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Required Record Length for a Nonlinear Weekly Air-Stream Temperature Regression Model

by

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ABSTRACT

A four-parameter, logistic stream temperature model was fitted to nine records ranging in length from approximately 12 to 29 years. Samples ranging in length from 3 to 15 years were extracted from each of the nine records and also fitted with the model. Statistical comparisons of the model parameters derived from the long-term records were made with those obtained from the samples by means of an F-test. No significant change in the percentage of sample models determined to be statistically nonsimilar occurred until 15-year sample models were introduced. Of the sample models derived with 15-years of data, 19% were not statistically similar to corresponding population models, assuming that the full record represented the population. Stream temperature/air temperature relationships obtained from short record lengths, e.g. three years, are characterized by fluctuations due to extraordinary meteorological and/or anthropogenic influences. Population stream temperature/air temperature relationships are, in essence, composed of an aggregate of characteristic stream temperature/air temperature relationships. Because fluctuations in weather parameters have many different time scales, i.e. diurnal, seasonal, multiyear (El Nino) and longer (cooling and warming cycles), the most consistent representation of long-term stream temperatures will therefore result from stream temperature/air temperature relationships developed from records of more than 15 years length.

ACKNOWLEDGMENTS

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1. INTRODUCTION

Mohseni et al. (1998a) developed a nonlinear stream temperature model to describe the relationship between weekly stream temperatures and air temperatures. Nonlinear, least squares regression was used to fit the model to three-year records. The relationship, also known as a 4-parameter logistic function, is defined as

$$T_s = \mu + \frac{\alpha - \mu}{1 + \exp\left(\gamma\left(\beta - T_a\right)\right)} \qquad (1)$$

Weekly air temperature and predicted weekly stream temperature are represented by T_a and T_s, respectively. The four parameters of the model define thermal characteristics of the nonlinear relationship. Figure 1.1 shows a schematic diagram of the function and its parameters. The parameter α represents an upper bound stream temperature; β and γ define the air temperature at the inflection point and a measure of the steepest slope of the S-shaped relationship, respectively; and μ represents a lower bound stream temperature. An analysis of Mohseni et al.'s (1998a) study prompted a modification of the logistic stream temperature model (Erickson et al., 1998a) and revealed the inadequacy of three-year records for the representation of long-term relationships (Erickson et al., 1998b). Using the modified logistic stream temperature model, the objective of this study is to determine the record length for which all sample stream temperature/air temperature relationships are statistically similar to their true, long-term relationships.

The study by Erickson et al. (1998b) investigated the representation of the original logistic stream temperature model developed from long-term records (12 to 32 years in length) with stream temperature models developed from three-year samples of the same long-term records. Four and three paired weekly air temperature and stream temperature records were studied from Minnesota and Oklahoma, respectively. The results of the study showed that approximately 32% of the three-year sample models were not statistically similar to their corresponding long-term models. No cause was determined for the large number of statistical nonsimilarities. A contributing factor may have been the variations in the thermal regime of the streams caused by changes of shading and wind sheltering characteristics and/or the addition/removal of thermal effluents over the periods of record. In addition, nonlinear, least squares estimates of the logistic function's parameters are inherently biased; the bias varies with respect to the number of data a relationship is developed with, as well as the character of the data with respect to the fitted model (Ratkowsky, 1983). The parameter representing upper bound stream temperature, α, was thought to be affected most by this bias. This parameter was underestimated relative to the long-term model value in approximately 84% of the three-year sample models; the α estimates determined for three-year samples were also highly variable.

To avoid biased parameter estimates, especially upper bound stream temperature, α, the logistic stream temperature model was modified. An independent, rather than a nonlinear, least squares estimate of α was used. Utilizing the methodology developed by Hershfield (1961) for the determination of probable maximum precipitation events, an enveloping standard deviate, K_E, was evaluated for maximum weekly stream temperatures (Erickson et al., 1998a). The parameter K_E used in combination with the mean, $\overline{T}_{MAX}$, and the standard deviation, S_{MAX}, of maximum stream temperature series gives estimates of α as

$$\alpha = \overline{T}_{MAX} + K_E S_{MAX} \qquad (2)$$

The parameters β, γ, and μ remained least squares estimates. In addition, the determination of the four model parameters, α, β, γ and μ, was not restricted to three-year records. Because the bias of the nonlinear parameters β, γ, and μ are reduced with increasing record length, and increasingly more representative sample statistics of the corresponding maximum stream temperature series are obtained for the estimation of α, stream temperature records of maximum available length were used. Both modifications of Mohseni et al.'s (1998a) model were successfully applied in studies by Erickson et al. (1998a) and Mohseni et al. (1998b).

The length of existing stream temperature records in the USGS water quality monitoring station network is highly variable. For instance, of the 293 stream temperature records used in Erickson et al.'s (1998a) study, only 146 (approximately 50%) had a length of five years or greater. Stream temperature records of short duration, e.g. records less than or equal to five years in length, are not representative of long-term relationships on a consistent basis. Stream temperature records of long duration, e.g. records greater than or equal to 25 years in length, should reveal the true stream temperature/air temperature relationship at a particular location much better and should allow for mostly unbiased estimates of model parameters. The objective of this study, therefore, is to determine the relationship between record length and the quality of a sample stream temperature/air temperature relationship.

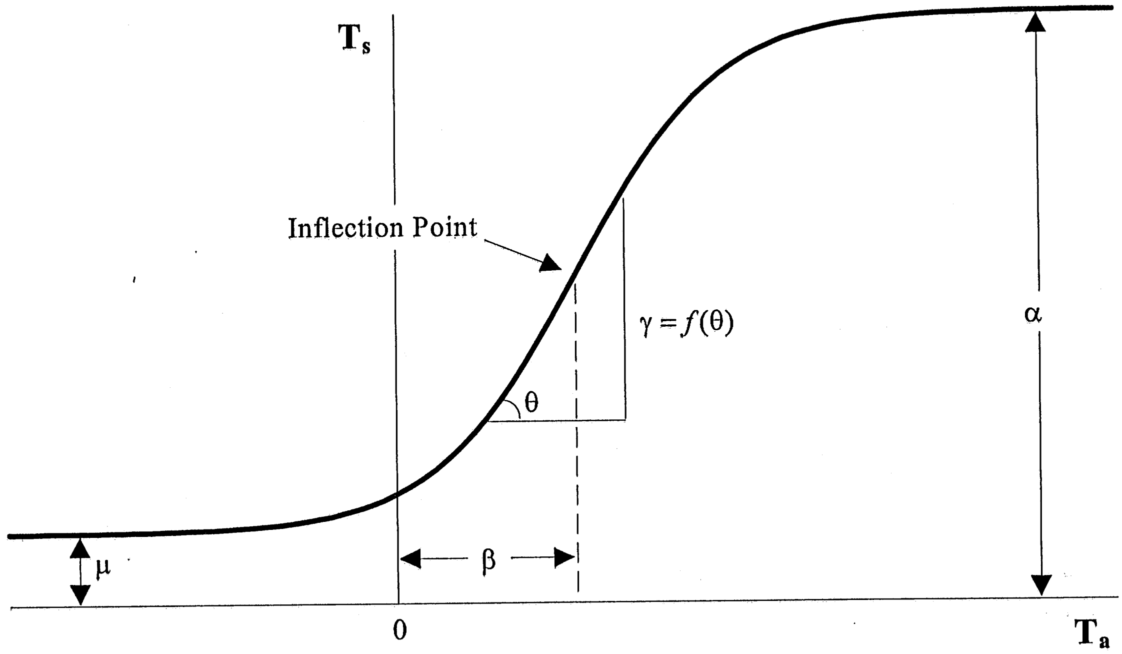

Figure 1.1 Schematic representation of the logistic stream temperature model and its parameters.

2. METHOD OF ANALYSIS

2.1 Stream Temperature and Air Temperature Data

The data used for this study consist of paired weekly stream temperature and air temperature records obtained from past studies by Erickson et al. (1998a) and Mohseni et al. (1998b). Air temperature data were obtained from first order weather monitoring stations in the Solar and Meteorological Surface Observation Network provided by the National Oceanic and Atmospheric Administration (NOAA) and the National Renewable Energy Laboratory (NREL). Stream temperature data were obtained from the Mid Continent Ecology Division, US Environmental Protection Agency, Duluth, Minnesota in cooperation with the US Geological Survey (USGS). Nine records were investigated. Table 2.1 provides information about each paired stream temperature and air temperature record. Included in Table 2.1 is the USGS water quality monitoring station identification number, stream name, descriptive stream location, stream location in degrees northern latitude and western longitude, NREL-NOAA weather monitoring station location, weather monitoring station location in degrees northern latitude and western longitude and distance between the water quality monitoring and weather monitoring stations. On average, the distance between weather monitoring stations and corresponding water quality monitoring stations was 66 km; the range of these distances was 5 km to 129 km. Other information concerning the USGS water quality monitoring stations or the NREL-NOAA weather monitoring stations can be found in reports by Erickson et al. (1998a) and Mohseni et al. (1998b).

The nine stream temperature records selected for this study were chosen primarily because of record length and record completeness. Record length was the number of years between the first and the final recorded stream temperature. Record completeness was determined by a ratio of the actual number of data and the total possible number of data. Table 2.2 lists characteristics of each stream temperature record: beginning year and week, ending year and week, range of stream temperature data in years, actual number of data, total possible number of data and completeness as a percentage. The stream temperature records ranged in length from 12.8 to 29.0 years. Eight of the nine stream temperature records had more than 20 years of data. All stream temperature records were more than 91% complete.

The nine stream temperature records selected for this study were chosen on a secondary basis because of geographic diversity. Geographic diversity was of concern because of the effect that climate, as well as the characteristics of the stream have on the stream temperature/air temperature relationship. Stream temperature/air temperature relationships are affected by the following meteorological parameters: air temperature, net solar radiation, relative humidity, wind speed and precipitation. Other parameters affecting the stream temperature/air temperature relationship are water depth, stream flow, groundwater inflow rate and temperature, thermal conductivity of the sediments, wind sheltering and shading. Characteristic stream temperature/air temperature relationships are associated with certain environments. Because the parameters affecting the stream temperature/air temperature relationship vary from location to location, stream temperature records were selected from throughout the US to obtain a diverse assortment. The streams included in this study are from the states of California, Georgia, Michigan, Minnesota, Nebraska, North Carolina, Ohio, Oklahoma and Washington. The corresponding long-term stream temperature/air temperature relationships are shown in Figures 2.1 to 2.9; all are S-shaped to varying degrees. Differences exist between the relationships with respect to the range of air temperatures and stream temperatures experienced, the magnitude of the maximum and minimum stream temperatures and air temperatures, and the variance of the data throughout the extent of the relationship. Stream temperature/air temperature relationships with significant variance may be influenced by hysteresis, i.e. the occurrence of lagged water temperatures with respect to air temperatures over an extended period of time due to heat storage effects (Mohseni et al., 1998a).

Table 2.1 Locations of water quality monitoring and weather monitoring stations.

USGS ID	Stream Name	Water Quality Monitoring Station Location	Lat. (°N)	Long. (°W)	Weather Monitoring Station Location	Lat. (°N)	Long. (°W)	Distance (km)
02077200	Hyco Creek	Leasburg, NC	36.399	79.197	Raleigh, NC	35.867	78.783	69.9
02213700	Ocmulgee River	Warner Robbins, GA	32.671	83.603	Macon, GA	32.700	83.650	5.4
04121500	Muskegon River	Evart, MI	43.899	85.255	Muskegon, MI	43.167	86.250	114.2
04208000	Cuyahoga River	Independence, OH	41.395	81.630	Cleveland, OH	41.400	81.850	18.4
05331000	Mississippi River	St. Paul, MN	44.944	93.088	Minneapolis, MN	44.883	93.217	12.2
06465500	Niobrara River	Verdel, NE	42.740	98.212	Norfolk, NE	41.983	97.433	105.8
07150500	Salt F. Arkansas River	Jet, OK	36.752	98.128	Wichita, KS	37.650	97.417	118.0
11394500	M. F. Feather River	Merrimac, CA	39.708	121.26	Reno, NV	39.500	119.78	129.4
12113000	Green River	Auburn, WA	47.312	122.20	Seattle, WA	47.450	122.30	16.9

Table 2.2 Characteristics of long-term stream temperature records.

