148

THE EFFECTS OF CLIMATE CHANGE ON HYDROLOGIC VARIABLES

by

Jason R. Westmacott

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EFFECTS OF CLIMATE CHANGE ON HYDROLOGIC VARIABLES

BY

JASON R. WESTMACOTT

A Thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

ABSTRACT

There has been increasing concern about the threat of global warming. This warming scenario, called the greenhouse effect, is believed to be caused by increased concentrations of carbon dioxide and other greenhouse gases over the past half century. Presently, efforts are being made to evaluate the consequences of any potential impacts of climatic change on the earth's natural resources. Specifically, as the demands placed on the earth's water resources continue to increase, it becomes more important to investigate the likely response of the hydrologic regime to changes in climatic conditions.

The main objective of the research is to investigate relationships and expected impacts of climatic change on hydrologic parameters of relevance to water resources planning and management strategies. Temperature data records are used to monitor the response of climatic change, and are compared with the behavioral pattern of seven different hydrologic parameters which include the mean annual flow, mean seasonal flow, mean monthly flow, extreme annual flow, cumulative annual mean monthly negative deviations, maximum summer precipitation event, and the Julian day of first spring melt.

The area of study consists of the Northwestern Forest, Northeastern Forest and Prairie climatic regions with 117 natural flowing rivers encompassed by the Churchill-Nelson River Basin. The tools used to detect the effects of global warming are the Mann-Kendall statistical test for trend, a locally weighted least squares regression analysis to illustrate the general patterns of the trend, and the Kendall correlation test describing the magnitude of association between the hydrologic variables and the temperature time series. Generally variables which are influenced the most by increased evaporation and/or net precipitation losses due to temperature would experience decreasing hydrologic trends and negative correlations with temperature. When snow melting and snow accumulation are the dominating component for a particular time of year, increasing hydrologic trends and positive correlation with temperature were the results obtained.

The final stages of the analysis involve locating and grouping any spatial similarities of statistically significant and insignificant hydrologic trends, and spatial similarities for expected and unexpected behavioral responses with respect to the trend and correlation results for each hydrologic variable. The expected trends were primarily found in the southern parts of Alberta in the Prairie region, the mid-latitudes of Saskatchewan, and along the Manitoba/Ontario border spanning all three climatic regions. The unexpected significant trends were primarily located in central Alberta near the Prairie/Northwestern Forest Region boundaries, and in the southwest portion of Ontario in the Northeastern Forest Region. The insignificant trends were generally scattered throughout the region of study, with the exception of a small tendency for more insignificant trends to occur on the west side of Lake Winnipeg. It was found that both the trend and behavioral responses would cluster in similar areas. These results indicate the regions most susceptible to climate change and will help engineers plan and prepare for the possible impacts of climatic change on water resource planning and management systems.

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CHAPTER 1

1.0 INTRODUCTION

1.1 PROBLEM DEFINITION

There has been increasing concern about the threat of global warming in the past decade. This warming scenario, called the greenhouse effect, is believed to be caused by increased concentrations of carbon dioxide and other greenhouse gases in the atmosphere over the past half century. The concentration of greenhouse gases in the atmosphere has been increasing since the beginning of the Industrial Revolution. This has led to many concerns that these increases could result in global and regional climate change [Henderson-Sellers, Hansen, 1995]. These greenhouse gases entrap the sun's warmth in the lower atmosphere of the earth resulting in potentially serious consequences for temperature and temperature-dependent variables. Therefore, in this work, annual temperature records are used to monitor the effects and fluctuations of climatic change over several different climatic regions across west-central Canada. It has been statistically shown that temperature has increased within these regions over the past century [Gullett and Skinner, 1992]. On a global scale, average surface temperatures are about 0.5°C higher than average temperatures in the 19th century [Barron, 1995].

The primary intent in this work is to investigate relationships between the variability of hydrologic parameters and fluctuations in temperature over a period of time. Planning and management strategies for water resource systems rely heavily on being able to predict or prepare for variations in hydrologic variables such as streamflow. Water resource managers will have to deal with important considerations regarding climatic variability and climate change, since the climate also controls the distribution of water around the world [Ransom, 1990]. Since climatic change represents one of the sources of hydrologic variability due to fluctuations in temperature and other meteorlogic variables, the ability to predict future streamflow behavior based on general trends of temperature change will help determine and quantify any potential impacts on the earth's water resources. It is essential to investigate the possible impacts and consequences of climatic change for both the hydrologic regime and related water resource systems given the increasing demands that are being placed on the earth's water resources [Burn, 1994c].

The impacts of climate change on water resources could potentially be quite harmful. For example, future streamflow scenarios are required to evaluate the reliability and adequacy of power generation capabilities. Any potential reduction in streamflow over time could hinder hydropower generation and eventually result in millions of dollars of lost revenue. As well, the availability of water resources will be reduced. Kite [1993] indicates that any change in the availability or distribution of freshwater could possibly have serious consequences to the environment in some parts of the world where water usage is approaching the limits of water availability. Another concern deals with the deterioration of water quality. Generally, water quality deteriorates as streamflow decreases and is further impacted by increases in water temperatures which are also expected to occur with global warming [Lawford, 1994]. Essentially, increased temperatures caused by global warming result in decreased flows which will gradually lower the dissolved oxygen levels in rivers over time. Other potentially harmful effects of climatic change on extreme hydrologic events include increased droughts in the wetlands, and floods on the coastal areas caused by melting of polar ice caps.

1.2 PROBLEM SCOPE

The investigation of responses to hydrologic variability affected by fluctuations in the climate will be investigated within three different climatic regions encompassed by the

Churchill-Nelson River Basin. The different climatic regions should help display various responses which are common for a particular region. A large number of natural rivers are selected within these regions, and a variety of hydrologic variables are used in order to analyse the affects on long term variability of changes in the climate. However, detecting changes in the hydrologic regime that might result from climate change is difficult due to the inherent variability and randomness in most of the hydrologic variables commonly used for this type of evaluation [Askew, 1987; Burn and Soulis, 1992]. Further complications arise when anthropogenic effects are present. Therefore, the selection of natural rivers for the analysis will reduce the effect of human interaction on streamflow variability.

The hydrologic variables analysed in this thesis include annual mean and extreme flows, seasonal average flows, monthly average flows, and cumulative deviations from average monthly flow values on an annual basis. Timing of hydrologic events, such as the Julian day of spring snow melt, are also compared to historical temperature fluctuations. Finally, the largest peak magnitude of flow caused by a summer rain storm is analysed each year to account for the effects of climate change on precipitation. It is important to have a wide range of hydrologic variables to analyse in order to determine the diverse effects of climatic change on the hydrologic regime.

In order to properly investigate the relationships between these hydrologic variables and climatic change, it is important to find tools to detect the effects of global warming and accurately identify the general tendencies existing in the streamflow and temperature time series. This will be accomplished by applying a non-parametric statistical test for trend which indicates the statistical significance of possible trends in the time series. An exploratory data analysis technique for scatterplots is used to visually illustrate smoothed representations of the trends and patterns in the data. The last detection tool describes the magnitude of association between the hydrologic variables and the temperature data. This is done by a non-parametric correlation test.

The final stages of the analysis involve developing a method with which to locate and group any spatial similarities among the individual and combined results for each hydrologic variable. This regionalization approach used for the individual results will identify those rivers which displayed statistically significant trends in streamflow, deviations, and timing of hydrologic events at various significance levels. The combined results will recognize the severity of climatic change affecting each hydrologic parameter for each river. This will be accomplished by categorizing the expected behavioral patterns for each hydrologic variable. It is hypothesized that there will be different sensitivities to climatic change for the different climatic regions. Therefore, one would expect that the different significance levels will cluster in different areas. Final conclusive results of the study will indicate which regions are more susceptible to climate change and will help engineers plan and prepare for the possible impacts of climatic change on water systems.

The remaining sections of this thesis are organized as follows. Chapter 2 describes the essential background information on climate change, and the associated effects on the environment. Chapter 2 also goes into detail about procedures used to analyse the effects of climate change on hydrologic variables. Chapter 3 outlines the region of study and the hydrologic variables analysed for the study. Chapter 4 describes the method of evaluation, and Chapter 5 outlines the results obtained from the analysis. Chapter 6 will give a general summary of the results, and Chapter 7 will have the concluding remarks. Finally, Chapter 8 suggests other possible future work extensions related to this thesis.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 CLIMATIC CHANGE

Before discussing changes in our climate, it is essential to know how "climate" is defined. The climate of a place may be defined as a "composite" of the long-term prevailing weather that occurs at a given location. It is the normal weather pattern for a specific area which, with some certainty, will occur each year. Gullett and Skinner [1992] describe local and regional climates as being highly influenced by latitude, altitude, topography, and the proximity of large water bodies such as the oceans. Globally, climate is affected by complex interactions involving the sun, the land, the sea, the air, the earth's ice cover, and its plants and all other life forms.

In general, climatic change is a very broad topic with ample information describing possible causes and effects. Currently there are numerous and conflicting opinions on the subject of climatic change with new studies being completed on a regular basis. There have been various convincing reports documented world wide of the current existence of climatic change and the related causes and effects. The following sections will summarize relevant work collected for this thesis research. The main intent of the following sections is to give the necessary basic understanding of how climatic change has affected the world in the past, and how climate change might affect the world in the present and future.

2.1.1 Causes of Climate Change

Climate change is influenced by both natural and human induced factors. As a natural process, Gullett and Skinner [1992] list several influences by which climate change occurs on a variety of scales. These influences include changes in the sun's radiation, volcanic activity, alterations of ecology or topography, or various other natural factors. Some of these have been sufficient to cause the earth's climate to shift from the ice age conditions that existed 15,000 years ago to the temperate conditions that have predominated for the past 10,000 years [Gullett and Skinner, 1992]. Specifically, the long-term climatic changes of the last 15,000 years have been attributed to the variation of incoming solar radiation [Anderson et al., 1988]. Since the early 1970s, scientists around the world have become concerned that certain human activities influence factors contributing to the process of changing climatic conditions. It appears that these factors may now be causing unprecedented changes within the earth's climate system. The results from these changes may eventually increase the global surface temperatures to their highest levels in several hundred thousand years [Gullett and Skinner, 1992].

Recent climatic changes have been partly caused by manmade releases of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NO_x), chlorofluorocarbons, and other trace gasses through the "greenhouse effect" [Harrison, 1984]. Greenhouse gases absorb and re-emit infrared radiation, which includes the radiation emitted by atmospheric gases and clouds and by the Earth's land and oceans [Barron, 1995]. Essentially the greenhouse gases entrap the warmth from the incoming solar radiation and will gradually increase the atmospheric temperatures. Atmospheric concentration of these greenhouse gases have increased significantly above preindustrial levels, and it is believed that the increase is due to anthropogenic activities [Barron, 1995]. Barron [1995] concluded that the atmospheric concentrations of CO_2, CH_4, and NO_x, have increased 30%, 100%, and 10% respectively, above preindustrial levels as determined from air trapped in ice cores and direct measurements.

The increased concentration of these greenhouse gases exerts a global warming influence. It could take centuries for the reduction of the augmented CO_2, CH_4, and NO_x concentrations to near its preindustrial level, even if emissions were reduced substantially.

There are numerous factors affecting the prediction for the time needed to reduce the current level of greenhouse gases. A comparison would have to be made between the plausible sinks of emitted greenhouse gases and the following factors: projected growth of world population, the dependence of the world on the use of fossil fuels for energy, present trends in agriculture and deforestation, and the expected transportation, commercial, residential, and industrial use and emission of these gases [Barron, 1995].

The temperature at the earth's surface is influenced by a number of factors, including the amount of energy received from the sun, the amount of solar energy reflected back to space by the earth's surface and atmosphere, and the amount of heat kept within the atmosphere by heat-retaining greenhouse gases [Gullett and Skinner, 1992]. Barron [1995] believes that the extent of warming will be affected by the strength of water vapor and cloud feedback processes. These processes are major factors in controlling the natural greenhouse effect and would likely respond to the radiative changes. These feedbacks change the magnitude of the warming, but not the presence of the warming.

The magnitude and timing of the warming scenario is less certain. Observations and measurements of past and present radiative effects and concentrations of greenhouse gases can only indicate the presence, rather than the magnitude or timing, of induced global warming resulting from changes in the radiation balance of increasing greenhouse gas concentration [Barron, 1995]. Criteria for scientifically acceptable methods that provide conclusive evidence that climatic change has taken place have not yet been developed. However, there are numerous studies showing more evidence that the existence of climate change is present. Although uncertainty exists as to the rate of global temperature increase in the next few decades, there is some consensus that greenhouse gas emissions will contribute to and accelerate the global warming [Nikolaidis et al., 1993]. It is essential that there be continuous efforts to study climate change and its associated effects on the environment.

A graph is shown in figure 1 below of the carbon dioxide and temperature records over the last 160,000 years. These results were obtained from the Vostok ice core. The temperature was obtained from the $18_O/16_O$ (18 isotopes of oxygen/16 isotopes of oxygen) ratio in the ice and the carbon dioxide concentration was measured in gas bubbles enclosed in the ice [Harrington, 1989]. The incredible similarity between the fluctuations in CO_2 and temperature can be seen in this figure. This emphasizes the effect that carbon dioxide concentrations have on the global average temperatures. It would be premature to dismiss the presence of rising global temperatures caused by the anthropogenic related increases in carbon dioxide concentrations based on the findings of the Vostak ice core.

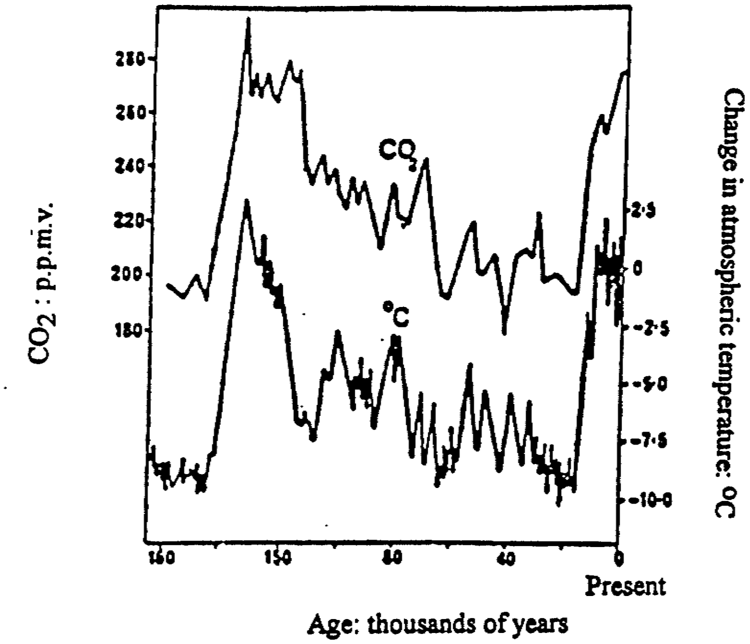

Figure 1: Antarctica, the Vostok record of temperature and concentration of carbon dioxide in the atmosphere [Harrington, 1989].

In the past, there have been scientists who were skeptical about the method used to analyse the past global temperatures. A recent paper by Thompson [1995] suggests that global temperature analyses need to be revised, and that when corrected, will lead to greater support towards concerns about global warming from fossil fuel combustion. Thompson [1995] indicates that current standard methods of correcting temperature data, which are based on the calendar year, are incorrect, and that the annual cycle of temperatures and seasons follow the "anomalistic" year. The "anomalistic" year is based on the earth's closest approach to the sun. Through summarized findings of Thompson's work, the following important differences were found when using the anomalistic year rather than the calendar year:

- Climatologists generally agree that the earth has warmed by about 0.6°C over the past century. They found the warming to be greater in winter (≈1.0°C) compared to the summer (≈0.4°C). This has puzzled researchers, but Thompson's data indicates that it is largely caused by using the calendar year instead of the anomolistic year.
- The statistical significance of the rise in temperature is greater when the anomalistic year is used.
- After 1940, the change in the timing of the seasons during the calendar year differs from the anomalistic year, with the seasons coming significantly earlier than they should. According to Thompson [1995], the change in central England over the past 50 years has been more than that in the preceding 300 years. Thompson [1995] contributes this shift to the rising levels of greenhouse gases in the earth's atmosphere. It was found that the seasons shift by approximately 1.7 days/century.
- With the anomalistic year approach, the southern hemisphere data shows a different pattern with a more modest shift. The presence of this shift

would rule out variations in the brightness of the sun as the source of the temperature change, since solar radiation would have equal effects worldwide.

2.1.2 Climate Change Effects

Barron [1995] summarized a report on the projection of climate change by global change researchers. Barron [1995] composed a list of very probable to probable effects of climate change. Several points from this list are shown below. These findings are based on the assumption that the concentration of anthropogenic greenhouse gases will increase.

- Globally, the rate of warming of the mean surface temperature will increase by the mid-21st century. These surface temperatures will increase by about 0.5°C - 2.0°C from 1990 to 2050 assuming no significant actions are taken to reduce these gases. Stone [1992] reported information from the Intergovernmental Panel on Climate Change in the fall of 1992 which suggested that global temperatures could increase by about 0.3°C per decade. This increase would be greater than that seen over the past 10,000 years.
- Globally, mean precipitation will increase. The distribution of this change is less certain. A warming of the surface temperature over the globe will increase global-mean precipitation because of the relationship between evaporation rate and surface temperature.
- Northern Hemisphere sea-ice will be reduced. Studies of past climates provide evidence for polar-amplification of warming and reduced extent of sea ice.
- Arctic land areas will experience wintertime warming. Paleoclimate and model studies provide evidence for polar-amplification of warming and

reduction in snow cover over the land surface. In January 1995, Argentine researchers discovered a 65 km crack in the Larsen Ice Shelf. Various reports have described the shelf to be cracking into bits resulting from the warming air. The big crack followed another major change in the Larsen Shelf. Earlier in January, a large iceberg with a surface area of around 2,900 km^2, and a thickness of 200 meters, broke off the Larsen Shelf. This has changed the shape of Antarctica and reportedly new maps will now have to be drawn.

- Globally, sea level will rise at an increasing rate, although the rate of rise may not be significantly greater than at present. The most reasonable estimates for the rise in sea level are 5-40 cm by 2050 as compared to a rise of 5-12 cm if the increases of the rise over the past century continue.
- Summer dryness in the mid-latitude of the Northern Hemisphere will increase. Evaporation increases strongly with increase in temperature. Models show that summer dryness occurs because the increase in evaporation is larger than the precipitation increase. A paper by Woo [1992] indicates the potential for the depletion of Canadian wetlands resulting from evaporative losses exceeding the supply of water. This reduction in soil moisture may also result in a decrease in summer runoff potential for the Canadian Prairies [Lawford, 1994].
- High-latitude precipitation will increase, with potential feedback effects related to the influence of additional freshwater on the thermocline circulation and increased precipitation on the mass balance of polar ice caps. As opposed to the previous point on summer dryness, this increase in precipitation may increase soil moisture and thus increase runoff potential in northern Canada.

Most changes are expected to occur before the middle of the 21^{st} century. Given the potential impacts of climatic change on the environment, many human societies and natural ecosystems could face serious problems of adaptation and survival [Gullett and Skinner, 1992]. Such problems or consequences that may occur due to the predicted change in climate include agricultural regions shifting, permafrost degradation, poor vegetation adaptability, increased forest fire potential, and changes in wildlife habitat, migration and population. These latter consequences play a significant role on the movement of the Arctic treeline which is described in a recent report done by the National Hydrology Research Institute on detection and assessment of climatic change [Watson, 1994]. Smit [1993] discusses the adaptability to climatic variability and change with respect to the forestry, construction, energy, recreation, and agriculture industries. Finally, more pertinent to this study, changes in the climate could lead to a depletion and alteration of the availability of water resources. It is essential for water resource planners to be prepared to deal with the effects of climatic change [Lawford, 1994].

There are a few positive aspects resulting from climatic change which may increase opportunities to the region, such as longer growing seasons for agriculture, longer shipping seasons, increased demand for tourism services, and greater productivity for northern forests [Cohen, 1992]. However, in comparison, it appears that the present day negative consequences out weigh the positive consequences of climatic change. Overall, in view of potentially dangerous consequences resulting from major climatic changes, Gullett and Skinner [1992] indicate the importance of having an early warning not only of the changes themselves, but also of their nature and the rate at which they are occurring.

2.1.3 Indicators of Climatic Change

There are numerous considerations to be aware of when choosing an appropriate variable to describe changes in the climate. For instance, temperature, rainfall, streamflow, and other climatic elements can vary substantially from one year to another at a given location. Therefore it is extremely difficult to distinguish an important emerging trend from a mere short-term irregularity in the climatic pattern [Gullett and Skinner, 1992]. This statement is true for virtually all variables used to monitor climate change. The natural variations and fluctuations in many variables are hard to separate out from the effects of climatic change. It is therefore essential to have data records that extend far back in time to properly display a regular pattern or trend over time.

Climate is most commonly described in terms of the familiar elements of the weather. Gullett and Skinner [1992] explain that temperature and precipitation are the essential indicators, but others such as sunshine, wind, cloud cover, atmospheric pressure, humidity, and evaporation can be added to provide a more concise and complete picture. The latter descriptive variables, with the exception of temperature, are difficult to use for analysing the effects of climate change due to the lack of physical data to manipulate. Therefore, temperature data would be a logical choice to represent the climatic tendencies over the past century since temperature records are easily accessible.

2.2 WATER RESOURCE STUDIES ON CLIMATIC CHANGE

It is very important for water resource managers to be aware of and prepared to deal with the effects of climatic change on hydrologic parameters. It is believed that hydrological and hydrometeorological measurements could be used to detect any possible indication of climatic change. Various efforts have been made to monitor the effects of climate change by water balance components [Schadler, 1987], levels of lakes [Churchill et al., 1978], tree-ring growth rates or information from ice cores [Lawford, 1988], and streamflow [Pilon et al., 1991]. The tree-ring chronologies, or dendrochronology, are advantageous to work with since hydrologic data can be estimated over the past 1000 years. Dendrochronologists have correlated tree growth with many environmental variables, and long tree-ring chronologies can be used to reconstruct the past history of snowpack, precipitation, temperature, drought indices, lake levels, and streamflow [Maidment, 1992].

There have been several other studies investigating the effects of climate change on water resource systems. The sensitivity of annual and seasonal runoff to changes in temperature and precipitation [McCabe and Hay, 1995] were examined in a sub-basin of the Gunnison River Basin in Colorado. A study of drought risks for three river basins draining about 19,600 square miles in Georgia, Alabama, and Florida [Tasker, 1993] showed lower flows occurring more frequently if the regional climate warms and monthly precipitation decreases during critical summer months. Drought risk studies could lead to other concerns such as negative impacts of water supply availability [Revelle and Waggoner, 1983; Gleick, 1987]. In general, the operation of many water resource systems could be adversely affected due to the impacts of changing climatic conditions [Nemec and Schaake, 1982].

A paper by Nkemdirim and Purves [1994] estimates the potential impacts of climatic change on streamflow in the Oldman River Basin, Alberta. They develop a multiple regression equation relating historical mean annual streamflow in the basin to the mean annual temperature and precipitation. Three general conclusions resulted from this analysis. First, the 95% control interval constructed around the partial regression coefficient for temperature were negative in both directions. This implies that the streamflow will decrease if temperature rises. Second, the 95% control interval constructed around the coefficient for precipitation ranges from negative to positive. Nkemdirim and Purves [1994] suggested that within the present climate, the instability in the sign of the coefficient suggests that the changes in precipitation at the levels encountered may not have been decisive in their determination of the magnitude of change in streamflow. Third, Nkemdirim and Purves [1994] concluded that the statistics from the equation indicate that temperature is more than six times as important as precipitation in determining changes in streamflow. These arguments again emphasize the importance of temperature in the evaluation of climatic trends.

Streamflow measurements are essential in order to provide an indication of the extent of the impacts of climatic change on water resources. As mentioned earlier, precipitation is also considered an important component used to monitor climatic change. However, from climatic change perspective streamflow is more desirable to monitor because it integrates the effects of precipitation over time and space [Lawford, 1994]. Streamflow represents an integrated response to hydrologic inputs on the surrounding drainage basin area and therefore affords good spatial coverage [Burn, 1994b].

CHAPTER 3

3.0 TECHNIQUES USED TO ANALYSE CLIMATE CHANGE

Given the variable nature of changing climatic conditions on hydrologic variables, Lawford [1994] points out the importance of developing robust data collection and monitoring systems which provide a basis for determining when unambiguous climatic signals are occurring and for monitoring the rate and extent of this change and its effects. It is common to estimate global warming based on applications of general circulation models (GCMs). These models attempt to predict the impacts of increased atmospheric CO_2 concentrations on weather variables [Tung and Haith, 1995]. Tung and Haith [1995] used primary weather variables such as temperature and precipitation from GCM simulations for current and doubled CO_2 levels. However, the simple GCM parametric method simply deals with the consequences of future increases in CO_2 levels. This thesis deals with past occurrences of temperature fluctuations which were potentially at least partially caused by the increased concentrations of greenhouse gases. The following four sections will describe the tools used to examine the past climatic signals. Each tool is essential for developing accurate representations of the effects of climatic change on hydrologic variables. The results should elude to possible future consequences of hydrologic behavior with the continuation of global warming.

3.1 STATISTICAL TEST FOR TREND

The initial procedure for determining the existence of patterns and trends in the streamflow (or streamflow related) and temperature time series is done using the Mann-Kendall test for trend. The Kendall statistic was originally devised by Mann [1945] as a non-parametric test for trend. Later the exact distribution of the test statistic was derived by Kendall [1975]. The Mann-Kendall test has been used by other researchers in similar applications and was found to be an effective tool for identifying trends in hydrologic and other related variables [Hirsch et al., 1982; Gan 1992; Burn, 1994a]. The test statistic for the Mann-Kendall test is given as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_j - x_k) \qquad (1)$$

where the x_j are the sequential data values, n is the length of the data set and

$$\operatorname{sgn}(\theta) = \begin{bmatrix} 1 \text{ if } \theta > 0 \\ 0 \text{ if } \theta = 0 \\ -1 \text{ if } \theta < 0 \end{bmatrix} \qquad \text{(tie situation)} \qquad (2)$$

The null hypothesis, H_0, is that the data $(x_1, \ldots, x_n)$ are independently identically distributed random variables (i.e., no existing trend in the data set). The mean and variance of S under the null hypothesis is:

$$E[S] = 0 \qquad (3)$$

$$Var[S] = \frac{n(n-1)(2n+5) - \sum t(t-1)(2t-5)}{18} \qquad (4)$$

where t is the number of data points involved in a tie and the summation is over all ties. For sample sizes larger than 10, the statistic is very nearly Normally distributed if a continuity correction is applied giving:

$$S' = S - sgn(S) \qquad (5)$$

where S' is the corrected test statistic value. Assuming the corrected test statistic follows the Normal distribution, a Z value associated with the trend statistic can be calculated [Burn, 1994c]. The Z value can be converted to a probability indicating the percentage chance of no trend existing. The Z value is a standard Normal variate and the equation is given as:

$$Z = \frac{S'}{\sqrt{Var[S]}} \qquad (6)$$

A non-parametric estimate for the magnitude of the slope was determined by Hirsch et al. [1982]. The following equation is a robust estimate of the slope, β. This beta value represents the magnitude of the trend.

$$\beta = Median\left\{\frac{x_j - x_k}{j-k}\right\} \quad \forall \; k<j \qquad (7)$$

The advantage of the Mann-Kendall test with respect to the probability of rejecting the null hypothesis (detecting a trend) when one really exists, is that the power of the test is nearly as high as the parametric tests, such as the t-test for regression-based slope estimates [Lettenmaier et al., 1994]. On the other hand, one disadvantage for the parametric tests is the requirement that the data be normally distributed, which is not usually the case for climatological data, particularly precipitation and streamflow [Lettenmaier et al., 1994].

The two most relevant results for this thesis derived from the Mann-Kendall statistical test are the general slope of the trend, where the slope magnitude indicates an increasing or decreasing tendency by a positive or negative value respectively, and the significance level of the trend. The significance level, calculated from the standard Normal variate, gives the probability of obtaining the observed value for the Mann-Kendall Statistic when in fact no trend exists. The closer the significance level is to zero, the greater the chance that a trend actually exists in the data set.

3.2 EXPLORATORY DATA ANALYSIS

An exploratory data analysis technique is used to help identify existing patterns and trends in the time series data. This technique is essentially a smoothing procedure which was developed by Cleveland [1979] and is referred to as LOWESS; **lo**cally **we**ighted least squares regression. The smoothing analysis is essentially a tool used for two purposes: (1) to help visualize the pattern and trends that exist in the time series, and (2) to enable comparisons to be made between the smoothed curves of a particular hydrologic variable and the corresponding temperature series by using correlation tests. A correlation analysis is more meaningful between the two smoothed curves rather than the original scatterplot of data due to the inherent variability which may tend to obscure the results. This approach is analogous to removing the random component (stochastic component) from a variable time series and just using the left over deterministic portion of the time series for the correlation analysis.

Basically, the LOWESS procedure involves fitting the locally weighted least squares regression at each observation point. The set of data points used at each regression consists only of those data points that are within a defined neighborhood of the observation. The points which are further away from the observation point will receive low weights, while the data points closest to the observation point will have higher weights for the regression analysis. This method also accounts for the inherent variability in hydrologic data by identifying outlying observations, which are then given reduced weights. There are two parameters in LOWESS that control the range of data used for each regression and the number of iterations necessary to obtain an acceptable smoothed value. These parameter values were determined through a heuristic proceedure and kept constant throughout the entire analysis for all hydrologic variables of interest. The final results of LOWESS produce a smoothed curve describing the general tendencies of the data which are often masked by the variability of the data values. The smoothed curves will help identify the existing patterns and trends in the streamflow and temperature data. A preliminary visual inspection of a time series can provide valuable information about the structure of the series so that a focused analysis can be conducted [Garbrecht and Fernandez, 1994]. A more indepth description of this smoothing procedure is documented in Cleveland [1979].

The most common misconception of smoothing techniques is the belief that there should be statistical tests to indicate the accuracy of the curve developed. This smoothing procedure is more of an art than a science. There is no statistical significance involved with this technique. The statistically significant evidence of detected trends are done using the Mann-Kendall test described earlier.

3.3 CORRELATION TECHNIQUES

As mentioned in the previous section, the smoothed curves developed for streamflow and temperature time series will be used as input data for the correlation test. The purpose of a correlation test is to indicate the possible relationship between streamflow and temperature, or in other words, between hydrologic variables and climatic change.

The calculations involved with determining the correlation between the smoothed flow series and the smoothed temperature series are accomplished by using a non-parametric correlation test. Non-parametric correlation is concerned largely with paired observations consisting of ranks [Sprent, 1992]. The key concept of non-parametric correlation is described as follows: the value of each [x_i, y_i] (streamflow, time) and [x_j, y_j] (temperature, time) are replaced with the value of their rank amongst all the other [x_i, y_i] and [x_j, y_j] points in the sample, then the resulting list of numbers will be drawn from a perfectly known distribution function (e.g., uniform) from the integers between 1,2,3,...,N, inclusive [Press, 1989]. Statistics can be used to detect correlations between uniform sets of integers between 1 and N, keeping in mind the possibility of ties in the ranks. There is some loss of information in replacing the original numbers by ranks, but non-parametric correlation is more robust than linear correlation and more resistant to unplanned defects in the data, in the same way that the median is more robust than the mean [Press, 1989].

Kendall's tau (τ) is the statistic chosen to detect correlations between the uniform sets of integers. The Kendall's tau non-parametric correlation test produces a correlation value, and a probability associated with that correlation. This probability is based on the null hypothesis that there is no existing correlation. The tau value is approximately normally distributed, with zero expectation value and a variance of

$$Var(\tau) = \frac{4N+10}{9N(N-1)} \qquad (8)$$

The derivation of the tau value is beyond the scope of this thesis, however, a detailed derivation is provided by Press [1989]. The standard Normal variate value Z can be calculated by the following:

$$Z = \frac{\tau}{\sqrt{Var(\tau)}} \qquad (9)$$

Very small probabilities would indicate excellent correlation values. The extreme limits of the tau correlation value are positive and negative 1. The positive value would imply an identical relationship between the two smoothed curves, for example, the fluctuations between temperature and streamflow would be similar. Alternatively, negative correlations indicate an inverse relationship between temperature and streamflow.

3.4 REGIONALIZATION TECHNIQUES

As a result of the randomness involved with analysing the effects of climatic change on hydrologic variables, it is important to establish some kind of method that encompasses all results to define or illustrate the general tendencies of climatic change. Regionalization techniques will lead to more effective detection of climatic change impacts, and identify the catchments that have similar hydrologic response characteristics [Burn, 1994b]. Burn and Soulis [1992] believe this may be accomplished by obtaining a spatially integrated response that attempts to enhance the capability for detecting any underlying signal by filtering the noise inherent in the individual data series. Here the main challenge is to properly detect the actual trend while carefully filtering out the inherent noise. However, Burn and Soulis [1992] also indicate the possible disadvantage of the regionalization approach is that the grouping of hydrologic responses from different locations could result in the masking of spatially divergent responses to climatic change. Therefore a separate evaluation would also be necessary to evaluate the spatial responses for each hydrologic variable considered.

It is difficult to estimate how various regions will respond to global climate change. There are also a number of ways in which to classify these regions. Regions may be classified by a combination of different criteria such as climatological areas, geographical boundaries, geological boundaries, and hydrological and statistical results. The climatological areas would separate regions based on climatic conditions. Therefore, gauging stations located in the same climatic zone are combined to form a region. Information recorded for each gauging station is essentially governed by the physical characteristics of the surrounding catchment (drainage basin). Therefore, drainage basins which are in close proximity to one another may be combined to form regions based on geographical boundaries (i.e., provinces, latitude and longitude separations). It is expected that drainage basins which are close together would have similar responses to climatic change since they experience similar hydrologic inputs. Another scenario would involve separating drainage basins based on land use, and geological boundaries. For example, the hydrologic responses for regions having a rocky ground surface (Canadian Shield in northwestern Ontario) compared to rich soil conditions (Canadian prairies) would be different for similar hydrologic inputs.

An alternative way of separating drainage basins into regions could be based on the results of hydrological, or statistical analysis. A number of hydrologic variables analysed (extreme flows, mean flows, etc.) may have similar responses. On the other hand, statistical tests (trends, correlations, etc.) may be similar in various regions. The chance that any region developed is completely homogenous is very remote. Due to the diversity of hydrologic responses that can occur within a single climatic region, Burn and Soulis [1992] point out the difficulty of identifying homogeneous regions.

There are numerous regionalization techniques which may be used for gathering similar behavioral patterns of streamflow resulting from the effects of global warming. Burn and Goulter [1991] developed a new two-phased procedure for rationalizing a streamflow data collection network where a hierarchical clustering technique is used to identify groups of similar gauging stations. Anderson et al. [1992], described clustering as a strategy for finding natural groupings or associations based on the concept of similarity or likeness. This clustering technique may be beneficial to this research by indicating the expected response of various groups of gauging stations affected by climatic change. One may use well established techniques, like the clustering approach, that have been employed by various researchers; or one may find that the development of a specific regionalization method, more suited to the overall understanding of what is being studied, will emphasize the general results more accurately. This thesis uses the latter approach. A description of logic behind the developed regionalization procedure will be explained later in Chapter 4.

CHAPTER 4

4.0 CASE STUDY

This chapter gives the foundation for the research on the effects of climate change on hydrologic variables. Information is given about Canada's current climatic condition and the condition of the area which will be studied. Based in part on the latter part of the discussion in Chapter 2, streamflow and variables derived from streamflow will be used as the hydrologic variables to analyse the effects of climatic change. As well, annual temperature records will represent the changing climatic conditions. Finally, the hydrologic variables used to monitor the effects of climate change, and how the evaluating procedure is to be accomplished, will be described in detail.

4.1 REGION OF INTEREST

The region under study includes the west-central portion of Canada encompassed by the Churchill-Nelson River Basin. Gullett and Skinner [1992] mentioned that with the exception of the Baffin and Ellesmere Island area, all regions of Canada have shown some degree of warming, although the trends have not been statistically significant in all areas. The evidence of warming is most strongly shown in central Canada running from northwest to southeast through the Mackenzie District and the Prairie Provinces. Warming is less pronounced but still significant farther east in the Great Lakes Basin/St. Lawrence Lowlands and in the Canadian Shield country of Ontario and Quebec, and weakest on the country's Atlantic and Pacific edges and in most areas of the Arctic [Gullett and Skinner, 1992].

4.1.1 Climatic Regions

The Churchill-Nelson River Basin is the region under investigation. The three different climatic regions encompassed by this area include the Northeastern Forest, the Prairies, and the Northwestern Forest. Figure 2 shows the location of these regions and Figure 3 shows the location of the Churchill-Nelson Drainage Basin boundaries. The transition between the regions are not precise, but the boundaries serve as a general guideline to decide which climatic region affects a particular river of interest.

