	28.89
159	26.20	25.28	27.70	28.61
160	24.20	28.61	28.10	28.89
161	22.90	26.94	28.30	27.78
162	22.10	25.00	28.30	26.11
163	21.60	26.11	28.30	26.11
164	22.30	26.39	27.50	24.72
165	23.00	26.39	27.00	24.72
166	22.50	24.72	27.70	25.28
167	22.10	25.56	28.30	26.67
168	22.80	27.50	28.10	26.94
169	23.60	28.06	27.50	24.72
170	23.70	27.78	27.40	25.00
171	23.30	28.06	28.50	25.56
172	24.30	26.67	29.40	25.56
173	24.90	26.39	29.80	26.11
174	23.70	24.72	29.50	26.94
175	23.50	26.11	28.20	23.89
176	24.00	25.56	26.60	22.50
177	24.90	25.83	26.00	24.17
178	30.00	26.39	25.80	22.50
179	27.00	26.39	26.00	21.94
180	26.00	25.83	26.50	23.61
181	26.00	26.11	27.20	23.61
182	27.50	25.56	27.80	25.28
183	26.50	26.11	28.70	25.56
184	26.50	26.67	29.20	26.67
185	27.00	26.67	28.70	26.39

186	28.00	28.61	28.70	26.11
187	28.50	27.78	25.30	24.72
188	29.00	28.06	24.70	24.17
189	28.50	28.06	26.30	25.56
190	28.00	26.39	27.70	26.94
191	26.50	26.67	29.40	28.61
192	25.00	23.89	30.00	27.22
193	25.00	25.83	30.40	29.17
194	25.50	26.39	30.00	28.06
195	26.00	25.00	29.30	27.50
196	26.50	25.56	29.20	26.94
197	27.50	26.39	29.50	26.39
198	28.00	26.67	29.30	26.39
199	28.50	27.78	28.90	26.11
200	28.00	27.22	29.80	25.83
201	27.00	26.94	30.40	27.50
202	27.50	27.50	29.80	25.00
203	27.50	26.67	29.70	27.50
204	25.50	26.39	30.70	27.50
205	26.50	25.83	28.60	26.94
206	27.50	27.50	27.20	26.39
207	28.00	27.78	28.30	27.50
208	28.50	27.78	27.50	28.61
209	29.00	28.33	28.50	27.78
210	28.50	28.61	29.80	28.06
211	27.50	27.22	29.70	28.33
212	25.50	24.72	27.80	26.67
213	24.50	24.17	28.30	26.67
214	24.00	26.11	27.70	26.67
215	24.00	25.83	27.80	24.72
216	24.50	26.94	28.10	24.72
217	24.50	25.00	26.30	25.28
218	24.00	25.00	27.30	26.11
219	25.40	26.11	26.50	24.17
220	25.40	24.72	26.40	26.67
221	25.70	24.44	27.80	27.50
222	25.10	26.11	29.30	27.50
223	24.90	25.28	30.10	27.22
224	25.80	27.22	30.00	27.50
225	27.60	28.61	28.90	26.67
226	28.50	28.61	28.70	27.22
227	28.70	28.61	29.60	27.22
228	28.80	28.06	30.40	27.78
229	27.60	27.50	30.20	28.06
230	28.80	28.61	29.80	27.22
231	28.90	28.61	29.50	27.22
232	29.60	27.78	29.90	28.33
233	27.30	27.50	29.40	27.22
234	26.70	27.50	28.80	26.94
235	27.40	27.22	28.60	26.94
236	27.10	27.22	28.30	27.22
237	26.90	28.61	27.20	27.50
238	25.80	27.50	27.00	27.22
239	28.30	28.06	26.20	26.94
240	29.40	28.61	25.70	26.67

241	29.20	26.67	26.20	28.61
242	28.70	26.39	26.50	27.22
243	29.00	26.94	26.80	26.67
244	28.50	28.33	27.50	27.22
245	29.50	28.61	28.20	27.50
246	30.50	28.61	26.20	23.33
247	28.10	27.22	25.00	20.83
248	25.50	25.56	24.60	22.78
249	25.40	26.11	24.70	24.72
250	25.30	26.11	23.50	22.78
251	25.20	26.94	22.80	25.28
252	25.60	26.94	24.40	26.94
253	25.10	27.22	25.40	27.50
254	25.10	26.67	25.60	26.67
255	25.70	27.78	25.90	28.61
256	25.40	25.00	26.60	27.50
257	24.60	23.89	26.50	26.39
258	24.70	24.72	26.50	25.00
259	24.20	24.17	26.80	25.56
260	24.10	24.17	27.20	25.56
261	23.30	24.44	27.40	26.39
262	22.70	25.00	27.20	25.00
263	22.60	25.28	27.20	25.28
264	22.70	25.28	27.60	26.39
265	22.00	19.72	26.60	23.89
266	19.80	20.28	23.90	21.11
267	19.90	18.33	22.80	23.61
268	20.50	18.61	23.80	25.83
269	21.00	16.67	23.70	24.44
270	20.90	17.22	24.20	24.17
271	21.00	17.50	24.70	25.56
272	21.20	19.44	24.90	23.06
273	21.80	21.39	23.20	20.83
274	23.20	25.28	22.50	20.56
275	21.90	20.56	22.00	21.39
276	19.80	18.33	21.50	15.28
277	19.60	21.39	21.20	16.94
278	20.60	21.11	21.30	18.06
279	20.90	21.67	21.90	18.33
280	21.00	20.56	22.10	19.17
281	21.60	23.33	22.50	21.39
282	22.50	23.89	22.70	20.83
283	23.10	23.61	22.40	19.72
284	23.40	23.89	22.40	19.17
285	23.70	22.22	23.40	22.50
286	23.60	22.22	23.50	21.39
287	23.10	22.50	23.60	22.78
288	23.40	25.56	23.20	18.89
289	23.40	22.22	20.10	16.39
290	22.00	21.11	19.10	15.28
291	20.90	18.33	19.70	18.06
292	19.60	15.00	20.60	18.61
293	19.10	16.94	20.60	17.22
294	19.30	16.67	19.50	18.33
295	19.20	16.94	19.20	20.28

296	19.50	21.11	19.70	17.78
297	20.90	23.06	19.60	16.94
298	22.20	21.67	19.00	16.67
299	20.90	18.61	19.20	18.06
300	19.80	21.94	19.30	17.78
301	21.20	22.22	20.10	21.39
302	21.80	21.94	21.60	23.89
303	21.80	20.83	21.50	24.44
304	20.20	16.67	21.80	23.89
305				

APPENDIX B.9 PEARL RIVER

DAILY MEAN WATER TEMPERATURE DATA Tw COMPILED FROM USGS RECORDS (YEARS 1975-1981)
STATION 02489500 PEARL RIVER NEAR BOGALUSA, LA
Lat 304735, Long 894915
DAILY MEAN AIR TEMPERATURE DATA Ta COMPILED FROM THE U.S. NATIONAL WEATHER SERVICE RECORD
AT NEW ORLEANS, LA (AVERAGE OF DAILY MIN. AND MAX. AIR TEMPERATURES)
Lat 295724, Long 900348