USGS ID	Beginning Year/Week	Ending Year/Week	Range of Record (yrs)	Actual Number of Data Points	Total Number of Possible Data Points	Completeness (%)
02077200	1964 / 19	1988 / 52	24.7	1176	1282	91.7
02213700	1970 / 08	1990 / 37	20.6	1027	1070	96.0
04121500	1961 / 01	1983 / 39	22.8	1170	1183	98.9
04208000	1961 / 01	1989 / 50	29.0	1428	1506	94.8
05331000	1961 / 01	1987 / 39	26.8	1317	1391	94.7
06465500	1961 / 01	1984 / 39	23.8	1158	1235	93.8
07150500	1969 / 18	1982 / 08	12.8	609	667	91.3
11394500	1962 / 40	1982 / 40	20.0	970	1041	93.2
12113000	1961 / 01	1986 / 41	25.8	1223	1341	91.2

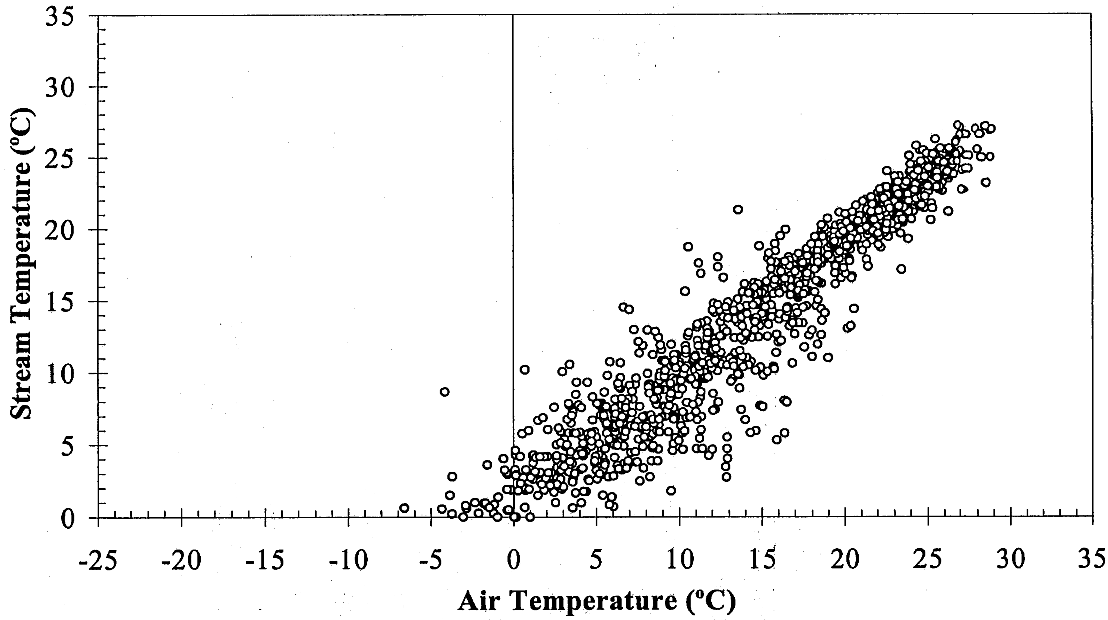

Figure 2.1 Stream temperature/air temperature relationship for water quality monitoring station at Hyco Creek, Leasburg, NC - 02077200.

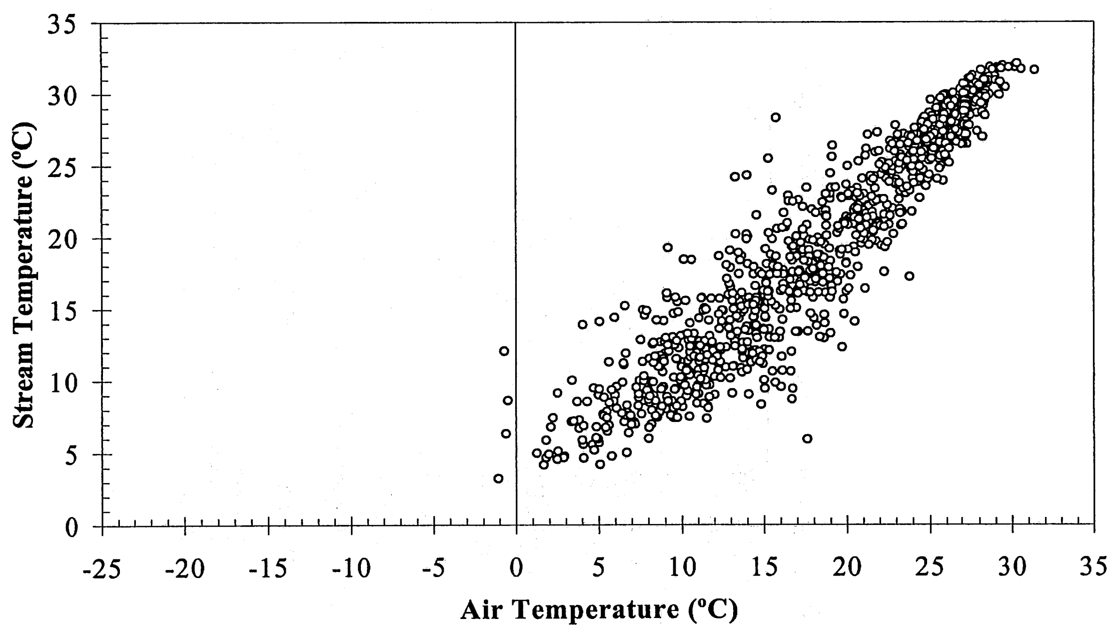

Figure 2.2 Stream temperature/air temperature relationship for water quality monitoring station at Ocmulgee River, Warner Robins, GA - 02213700.

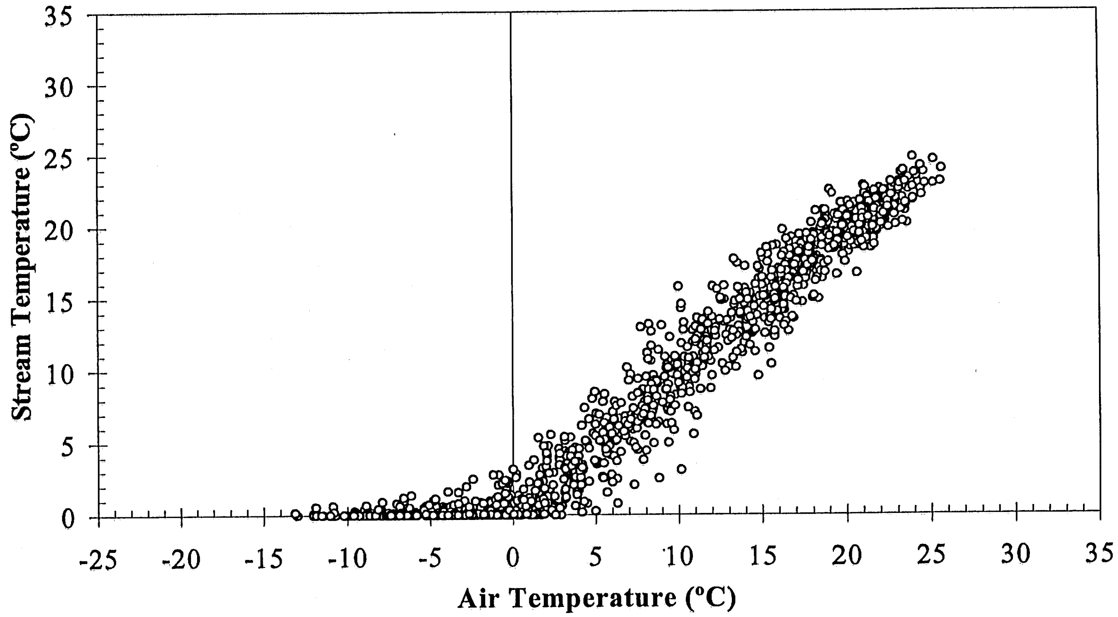

Figure 2.3 Stream temperature/air temperature relationship for water quality monitoring station at Muskegon River, Evart, MI - 04121500.

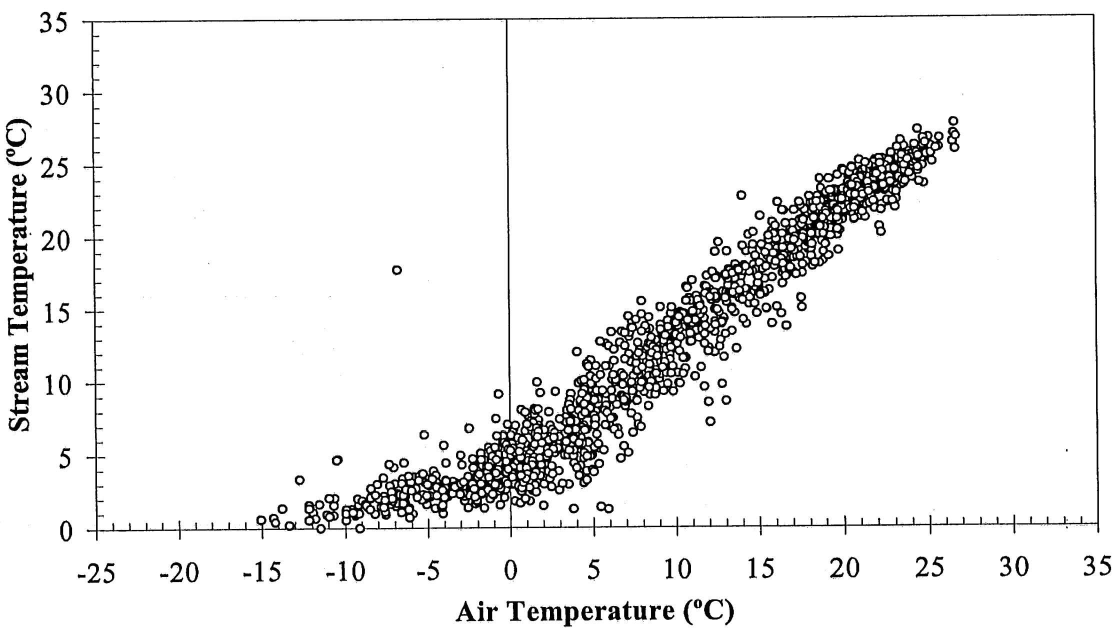

Figure 2.4 Stream temperature/air temperature relationship for water quality monitoring station at Cuyahoga River, Independence, OH - 04208000.