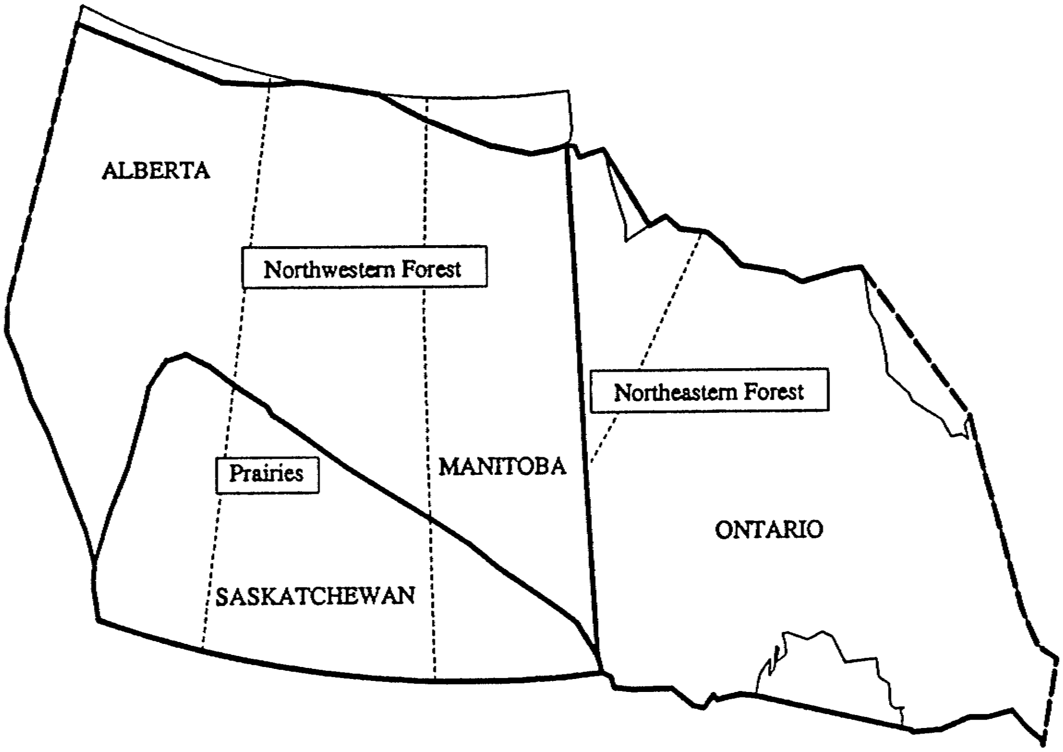

Figure 2: Location of Climatic Regions within the Churchill-Nelson River Basin

By studying the effect of climate change in several geographic regions for different hydrologic variables, one may anticipate that the variation in the severity of climate change will differ from region to region. Impacts will vary over space and time. It is apparent that watersheds in different locations will experience different patterns of climate change, and watersheds with different physical basin characteristics may respond in dissimilar ways [Tung and Haith, 1995]. The sections below briefly describe the environment and basic characteristic of each region. These regions are described in further detail by Gullett and Skinner [1992].

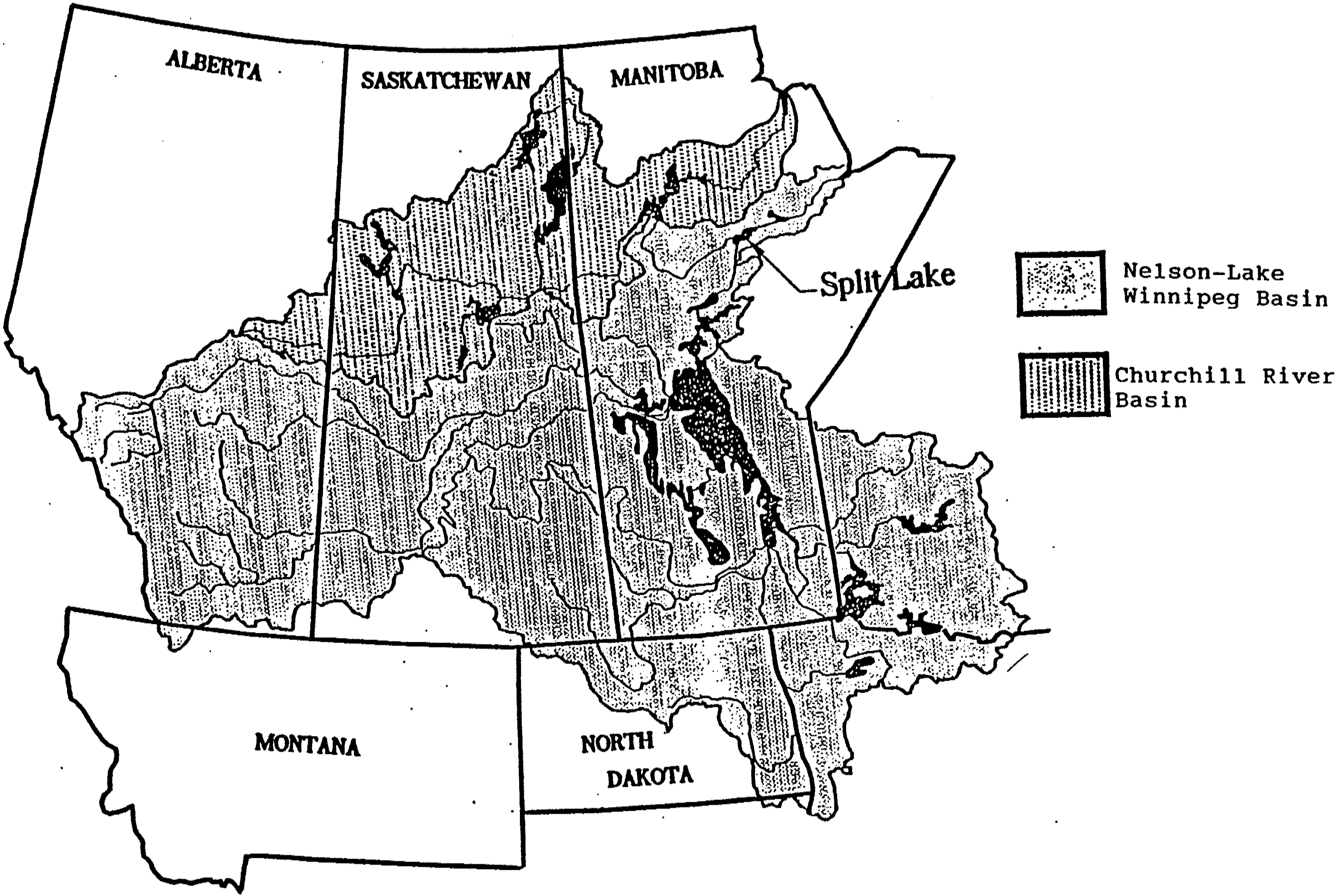

Figure 3: Location of Churchill-Nelson River Basin Boundaries

4.1.1.1 Prairies Region

The Prairies Region is comprised of the southern portion of the Alberta, Saskatchewan, and Manitoba provinces. There are no major relief features, however, there is a gradual downward slope from the foothills of the Rocky Mountains in Alberta to the Manitoba/Ontario border. The passage of Pacific air into the region is frequently blocked by the western mountain ranges, and therefore, air masses from the Arctic and the southern United States are the primary sources of air flow into the Prairies. Most of the moisture from the Pacific air is lost as a result of its passage across the mountains before entering the Prairies. This promotes dry conditions for the region's climate and greater tendency for extremes in temperatures.

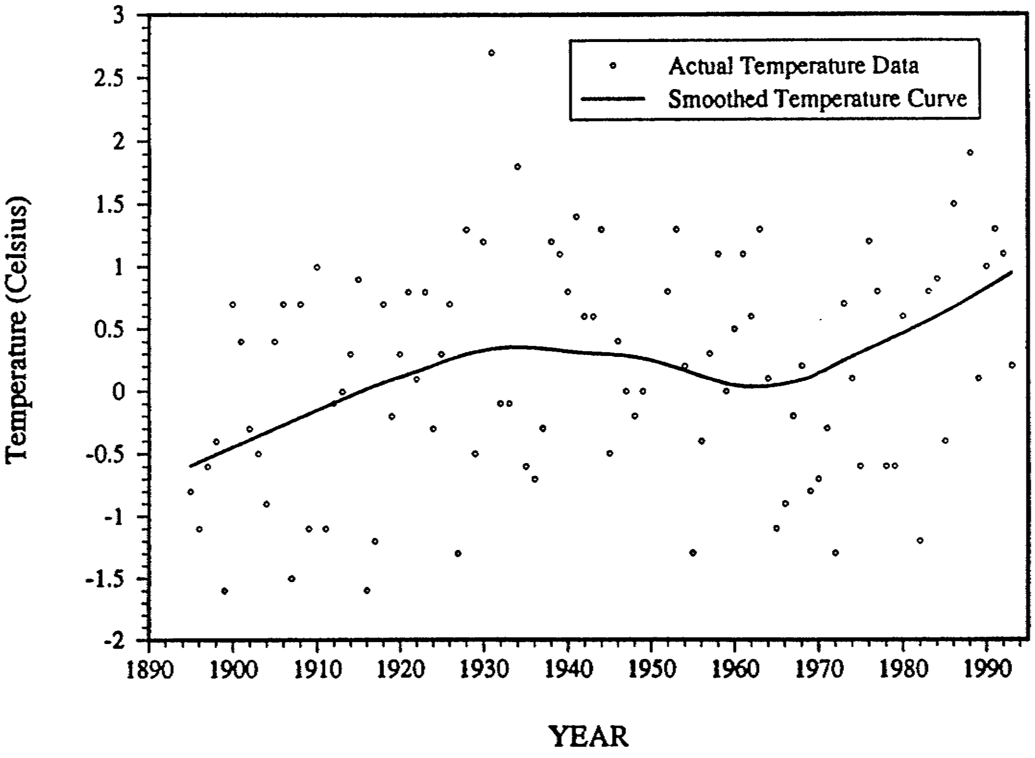

Figure 4: Temperature time series for Prairies region

Annual average temperatures could range from 1.0^{o}C to 4.0^{o}C within the region. The difference between summer and winter temperatures are greatest in the Prairies compared to the rest of Canada. The temperature change for the region is a statistically significant 0.9° Celsius increase over the last century. Figure 4 shows a gradual warming between the early 1900s and the 1940s, a cooling between the 1940s and 1970s, and once again a warming from the 1970s to the 1990s.

4.1.1.2 Northwestern Forest Region

The Northwestern Forest extends north from the northern boundary of the Prairies Region to the Mackenzie District at about the 60th parallel and east from the foothills of the Rocky Mountains to the Manitoba/Ontario border. The landscape is similar to the Prairies with respect to prominent relief features. The region is generally under the influence of the cold, dry Arctic air mass. If Pacific air masses make it over the mountains, the air tends to be milder with most of its moisture lost as a result of its passage over the mountains.

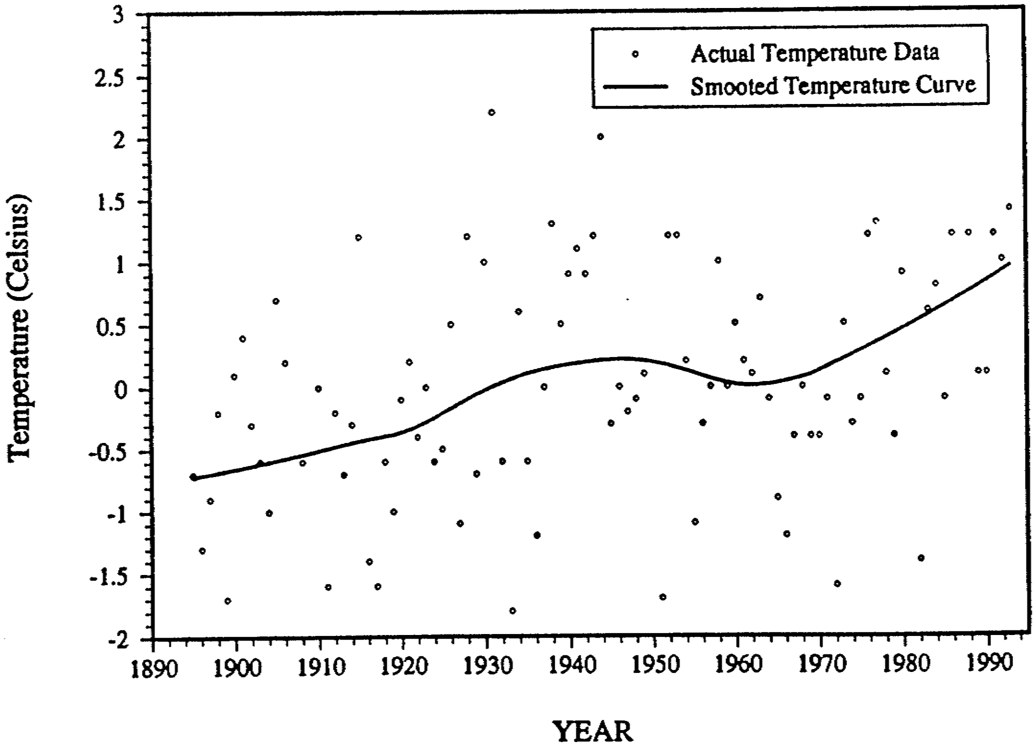

Figure 5: Temperature time series for Northwestern Forest region

Annual average temperatures range from about -1.0°C to 2.0°C. Winters are long and very cold with persistent snow cover, and summers tend to be short and cool. Annual precipitation averages about 450 mm across the region, with more precipitation falling in the summer than in the winter in most parts of the region. Figure 5 shows the pattern of temperature variation over the last century for the region. The behavior is very similar to that for the Prairies. Overall, there is a statistically significant warming over the last century of 1.3° Celsius.

4.1.1.3 Northeastern Forest Region

Finally, the Northeastern Forest region lies within the northeastern portion of Manitoba, and extends east from approximately the Ontario/Manitoba border to the Atlantic coast of Labrador including the Lower Saint-Lawerence and the Gaspé Peninsula. However, for this thesis the eastern boundary of the region is the Ontario/Quebec border.

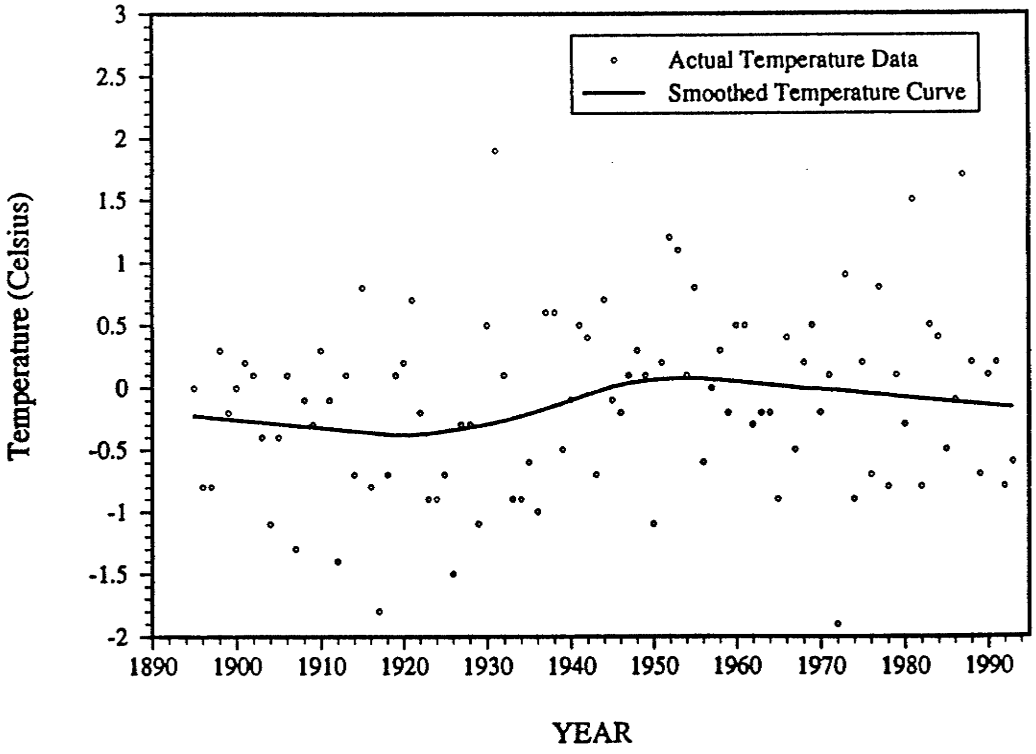

Figure 6: Temperature time series for Northeastern Forest region

The Canadian Shield forms a major portion of the ground cover. Storm systems from the Ohio Valley/Great Lakes area are common in this region. Generally, the Northeastern Forest is more humid than the Northwestern Forest because of these storm systems. Winters are long, cold and snowy, and summers are short and cool. Annual precipitation is about 400 mm at Churchill, Manitoba, and increases to the southeast while annual temperatures average about -7.0°C at Churchill to 1.0°C near the mouth of the St. Lawrence. Figure 6 shows a moderate regional warming which is a statistically significant 0.5° Celsius over the past century.

4.1.2 Selected Rivers of Interest

There are several guidelines to follow when dealing with studies involving the determination of trends and patterns in time series data. The first important factor deals with the length of the data records. Long-term records are essential to determine the existence and rate of change of climatic effects [Lawford, 1992]. Another factor pertaining to the streamflow data is whether or not the river is regulated. The influence of regulation, or in general the human interaction with the natural environment, makes it difficult to attribute any observed impacts on hydrologic variables caused by climatic changes [Refsgaard, 1987]. As well, Burn [1994a] points out the difficulty of detecting changes in the hydrologic regime that might result from climatic change due to the inherent variability in virtually all of the hydrologic variables of interest. The signal, that results from the impacts of climatic change, must be separated from the natural noise component of the hydrologic record [Burn, 1994b]. Therefore, it is advantageous to have natural flowing rivers with long record lengths which are unaffected by regulation in order to properly identify long term trends associated with climatic change.

Based on this discussion, 30 years of record length was arbitrarily chosen to be a minimum bench mark for the number of years that could adequately indicate any existing trends or patterns. For rivers which had greater than 30 years of data, the entire record length ranging from this earliest record to the most recent record could not have more than 25% of missing data points. This percentage value was also used in similar studies done by Changnon and Kunkel [1995]. As well, a particular record length may not have more than 25% zero values, and no more than 2 successive years of missing data. For monthly data only, simple linear regression was used to fill gaps for any months with no available data. However the linear regression was done only for those months having preceding and following known monthly values. The reason for these restrictions is to have a set of data that will properly represent the catchment area for the river, and to decrease the error in discovering trends or patterns in the time series. There are only three rivers which are exceptions to the rule of missing data points; the Gods River, Hayes River, and the Kettle River. These rivers had more frequent gaps that were filled by regression techniques in order to satisfy the above requirements. This was done to further explore the effects of climatic change in the northern parts of Manitoba, an area that is sparsely gauged.

The streamflow data was obtained through a hydrologic CD-ROM disc ('Hydat', Version 4.0, Earthinfo Inc.) which is supplied by Environment Canada. All natural rivers that were within the Churchill Nelson River Basin and had greater than 30 years of record were chosen. There are 117 rivers selected in total; 78 rivers fall in the range of 30 - 39 years of record length, 17 rivers ranging between 40 - 49 years, 10 rivers ranging between 50 - 59 years, 2 rivers ranging between 60 - 69 years, 9 rivers ranging between 70 - 79 years, and 1 river above 80 years of record length. There are 57 rivers in the Prairie region, 16 rivers in the Northeastern Forest region, and 44 rivers in the Northwestern Forest Region. The contributing drainage area for these rivers range from 78 to 133 000 square km with a median of 1040 km^2.

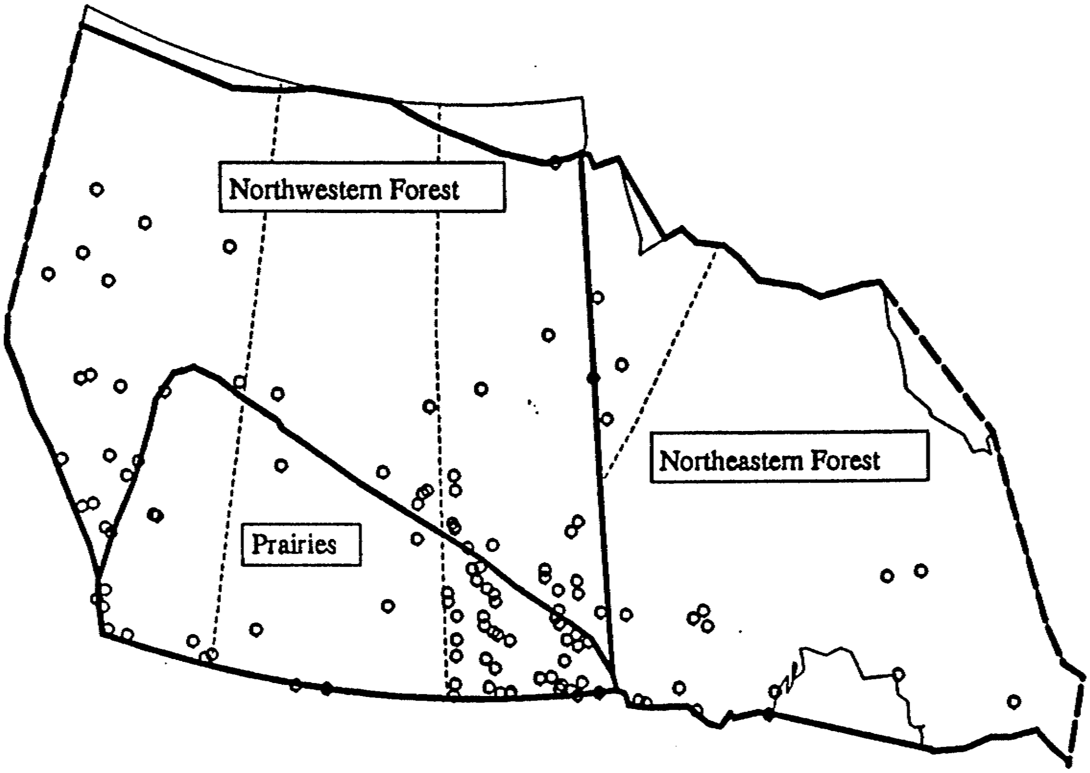

Figure 7: Location of Rivers within Churchill-Nelson River Basin

The points on figure 7 represent the gauging stations of each river analysed. For the stations bordering the climate region boundaries, another map of the drainage basins for each river was used to find where the main portion of the basins lies. A list of each river's station number, record lengths, basin areas, and their locations are given in appendix A.

4.2 VARIABLES USED TO MONITOR CLIMATIC CHANGE

4.2.1 Temperature

It was mentioned earlier that temperature would be used to monitor the effect of climatic change since changes in temperature may have serious environmental consequences. Temperature is also arguably the most significant of all climatic variables for a number of reasons; (1) temperature has the most effect on human comfort, (2) temperature plays an important role in determining the composition of the ecosystem, and (3) temperature is strongly related to other important atmospheric processes such as evaporation and precipitation [Gullett and Skinner, 1992]. Historically, warmer and colder climates have been alternating over hundreds of thousands of years. Since the end of the last ice age about 10,000 years ago, the stability of the earth's average temperature has been relatively constant, varying only within a range of 1.5°C to 2.0°C [Gullett and Skinner, 1992]. However, even the smallest variation in temperature can have significant environmental effects.

The temperature data used for this report resulted from a collaborative effort initially started by the World Meteorological Organization (WMO) to establish a global reference climatic station network for use in climatic change studies. Gullett [1992] described the foundation for developing a global reference climatic station network database. The database contains data from 131 Canadian climate stations from 1895 to 1991. It was assembled after missing data gaps were filled, homogeneity tests were completed, and data adjustments performed to remove local effects that might result from changes of site, station relocation, and instrument changes.

There are separate temperature time series extracted from the database for each climatic region within the Churchill-Nelson River Basin. Figures 4, 5 and 6 are the temperature time series plots for these regions. The temperature time series that will be used for the analysis depends on the climatic region for the river.

4.2.2 Hydrologic Variables

Analysing different hydrologic variables would indicate which hydrologic variable is more prominently affected by changes in the climate. Ideally, Burn and Soulis [1992] suggest that a wide range of hydrologic variables should be monitored since it is to be expected that climatic change will result in a diversity of environmental responses. As previously mentioned, streamflow and variables related to streamflow will be used for this report. The number of rivers analysed for each variable may vary due to the lack of streamflow data for certain months, seasons or years. The impacts of this were partially alleviated by interpolation of streamflows where ever practical.

The following sections discuss the selection of seven different hydrologic variables used in this study, and how each variable may be expected to respond to changing climatic conditions. The selection of these variables were based upon two criteria: (1) hydrologic variables which are anticipated to be affected by climate change, and (2) hydrologic variables which are of interest to Manitoba Hydro. The expected response of each hydrologic variable will be heavily based upon the logic of decreasing flows resulting from increasing temperatures over time. This natural phenomenon would primarily be attributed to an increase in evaporation potential and/or a decrease in net precipitation. Therefore, suggestions will be made as to the hypothesized behaviors for each variable, however, the expected behavior will be reflected through the statistical trend and correlation test results. The procedures for an expected/accepted behavior are discussed in section 4.3.

4.2.2.1 Mean Annual Streamflow

This is the most basic variable analysed. The mean annual flow will indicate what is generally happening on a yearly basis for average streamflows. The results may show any periodic trends over many years for streamflow and temperature time series. The mean annual flow was obtained by directly extracting the value from the mean monthly flow files on HYDAT. Due to the lack of monthly data available for January, February, November and December flows, a minimum range from March to October was considered an acceptable time period to represent the annual flow variable. Therefore the mean annual streamflow value was calculated using the months March to October. Another time period from May to August was used to define a general summer period in which runoff, streamflow, and drought conditions are generally most prominent. The difference between the two time periods would help identify any relationships between a complete year and a summer season. It is hypothesized that the mean annual flow will decrease with increasing temperatures over time. Therefore, decreasing trends and negative correlations are the most likely results to be obtained.

4.2.2.2 Cumulative Annual Mean Monthly Negative Deviations

This evaluation helps identify the possibility of changes in the frequency of drought conditions. It is difficult to do a standard evaluation of actual drought conditions given the nature of this study. This study requires one value of each variable per year in order to analyse the effects of climate change on any of the hydrologic variables. Since drought conditions can not be described by a single value, another method had to be devised to account for the possible changes in dry annual conditions. This was done by analysing the behavior of mean monthly flows with respect to average monthly flows for the entire record length available. Monthly intervals, as compared to seasonal or annual intervals, where used in order to more accurately represent the fluctuations in streamflow from an average flow value.

The cumulative annual mean monthly negative deviation is found by adding the negative deviations, for each month (j) in a year, between the average mean monthly flow, based on the entire record length, and the actual mean monthly flow for year (i). Only the negative differences are accumulated because the parameter is dealing with drought conditions, and therefore positive deviations are considered to be zero. Essentially the flow is expected to decrease over time, and therefore, the deviation will increase, resulting in further separations between the average mean monthly flow and the actual mean monthly flow.

This behavior would result in increasing trends and a positive correlation with temperature. The opportunity for drought conditions to occur would increase due to this behavior. A simple equation for calculating the cumulative annual mean monthly negative deviation (CND) is as follows:

$$CND_i = \sum_{j=3}^{j=10} \overbrace{\left|(x_{ji} - m_j)\right|}^{\substack{\textit{negative}\\ \textit{deviations}\\ \textit{only}}} \qquad \text{for i = 1,..,n} \tag{10}$$

The number of years of record is indicated by the n value. The x_{ji} value is the mean monthly flow for month j and year i, and m_j is defined as:

$$m_j = \frac{\sum_{i=1}^{i=n} x_{ji}}{n} \qquad \text{for j = 3,...,10} \tag{11}$$

Due to the lack of mean monthly data for the winter months, it was again decided to have March to October define an entire year of record. This would significantly increase the number of rivers available for analysis. As well, the range from May to August was used to define a general summer period.

4.2.2.3 Mean Seasonal Streamflow

The mean seasonal flow is essentially a breakdown in the response of the mean annual flow analysis. It is important to not only see the effects of climatic change on an annual basis, but also on a seasonal time scale. The summation of the mean seasonal results would theoretically be equivalent to the mean annual results. The seasons are separated into the following categories:

Spring -- March, April, May **Summer** -- June, July, August

Fall -- September, October, November **Winter** -- December, January, February

The mean flow for each season was calculated by averaging the three consecutive months. If a month was missing, then that year would be skipped. If there were less than 30 years of record, then the season analysed would be discarded for that river. One might anticipate slight variations in the behaviors for each season. It is expected to have decreasing seasonal flows over time (decreasing trends and negative correlations with temperature), but with more specific yearly divisions, it is possible to see increasing flows over time (increasing trends and positive correlations with temperature) in seasons where snow melting and snow accumulation is dominant.

4.2.2.4 Mean Monthly Streamflow

The mean monthly flow is a further break down of the mean seasonal flow analysis. This evaluation will indicate the general periods in a year which are affected differently by climate change. This analysis may be considered more accurate than the mean annual or seasonal flow analysis only if the hydrologic responses fluctuate more frequently than four times a year or more than once a year. Similarly to the seasonal responses, the explanation for the hypothesized behavior of each month will depend on the natural climatic characteristics for a particular time of year. It is expected to have decreasing flow trends with negative correlations for months where evaporation is the major influence, and increasing flow trends with positive correlations for months where snow melting and snow accumulation is the major influence. All of the data for the above variables thus far were extracted from the monthly data files on the HYDAT disc.

4.2.2.5 Extreme Annual Streamflow

Studies have shown that increased climatic variability could lead to more frequent extremes in the hydrologic cycle [Burn and Soulis, 1992]. The extreme annual flow analysis may not show changes in the frequency of occurrence of extreme events, but instead will indicate the changes in magnitude of the extreme events. The data for this was obtained by extracting the largest flow from the daily flow series for each year of record. It is possible that fluctuations at the extreme level may be different from those fluctuations at the mean streamflow level. These results may also not be as accurate as the mean streamflow evaluation because the maximum flow for each year may be dependent on completely different hydrologic events (snowmelt, precipitation, etc.). However it is anticipated to have decreasing extreme flow trends over time which are negatively correlated with the increase in temperature over time. The data for this variable was obtained from the extreme flow files from HYDAT.

4.2.2.6 Maximum Summer Precipitation Event

Ashfield et al. [1992] referenced numerous papers suggesting that a net rise in the temperature could result in an increase in annual precipitation. However, a question may be posed about the actual changes in storm events which could account for this increase in annual precipitation. For example, is the increase in precipitation caused by more frequent rainstorm events, or storm events resulting in larger peak flows, or by a combination of these scenarios?

Due to the difficulty and time restrictions to collect precipitation data for the region of study, it was decided to evaluate the fluctuations in flow during the summer months. Large sudden peaks in the hydrographs would indicate that a storm event has occurred. Therefore, this variable examines the possibility of storm events resulting in larger peak flows, rather than more frequent events. This variable will also reflect changes in runoff amounts for summer storms. The flow value was obtained by manually viewing the daily flow records for each year, and extracting the peak summer time flow which appeared to be caused by a storm event.

Unfortunately, there are numerous uncertainties involved with this analysis. One can not be certain if a large spike on the hydrograph would be caused by a precipitation event. For example, northern rivers may experience late thaw, and therefore, ice jams may be a cause of large flows. Other uncertainties include runoff characteristics. Changes in the ground surface, or soil characteristics, may alter the standard runoff behavior. Due to these possible unknown factors, caution should be taken when analysing and drawing conclusions for the results of this hydrologic variable. However, to be consistent with the previous expected behaviors relating to streamflow, it is anticipated that decreasing peak flow values will occur due to summer storm events with a negative correlation corresponding to increasing temperatures over time.

4.2.2.7 Timing of Annual Spring Melt

Climatic change affects not only the magnitude of hydrologic events, but also Burn and Soulis [1992] indicate the importance of evaluating the associated frequency and timing of the hydrologic events. Hydro-meteorological and hydrologic parameters such as permafrost, glacier melt, ice freeze-up and break-up on lakes and rivers, snow cover and the timing of snow melt peak flows could be expected to show a greater response to climatic change than volumetric runoff and precipitation because temperature has a direct influence on them [Lawford, 1994]. For rivers draining many catchments in Canada, as well as other northerly countries, snow melt runoff constitutes a considerable portion of the total annual flow. For these reasons, the final hydrologic parameter used to monitor climatic change is the Julian day of spring snow melt.

The Julian day of spring snow melt was obtained from plotting the daily flow series for each river analysed. The maximum flow value for each year of record was initially extracted and then the daily flow series plot was used to see if this extracted global maximum occurred at the time of spring snow melt. If the day did not match the peak spring date, then a revised date was recorded for that year to represent the Julian day. Burn [1994a] also evaluated the Julian day of spring snow melt and found it necessary to manually examine the plots of the daily flow records since judgment was sometimes required to define precisely the occurrence of the spring snow melt runoff event. Since increasing temperatures would result in earlier spring snow melts, the behavior of decreasing Julian day trends and negative correlations with temperature would be expected.

4.3 METHOD OF EVALUATION

4.3.1 Compiling and Manipulating Data

The extraction and manipulation of data from the appropriate data file, along with evaluating the effects of climatic change on the hydrologic data accumulated was done by executable fortran programs on SUN SPARC stations. The SUN station memory capacity allows for large quantities of flow and temperature data to be compiled and analysed at once. The fortran programs integrate the Mann-Kendall statistical trend test, the LOWESS smoothing procedure, and the Kendall statistical correlation test, which made the evaluation more efficient. There was a different fortran program used for each hydrologic variable because of different data extraction rules and preparations for each analysis.

The following three sections describe the evaluation process for the results obtained by the fortran programs. The evaluation process is consistent for all hydrologic variables. These results are summarized in output files developed by the programs. The summary is in a tabular format containing the station number, record length, series analysed (hydrologic variable, or temperature), trend of the series, significance level of trend, slope of the trend, correlation between hydrologic variable and temperature, and the probability associated with the correlation value. The results for each variable, with the exception of the mean seasonal and monthly analysis, will be given in Appendix B.

4.3.2 Significance of Trends

The percent significance level (SL) calculated from the Mann-Kendall trend test is an essential parameter for determining whether or not a significant trend exists in the data set. However, it is necessary to decide on what range of significant levels correspond to strong, moderate and weak trends. Therefore, the following categories will group the rivers corresponding to different significant level percentages which are commonly used in statistical evaluations.

Category 1: Increasing Trend with $SL \leq 5\%$ (strong trend)
Category 2: Increasing Trend with $5\% < SL \leq 10\%$ (moderate trend)
Category 3: No detected Trend with $SL > 10\%$ (weak trend)
Category 4: Decreasing Trend with $5\% < SL \leq 10\%$ (moderate trend)
Category 5: Decreasing Trend with $SL \leq 5\%$ (strong trend)

A percentage of the total number of rivers analysed for a particular hydrologic variable is determined for each of the above categories. These percentages will indicate which behavior is most prominent, and will also indicate whether or not the percentage of rivers in each category exceeds or falls below the expected number of occurrences.

The second parameter of interest from the trend test is the slope. The slope is basically used as an indication for the degree of inclination of the trend. Usually, high values of the slope will correspond to strong trends. The slope value will also help determine whether or not a trend is important in the evaluation. If a slope is near zero (horizontal trend) then the correlation will be the last factor used to describe any possible existing relationships between temperature and the hydrologic variables.

4.3.3 Correlations Between Hydrologic Variables and Temperature

The Kendall's tau (τ) correlation test helps describe the connection between the general fluctuations of temperature and the hydrologic variables. The tau value will verify possible similarities or dissimilarities between the two time series. However, the tau value can range from -1 to +1, and it is therefore necessary to categorize the possible outcomes. The following categories were selected in order to describe the variations in strength of the correlation, and whether the time series follow identical or symmetrical patterns.

Category 1: $-1.00 \geq \tau > -0.50$ (strong symmetrical correlation)
Category 2: $-0.50 \geq \tau > -0.25$ (moderate symmetrical correlation)
Category 3: $-0.25 \geq \tau \geq 0.00$ (weak symmetrical correlation)
Category 4: $0.00 > \tau \geq +0.25$ (weak identical correlation)
Category 5: $+0.25 > \tau \geq +0.50$ (moderate identical correlation)
Category 6: $+0.50 > \tau \geq +1.00$ (strong identical correlation)

It is desired to have strong correlations with which to infer any direct relationship between the climate and the hydrologic behavior. The correlations may be positive or negative depending on the type of hydrologic variable evaluated. Once again a percentage of the total number of rivers analysed for a particular hydrologic variable is determined for each of the above categories. These percentages will indicate which behavior is most prominent. It is anticipated that the most prominent behavior would be the expected or hypothesized behavior. The second parameter of interest from the correlation test is the probability associated with the tau value. The probability value indicates the chance that no correlation exists. Therefore, low values imply excellent correlations.

The results from the correlation test are best understood when graphically represented. Therefore, the smoothed LOWESS data from the hydrologic variable and temperature series are plotted against time (years). The superposition of the plots illustrates the behavior between the two variables. Only a few selected rivers where chosen to portray the effects of climatic change on each hydrologic variable analysed. These graph are shown and explained in Chapter 5.

4.3.4 Spatial Distribution of Results

The regionalization approach for this thesis could be considered as a reversal of standard regionalization logic. Instead of defining the areas or regions based on climatic zones or geographical boundaries, the regions will be developed based on the results of the analysis. Various combinations of the results from the Mann-Kendall trend test and Kendall correlation test will define different regions. Particularly, the possible response measures used to define the categories include the significance level of the trends, correlation results, drainage basin area, and a common period of record used for each river. Once these regions are created, an evaluation will be made of the spatial distribution of each region. It is anticipated that the distribution of gauging stations may reflect the expected responses for different climatic zones or geographical boundaries based on the surrounding environmental conditions of the drainage basins.

There are three general regionalization approaches used for this thesis; (1) analysing the spatial similarities of significant trends for each hydrologic variable separately, (2) analysing the spatial similarities on all hydrologic variables combined by evaluating the expected hypothesized behaviors based on correlations and trend results, and (3) analysing the spatial similarities of each hydrologic variable separately, based again on the expected behaviors.

Only five of the original hydrologic variables will be used for the regionalization analysis. The mean seasonal and mean monthly variables will not be considered directly into the regionalization evaluation because the variables are essentially represented by the mean annual flow behavior. Furthermore, the regionalization method only requires one value per year, therefore the mean seasonal and mean monthly results are disregarded. A total of seven different variables will be used for the regionalization analysis since the mean annual flow and the cumulative annual mean monthly negative deviation variables are separated into a semi-annual (March to October) and summer (May to August) intervals to justify the differences between general yearly responses, and the summer responses.

The regionalization categories for the first technique are the same categories as given in section 4.3.2. All possible rivers for each hydrologic variable are evaluated based on the Mann-Kendall statistical trend test results. A map of the region of study is used to illustrate the spatial distribution of statistically significant increasing and decreasing trends, and statistically insignificant trends. The plot will indicate whether the response to climate change is localized in different areas depending on the level of significance in the hydrologic trends.