Calendar	1976		1979		1979	
Day	Tw	Ta	Tw	Ta	Tw	Ta
91			19.30	23.61	16.20	18.06
92	17.40	13.89	20.00	23.89	16.20	20.00
93	17.50	15.56	19.20	20.28	16.40	22.50
94	17.60	17.78	17.60	19.44	16.80	18.61
95	17.60	16.39	17.50	15.83	16.80	17.22
96	17.90	19.72	17.80	16.67	17.10	17.50
97	18.20	18.89	17.80	17.50	17.30	18.89
98	18.10	18.89	18.10	23.33	17.80	21.39
99	18.50	21.94	18.50	22.22	17.90	17.22
100	18.50	17.50	18.60	21.94	18.10	16.39
101	18.50	17.22	19.20	25.83	18.10	20.56
102	18.50	17.50	20.00	25.83	17.80	20.56
103	19.00	20.28	20.30	25.28	17.30	15.83
104	19.40	20.56	20.70	23.06	16.10	12.22
105	19.70	21.11	20.80	22.22	15.80	17.50
106	20.10	21.67	20.80	20.83	15.90	16.94
107	20.40	24.44	20.60	20.00	16.10	16.39
108	20.70	24.17	20.40	23.89	16.00	17.22
109	21.00	23.06	20.40	21.11	15.90	17.50
110	21.40	20.83	20.40	22.22	16.30	18.61
111	22.00	23.61	20.40	23.89	16.90	20.83
112	22.00	22.78	20.30	22.78	17.60	23.06
113	22.40	20.56	20.20	22.50	18.20	22.50
114	22.50	20.83	20.20	22.50	18.60	19.72
115	23.30	25.00	20.30	23.06	18.90	24.17
116	23.50	21.94	20.60	24.44	19.40	23.06
117	23.00	19.44	20.40	20.00	19.00	15.28
118	22.50	18.06	20.10	18.33	18.50	17.50
119	22.00	19.17	19.60	18.06	18.70	20.83
120	22.30	21.94	19.50	20.83	18.80	21.94
121	22.20	22.78	19.90	22.50	19.20	23.61
122	21.50	20.56	20.30	25.28	19.50	24.17
123	20.90	19.17	20.90	26.67	19.80	23.33
124	21.50	20.00	21.30	23.33	20.30	22.50
125	21.50	21.11	21.10	21.67	20.50	21.94
126	22.00	20.56	21.20	20.56	20.90	26.39
127	22.40	26.11	21.90	25.56	21.20	25.83
128	22.50	23.33	22.20	23.89	21.30	26.39
129	22.30	23.06	22.50	25.00	21.70	22.22
130	22.00	21.94	23.10	27.22	21.80	22.78

131	22.00	21.94	23.80	27.22	22.30	26.94
132	21.00	23.61	24.00	25.56	23.00	27.50
133	21.20	24.44	23.30	20.00	23.30	26.67
134	21.50	23.89	22.80	21.39	23.30	26.39
135	21.00	23.06	22.80	21.94	23.10	26.67
136	21.50	20.28	23.40	24.17	22.60	24.17
137	22.00	21.94	23.90	25.28	21.70	24.44
138	22.20	23.06	24.00	23.33	21.40	25.83
139	21.00	20.56	24.20	23.33	21.40	24.72
140	20.40	18.89	24.50	24.17	21.20	25.00
141	21.00	19.44	25.20	23.61	21.50	23.33
142	21.00	21.39	24.80	25.28	21.90	25.28
143	22.00	22.22	24.30	25.28	22.50	26.67
144	22.10	24.44	24.20	24.17	23.00	25.56
145	22.60	24.44	23.80	20.83	23.30	27.78
146	23.00	22.50	23.50	16.94	24.00	28.89
147	23.00	22.50	23.60	20.83	24.50	27.50
148	22.90	25.28	23.70	25.00	25.00	27.50
149	22.50	22.22	24.10	25.83	25.40	26.11
150	22.60	22.22	23.70	23.06	25.60	28.06
151	23.40	23.61	23.40	24.44	25.80	26.67
152	24.00	26.67	24.20	27.78	26.10	25.56
153	23.50	25.83	25.20	27.50	26.60	27.50
154	23.70	25.56	26.00	27.50	26.90	27.50
155	24.50	24.44	26.50	28.06	27.20	26.94
156	24.90	24.44	26.70	27.78	27.70	27.50
157	25.30	24.17	26.90	27.50	28.20	29.17
158	25.30	23.89	27.20	28.61	28.40	30.28
159	25.30	23.33	27.70	28.06	28.50	29.44
160	25.30	23.33	28.00	28.61	27.80	27.78
161	25.60	24.44	27.90	26.94	27.00	25.56
162	26.10	25.28	27.00	26.11	27.20	26.11
163	26.80	25.83	26.20	25.28	26.90	27.22
164	27.50	24.72	26.10	24.44	26.50	26.94
165	27.80	24.44	26.10	24.17	26.80	27.22
166	28.00	25.56	25.90	24.72	27.10	29.44
167	28.10	27.50	26.00	25.28	27.50	26.67
168	28.00	26.67	27.00	26.11	27.70	28.06
169	26.90	28.61	27.70	28.61	27.90	29.72
170	26.00	27.22	28.20	27.78	27.70	29.44
171	26.00	26.39	28.50	26.67	27.60	28.06
172	26.50	26.39	28.60	26.67	27.70	27.78
173	27.00	24.72	28.50	27.78	27.90	28.33
174	27.50	23.89	28.80	28.06	27.40	28.61
175	28.00	26.11	29.00	28.06	26.90	29.44
176	28.50	27.22	29.10	28.06	26.90	30.00
177	28.50	26.11	28.80	28.06	27.20	31.39
178	29.50	26.39	28.80	27.78	27.90	30.00
179	29.00	26.94	28.80	26.94	28.50	30.56
180	29.50	28.06	28.70	28.61	28.80	31.11
181	30.00	26.94	28.30	30.00	29.60	31.11
182	29.00	26.11	28.50	29.72	30.40	32.22
183	27.50	26.11	28.70	29.44	30.60	29.44
184	27.70	26.94	29.30	28.33	30.40	28.61
185	27.20	26.94	30.00	29.17	30.50	30.56