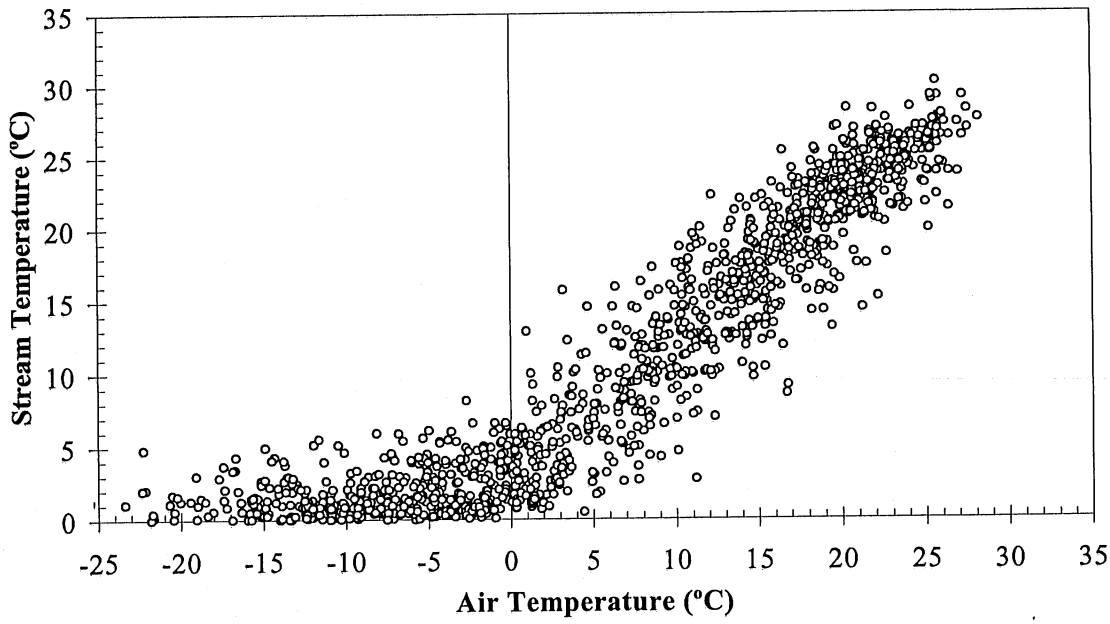

Figure 2.5 Stream temperature/air temperature relationship for water quality monitoring station at Mississippi River, St. Paul, MN - 05331000.

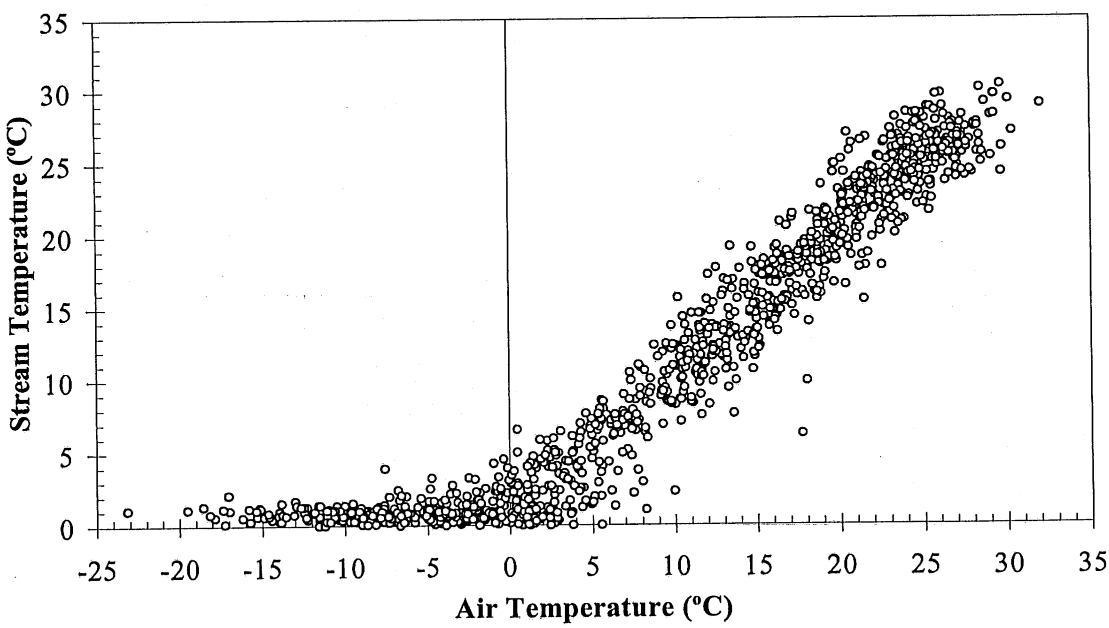

Figure 2.6 Stream temperature/air temperature relationship for water quality monitoring station at Niobrara River, Verdel, NE - 06465500.

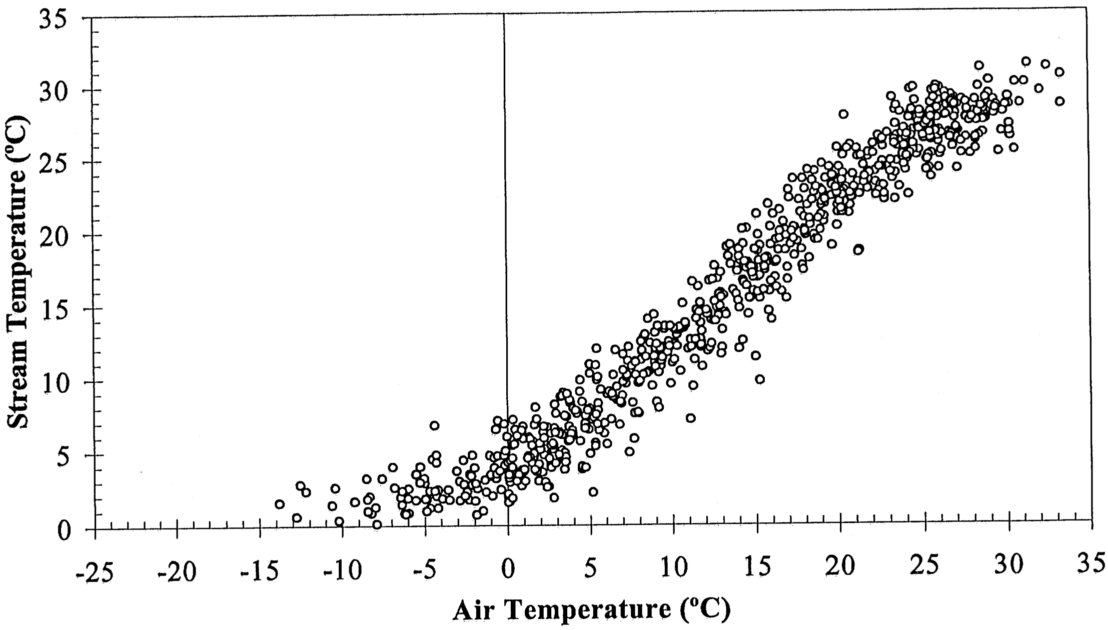

Figure 2.7 Stream temperature/air temperature relationship for water quality monitoring station at Salt Fork of the Arkansas River, Jet, OK - 07150500.

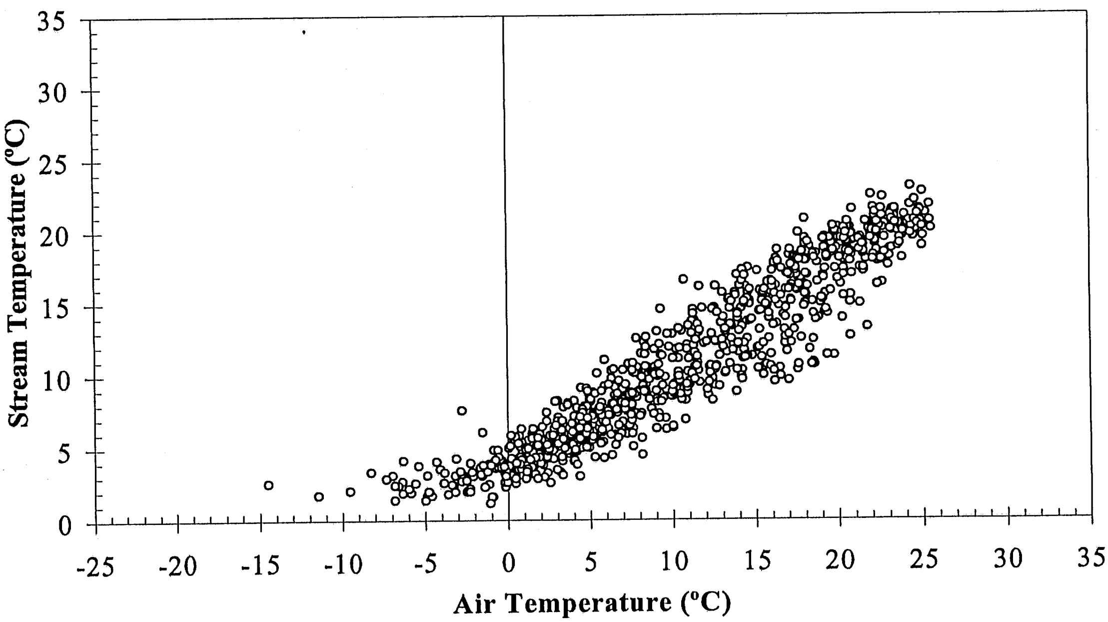

Figure 2.8 Stream temperature/air temperature relationship for water quality monitoring station at M. Fork Feather River, Merrimac, CA - 11394500.

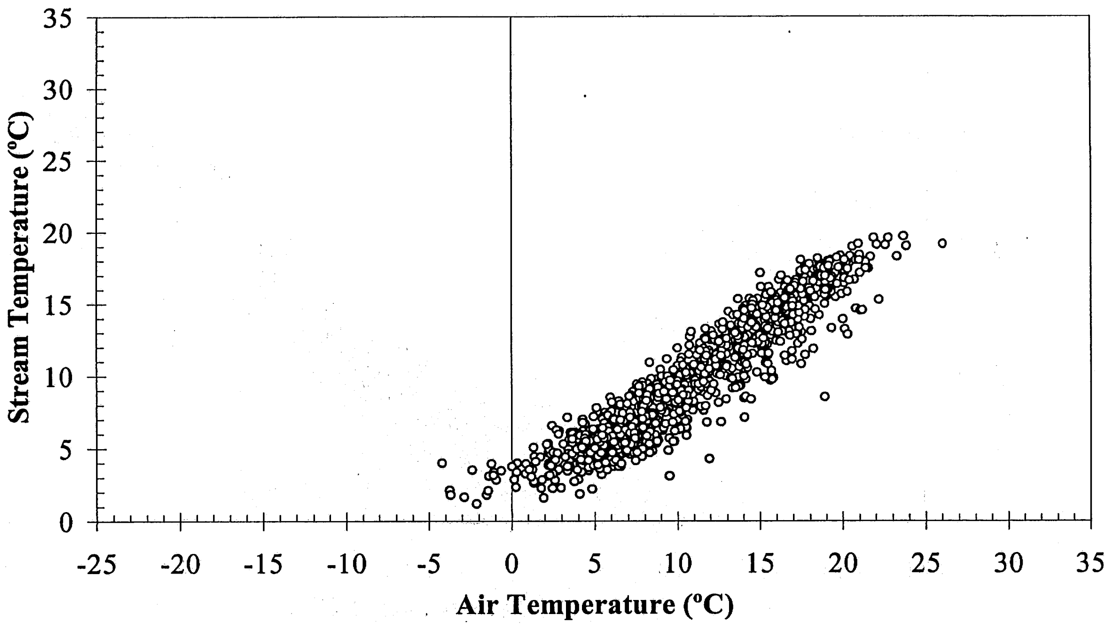

Figure 2.9 Stream temperature/air temperature relationship for water quality monitoring station at Green River, Auburn, WA - 12113000.