The categories for the second approach are as follows:

Category 1: Expected Behavior (expected correlation, expected trend)
Category 2: First Half Expected Behavior (expected correlation, unexpected trend)

Category 3: Second Half Expected Behavior (unexpected correlation, expected trend)

Category 4: Unexpected Behavior (unexpected correlation, unexpected trend)

Essentially, the results for each hydrologic variable are examined in order to determine the expected behaviors. The most frequent occurrence of the combination between the correlation and trend results are considered to be the expected behavior. For example, it is hypothesized that the expected response behavior for the Julian day evaluation would result in negative trends and negative correlations with temperature. This particular behavior may be explained by earlier spring snowmelt events corresponding to increasing temperatures over time. Therefore, on this hypothesis the recorded Julian day for each succeeding year will be earlier (negative trends), on average, and will have an opposite response to temperature (negative correlations). Based on this logic, the unexpected behavior (category 4) would be positive trends and positive correlations.

A map of the region under study is again used to illustrate the location and distribution of rivers falling in one of the above four categories. Each river will be assigned to a category (X) which is determined by the majority number of hydrologic variables falling into category (X). For example, if a particular river has unexpected behaviors for 5 of the 7 hydrologic variables, then the river will be assigned to Category 4. This technique will show the areas where climatic change has had an effect based on the entire set of trend and correlation results for all variables.

The third and final regionalization method studies the response behavior for each hydrologic variable individually. A map of the study area will be used for each variable to illustrate the different regions where climatic change influences the trend and correlation behaviors for each river. Therefore, the same categories mentioned above are used to describe the four possible behavioral combinations for the hydrologic variables. For example, if the Julian day variable is analysed, each available river would be evaluated and assigned to one of the four categories. After all assignments have been made, the river locations will be plotted on the map with symbols representing the assigned categories. This examination will show any spatial difference of behavioral responses between each hydrologic variable.

CHAPTER 5

5.0 RESULTS

5.1 SIGNIFICANCE OF TRENDS AND CORRELATIONS

This section of the results will discuss the general findings of the Mann-Kendall trend test and Kendall correlation test for each hydrologic variable. The categories from section 4.3.2 and sections 4.3.3 will be used during the discussion. The following sections, under section 5.1, will have summary tables for the Mann-Kendall trend test and the Kendall correlation test. These tables include the percentage of the rivers in each category. There will also be various illustrative figures to display the relationship between the temperature and hydrologic variable time series for a typical result for the given hydrologic variable. Detailed summaries for each hydrologic variable can be found in Appendix B with the exception of the mean seasonal and monthly results.

5.1.1 Mean Annual Streamflow

There were 99 and 109 rivers with a data record that met the criteria for each of the two different definitions for 'annual' flow; March to October and May to August respectively. Tables 1 and 2 below give the trend and correlation results respectively.

Table 1: Mann-Kendall Trend Test Summary Results for Mean Annual Flow

	PERCENT OF RIVERS FOR EACH SIGNIFICANT LEVEL (SL) CATEGORY FROM THE MANN-KENDALL TREND TEST (I = increasing, D = decreasing)				
Hydrologic Variable	**SLI ≤ 5%**	**5% < SLI ≤ 10%**	**SL > 10%**	**5% < SLD ≤ 10%**	**SLD ≤ 5%**
Annual (Mar. -Oct.)	5.05	3.03	52.53	11.11	28.28
Annual (May-Aug.)	0.92	3.67	58.72	10.09	26.61

Table 2: Kendall Correlation Summary Results for Annual Flow

	PERCENT OF RIVERS FOR EACH CATEGORY FROM KENDALL CORRELATION TEST	
Correlation (Tau) Ranges	**Annual (Mar. - Oct.)**	**Annual (May - Aug.)**
$-1.00 \leq \tau < -0.50$	45.30	38.46
$-0.50 \leq \tau < -0.25$	14.53	25.46
$-0.25 \leq \tau \leq 0.00$	25.64	18.80
$0.00 < \tau \leq 0.25$	8.55	11.11
$0.25 < \tau \leq 0.50$	4.27	3.42
$0.50 < \tau \leq 1.00$	1.71	2.56

The significant level categories are valuable sources of information with which to determine the presence of any existing trends that may have a better than average chance of occurring. For example, the significant increasing trend with a significance level less than or equal to 5% indicates, on average, the percent number of times that increasing trends should occur for any random data set. Therefore, if 100 gauging stations were analysed, it would be expected to have only 5 stations with increasing trends for the significance level less than or equal to 5%. As well, there would theoretically be only 5 stations having increasing trends between 5 and 10 percent significance. However, from the above results, there are far more rivers with decreasing trends than should occur by chance and fewer exhibit increasing trends than should occur by chance for both the March to October and the May to August ranges.

The behavior described above may result from larger amounts of evaporation caused by the increase in temperature over time. This also suggests that a decrease in net precipitation may be occurring either through reductions in total precipitation or increases in precipitation losses (i.e., evaporation, infiltration, etc.). The combination of increased evaporation and/or decreased net precipitation would result in reductions in runoff, ground water flow, and other hydrologic inputs that would normally contribute to streamflow in rivers. The outcome would be a decrease in streamflow over time. For the results presented above, there was less tendency to have increasing trends for the May to August time period. It is logical to attribute this occurrence to the greater tendencies for evaporation in the summer, and therefore, less chance of increasing trends would occur.

The correlation results also logically correspond with the trend results. The majority of the rivers (above 80% for each of the two annual flow variables) had negative correlations with the temperature series. This is natural to expect since increasing temperatures are hypothesized to result in decreasing flows. Therefore the smoothed plots of temperature and mean annual flow time series would be opposite to each other. The behaviors described above indicate the expected response for the mean annual flow from changing climatic conditions. The expected behavior of decreasing trends and negative correlations is shown in Figure 8 for the Red Deer River (05LC001) located in the Northwestern Forest. The river has 34 years of record during the March to October time period. The results for the Red Deer River are shown in Table 3.

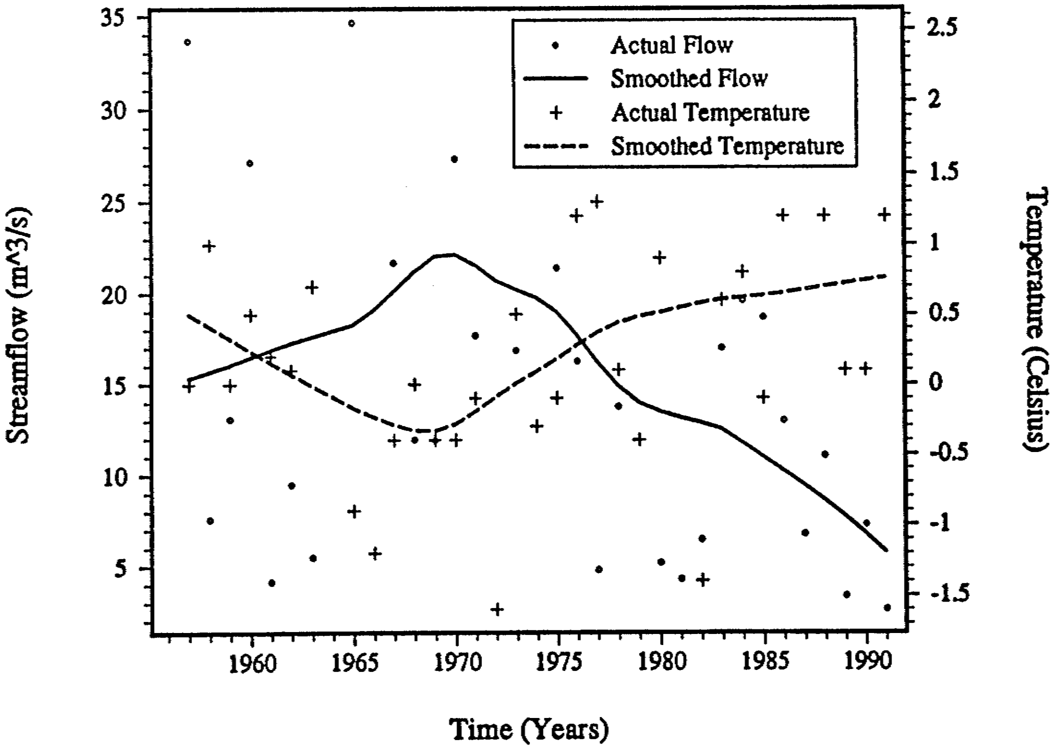

Figure 8: Smoothed Curves of Temperature and Mean Annual Flow Time Series

Table 3: Red Deer River Summary Results

River	Series	Trend	S.L. (%)	Slope (cms/yr)	Correlation
Red Deer	Ann. (M-O)	Decreasing	2.19	-3.96	-0.90

5.1.2 Annual Cumulative Mean Monthly Negative Deviations (CND)

There were 84 and 93 rivers with a data record that met the criteria for each of the two different definitions for 'CND' flow; March to October and May to August respectively. Tables 4 and 5 below give the trend and correlation results respectively.

Table 4: Mann-Kendall Trend Test Summary Results for CND

	PERCENT OF RIVERS FOR EACH SIGNIFICANT LEVEL (SL) CATEGORY FROM THE MANN-KENDALL TREND TEST (I = increasing, D = decreasing)				
Hydrologic Variable	SLI ≤ 5%	5% < SLI ≤ 10%	SL >10%	5% < SLD ≤ 10%	SLD ≤ 5%
CND (Mar. -Oct.)	28.57	14.29	51.19	4.76	1.19
CND (May-Aug.)	29.03	11.83	54.84	3.23	1.08

Table 5: Kendall Correlation Summary Results for CND

	PERCENT OF RIVERS FOR EACH CATEGORY FROM KENDALL CORRELATION TEST	
Correlation (Tau) Ranges	**CND (Mar. - Oct.)**	**CND (May - Aug.)**
$-1.00 \leq \tau < -0.50$	0.00	1.08
$-0.50 \leq \tau < -0.25$	3.57	3.23
$-0.25 \leq \tau \leq 0.00$	11.90	5.38
$0.00 < \tau \leq 0.25$	9.52	16.13
$0.25 < \tau \leq 0.50$	23.81	24.73
$0.50 < \tau \leq 1.00$	51.19	49.46

The cumulative annual mean monthly negative deviations show opposite results to the mean annual flow analysis. However, the results here tend to be more pronounced since there are a greater percentage of rivers for the increasing significant levels and a smaller percentage of significant decreasing results. These percentages imply that there is a greater than average tendency for increasing trends to occur. What is essentially happening over time is that the negative deviation is increasing between each mean monthly flow value and the average mean monthly flow for the entire period of record, and for any particular month. This phenomena may again be attributed to the increase in evaporation potential resulting in decreased mean monthly flows. It is possible that this behavior may lead to increased drought frequencies over time. The relatively small percentage of rivers having statistically significant decreasing trend levels and the large numbers of increasing trend levels would indicate the importance of preparing for the increased potential of drought occurrences.

There are a large percentage of rivers having positive correlations for both the March to October and May to August time ranges. The positive correlations indicate that fluctuations over time for temperature will be similar to the fluctuations for the cumulative annual mean monthly negative deviations. There are only approximately 6% more rivers having positive correlations for the May to August range than for the March to October range. As well, there is not much difference between the two variables for the trend results. The Pembina River (05OA008) located in the Prairies region, having 33 years of record for the May to August range, is used to demonstrate the expected behavior of increasing trends with positive correlations for this analysis. Therefore, Figure 9 illustrates the similarity between the temperature and the CND variable over time. The results for the Pembina River are as shown in Table 6.

Table 6: Pembina River Summary Results

River	**Series**	**Trend**	**S.L. (%)**	**Slope** (cms/yr)	**Correlation**
Pembina	CND	Increasing	0.50	+0.024	+0.936

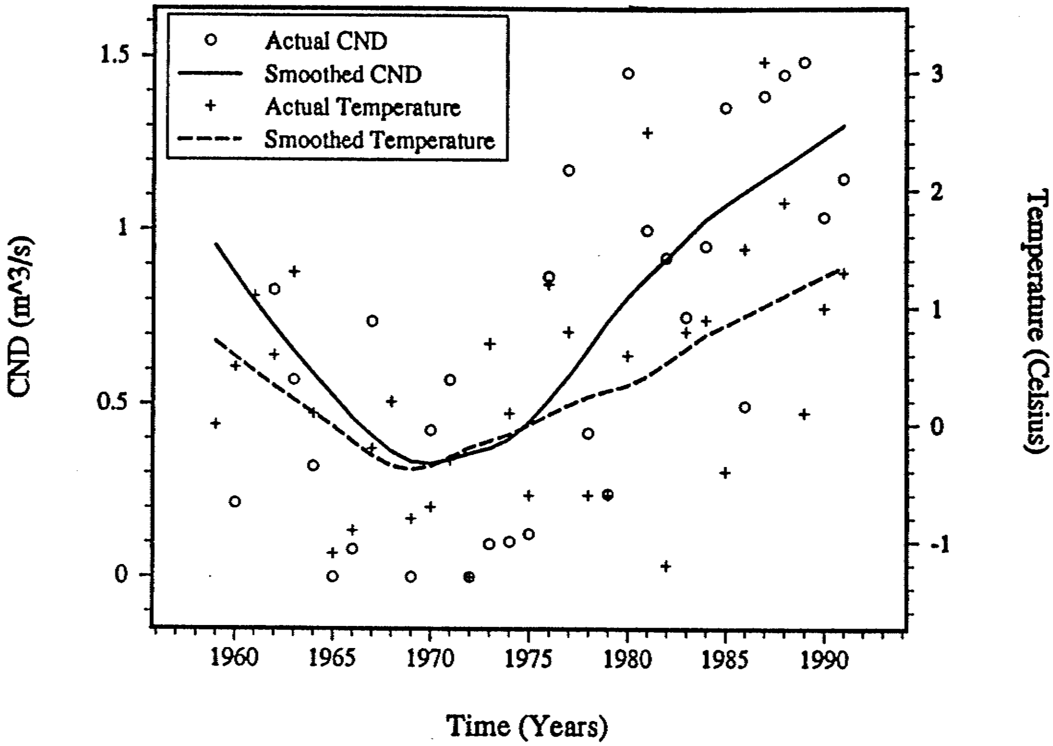

Figure 9: Smoothed Curves for Temperature and CND Time Series

5.1.3 Mean Seasonal Streamflow

The number of rivers with a data record that met the criteria for each of the four different definitions for 'seasonal' flow include 106 for spring, 104 for summer, 51 for fall, and 45 for the winter. Tables 7 and 8 below give the trend and correlation results respectively.

Table 7: Mann-Kendall Trend Test Summary Results for Seasonal Flow

	PERCENT OF RIVERS FOR EACH SIGNIFICANT LEVEL (SL) CATEGORY FROM THE MANN-KENDALL TREND TEST (I = increasing, D = decreasing)				
Hydrologic Variable	SLI ≤ 5%	5% < SLI ≤ 10%	SL > 10%	5% < SLD ≤ 10%	SLD ≤ 5%
Seasonal - Spring	3.77	4.72	53.77	14.15	23.58
Seasonal - Summer	2.88	2.88	64.42	12.50	17.31
Seasonal - Fall	3.92	7.84	70.59	5.88	11.76
Seasonal - Winter	17.78	2.22	51.11	11.11	17.78
Combined Weighted Ave.	5.56	4.25	59.80	11.76	18.63

Table 8: Kendall Correlation Summary Results for Seasonal Flow

	PERCENT OF RIVERS FOR EACH CATEGORY FROM KENDALL CORRELATION TEST			
Correlation (Tau) Ranges	**Spring**	**Summer**	**Fall**	**Winter**
$-1.00 \le \tau < -0.50$	51.89	31.73	27.45	22.22
$-0.50 \le \tau < -0.25$	18.87	28.85	25.49	22.22
$-0.25 \le \tau \le 0.00$	13.21	16.35	19.61	13.33
$0.00 < \tau \le 0.25$	6.60	12.50	5.88	15.56
$0.25 < \tau \le 0.50$	5.66	7.69	15.69	20.00
$0.50 < \tau \le 1.00$	3.77	2.88	5.88	6.67

The general behavior resulting for all seasons is a statistically significant decreasing trend with negative correlation. However each season does have its own separate tendency. The summer and spring seasons have the largest percentages of significant decreasing trends of 37.63% and 29.81% respectively. This behavior is expected due to the increase in evaporation potential. The percentage of significant increasing trends for spring were higher than that for summer (8.49% compared to 5.76%). The summer had the lowest percentage of increasing trends compared to the other seasons. Again this is expected from the evaporation potential peaking in the summer months.

The fall has the smallest percentage of decreasing trends and the largest percentage of insignificant trends. This would not be unexpected for two reasons, (1) fall is typically a season with very low flows making it difficult to find a common behavioral pattern based on statistically significant trends, and (2) the fall period resulted in a very small sample of river data to analyse, and therefore it is hard to make definitive conclusions about the behavior. Nevertheless, fall does have more decreasing trends than increasing trends. Winter also has a small data set to evaluate. However, winter also had the largest number of significant increasing trends (20.0%) compared to the other seasons. This may be attributed to the greater quantity of volumetric runoff due to snow accumulation and snow melting which may tend to increase the flow in the river with increasing temperatures.

When the combined weighted average for each season was calculated, it was found that the overall behavior was similar to the mean annual behavior. It is expected to find matching behaviors between the superimposed mean seasonal results and the mean annual results. It is also important that the combined weighted seasonal values reflect the behavior of the mean annual results in order to justify using the mean annual results instead of seasonal results for the regionalization analysis. Recall that the regionalization analysis requires that there be only one value of the hydrologic variable per year.

The correlation results for spring and summer showed more than 75% of the rivers having negative correlations, while the winter had a large amount of positive correlations (42.23%). This large percentage of positive correlations corresponds to the large percentage of increasing trends. It is anticipated that any increasing trends would result in positive correlations assuming that hydrologic trends result from temperature fluctuations. Figures 10 and 11 below illustrate the two possible types of behaviors for the winter and summer season respectively. The unexpected behavior of a positive trend and correlation was chosen for the winter month to emphasize the effects of snowmelting on streamflow, and expected behavior of a decreasing trend and negative correlation was selected for the summer to represent the evaporation potential on streamflow. The Missinaibi River (04LJ001) located in the Northeastern Forest region was selected for the winter behavior, and the Oldman River (05AA023) located in the Prairies was selected for the summer behavior. The results for both rivers are given in Table 9.

Table 9: Missinaibi River and Oldman River Summary Results

River	**Series**	**Trend**	**S.L. (%)**	**Slope** (cms/yr)	**Correlation**
Missinaibi	Winter flow	Increasing	28.1	+0.025	+0.760
Oldman	Summer flow	Decreasing	1.36	-0.352	-0.840

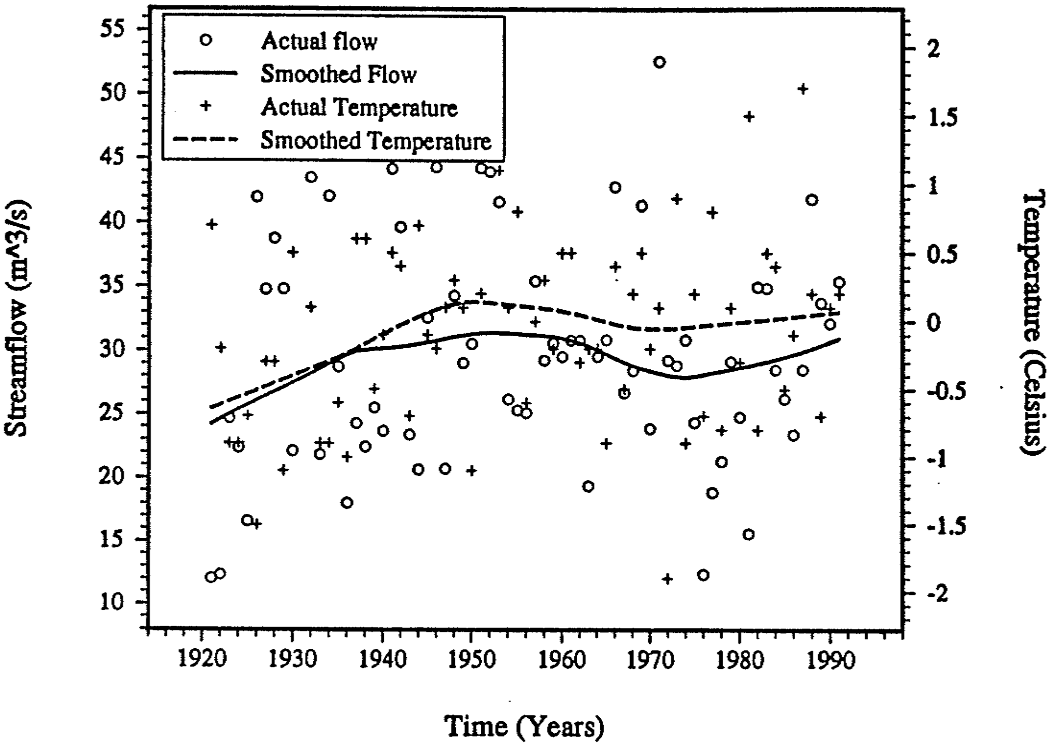

Figure 10: Smoothed Curves of Temperature and Mean Winter Flow Time Series

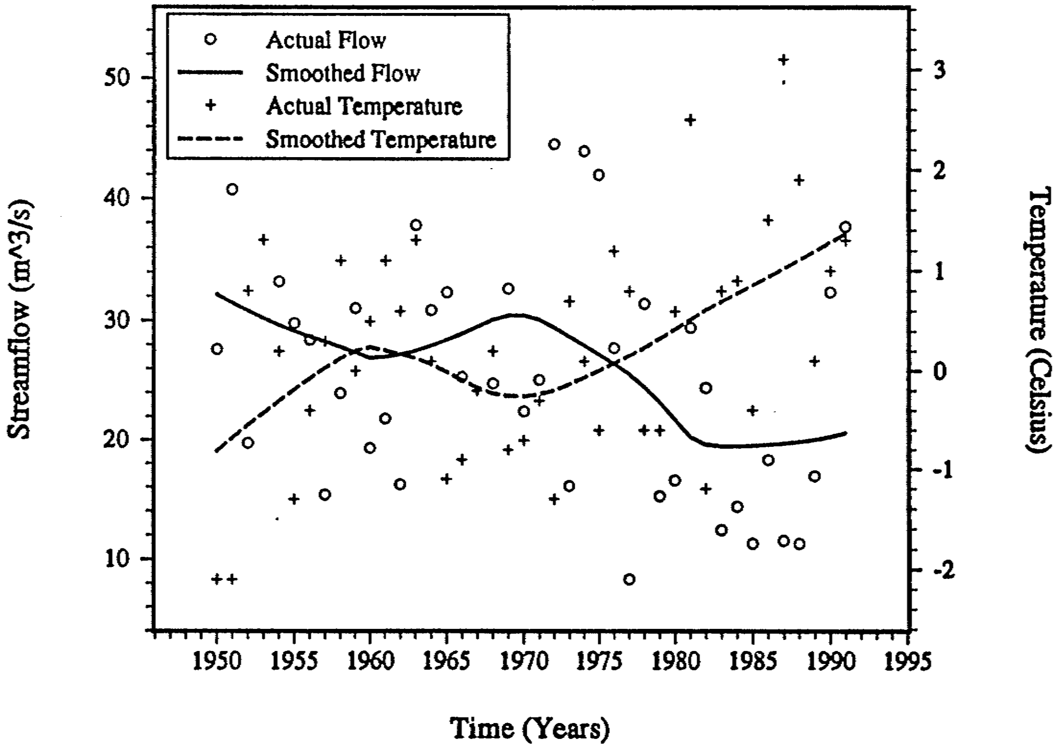

Figure 11: Smoothed Curves of Temperature and Mean Summer Flow Time Series

5.1.4 Mean Monthly Streamflow

Table 10 indicates the number of rivers with a data record that met the criteria for each of the twelve different months in a year. Tables 11 and 12 (a and b) give the trend and correlation results respectively.

Table 10: Number of Rivers Available for Mean Monthly Analysis

Month	**Rivers**	**Month**	**Rivers**	**Month**	**Rivers**	**Month**	**Rivers**
January	52	April	116	July	96	October	88
February	51	May	113	August	92	Nov.	52
March	85	June	108	Sept.	86	Dec.	52

Table 11: Mann-Kendall Trend Test Summary Results for Monthly Flows

	PERCENT OF RIVERS FOR EACH SIGNIFICANT LEVEL (SL) CATEGORY FROM THE MANN-KENDALL TREND TEST (I = increasing, D = decreasing)				
Monthly Hydrologic Variable	**SLI ≤ 5%**	**5% < SLI ≤ 10%**	**SL> 10%**	**5% <SLD ≤ 10%**	**SLD ≤ 5%**
January	11.54	3.85	65.38	7.69	11.54
February	13.73	3.92	66.67	5.88	9.80
March	15.29	8.24	69.41	2.35	4.71
April	6.90	6.03	59.48	9.48	18.10
May	1.77	0.88	58.41	12.39	26.55
June	0.00	1.85	62.04	12.96	23.15
July	5.21	5.21	66.67	13.54	9.38
August	2.17	6.52	67.39	10.87	13.04
September	4.65	2.33	65.12	11.63	16.28
October	3.41	9.09	70.45	7.95	9.09
November	3.85	15.38	61.54	7.69	11.54
December	9.62	7.69	63.46	11.54	7.69
Combined Weighted Average	5.75	5.45	64.38	9.89	14.53

Table 12(a): Kendall Correlation Summary Results for Monthly Flows

	PERCENT OF RIVERS FOR EACH CATEGORY FROM KENDALL CORRELATION TEST					
Correlation (Tau) Ranges	**January**	**February**	**March**	**April**	**May**	**June**
$-1.00 \le \tau < -0.50$	30.77	17.65	15.29	39.66	43.63	36.11
$-0.50 \le \tau < -0.25$	11.54	21.57	12.94	22.41	29.20	30.56
$-0.25 \le \tau \le 0.00$	21.15	21.57	15.29	12.07	12.39	16.67
$0.00 < \tau \le 0.25$	13.46	11.76	22.35	11.21	7.96	7.41
$0.25 < \tau \le 0.50$	17.31	23.53	17.65	9.48	1.77	9.26
$0.50 < \tau \le 1.00$	5.77	3.92	16.47	5.17	5.31	0.00

Table 12(b): Kendall Correlation Summary Results for Monthly Flows

	PERCENT OF RIVERS FOR EACH CATEGORY FROM KENDALL CORRELATION TEST					
Correlation (Tau) Ranges	**July**	**August**	**Sept.**	**October**	**Nov.**	**December**
$-1.00 \le \tau < -0.50$	20.83	31.52	26.74	34.09	21.15	19.23
$-0.50 \le \tau < -0.25$	19.79	26.09	29.07	22.73	26.92	19.23
$-0.25 \le \tau \le 0.00$	21.88	17.39	19.77	18.18	17.31	25.00
$0.00 < \tau \le 0.25$	13.54	15.22	8.14	15.91	23.08	13.46
$0.25 < \tau \le 0.50$	13.54	4.35	11.63	9.09	5.77	21.15
$0.50 < \tau \le 1.00$	10.42	5.43	4.65	0.00	5.77	1.92

Some of the early spring, late fall, and winter months (October through to April) have a larger percentage of statistically significant increasing trends (0%< SLI ≤ 10%) than that occurring in the summer or early fall months. The percent of rivers within this trend category range mainly between 10% and 25% which indicates a larger than expected response for increasing trends. The months of February and March actually have more statistically significant increasing trends than decreasing trends, with the largest percentage of increasing trends between the 0% and 10% significance in the month of March (23.53%). The late spring, the summer, and the early fall months (May to September) generally have less than 10% of the rivers falling in the significant increasing trend category between 0% and 10% significance. The month of June has the lowest percentage

(1.85%) of increasing trends within this category. The late spring and summer time period (May to August) dominates for the percentage of rivers in the significant decreasing trend category resulting from large evaporation potential during this period. The months of May and June have the highest percentage of decreasing trends, 38.94% and 36.11% respectively, within the 0% to 10% significance range. The fall months also have comparable percentages of increasing and decreasing trends, but there are larger amounts of insignificant trends which may result from the relatively small data sets and the tendency for low flows to occur. The largest percentage of rivers with insignificant trends occurs in the month of October (70.45%). Based on the latter discussion, Figure 12 below illustrates the fluctuations from month to month of the percentage of rivers in the significant increasing and decreasing categories between the 0% and 10% significance range. The fluctuations of the number of rivers for the two significant ranges are essentially opposite to each other. It appears that certain months over the course of a year may be clustered together to form seasonal categories.

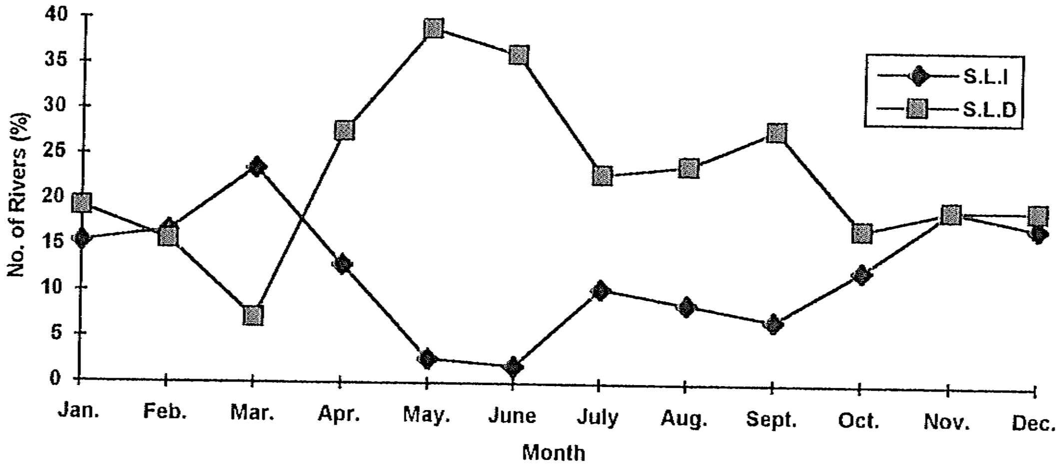

Figure 12: Percent of Rivers in the S.L.I and S.L.D Categories Between 0% and 10% Significance For Each Month

From Figure 12, four distinct periods with regards to the S.L.D behavior can be reasonably derived; (1) from January, February, to March there is a decreasing trend to approximately 7%, (2) from April, May, to June the S.L.D trends increase to a peak value of approximately 40% and then begins to taper off, (3) from July, August, to September the S.L.D value remains relatively constant between the 25% to 30% level, and (4) from October, November, to December S.L.D value remains relatively constant between the 15% to 20% level.

The percentage of rivers having negative correlations ranges between 60% and 85%. Once again there was a general behavior of more frequent negative correlations in the summer and fall months than in the winter and spring months. Specifically, January, February, March, November and December have a smaller number of negative correlations compared with the months April through to October, with the possible exception of July. The increased amounts of positive correlations may be from the snow melting potential during this time. The one odd occurrence in the correlation results is found in the month of July. There are a comparable number of increasing correlations as would be found in a typical spring or winter month. The surrounding months, June and August, have a very high amount of negative correlations, 83.3% and 75.0% respectively, compared to 62% for July.

The mean monthly flow results essentially reflect the behavior of the mean seasonal results, and as expected, the total combined weighted values of each month reflect the behavior of the mean annual results. Again, it is important that the combined weighted monthly values reflect the behavior of the mean annual results in order to justify using the mean annual results instead of monthly results for the regionalization analysis. Examples of the smoothed curves between temperature and the months April and June are shown in Figures 13 and 14 to represent the general expected behaviors for the spring and summer periods respectively. The fall months did not have particularly remarkable results for display in order to further the understanding of the general types of monthly behaviors throughout the year. Furthermore, the winter results displayed similar quantities of increasing and decreasing trends which would not necessarily aid the discussion if an illustration were provided. Therefore, no illustrations will be shown for fall or winter months. Table 13 below has the summary results for the Missinaibi River (04LJ001) located in the Northeastern Forest region, and the Red Deer River (05CE001) located in the Prairie region which will illustrate the April and June anticipated behaviors respectively.

Table 13: Summary Results for the Missinaibi River and the Red Deer River

River	Years	Series	Trend	S.L. (%)	Slope (cms/yr)	Correlation
Missinaibi	71	April	Increasing	1.12	+1.380	+0.567
Red Deer	33	June	Decreasing	8.16	-1.496	-0.811

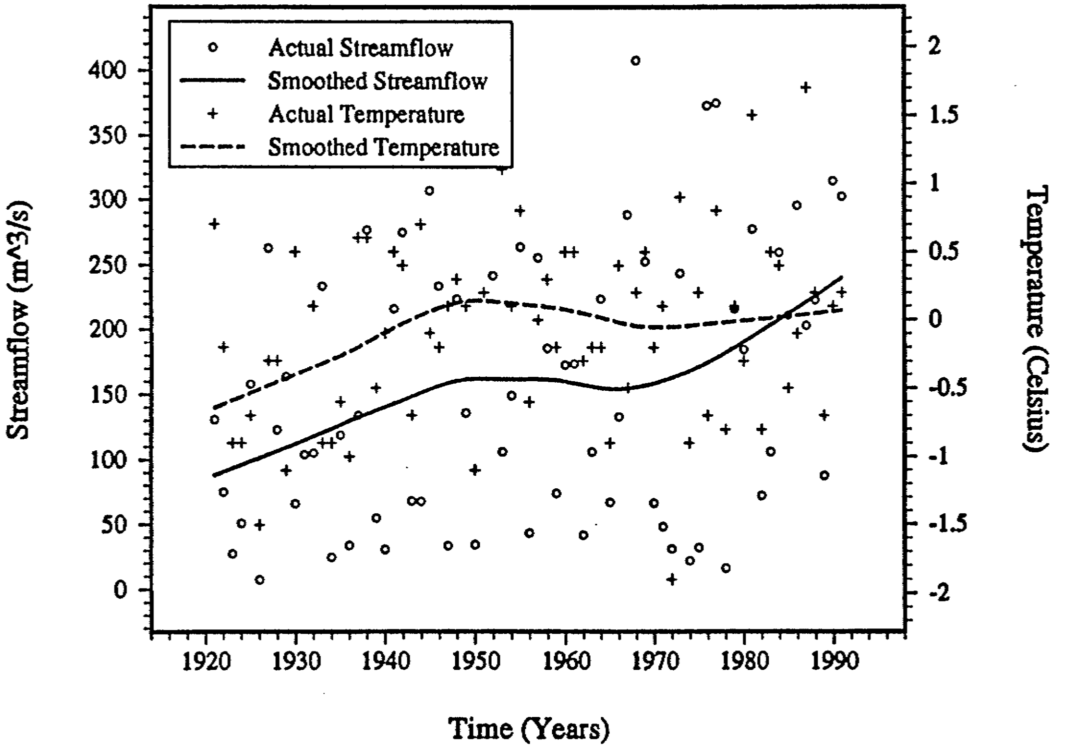

Figure 13: Smoothed Curves of Temperature and Mean Monthly Flows for April

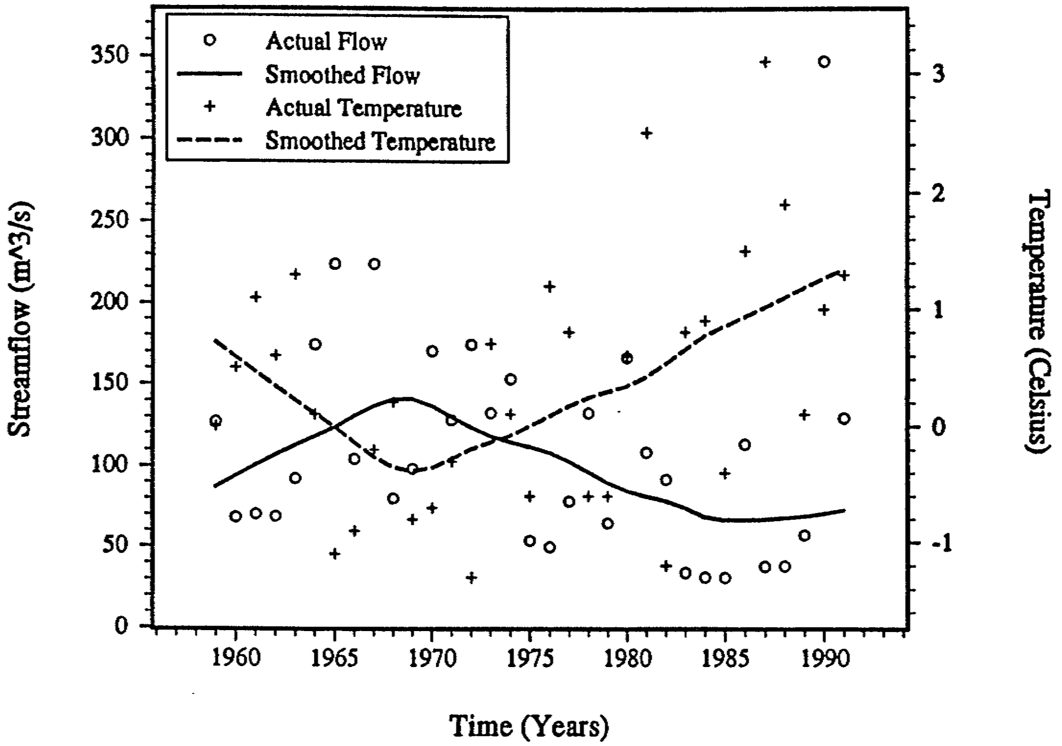

Figure 14: Smoothed Curves of Temperature and Mean Monthly Flows for June

5.1.5 Extreme Annual Streamflow

There were 116 rivers for the extreme annual streamflow analysis. Tables 14 and 15 below give the trend and correlation results respectively.