186	26.80	28.61	30.70	30.56	30.70	29.72
187	26.30	27.22	31.20	29.72	31.00	30.00
188	25.60	25.00	30.90	30.56	31.00	31.67
189	26.30	25.56	29.70	28.89	30.50	30.00
190	27.40	26.11	28.30	26.39	30.60	30.00
191	28.10	26.39	26.80	24.44	30.50	29.44
192	27.80	26.94	25.90	25.56	31.00	30.28
193	28.60	27.78	25.80	26.39	31.30	31.94
194	29.00	27.22	25.50	30.00	31.50	31.39
195	29.00	27.22	25.10	28.89	31.60	31.67
196	28.40	27.50	25.60	28.89	31.70	32.50
197	27.70	28.61	26.10	30.00	30.70	32.78
198	28.00	28.89	26.60	29.72	29.80	30.28
199	27.60	24.44	27.30	27.78	28.70	29.72
200	27.20	26.67	27.60	28.06	28.20	29.17
201	27.30	27.78	27.70	27.78	27.50	28.33
202	28.50	26.67	27.40	28.33	26.90	29.17
203	28.70	26.39	27.00	28.89	26.80	28.33
204	29.30	26.94	26.90	27.50	26.70	28.61
205	29.80	28.33	26.90	29.44	27.00	30.00
206	29.80	28.61	26.60	27.50	27.70	29.17
207	29.40	27.78	26.10	29.72	28.10	26.94
208	29.00	28.33	26.30	29.44	28.50	29.72
209	28.90	28.89	26.80	30.28	28.40	27.22
210	29.30	27.78	27.70	28.61	28.00	28.06
211	29.60	28.06	28.60	28.89	28.70	30.00
212	28.90	28.89	29.20	28.61	29.50	29.72
213	29.30	29.17	29.60	30.00	29.70	28.33
214	29.50	29.17	29.70	29.72	29.60	28.89
215	28.80	27.78	29.60	28.89	29.10	30.56
216	28.10	27.78	29.70	29.44	28.60	30.83
217	27.60	26.94	29.80	30.00	28.80	29.44
218	28.30	28.33	29.60	28.89	29.60	29.17
219	29.00	28.61	30.00	28.33	29.70	31.11
220	29.50	29.44	29.80	27.78	29.80	31.11
221	29.50	27.78	29.90	28.06	29.80	30.56
222	29.00	24.72	30.10	28.06	29.80	29.72
223	28.00	24.44	29.80	28.89	29.50	29.72
224	28.00	25.00	29.00	27.22	29.70	30.00
225	28.50	28.06	28.40	28.61	30.20	29.72
226	29.00	27.50	28.30	27.78	30.20	29.44
227	29.10	27.22	28.70	27.22	30.30	30.00
228	29.60	27.78	28.50	28.06	29.90	28.89
229	29.70	28.33	28.80	28.33	29.50	30.00
230	29.90	29.44	28.80	28.33	29.80	30.00
231	29.60	26.94	29.00	27.78	30.30	29.72
232	28.70	26.11	29.10	28.33	30.60	30.28
233	28.00	26.39	29.00	27.22	30.80	31.67
234	28.10	26.39	28.70	28.06	30.60	32.22
235	28.30	28.33	27.80	27.22	29.80	30.00
236	28.30	27.78	27.20	26.94	29.20	30.00
237	28.30	28.33	27.40	26.94	29.10	30.00
238	28.50	28.89	27.20	27.22	28.80	28.06
239	28.60	28.33	27.60	26.94	28.50	27.50
240	28.70	27.22	27.40	28.06	28.30	27.22

241	28.50	26.94	28.00	28.61	28.20	28.33
242	28.10	27.50	28.70	29.72	28.10	29.17
243	28.50	27.50	29.00	28.61	28.40	29.44
244	28.50	27.50	28.90	28.89	28.30	29.44
245	28.20	27.78	28.80	27.50	28.00	28.61
246	28.00	27.78	28.60	26.94	27.90	29.44
247	28.00	28.33	28.70	28.33	27.50	26.39
248	27.90	25.00	28.90	29.17	26.80	27.22
249	26.90	25.83	28.80	28.61	26.80	28.61
250	26.40	27.22	28.60	28.06	27.50	29.72
251	26.50	26.67	28.80	27.78	28.30	29.72
252	27.00	26.94	28.30	26.67	28.50	30.28
253	27.50	27.78	28.00	27.50	28.60	30.56
254	27.30	25.56	27.70	28.06	28.80	31.39
255	25.90	21.39	27.00	27.22	28.70	28.89
256	25.00	23.06	26.10	28.61	28.10	28.33
257	25.20	25.83	26.10	25.83	28.40	29.17
258	25.50	25.28	25.40	24.44	28.60	29.17
259	25.50	24.44	24.80	23.06	28.70	28.33
260	25.50	24.44	24.80	27.22	27.90	25.28
261	25.60	24.44	24.90	28.33	27.00	25.28
262	25.70	23.61	25.00	26.67	26.70	28.61
263	26.00	24.72	24.30	27.78	26.80	29.44
264	25.90	24.72	23.80	24.17	27.40	29.44
265	25.70	25.00	23.60	24.17	28.10	28.89
266	25.20	22.50	23.40	24.17	28.30	28.33
267	24.70	23.06	23.10	23.61	28.40	28.33
268	25.00	28.33	22.70	22.78	28.30	29.17
269	25.30	28.06	22.50	23.33	27.80	28.06
270	25.80	28.06	22.50	23.89	26.90	27.78
271	26.00	26.39	22.80	24.17	26.70	28.89
272	25.40	24.44	23.40	25.00	26.80	30.00
273	24.90	23.61	23.70	25.28	26.20	24.72
274	24.40	22.22	23.90	25.28	25.20	23.33
275	24.20	21.11	24.10	24.72	24.40	23.61
276	23.60	21.94	23.80	23.33	23.70	21.11
277	23.90	23.61	23.50	20.28	22.80	19.72
278	24.00	22.50	22.40	18.89	22.10	21.39
279	23.50	26.11	22.10	20.83	21.00	19.72
280	23.00	20.00	22.20	23.33	20.40	18.89
281	21.50	18.33	22.50	22.22	20.40	18.89
282	20.00	14.72	22.80	25.00	20.80	20.28
283	19.00	13.89	22.50	16.39	21.30	21.94
284	18.50	15.00	21.30	16.39	21.70	24.72
285	19.00	16.39	21.10	20.28	21.20	18.33
286	19.50	16.94	21.50	21.94	20.50	17.78
287	19.50	18.61	20.90	17.78	20.00	19.17
288	20.00	19.72	20.10	20.56	20.10	21.67
289	20.50	19.17	20.50	22.22	20.90	26.67
290	20.00	19.44	21.30	22.78	22.00	29.17
291	19.00	16.94	21.70	23.61	22.40	25.00
292	18.50	15.83	22.40	25.28	21.80	21.94
293	18.50	20.56	22.90	26.39	20.40	18.33
294	18.50	13.89	23.40	28.06	19.30	18.33
295	17.00	12.78	22.40	24.44	19.50	20.56

296	16.50	13.61	21.40	18.06	20.20	24.17
297	16.80	17.78	20.40	18.33	20.90	21.67
298	17.80	21.39	19.10	16.11	19.80	13.61
299	18.40	20.00	18.60	17.22	18.70	15.28
300	18.00	15.83	18.80	19.44	18.50	24.17
301	16.90	12.78	19.30	21.39		
302	15.90	13.89	19.90	22.78		
303	15.00	16.94	20.90	25.83		
304	15.70	16.67	21.20	21.94		
305	15.60	13.61				

APPENDIX B.10 NORTH WICHITA RIVER

DAILY MEAN WATER TEMPERATURE DATA Tw COMPILED FROM USGS RECORDS (YEARS 1981-1988)
STATION 07311700 NORTH WICHITA RIVER, TX
Lat 334910, Long 994710
DAILY MEAN AIR TEMPERATURE DATA Ta COMPILED FROM THE U.S. NATIONAL WEATHER SERVICE RECORD
AT WICHITA FALLS, TX (AVERAGE OF DAILY MIN. AND MAX. AIR TEMPERATURES)
Lat 335412, Long 982936