2.2 Development of Sample Records

A coarse array of sample records varying in length was established. The array of sample records consisted of 3, 6, 9, 12 and 15 years of data, i.e. a maximum of 156, 312, 468, 624 and 780 paired stream temperatures and air temperatures, respectively. For the records that have a total length of more than 20 years, a maximum sample record length of 15 years is utilized; a maximum sample record length of 9 years is utilized for the single record with a total length of 12.8 years (Table 2.2). The maximum sample record lengths were chosen to minimize the overlap of data, i.e. the inclusion of the same data in more that one sample record of the same length. Sample records of 3, 6 and 9 years length are constructed by segmenting the long-term records. If the long-term records are not divisible by 3, 6 or 9 years, the tail of the data is excluded from analysis, i.e. excluded from any sample records. Sample records of 12 and 15 years length are formulated by extracting data from the beginning and from the end of the long-term record. Depending on the length of the long-term records with respect to the sample records, some data are excluded from both or included in both 12 and 15-year sample records. Because of missing data within the specified sample periods, the actual number of data composing a sample record is usually less than the total possible number.

2.3 Determination of Sample and Population Model Parameters

The modified logistic stream temperature model (Erickson et al., 1998b; Mohseni et al., 1998b) was fitted to the nine long-term records and all corresponding sample records. The fitted model parameters obtained from the long-term records provide the population parameters of Equation 1. Technically, the term "population" refers to an infinitely large collection of data. Although the nine long-term records are indeed a finite collection of weekly stream temperatures and air temperatures, it is assumed that the "true" stream temperature/air temperature relationships are obtained. The model parameters obtained from the sample records will therefore be sample estimates of the population parameters.

The modified logistic stream temperature model fitting algorithm accounts for stream temperature/air temperature relationships with hysteresis by fitting two functions to the data: one function representing the rising limb and a second function representing the falling limb. Stream temperature/air temperature relationships without hysteresis are fitted with one function. To maintain the integrity of the statistical comparison, hysteresis is neglected. Erickson et al.'s (1998a) study revealed the inconsistency between sample models and corresponding population models not only for the model parameter values, but also with regard to the presence of hysteresis. In several instances when a population model did not exhibit hysteresis, some of the corresponding sample models did exhibit hysteresis; the opposite scenario was also true. The presence of hysteresis within a stream temperature/air temperature relationship is influenced by record length, as well as the period over which the record was extracted.

Two statistical parameters were used as measures of the goodness-of-fit between simulated sample or population stream temperatures and observed stream temperatures. The two goodness-of-fit parameters NSC and RMSE represent the Nash-Sutcliffe coefficient (Nash and Sutcliffe, 1970) and the root mean squared error, respectively. The Nash-Sutcliffe coefficient is defined as

$$\mathrm{NSC} = 1 - \frac{\sum_{i=1}^{n}\left(T_{sim_i} - T_{obs_i}\right)^2}{\sum_{i=1}^{n}\left(\overline{T}_{obs} - T_{obs_i}\right)^2} \tag{3}$$

where T_{sim}, T_{obs} and $\overline{T}_{obs}$ represent simulated stream temperature, observed stream temperature and mean observed stream temperature, respectively. The NSC coefficient ranges from one to negative infinity; a coefficient value of one represents perfect agreement between observed data and a fitted model. The parameter RMSE is defined as

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}\left(T_{sim_i} - T_{obs_i}\right)^2}{n-4}} \tag{4}$$

2.4 Formulation and Interpretation of Test Statistics

The statistical similarity between sample models and corresponding population models is evaluated by performing an F-test. In the F-test, the residual sum of squared errors of both sample and population models is compared. Methods do exist for the comparison of the individual model parameters α, β, γ and μ of Equation 1; however, they are complex and somewhat subjective due to the nonlinearity of model parameters (Ratkowsky, 1983). While the F-test does not provide information on any specific discrepancy, it does provide an effective, overall means of comparison.

The F-test statistic is evaluated as follows (Weisberg, 1985):

$$F = \frac{\dfrac{RSS_p - RSS_s}{df_1}}{\dfrac{RSS_s}{df_2}} \tag{5}$$

where

$$RSS = \sum_{i=1}^{n} \left(T_{sim_i} - T_{obs_i} \right)^2 \tag{6}$$

and

$$df_1 = \left(n_p - 4 \right) - \left(n_s - 4 \right) \tag{7}$$

and

$$df_2 = \left(n_s - 4 \right) \tag{8}$$

The subscripts p and s identify parameters associated with population relationships and sample relationships, respectively. The parameter RSS is the residual sum of squared errors. The residual sum of squared errors, RSS, defined previously in Equation 4, can be evaluated by squaring RMSE and multiplying the resulting product by the quantity (n-4). Numerator degrees of freedom and denominator degrees of freedom are denoted by df_1 and df_2, respectively.

The statistical similarity between population and sample relationships is determined by comparison of a calculated F-test statistic's associated probability of occurrence, i.e. p-value, and a prescribed significance level, i.e. a minimum acceptable probability of occurrence. The p-value corresponding to a specific F-test statistic can be determined from tabulated results or computationally. In either case, three input parameters are required: the F-test statistic (Equation 5), the numerator degrees of freedom, df_1 (Equation 7), and the denominator degrees of freedom, df_2 (Equation 8). For this study, p-values were determined computationally using an inverse F-distribution function provided on Microsoft Excel. This hypothesis test assumes that population and sample relationships are equivalent when the calculated p-value is greater than the prescribed significance level and nonequivalent when the calculated p-value is less than the prescribed significance level. Large p-values, e.g. close to 1, indicate that there is strong agreement (statistical similarity) between population and sample models; small p-values, e.g. close to 0, indicate that there is little agreement between population and sample models.

A decision must be made regarding the minimum p-value that will constitute sufficient agreement between sample models and population models. The selection of an arbitrarily large significance level such as 0.10 would ensure statistical similarity between sample models population models. However, many sample models can not attain this value because the stream temperature model only accounts for air temperature as a predictor of stream temperature. Other influencing factors such as solar radiation, relative humidity, wind speed, water depth, groundwater inflow and artificial heat inputs were neglected as a means of simplification. Because of the potential for large variations (standard deviations) within each sample, a smaller significance level is more appropriate for this study. The significance level chosen for this analysis was 0.01. This significance level preserves the integrity of the analysis while allowing for some leniency to account for the numerous extraneous factors of influence upon the weekly stream temperature/air temperature relationship.

3. RESULTS

3.1 Models of Observed Stream Temperature/Air Temperature Relationships

The relation between population model parameters and corresponding sample model parameters, as well as the associated goodness-of-fit statistics are discussed in this section. Hysteresis as it relates to population and sample models is also discussed in this section. In Appendix A, Tables A.1 through A.9 contain, for each population and sample relationship, the number of data used to develop each relationship, the goodness-of-fit statistics NSC and RMSE, information on the presence of hysteresis, and the four model parameters α, β, γ and μ. Mean annual air temperatures and stream temperatures were also provided for each period of record as a means of characterizing the variability over time, and also between sample records of different durations. The presence of hysteresis was determined by allowing the model fitting algorithm to account for this characteristic. However, the model parameters listed in Tables A.1 through A.9 do not account for hysteresis even when hysteresis has been noted to be present.

In general, the sample estimates of the model parameters α, β, γ and μ tend to become less variable and more consistent, in essence converging to the population model parameter values, as the length of the sample records becomes greater. An example is shown in Table A.1, as well as Figures 3.1 to 3.4. The population and sample model parameters for stream temperature data obtained from Hyco Creek near Leasburg, NC, (02077200) and air temperature data obtained from Raleigh, NC, in Table A.1 show that the 3-year sample models have α values that range from 24.12 °C to 30.95 °C, β values that range from 14.58 °C to 17.79 °C, γ values that range from 0.14 °C^{-1} to 0.24 °C^{-1} , and μ values that range from 0.00 °C to 4.77 °C. The parameter values of the remaining sample model types, i.e. 6-year, 9-year, 12-year and 15-year models, become increasingly less variable and fall easily within the ranges specified for the 3-year sample models. In fact, the two 15-year sample models have parameters that closely approximate those of the population model. The population model parameters α, β, γ and μ are 29.17 °C, 15.56 °C, 0.14 °C^{-1} and 0.00 °C, respectively. There was no apparent change in the goodness-of-fit statistics NSC and RMSE as the duration of the sample models increased. However, there was a tendency for the NSC and RMSE to be more variable from sample to sample for models derived with less data, i.e. 3-year and 6-year sample models.

Sample estimates of model parameters tend to converge to the population model parameter values as the duration of the sample stream temperature/air temperature relationship becomes longer for two reasons. The first reason is that the population model parameters are obtained from a finite record instead of an infinite record, i.e. the population record is really a large sample. As the length of the samples is increased, the samples consist of a larger fraction of the total population. For example, the 15-year samples included 54% to 77% of the data contained in the "population" relationships (Tables A.1 to A.9). The second reason lies in the variability of meteorological conditions and/or possible reservoir operations on a stream and their influence on the stream temperature/air temperature relationship. According to these two factors, distinguished stream temperature/air temperature relationships will result for relatively short periods, e.g. hot years or wet years and specific reservoir operations. Only over a long time can the variance of the population stream temperature/air temperature relationship be replicated by the aggregate of characteristic stream temperature/air temperature relationships. An example of two 3-year sample stream temperature/air temperature relationships that are characteristically different but obtained from a common population record is shown in Figure 3.5. The 3-year sample stream temperature/air temperature relationships were from stream temperature data obtained at Verdel, NE (06465500) and air temperature data obtained at Norfolk, NE for two different time periods: 1961 to 1963 and 1982 to 1984 (Tables A.6 and B.6, first and eighth 3-year samples). The 3-year sample stream temperature/air temperature relationship from the period 1982 to 1984 has less variance and is offset from the 3-year sample stream temperature/air temperature relationship from the period 1961 to 1963. No precise cause could be determined to account for the differences, but variations in mean annual air temperature as well as streamflow/precipitation may have contributed. For the period 1961 to 1963 mean annual air temperature was 11.61 °C, while from 1982 to 1984 mean annual air temperature was 9.56 °C (Table A.6).

Hysteresis was not always found to be present, or absent, in both population models and sample models alike (Tables A.1 through A.9). Of the nine population models, five were found to have at least one sample model that was nonsimilar in character. Specifically, three population models with hysteresis each had associated sample models that did not have hysteresis and two population models without hysteresis each had associated sample models that did have hysteresis. Most often, 3-year and 6-year sample models were different in character than their associated population model. Stream temperature/air temperature relationships obtained from water quality monitoring stations located below dams or reservoirs or in watersheds with extended snow melt periods, i.e. snowmelt occurring into late spring or early summer, are typically characterized by hysteresis. As shown with sample models derived from 3-year and 6-year stream temperature/air temperature relationships, variations in dam or reservoir operation and/or meteorological conditions dictate the presence of hysteresis. In only one instance was a 15-year sample model characteristically different from its corresponding population model. The inconsistency occurred for data obtained from Auburn, WA and air temperature data obtained from Seattle, WA (Table A.9). While none of the 3-year sample models derived from this data set had hysteresis, both the 12-year and 15-year sample models surprisingly had hysteresis.