Table 14: Mann-Kendall Trend Test Summary Results for Extreme Annual Flows

	PERCENT OF RIVERS FOR EACH SIGNIFICANT LEVEL (SL) CATEGORY FROM THE MANN-KENDALL TREND TEST (I = increasing, D = decreasing)				
Hydrologic Variable	SLI ≤ 5%	5% < SLI ≤ 10%	SL > 10%	5% < SLD ≤ 10%	SLD ≤ 5%
Extreme	2.61	2.61	60.00	12.17	22.61

The extreme flow results followed the same pattern and behavioral explanations as the mean annual flow results. There were over 6.5 times more statistically significant decreasing trends than statistically significant increasing trends under the 10% significance range. Since only 5.21% of the rivers have increasing trends, compared to an expected 10%, it is safe to say that on average one would expect not to see many increasing trends.

Over 80% of the rivers had negative correlations reflecting the behavior of increases in temperature directly corresponding to decreases in the extreme flow. Cooks Creek (05OJ006) will be used to illustrate the anticipated behavior between the temperature series for the Prairies region and the extreme annual flow shown in Figure 15. Table 16 summarizes the results for Cooks Creek.

Table 15: Kendall Correlation Summary Results for Extreme Annual Flows

	PERCENT OF RIVERS FOR EACH CATEGORY FROM KENDALL CORRELATION TEST
Correlation (Tau) Ranges	**Extreme Annual Streamflow (January - December)**
$-1.00 \leq \tau < -0.50$	46.90
$-0.50 \leq \tau < -0.25$	20.35
$-0.25 \leq \tau \leq 0.00$	15.93
$0.00 < \tau \leq 0.25$	7.96
$0.25 < \tau \leq 0.50$	7.96
$0.50 < \tau \leq 1.00$	2.65

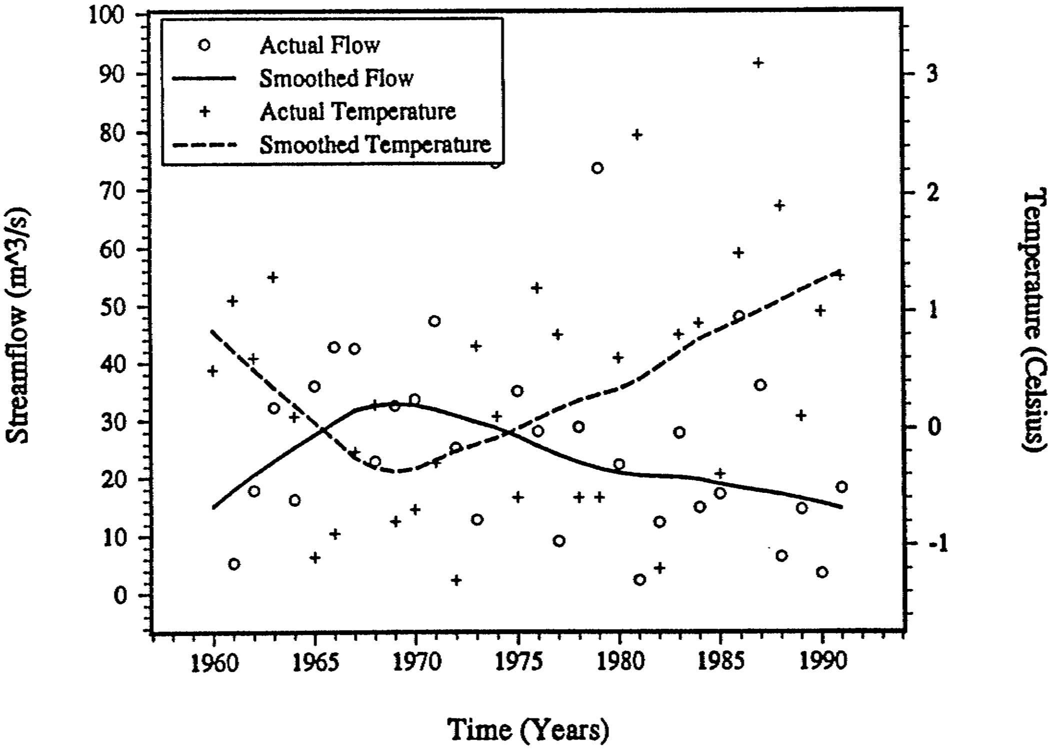

Figure 15: Smoothed Curves for Temperature and Extreme Annual Flow Time Series

Table 16: Cooks Creek Summary Results

River	Years	Series	Trend	S.L. (%)	Slope (cms/yr)	Correlation
Cooks Crk.	32	Extreme	decreasing	4.28	-0.650	-0.940

5.1.6 Maximum Summer Precipitation Event

There were 107 rivers for the maximum summer precipitation event analysis. Tables 17 and 18 below give the trend and correlation results respectively.

Table 17: Mann-Kendall Trend Test Summary Results for Maximum Summer Precipitation Event

	PERCENT OF RIVERS FOR EACH SIGNIFICANT LEVEL (SL) CATEGORY FROM THE MANN-KENDALL TREND TEST (I = increasing, D = decreasing)				
Hydrologic Variable	SLI ≤ 5%	5% < SLI ≤ 10%	SL > 10%	5% < SLD ≤ 10%	SLD ≤ 5%
Summer Precipitation	7.48	5.61	71.03	5.61	10.28

Table 18: Kendall Correlation Summary Results for Maximum Summer Precipitation Event

	PERCENT OF RIVERS FOR EACH CATEGORY FROM KENDALL CORRELATION TEST
Correlation (Tau) Ranges	**Maximum Summer Precipitation Event Analysis**
$-1.00 \leq \tau < -0.50$	15.89
$-0.50 \leq \tau < -0.25$	22.43
$-0.25 \leq \tau \leq 0.00$	25.23
$0.00 < \tau \leq 0.25$	14.95
$0.25 < \tau \leq 0.50$	14.95
$0.50 < \tau \leq 1.00$	6.54

The maximum summer precipitation event evaluation did not show any significant results that could be explained with confidence. There were more statistically insignificant trends (71.03%) than any other hydrologic variable analysed. However this is still less than the 80% of rivers expected to be in this range. There was a total of 13.09% of the rivers having significant increasing trends and 15.89% having significant decreasing trends. Even the correlation results were not all that confident with only about 60% of the rivers having negative correlations. Also the correlation magnitudes are relatively low (close to zero) which may indicate that the behavior for this variable is not necessarily temperature related. From these results, no particular behavior could be properly defined, although at best, for chances just slightly better than average, one could say the anticipated behavior would be decreasing trends with corresponding negative correlations.

There could be a variety of reasons for the different combination of trend and correlation results. For example, the maximum storm event decreasing over time may be caused from less runoff to the rivers after a precipitation event due to dry ground conditions. These dry conditions in turn may be caused by the increased amounts of evaporation. On the other hand, urbanization over the last century may cause more runoff into rivers from impermeable ground cover which would result in higher peak flows during storm events and likely correspond to increasing trends. Increased runoff may also be predominent in northern regions, and therefore causing higher peak flows. Figure 16 will illustrate the expected behavior for this event using the Black River (05RA002) located in the Northwestern Forest region. The less frequent behavior of increasing trends with positive correlations will be illustrated in Figure 17 by using the East Prairie River (07BF001) located in the Northwestern Forest region. The summarized results for these rivers are given in Table 19.

Table 19: Summary Results for the Black and East Prairie Rivers

River	**Years**	**Series**	**Trend**	**S.L. (%)**	**Slope** (cms/yr)	**Correlation**
Black	32	MSPE	decreasing	4.58	-0.151	-0.823
East Prairie	33	MSPE	increasing	0.69	+1.569	+0.545

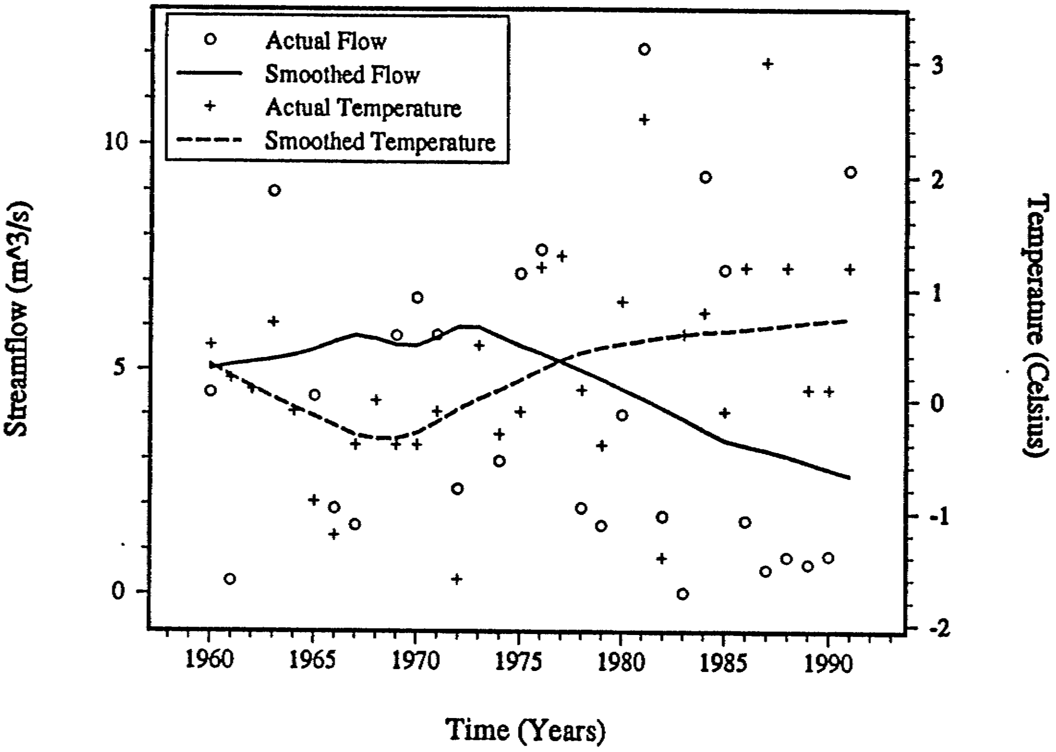

Figure 16: Smoothed Curves of Temperature and the Expected MSPE

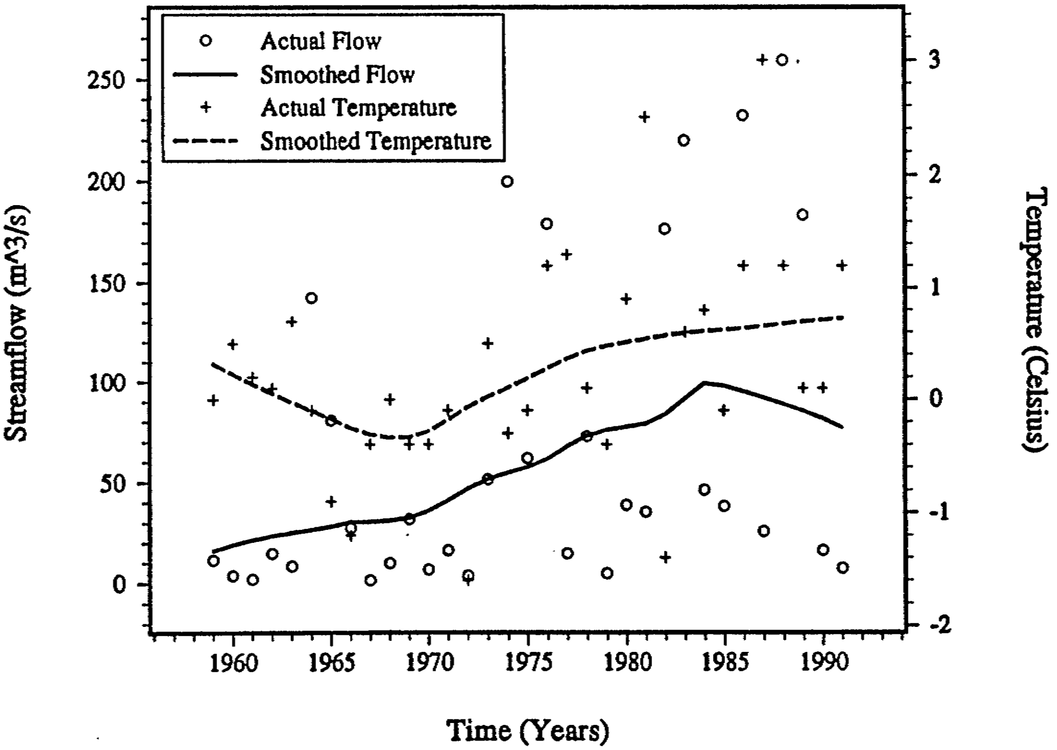

Figure 17: Smoothed Curves for Temperature and the Unexpected MSPE

5.1.7 Timing of First Annual Spring Melt

There were 113 rivers for the Julian day of spring snowmelt analysis. Tables 20 and 21 below give the trend and correlation results respectively.

Table 20: Mann-Kendall Trend Test Summary Results for Julian Day of Spring Snowmelt

	PERCENT OF RIVERS FOR EACH SIGNIFICANT LEVEL (SL) CATEGORY FROM THE MANN-KENDALL TREND TEST (I = increasing, D = decreasing)				
Hydrologic Variable	**SLI ≤ 5%**	**5% < SLI ≤ 10%**	**SL > 10%**	**5% < SLD ≤ 10%**	**SLD ≤ 5%**
Julian Day of Spring Melt	0.00	0.88	43.36	13.27	42.48

Table 21: Kendall Correlation Summary Results for Julian Day of Spring Snowmelt

	PERCENT OF RIVERS FOR EACH CATEGORY FROM KENDALL CORRELATION TEST
Correlation (Tau) Ranges	**Julian Day Analysis**
$-1.00 \leq \tau < -0.50$	44.25
$-0.50 \leq \tau < -0.25$	32.74
$-0.25 \leq \tau \leq 0.00$	11.50
$0.00 < \tau \leq 0.25$	7.08
$0.25 < \tau \leq 0.50$	4.42
$0.50 < \tau \leq 1.00$	0.00

The Julian day of spring snowmelt has the best results out of all the hydrologic variables analysed. This evaluation has the most anticipated statistically significant decreasing trends (55.75% of the rivers), the least amount of increasing trends (less than one percent), and the least amount of insignificant trends (43.36%). These percentages indicate the presence of a very influential component affecting the Julian day of spring snowmelt that is not normally expected by an average set of hydrologic data. Since temperature is the component affecting the occurrence of the Julian day, it is obvious that climatic change has more of an influence on the timing of hydrologic events than on the magnitudes of hydrologic events. The general behavior of decreasing trends may be attributed to the earlier occurrence of the first spring snowmelt due to increasing temperatures over time. As a result, the Julian day would eventually take place closer to the first day of the year.

The correlation values also support the above trend results. Over 88% of the rivers have negative correlations with the majority occurring in the -1.00 to -0.50 range. These are very strong results in comparison to the other hydrologic variables. The Roseau River (05OD004) of the Prairie region is used to illustrate the expected behavior of decreasing trends with negative correlations in Figure 18. Table 22 gives the summary results.

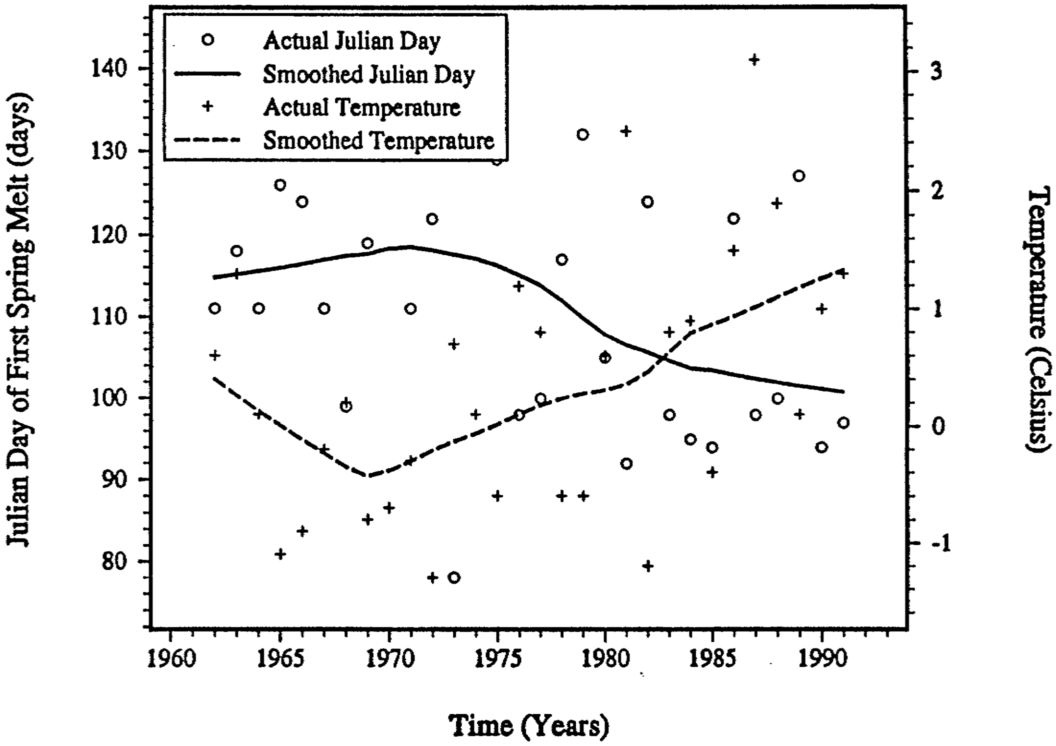

Figure 18: Smoothed Curves for Temperature and Julian Day Time Series

Table 22: Roseau River Summary Results

River	**Years**	**Series**	**Trend**	**S.L. (%)**	**Slope** (days/yr)	**Correlation**
Roseau	30	Julian Day	decreasing	3.87	-0.607	-0.903

5.2 REGIONALIZATION DISTRIBUTIONS

As previously discussed in chapter 4, there are many different possible response measures that could be used to define the regions for this analysis. The obvious response measures already described are the trend and correlation results. However, two other possibilities were the drainage basin area, and defining a common range of years. Through several evaluations, it was found that there were no significant results using the drainage basin area as a regionalization parameter. For example, no major differences were discovered in the distribution of results for the drainage areas between 0 and 1000 km^2, and greater than 1000 km^2 (median value for the drainage basin areas for all rivers is approximately 1000 km^2). However, a fixed common record length for all the rivers analysed showed interesting results when compared with the evaluations done by the maximum amount of data available for each river.

The common record length is defined between the years 1957 and 1991. This range is only 35 years long, but if the length was extended further, there would be a substantial decrease in the number of rivers available for evaluation. The advantage to having a common range is for consistency in the data sets with respect to the period in time in which the hydrologic variables will be analysed. The findings will not be affected by unequal lengths of data from river to river, and as a result, the statistical tests will become more meaningful and reliable for a common period of record. However, one main disadvantage is the difficulty in determining long term trends with only 35 years of record and with only a limited number of rivers. There were only 42 rivers remaining in the data sets after all the hydrologic variables were considered. Therefore, not much emphasis was made for a thorough examination of the 35 year record length. The 35 year range was only used for the expected behavior analysis for all hydrologic variables in section 5.2.2.1.

5.2.1 Regionalization of Trend Results

Each hydrologic variable considered for this evaluation will be discussed in detail with respect to the spatial patterns existing between the statistically significant (between 0% and 10% significance) and insignificant (greater than 10% significance) trends. Illustrative examples may be given to properly indicate these spatial patterns. The regionalization maps for each hydrologic variable in this section are shown in Appendix C.

5.2.1.1 Mean Annual Streamflow

The regionalization results for the March to October and May to August range are quite similar with only minor differences. Both ranges have a large number of expected significant decreasing trends in the southern portions of Manitoba and Alberta within the Prairies region, while small amounts of unexpected significant increasing trends exist mainly in the northern parts of Alberta (Northwestern Forest region) and the southern portions of Ontario (Northeastern Forest region). There is also a tendency for significant decreasing trends to exist in the middle and northern portions of Saskatchewan and Manitoba which is primarily encompassed by the Northwestern Forest and parts of the Northeastern Forest. The insignificant trends are essentially scattered throughout the study area with no localized distributions, except for a small tendency for insignificant trends to occur on the west side of Lake Winnipeg.

The minor changes between the March to October and May to August ranges are basically the difference from a significant increasing or decreasing trend at the 0 to 5% level changing to the 5 to 10% level (or vice versa). There were almost 5 times more significant decreasing trends than increasing trends for the March to October range, and 8 times more significant decreasing trends than increasing trends for the May to August range. Figure 19 below illustrates the spatial results for the May to August range.

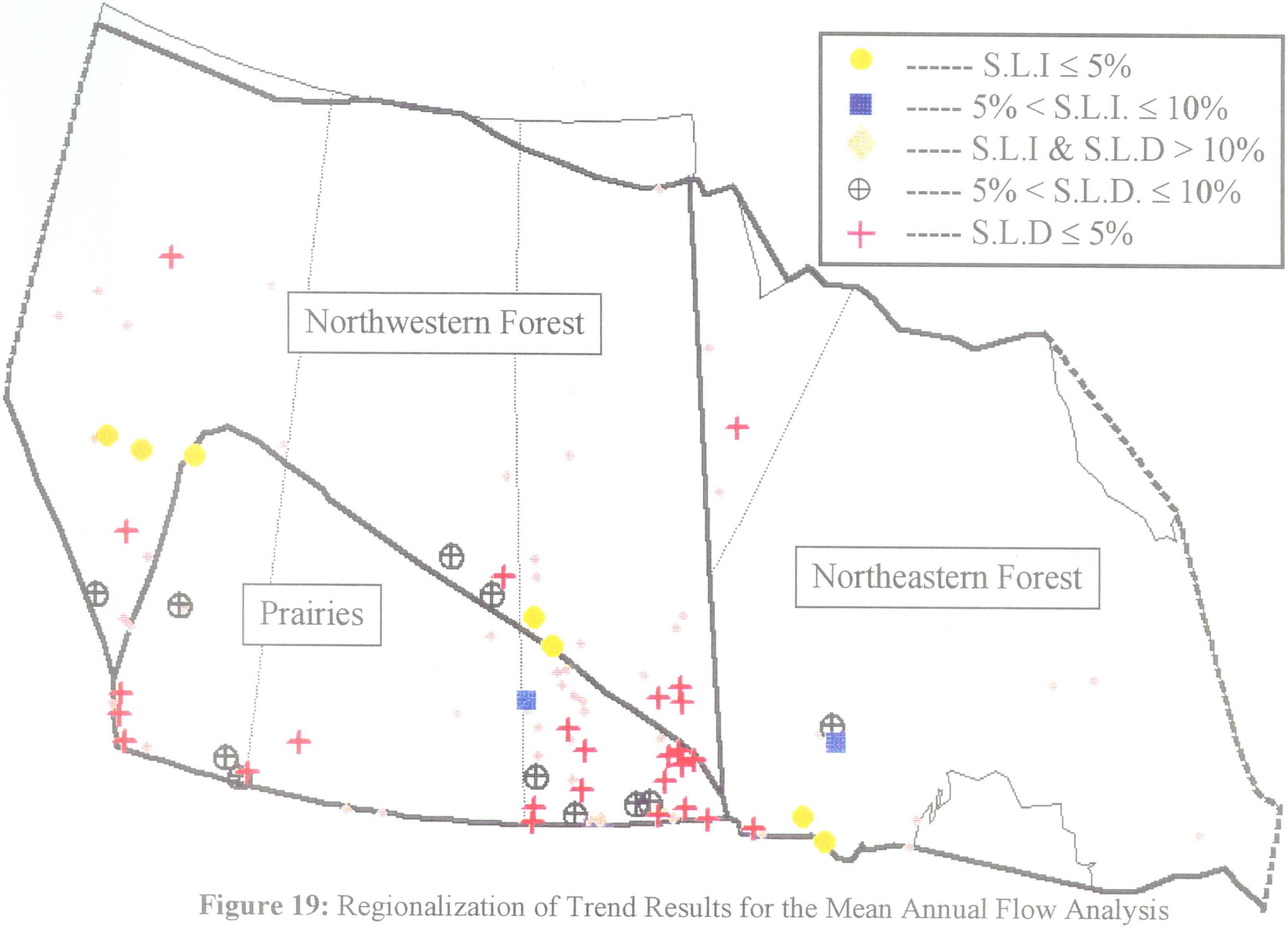

Figure 19: Regionalization of Trend Results for the Mean Annual Flow Analysis

5.2.1.2 Annual Cumulative Mean Monthly Negative Deviations

It is anticipated that there would be opposite results between the mean annual analysis and the annual cumulative mean monthly negative deviations. It is expected that there will be increasing trends relating to larger negative deviations over time. This is exactly what occurred, and Figure 20 below essentially illustrates the reverse behavior of trend results compared to the mean annual flows. Once again the regionalization results for the March to October and May to August range are quite similar with minor differences. There are over 7 and 9 times more significant increasing trends than decreasing trends for the March to October and May to August range respectively. The May to August range is selected in Figure 20 for comparison purposes against Figure 19.

Both ranges have a large number of expected significant increasing trends in the southern portions of Manitoba and Alberta within the Prairies region, while small amounts of unexpected significant decreasing trends exist mainly in the mid-section of Alberta (Northwestern Forest region) and the southern portions of Ontario (Northeastern Forest region). There is also a tendency for significant increasing trends to exist in the mid-portions of Saskatchewan and Manitoba in the Northwestern Forest region. The insignificant trends are again scattered throughout the study area with no localized distributions except for the tendency of insignificant trends to exist on the west side of Lake Winnipeg.

5.2.1.3 Mean Seasonal Streamflow

The expected response for all seasons are statistically significant decreasing trends. However, as indicated earlier, the spring and winter seasons will tend to have a few more increasing trends than average due to the snowmelt. There were 4 and 5 times more significant decreasing trends than increasing trends for the spring and summer seasons,

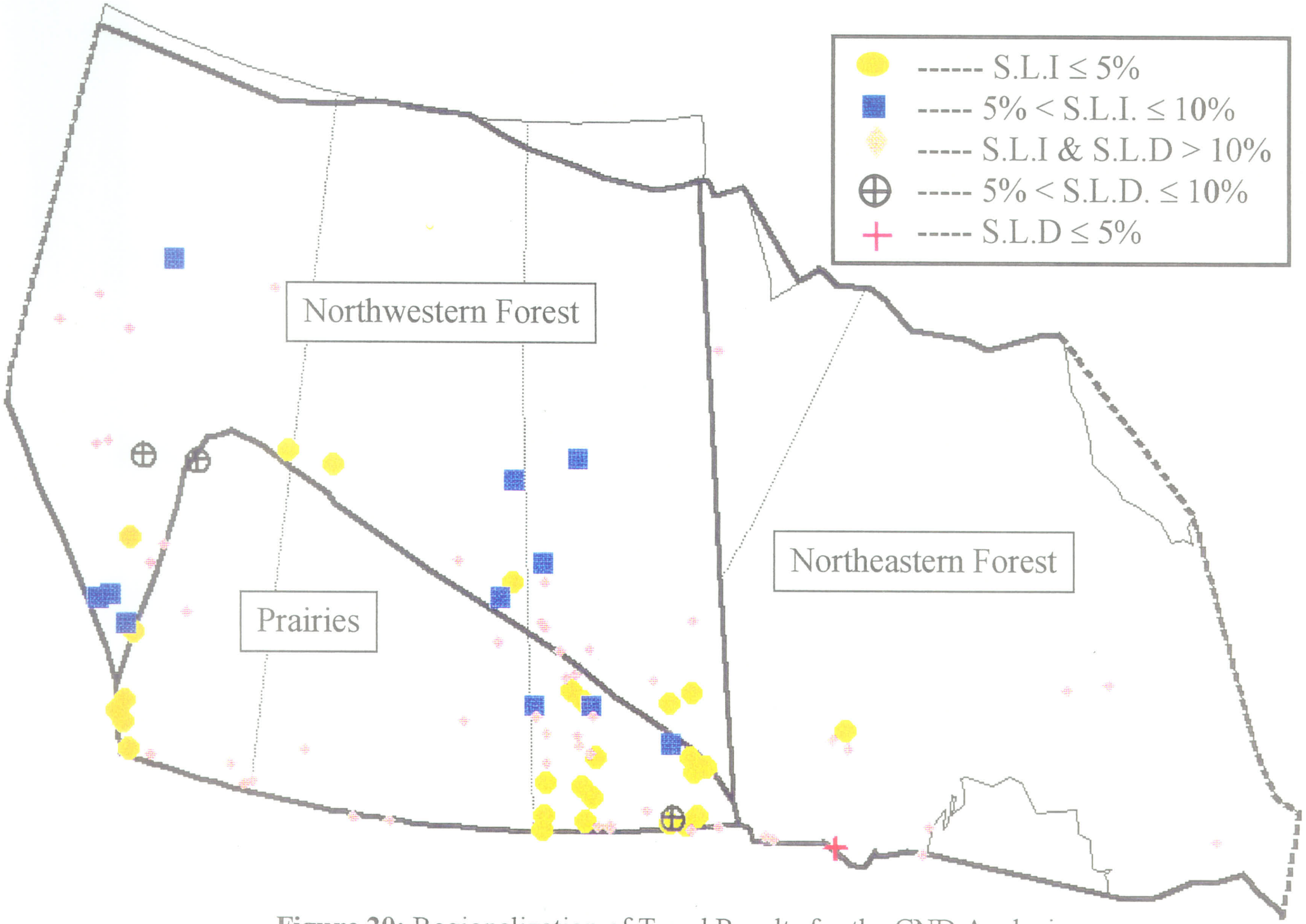

Figure 20: Regionalization of Trend Results for the CND Analysis

while both the fall and winter had approximately one and a half times more significant decreasing trends.

The spring and summer seasons had the most rivers available for analysis. Once again similar spatial patterns are present as compared to the mean annual analysis with only minor differences between each season. The significant decreasing trends appear to be clustered around the southwest portion of Alberta within the Prairies and Northwestern Forest, and in the mid-section of Saskatchewan and southern portions (with some northern occurrences) of Manitoba. There is a greater tendency for decreasing trends to appear in the northwestern parts of Alberta for the spring season. Most of the significant increasing trends for spring and summer are found in the mid-latitudes of Alberta and southwestern portions of Ontario (Northeastern Forest). The spring season has a few more increasing trends just above the Prairie region of Manitoba and into the Island Lake area of the Northeastern Forest. The insignificant trends for the spring and summer seasons are scattered throughout the Churchill-Nelson River Basin. However, there is a large cluster of insignificant trends on the west side of Lake Winnipeg for the spring season, but not in the summer.

The fall and winter months have similar but more sparse patterns compared to the summer season. This is due to the relatively small data set for the fall and winter evaluations. The insignificant trends that existed on the west side of Lake Winnipeg for the spring and summer seasons have disappeared in the fall and winter analysis. It appears that the absence of rivers available for the analysis are directly related to the decreased amounts of insignificant trends. Figures 21 and 22 below illustrate the summer and winter spatial trend patterns.

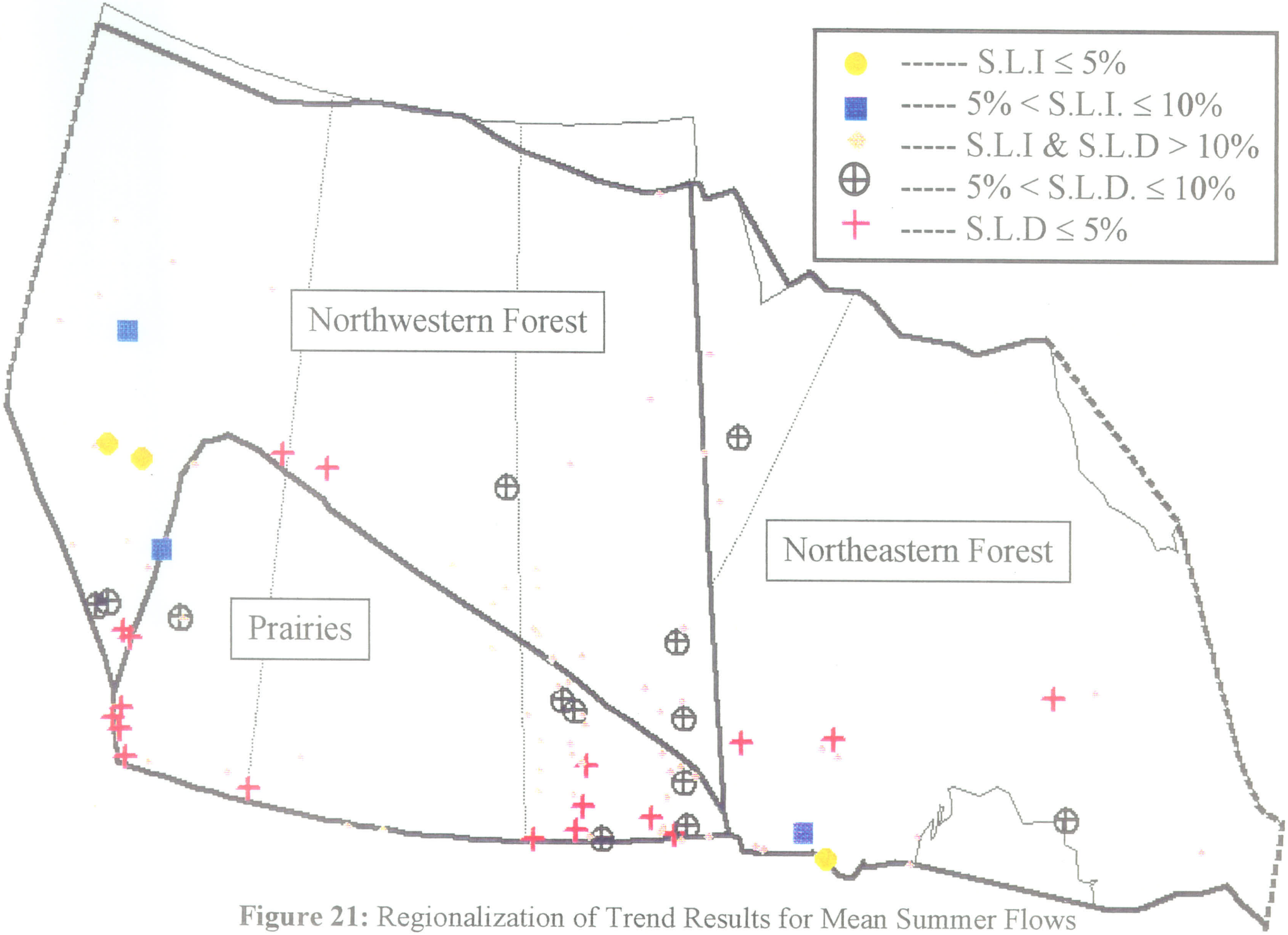

Figure 21: Regionalization of Trend Results for Mean Summer Flows

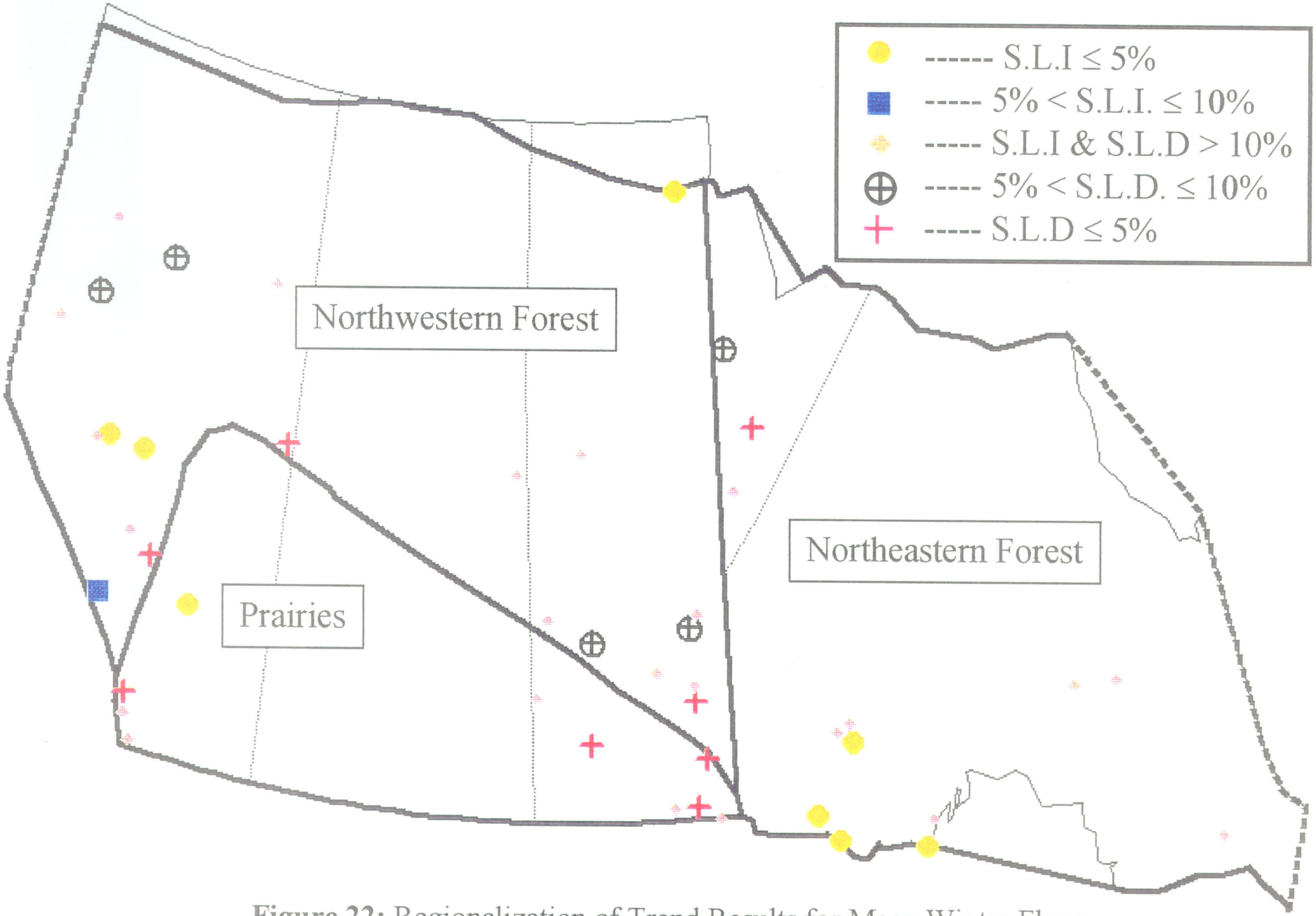

Figure 22: Regionalization of Trend Results for Mean Winter Flows

5.2.1.4 Mean Monthly Streamflow

The general directional expectation of a trend for the mean monthly analysis would be decreasing. However the late winter and early spring months, February and March, have more significant increasing trends than decreasing trends. The late spring and summer months have more significant decreasing trends than increasing trends, and to a lesser extent, the fall and winter months experience the same ratio of significant decreasing to increasing trends. Table 23 below summarizes the total ratio of statistically significant decreasing (D) and increasing (I) trends for each month.