Calendar	1983		1987		1988	
Day	Tw	Ta	Tw	Ta	Tw	Ta
91	13.40	14.44	15.80	16.94		
92	11.70	10.56	11.70	6.39	13.5	13.61
93	14.80	14.17	12.70	6.67	13.4	15
94	12.60	10.56	14.00	7.78	16.7	16.11
95	9.20	6.67	11.40	8.33	19	23.89
96	9.40	6.67	13.00	10.56	18.8	19.44
97	8.00	6.67	13.50	10.56	18.1	14.72
98	8.30	5.56	15.50	14.44	19.5	18.33
99	10.90	9.17	18.00	16.11	19.6	18.89
100	15.30	14.44	19.00	16.11	16.4	12.22
101	17.90	18.33	20.60	18.89	14.4	10.83
102	18.10	20.00	21.40	20.56	14.9	10.83
103	17.50	12.22	16.50	12.22	16.2	12.78
104	13.70	8.33	13.50	14.44	18.3	15.28
105	14.40	8.61	17.10	16.39	20.1	18.06
106	16.70	13.33	21.20	18.06	20.8	17.22
107	18.20	15.56	23.30	21.39	19.8	18.33
108	18.80	15.28	24.20	23.89	18.9	17.22
109	18.70	12.78	24.10	24.72	16.4	9.44
110	15.90	9.44	23.30	22.22	16.8	11.11
111	15.80	15.83	16.60	13.06	20.3	19.17
112	18.30	18.89	18.20	14.17	22.5	23.61
113	18.00	15.83	21.30	19.17	21.5	23.06
114	18.90	14.17	22.50	17.50	20.7	15.56
115	19.40	16.94	23.30	19.44	19.1	16.39
116	20.40	20.28	23.80	20.28	19.6	16.94
117	22.50	22.78	24.40	21.67	19.4	15.28
118	22.10	23.06	25.10	21.39	17.9	13.33
119	22.60	22.50	24.90	24.17	19.6	17.22
120	23.90	26.94	24.60	23.33	22.1	19.72
121	22.80	25.56	25.00	21.94	21.1	16.67
122	20.30	16.67	25.20	26.67	20.2	18.89
123	19.70	16.11	23.50	23.33	19.7	20.28
124	20.70	18.06	22.50	20.56	18.3	16.67
125	20.80	20.83	22.70	20.56	19.8	16.67
126	21.70	25.28	20.40	18.06	21.8	19.44
127	21.90	21.67	21.50	20.83	22.2	23.33
128	20.70	15.28	22.90	20.83	23.1	23.06
129	20.60	16.11	23.80	21.11	22.3	22.5
130	20.60	16.94	24.80	22.22	21.6	21.11

131	21.00	21.94	25.50	23.89	22.7	21.39
132	23.70	25.00	25.80	24.17	21.4	22.22
133	21.30	23.33	24.60	23.89	22.3	21.39
134	18.00	17.50	25.20	25.00	24.4	23.89
135	18.40	14.72	25.40	21.94	24.5	24.17
136	20.50	15.83	25.90	23.89	25.8	26.67
137	21.70	20.28	27.20	24.17	26.9	26.39
138	20.90	18.61	26.90	28.33	26.7	26.67
139	20.60	20.56	22.20	22.22	25.5	24.44
140	19.30	18.89	24.30	24.72	22.5	23.06
141	18.50	17.78	25.70	26.94	22.6	21.94
142	21.90	20.28	21.90	21.11	19.3	18.89
143	23.50	20.56	19.30	21.67	17	17.78
144	23.90	20.83	21.30	22.22	19.6	21.11
145	24.00	23.61	23.90	23.06	22.9	22.5
146	26.20	22.50	23.60	25.83	22.5	20.83
147	27.00	24.17	19.20	22.22	23	21.67
148	26.80	25.00	17.30	17.50	24.2	21.94
149	26.60	24.44	17.50	20.00	23.8	24.72
150	22.00	15.00	20.60	23.61	23.8	26.67
151	16.50	14.17	23.20	24.72	23.3	26.39
152	17.80	16.67	24.50	23.89	22.8	23.61
153	23.70	24.44	25.50	24.72	23.7	23.06
154	26.70	26.39	23.90	20.83	25.9	26.39
155	26.50	24.72	22.30	20.56	23.2	23.33
156	23.90	23.89	23.80	22.22	25	23.33
157	20.40	17.78	24.90	22.50	24.8	21.11
158	22.10	18.33	25.20	23.33	25.7	22.78
159	25.30	21.39	24.60	25.00	27.7	26.39
160	26.00	23.89	23.60	22.50	29.4	31.39
161	25.20	24.17	23.90	25.56	28.2	27.22
162	24.70	22.78	26.00	25.28	26.6	23.06
163	24.50	26.39	26.90	24.44	26.3	21.39
164	25.60	25.83	27.40	26.94	25.5	24.44
165	24.70	23.06	28.90	28.89	25.6	25
166	24.70	22.22	28.90	30.00	26.7	26.11
167	24.70	22.78	28.50	28.61	25.9	26.11
168	24.50	23.33	28.50	28.89	26.4	27.5
169	27.40	25.28	26.30	26.39	27.6	26.11
170	27.90	26.94	26.40	28.06	28.9	28.06
171	27.70	27.50	26.10	26.67	28.9	28.89
172	28.20	26.11	26.50	27.78	29	28.61
173	28.50	26.11	25.70	26.67	29	28.61
174	27.80	26.39	27.40	28.61	29	27.78
175	27.20	25.28	28.50	27.78	28.8	27.22
176	27.20	24.72	27.00	25.83	28.5	28.61
177	27.50	26.67	26.70	24.44	27.5	27.78
178	27.60	27.50	26.90	26.11	23.7	25.83
179	25.90	24.17	26.20	28.06	26.8	28.33
180	27.00	25.83	25.00	25.83	28.6	27.5
181	26.50	26.67	25.30	24.17	29.5	29.17
182	28.30	30.28	27.10	25.00	29.5	30.83
183	28.40	31.11	27.90	25.00	29.3	29.17
184	28.30	30.83	28.10	27.50	25.2	26.39
185	28.80	29.72	28.40	30.28	26.7	29.17