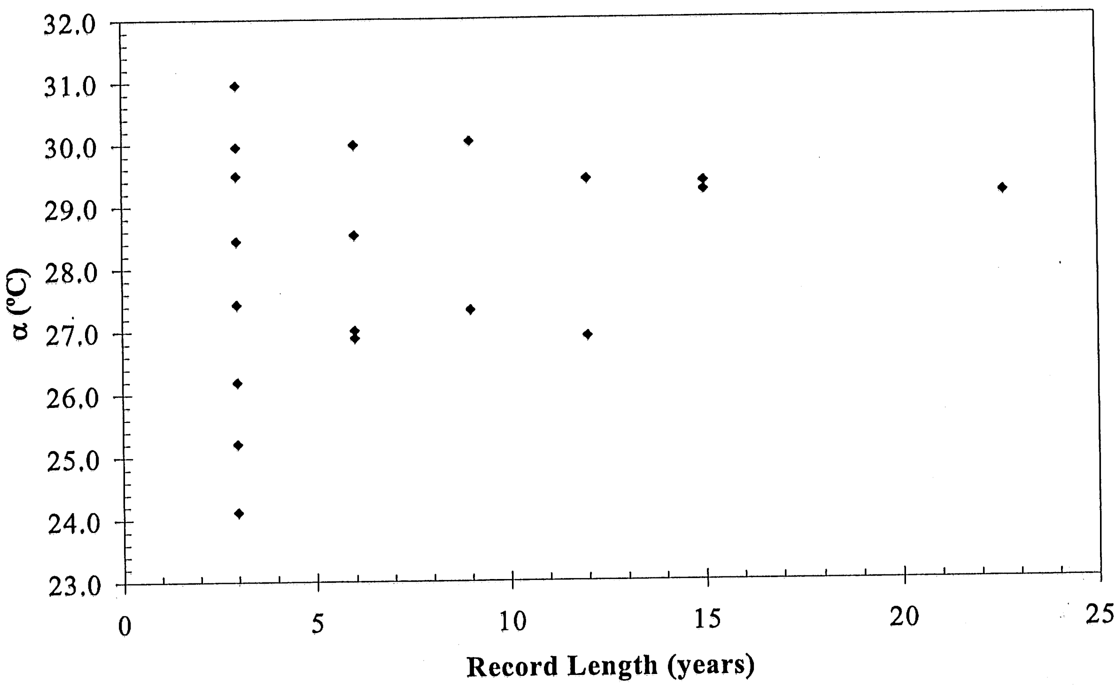

Figure 3.1 The model parameter α versus record length for the water quality monitoring station located at Hyco Creek near Leasburg, NC - 02077200.

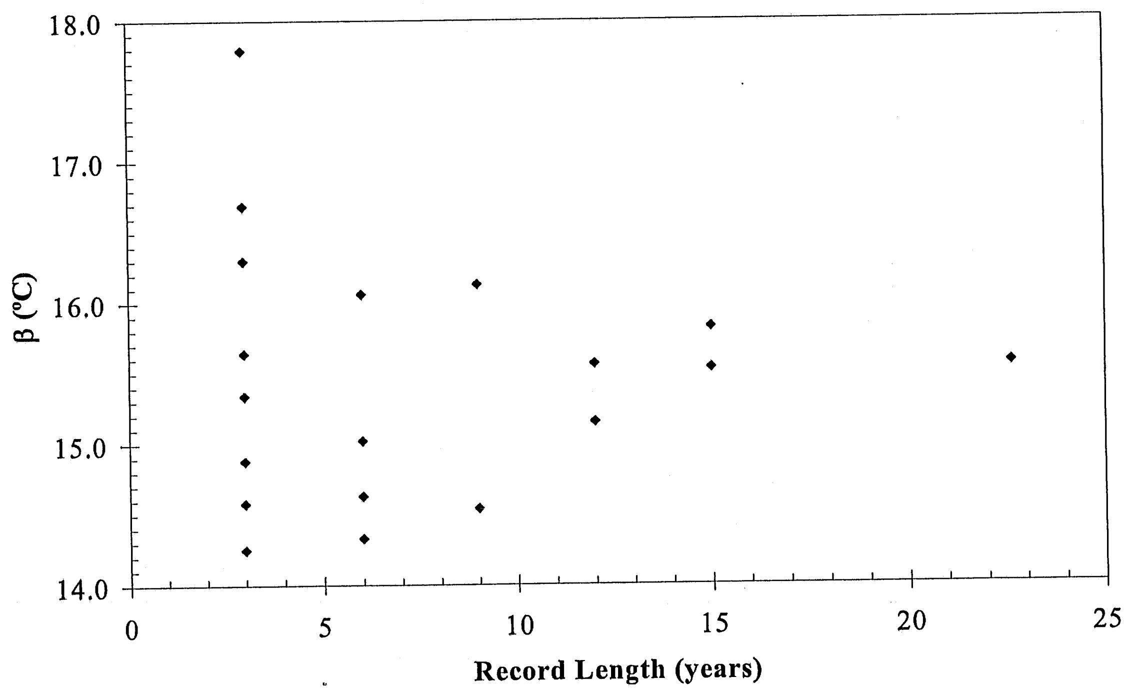

Figure 3.2 The model parameter β versus record length for the water quality monitoring station located at Hyco Creek near Leasburg, NC - 02077200.

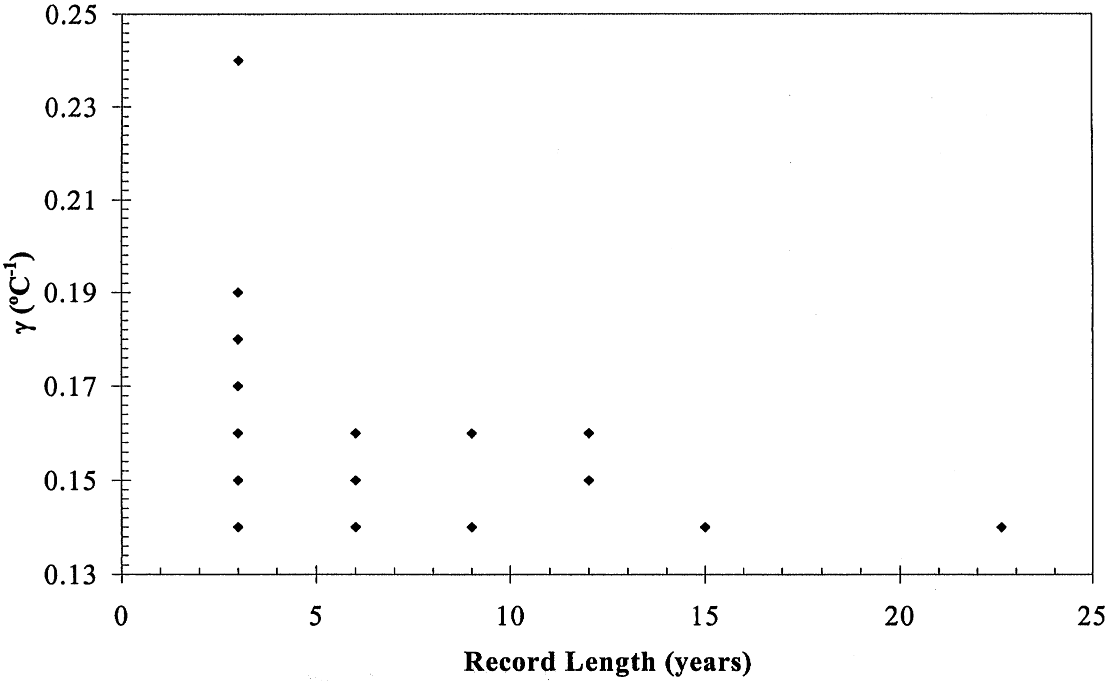

Figure 3.3 The model parameter γ versus record length for the water quality monitoring station located at Hyco Creek near Leasburg, NC - 02077200.

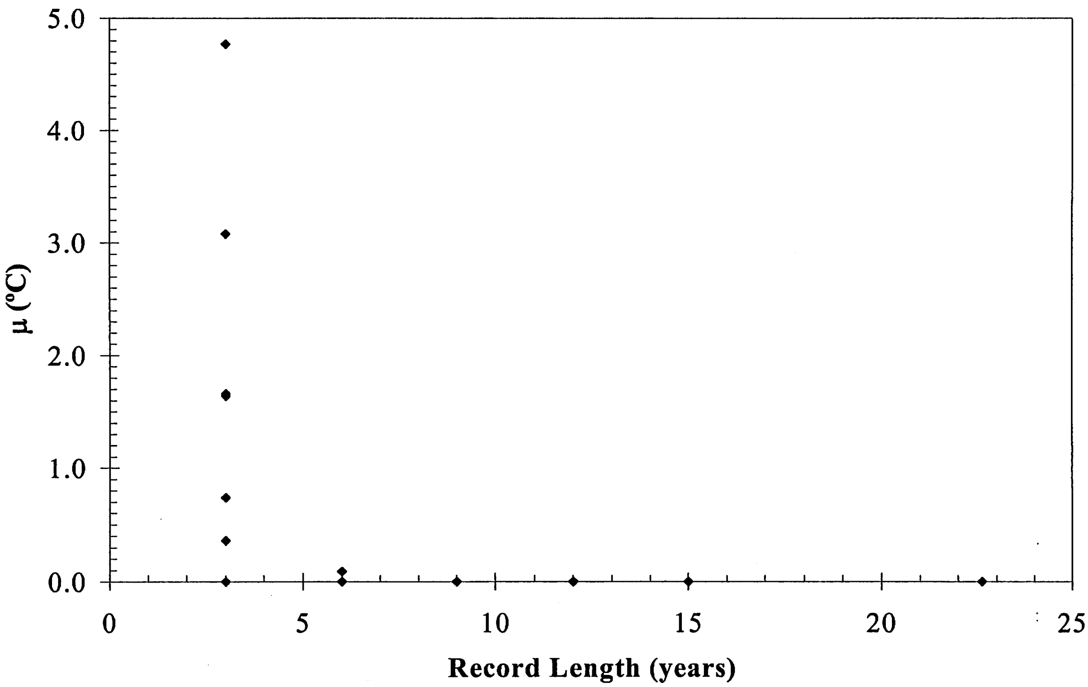

Figure 3.4 The model parameter μ versus record length for the water quality monitoring station located at Hyco Creek near Leasburg, NC - 02077200.

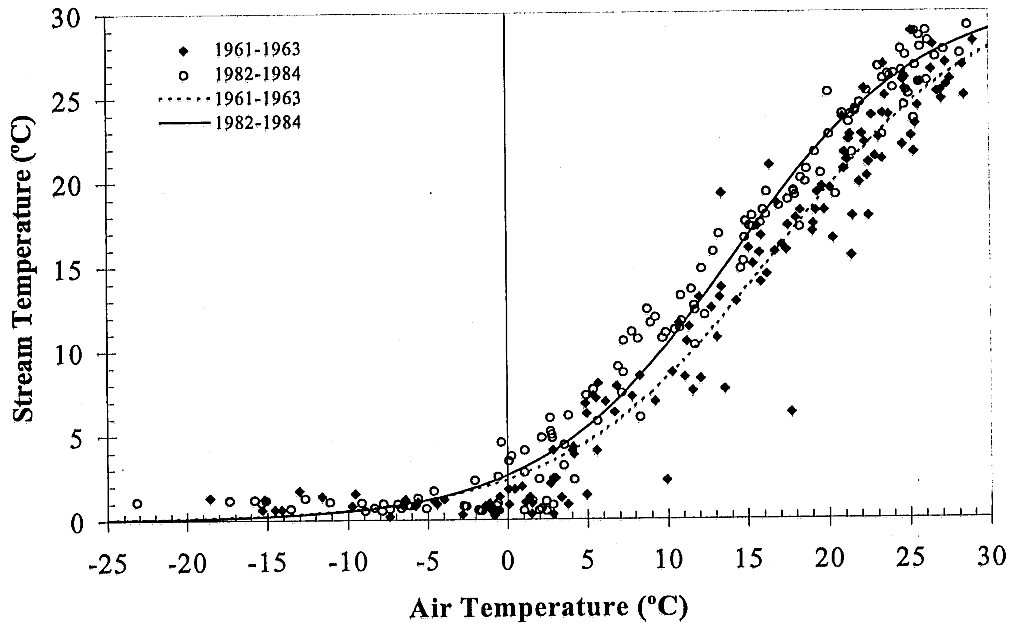

Figure 3.5 3-year sample stream temperature/air temperature relationships for the periods 1961 to 1963 and 1982 to 1984. Stream temperature data were obtained at Verdel, NE (06465500) and air temperature data were obtained at Norfolk, NE.