Table 23: Ratio of Statistically Significant Increasing and Decreasing Trends

Month	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
Ratio	D/I	D/I	D/I	D/I	D/I	D/I	D/I	D/I	D/I	D/I	D/I	D/I
Value	1.25	1.13	0.30	0.47	14.69	19.52	2.20	2.75	4.00	1.36	1.00	1.11

The winter months, December to February, have very similar responses. There are some significant decreasing trends throughout Alberta in the Prairies and Northwestern Forest regions, and also in the southern and northern parts of Manitoba along the east side close to the border encompassing the Prairies, the Northwestern Forest, and the Northeastern Forest region. There are several significant increasing trends in the mid-sections of Alberta and southern portions of Ontario. There is not much data for any of these months, and therefore, the insignificant trends are sparsely located in all three climatic regions. Figure 23 illustrates the trend patterns for the month of January.

As the spring months progress, there are increasingly more significant decreasing trends concentrated in the areas mentioned above, while the increasing trends from the winter months tend to behave as decreasing or insignificant trends. Once again there is a larger

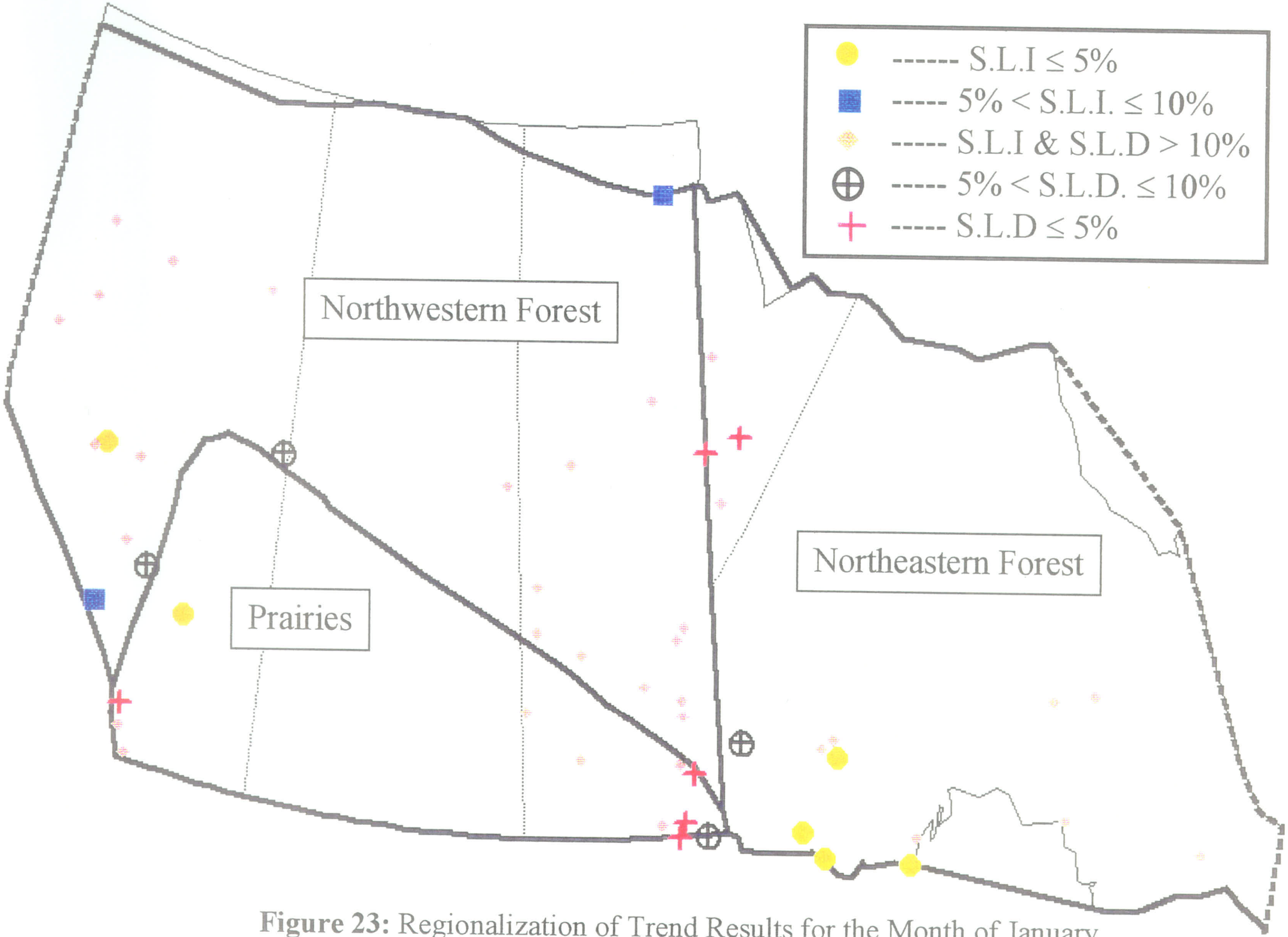

Figure 23: Regionalization of Trend Results for the Month of January

tendency for decreasing trends to appear on the east side of Lake Winnipeg, and a large amount of insignificant trends (with still some decreasing trends) on the west side of Lake Winnipeg. Concentrated amounts of significant decreasing trends in the summer months continue to increase in the southern portions of Alberta, and the northern and southern parts of Manitoba. June has the largest amount of decreasing trends compared to increasing trends (only two increasing trends in southern Ontario). As the summer progresses into the fall, once again more increasing trends start to appear in the common locations previously mentioned. Interesting observations were found for the insignificant trends around Lake Winnipeg for the summer months. There seemed to be an equal amount of significant and insignificant trends found on both the east and west sides of the lake for the months of June and August. However, July showed more insignificant trends on the east side of the Lake.

As the fall months approach, the standard spatial patterns for significant increasing and decreasing trends appear. As well, the insignificant trends are found more prominently on the west side of Lake Winnipeg, while scattered in all other areas. As winter nears, there are less rivers available for analysis which leads to evenly dispersed insignificant trends. Figure 24 will illustrate the trend behavior for the month of June.

5.2.1.5 Extreme Annual Streamflow

As indicated in section 5.1, the extreme annual flow behaves in a similar manner to the mean annual flow with the anticipated significant decreasing trends dominating. There are over six and a half times more decreasing trends than increasing trends. Figure 25 illustrates that the significant decreasing trends are most commonly found in the eastern half of Manitoba encompassed by all three climatic regions, and also along the southern

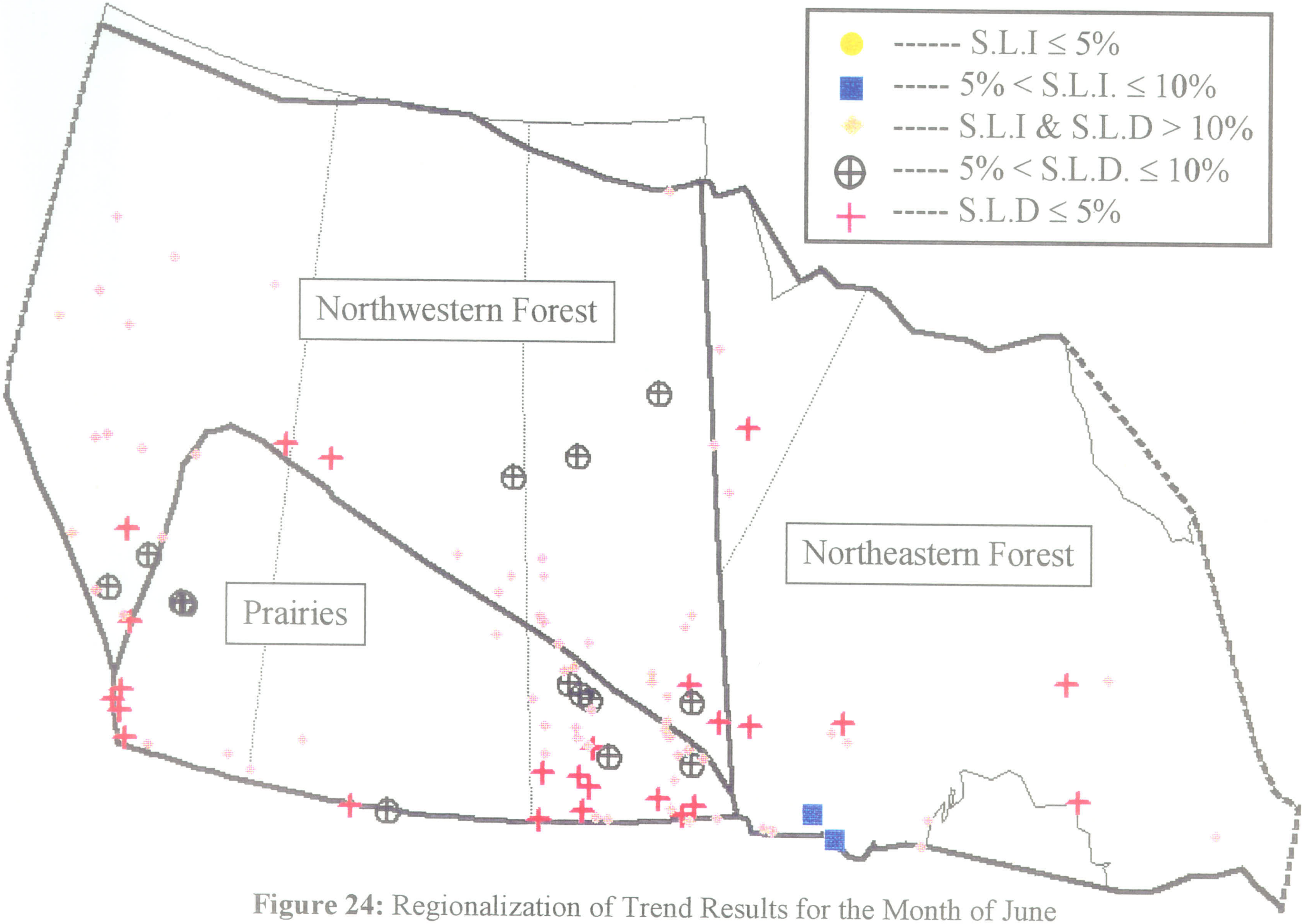

Figure 24: Regionalization of Trend Results for the Month of June

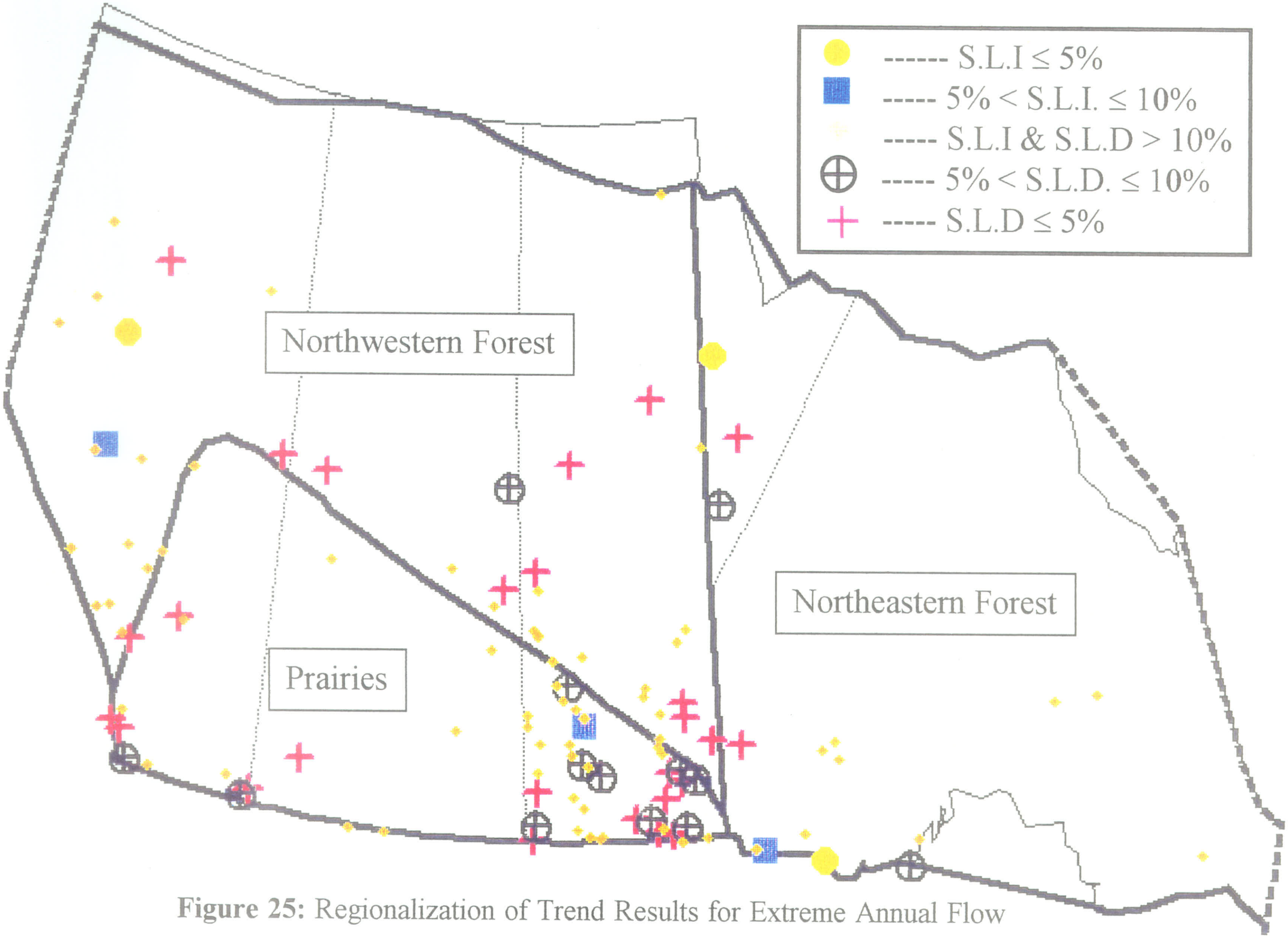

Figure 25: Regionalization of Trend Results for Extreme Annual Flow

parts of Alberta and Saskatchewan within the Prairie region. The increasing trends are found in the northern parts of Alberta in the Northwestern Forest and in the southeastern parts of the Northeastern Forest in Ontario. The insignificant trends are again sparsely located within the entire region of study, with a slight increase in concentration on the west side of Lake Winnipeg.

5.2.1.6 Maximum Summer Precipitation Event

The maximum summer precipitation event (MSPE) did not show many strong spatial trend patterns. Recall that statistically, there was only slightly better than average chance that decreasing trends would dominate. As a result, there are only 1.2 times more significant decreasing trends than increasing trends. The spatial patterns for the increasing and decreasing trends found from the past hydrologic variables can generally be spotted from the map shown in Figure 26. However, it would appear that the spatial patterns of the significant increasing and decreasing trends are just as clearly defined as the insignificant trends which are essentially distributed evenly throughout the climatic regions. Once again, the random nature of these results indicate the numerous unknown factors affecting the response of this variable to changing climatic conditions.

5.2.1.7 Timing of First Annual Spring Melt

The timing of the first annual spring melt had by far the most responses for significant decreasing trends. There are approximately 63 times more significant decreasing trends than increasing trends. This means that there are approximately 63 gauging stations with decreasing trends since there is only 1 station having a statistically significant increasing trend in the mid-latitudes of Manitoba. Figure 27 illustrates the regional trend patterns for the Julian day analysis. The decreasing trends are strongly concentrated in the southern parts of Manitoba and scattered consistently throughout Alberta. It also appears that the insignificant trends are evenly distributed throughout the entire region of study. There are

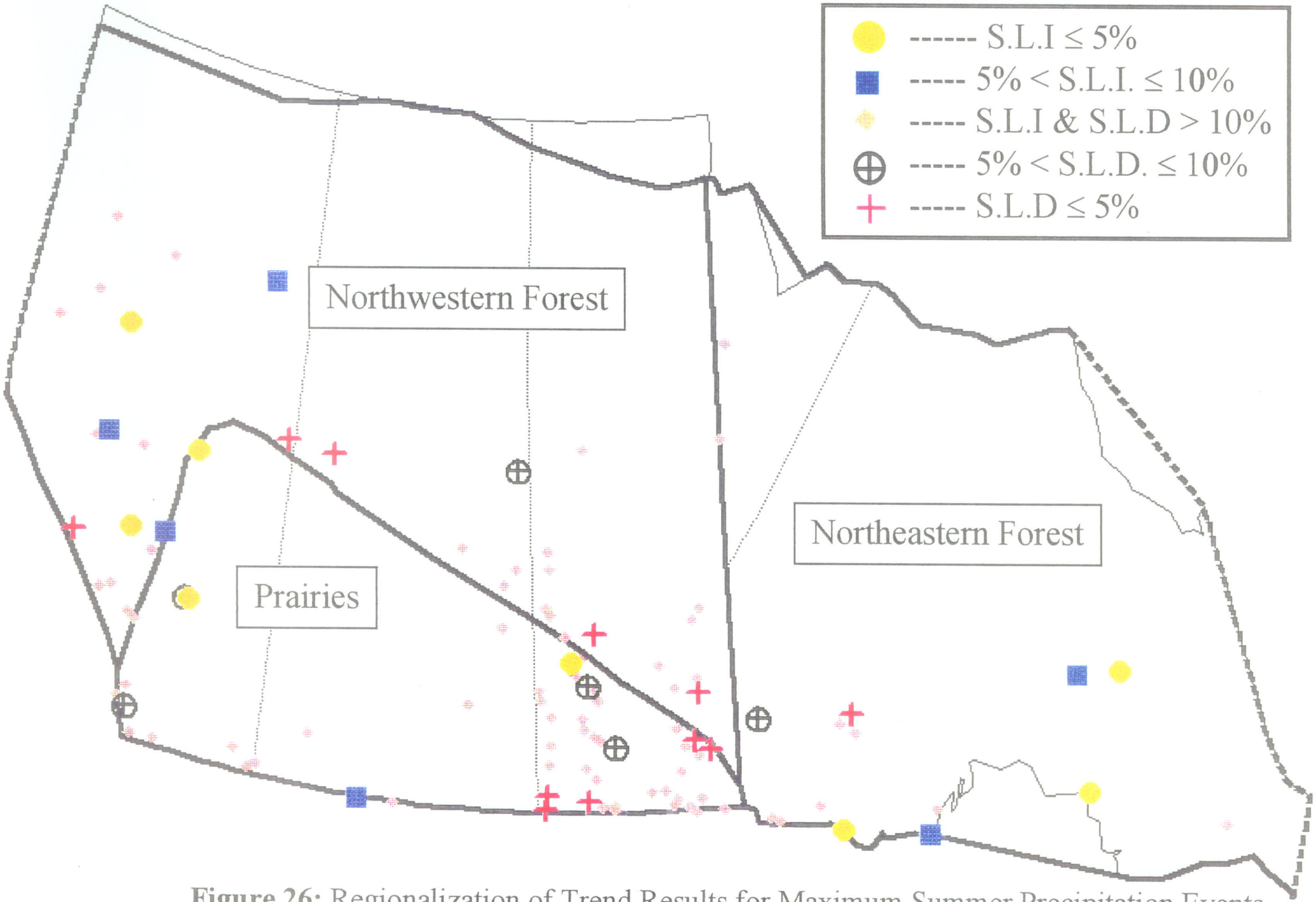

Figure 26: Regionalization of Trend Results for Maximum Summer Precipitation Events

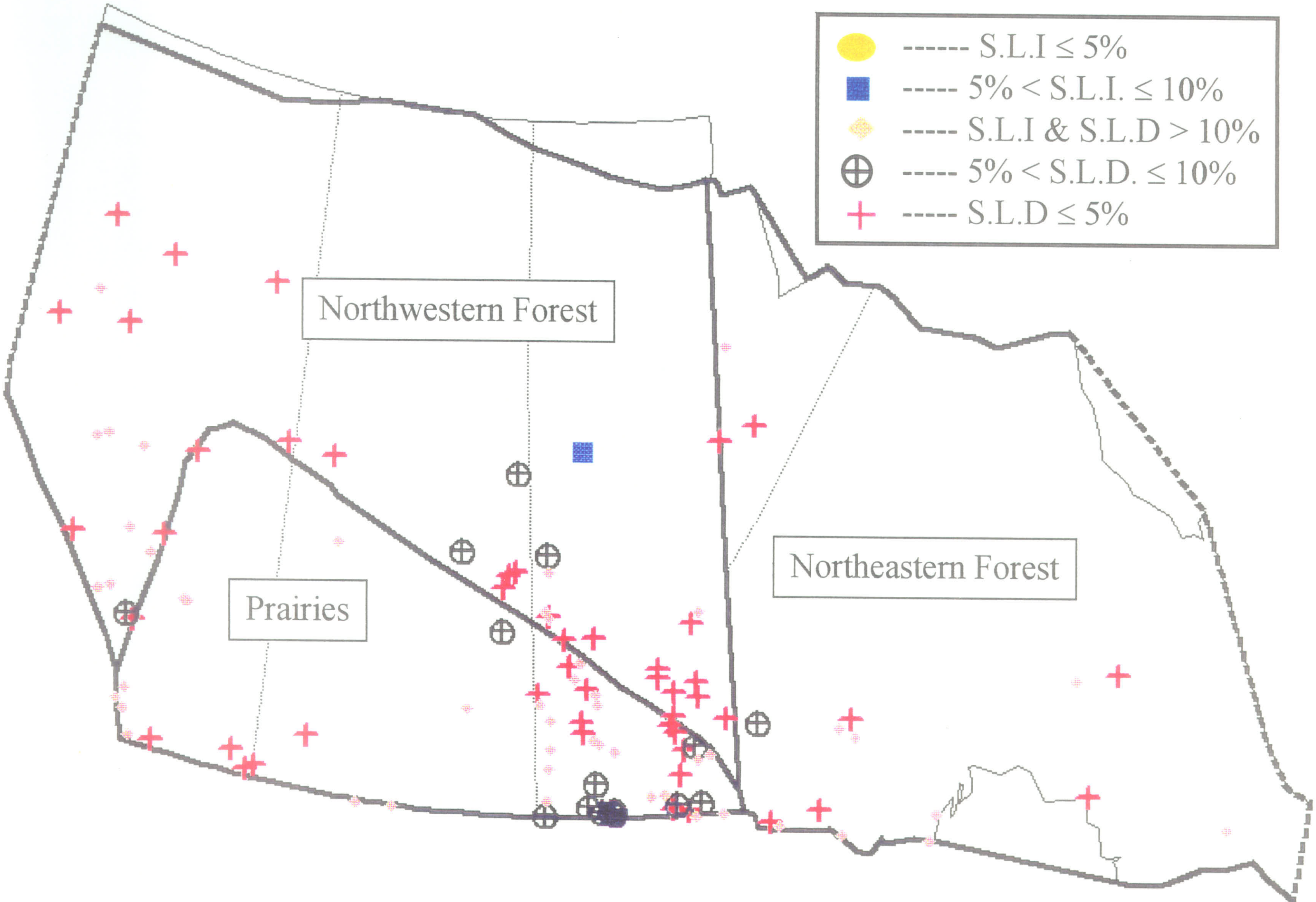

Figure 27: Regionalization of Trend Results for the Julian Day of Spring Melt

still a slightly greater number of insignificant trends on the west side of Lake Winnipeg as compared to the east side.

5.2.2 Regionalization of Expected Behavior

The following two regionalization approaches will indicate how each river behaved based on the four categories mentioned in section 4.3.4. Recall that the different types of expected behaviors are from various combinations of trend and correlation results. Table 24 has a general summary of results for each applicable hydrologic variable. The table indicates the expected behaviors (EB), the percent of rivers having the expected behavior, the percent of rivers with the EB having significant trends (ST) between the 0% and 10% significance range, the percent of rivers with the EB having correlations greater/less than (CGL) +/- 0.50, and the percent of rivers with the EB having both significant trends and correlations greater/less than +/- 0.50.

Table 24: Summary of Expected Behaviors

Hydrologic Variable	**EB, (correl./ trend)**	**# of rivers available for analysis**	**% of rivers with EB**	**% of rivers with EB, & ST**	**% of rivers with EB, & CGL +/- 0.5**	**% of rivers with EB, ST, &CGL +/- 0.5**
Mean Ann. (Mar.- Oct.)	neg./ decr.	99	68.7	38.4	46.5	27.3
Mean Ann. (May - Aug.)	neg./ decr.	109	66.1	36.7	35.8	20.2
CND (Mar.- Oct.)	pos./ incr.	84	73.8	41.7	48.8	27.4
CND (May - Aug.)	pos./ incr.	93	73.1	40.9	44.1	29.0
Extreme	neg./ decr.	116	66.4	31.9	42.2	20.7
Julian Day	neg./ decr.	107	80.5	50.4	42.5	26.5
MSPE	neg./ decr.	113	43.9	15.9	14.0	2.8

The above summary gives a general indication of the ability to obtain the expected behaviors, from weak to strong conditions, for each hydrologic variable. These results clearly show strong consistent relationships with changing climatic conditions (change in temperatures) for all hydrologic variables with the exception of the maximum summer precipitation event. The Julian day analysis has the most number of rivers falling into the expected behavior category, and continues to have a large percent of rivers in the other categories. The second most responsive variable would be the cumulative annual mean monthly negative deviations, followed by the mean annual and extreme evaluations. There also appears to be more frequent occurrences (larger percent of rivers) having strong correlations with the expected behavior, than significant trends with the expected behavior. This indicates a greater tendency for a strong correlation to be present for the anticipated behaviors.

It is interesting to note that the May to August ranges did not have a greater representation of strong results as compared with the March to October range. One might expect a greater susceptibility of hydrologic variations in the summer time, due to higher evaporation rates and/or lower net precipitation as compared to the entire year. The separation of hydrologic variables into summer and entire year ranges does not necessarily result in significantly different results. It appears that the inclusion of the spring and fall seasons are important for contributing to the effects of climatic change on hydrologic variables. However, it would be more logical to expect the spring season to have a greater influence since there are more hydrologic processes occurring in the spring than in the fall seasons. It would be interesting to evaluate a winter range, but with the frequent number of missing data values during the winter season, it would be impossible to have an appropriate number of rivers for a proper analysis.

5.2.2.1 Regionalization Based on All Hydrologic Variables

This regionalization analysis considers two types of data sets, (1) the data extracted for each hydrologic variable must be within the years 1957 to 1991, and (2) the data extracted has no limits to the possible range of years for each variable (as long as it has at least 30 years of record). As described in section 4.3.4, each available river was assigned as one of the four behavioral categories and then plotted on the study area map. These categories only consider the combination of anticipated trend and correlation results without using the strong relationship divisions as in Table 21, columns 4 through 6, in order to have a larger data set in which to evaluate the spatial patterns. When using the 1957 to 1991 year range, only 42 possible rivers are available when each hydrologic variable is considered. The spatial distribution of the hydrologic behaviors for this range is shown below in figure 28.

The map indicates some recognizable spatial patterns or clusters for three of the categories. From the map, there is a tendency for expected behaviors (circles) to occur in the southeastern part of Manitoba within the Prairie region, and in the southern part of Alberta in the Prairies and Northwestern Forest region. These areas are directly related to the localized patterns of the general anticipated significant trends from the regionalization maps of section 5.2.1. With correct correlations and wrong trend directions, the rivers in category two are primarily located on the northwest side of Lake Winnipeg and along the western half of Alberta, both of which are located in the Prairies and Northwestern Forest region. There are also a few located in the southwestern part of Ontario in the Northeastern Forest region. Since the wrong trends describe part of the behavior for category two, it also corresponds to the localized results of unexpected significant trends from the regionalization maps of section 5.2.1.

There are no occurrences of rivers behaving with wrong correlations and correct trend directions (category 3). This may indicate a potential relationship between the trend and correlation results. For example, if a river behaves as anticipated with respect to the trend direction, it appears that the corresponding correlation must accompany the correct trend.

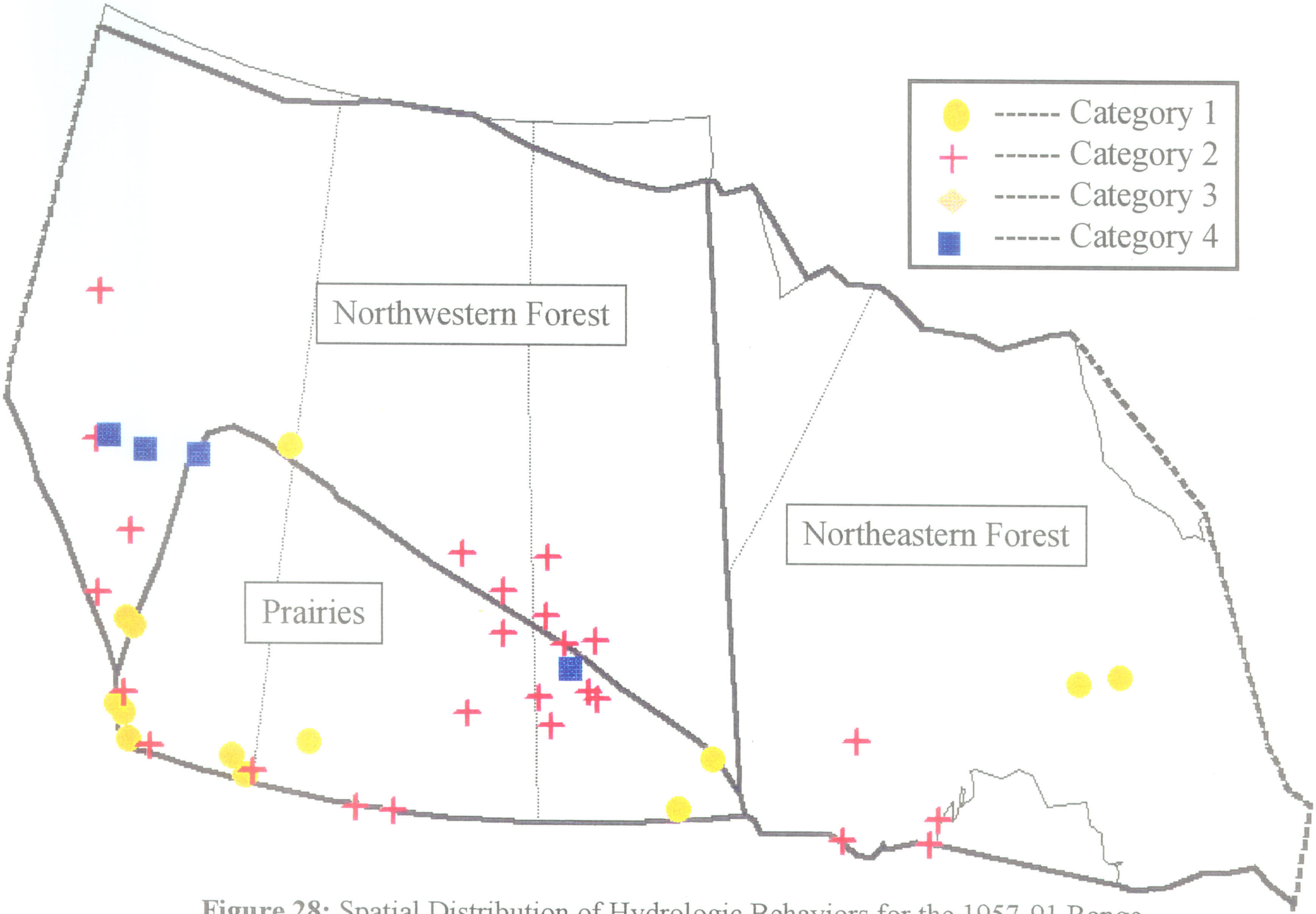

Figure 28: Spatial Distribution of Hydrologic Behaviors for the 1957-91 Range

It is anticipated that the corresponding correlation for significant decreasing hydrologic trends is negative since temperature increases over time, while for significant increasing hydrologic trends the correlation would likely be positive. On the other hand, the reverse situation of having a correct correlation with a wrong trend is more likely since the wrong trend could simply be near horizontal. Another interesting comparison between category two and category three results is the greater frequency for correct correlations to occur compared to the occurrence of correct trends. This may indicate a greater sensitivity and response towards the correlation results between temperature and hydrologic variables, as compared to the direct trend response caused by a change in temperature. This argument is also supported from the results in Table 24.

Finally, there were only a few rivers having unexpected trends and unexpected correlations together. It is possible that the combination of this reverse behavior, with such a small data base, would not have a large chance of existing. Unfortunately, without a large data set, it may be premature to make conclusive generalizations about the spatial distribution of any category in Figure 28. For this reason, the restriction for the common period between 1957 and 1991 was relaxed and revised to an open ended possibility of any record length greater or equal to 30 years. Figure 29 illustrates the spatial distribution patterns for the hydrologic behaviors having no bounded record lengths.

Figure 29 includes all the 117 rivers collected. It appears, with only few exceptions, that each category is clustered in the same areas as in the common year analysis. Category one is heavily concentrated on the east side of Lake Winnipeg, while there is more of a tendency for categories two and four to appear on the west side of Lake Winnipeg. This once again primarily corresponds to the unexpected trends as previously shown in section 5.2.1. However, based on the number of category two responses, correct correlations

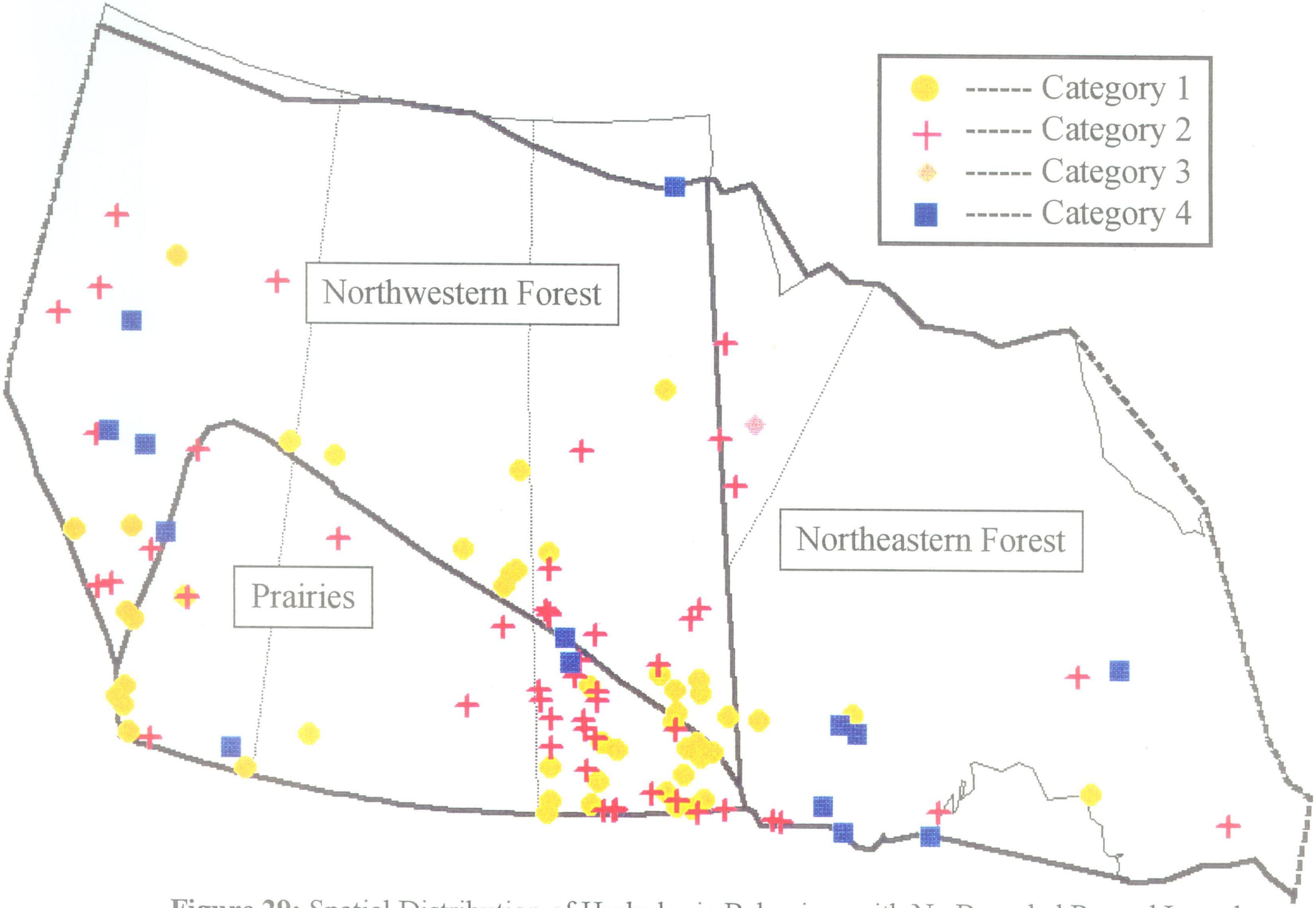

Figure 29: Spatial Distribution of Hydrologic Behaviors with No Bounded Record Length

would appear to dominate on the west side of Lake Winnipeg. There are also a fair number of category one responses in the southern portions of Alberta and mid-latitudes of Saskatchewan and Manitoba. With almost 3 times more rivers available, category 3 still had only one occurrence, and this again alludes to more frequent occurrences of correct correlation results compared to correct trend results. The spatial clusters of category 4 are primarily in the middle parts of Alberta and southeastern portions of Ontario which, from previous results, are the locations for unexpected behaviors.