186	28.40	26.67	26.70	29.17	29.1	28.06
187	27.70	25.56	27.30	29.72	30.6	28.61
188	27.40	25.56	28.00	28.61	29.3	28.06
189	27.30	24.44	27.80	27.78	28.7	26.94
190	27.50	24.44	27.90	28.06	27.5	26.39
191	27.80	26.67	27.20	28.61	28.8	27.5
192	27.90	28.06	27.10	28.89	27.9	27.5
193	27.80	28.33	28.10	26.94	27.4	26.67
194	27.70	28.06	24.50	22.22	30.6	28.33
195	27.30	25.28	25.90	22.50	31.7	30.56
196	26.90	26.94	27.80	25.83	31.1	31.39
197	26.30	26.67	26.60	25.83	30.2	31.39
198	27.80	28.61	26.50	28.61	30	31.39
199	29.00	29.44	27.80	29.72	30.8	32.5
200	27.30	29.72	28.70	29.44	30.5	32.22
201	28.70	30.28	28.50	27.50	30.3	28.89
202	28.00	30.00	28.50	27.22	27.8	26.11
203	28.30	30.00	28.80	28.33	27.5	26.39
204	29.30	31.67	29.10	28.06	27.7	27.78
205	29.40	32.50	29.20	29.44	27.1	30.28
206	30.10	33.06	29.40	28.33	27.2	31.11
207	29.50	32.50	28.90	27.50	26.6	28.89
208	28.50	33.33	28.60	27.50	29.9	30
209	28.70	32.78	28.60	28.61	30.3	31.11
210	29.30	31.67	29.00	30.00	30.1	31.94
211	29.20	31.11	29.00	30.28	29	31.39
212	29.10	30.56	29.40	31.67	29.2	31.11
213	29.80	31.11	29.50	31.39	28.7	30.28
214	29.40	30.56	29.80	31.67	27.7	29.72
215	29.20	28.61	29.90	31.94	28.1	30.56
216	27.90	27.50	29.50	31.67	29	30.56
217	29.30	29.44	27.30	29.17	29.2	30.83
218	30.10	31.39	28.50	31.67	29.1	30.83
219	28.00	27.22	29.10	32.22	28.5	31.11
220	28.20	26.67	28.60	32.50	29.4	32.78
221	28.50	27.50	28.30	31.67	29.3	32.78
222	28.80	29.72	28.10	27.78	29.7	32.22
223	30.10	31.11	29.60	30.00	28.4	30
224	30.70	33.33	29.30	30.83	29.2	30
225	30.10	31.67	29.60	31.11	28.5	29.44
226	29.50	32.78	29.20	31.39	29.9	33.06
227	29.40	31.11	29.50	31.67	30.5	32.5
228	29.30	31.94	29.00	32.78	30.5	31.67
229	29.50	32.50	28.40	31.39	29.8	29.72
230	28.80	28.61	26.60	30.83	29.3	30.56
231	27.70	25.83	28.90	30.28	28.9	29.17
232	27.90	29.72	29.10	30.83	28.1	31.67
233	28.20	30.83	28.50	30.56	28.3	29.17
234	28.50	31.94	29.30	30.56	29.2	31.39
235	28.60	30.00	28.50	28.06	29.7	31.11
236	28.50	30.28	27.30	27.22	30.1	33.61
237	28.70	29.72	27.80	31.11	30	29.72
238	28.90	30.28	25.70	28.61	28.3	30.28
239	28.90	29.72	23.60	20.00	28	31.94
240	28.60	30.00	23.40	21.39	26.9	32.78

241	29.10	30.28	25.30	23.06	22.1	21.39
242	29.10	31.94	26.80	25.28	21.4	24.17
243	28.90	33.33	24.20	24.72	24.1	24.17
244	27.80	27.78	26.50	23.33	26.1	23.61
245	26.30	26.39	26.80	24.72	25.2	25.28
246	26.30	25.83	26.40	25.00	24.7	25
247	26.10	29.44	25.70	25.28	23.9	25
248	25.90	31.11	25.60	25.56	23.2	21.67
249	27.10	31.39	25.20	25.00	23.5	22.22
250	27.70	31.11	25.70	25.56	24.1	23.06
251	27.20	28.89	26.10	24.72	23.8	26.67
252	26.90	27.50	26.80	24.44	24.1	26.11
253	27.20	28.61	26.10	23.89	24.9	26.39
254	27.00	29.17	25.80	23.89	25.3	25
255	27.30	28.33	25.60	22.22	25.8	25.28
256	24.70	21.94	26.30	26.94	25.6	27.22
257	24.00	23.06	24.90	26.67	26.7	25.83
258	25.00	28.33	24.60	26.11	26.1	24.17
259	26.30	26.67	24.40	24.17	26.1	25.83
260	26.70	30.00	25.20	25.83	27.3	27.22
261	26.20	30.28	22.00	20.00	26	25.28
262	26.00	26.11	21.60	20.28	23.2	24.72
263	19.70	16.94	22.60	21.94	23	21.67
264	16.60	12.22	22.50	20.56	22.7	22.78
265	17.80	18.33	22.40	20.00	25.7	28.06
266	18.80	18.33	22.10	21.39	26.7	27.22
267	19.70	23.33	22.20	23.61	26	25
268	21.70	22.78	22.30	23.33	23.6	19.72
269	23.50	24.72	21.70	23.89	23.9	20.28
270	24.00	25.83	22.90	25.56	24.8	22.78
271	23.70	25.83	21.70	21.94	25.3	23.89
272	22.90	24.72	21.20	21.39	25.4	25.56
273	22.30	21.94	21.30	19.44	20.1	16.94
274	22.90	25.28	20.20	19.72	19.3	17.78
275	23.80	26.67	21.90	17.22	20.6	20
276	25.00	26.67	17.80	13.61	20.1	18.33
277	24.10	22.78	18.30	17.78	19.8	17.5
278	21.60	20.83	19.10	19.72	19.8	17.78
279	21.40	17.50	18.20	16.94	18.4	16.94
280	21.10	19.44	18.30	17.22	18.2	18.06
281	19.60	18.33	19.10	22.50	18.6	15
282	20.10	20.83	20.00	23.06	18.7	15.28
283	21.20	20.56	19.00	15.83	18	14.17
284	20.20	19.44	15.30	10.56	17.5	17.5
285	17.50	13.61	15.60	12.78	18.1	16.94
286	17.10	16.94	17.50	15.83	17.3	14.17
287	18.00	19.72	18.90	18.89	17.8	16.94
288	19.80	20.56	18.10	18.06	19.2	20.83
289	21.20	22.22	18.80	20.28	20.9	21.11
290	19.80	19.72	17.30	15.56	22.4	23.89
291	21.50	22.22	18.20	19.17	23	26.11
292	18.40	22.22	18.60	17.50	19.9	17.78
293	15.70	18.06	15.90	12.78	17.5	14.17
294	14.60	13.61	14.00	11.94	18.2	17.22
295	15.70	13.33	15.50	16.67	18.6	18.33

296	17.10	14.17	17.10	18.61	19.5	20
297	18.60	16.67	19.10	20.56	18.5	16.11
298	18.30	13.61	19.50	20.00	16.1	16.39
299	15.40	13.89	19.60	20.83	17.6	19.17
300	17.00	16.11	16.90	15.00	17.1	15.83
301	18.10	17.78	15.70	15.28	19	23.33
302	19.30	19.17	17.60	20.00	14.3	13.89
303	19.20	17.78	19.50	23.61	15	16.11
304	19.60	20.83	20.30	22.22	15.3	11.39
305					15.7	12.5

APPENDIX B.11 PLUM CREEK

DAILY MEAN WATER TEMPERATURE DATA Tw COMPILED FROM USGS RECORDS (YEARS 1981-1986)
STATION 08173000 PLUM CREEK, TX
Lat 294158, Long 973612
DAILY MEAN AIR TEMPERATURE DATA Ta COMPILED FROM THE U.S. NATIONAL WEATHER SERVICE RE
AT SAN ANTONIO, TX (AVERAGE OF DAILY MIN. AND MAX. AIR TEMPERATURES)
Lat 292524, Long 982942