3.2 Test Statistics

The F-test statistics and corresponding p-values calculated for the comparison of variably length sample models and their associated population models are discussed in this section. In Appendix B, Tables B.1 through B.9 contain the F-test statistics and corresponding p-values for each sample model type, i.e. 3-year, 6-year, 9-year, 12-year and 15-year sample models. In addition, the parameters pertinent to the determination of the F-test statistics and associated p-values, such as the number of data within each sample, RMSE, RSS, df_1 and df_2, can also be found in Tables B.1 through B.9. A lumped analysis of the tabulated p-values revealed that when compared to the specified significance level of 0.01, 44 of 65 3-year sample models (67.7%), 21 of 31 6-year sample models (67.7%), 6 of 20 9-year sample models (70.0%), 11 of 16 12-year sample models (68.7%) and 13 of 16 15-year sample models (81.2%) were statistically similar to their corresponding population models. No significant change in the percentage of sample models determined to be statistically similar occurred until 15-year sample models were introduced.

Each of the nine population (long-term) models had associated sample models that were statistically nonsimilar (Tables B.1 through B.9). In many instances, statistical nonsimilarities that occurred between 3-year sample models and corresponding population models persisted in sample models of greater duration that were derived from larger data sets that contained the same 3 years of data that was originally statistically nonsimilar to the population model. Therefore, statistical nonsimilarities were commonly present for 6-year sample models, 9-year sample models, etc. An example is found in Table B.4, i.e. the comparison of population and sample models derived from stream temperature data obtained from the Cuyahoga River in Independence, OH (04208000) and air temperature data obtained from Cleveland, OH. Of the population models that were derived with greater than 20 years of data, three had one 15-year sample model that was statistically nonsimilar. Therefore, the statistical nonsimilarities of 3-year and 6-year sample models were not always carried through to the sample models of longer duration.

4. Conclusions

The results of this study show that stream temperature/air temperature relationships are dynamic and have the potential to change from one period of record to the next. If the thermal regime of a stream is maintained throughout a period of record, sample models derived from the population data set are expected to be statistically similar, as well as characteristically similar in terms of variance and the presence, or absence, of hysteresis. Variations in stream temperature/air temperature relationships are likely attributed to meteorological changes, as well as anthropogenic effects that occur within a watershed over time. Stream temperature/air temperature relationships show changes in the range of stream temperatures and air temperatures that were attained, the variance (scatter) of data, and the slope of the relationship. As a result, the four parameters of the logistic stream temperature model change.

Because the thermal regime of streams commonly changes over time in accordance with various meteorological and anthropogenic influences, long-term (population) stream temperature/air temperature relationships can be assumed an "aggregate" of characteristic stream temperature/air temperature relationships. This "aggregate" of individual stream temperature/air temperature relationships from which a population relationship is derived typically has a variance, as well as fitted model parameters that can not consistently be replicated in sample models derived from relatively short records, e.g. records less than 12 years in length. In order to obtain a stream temperature/air temperature relationship and fitted model representative of a population, a sufficiently long record is required to account for the variability associated with the total range of characteristic stream temperature/air temperature relationships possibly experienced. For streams located in regions with relatively stable meteorological conditions and minimal anthropogenic influences, records of 12-years length, or possibly shorter, may suffice for the representation of long-term stream temperature/air temperature relationships and corresponding models. In most instances, however, meteorological conditions are variable and anthropogenic influences are significant. Sample models derived from 15-year stream temperature/air temperature records showed the largest tendency to replicate the variance, as well as the fitted model parameters of long-term (population) stream temperature/air temperature relationships. Therefore, stream temperature/air temperature relationships of 15-years length and greater will most consistently represent the long-term thermal characteristics of a stream.

REFERENCES

Erickson, T. R., O. Mohseni and H. G. Stefan, 1998a. Estimation of an Upper Bound for Weekly Stream Temperatures. *St. Anthony Falls Laboratory, Project Report No. 424*. University of Minnesota, Minneapolis, MN.

Erickson, T. R., O. Mohseni and H. G. Stefan, 1998b. The Effect of Record Length on a Nonlinear Regression Model for Weekly Stream Temperatures. *St. Anthony Falls Laboratory, Project Report No. 419*. University of Minnesota, Minneapolis, MN.

Hershfield, D. M., 1961. Estimating the Probable Maximum Precipitation. *Journal of the Hydraulics Division*, ASCE, 87 (HY5):99-116.

Mohseni, O., H. G. Stefan and T. R. Erickson, 1998a. A Non-Linear Regression Model for Weekly Stream Temperatures. *Water Resources Research*, 34 (10):2685-2692.

Mohseni, O., T. R. Erickson and H. G. Stefan, 1998b. Sensitivity of the Stream Temperatures in the U.S. to Air Temperatures Projected under a Global Warming Scenario, *Water Resources Research*, in press.

Nash, J. E. and J. V. Sutcliffe, 1970. River Flow Forecasting through Conceptual Models, Part I-A Discussion of Principles. *Journal of Hydrology*, (10):282-190.

Ratkowsky, D. A., 1983. *Nonlinear Regression Modeling: A Unified Practical Approach*. Marcel Dekker, Inc., New York, NY.

Weisberg, S., 1985. *Applied Linear Regression*. John Wiley and Sons, Inc., New York, NY.

APPENDIX A: MODEL PARAMETERS AND GOODNESS-OF-FIT STATISTICS FOR POPULATION AND SAMPLE RECORDS

Table A.1 Regression parameters and goodness-of-fit statistics of population and sample models for water quality monitoring station on Hyco Creek, Leasburg, NC - 02077200.

Record Length	Number of Data Points	NSC	RMSE (°C)	Mean Air Temperature (°C)	Mean Stream Temperature (°C)	Hysteresis	α (°C)	β (°C)	γ (°C^{-1})	μ (°C)
Population	1176	0.92	2.14	14.86	14.15	no	29.17	15.56	0.14	0.00
3-year	137	0.94	1.69	14.91	13.73	no	25.21	14.88	0.19	1.64
	125	0.94	1.90	13.60	13.01	no	27.43	14.58	0.16	0.00
	156	0.90	2.21	14.70	14.04	no	28.44	15.34	0.15	0.36
	151	0.89	2.15	15.10	14.29	no	24.12	15.64	0.24	4.77
	151	0.92	2.27	14.30	13.69	no	30.95	16.69	0.14	0.00
	149	0.94	1.87	15.13	14.53	no	29.95	16.30	0.15	0.74
	142	0.90	2.34	15.04	14.32	no	29.49	17.79	0.17	3.08
	132	0.89	2.50	15.32	14.95	no	26.19	14.25	0.18	1.66
6-year	262	0.94	1.80	14.29	13.38	no	26.89	14.63	0.16	0.09
	307	0.90	2.20	14.90	14.16	no	27.01	14.33	0.15	0.00
	300	0.93	2.09	14.71	14.11	no	29.98	16.06	0.14	0.00
	274	0.89	2.47	15.18	14.62	no	28.53	15.02	0.15	0.00
9-year	418	0.93	1.98	14.44	13.63	no	27.33	14.54	0.16	0.00
	451	0.92	2.10	14.84	14.17	no	30.03	16.13	0.14	0.00
12-year	569	0.92	2.04	14.62	13.80	no	26.91	14.15	0.16	0.00
	578	0.92	2.19	15.04	14.41	no	29.41	15.56	0.15	0.00
15-year	720	0.92	2.07	14.55	13.78	no	29.23	15.82	0.14	0.00
	729	0.91	2.21	14.99	14.37	no	29.37	15.53	0.14	0.00

Table A.2 Regression parameters and goodness-of-fit statistics of population and sample models for water quality monitoring station on Ocmulgee River, Warner Robbins, GA - 02213700.

Record Length	Number of Data Points	NSC	RMSE (°C)	Mean Air Temperature (°C)	Mean Stream Temperature (°C)	Hysteresis	α (°C)	β (°C)	γ (°C^{-1})	μ (°C)
Population	1027	0.88	2.64	18.28	19.56	yes	34.01	15.22	0.13	0.00
3-year	129	0.92	2.12	19.22	20.22	no	30.79	19.04	0.25	8.34
	154	0.85	2.71	18.11	19.18	no	30.18	19.12	0.25	9.29
	153	0.92	2.33	17.52	18.87	no	33.77	17.6	0.16	3.43
	153	0.92	2.15	18.06	19.37	yes	32.45	19.00	0.22	7.57
	155	0.87	2.71	17.98	18.82	yes	35.09	16.86	0.12	0.00
	151	0.86	2.95	18.45	20.42	yes	33.18	18.18	0.18	6.66
6-year	283	0.83	2.89	18.62	19.66	no	31.03	13.47	0.14	0.57
	306	0.91	2.43	17.79	19.12	yes	33.68	15.05	0.13	0.00
	306	0.85	3.01	18.21	19.61	yes	33.6	14.8	0.13	0.04
9-year	436	0.88	2.65	18.23	19.38	no	32.9	14.59	0.13	0.00
	459	0.87	2.83	18.16	19.53	yes	33.31	15.08	0.13	0.79
12-year	589	0.89	2.50	18.19	19.38	yes	34.53	15.72	0.13	0.00
	613	0.88	2.68	18.12	19.47	yes	33.57	15.14	0.13	0.49
15-year	744	0.89	2.56	18.14	19.26	yes	34.51	15.81	0.13	0.00
	766	0.88	2.64	17.99	19.34	yes	33.64	15.11	0.13	0.30

Table A.3 Regression parameters and goodness-of-fit statistics of population and sample models for water quality monitoring station on Muskegon River, Evart, MI - 04121500.

Record Length	Number of Data Points	NSC	RMSE (°C)	Mean Air Temperature (°C)	Mean Stream Temperature (°C)	Hysteresis	α (°C)	β (°C)	γ (°C^{-1})	μ (°C)
Population	1170	0.96	1.70	8.67	9.64	no	26.26	14.43	0.18	0.00
3-year	156	0.97	1.52	8.47	9.83	no	27.09	13.82	0.18	0.00
	156	0.97	1.47	9.03	9.42	no	25.17	13.46	0.20	0.00
	156	0.97	1.43	8.67	9.16	no	25.50	13.76	0.19	0.00
	156	0.97	1.46	8.27	9.52	no	25.36	13.05	0.20	0.00
	156	0.96	1.68	8.86	9.63	no	26.12	13.43	0.18	0.00
	156	0.96	1.68	8.14	9.55	no	27.92	14.29	0.18	0.00
	143	0.97	1.51	8.81	10.02	no	24.44	12.16	0.20	0.00
6-year	312	0.97	1.52	8.75	9.63	no	26.39	13.78	0.19	0.00
	312	0.97	1.47	8.47	9.34	no	25.20	13.27	0.19	0.00
	312	0.96	1.68	8.50	9.59	no	26.90	13.80	0.18	0.00
9-year	468	0.97	1.51	8.72	9.47	no	26.37	13.92	0.19	0.00
	468	0.96	1.61	8.42	9.57	no	26.30	13.49	0.19	0.00
12-year	624	0.97	1.50	8.61	9.48	no	26.03	13.65	0.19	0.00
	611	0.95	1.75	8.59	9.68	yes	26.42	14.37	0.18	0.00
15-year	780	0.96	1.68	8.66	9.51	no	25.98	14.42	0.19	0.00
	767	0.96	1.71	8.55	9.62	no	26.21	14.28	0.18	0.00

Table A.4 Regression parameters and goodness-of-fit statistics of population and sample models for water quality monitoring station on Cuyahoga River, Independence, OH - 04208000.