5.2.2.2 Separate Regionalization Analysis for Each Hydrologic Variable

The sections below describe the distribution patterns of the four possible behavior combinations for each hydrologic variable. Analysing each hydrologic variable will help clarify which variables were responsible for the assigned behavioral categories in section 5.2.2.1. More importantly, this analysis will provide information as to the location where a particular variable may be most responsive with respect to climatic change. It is expected that the general spatial patterns from combined variable analysis in section 5.2.2.1 will be quite similar to the spatial patterns described below. The maps used to illustrate the spatial distributions are given in Appendix D.

5.2.2.2.1 Mean Annual Streamflow

There are very few minor differences between the March to October range and the May to August range. Basically both ranges can be described in the same manner. Figure 30 illustrates the spatial distributions of the mean annual flow responses for the March to October period. The expected behaviors from category one are primarily found in the southern portions of Alberta, mid-latitudes of Saskatchewan, and in the southern parts of Manitoba within the Prairies and Northwestern Forest Regions. Category two is found in the middle and northern parts of Alberta in the Northwestern Forest and in the southern parts of Manitoba with a larger concentration on the west side of Lake Winnipeg. There

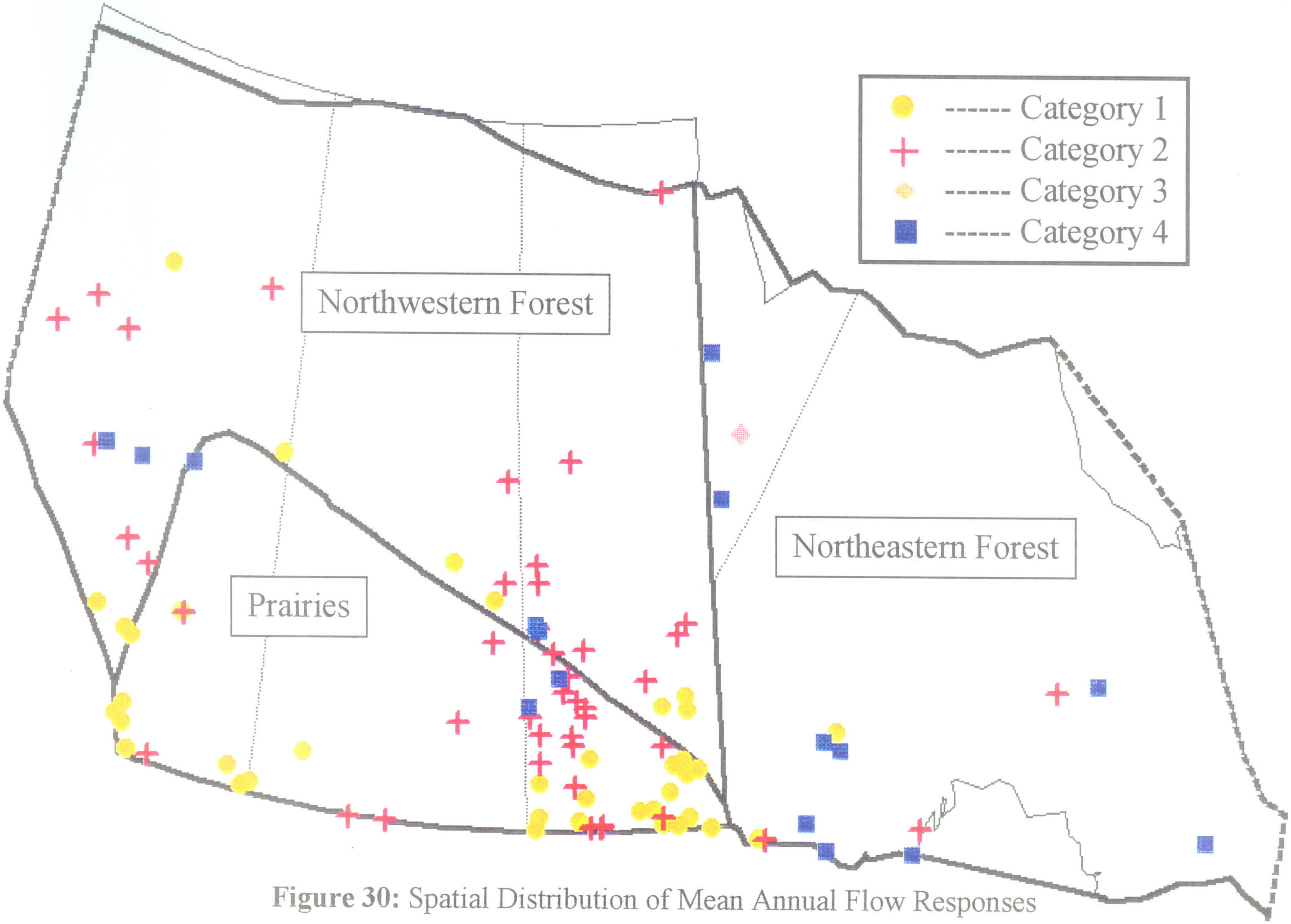

Figure 30: Spatial Distribution of Mean Annual Flow Responses

is only one river with the wrong correlation and correct trend in the Northeastern Forest in Manitoba. The reverse anticipated behaviors (category 4) are generally found in smaller quantities where the category two behaviors are located. There is also a greater tendency for the category 4 responses to cluster in Northeastern Manitoba and Southern Ontario within the Northeastern Forest region.

5.2.2.2.2 Annual Cumulative Mean Monthly Negative Deviations

The expected behavior of category one for the CND evaluation is increasing trends and positive correlations. Once again category one is generally clustered in the southern parts of Alberta, the mid-section of Saskatchewan above the Prairie/Northwestern Forest region boundary, and the southern parts of Manitoba. Category two is fairly evenly distributed throughout Alberta and primarily on the west side of Lake Winnipeg. There again are very few occurrences of category three behaviors (wrong correlation and correct trend), and a consistent cluster of category four responses in the mid-latitudes of Alberta, the southwestern/southern parts of Ontario, and northwest of Lake Winnipeg in Manitoba. Figure 31 illustrates these behavioral patterns for the March to October period.

5.2.2.2.3 Extreme Annual Streamflow

The extreme annual flow patterns are very similar to the last two variables evaluated. Figure 32 illustrates the spatial distribution of the extreme annual flow responses. Category one is spatially distributed in the south parts of Alberta, mid-latitudes of Saskatchewan and Manitoba, and in the southern parts of Manitoba mainly on the east side of Lake Winnipeg. Category two and four again dominate the west side of Lake Winnipeg area, the mid-section of Alberta, and southwestern corner of Ontario. The only two occurrences of category three are in the northeastern part of Manitoba within the Northeastern Forest region.

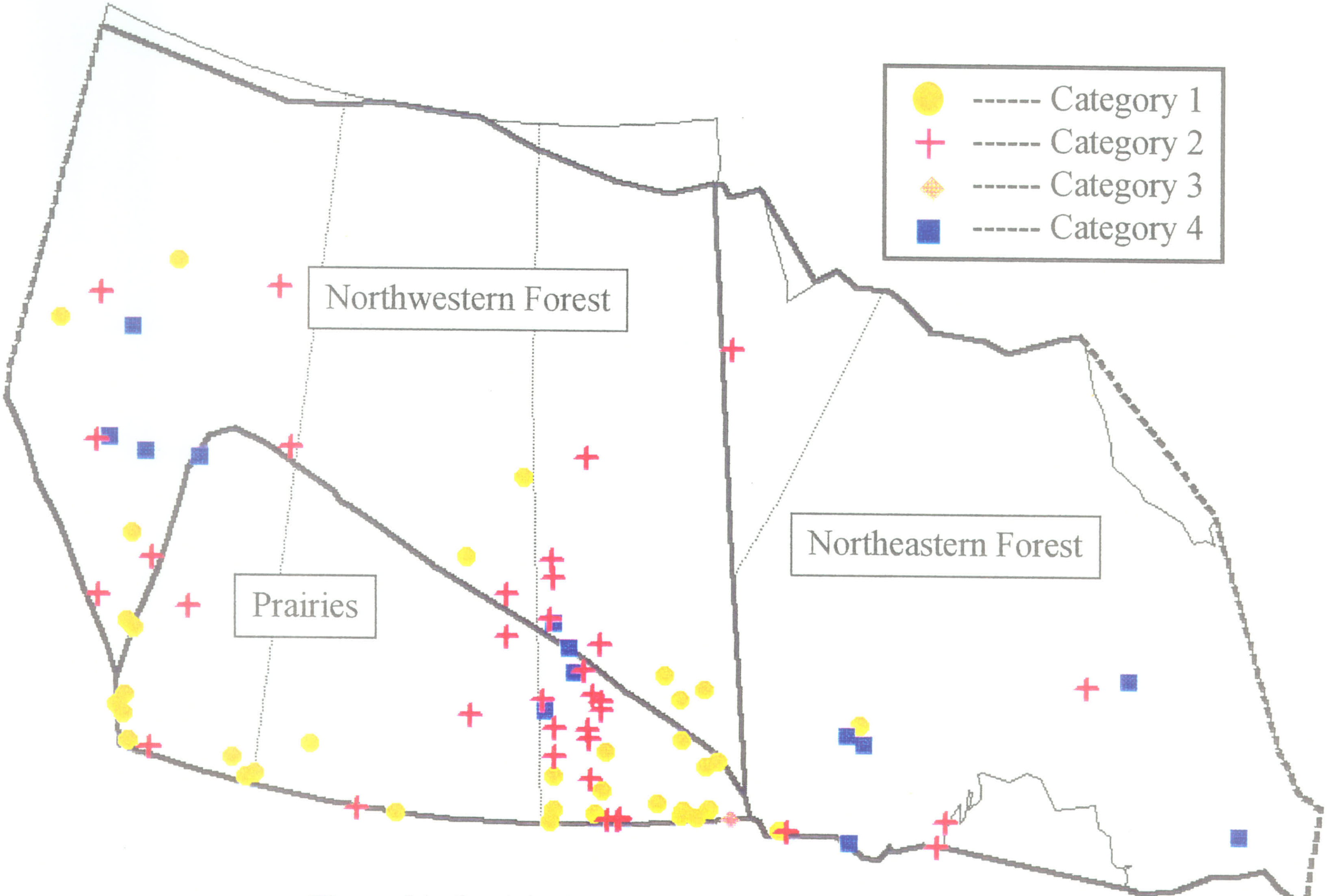

Figure 31: Spatial Distribution of CND Responses

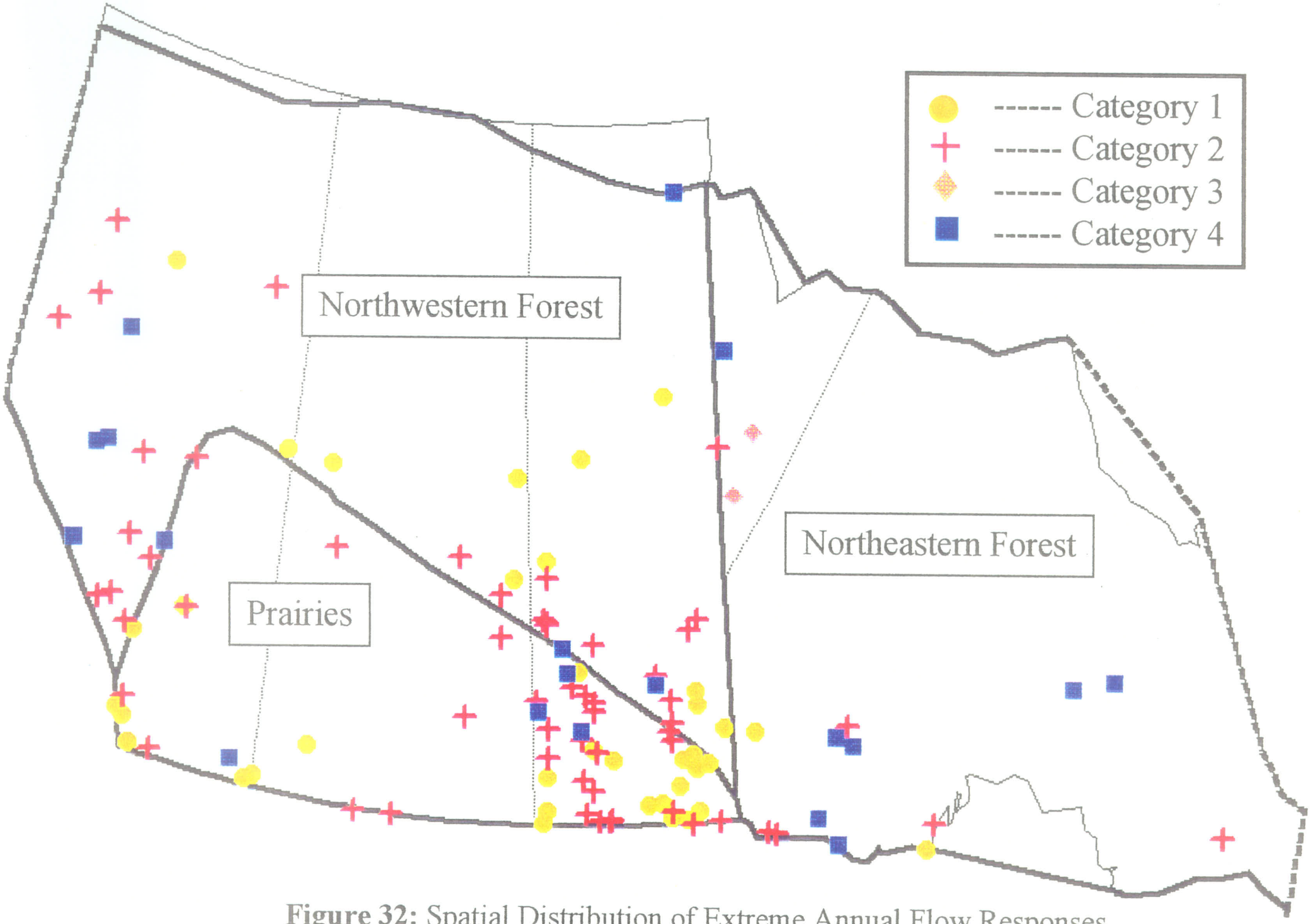

Figure 32: Spatial Distribution of Extreme Annual Flow Responses

5.2.2.2.4 Maximum Summer Precipitation Event

The maximum summer precipitation event differs the most out of the general spatial tendencies for each hydrologic variable. The expected behavior of decreasing trends with negative correlations are quite sparse. The only clustering of this category may be found in the southern parts of Manitoba with no special location around Lake Winnipeg. Category two is found in the southern and northern parts of Alberta, and again evenly located around the southern portions of Manitoba around Lake Winnipeg. There are, however, many more category two results than category one. There are no category three results, but there are many unexpected results (category 4) compared to the other hydrologic variables. This accounts for the comparable amount of significant increasing trends compared with the expected significant decreasing trends (recall section 5.1.6). It is also very likely that positive correlations will accompany the large amounts of increasing trends, and therefore, large quantities of category four responses will result. Category four clusters are primarily found along the west side of Alberta in the Northwestern Forest region, the southern part of Manitoba mainly along the west side of Lake Winnipeg, and in the southwestern parts of Ontario. Figure 33 illustrates the spatial responses of the maximum summer precipitation event.

5.2.2.2.5 Timing of First Annual Spring Melt

Once again the general behavioral patterns are present for the Julian day analysis. However there are a larger number of expected behaviors compared to the other variables. This is anticipated since the results of the Julian day evaluation were the most responsive to the fluctuations in temperature. Category one is primarily located throughout all of Alberta in the Northwestern Forest region and in the southern part of Manitoba split between the Prairies and the Northwestern Forest region. It appears that the distribution of category one around Lake Winnipeg is evenly clustered, however, category two is more densely located on the west side of Lake Winnipeg. Other clusters of category two can be

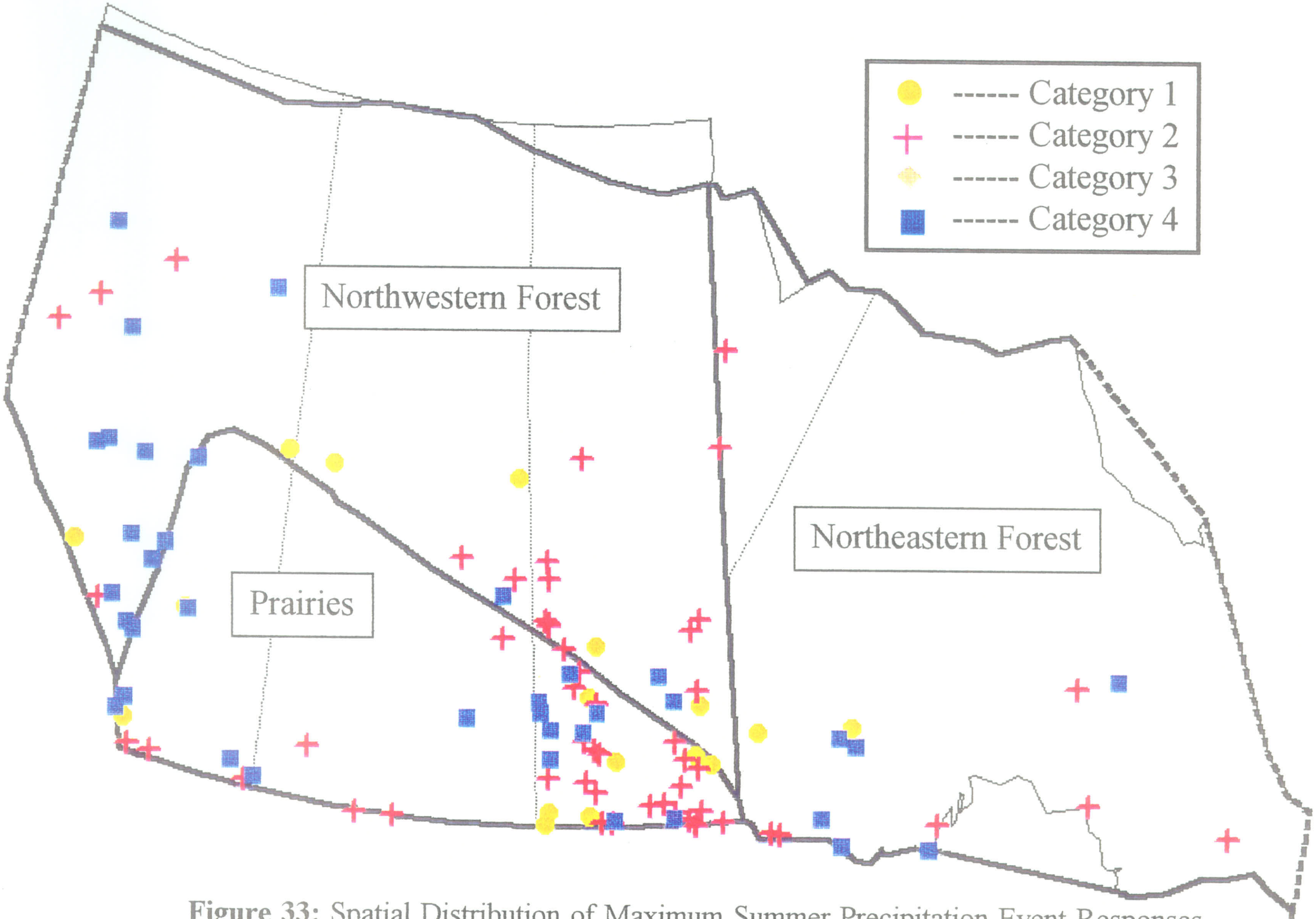

Figure 33: Spatial Distribution of Maximum Summer Precipitation Event Responses

found in the southern parts of Alberta within the Prairies and Northwestern Forest region, and in the southern parts of Ontario. There are very few category three and four responses, and it would be impossible to identify any spatial patterns for these categories. However the category three behaviors are located in the primary spatial areas of the past hydrologic variables. For unknown reasons, there are also more unexpected behaviors (category 4) compared to the other variables. There are only 5 occurrences; 2 are located in southern Alberta, and the other three are spread across the southern part of Ontario. This may indicate areas where the timing of hydrologic events are not of great importance. This would likely be in the areas of low annual accumulations of snowfall. Figure 34 illustrates the spatial distribution of the Julian day responses.

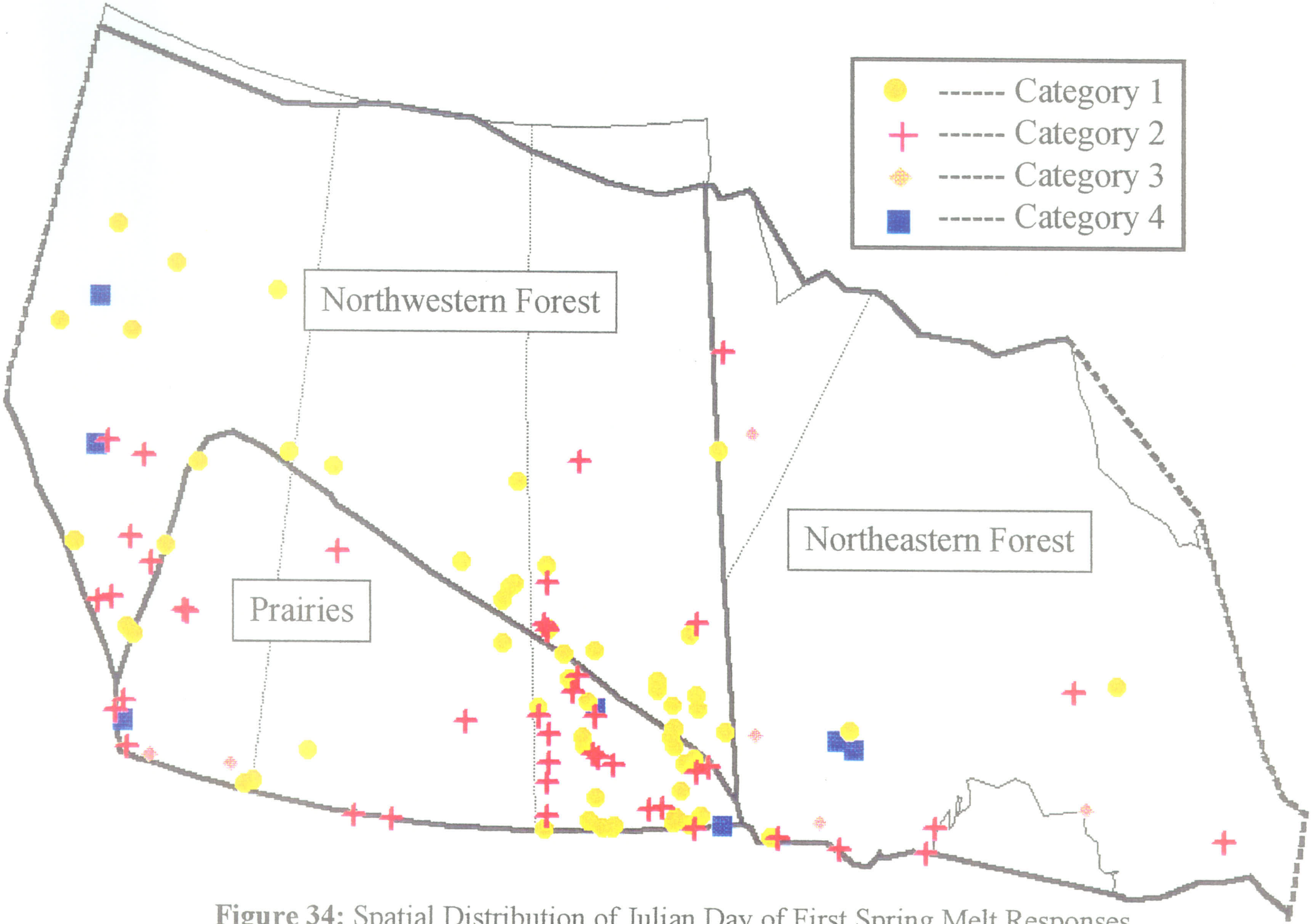

Figure 34: Spatial Distribution of Julian Day of First Spring Melt Responses

CHAPTER 6

6.0 SUMMARY OF RESULTS

Based on the Mann-Kendall trend and Kendall correlation tests performed on all 7 hydrologic variables, generalizations were able to be made about the characteristic behavior of each variable. The reasoning behind the hydrologic behavior of each variable was interpreted in a way that would best describe and explain these natural occurrences. With the exception of the maximum annual precipitation event, all variables where in strong agreement with respect to possible related effects of climatic change on the hydrologic regime and the surrounding environment. For example, for all the annual evaluations, it appeared that decreasing trends were the anticipated behaviors (increasing trends for cumulative annual mean monthly negative deviations), and that these behaviors could be explained by the potential increase in evaporation due to increasing temperatures over time. The resulting correlations corresponding to the decreasing trends were negative, and the correlations were positive for increasing trends. This is expected due to the general decreasing tendency of hydrologic variables such as streamflow which appears to correspond to the increasing temperatures. In many situations, where temperature had a tendency to increase in a particular time period, streamflow then started to increase or level off from the original decreasing trend.

The further breakdown from an annual evaluation to seasonal and monthly time intervals indicated other characteristic behaviors. The seasonal and monthly time intervals indicated various expected behavior strengths similar to the annual results, and as anticipated, slightly opposite results were obtained for seasons and months were snow melting and snow accumulation were dominant. All the seasons had decreasing streamflow trends with negative correlations. However, the spring and winter seasons would have slightly more increasing flow trends compared to the other seasons, while the summer would have the highest amount of decreasing flow trends. Due to the low flows and small quantity of data for the fall, there were a large number of insignificant trends.

When the monthly divisions were studied, a further understanding was developed about the occurrence of increasing trends, insignificant trends, and decreasing trends. Figure 12 illustrated the occurrence of the significant increasing and decreasing trends between the 0% and 10% significance level. From this figure, it is easy to locate the time periods of similar behaviors. For example, October, November, December and January had similar occurrences of increasing and decreasing trends. February and March had more significant increasing trends than decreasing trends which may be attributed to increased snow melting potential during that period. April, May and June had very large amounts of significant decreasing flow trends which appear to dominate when all the months/seasons are considered together. Finally, July, August, and September had relatively the same percent of rivers with significant increasing trends and the same percentage of rivers with significant decreasing trends.

The type of behavior found throughout the results for the mean annual, mean seasonal, and mean monthly streamflow evaluations are reflected in the extreme annual analysis. Valuable information was obtained from evaluating the annual extreme flow event. It appeared that climatic change had relatively the same effect on the entire spectrum of flow values ranging from low flow to extreme flow conditions. For example, the low flow conditions for the month of September, and the mean annual and extreme annual flows have similar results to changing climatic conditions.

Based on the frequency of occurrence of the expected behavior patterns for each variable, one could conclude which hydrologic variable is affected the greatest by changing climatic conditions. From the results, the Julian day of the first spring melt was the primary influenced variable affected by temperature fluctuations. This may indicate a greater need to study the effect of climate change on the timing of hydrologic events. However, significant results were also obtained from the streamflow magnitude related variables. It is probably important to know what hydrologic processes may be affected by climate change, as well as the magnitude or degree by which the hydrologic variable is affected by climate change. It is also important to know the locations of greatest potential for hydrologic variations caused by changes in the climate. This can be accomplished by evaluating spatial distributions of the hydrologic responses from fluctuating temperatures.

When evaluating the spatial distribution of the Mann-Kendall trend test results, it was found that a common pattern appeared for the statistically significant trends and insignificant trends. Basically, both the anticipated and unexpected trends for each hydrologic variable clustered around similar locations within the area of study. For example, the anticipated trends were primarily found in the southern parts of Alberta in the Prairie region, the mid-latitudes of Saskatchewan, and along the Manitoba/Ontario border spanning all three climatic regions. Of course there were usually a larger amount of expected trends in southeastern Manitoba due to the large quantity of rivers available for analysis in that area. From the results, one would anticipate the unexpected trends to be located in the mid-latitudes of Alberta near the Prairie/Northwestern Forest boundaries, and in the southwest portion of Ontario in the Northeastern Forest region. Finally, the insignificant trends were generally scattered throughout the region of study, however, there was a tendency for more insignificant trends to occur on the west side of Lake Winnipeg.

The regionalization techniques showed similar spatial patterns when using the behavioral combinations of trend and correlation results for all variables combined, and considered separately. These results directly corresponded to the distribution clusters found from the evaluation of the statistically significant and insignificant trends in section 5.2.1. Essentially, expected behavioral patterns for all hydrologic variables were found in the southern regions of Alberta, the mid-latitudes of Saskatchewan and Manitoba, and with the greatest concentration in the southern parts of Manitoba primarily on the east side of Lake Winnipeg. The combination of expected correlations and unexpected trends were mainly throughout all of Alberta and Manitoba, with larger amounts on the west side of Lake Winnipeg. The chance of unexpected correlations with expected trends to occur was very remote, but if the behavior was present, it would be mainly found in the southern parts of Alberta, and Ontario. Results with completely opposite trends and correlations were generally found in the mid-sections of Alberta and southern portions of Ontario.

The unexpected behaviors for each hydrologic variable analysed would be hard to explain and accurately describe without knowing the hydrologic and environmental conditions for the surrounding area of study. Tung and Haith [1995] point out that any watershed is a unique combination of soils, land uses, and topography, and its response to change would be best estimated by analysing that watershed. Without an indepth analysis of each watershed, one can only speculate why particular rivers behave differently. For example, some factors affecting the response to each variable may include the changes in runoff potential in certain areas caused by various types of vegetation, or recent urbanization. On the other hand, natural causes such as ice jams, late spring melting, unusually dry or wet years, and other possible scenarios may result in changing runoff conditions.

Other difficulties exist when identifying trends based on short data sets. The evaluation of short data sets, combined with the natural variability inherent in all hydrologic data, introduces more uncertainty to the results. For example, where no trends existed for a particular hydrologic variable, it is possible that an inadequate period of record was available to properly identify an existing trend. Even though a minimum of 30 years was chosen as an acceptable period, it is likely that some climatic regions would have a more sensitive impact on hydrologic variables in a 30 year time span than other climatic regions. In such cases, it is possible to have very poor hydrologic trends, and yet possess strong relationships (correlations) with the temperature series for that time interval. The winter representation in Figure 10 illustrated this phenomenon on the Missinaibi River which had an insignificant increasing trend (28.1% significance) with a strong positive correlation of 0.76.

There is one last concern with identifying proper trends and correlations with temperature. This concern deals with the non-uniformity of each temperature series associated with a particular climatic region. The non-uniformity essentially refers to the various segments of time extracted from the corresponding temperature series based on the record length of the hydrologic variable of interest. It was previously documented that over the past century each of the three climatic regions had statistically significant increasing trends, even though rising and falling temperature patterns existed between the beginning of the 1900's and the present time. However, when these segments of time were extracted from the temperature time series, and new trend tests were applied, it was possible to have less significant (or insignificant) increasing temperature trends. This possibility arose from the segments of time which would predominantly have a large drop in temperature before or after a slight increase in temperature. Fortunately by segmenting out the specified period of time associated with the hydrologic series, it improved the accuracy of comparing the fluctuations between temperature and the hydrologic variability. In general, each variable showed significant results leading to the conclusion that climatic change does have an effect on hydrologic events. The natural variability of these events clearly show influential tendencies from changing climatic conditions.

CHAPTER 7

7.0 CONCLUSIONS

This study of the effects of climate change on hydrologic variables provides further evidence that changes in the magnitude and timing of hydrologic events from increasing temperatures is a reality. Based on the Mann-Kendall trend and Kendall correlation tests, the predicted behavior was shown to exist for all seven hydrologic variables analysed, given the conditions of increasing temperatures over the past century. The Julian day evaluation was influenced the greatest amount by climate change with 80.5% of the rivers having the anticipated behavior of decreasing trends and negative correlations with temperature over time. The second most influenced variable was the cumulative annual mean monthly negative deviations. Due to the nature of this variable the expected behavior resulted in increasing negative deviation trends and positive correlations with temperature. The next set of variables influenced by climate change were the mean annual, seasonal and monthly evaluations. All three hydrologic variables would have decreasing flow trends and negative correlations with temperature with the exception of the months of March and April when snow melting was the dominant component resulting in increasing flow trends with positive correlations with temperature. It was evident that different trend and correlation results occurred between the seasons, months, or particular periods in a year where snow melting, snow accumulation, and evaporation and precipitation potential were the dominating component. The evaluation of the maximum summer precipitation event had the least conclusive results. Due to the complexity of properly determining the effects of climatic change on this variable, it is necessary to develop a better understanding of the physical and natural factors influencing the responses concerning the direction of a possible peak precipitation trend and correlation with temperature. However, from the results, there was a better than average chance that decreasing trends would occur with negative correlations.

The evaluation of the spatial distribution using the Mann-Kendall trend test results indicated common patterns for both statistically significant trends and insignificant trends. Both the expected and unexpected trends for each hydrologic variable clustered around similar locations within the Churchill-Nelson River Basin. The expected trends were primarily found in the southern parts of Alberta in the Prairie region, the mid-latitudes of Saskatchewan along the Prairie/Northwestern Forest Region boundary, and along the Manitoba/Ontario border spanning all three climatic regions. The unexpected significant trends were primarily located in the mid-latitudes of Alberta near the Prairie/Northwestern Forest Region boundaries, and in the southwest portion of Ontario in the Northeastern Forest Region. The insignificant trends were generally scattered throughout the region of study, with the exception of a small tendency for more insignificant trends to occur on the west side of Lake Winnipeg.

The regionalization techniques illustrating the distribution of the four possible trend and correlation combinations, from expected to unexpected behaviors, showed similar spatial patterns for the combined variable analysis, and the individual variable analysis. These patterns also directly corresponded with the latter statistically significant and insignificant trend distributions. The expected behavioral patterns for each variable were primarily found in the southern regions of Alberta, the mid-latitudes of Saskatchewan and Manitoba, and with the greatest concentration in the southern parts of Manitoba primarily on the east side of Lake Winnipeg. Expected correlations with unexpected trends were mainly throughout all of Alberta and Manitoba, with larger amounts on the west side of Lake Winnipeg. The chance of unexpected correlations with expected trends to occur was very remote, however on the odd occasion it was found to appear in the southern parts of

Alberta, and Ontario. Results with completely opposite trends and correlations were generally found in the mid-sections of Alberta and southern parts of Ontario.

Changing climatic conditions is not something new to our environment. However the rate of climate change is a topic of growing concern in the past half century. Based on the various studies involved with the existence of a rapidly changing climate, whether it is caused by human induced factors or naturally occurring effects, it is important to not lose sight of the fact that our environment is changing. It would be a mistake to ignore these changes until confirmative evidence is available to prove that increasing temperatures and climate change are taking place. Based on the results presented in this thesis, it is clear that temperature changes, which the environment has experienced over the last 100 years, have affected the magnitude and timing of hydrologic events within the Churchill-Nelson River Basin. It is therefore essential to be prepared and aware of the consequences of climatic change affecting the earth's water resources, and the impacts that these changes will have on the planning and management strategies for present and future water resources systems.

CHAPTER 8

8.0 FUTURE WORK

There are several options available to expand on the study of climatic change and how it affects the hydrologic regime. A few limitations and assumptions made throughout the study may have had consequences on the results obtained. For example, by accepting only natural rivers without the influence of regulation, the quantity of available data decreases substantially. One possible way around this problem could be to develop and apply deregulation techniques to the regulated rivers. This way the number of rivers available for evaluation would increase and be more consistently distributed throughout the region of study.

Other drawbacks include the number of years of recorded streamflow data available for analysis. Where it was necessary, simple linear interpolation techniques were used to fill in some data, but a large number of rivers were discarded due to the absence of data. One might consider the use of proxy data, such as tree ring-growth rates or ice core data. In this case, long tree-ring growth records may be used to reconstruct the past history of streamflow. Not only will this lead to a more consistent data set, but it will also allow a more accurate evaluation of possible trends in streamflow over the past couple of centuries. This may lead to a better understanding of the causative factors of possible trends resulting from climatic change.

There are also many other possible types of hydrologic/hydrometeorologic variables that may be of interest to evaluate the effects of climatic change on the hydrologic regime. Some of these variables or study areas may include, permafrost shifting, glacier melting, ice freeze-up and break-up dates on lakes and rivers, and moving average analysis on minimum and maximum annual flows. Another suggestion based on the mean monthly results in section 5.1.4, one might consider an alternate seasonal evaluation based on the divisions originating from the discussion of Figure 12. It appeared that the original seasonal divisions used were different from those found by analysing the number of rivers in the statistically significant increasing and decreasing flow trends.

One last suggestion is with regards to the regionalization approach used in this thesis. The approach was developed with the intention to clearly describe the spatial distributions of the various combinations of trend and correlation results. However, there are numerous ways to approach this problem. One might consider using a standard regionalization method such as cluster analysis, or develop an entirely different means of evaluating spatial patterns. Regardless of the technique used, one would expect similar patterns from the collected results of each hydrologic variable.