Calendar	1981		1982		1983		1984		1985	
Day	Tw	Ta	Tw	Ta	Tw	Ta	Tw	Ta	Tw	Ta
91	18.80	20.83	20.20	22.22	19.00	19.44			18.00	15.83
92	18.80	16.67	20.70	25.28	17.70	15.00	17.40	17.78	17.70	15.28
93	19.60	25.83	20.50	18.33	16.50	15.56	18.30	20.28	18.10	18.33
94	20.30	19.72	19.40	20.56	17.70	23.33	18.70	18.06	19.20	21.11
95	18.80	16.39	20.00	23.06	18.00	15.00	17.50	17.22	20.10	19.17
96	17.60	16.11	18.60	15.00	16.40	14.17	16.40	13.61	19.50	18.06
97	17.90	21.67	17.00	16.11	15.30	13.06	15.90	15.28	20.10	19.17
98	18.90	24.44	18.20	24.17	14.80	10.83	16.70	19.72	18.20	13.33
99	19.90	25.00	17.90	12.50	14.10	11.11	18.10	20.56	17.20	16.67
100	20.80	24.72	15.80	14.17	14.90	16.67	18.50	20.83	17.30	15.28
101	21.10	23.06	15.00	14.17	16.20	17.78	19.20	21.67	17.20	18.06
102	21.30	25.56	16.00	20.28	17.70	22.78	19.20	21.11	19.30	20.56
103	21.70	25.28	18.20	26.11	19.00	21.67	19.50	20.83	20.00	19.72
104	22.00	24.17	19.80	24.17	17.40	14.17	19.30	21.11	19.80	20.00
105	21.70	20.56	20.50	23.89	15.40	11.67	19.60	19.17	20.70	23.61
106	21.40	22.22	21.20	24.72	14.90	13.61	17.90	17.22	21.50	21.67
107	21.50	24.72	21.00	21.67	15.30	15.56	16.60	16.94	22.70	22.22
108	21.50	24.44	19.80	18.89	16.50	20.28	16.10	17.50	22.80	22.50
109	21.70	25.56	20.00	25.28	17.10	20.56	17.70	21.39	22.30	22.78
110	22.30	26.39	20.30	18.61	17.50	23.61	19.80	25.28	22.50	24.44
111	22.50	24.44	17.70	14.72	19.30	22.78	21.90	29.17	22.20	21.67
112	22.10	22.78	15.60	9.44	19.60	22.50	22.50	25.56	22.50	27.22
113	20.50	20.83	14.50	12.22	19.10	18.89	20.80	20.56	23.70	24.17
114	19.40	18.61	14.20	12.50	18.20	16.94	19.20	18.89	22.90	20.28
115	19.10	19.44	15.00	20.83	17.60	16.94	19.30	21.67	21.90	20.83
116	19.80	22.78	16.50	19.72	17.80	19.72	19.70	23.06	21.50	22.50
117	20.90	23.89	17.70	19.44	18.80	23.33	21.30	28.06	22.70	24.17
118	21.80	24.72	18.80	21.67	20.50	25.56	22.20	25.00	23.40	24.72
119	22.30	25.28	19.60	21.94	21.30	24.44	22.20	24.72	23.50	23.89
120	23.10	25.83	20.00	19.72	21.80	26.39	22.70	26.11	23.50	25.28
121	23.70	27.22	20.00	21.39	22.50	28.61	20.80	19.17	23.50	24.17
122	22.40	21.67	20.00	21.39	23.30	27.78	20.10	23.33	23.00	22.22
123	22.00	22.50	20.20	22.22	22.60	20.28	20.50	26.94	22.70	20.83
124	22.20	23.61	20.60	23.61	20.80	19.17	21.70	26.67	22.30	20.83
125	22.10	24.44	20.90	21.94	20.20	20.56	22.20	26.11	22.30	22.78
126	22.10	23.33	20.50	20.00	20.40	24.17	23.40	29.72	22.20	22.78
127	22.00	23.06	19.80	16.94	21.70	28.06	24.40	29.17	22.70	25.00
128	22.40	24.44	19.10	18.33	21.70	21.94	25.30	29.72	23.40	26.11
129	22.60	24.44	19.50	20.83	20.40	20.00	23.30	20.56	23.00	23.89
130	21.00	18.89	19.90	20.83	20.50	21.67	21.00	17.22	23.20	26.11

131	19.30	18.06	20.80	22.78	21.40	24.44	19.90	20.00	24.00	26.39
132	19.40	22.50	21.40	25.00	22.40	24.72	20.50	24.44	24.20	26.39
133	20.60	25.56	21.30	21.94	22.70	25.28	21.80	26.94	24.30	26.94
134	21.50	23.06	22.60	22.78	22.90	21.94	23.00	26.94	22.70	22.78
135	20.60	20.00	23.10	25.28	21.00	17.78	23.50	25.56	22.00	23.33
136	21.00	26.11	22.80	25.28	19.20	18.33	23.40	23.61	22.80	26.39
137	22.50	28.33	22.80	22.78	19.40	19.72	23.00	24.17	23.30	23.33
138	24.10	28.33	23.40	24.17	20.50	23.89	22.40	21.39	22.90	21.94
139	23.50	23.33	24.20	25.83	20.70	20.83	21.90	21.67	22.60	22.22
140	21.50	20.56	24.40	26.11	20.10	18.89	21.60	23.61	23.00	25.00
141	20.60	21.11	24.70	25.83	20.30	23.06	22.50	25.83	23.20	24.44
142	21.20	26.67	24.70	25.00	22.80	25.56	23.10	26.67	23.50	23.61
143	22.60	25.00	24.50	22.50	22.50	25.00	24.00	28.89	23.90	25.56
144	23.00	22.78	24.10	22.50	22.80	24.44	24.80	28.61	23.80	23.61
145	22.90	24.44	24.70	25.56	23.60	23.89	25.20	27.78	23.50	24.17
146	23.50	28.06	25.50	26.11	24.20	25.56	25.60	27.50	24.20	25.83
147	24.40	27.78	25.60	26.11	24.30	24.72	25.80	27.78	24.30	27.22
148	25.10	28.61	25.30	26.94	24.20	25.56	26.10	28.61	24.30	28.06
149	24.00	23.06	25.60	27.78	24.50	26.11	25.90	26.11	25.00	28.61
150	22.40	24.44	25.90	27.22	24.60	25.28	24.20	21.39	25.90	28.61
151	22.60	24.17	25.60	26.39	23.40	19.72	22.20	19.17	26.50	29.17
152	23.70	25.83	24.30	23.61	21.70	21.11	21.20	19.44	27.00	29.44
153	24.30	27.78	24.00	26.11	22.30	27.22	21.50	21.94	26.80	28.61
154	24.20	27.50	24.30	26.67	23.40	28.06	22.10	22.78	26.70	29.44
155	24.50	25.83	24.80	26.94	24.20	28.61	22.60	24.17	26.90	29.44
156	24.90	27.22	25.00	26.67	23.90	25.28	23.00	27.22	26.60	26.94
157	25.50	28.33	24.90	27.22	23.10	21.11	23.80	28.33	25.70	24.72
158	26.10	30.00	25.00	28.33	22.30	21.39	24.10	25.83	24.50	28.33
159	26.90	30.83	24.90	27.50	22.30	23.06	24.30	29.17	25.60	28.61
160	27.20	30.28	24.60	28.06	22.70	24.44	25.40	29.17	26.30	28.33
161	27.20	30.00	25.00	28.06	22.90	25.28	25.70	28.89	26.50	29.17
162	26.20	24.72	25.60	29.17	23.20	25.83	25.80	28.06	26.80	28.61
163	24.20	25.83	24.40	22.50	23.70	27.50	25.80	27.50	26.60	25.00
164	24.70	25.00	23.70	25.28	24.20	27.50	25.70	26.94	25.60	23.06
165	25.20	26.67	24.00	26.39	24.60	27.50	25.40	27.22	25.20	26.11
166	26.30	28.89	24.80	28.89	24.40	23.06	25.70	27.22	25.70	28.06
167	25.40	22.78	24.90	27.78	23.90	23.61	25.90	27.50	26.10	27.78
168	24.10	23.89	25.20	26.94	24.00	23.89	26.10	27.78	26.80	29.44
169	25.00	27.50	25.50	28.61	24.50	25.83	26.10	28.06	26.40	25.56
170	25.80	28.06	25.60	28.33	24.90	25.83	26.20	29.17	24.80	24.17
171	26.30	28.89	25.80	27.78	25.20	26.11	26.00	28.33	24.50	25.00
172	26.50	29.17	25.60	27.22	25.20	27.22	26.20	29.17	25.00	26.11
173	26.80	28.89	25.70	28.06	25.40	26.67	26.50	29.72	24.90	25.00
174	27.20	28.61	25.00	26.67	25.10	26.67	26.90	29.44	25.00	28.06
175	27.40	28.06	25.60	29.17	25.20	26.94	27.20	29.72	25.90	26.11
176	27.00	27.22	25.60	27.78	24.70	26.39	27.60	30.00	26.20	27.22
177	27.40	26.94	25.70	30.00	24.10	27.78	27.80	30.83	26.70	28.06
178	27.30	26.39	25.80	29.44	25.70	30.83	27.90	31.11	27.10	25.83
179	27.40	27.50	26.00	30.56	26.40	30.56	27.70	30.28	26.50	23.61
180	27.60	27.78	26.20	30.00	26.70	31.11	27.20	28.06	25.10	22.78
181	27.50	28.33	26.20	26.67	27.00	30.56	27.30	30.83	24.50	24.17
182	27.50	28.06	26.20	28.06	27.20	31.67	27.50	31.11	24.60	25.00
183	27.70	29.17	26.40	29.72	27.20	31.39	27.10	29.17	25.10	27.50
184	27.90	28.89	26.50	30.00	27.10	31.39	27.20	29.44	24.80	23.89
185	27.80	27.78	26.50	29.44	27.00	30.83	27.30	29.44	22.90	23.61