Record Length	Number of Data Points	NSC	RMSE (°C)	Mean Air Temperature (°C)	Mean Stream Temperature (°C)	Hysteresis	α (°C)	β (°C)	γ (°C^{-1})	μ (°C)
Population	1428	0.96	1.63	9.95	13.35	no	28.70	11.87	0.15	0.26
3-year	152	0.96	1.71	9.60	13.19	no	27.07	11.19	0.17	0.58
	145	0.94	2.06	10.44	13.87	no	26.92	11.45	0.18	1.84
	117	0.94	1.79	8.34	12.43	no	29.08	12.01	0.14	1.08
	147	0.97	1.48	9.92	13.86	no	28.37	11.12	0.15	0.60
	153	0.96	1.49	10.70	13.39	no	29.31	13.13	0.15	0.87
	156	0.97	1.55	9.56	13.39	no	29.31	12.08	0.15	0.30
	156	0.97	1.45	9.48	12.85	no	31.18	13.24	0.14	0.00
	154	0.98	1.14	10.16	13.19	no	28.34	12.13	0.15	0.42
	156	0.97	1.28	10.47	13.60	no	27.53	11.31	0.16	0.35
6-year	297	0.95	1.90	10.01	13.52	no	27.06	11.23	0.18	1.01
	264	0.96	1.63	9.22	13.23	no	28.44	11.36	0.15	0.83
	309	0.96	1.54	10.12	13.39	no	29.35	12.58	0.15	0.49
	310	0.97	1.30	9.82	13.02	no	29.92	12.66	0.14	0.00
9-year	414	0.95	1.90	9.54	13.21	no	27.25	11.29	0.17	1.20
	456	0.96	1.56	10.06	13.54	no	29.07	11.91	0.14	0.18
	466	0.97	1.29	10.04	13.22	no	29.20	12.31	0.15	0.00
12-year	561	0.95	1.81	9.64	13.38	no	27.25	10.99	0.17	1.00
	622	0.97	1.29	10.05	13.23	no	29.04	12.19	0.15	0.00
15-year	714	0.95	1.77	9.86	13.38	no	27.74	11.54	0.16	0.95
	768	0.97	1.46	10.03	13.29	no	29.12	12.15	0.15	0.00

Table A.5 Regression parameters and goodness-of-fit statistics of population and sample models for water quality monitoring station on Mississippi River, St. Paul, MN - 05331000.

Record Length	Number of Data Points	NSC	RMSE (°C)	Mean Air Temperature (°C)	Mean Stream Temperature (°C)	Hysteresis	α (°C)	β (°C)	γ (°C^{-1})	μ (°C)
Population	1317	0.93	2.47	7.24	11.75	yes	31.74	14.19	0.14	0.00
3-year	156	0.91	2.69	6.84	12.50	yes	27.70	11.77	0.17	1.87
	151	0.94	2.38	6.74	11.62	yes	33.62	14.44	0.13	0.00
	100	0.90	2.73	6.42	11.45	yes	28.87	13.27	0.16	1.79
	148	0.92	2.59	5.88	11.56	no	30.08	13.47	0.16	1.59
	156	0.91	2.61	7.72	11.39	yes	34.32	16.09	0.12	0.00
	155	0.94	2.38	7.59	12.48	yes	29.74	12.83	0.16	0.44
	156	0.94	2.19	7.49	11.33	no	33.18	15.08	0.14	0.00
	155	0.97	1.75	7.66	11.45	no	28.09	12.59	0.18	0.27
	140	0.96	1.89	8.59	11.91	no	27.42	12.53	0.19	0.00
6-year	307	0.92	2.60	6.79	12.07	yes	33.65	14.52	0.12	0.00
	248	0.91	2.65	6.10	11.51	no	29.35	13.28	0.16	1.70
	311	0.93	2.52	7.65	11.93	yes	32.11	14.32	0.14	0.00
	311	0.96	1.97	7.57	11.39	no	30.44	13.66	0.15	0.00
9-year	407	0.91	2.65	6.70	11.92	yes	33.14	14.36	0.12	0.00
	459	0.92	2.59	7.08	11.81	yes	31.80	14.12	0.13	0.00
	450	0.96	1.96	7.95	11.58	no	29.95	13.75	0.16	0.00
12-year	560	0.92	2.63	6.59	11.91	yes	32.15	13.76	0.13	0.00
	674	0.95	2.06	7.63	11.67	no	31.71	14.52	0.15	0.00
15-year	711	0.91	2.67	6.75	11.72	yes	32.94	14.60	0.13	0.00
	775	0.94	2.26	7.64	11.62	yes	31.50	14.48	0.15	0.00

Table A.6 Regression parameters and goodness-of-fit statistics of population and sample models for water quality monitoring station on Niobrara River, Verdel, NE - 06465500.

Record Length	Number of Data Points	NSC	RMSE (°C)	Mean Air Temperature (°C)	Mean Stream Temperature (°C)	Hysteresis	α (°C)	β (°C)	γ (°C^{-1})	μ (°C)
Population	1158	0.96	1.91	10.19	12.20	no	32.44	16.43	0.15	0.00
3-year	143	0.95	2.13	11.61	12.51	no	31.74	16.85	0.15	0.00
	98	0.98	1.50	10.47	12.07	no	33.98	17.47	0.14	0.00
	152	0.96	1.83	10.07	11.65	no	34.77	17.61	0.14	0.00
	156	0.97	1.59	10.18	11.69	no	29.78	15.30	0.17	0.00
	155	0.97	1.73	10.83	12.21	no	32.47	16.52	0.15	0.00
	156	0.96	1.83	9.50	12.05	no	29.22	14.37	0.17	0.13
	156	0.97	1.60	9.45	12.85	no	32.92	14.75	0.16	0.00
	142	0.98	1.47	9.56	12.53	no	30.80	14.02	0.17	0.00
6-year	241	0.96	1.91	11.15	12.33	no	32.30	16.93	0.15	0.00
	308	0.97	1.73	10.13	11.67	no	32.80	16.77	0.15	0.00
	311	0.97	1.79	10.16	12.13	no	31.86	15.97	0.15	0.00
	298	0.98	1.56	9.50	12.70	no	32.13	14.53	0.16	0.00
9-year	393	0.96	1.91	10.73	12.07	no	33.13	17.55	0.14	0.00
	467	0.97	1.75	10.17	11.98	no	31.38	16.14	0.16	0.00
12-year	549	0.96	1.84	10.57	11.96	no	32.62	17.25	0.15	0.00
	622	0.97	1.83	9.67	12.25	no	32.35	15.81	0.15	0.00
15-year	704	0.96	1.82	10.63	12.02	no	32.46	17.11	0.15	0.00
	778	0.96	1.85	9.80	12.13	no	32.31	16.04	0.15	0.00

Table A.7 Regression parameters and goodness-of-fit statistics of population and sample models for water quality monitoring station on Salt Fork of the Arkansas River - 07150500.

Record Length	Number of Data Points	NSC	RMSE (°C)	Mean Air Temperature (°C)	Mean Stream Temperature (°C)	Hysteresis	α (°C)	β (°C)	γ (°C^{-1})	μ (°C)
Population	609	0.96	1.86	13.16	15.73	no	33.22	16.02	0.14	2.14
3-year	123	0.97	1.67	12.38	15.27	no	30.70	13.78	0.17	1.93
	143	0.97	1.62	13.06	16.02	no	33.85	14.33	0.14	0.08
	154	0.96	1.91	13.24	15.24	no	30.60	14.53	0.16	1.14
	146	0.97	1.57	13.68	16.11	no	35.64	16.84	0.11	1.09
6-year	266	0.97	1.64	12.75	15.67	no	33.17	14.42	0.14	0.78
	300	0.96	1.84	13.45	15.66	no	33.54	16.43	0.13	1.75
9-year	420	0.96	1.82	12.93	15.51	no	32.92	14.67	0.14	0.46
	453	0.96	1.89	13.33	15.78	no	33.75	16.26	0.14	1.81

Table A.8 Regression parameters and goodness-of-fit statistics of population and sample models for water quality monitoring station on Middle Fork of the Feather River, Merrimac, CA - 11394500.

Record Length	Number of Data Points	NSC	RMSE (°C)	Mean Air Temperature (°C)	Mean Stream Temperature (°C)	Hysteresis	α (°C)	β (°C)	γ (°C^{-1})	μ (°C)
Population	970	0.91	1.74	10.07	10.66	yes	24.28	12.79	0.13	0.00
3-year	132	0.91	1.76	9.53	10.44	yes	22.56	13.05	0.20	2.90
	149	0.91	1.79	10.65	10.85	no	23.01	11.64	0.15	0.00
	155	0.90	1.71	10.61	10.68	yes	22.05	12.43	0.15	1.49
	156	0.91	1.72	9.95	10.65	yes	23.02	13.26	0.16	1.99
	154	0.93	1.67	9.86	10.92	yes	24.57	11.87	0.13	0.00
	123	0.93	1.38	9.44	9.87	no	22.99	13.77	0.16	2.22
6-year	281	0.91	1.80	10.12	10.66	no	22.82	12.29	0.17	1.33
	311	0.91	1.72	10.28	10.66	yes	22.86	13.03	0.15	1.65
	277	0.92	1.61	9.67	10.46	no	24.53	12.58	0.13	0.21
9-year	436	0.90	1.80	10.30	10.67	yes	22.46	12.19	0.16	1.29
	433	0.92	1.66	9.77	10.53	yes	24.08	12.23	0.13	0.00
12-year	592	0.90	1.80	10.21	10.66	yes	22.83	11.87	0.14	0.14
	585	0.92	1.67	9.88	10.60	yes	24.64	13.02	0.13	0.00
15-year	746	0.91	1.79	10.13	10.72	yes	23.80	12.37	0.13	0.00
	741	0.91	1.69	10.06	10.68	yes	24.50	12.93	0.13	0.00

Table A.9 Regression parameters and goodness-of-fit statistics of population and sample models for water quality monitoring station on Green River, Auburn, WA - 12113000.

Record Length	Number of Data Points	NSC	RMSE (°C)	Mean Air Temperature (°C)	Mean Stream Temperature (°C)	Hysteresis	α (°C)	β (°C)	γ (°C^{-1})	μ (°C)
12113000	1223	0.89	1.44	10.85	9.87	no	21.23	12.30	0.17	0.00
3-year	146	0.90	1.36	10.79	10.19	no	22.98	13.60	0.17	1.74
	142	0.92	1.23	10.89	10.01	no	19.62	12.52	0.24	2.79
	153	0.92	1.26	11.14	10.32	no	20.77	13.68	0.23	3.61
	156	0.88	1.55	10.51	9.40	no	19.38	12.37	0.22	2.18
	136	0.78	1.60	9.97	8.49	no	17.94	10.99	0.15	0.36
	139	0.94	1.10	11.56	10.29	no	22.49	13.74	0.18	1.57
	138	0.92	1.20	10.94	9.87	no	24.16	13.76	0.16	0.38
	137	0.95	1.00	11.34	10.49	no	19.37	11.83	0.24	2.30
6-year	288	0.91	1.30	10.84	10.10	no	21.67	13.17	0.19	2.12
	309	0.90	1.44	10.83	9.86	no	20.28	13.10	0.22	2.81
	275	0.86	1.52	10.77	9.40	yes	23.68	14.37	0.13	0.00
	275	0.93	1.11	11.14	10.18	no	21.66	12.81	0.20	1.44
9-year	441	0.91	1.29	10.94	10.18	no	21.25	13.37	0.21	2.79
	431	0.86	1.54	10.68	9.40	yes	21.82	12.84	0.15	0.00
12-year	603	0.90	1.42	10.81	9.95	yes	20.82	11.74	0.17	0.00
	559	0.91	1.28	10.88	9.94	yes	21.62	12.51	0.17	0.00
15-year	733	0.87	1.56	10.67	9.70	yes	20.83	12.10	0.16	0.00
	689	0.88	1.51	10.75	9.64	yes	21.85	13.15	0.15	0.00

APPENDIX B: F-TEST STATISTICS AND OBSERVED SIGNIFICANCE VALUES FOR COMPARISON OF POPULATION AND SAMPLE MODELS

Table B.1 F-Test statistics and observed significance levels for comparison of population models and sample models for Hyco Creek, Leasburg, NC - 02077200.