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APPENDIX A:

Summary Characteristics of Each River Analysed

NAME OF RIVER	STATION NUMBER	YEARS OF RECORD	BASIN AREA	CLIMATIC REGION	PROVINCE
PIGEON RIVER	2aa001	71	1550	NORTHEASTERN FOREST	ONTARIO
NEEBING RIVER	2ab008	39	187	NORTHEASTERN FOREST	ONTARIO
MAGPIE RIVER	2bd003	52	1930	NORTHEASTERN FOREST	ONTARIO
WHITSON RIVER	2cf007	32	243	NORTHEASTERN FOREST	ONTARIO
HAYES RIVER	4aa001	37	9190	NORTHWESTERN FOREST	MANITOBA
GODS RIVER	4ac005	46	25900	NORTHEASTERN FOREST	MANITOBA
ISLAND LAKE RIVER	4ac007	59	14000	NORTHEASTERN FOREST	MANITOBA
NAGAGAMI RIVER	4jc002	42	2410	NORTHEASTERN FOREST	ONTARIO
MISSINAIBI RIVER	4lj001	72	8940	NORTHEASTERN FOREST	ONTARIO
CROWSNEST RIVER	5aa008	43	404	PRAIRIES	ALBERTA
CASTLE RIVER	5aa022	47	823	PRAIRIES	ALBERTA
OLDMAN RIVER	5aa023	43	1440	PRAIRIES	ALBERTA
WATERTON RIVER	5ad003	44	614	PRAIRIES	ALBERTA
ROLPH CREEK	5ae005	56	221	PRAIRIES	ALBERTA
MANYBERRIES CREEK	5af010	77	339	PRAIRIES	ALBERTA
BOW RIVER	5bb001	83	2210	NORTHWESTERN FOREST	ALBERTA
GHOST RIVER	5bg002	51	211	NORTHWESTERN FOREST	ALBERTA
ELBOW RIVER	5bj004	58	791	PRAIRIES	ALBERTA
FISH CREEK	5bk001	36	259	PRAIRIES	ALBERTA
LITTLE RED DEER RIVER	5cb001	32	2560	NORTHWESTERN FOREST	ALBERTA
BLINDMAN RIVER	5cc001	30	1790	NORTHWESTERN FOREST	ALBERTA
RED DEER RIVER	5ce001	33	24800	PRAIRIES	ALBERTA
KNEEHILLS CREEK	5ce002	35	2430	PRAIRIES	ALBERTA
MISTAYA RIVER	5da007	42	249	NORTHWESTERN FOREST	ALBERTA
PRAIRIE CREEK	5db002	41	859	NORTHWESTERN FOREST	ALBERTA
STURGEON RIVER	5ea001	72	3350	NORTHWESTERN FOREST	ALBERTA
CRYSTAL CREEK	5eg004	32	500	PRAIRIES	SASK.
SWIFT CURRENT CREEK	5hd036	37	1430	PRAIRIES	SASK.
INDIANHEAD CREEK	5jl002	51	327	PRAIRIES	SASK.
CARROT RIVER	5kb003	37	4400	NORTHWESTERN FOREST	SASK.
STURGEON-WEIR RIVER	5kg002	33	14600	NORTHWESTERN FOREST	SASK.
ETOMAMI RIVER	5lb002	37	2050	NORTHWESTERN FOREST	SASK.
LOISELLE CREEK	5lb004	36	181	NORTHWESTERN FOREST	SASK.
RED DEER RIVER	5lc001	38	11000	NORTHWESTERN FOREST	SASK.
RED DEER RIVER	5lc004	36	14500	NORTHWESTERN FOREST	MANITOBA
OVERFLOWING RIVER	5ld001	38	3350	NORTHWESTERN FOREST	MANITOBA
WOODY RIVER	5le004	38	2110	NORTHWESTERN FOREST	MANITOBA
ROARING RIVER	5le005	33	838	NORTHWESTERN FOREST	MANITOBA
SWAN RIVER	5le006	32	4230	NORTHWESTERN FOREST	MANITOBA
NORTH PINE RIVER	5lg001	38	210	NORTHWESTERN FOREST	MANITOBA
WATERHEN RIVER	5lh005	42	55000	NORTHWESTERN FOREST	MANITOBA
OCHRE RIVER	5lj005	44	342	PRAIRIES	MANITOBA
TURTLE RIVER	5lj007	45	938	PRAIRIES	MANITOBA
WILSON RIVER	5lj011	34	925	PRAIRIES	MANITOBA
FISHING RIVER	5lj015	35	263	PRAIRIES	MANITOBA
MINK CREEK	5lj019	38	131	PRAIRIES	MANITOBA
MCKINNON CREEK	5lj027	33	78	PRAIRIES	MANITOBA
PINE CREEK	5ll007	33	635	PRAIRIES	MANITOBA
STONY CREEK	5ll009	33	163	PRAIRIES	MANITOBA
BOGGY CREEK	5ll013	31	515	PRAIRIES	MANITOBA
ASSINIBOINE RIVER	5mc001	47	1930	PRAIRIES	SASK.
SHELL RIVER	5md005	44	2000	PRAIRIES	MANITOBA
BIRDTAIL CREEK	5me003	39	1120	PRAIRIES	MANITOBA
CONJURING CREEK	5me005	33	88	PRAIRIES	MANITOBA
LITTLE SASK. RIVER	5mf001	33	2630	PRAIRIES	MANITOBA
ROLLING RIVER	5mf008	31	760	PRAIRIES	MANITOBA
ARROW RIVER	5mg001	33	670	PRAIRIES	MANITOBA
GOPHER CREEK	5mg003	33	298	PRAIRIES	MANITOBA
LITTLE SOURIS RIVER	5mh006	31	461	PRAIRIES	MANITOBA
ANTLER RIVER	5nf002	49	3210	PRAIRIES	MANITOBA
GRAHAM CREEK	5nf008	49	730	PRAIRIES	MANITOBA
OAK CREEK	5ng010	31	1030	PRAIRIES	MANITOBA

BADGER CREEK	5oa007	33	1530	PRAIRIES	MANITOBA
PEMBINA RIVER	5oa008	33	335	PRAIRIES	MANITOBA
CRYSTAL CREEK	5ob006	32	135	PRAIRIES	MANITOBA
CYPRESS CREEK	5ob010	33	398	PRAIRIES	MANITOBA
ROSEAU RIVER	5od001	78	5260	PRAIRIES	MANITOBA
ROSEAU RIVER	5od004	30	4390	PRAIRIES	MANITOBA
DRAIN NEAR DOMINION	5od028	32	240	PRAIRIES	MANITOBA
ROSEAU RIVER	5od030	72	4150	PRAIRIES	MANITOBA
SPRAGUE CREEK	5od031	54	455	PRAIRIES	MANITOBA
RAT RIVER	5oe004	32	398	PRAIRIES	MANITOBA
MANNING CANAL	5oe006	31	496	PRAIRIES	MANITOBA
SHANNON CREEK	5of014	32	649	PRAIRIES	MANITOBA
NORTH SHANNON CREEK	5of015	32	165	PRAIRIES	MANITOBA
COOKS CREEK	5oj006	32	999	PRAIRIES	MANITOBA
NETLEY CREEK	5oj008	32	645	PRAIRIES	MANITOBA
NETLEY CREEK	5oj009	32	999	PRAIRIES	MANITOBA
NAMAKAN RIVER	5pa006	71	13400	NORTHEASTERN FOREST	ONTARIO
TURTLE RIVER	5pb014	78	4870	NORTHEASTERN FOREST	ONTARIO
STURGEON RIVER	5pc010	35	168	NORTHEASTERN FOREST	ONTARIO
PINEWOOD RIVER	5pc011	40	461	NORTHEASTERN FOREST	ONTARIO
WHITEMOUTH RIVER	5ph003	50	3750	PRAIRIES	MANITOBA
BIRD RIVER	5pj001	32	1040	NORTHWESTERN FOREST	MANITOBA
ENGLISH RIVER	5qa001	61	13900	NORTHEASTERN FOREST	ONTARIO
ENGLISH RIVER	5qa002	71	6230	NORTHEASTERN FOREST	ONTARIO
STURGEON RIVER	5qa004	31	4450	NORTHEASTERN FOREST	ONTARIO
STURGEON RIVER	5qe009	32	1530	NORTHEASTERN FOREST	ONTARIO
MANIGOTAGAN RIVER	5ra001	32	1830	NORTHWESTERN FOREST	MANITOBA
BLACK RIVER	5ra002	32	712	NORTHWESTERN FOREST	MANITOBA
BERENS RIVER	5rd007	35	1001	NORTHWESTERN FOREST	MANITOBA
PIGEON RIVER	5rd008	35	1001	NORTHWESTERN FOREST	MANITOBA
BROKENHEAD RIVER	5sa002	50	1610	PRAIRIES	MANITOBA
BROKENHEAD RIVER	5sa004	32	857	PRAIRIES	MANITOBA
WILLOW CREEK	5sb002	31	253	NORTHWESTERN FOREST	MANITOBA
ICELANDIC RIVER	5sc002	34	1270	NORTHWESTERN FOREST	MANITOBA
FISHER RIVER	5sd003	31	1720	NORTHWESTERN FOREST	MANITOBA
EAST FISHER RIVER	5sd004	31	390	NORTHWESTERN FOREST	MANITOBA
GRASS RIVER	5tb002	35	3250	NORTHWESTERN FOREST	MANITOBA
GRASS RIVER	5td001	33	15400	NORTHWESTERN FOREST	MANITOBA
KETTLE RIVER	5uf004	33	1090	NORTHWESTERN FOREST	MANITOBA
BEAVER RIVER	6ad001	32	20500	NORTHWESTERN FOREST	SASK.
BEAVER RIVER	6ad006	37	14500	NORTHWESTERN FOREST	ALBERTA
SEAL RIVER	6gd001	37	48100	NORTHWESTERN FOREST	ALBERTA
MCLEOD RIVER	7af002	38	2560	NORTHWESTERN FOREST	ALBERTA
WOLF CREEK	7ag003	38	829	NORTHWESTERN FOREST	ALBERTA
PEMBINA RIVER	7bb002	38	4420	NORTHWESTERN FOREST	ALBERTA
EAST PRAIRIE RIVER	7bf001	33	1460	NORTHWESTERN FOREST	ALBERTA
CLEARWATER RIVER	7cd001	36	30800	NORTHWESTERN FOREST	ALBERTA
ATHABASCA RIVER	7da001	35	133000	NORTHWESTERN FOREST	ALBERTA
WAPITI RIVER	7ge001	32	11300	NORTHWESTERN FOREST	ALBERTA
SMOKY RIVER	7gj001	37	50300	NORTHWESTERN FOREST	ALBERTA
NOTIKEWIN RIVER	7hc001	31	4680	NORTHWESTERN FOREST	ALBERTA
SAGE CREEK	11aa26	57	456	PRAIRIES	ALBERTA
LODGE CREEK	11ab82	41	908	PRAIRIES	SASK.
POPLAR RIVER	11ae08	61	928	PRAIRIES	SASK.
ROCK CREEK	11ae09	36	837	PRAIRIES	SASK.

Location of Gauging Stations in Proviences and Climatic Regions

ALBERTA	ALBERTA	SASKATCHEWAN	SASKATCHEWAN
Northwestern Forest	Prairies	Northwestern Forest	Prairies
5bb001	5aa008	5kb003	5eg004
5bg002	5aa022	5kg002	5hd036
5cb001	5aa023	5lb002	5jl002
5cc001	5ad003	5lb004	5mc001
5da007	5ae005	5lc001	11ab82
5db002	5af010	6ad001	11ae08
5ea001	5bj004		11ae09
6ad006	5bk001		
7af002	5ce001		
7ag003	5ce002		
7bb002	11aa26		
7bf001			
7cd001			
7da001			
7ge001			
7gj001			
7hc001			

MANITOBA	MANITOBA	MANITOBA	ONTARIO
Northwestern Forest	Northeastern Forest	Prairies	Northeastern Forest
4aa001	4ac005	5lj005	2aa001
5lc004	4ac007	5lj007	2ab008
5ld001		5lj011	2bd003
5le004		5lj015	2cf007
5le005		5lj019	4jc002
5le006		5lj027	4lj001
5lg001		5ll007	5pa006
5lh005		5ll009	5pb014
5pj001		5ll013	5pc010
5ra001		5md005	5pc011
5ra002		5me003	5qa001
5rd007		5me005	5qa002
5rd008		5mf001	5qa004
5sb002		5mf008	5qe009
5sc002		5mg001	
5sd003		5mg003	
5sd004		5mh006	
5tb002		5nf002	
5td001		5nf008	
5uf004		5ng010	
6gd001		5oa007	
		5oa008	
		5ob006	
		5ob010	
		5od001	
		5od004	
		5od028	
		5od030	
		5od031	
		5oe004	
		5oe006	
		5of014	
		5of015	
		5oj006	
		5oj008	
		5oj009	
		5ph003	
		5sa002	
		5sa004	

APPENDIX B: Summary Results

B-1: Mean Annual Flow
B-2: CND
B-3: Extreme Annual Flow
B-4: Maximum Summer Precipitation Event
B-5: Julian Day of Spring Melt

SUMMARY OF RESULTS FOR MEAN ANNUAL FLOW: March - October

STAT. #	YRS.	SERIES	TREND	SL (%)	SLOPE	CORREL.	PROB.(%)
2aa001	68	Flow	increasing	46.00	0.002	0.047	56.75338
		Temp	increasing	9.82	0.006		
2ab008	38	Flow	increasing	27.31	0.005	-0.764	0.00000
		Temp	increasing	47.50	0.000		
2cf007	31	Flow	increasing	16.21	0.009	0.140	26.92606
		Temp	increasing	25.36	0.008		
4ac005	44	Flow	decreasing	2.43	-1.299	0.636	0.00000
		Temp	decreasing	12.24	-0.010		
4ac007	54	Flow	decreasing	32.19	-0.149	0.092	32.45665
		Temp	increasing	11.92	0.007		
4jc002	41	Flow	decreasing	16.42	-0.074	-0.254	1.94786
		Temp	decreasing	21.59	-0.007		
41j001	71	Flow	increasing	44.87	0.016	0.293	0.02963
		Temp	increasing	10.19	0.005		
5aa008	41	Flow	decreasing	1.13	-0.058	-0.507	0.00030
		Temp	increasing	3.44	0.027		
5aa022	46	Flow	decreasing	2.56	-0.146	-0.517	0.00004
		Temp	increasing	2.28	0.024		
5aa023	42	Flow	decreasing	2.19	-0.175	-0.761	0.00000
		Temp	increasing	1.43	0.033		
5ad003	43	Flow	decreasing	2.71	-0.133	-0.779	0.00000
		Temp	increasing	1.36	0.030		
5ae005	56	Flow	decreasing	38.87	-0.001	-0.650	0.00000
		Temp	increasing	19.62	0.007		
5af010	35	Flow	decreasing	5.75	-0.005	-0.414	0.04714
		Temp	increasing	5.58	0.025		
5bb001	81	Flow	decreasing	7.05	-0.060	-0.948	0.00000
		Temp	increasing	0.51	0.011		
5bj004	40	Flow	decreasing	0.72	-0.090	-0.264	1.63900
		Temp	increasing	7.76	0.021		
5bk001	36	Flow	decreasing	1.99	-0.014	-0.898	0.00000
		Temp	increasing	4.06	0.028		
5cb001	31	Flow	decreasing	14.60	-0.063	-0.402	0.14813
		Temp	increasing	0.86	0.042		
5ce001	32	Flow	decreasing	33.08	-0.100	-0.520	0.00287
		Temp	increasing	2.40	0.036		
5ce002	32	Flow	decreasing	5.79	-0.014	-0.500	0.00578
		Temp	increasing	2.78	0.037		
5db002	40	Flow	decreasing	11.96	-0.033	-0.210	5.60342
		Temp	increasing	10.37	0.016		

5ea001	57	Flow	increasing	1.18	0.044	0.112	22.04528
		Temp	increasing	21.03	0.005		
5hd036	37	Flow	decreasing	3.35	-0.020	-0.667	0.00000
		Temp	increasing	1.65	0.033		
5jl002	51	Flow	increasing	48.70	0.000	-0.515	0.00001
		Temp	increasing	12.10	0.013		
5kb003	37	Flow	decreasing	9.32	-0.073	-0.498	0.00141
		Temp	increasing	1.22	0.031		
5kg002	31	Flow	decreasing	15.39	-0.442	-0.449	0.03820
		Temp	increasing	0.86	0.042		
5lb002	37	Flow	decreasing	8.48	-0.076	-0.607	0.00001
		Temp	increasing	1.22	0.031		
5lc001	34	Flow	decreasing	14.97	-0.192	-0.629	0.00002
		Temp	increasing	3.18	0.027		
5lc004	34	Flow	decreasing	37.22	-0.108	-0.480	0.00667
		Temp	increasing	2.60	0.027		
5ld001	36	Flow	decreasing	15.35	-0.111	-0.603	0.00002
		Temp	increasing	2.65	0.025		
5le004	35	Flow	increasing	1.24	0.152	0.188	11.14075
		Temp	increasing	3.90	0.025		
5le005	30	Flow	increasing	10.58	0.047	0.021	87.24326
		Temp	increasing	1.91	0.041		
5le006	31	Flow	increasing	17.94	0.120	-0.105	40.49438
		Temp	increasing	0.86	0.042		
5lg001	35	Flow	increasing	3.25	0.018	0.000	100.0000
		Temp	increasing	3.90	0.025		
5lh005	38	Flow	decreasing	23.30	-0.522	-0.101	37.20687
		Temp	increasing	3.40	0.025		
5lj005	36	Flow	decreasing	34.64	-0.009	-0.657	0.00000
		Temp	increasing	4.06	0.028		
5lj007	35	Flow	increasing	35.60	0.009	-0.644	0.00001
		Temp	increasing	5.58	0.025		
5lj011	33	Flow	decreasing	18.03	-0.026	-0.708	0.00000
		Temp	increasing	19.71	0.020		
5lj015	35	Flow	decreasing	13.40	-0.005	-0.496	0.00280
		Temp	increasing	37.20	0.007		
5lj019	36	Flow	increasing	15.35	0.003	0.399	0.06226
		Temp	increasing	4.06	0.028		
5lj027	33	Flow	increasing	47.53	0.000	-0.602	0.00008
		Temp	increasing	2.20	0.035		
5ll013	31	Flow	decreasing	3.58	-0.007	-0.755	0.00000
		Temp	increasing	1.83	0.042		
5mc001	34	Flow	increasing	50.00	-0.001	-0.668	0.00000
		Temp	increasing	4.27	0.029		

5md005	36	Flow Temp	increasing increasing	6.53 4.06	0.035 0.028	0.105	36.86639
5me003	38	Flow Temp	decreasing increasing	27.31 2.02	-0.014 0.030	-0.440	0.01024
5me005	33	Flow Temp	increasing increasing	15.67 2.20	0.001 0.035	-0.059	63.06713
5mf001	33	Flow Temp	decreasing increasing	45.68 2.20	-0.009 0.035	-0.636	0.00002
5mf008	31	Flow Temp	decreasing increasing	25.92 1.83	-0.017 0.042	-0.720	0.00000
5mg001	33	Flow Temp	increasing increasing	45.07 2.20	0.001 0.035	-0.596	0.00011
5mg003	33	Flow Temp	decreasing increasing	4.41 2.20	-0.004 0.035	-0.898	0.00000
5mh006	31	Flow Temp	decreasing increasing	21.71 1.83	-0.004 0.042	-0.686	0.00001
5nf002	49	Flow Temp	decreasing increasing	1.63 4.39	-0.012 0.020	-0.340	0.05649
5nf008	49	Flow Temp	decreasing increasing	1.81 4.39	-0.001 0.020	-0.550	0.00000
5ng010	31	Flow Temp	decreasing increasing	2.96 1.83	-0.015 0.042	-0.835	0.00000
5oa007	33	Flow Temp	decreasing increasing	30.45 2.20	-0.006 0.035	-0.674	0.00000
5oa008	33	Flow Temp	decreasing increasing	6.06 2.20	-0.009 0.035	-0.807	0.00000
5ob006	32	Flow Temp	decreasing increasing	19.96 0.93	-0.002 0.040	-0.806	0.00000
5ob010	33	Flow Temp	decreasing increasing	21.02 2.20	-0.004 0.035	-0.809	0.00000
5od001	44	Flow Temp	decreasing increasing	15.84 1.86	-0.075 0.029	-0.463	0.00094
5od004	30	Flow Temp	decreasing increasing	0.62 0.66	-0.476 0.050	-0.526	0.00440
5od028	32	Flow Temp	decreasing increasing	1.11 2.40	-0.013 0.036	-0.634	0.00003
5od031	42	Flow Temp	decreasing decreasing	5.09 20.20	-0.028 -0.011	-0.029	78.64414
5oe004	32	Flow Temp	decreasing increasing	0.71 2.40	-0.043 0.036	-0.448	0.03182
5oe006	30	Flow Temp	decreasing increasing	1.02 1.29	-0.021 0.050	-0.862	0.00000
5of014	31	Flow Temp	decreasing increasing	5.90 2.16	-0.022 0.040	-0.518	0.00420

5of015	32	Flow Temp	decreasing increasing	5.07 2.40	-0.005 0.036	-0.661	0.00001
5oj006	31	Flow Temp	decreasing increasing	0.44 4.62	-0.033 0.031	-0.768	0.00000
5oj008	32	Flow Temp	decreasing increasing	10.59 2.40	-0.015 0.036	-0.702	0.00000
5pa006	69	Flow Temp	increasing increasing	1.18 6.20	0.520 0.006	0.223	0.68571
5pb014	71	Flow Temp	increasing increasing	2.70 4.77	0.169 0.008	0.294	0.02852
5pc010	35	Flow Temp	increasing decreasing	18.17 11.09	0.011 -0.017	-0.331	0.51471
5pc011	33	Flow Temp	decreasing increasing	4.87 31.55	-0.059 0.005	-0.485	0.00729
5ph003	41	Flow Temp	decreasing increasing	9.82 5.79	-0.179 0.023	-0.510	0.00027
5qa001	60	Flow Temp	increasing increasing	44.17 6.94	0.088 0.009	0.524	0.00000
5qa002	70	Flow Temp	increasing increasing	11.77 5.86	0.135 0.006	0.437	0.00001
5qa004	30	Flow Temp	decreasing increasing	3.72 14.63	-0.597 0.014	-0.315	1.45165
5ra001	32	Flow Temp	decreasing increasing	0.09 1.61	-0.271 0.038	-0.710	0.00000
5ra002	31	Flow Temp	decreasing increasing	0.03 1.35	-0.143 0.041	-0.656	0.00002
5rd007	33	Flow Temp	decreasing increasing	39.61 6.83	-0.082 0.024	-0.659	0.00001
5rd008	32	Flow Temp	decreasing increasing	19.50 5.78	-0.694 0.026	-0.758	0.00000
5sa002	35	Flow Temp	decreasing increasing	0.08 3.56	-0.148 0.029	-0.644	0.00001
5sa004	31	Flow Temp	decreasing increasing	0.03 1.83	-0.065 0.042	-0.600	0.00021
5sc002	33	Flow Temp	decreasing increasing	4.87 1.68	-0.032 0.036	-0.231	5.87154
5sd003	30	Flow Temp	decreasing increasing	24.89 0.45	-0.020 0.050	-0.218	9.00948
5tb002	34	Flow Temp	decreasing increasing	11.20 4.00	-0.128 0.025	-0.740	0.00000
5uf004	33	Flow Temp	increasing increasing	21.47 0.21	0.077 0.045	0.034	78.03220
6ad006	36	Flow Temp	decreasing increasing	0.02 2.65	-0.849 0.025	-0.562	0.00014

6gd001	34	Flow	increasing	39.48	0.234	-0.230	5.58309
		Temp	increasing	3.19	0.029		
7af002	37	Flow	increasing	38.18	0.051	-0.069	54.74215
		Temp	increasing	1.22	0.031		
7ag003	37	Flow	increasing	5.38	0.076	0.222	5.29076
		Temp	increasing	1.22	0.031		
7bb002	37	Flow	increasing	5.11	0.340	0.354	0.20245
		Temp	increasing	1.22	0.031		
7bf001	33	Flow	increasing	12.26	0.110	-0.057	64.20513
		Temp	increasing	1.68	0.036		
7cd001	34	Flow	decreasing	1.41	-1.129	-0.494	0.00402
		Temp	increasing	4.00	0.025		
7da001	34	Flow	decreasing	45.28	-0.605	-0.152	20.76414
		Temp	increasing	4.00	0.025		
7ge001	31	Flow	decreasing	20.73	-0.894	-0.591	0.00030
		Temp	increasing	0.86	0.042		
7gj001	36	Flow	decreasing	36.67	-0.715	-0.638	0.00000
		Temp	increasing	2.65	0.025		
11aa26	57	Flow	decreasing	6.32	-0.003	-0.253	0.54179
		Temp	increasing	14.45	0.009		
11ab82	41	Flow	decreasing	1.89	-0.016	-0.507	0.00030
		Temp	increasing	3.44	0.027		
11ae08	60	Flow	decreasing	26.18	-0.002	-0.891	0.00000
		Temp	increasing	34.63	0.003		
11ae09	35	Flow	decreasing	30.98	-0.005	-0.728	0.00000
		Temp	increasing	5.58	0.025		

SUMMARY OF RESULTS FOR MEAN ANNUAL FLOW : May - August

STAT. #	YRS.	SERIES	TREND	SL (%)	SLOPE	CORREL.	PROB.(%)
2aa001	70	Flow Temp	increasing increasing	45.56 5.86	0.004 0.006	0.041	61.21051
2ab008	38	Flow Temp	increasing increasing	39.10 47.50	0.004 0.000	-0.715	0.00000
2bd003	45	Flow Temp	decreasing decreasing	10.00 20.83	-0.187 -0.006	-0.129	21.05200
2cf007	31	Flow Temp	increasing increasing	44.59 25.36	0.005 0.008	0.088	48.58948
4aa001	31	Flow Temp	increasing increasing	48.64 5.89	0.005 0.030	-0.419	0.09187
4ac005	44	Flow Temp	decreasing decreasing	5.18 12.24	-1.176 -0.010	0.679	0.00000
4ac007	54	Flow Temp	decreasing increasing	22.33 11.92	-0.270 0.007	0.006	95.23911
4jc002	41	Flow Temp	decreasing decreasing	2.60 21.59	-0.249 -0.007	-0.039	71.92795
4lj001	72	Flow Temp	decreasing increasing	21.69 12.56	-0.261 0.004	0.076	34.80368
5aa008	42	Flow Temp	decreasing increasing	0.34 1.43	-0.128 0.033	-0.682	0.00000
5aa022	47	Flow Temp	decreasing increasing	1.32 1.20	-0.284 0.027	-0.597	0.00000
5aa023	42	Flow Temp	decreasing increasing	2.43 1.43	-0.313 0.033	-0.803	0.00000
5ad003	44	Flow Temp	decreasing increasing	0.62 1.20	-0.319 0.030	-0.829	0.00000
5ae005	56	Flow Temp	increasing increasing	48.03 19.62	0.000 0.007	-0.701	0.00000
5af010	35	Flow Temp	increasing increasing	42.12 5.58	0.000 0.025	0.151	20.08252
5bb001	82	Flow Temp	decreasing increasing	6.41 0.59	-0.098 0.011	-0.921	0.00000
5bg002	49	Flow Temp	decreasing increasing	10.41 12.72	-0.022 0.009	-0.469	0.00020
5bj004	43	Flow Temp	decreasing increasing	2.22 1.36	-0.148 0.030	-0.697	0.00000
5bk001	36	Flow Temp	decreasing increasing	2.34 4.06	-0.019 0.028	-0.736	0.00000
5cb001	31	Flow Temp	decreasing increasing	13.84 0.86	-0.078 0.042	-0.488	0.01142

5cc001	30	Flow	increasing	5.42	0.058	0.784	0.00000
		Temp	increasing	0.45	0.050		
5ce001	33	Flow	decreasing	20.58	-0.415	-0.568	0.00033
		Temp	increasing	2.20	0.035		
5ce002	34	Flow	decreasing	5.80	-0.005	-0.501	0.00310
		Temp	increasing	6.91	0.027		
5da007	31	Flow	decreasing	29.33	-0.017	-0.127	31.59630
		Temp	increasing	0.90	0.042		
5db002	40	Flow	decreasing	8.28	-0.084	-0.318	0.38591
		Temp	increasing	10.37	0.016		
5ea001	69	Flow	increasing	38.19	0.005	-0.222	0.70738
		Temp	increasing	4.23	0.009		
5hd036	37	Flow	decreasing	34.26	-0.002	-0.670	0.00000
		Temp	increasing	1.65	0.033		
5jl002	51	Flow	decreasing	41.32	0.000	-0.453	0.00027
		Temp	increasing	12.10	0.013		
5kb003	37	Flow	decreasing	10.00	-0.041	-0.462	0.00562
		Temp	increasing	1.22	0.031		
5kg002	32	Flow	decreasing	10.59	-0.537	-0.621	0.00006
		Temp	increasing	1.61	0.038		
5lb002	37	Flow	decreasing	8.90	-0.095	-0.619	0.00001
		Temp	increasing	1.22	0.031		
5lc001	38	Flow	decreasing	1.63	-0.679	-0.471	0.00316
		Temp	increasing	1.95	0.026		
5lc004	36	Flow	decreasing	23.52	-0.359	-0.498	0.00189
		Temp	increasing	2.65	0.025		
5ld001	38	Flow	decreasing	7.96	-0.295	-0.516	0.00050
		Temp	increasing	1.95	0.026		
5le004	38	Flow	increasing	46.99	0.012	-0.004	96.99143
		Temp	increasing	1.95	0.026		
5le005	32	Flow	increasing	11.19	0.041	-0.077	53.77458
		Temp	increasing	2.47	0.033		
5le006	31	Flow	increasing	24.83	0.062	-0.265	3.65676
		Temp	increasing	0.86	0.042		
5lg001	38	Flow	increasing	16.03	0.016	0.169	13.46389
		Temp	increasing	1.95	0.026		
5lh005	38	Flow	decreasing	21.06	-0.488	-0.081	47.36217
		Temp	increasing	3.40	0.025		
5lj005	44	Flow	decreasing	6.34	-0.029	-0.719	0.00000
		Temp	increasing	1.20	0.030		
5lj007	43	Flow	decreasing	14.53	-0.029	-0.790	0.00000
		Temp	increasing	1.36	0.030		
5lj011	34	Flow	decreasing	4.85	-0.047	-0.608	0.00004
		Temp	increasing	30.19	0.012		

51j015	35	Flow	decreasing	11.09	-0.003	-0.449	0.01458
		Temp	increasing	37.20	0.007		
51j019	38	Flow	increasing	49.50	0.000	0.209	6.45923
		Temp	increasing	2.02	0.030		
51j027	33	Flow	increasing	45.07	0.001	-0.356	0.35803
		Temp	increasing	2.20	0.035		
51l009	33	Flow	decreasing	34.35	-0.001	-0.474	0.01040
		Temp	increasing	2.20	0.035		
51l013	31	Flow	decreasing	0.06	-0.010	-0.772	0.00000
		Temp	increasing	1.83	0.042		
5mc001	47	Flow	decreasing	13.96	-0.020	-0.475	0.00025
		Temp	increasing	2.65	0.025		
5md005	44	Flow	decreasing	24.27	-0.032	-0.389	0.01976
		Temp	increasing	1.20	0.030		
5me003	38	Flow	decreasing	25.26	-0.016	-0.437	0.01136
		Temp	increasing	2.02	0.030		
5me005	33	Flow	increasing	36.66	0.000	-0.311	1.08993
		Temp	increasing	2.20	0.035		
5mf001	33	Flow	decreasing	46.91	-0.003	-0.534	0.00125
		Temp	increasing	2.20	0.035		
5mf008	31	Flow	decreasing	27.03	-0.025	-0.544	0.00171
		Temp	increasing	1.83	0.042		
5mg001	33	Flow	increasing	45.07	0.000	-0.616	0.00005
		Temp	increasing	2.20	0.035		
5mg003	33	Flow	decreasing	1.81	-0.002	-0.828	0.00000
		Temp	increasing	2.20	0.035		
5mh006	31	Flow	decreasing	11.70	-0.002	-0.626	0.00008
		Temp	increasing	1.83	0.042		
5nf002	49	Flow	decreasing	0.60	-0.009	-0.363	0.02312
		Temp	increasing	4.39	0.020		
5nf008	49	Flow	decreasing	0.31	-0.001	-0.550	0.00000
		Temp	increasing	4.39	0.020		
5ng010	31	Flow	decreasing	0.95	-0.014	-0.806	0.00000
		Temp	increasing	1.83	0.042		
5oa007	33	Flow	decreasing	25.26	-0.004	-0.807	0.00000
		Temp	increasing	2.20	0.035		
5oa008	33	Flow	decreasing	0.44	-0.012	-0.939	0.00000
		Temp	increasing	2.20	0.035		
5ob006	32	Flow	decreasing	17.76	0.000	-0.590	0.00021
		Temp	increasing	0.93	0.040		
5ob010	33	Flow	decreasing	13.91	-0.001	-0.761	0.00000
		Temp	increasing	2.20	0.035		
5od001	77	Flow	increasing	13.11	0.070	-0.412	0.00001
		Temp	increasing	27.04	0.003		

5od004	30	Flow Temp	decreasing increasing	0.51 0.66	-0.645 0.050	-0.637	0.00008
5od028	32	Flow Temp	decreasing increasing	5.18 2.40	-0.004 0.036	-0.427	0.05863
5od030	72	Flow Temp	increasing increasing	23.75 39.64	0.034 0.000	-0.731	0.00000
5od031	53	Flow Temp	increasing decreasing	40.90 13.64	0.003 -0.011	-0.587	0.00000
5oe004	32	Flow Temp	decreasing increasing	2.30 2.40	-0.041 0.036	-0.218	7.98810
5oe006	30	Flow Temp	decreasing increasing	6.70 1.29	-0.014 0.050	-0.628	0.00011
5of014	31	Flow Temp	decreasing increasing	4.30 2.16	-0.010 0.040	-0.377	0.28751
5of015	32	Flow Temp	decreasing increasing	13.16 2.40	-0.001 0.036	-0.516	0.00330
5oj006	31	Flow Temp	decreasing increasing	3.86 4.62	-0.020 0.031	-0.247	5.06318
5oj008	32	Flow Temp	decreasing increasing	20.87 2.40	-0.006 0.036	-0.016	89.67788
5pa006	70	Flow Temp	increasing increasing	2.52 5.86	0.873 0.006	0.244	0.28677
5pb014	73	Flow Temp	increasing increasing	5.12 7.52	0.236 0.006	0.444	0.00000
5pc010	35	Flow Temp	increasing decreasing	31.49 11.09	0.004 -0.017	-0.264	2.57724
5pc011	40	Flow Temp	decreasing decreasing	29.20 23.51	-0.019 -0.008	-0.467	0.00223
5ph003	49	Flow Temp	decreasing increasing	4.81 4.39	-0.214 0.020	-0.413	0.00280
5qa001	60	Flow Temp	increasing increasing	25.56 6.94	0.322 0.009	0.527	0.00000
5qa002	70	Flow Temp	increasing increasing	16.77 5.86	0.199 0.006	0.413	0.00004
5qa004	30	Flow Temp	decreasing increasing	8.76 14.63	-0.715 0.014	-0.324	1.18835
5qe009	30	Flow Temp	decreasing increasing	0.92 27.79	-0.450 0.008	-0.402	0.17952
5ra001	32	Flow Temp	decreasing increasing	0.28 1.61	-0.409 0.038	-0.310	1.25131
5ra002	31	Flow Temp	decreasing increasing	0.59 1.35	-0.191 0.041	-0.600	0.00021
5rd007	34	Flow Temp	decreasing increasing	36.10 4.00	-0.185 0.025	-0.579	0.00015

5rd008	33	Flow	decreasing	22.38	-0.846	-0.754	0.00000
		Temp	increasing	3.36	0.028		
5sa002	49	Flow	decreasing	2.96	-0.060	-0.427	0.00151
		Temp	increasing	4.39	0.020		
5sa004	32	Flow	decreasing	0.49	-0.071	-0.363	0.35120
		Temp	increasing	2.40	0.036		
5sc002	33	Flow	decreasing	3.26	-0.025	-0.250	4.08290
		Temp	increasing	1.68	0.036		
5sd003	31	Flow	decreasing	27.03	-0.012	-0.308	1.50785
		Temp	increasing	0.86	0.042		
5tb002	34	Flow	decreasing	11.78	-0.156	-0.818	0.00000
		Temp	increasing	4.00	0.025		
5uf004	33	Flow	increasing	26.26	0.090	0.155	20.38917
		Temp	increasing	0.21	0.045		
6ad001	31	Flow	decreasing	0.33	-1.607	-0.647	0.00003
		Temp	increasing	0.86	0.042		
6ad006	36	Flow	decreasing	0.08	-1.005	-0.635	0.00001
		Temp	increasing	2.65	0.025		
6gd001	34	Flow	decreasing	44.11	-0.442	0.230	5.58309
		Temp	increasing	3.19	0.029		
7af002	37	Flow	increasing	33.30	0.126	-0.207	7.10926
		Temp	increasing	1.22	0.031		
7ag003	37	Flow	increasing	8.09	0.086	0.318	0.55590
		Temp	increasing	1.22	0.031		
7bb002	37	Flow	increasing	6.63	0.514	0.360	0.16957
		Temp	increasing	1.22	0.031		
7bf001	33	Flow	increasing	14.25	0.181	0.114	35.25447
		Temp	increasing	1.68	0.036		
7cd001	34	Flow	decreasing	11.78	-1.047	-0.451	0.01764
		Temp	increasing	4.00	0.025		
7da001	34	Flow	increasing	42.94	0.520	-0.155	19.71456
		Temp	increasing	4.00	0.025		
7ge001	31	Flow	decreasing	24.83	-1.061	-0.505	0.00649
		Temp	increasing	0.86	0.042		
7gj001	37	Flow	decreasing	32.36	-1.423	-0.532	0.00037
		Temp	increasing	1.22	0.031		
7hc001	30	Flow	decreasing	32.14	-0.167	-0.159	21.83113
		Temp	increasing	1.16	0.043		
11aa26	57	Flow	decreasing	42.63	0.000	0.136	13.58062
		Temp	increasing	14.45	0.009		
11ab82	41	Flow	decreasing	3.52	-0.006	0.153	16.00662
		Temp	increasing	3.44	0.027		
11ae08	61	Flow	decreasing	49.75	0.000	-0.566	0.00000
		Temp	increasing	31.59	0.004		

11ae09	35	Flow	increasing	34.02	0.001	-0.782	0.00000
		Temp	increasing	5.58	0.025		