186	26.40	25.56	26.50	30.00	26.90	29.44	27.40	30.00	24.20	25.83
187	25.00	25.00	26.30	30.28	26.20	27.22	27.60	30.00	25.10	26.39
188	25.60	25.56	26.20	29.72	25.80	27.50	28.20	30.00	25.60	27.22
189	26.10	27.22	26.20	28.89	25.30	27.50	27.80	29.72	26.10	26.67
190	26.50	28.89	26.20	28.61	25.30	26.67	27.70	30.00	26.60	27.78
191	26.50	28.06	26.30	29.44	25.20	27.78	27.70	30.00	27.00	28.89
192	26.80	28.06	26.30	29.44	25.50	27.78	27.80	30.28	27.10	27.50
193	27.20	28.06	26.40	29.17	25.30	26.11	27.90	30.56	26.00	26.11
194	27.50	29.17	26.30	28.33	24.90	25.56	27.50	29.72	26.30	28.06
195	27.60	29.72	26.30	28.89	24.70	24.72	27.20	29.17	26.60	28.61
196	27.50	28.89	26.50	30.28	24.20	23.89	27.70	29.44	26.90	27.78
197	27.20	29.17	26.60	30.00	23.90	25.83	27.40	29.72	27.10	28.33
198	27.10	29.44	26.60	29.72	24.60	27.78	27.40	30.83	27.00	28.33
199	27.10	30.00	26.60	29.44	25.20	26.94	27.20	31.11	27.10	28.61
200	27.00	30.56	26.60	29.72	25.30	26.67	27.30	31.39	26.90	27.22
201	27.00	29.44	26.50	29.72	25.50	27.22	26.80	30.28	26.70	27.78
202	26.80	30.28	26.70	29.44	25.80	28.06	26.70	30.00	26.90	28.61
203	27.00	30.28	26.60	29.17	26.00	27.50	26.90	30.00	27.20	29.17
204	27.00	30.83	26.60	30.28	26.30	28.33	26.80	29.17	27.40	28.89
205	27.00	30.00	26.70	30.28	26.50	29.72	26.80	30.00	27.40	29.44
206	27.00	30.83	26.70	30.56	26.70	30.00	26.30	25.83	27.40	30.28
207	26.70	29.44	26.80	30.28	26.80	30.00	25.30	27.22	27.60	29.44
208	26.60	29.72	27.10	30.28	26.90	30.00	25.70	29.44	27.50	28.89
209	26.70	30.56			27.00	30.00	26.20	29.17	27.20	28.89
210	26.60	29.72			27.00	30.00	25.90	27.50	27.20	29.72
211	26.70	30.00			27.10	30.00	26.10	28.61	27.20	30.00
212	26.80	30.83			26.90	28.61	25.50	26.94	27.20	30.00
213	26.90	30.56			26.80	28.89	25.10	27.22	27.50	29.72
214	26.80	29.72			26.70	29.44	25.20	27.50	27.60	30.28
215	26.60	30.00			26.70	29.17	25.30	28.89	27.50	29.44
216	26.60	30.83			26.30	26.67	25.70	30.00	27.50	29.44
217	26.70	31.39			26.00	25.83	25.70	29.44	27.50	30.00
218	26.80	31.39			26.10	27.78	25.90	29.44	27.60	30.28
219	26.80	30.83			26.30	28.61	26.40	30.56	27.70	30.56
220	26.90	30.83			25.90	27.22	26.50	30.28	27.80	30.56
221	25.70	28.89			25.40	27.78	26.80	30.00	27.80	31.11
222	25.70	30.28			25.90	28.89	26.80	29.17	27.50	30.00
223	25.90	30.83			26.50	29.72	26.80	29.72	27.40	30.00
224	26.10	30.83			27.00	29.17	27.00	29.72		
225	25.90	30.00			26.80	28.89	26.80	29.44		
226	26.00	30.56			26.60	28.89	26.50	28.06		
227	26.40	30.83			26.90	29.17	26.20	27.50		
228	26.90	31.39			26.90	29.44	25.90	26.94		
229	27.20	30.28			26.90	28.61	25.90	26.94		
230	26.60	28.61			26.40	29.44	26.30	28.33		
231	25.70	26.67			26.00	29.17	26.70	29.17		
232	25.40	27.78			26.40	30.83	26.90	30.28		
233	25.30	27.50			26.80	31.11	27.50	31.11		
234	25.00	26.67			27.00	30.56	27.30	29.72		
235	25.10	26.67			27.10	30.56	27.60	30.00		
236	25.60	28.61			27.20	30.28	27.30	28.89		
237	25.80	28.33			26.90	29.72	27.50	30.56		
238	25.90	28.89			26.70	28.89	27.20	28.89		
239	25.90	28.61			26.70	29.72	26.70	28.06		
240	25.80	28.89			26.70	29.17	27.10	30.00		