Model Type	Number of Data	RMSE	RSS	df_1	df_2	F-Test Statistic	p-value
3-year	137	1.69	379.86	1039	133	1.6807	0.0001
	125	1.90	436.81	1051	121	1.2995	0.0339
	156	2.21	742.38	1020	152	0.9284	0.7389
	151	2.15	679.51	1025	147	0.9894	0.5465
	151	2.27	757.48	1025	147	0.8728	0.8729
	149	1.87	507.05	1027	145	1.3533	0.0110
	142	2.34	755.63	1034	138	0.8145	0.9530
	132	2.50	800.00	1044	128	0.7000	0.9978
6-year	262	1.80	835.92	914	258	1.5302	0.0000
	307	2.20	1466.52	869	303	0.9274	0.7933
	300	2.09	1292.96	876	296	1.0648	0.2609
	274	2.47	1647.24	902	270	0.6760	1.0000
9-year	418	1.98	1623.05	758	414	1.2600	0.0042
	451	2.10	1971.27	725	447	1.0622	0.2418
12-year	569	2.04	2351.30	607	565	1.19393	0.01624
	578	2.19	2752.96	598	574	0.91153	0.86889
15-year	720	2.07	3067.99	456	716	1.17677	0.02637
	729	2.21	3540.97	447	725	0.83654	0.98101

Table B.2 F-Test statistics and observed significance levels for comparison of population models and sample models for Ocmulgee River, Warner Robbins, GA - 02213700.

Model Type	Number of Data	RMSE	RSS	df_1	df_2	F-test Statistic	p-value
3-year	129	2.12	561.80	898	125	1.62739	0.00040
	154	2.71	1101.62	873	150	0.94024	0.70043
	153	2.33	808.91	874	149	1.33218	0.01461
	153	2.15	688.75	874	149	1.59432	0.00024
	155	2.71	1108.96	872	151	0.94018	0.70105
	151	2.95	1279.27	876	147	0.76746	0.98590
6-year	283	2.89	2330.24	744	279	0.77240	0.99614
	306	2.43	1783.28	721	302	1.25583	0.01079
	306	3.01	2736.15	721	302	0.67262	0.99999
9-year	436	2.65	3033.72	591	432	0.98696	0.56010
	459	2.83	3644.05	568	455	0.76628	0.99867
12-year	589	2.50	3656.25	438	585	1.26891	0.00368
	613	2.68	4374.08	414	609	0.92679	0.79834
15-year	744	2.56	4849.66	283	740	1.22946	0.01640
	766	2.64	5310.84	261	762	1.00000	0.49339

Table B.3 F-Test statistics and observed significance levels for comparison of population models and sample models for Muskegon River, Evart, MI - 04121500.

Model Type	Number of Data	RMSE	RSS	df_1	df_2	F-test Statistic	p-value
3-year	156	1.52	351.18	1014	152	1.28847	0.02468
	156	1.47	328.46	1014	152	1.38798	0.00574
	156	1.43	310.82	1014	152	1.47522	0.00144
	156	1.46	324.00	1014	152	1.40912	0.00414
	156	1.68	429.00	1014	152	1.02754	0.42478
	156	1.68	429.00	1014	152	1.02754	0.42478
	143	1.51	316.93	1027	139	1.30369	0.02428
6-year	312	1.52	711.60	858	308	1.34092	0.00121
	312	1.47	665.56	858	308	1.45853	0.00005
	312	1.68	869.30	858	308	1.03255	0.37253
9-year	468	1.51	1057.97	702	464	1.44429	0.00001
	468	1.61	1202.73	702	464	1.19089	0.02045
12-year	624	1.50	1395.00	546	620	1.60744	0.00000
	611	1.75	1858.94	559	607	0.88251	0.93372
15-year	780	1.68	2190.18	390	776	1.07161	0.21181
	767	1.71	2231.09	403	763	0.96626	0.64962

Table B.4 F-Test statistics and observed significance levels for comparison of population models and sample models for Cuyahoga River, Independence, OH - 04208000.

Model Type	Number of Data	RMSE	RSS	df_1	df_2	F-test Statistic	p-value
3-year	152	1.71	432.77	1276	148	0.89802	0.82129
	145	2.06	598.35	1283	141	0.58500	1.00000
	117	1.79	362.06	1311	113	0.81450	0.94074
	147	1.48	313.23	1281	143	1.23675	0.05235
	153	1.49	330.79	1275	149	1.21974	0.06090
	156	1.55	365.18	1272	152	1.11854	0.19019
	156	1.45	319.58	1272	152	1.29520	0.02132
	154	1.14	194.94	1274	150	2.16737	0.00000
	156	1.28	249.04	1272	152	1.69593	0.00003
6-year	297	1.9	1057.73	1131	293	0.66759	1.00000
	264	1.63	690.794	1164	260	1.00000	0.50819
	309	1.54	723.338	1119	305	1.15309	0.06426
	310	1.3	517.14	1118	306	1.72872	0.00000
9-year	414	1.9	1480.1	1014	410	0.62923	1.00000
	456	1.56	1099.987	972	452	1.13443	0.06132
	466	1.29	768.8142	962	462	1.88312	0.00000
12-year	561	1.81	1824.79	867	557	0.68957	1.00000
	622	1.29	1028.41	806	618	2.05404	0.00000
15-year	714	1.77	2224.36	714	710	0.69698	1.00000
	768	1.46	1628.54	660	764	1.53170	0.00000

Table B.5 F-Test statistics and observed significance levels for comparison of population models and sample models for Mississippi River, St. Paul, MN - 05331000.

Model Type	Number of Data	RMSE	RSS	df_1	df_2	F-test Statistic	p-value
3-year	156	2.69	1099.89	1161	152	0.82258	0.95272
	151	2.38	832.67	1166	147	1.08678	0.26348
	100	2.73	715.48	1217	96	0.80428	0.93825
	148	2.59	965.97	1169	144	0.89833	0.81658
	156	2.61	1035.44	1161	152	0.88193	0.85932
	155	2.38	855.32	1162	151	1.08707	0.26000
	156	2.19	729.01	1161	152	1.30767	0.01821
	155	1.75	462.44	1162	151	2.12106	0.00000
	140	1.89	485.81	1177	136	1.78973	0.00001
6-year	307	2.60	2048.28	1010	303	0.87325	0.93276
	248	2.65	1713.49	1069	244	0.83881	0.96439
	311	2.52	1949.57	1006	307	0.94872	0.72228
	311	1.97	1191.44	1006	307	1.74660	0.00000
9-year	407	2.65	2830.07	910	403	0.81065	0.99417
	459	2.59	3052.19	858	455	0.86148	0.96703
	450	1.96	1713.35	867	446	1.89065	0.00000
12-year	560	2.63	3845.80	765	556	0.74736	0.99990
	674	2.06	2843.21	651	670	1.79439	0.00000
15-year	711	2.67	5040.13	606	707	0.68756	1.00000
	775	2.26	3937.96	542	771	1.47112	0.00000

Table B.6 F-Test statistics and observed significance levels for comparison of population models and sample models for Niobrara River, Verdel, NE - 06465500.

Model Type	Number of Data	RMSE	RSS	df_1	df_2	F-test Statistic	p-value
3-year	143	2.13	630.63	1015	139	0.77727	0.98052
	98	1.50	211.50	1060	94	1.67648	0.00091
	152	1.83	495.64	1006	148	1.10249	0.22879
	156	1.59	384.27	1002	152	1.51023	0.00081
	155	1.73	451.93	1003	151	1.25188	0.04106
	156	1.83	509.03	1002	152	1.10290	0.22503
	156	1.60	389.12	1002	152	1.48952	0.00115
	142	1.47	298.20	1016	138	1.78171	0.00002
6-year	241	1.91	864.60	917	237	1.00000	0.50808
	308	1.73	909.84	850	304	1.29721	0.00369
	311	1.79	983.66	847	307	1.18880	0.03634
	298	1.56	715.48	860	294	1.66966	0.00000
9-year	393	1.91	1419.11	765	389	1.00000	0.50382
	467	1.75	1417.94	691	463	1.31934	0.00064
12-year	549	1.84	1845.15	609	545	1.14692	0.05062
	622	1.83	2069.62	536	618	1.19235	0.01735
15-year	704	1.82	2318.68	454	700	1.2576	0.0033
	778	1.85	2649.02	380	774	1.2002	0.0183

Table B.7 F-Test statistics and observed significance levels for comparison of population models and sample models for Salt Fork of the Arkansas River, Jet, OK - 07150500.

Model Type	Number of Data	RMSE	RSS	df_1	df_2	F-test Statistic	p-value
3-year	123	1.67	331.88	486	119	1.29937	0.04170
	143	1.62	364.79	466	139	1.41317	0.00770
	154	1.91	547.22	455	150	0.93129	0.71213
	146	1.57	350.02	463	142	1.52731	0.00146
6-year	266	1.64	704.68	343	262	1.50497	0.00026
	300	1.84	1002.14	309	296	1.04279	0.35825
9-year	420	1.82	1377.96	189	416	1.14225	0.13669
	453	1.89	1603.87	156	449	0.87786	0.83107

Table B.8 F-Test statistics and observed significance levels for comparison of population models and sample models for Middle Fork of the Feather River, Merrimac, CA - 11394500.

Model Type	Number of Data	RMSE	RSS	df_1	df_2	F-test Statistic	p-value
3-year	132	1.76	396.49	838	128	0.97395	0.59098
	149	1.79	464.59	821	145	0.93519	0.71208
	155	1.71	441.54	815	151	1.04195	0.38304
	156	1.72	449.68	814	152	1.02776	0.42477
	154	1.67	418.34	816	150	1.10132	0.23262
	123	1.38	226.62	847	119	1.67266	0.00028
6-year	281	1.80	897.48	689	277	0.90809	0.83608
	311	1.72	908.23	659	307	1.03429	0.36986
	277	1.61	707.64	693	273	1.23420	0.02099
9-year	436	1.80	1399.68	534	432	0.88141	0.91689
	433	1.66	1182.15	537	429	1.17756	0.03802
12-year	592	1.80	1905.12	378	588	0.83247	0.97409
	585	1.67	1620.35	385	581	1.21475	0.01740
15-year	746	1.79	2377.44	224	742	0.76244	0.99251
	741	1.69	2104.95	229	737	1.25330	0.01506

Table B.9 F-Test statistics and observed significance levels for comparison of population models and sample models for Green River, Auburn, WA - 12113000.

Model Type	Number of Data	RMSE	RSS	df_1	df_2	F-test Statistic	p-value
3-year	146	1.36	262.64	1077	142	1.13707	0.16655
	142	1.23	208.78	1081	138	1.41792	0.00499
	153	1.26	236.55	1070	149	1.34875	0.01080
	156	1.55	365.18	1067	152	0.84360	0.92601
	136	1.60	337.92	1087	132	0.78693	0.97316
	139	1.10	163.35	1084	135	1.80260	0.00001
	138	1.20	192.96	1085	134	1.49434	0.00181
	137	1.00	133.00	1086	133	2.20508	0.00000
6-year	288	1.30	479.96	935	284	1.29593	0.00435
	309	1.44	632.45	914	305	1.00000	0.50621
	275	1.52	626.12	948	271	0.86821	0.93147
	275	1.11	333.90	948	271	1.87822	0.00000
9-year	441	1.29	727.21	782	437	1.38359	0.00008
	431	1.54	1012.67	792	427	0.80660	0.99482
12-year	603	1.42	1207.82	645	599	1.02726	0.36920
	559	1.28	909.31	689	555	1.44796	0.00000
15-year	733	1.56	1774.09	490	729	0.63199	1.00000
	689	1.51	1561.87	534	685	0.79326	0.99757