241	25.60	27.22			26.70	28.61	27.50	30.28		
242	25.30	24.72			26.90	30.56	27.60	30.00		
243	24.70	28.89			27.10	30.83	27.60	29.72		
244	26.40	29.17			26.70	30.00	27.10	28.61		
245	26.20	28.33			26.30	28.61	26.40	28.33		
246	26.30	27.22			25.90	27.78	26.00	27.22		
247	26.00	28.61			25.90	28.61	25.50	25.83		
248	25.90	27.22			26.10	30.28	25.20	25.28		
249	26.10	28.89			26.60	31.67	24.20	24.44		
250	26.20	29.44			26.80	27.78	23.70	24.17		
251	26.30	26.11			26.30	27.50	23.60	25.56		
252	25.10	25.56	25.80	27.78	25.70	25.83	24.60	28.33		
253	24.10	25.56	25.10	26.67	25.60	27.22	25.60	30.00		
254	24.50	26.11	25.50	28.33	25.40	27.22	26.20	29.72		
255	24.60	27.22	26.10	30.83	25.50	28.06	26.20	29.17		
256	24.80	28.89	26.30	28.33	25.40	28.06	26.30	29.17		
257	25.20	26.94	25.80	28.06	25.20	26.94	26.40	28.33		
258	24.80	26.94	25.60	27.22	24.90	26.11	26.20	27.50		
259	24.60	25.83	25.30	26.94	25.40	29.17	25.90	27.50		
260	23.00	21.11	25.40	27.22	25.70	29.72	24.70	24.72		
261	20.70	19.17	25.70	27.78	25.30	25.83	23.50	23.89		
262	19.30	17.22	26.00	27.78	24.50	26.94	23.00	25.56		
263	19.00	20.28	25.40	23.89	24.80	24.72	23.00	24.72		
264	19.80	23.89	23.70	22.22	21.90	17.50	22.80	24.44		
265	21.10	26.11	21.80	20.28	19.70	16.11	22.20	21.94		
266	22.30	28.06	20.90	19.72	19.00	18.89	23.30	26.39	25.10	26.67
267	23.10	27.50	21.00	21.94	19.10	20.00	24.00	28.06	24.00	24.17
268	23.20	26.39	21.50	24.72	20.00	23.61	25.20	29.44	24.30	28.61
269	23.70	28.33	21.30	23.33	21.30	24.72	25.40	27.22	23.30	22.22
270	24.00	27.22	21.90	26.39	22.10	25.00	23.90	22.22	21.60	21.94
271	23.90	26.11	22.80	26.67	22.50	24.72	22.60	21.11	21.50	23.89
272	23.60	25.00	23.50	27.50	22.30	23.33	21.70	18.33	21.20	18.06
273	23.60	26.94	23.90	27.50	21.90	22.22	19.50	14.72	19.30	12.78
274	23.80	28.06	24.30	26.67	21.40	21.67	18.30	16.39	17.60	15.56
275	24.00	27.22	24.30	26.67	21.60	24.72	17.50	16.39	17.30	17.78
276	24.40	29.17	24.30	26.94	22.20	26.11	17.80	18.89	17.90	19.44
277	24.70	28.89	24.00	25.83	23.00	27.22	18.70	23.33	18.90	21.94
278	25.00	28.89	23.90	25.28	23.80	26.67	19.30	21.11	18.50	17.78
279	24.70	23.33	24.10	26.94	24.20	26.94	21.00	26.67	17.50	17.22
280	24.60	21.94	24.40	26.11	24.00	26.67	22.50	25.83	17.90	20.28
281	22.40	19.17	24.80	28.33	23.90	25.28	22.30	22.22	19.40	24.72
282	21.00	22.22	24.70	21.94	23.30	19.72	22.30	24.44	21.10	26.11
283	21.50	25.56	22.40	16.67	22.10	21.94	20.50	22.50	22.60	27.22
284	22.90	28.33	20.40	15.83	21.80	21.39	21.00	23.89	23.50	27.22
285	24.10	29.17	18.60	14.44	20.90	16.67	21.30	20.83	24.00	26.67
286	24.80	28.89	18.20	18.33	18.40	15.00	22.10	24.44	24.40	27.78
287	25.20	28.89	18.10	17.50	18.00	18.89	22.10	21.39	24.70	25.56
288	25.20	28.33	18.20	19.17	18.50	20.00	21.20	21.94	23.20	19.72
289	25.20	27.50	18.30	19.44	19.80	23.33	21.60	23.61	21.80	20.28
290	25.50	27.50	18.70	20.00	21.00	25.56	23.00	26.94	22.10	24.17
291	24.20	18.61	19.50	21.11	22.00	25.83	22.40	21.11	23.50	26.94
292	21.40	15.83	20.50	24.17	23.00	26.67	22.70	26.67	23.30	21.94
293	19.60	17.50	19.80	18.33	23.40	23.06	22.30	20.56	21.90	20.56
294	19.50	20.83	18.00	16.94	22.00	20.00	21.50	25.28	21.30	20.00
295	19.30	15.83	16.90	15.56	20.50	19.17	21.50	18.61	21.50	22.78

296	16.80	12.50	16.00	14.72	19.40	18.33	19.10	14.17	22.00	23.06
297	15.40	12.22	15.50	14.17	18.80	19.72	15.30	13.61	22.50	24.44
298	16.00	19.72	14.00	12.50	18.60	18.33	15.30	14.44	22.60	23.33
299	15.90	14.44	14.20	15.83	17.80	16.94	16.00	16.39	22.00	22.78
300	14.80	13.61	15.50	21.39	16.60	15.56	17.60	21.67	21.10	20.28
301	14.90	15.28	17.50	22.50	16.00	15.83	19.70	21.94	19.60	20.28
302	15.60	16.94	18.40	20.56	16.50	20.00	21.10	23.61	18.10	20.28
303	16.80	20.28	19.20	22.78	17.70	21.67	21.80	23.89	17.10	19.17
304	19.50	19.44	20.40	26.11	18.30	20.00	22.20	23.61	16.40	18.33
305							22.70	25.83		

APPENDIX C

DEPTH VS. DISCHARGE RELATIONSHIP FOR STREAMS

Examples of values for the Relationship $h = aQ^b$ giving the Water Depth vs. the Discharge

River, River Basin or area	a	b	Mean annual Discharge Range (cfs)	Reference
State of Minnesota	0.074	0.55	400-20,000	MacDonald et al. (1991)
Republican-Kansas R. (Kansas)	0.14	0.43	30-10,000	Leopold et al. (1953)
Tombigbee (Ala.)	0.78	0.34	600-40,000	Leopold et al. (1953)
French Broad (N.C.)	0.20	0.37	40-20,000	Leopold et al. (1953)
Belle Fourche (Wyo.)	0.11	0.45	40-700	Leopold et al. (1953)
Yellostone-Bighorn (Wyo.)	0.16	0.40	300-10,000	Leopold et al. (1953)
Loup (Nebr.)	0.69	0.087	100-4,000	Leopold et al. (1953)
MIssissippi, main stem	0.25	0.39	150,000-650,000	Leopold et al. (1953)
Madras irrigation canals (India)	0.40	0.33	45-6,000	Leopold et al. (1953)
Missouri, main trunk and Lower Mississippi R.	0.036	0.55	15,000-700,000	Leopold et al. (1953)
Great Plains and Southwest		0.40		Thomann et al. (1987)
Tennessee Valley		0.48		Thomann et al. (1987)
Scioto River, Susquehanna basin, PA		0.30		Thomann et al. (1987)
Willamette River, Eugene		0.61		Thomann et al. (1987)
to Oregon City, OR		0.40		Thomann et al. (1987)
Black River, NY				
Watertown (MP11-16)		0.1		Thomann et al. (1987)
(MP54-65)		0.4		Thomann et al. (1987)
Deleware River, below Easton, PA (MP135-185)		0.5		Thomann et al. (1987)