SUMMARY OF RESULTS FOR DEVIATIONS FROM MEAN MONTHLY FLOW: March - October

STAT. #	YRS.	SERIES	TREND	SL (%)	SLOPE	CORREL.	PROB.(%)
2aa001	68	Dev.	decreasing	24.08	-0.069	0.025	75.88303
		Temp	increasing	9.82	0.006		
2ab008	38	Dev.	decreasing	22.53	-0.030	0.616	0.00001
		Temp	increasing	47.50	0.000		
2cf007	31	Dev.	decreasing	14.60	-0.068	-0.062	62.20860
		Temp	increasing	25.36	0.008		
4jc002	41	Dev.	increasing	34.71	0.172	0.427	0.00845
		Temp	decreasing	21.59	-0.007		
4lj001	71	Dev.	decreasing	45.25	-0.078	-0.235	0.36875
		Temp	increasing	10.19	0.005		
5aa008	40	Dev.	increasing	5.27	0.178	0.613	0.00000
		Temp	increasing	7.76	0.021		
5aa022	41	Dev.	increasing	2.41	0.566	0.749	0.00000
		Temp	increasing	3.44	0.027		
5aa023	42	Dev.	increasing	4.14	0.624	0.856	0.00000
		Temp	increasing	1.43	0.033		
5ad003	43	Dev.	increasing	2.22	0.533	0.453	0.00187
		Temp	increasing	1.36	0.030		
5ae005	56	Dev.	increasing	31.36	0.003	0.545	0.00000
		Temp	increasing	19.62	0.007		
5af010	35	Dev.	increasing	2.50	0.021	0.395	0.08459
		Temp	increasing	5.58	0.025		
5bb001	81	Dev.	increasing	15.20	0.129	0.857	0.00000
		Temp	increasing	0.51	0.011		
5bj004	40	Dev.	increasing	2.02	0.282	0.333	0.24515
		Temp	increasing	7.76	0.021		
5bk001	36	Dev.	increasing	5.25	0.047	0.863	0.00000
		Temp	increasing	4.06	0.028		
5cb001	31	Dev.	increasing	17.06	0.206	0.492	0.00993
		Temp	increasing	0.86	0.042		
5ce001	32	Dev.	increasing	24.28	1.110	0.585	0.00026
		Temp	increasing	2.40	0.036		
5db002	40	Dev.	increasing	7.59	0.128	0.300	0.64041
		Temp	increasing	10.37	0.016		
5ea001	39	Dev.	decreasing	24.91	-0.110	-0.306	0.60329
		Temp	increasing	4.98	0.022		
5hd036	37	Dev.	increasing	2.34	0.054	0.706	0.00000
		Temp	increasing	1.65	0.033		
5jl002	51	Dev.	increasing	18.80	0.003	0.561	0.00000
		Temp	increasing	12.10	0.013		

5kb003	37	Dev. Temp	increasing increasing	6.63 1.22	0.353 0.031	0.315	0.60223
5kg002	31	Dev. Temp	increasing increasing	8.95 0.86	1.280 0.042	0.505	0.00649
51b002	37	Dev. Temp	increasing increasing	19.04 1.22	0.136 0.031	0.514	0.00077
51c004	31	Dev. Temp	decreasing increasing	43.24 0.86	-0.156 0.042	0.282	2.59787
51d001	36	Dev. Temp	increasing increasing	27.91 2.65	0.244 0.025	0.444	0.01368
51e004	35	Dev. Temp	decreasing increasing	13.40 3.90	-0.305 0.025	0.071	55.05328
51e006	31	Dev. Temp	decreasing increasing	17.94 0.86	-0.467 0.042	0.002	98.64394
51g001	35	Dev. Temp	decreasing increasing	10.06 3.90	-0.051 0.025	-0.037	75.45129
51h005	37	Dev. Temp	increasing increasing	38.09 1.22	0.000 0.031	0.051	65.65496
51j005	36	Dev. Temp	increasing increasing	16.67 4.06	0.044 0.028	0.686	0.00000
51j007	35	Dev. Temp	increasing increasing	38.82 5.58	0.031 0.025	0.778	0.00000
51j015	35	Dev. Temp	increasing increasing	12.21 37.20	0.022 0.007	0.523	0.00100
51j019	36	Dev. Temp	increasing increasing	45.66 4.06	0.002 0.028	-0.116	31.96802
51j027	33	Dev. Temp	increasing increasing	45.68 2.20	0.002 0.035	0.772	0.00000
511013	31	Dev. Temp	increasing increasing	0.79 1.83	0.036 0.042	0.849	0.00000
5mc001	34	Dev. Temp	increasing increasing	36.10 4.27	0.032 0.029	0.594	0.00008
5md005	36	Dev. Temp	decreasing increasing	14.72 4.06	-0.056 0.028	0.060	60.47416
5me003	38	Dev. Temp	increasing increasing	30.75 2.02	0.031 0.030	0.357	0.16020
5me005	33	Dev. Temp	decreasing increasing	6.64 2.20	-0.005 0.035	-0.030	80.42036
5mf001	33	Dev. Temp	decreasing increasing	48.15 2.20	-0.006 0.035	0.705	0.00000
5mf008	31	Dev. Temp	increasing increasing	28.17 1.83	0.036 0.042	0.746	0.00000
5mg001	33	Dev. Temp	decreasing increasing	21.47 2.20	-0.005 0.035	0.269	2.77922

5mg003	33	Dev. Temp	increasing increasing	3.61 2.20	0.016 0.035	0.966	0.00000
5mh006	31	Dev. Temp	increasing increasing	27.03 1.83	0.012 0.042	0.406	0.13167
5nf002	49	Dev. Temp	increasing increasing	1.04 4.39	0.057 0.020	0.337	0.06414
5nf008	49	Dev. Temp	increasing increasing	3.79 4.39	0.004 0.020	0.539	0.00000
5ng010	31	Dev. Temp	increasing increasing	0.72 1.83	0.073 0.042	0.819	0.00000
5oa007	33	Dev. Temp	increasing increasing	34.93 2.20	0.020 0.035	0.644	0.00001
5oa008	33	Dev. Temp	increasing increasing	2.84 2.20	0.047 0.035	0.879	0.00000
5ob006	32	Dev. Temp	increasing increasing	29.63 0.93	0.005 0.040	0.690	0.00000
5ob010	33	Dev. Temp	increasing increasing	23.32 2.20	0.012 0.035	0.678	0.00000
5od001	43	Dev. Temp	increasing increasing	6.07 1.36	0.525 0.030	0.451	0.00205
5od004	30	Dev. Temp	increasing increasing	0.69 0.66	1.475 0.050	0.503	0.00934
5od028	32	Dev. Temp	increasing increasing	1.49 2.40	0.040 0.036	0.742	0.00000
5od031	41	Dev. Temp	increasing decreasing	6.47 29.88	0.071 -0.008	-0.071	51.47545
5oe004	32	Dev. Temp	increasing increasing	0.37 2.40	0.167 0.036	0.524	0.00248
5of015	32	Dev. Temp	increasing increasing	6.17 2.40	0.024 0.036	0.871	0.00000
5oj008	32	Dev. Temp	increasing increasing	4.58 2.40	0.077 0.036	0.774	0.00000
5pa006	69	Dev. Temp	decreasing increasing	0.46 6.20	-2.240 0.006	-0.231	0.49959
5pc010	35	Dev. Temp	decreasing decreasing	31.49 11.09	-0.031 -0.017	0.324	0.61276
5pc011	31	Dev. Temp	increasing increasing	1.75 25.36	0.362 0.008	0.368	0.36563
5ph003	36	Dev. Temp	increasing increasing	0.12 4.06	1.346 0.028	0.610	0.00002
5qa001	60	Dev. Temp	decreasing increasing	31.24 6.94	-0.573 0.009	-0.440	0.00007
5qa002	70	Dev. Temp	decreasing increasing	8.32 5.86	-0.637 0.006	-0.424	0.00002

5qa004	30	Dev. Temp	increasing increasing	2.70 14.63	2.171 0.014	0.126	32.64662
5ra001	32	Dev. Temp	increasing increasing	0.28 1.61	0.844 0.038	0.843	0.00000
5sa004	31	Dev. Temp	increasing increasing	0.06 1.83	0.289 0.042	0.690	0.00000
5sc002	33	Dev. Temp	increasing increasing	1.57 1.68	0.168 0.036	0.534	0.00125
5sd003	30	Dev. Temp	increasing increasing	9.95 0.45	0.158 0.050	0.411	0.14054
5tb002	34	Dev. Temp	increasing increasing	10.27 4.00	0.355 0.025	0.850	0.00000
5uf004	33	Dev. Temp	increasing increasing	22.38 0.21	0.423 0.045	0.326	0.76979
6ad006	36	Dev. Temp	increasing increasing	98.98 2.65	3.228 0.025	0.590	0.00004
7af002	37	Dev. Temp	increasing increasing	47.39 1.22	0.049 0.031	0.462	0.00562
7ag003	37	Dev. Temp	decreasing increasing	7.33 1.22	-0.196 0.031	-0.117	30.76560
7bb002	37	Dev. Temp	decreasing increasing	5.38 1.22	-0.967 0.031	-0.210	6.70941
7bf001	33	Dev. Temp	decreasing increasing	12.90 1.68	-0.321 0.036	-0.057	64.20513
7cd001	34	Dev. Temp	increasing increasing	5.30 4.00	3.773 0.025	0.455	0.01567
7da001	34	Dev. Temp	increasing increasing	45.28 4.00	0.988 0.025	0.191	11.26904
7ge001	31	Dev. Temp	increasing increasing	8.17 0.86	3.485 0.042	0.634	0.00005
7gj001	36	Dev. Temp	increasing increasing	17.72 2.65	6.384 0.025	0.724	0.00000
11aa26	57	Dev. Temp	increasing increasing	3.41 14.45	0.011 0.009	0.217	1.72277
11ab82	41	Dev. Temp	increasing increasing	1.60 3.44	0.052 0.027	0.605	0.00000
11ae08	59	Dev. Temp	increasing increasing	5.24 21.82	0.019 0.006	0.578	0.00000
11ae09	35	Dev. Temp	increasing increasing	21.33 5.58	0.022 0.025	0.795	0.00000

SUMMARY OF RESULTS FOR DEVIATIONS FROM MEAN MONTHLY FLOW: May - August

STAT. #	YRS.	SERIES	TREND	SL (%)	SLOPE	CORREL.	PROB.(%)
2aa001	70	Dev. Temp	decreasing increasing	40.97 5.86	-0.008 0.006	-0.071	38.31201
2ab008	38	Dev. Temp	decreasing increasing	11.37 47.50	-0.031 0.000	0.212	6.10389
2cf007	31	Dev. Temp	decreasing increasing	45.94 25.36	-0.006 0.008	0.015	90.52954
4jc002	41	Dev. Temp	increasing decreasing	11.25 21.59	0.310 -0.007	0.117	28.09151
4lj001	72	Dev. Temp	increasing increasing	27.62 12.56	0.205 0.004	-0.101	20.79186
5aa008	42	Dev. Temp	increasing increasing	1.19 1.43	0.163 0.033	0.744	0.00000
5aa022	47	Dev. Temp	increasing increasing	2.25 1.20	0.359 0.027	0.780	0.00000
5aa023	42	Dev. Temp	increasing increasing	3.36 1.43	0.490 0.033	0.889	0.00000
5ad003	44	Dev. Temp	increasing increasing	1.04 1.20	0.460 0.030	0.706	0.00000
5ae005	56	Dev. Temp	decreasing increasing	39.68 19.62	-0.001 0.007	0.690	0.00000
5af010	35	Dev. Temp	decreasing increasing	28.02 5.58	-0.002 0.025	0.150	20.54927
5bb001	82	Dev. Temp	increasing increasing	9.86 0.59	0.138 0.011	0.836	0.00000
5bg002	43	Dev. Temp	increasing increasing	5.57 2.50	0.069 0.025	0.668	0.00000
5bj004	43	Dev. Temp	increasing increasing	6.01 1.36	0.204 0.030	0.732	0.00000
5bk001	36	Dev. Temp	increasing increasing	4.56 4.06	0.039 0.028	0.733	0.00000
5cb001	31	Dev. Temp	increasing increasing	20.24 0.86	0.099 0.042	0.540	0.00199
5cc001	30	Dev. Temp	decreasing increasing	13.05 0.45	-0.120 0.050	-0.554	0.00171
5ce001	33	Dev. Temp	increasing increasing	22.84 2.20	0.690 0.035	0.644	0.00001
5db002	40	Dev. Temp	increasing increasing	4.45 10.37	0.131 0.016	0.346	0.16565
5ea001	57	Dev. Temp	decreasing increasing	5.43 18.54	-0.072 0.005	0.069	44.89161

5hd036	37	Dev. Temp	increasing increasing	13.31 1.65	0.012 0.033	0.646	0.00000
5jl002	51	Dev. Temp	increasing increasing	45.15 12.10	0.000 0.013	0.348	0.03136
5kb003	37	Dev. Temp	increasing increasing	12.48 1.22	0.089 0.031	0.342	0.28639
5kg002	32	Dev. Temp	increasing increasing	8.65 1.61	0.751 0.038	0.665	0.00001
5lb002	37	Dev. Temp	increasing increasing	9.99 1.22	0.102 0.031	0.610	0.00001
5lc001	38	Dev. Temp	increasing increasing	2.56 1.95	0.841 0.026	0.477	0.00254
5lc004	36	Dev. Temp	increasing increasing	35.54 2.65	0.000 0.025	0.432	0.02115
5ld001	38	Dev. Temp	increasing increasing	7.56 1.95	0.366 0.026	0.477	0.00254
5le004	38	Dev. Temp	increasing increasing	41.53 1.95	0.018 0.026	0.260	2.14109
5le006	31	Dev. Temp	decreasing increasing	27.59 0.86	-0.160 0.042	0.166	19.06279
5lg001	38	Dev. Temp	decreasing increasing	44.50 1.95	-0.009 0.026	-0.141	21.32721
5lh005	37	Dev. Temp	decreasing increasing	49.46 1.22	0.000 0.031	0.042	71.42094
5lj005	44	Dev. Temp	increasing increasing	1.77 1.20	0.072 0.030	0.554	0.00001
5lj007	43	Dev. Temp	increasing increasing	5.24 1.36	0.079 0.030	0.780	0.00000
5lj011	34	Dev. Temp	increasing increasing	1.46 30.19	0.128 0.012	0.597	0.00007
5lj015	35	Dev. Temp	increasing increasing	10.30 37.20	0.010 0.007	0.482	0.00459
5lj019	38	Dev. Temp	increasing increasing	18.60 2.02	0.006 0.030	0.186	9.95746
5lj027	33	Dev. Temp	increasing increasing	30.45 2.20	0.003 0.035	0.913	0.00000
5ll009	33	Dev. Temp	increasing increasing	24.29 2.20	0.002 0.035	0.856	0.00000
5ll013	31	Dev. Temp	increasing increasing	0.05 1.83	0.030 0.042	0.841	0.00000
5mc001	47	Dev. Temp	increasing increasing	11.12 2.65	0.051 0.025	0.473	0.00028
5md005	44	Dev. Temp	increasing increasing	8.58 1.20	0.072 0.030	0.311	0.29434

5me003	38	Dev.	increasing	26.07	0.026	0.317	0.50546
		Temp	increasing	2.02	0.030		
5me005	33	Dev.	decreasing	20.14	-0.001	0.182	13.61483
		Temp	increasing	2.20	0.035		
5mf001	33	Dev.	decreasing	43.84	-0.019	0.538	0.00108
		Temp	increasing	2.20	0.035		
5mf008	31	Dev.	increasing	36.05	0.019	0.583	0.00041
		Temp	increasing	1.83	0.042		
5mg001	33	Dev.	decreasing	42.63	-0.001	0.538	0.00108
		Temp	increasing	2.20	0.035		
5mg003	33	Dev.	increasing	3.14	0.005	0.814	0.00000
		Temp	increasing	2.20	0.035		
5mh006	31	Dev.	increasing	1.90	0.007	0.806	0.00000
		Temp	increasing	1.83	0.042		
5nf002	49	Dev.	increasing	0.91	0.018	0.474	0.00015
		Temp	increasing	4.39	0.020		
5nf008	49	Dev.	increasing	0.70	0.001	0.825	0.00000
		Temp	increasing	4.39	0.020		
5ng010	31	Dev.	increasing	0.59	0.044	0.837	0.00000
		Temp	increasing	1.83	0.042		
5oa007	33	Dev.	increasing	19.66	0.013	0.773	0.00000
		Temp	increasing	2.20	0.035		
5oa008	33	Dev.	increasing	0.50	0.024	0.936	0.00000
		Temp	increasing	2.20	0.035		
5ob006	32	Dev.	increasing	19.05	0.000	0.492	0.00760
		Temp	increasing	0.93	0.040		
5ob010	33	Dev.	increasing	23.80	0.003	0.788	0.00000
		Temp	increasing	2.20	0.035		
5od001	75	Dev.	decreasing	8.22	-0.137	0.455	0.00000
		Temp	increasing	28.52	0.003		
5od004	30	Dev.	increasing	0.46	0.952	0.522	0.00512
		Temp	increasing	0.66	0.050		
5od028	32	Dev.	increasing	4.28	0.010	0.476	0.01297
		Temp	increasing	2.40	0.036		
5od030	72	Dev.	decreasing	11.49	-0.090	0.662	0.00000
		Temp	increasing	39.64	0.000		
5od031	53	Dev.	decreasing	34.22	-0.011	0.536	0.00000
		Temp	decreasing	13.64	-0.011		
5oe004	32	Dev.	increasing	0.57	0.085	0.141	25.63118
		Temp	increasing	2.40	0.036		
5of015	32	Dev.	increasing	13.86	0.003	0.613	0.00008
		Temp	increasing	2.40	0.036		
5oj008	32	Dev.	increasing	7.44	0.017	0.524	0.00248
		Temp	increasing	2.40	0.036		

5pa006	70	Dev.	decreasing	0.26	-1.570	-0.176	3.07633
		Temp	increasing	5.86	0.006		
5pc010	35	Dev.	decreasing	21.74	-0.013	0.382	0.12653
		Temp	decreasing	11.09	-0.017		
5pc011	40	Dev.	increasing	29.19	0.020	0.467	0.00223
		Temp	decreasing	23.51	-0.008		
5ph003	49	Dev.	increasing	1.46	0.423	0.408	0.00351
		Temp	increasing	4.39	0.020		
5qa001	60	Dev.	decreasing	24.26	-0.286	-0.464	0.00002
		Temp	increasing	6.94	0.009		
5qa002	70	Dev.	decreasing	10.18	-0.287	-0.415	0.00004
		Temp	increasing	5.86	0.006		
5qa004	30	Dev.	increasing	3.51	1.002	0.126	32.64662
		Temp	increasing	14.63	0.014		
5ra001	32	Dev.	increasing	0.17	0.730	0.802	0.00000
		Temp	increasing	1.61	0.038		
5rd007	34	Dev.	increasing	37.19	0.107	0.640	0.00001
		Temp	increasing	4.00	0.025		
5sa002	49	Dev.	increasing	1.25	0.157	0.514	0.00002
		Temp	increasing	4.39	0.020		
5sa004	32	Dev.	increasing	0.06	0.144	0.444	0.03602
		Temp	increasing	2.40	0.036		
5sc002	33	Dev.	increasing	0.26	0.086	0.644	0.00001
		Temp	increasing	1.68	0.036		
5sd003	31	Dev.	increasing	11.05	0.053	0.411	0.11691
		Temp	increasing	0.86	0.042		
5tb002	34	Dev.	increasing	9.97	0.212	0.882	0.00000
		Temp	increasing	4.00	0.025		
5uf004	33	Dev.	increasing	32.10	0.161	0.341	0.52872
		Temp	increasing	0.21	0.045		
6ad001	31	Dev.	increasing	0.14	3.352	0.613	0.00013
		Temp	increasing	0.86	0.042		
6ad006	36	Dev.	increasing	0.06	2.249	0.730	0.00000
		Temp	increasing	2.65	0.025		
7af002	37	Dev.	increasing	35.71	0.137	0.547	0.00019
		Temp	increasing	1.22	0.031		
7ag003	37	Dev.	decreasing	10.22	-0.157	-0.264	2.13418
		Temp	increasing	1.22	0.031		
7bb002	37	Dev.	decreasing	7.89	-0.719	-0.123	28.35098
		Temp	increasing	1.22	0.031		
7bf001	33	Dev.	decreasing	11.64	-0.262	0.008	95.05806
		Temp	increasing	1.68	0.036		
7cd001	34	Dev.	increasing	8.14	2.134	0.444	0.02231
		Temp	increasing	4.00	0.025		

7da001	34	Dev.	increasing	38.33	1.276	0.230	5.58309
		Temp	increasing	4.00	0.025		
7ge001	31	Dev.	increasing	12.39	2.103	0.462	0.02580
		Temp	increasing	0.86	0.042		
7gj001	37	Dev.	increasing	24.00	3.030	0.601	0.00002
		Temp	increasing	1.22	0.031		
11aa26	57	Dev.	decreasing	39.42	0.000	0.092	31.05101
		Temp	increasing	14.45	0.009		
11ab82	41	Dev.	increasing	11.47	0.011	0.139	20.03901
		Temp	increasing	3.44	0.027		
11ae08	61	Dev.	increasing	20.93	0.002	0.540	0.00000
		Temp	increasing	31.59	0.004		
11ae09	35	Dev.	increasing	42.12	0.001	0.728	0.00000
		Temp	increasing	5.58	0.025		

SUMMARY OF RESULTS FOR MAXIMUM EXTREME YEARLY FLOW

STAT. #	YRS.	SERIES	TREND	SL (%)	SLOPE	CORREL.	PROB.(%)
2aa001	68	Flow	decreasing	5.68	-0.423	-0.238	0.41174
		Temp	increasing	9.82	0.006		
2ab008	38	Flow	decreasing	24.46	-0.160	-0.639	0.00000
		Temp	increasing	47.50	0.000		
2cf007	31	Flow	increasing	31.71	0.121	-0.213	9.24438
		Temp	increasing	25.36	0.008		
4aa001	37	Flow	decreasing	18.34	-0.825	-0.589	0.00003
		Temp	increasing	1.06	0.030		
4ac005	54	Flow	decreasing	0.17	-1.793	0.488	0.00002
		Temp	decreasing	19.13	-0.005		
4ac007	56	Flow	decreasing	8.74	-0.687	0.351	0.01320
		Temp	increasing	17.36	0.005		
4jc002	41	Flow	decreasing	29.88	-0.250	0.378	0.04979
		Temp	decreasing	21.59	-0.007		
4lj001	70	Flow	decreasing	46.36	-0.250	0.408	0.00006
		Temp	increasing	5.86	0.006		
5aa008	51	Flow	decreasing	6.34	-0.219	-0.393	0.00472
		Temp	increasing	0.66	0.026		
5aa022	47	Flow	decreasing	3.40	-0.864	-0.412	0.00449
		Temp	increasing	1.20	0.027		
5aa023	42	Flow	decreasing	23.73	-0.500	-0.224	3.64729
		Temp	increasing	1.43	0.033		
5ad003	43	Flow	decreasing	7.73	-0.700	-0.635	0.00000
		Temp	increasing	1.36	0.030		
5ae005	55	Flow	decreasing	46.24	-0.004	-0.556	0.00000
		Temp	increasing	27.34	0.005		
5af010	76	Flow	decreasing	15.64	-0.037	0.079	31.06141
		Temp	increasing	12.45	0.007		
5bb001	83	Flow	decreasing	12.38	-0.320	-0.818	0.00000
		Temp	increasing	0.26	0.012		
5bg002	49	Flow	increasing	40.13	0.014	-0.728	0.00000
		Temp	increasing	12.72	0.009		
5bj004	57	Flow	decreasing	19.48	-0.229	-0.759	0.00000
		Temp	increasing	14.45	0.009		
5bk001	36	Flow	decreasing	1.63	-0.226	-0.879	0.00000
		Temp	increasing	4.06	0.028		
5cb001	31	Flow	decreasing	20.73	-0.729	-0.471	0.01975
		Temp	increasing	0.86	0.042		
5cc001	30	Flow	increasing	10.91	0.910	0.301	1.94301
		Temp	increasing	0.45	0.050		

5ce001	33	Flow Temp	decreasing increasing	33.78 2.20	-1.161 0.035	-0.530	0.00144
5ce002	32	Flow Temp	decreasing increasing	0.05 2.40	-0.653 0.036	-0.734	0.00000
5da007	41	Flow Temp	decreasing increasing	38.09 4.80	-0.018 0.023	0.634	0.00000
5db002	40	Flow Temp	decreasing increasing	20.41 10.37	-0.220 0.016	-0.256	1.97952
5ea001	56	Flow Temp	increasing increasing	35.14 26.23	0.050 0.003	-0.565	0.00000
5eg004	31	Flow Temp	increasing increasing	36.05 1.68	0.011 0.040	-0.342	0.68835
5hd036	37	Flow Temp	decreasing increasing	1.14 1.65	-0.508 0.033	-0.441	0.01205
5ja002	48	Flow Temp	decreasing increasing	2.74 3.09	-0.700 0.023	-0.411	0.00372
5jl002	51	Flow Temp	increasing increasing	28.48 12.10	0.018 0.013	-0.667	0.00000
5kb003	37	Flow Temp	decreasing increasing	11.70 1.22	-1.103 0.031	-0.574	0.00006
5kg002	32	Flow Temp	decreasing increasing	8.16 1.61	-0.790 0.038	-0.718	0.00000
5lb002	37	Flow Temp	decreasing increasing	29.14 1.22	-0.400 0.031	-0.715	0.00000
5lc001	37	Flow Temp	decreasing increasing	1.18 1.59	-4.048 0.029	-0.628	0.00000
5lc004	36	Flow Temp	decreasing increasing	15.35 2.65	-1.000 0.025	-0.600	0.00003
5ld001	36	Flow Temp	decreasing increasing	3.30 2.65	-0.882 0.025	-0.873	0.00000
5le004	38	Flow Temp	increasing increasing	16.97 1.95	0.525 0.026	-0.061	58.87888
5le005	33	Flow Temp	increasing increasing	19.71 1.68	0.400 0.036	-0.174	15.40168
5le006	31	Flow Temp	increasing increasing	24.83 0.86	0.971 0.042	-0.187	13.92237
5lg001	38	Flow Temp	increasing increasing	22.53 1.95	0.066 0.026	0.218	5.44171
5lh005	39	Flow Temp	decreasing increasing	37.20 4.98	-0.353 0.022	-0.123	27.09770
5lj005	44	Flow Temp	decreasing increasing	27.54 1.20	-0.163 0.030	-0.581	0.00000
5lj007	42	Flow Temp	increasing increasing	50.00 1.43	0.000 0.033	-0.582	0.00001

51j011	34	Flow Temp	decreasing increasing	44.69 30.19	-0.088 0.012	-0.701	0.00000
51j015	36	Flow Temp	decreasing increasing	9.78 23.09	-0.114 0.015	-0.565	0.00012
51j019	37	Flow Temp	increasing increasing	15.69 1.65	0.055 0.033	0.434	0.01552
51j027	33	Flow Temp	increasing increasing	8.39 2.20	0.080 0.035	-0.038	75.66459
511007	33	Flow Temp	decreasing increasing	5.52 2.20	-0.158 0.035	-0.852	0.00000
511009	33	Flow Temp	decreasing increasing	5.19 2.20	-0.213 0.035	-0.913	0.00000
511013	31	Flow Temp	decreasing increasing	28.74 1.83	-0.016 0.042	-0.699	0.00000
5mc001	45	Flow Temp	increasing increasing	30.20 1.36	0.100 0.030	-0.236	2.20757
5md005	43	Flow Temp	decreasing increasing	48.33 2.64	-0.008 0.026	-0.313	0.30593
5me003	38	Flow Temp	decreasing increasing	43.02 2.02	-0.031 0.030	-0.536	0.00021
5me005	33	Flow Temp	increasing increasing	28.84 2.20	0.017 0.035	0.080	51.51980
5mf001	32	Flow Temp	increasing increasing	29.63 2.40	0.157 0.036	-0.488	0.00870
5mf008	30	Flow Temp	increasing increasing	32.78 0.66	0.068 0.050	0.044	73.46250
5mg001	33	Flow Temp	decreasing increasing	42.01 2.20	-0.004 0.035	-0.481	0.00830
5mg003	33	Flow Temp	decreasing increasing	4.56 2.20	-0.072 0.035	-0.848	0.00000
5mh006	31	Flow Temp	decreasing increasing	19.30 1.83	-0.092 0.042	-0.320	1.13263
5nf002	48	Flow Temp	decreasing increasing	2.42 7.62	-0.250 0.018	-0.133	18.24642
5nf008	47	Flow Temp	decreasing increasing	8.88 5.53	-0.018 0.020	-0.548	0.00001
5ng010	31	Flow Temp	decreasing increasing	10.42 1.83	-0.200 0.042	-0.234	6.39384
5oa007	33	Flow Temp	decreasing increasing	29.92 2.20	-0.114 0.035	-0.629	0.00003
5oa008	33	Flow Temp	decreasing increasing	16.45 2.20	-0.107 0.035	-0.750	0.00000
5ob006	32	Flow Temp	decreasing increasing	23.28 0.93	-0.067 0.040	-0.677	0.00001

5ob010	33	Flow	decreasing	24.77	-0.092	-0.705	0.00000
		Temp	increasing	2.20	0.035		
5od001	74	Flow	increasing	13.44	0.162	-0.286	0.03093
		Temp	increasing	21.24	0.004		
5od004	30	Flow	decreasing	0.97	-1.357	-0.821	0.00000
		Temp	increasing	0.66	0.050		
5od028	32	Flow	decreasing	2.40	-0.333	-0.319	1.04012
		Temp	increasing	2.40	0.036		
5od030	72	Flow	decreasing	47.29	-0.009	-0.806	0.00000
		Temp	increasing	40.21	0.000		
5od031	52	Flow	decreasing	37.02	-0.051	-0.397	0.00331
		Temp	decreasing	23.14	-0.007		
5oe004	32	Flow	decreasing	6.78	-0.222	-0.133	28.44907
		Temp	increasing	2.40	0.036		
5oe006	31	Flow	decreasing	2.07	-0.515	-0.862	0.00000
		Temp	increasing	1.83	0.042		
5of014	32	Flow	decreasing	7.44	-0.532	-0.302	1.49963
		Temp	increasing	2.40	0.036		
5of015	31	Flow	decreasing	3.86	-0.358	-0.652	0.00003
		Temp	increasing	4.62	0.031		
5oj006	32	Flow	decreasing	4.28	-0.650	-0.940	0.00000
		Temp	increasing	2.40	0.036		
5oj008	32	Flow	decreasing	12.48	-0.295	-0.306	1.37051
		Temp	increasing	2.40	0.036		
5oj009	32	Flow	decreasing	28.51	-0.034	-0.879	0.00000
		Temp	increasing	2.40	0.036		
5pa006	69	Flow	increasing	0.95	1.700	0.149	6.98579
		Temp	increasing	6.20	0.006		
5pb014	76	Flow	increasing	16.41	0.286	0.577	0.00000
		Temp	increasing	7.24	0.006		
5pc010	36	Flow	increasing	6.53	0.306	-0.600	0.00003
		Temp	decreasing	14.09	-0.014		
5pc011	40	Flow	decreasing	40.34	-0.067	-0.582	0.00001
		Temp	decreasing	23.51	-0.008		
5ph003	48	Flow	decreasing	7.49	-0.650	-0.594	0.00000
		Temp	increasing	3.35	0.022		
5pj001	31	Flow	decreasing	0.16	-0.544	-0.746	0.00000
		Temp	increasing	0.90	0.042		
5qa001	60	Flow	increasing	18.94	0.762	0.562	0.00000
		Temp	increasing	6.94	0.009		
5qa002	70	Flow	increasing	18.88	0.387	0.439	0.00001
		Temp	increasing	5.86	0.006		
5qa004	30	Flow	decreasing	10.91	-1.262	-0.264	4.01970
		Temp	increasing	14.63	0.014		

5qe009	30	Flow	decreasing	0.10	-1.067	-0.402	0.17952
		Temp	increasing	27.79	0.008		
5ra001	31	Flow	decreasing	0.15	-1.000	-0.432	0.06348
		Temp	increasing	0.86	0.042		
5ra002	31	Flow	decreasing	0.16	-0.650	-0.505	0.00649
		Temp	increasing	1.35	0.041		
5rd007	34	Flow	decreasing	19.91	-0.877	-0.665	0.00000
		Temp	increasing	4.00	0.025		
5rd008	34	Flow	decreasing	22.03	-1.316	-0.754	0.00000
		Temp	increasing	4.00	0.025		
5sa002	49	Flow	decreasing	7.63	-0.280	-0.653	0.00000
		Temp	increasing	4.39	0.020		
5sa004	32	Flow	decreasing	1.02	-0.295	-0.742	0.00000
		Temp	increasing	2.40	0.036		
5sb002	31	Flow	decreasing	11.37	-0.082	-0.534	0.00240
		Temp	increasing	3.18	0.027		
5sc002	33	Flow	decreasing	34.93	-0.270	-0.235	5.46930
		Temp	increasing	1.68	0.036		
5sd003	31	Flow	increasing	50.00	-0.050	-0.140	26.92606
		Temp	increasing	0.86	0.042		
5sd004	31	Flow	increasing	50.00	-0.007	0.101	42.43881
		Temp	increasing	0.86	0.042		
5tb002	34	Flow	decreasing	1.97	-0.362	-0.865	0.00000
		Temp	increasing	4.00	0.025		
5td001	31	Flow	decreasing	4.46	-1.446	-0.759	0.00000
		Temp	increasing	1.35	0.041		
5uf004	27	Flow	increasing	4.77	1.186	0.316	2.06673
		Temp	increasing	0.06	0.075		
6ad001	31	Flow	decreasing	0.26	-4.833	-0.712	0.00000
		Temp	increasing	0.86	0.042		
6ad006	36	Flow	decreasing	0.19	-3.208	-0.714	0.00000
		Temp	increasing	2.65	0.025		
6gd001	35	Flow	increasing	17.43	3.966	0.027	81.99530
		Temp	increasing	5.12	0.025		
7af002	37	Flow	decreasing	45.83	-0.247	0.117	30.76560
		Temp	increasing	1.22	0.031		
7ag003	37	Flow	increasing	9.77	0.617	0.081	48.00267
		Temp	increasing	1.22	0.031		
7bb002	37	Flow	increasing	10.94	2.067	-0.018	87.52870
		Temp	increasing	1.22	0.031		
7bf001	33	Flow	increasing	1.01	4.035	0.443	0.02882
		Temp	increasing	1.68	0.036		
7cd001	33	Flow	decreasing	1.82	-5.714	-0.352	0.39521
		Temp	increasing	3.85	0.026		

7da001	34	Flow	increasing	34.45	5.333	-0.244	4.22602
		Temp	increasing	4.00	0.025		
7ge001	31	Flow	decreasing	45.94	-1.500	-0.032	79.87646
		Temp	increasing	0.86	0.042		
7gj001	37	Flow	increasing	42.22	2.778	-0.429	0.01836
		Temp	increasing	1.22	0.031		
7hc001	31	Flow	decreasing	23.23	-1.867	-0.303	1.65527
		Temp	increasing	0.86	0.042		
11aa26	57	Flow	decreasing	5.07	-0.125	-0.064	48.25840
		Temp	increasing	14.45	0.009		
11ab82	41	Flow	decreasing	1.27	-0.463	-0.485	0.00078
		Temp	increasing	3.44	0.027		
11ae08	59	Flow	decreasing	38.68	-0.028	-0.749	0.00000
		Temp	increasing	21.82	0.006		
11ae09	35	Flow	decreasing	25.68	-0.141	-0.855	0.00000
		Temp	increasing	5.58	0.025		

SUMMARY OF RESULTS FOR MAXIMUM SUMMER PRECIPITATION EVENT

STAT. #	YRS.	SERIES	TREND	SL (%)	SLOPE	CORREL.	PROB.(%)
2aa001	71	Flow	increasing	9.33	0.150	0.471	0.00000
		Temp	increasing	7.02	0.006		
2ab008	39	Flow	increasing	12.27	0.061	-0.204	6.77558
		Temp	decreasing	37.20	0.000		
2bd003	51	Flow	increasing	4.72	0.502	-0.222	2.15285
		Temp	decreasing	35.14	0.000		
2cf007	32	Flow	decreasing	39.76	-0.031	-0.595	0.00017
		Temp	increasing	37.89	0.000		
4aa001	34	Flow	increasing	36.10	0.132	-0.383	0.14363
		Temp	increasing	5.79	0.023		
4jc002	42	Flow	increasing	7.47	0.336	-0.131	22.07166
		Temp	decreasing	36.84	0.000		
4lj001	72	Flow	increasing	4.31	1.300	0.442	0.00000
		Temp	increasing	12.56	0.004		
5aa008	43	Flow	decreasing	28.59	-0.010	0.397	0.01778
		Temp	increasing	1.36	0.030		
5aa022	47	Flow	decreasing	6.06	-0.109	-0.014	89.05907
		Temp	increasing	1.20	0.027		
5aa023	43	Flow	increasing	13.82	0.059	0.491	0.00035
		Temp	increasing	1.36	0.030		
5ad003	44	Flow	decreasing	33.18	-0.037	-0.362	0.05420
		Temp	increasing	1.20	0.030		
5ae005	56	Flow	decreasing	43.54	0.000	-0.594	0.00000
		Temp	increasing	19.62	0.007		
5af010	36	Flow	increasing	23.10	0.027	0.329	0.47760
		Temp	increasing	2.34	0.032		
5bb001	82	Flow	decreasing	10.35	-0.184	-0.092	21.89340
		Temp	increasing	0.59	0.011		
5bg002	51	Flow	increasing	37.26	0.014	0.854	0.00000
		Temp	increasing	17.48	0.005		
5bj004	45	Flow	increasing	33.70	0.029	0.658	0.00000
		Temp	increasing	1.19	0.029		
5bk001	36	Flow	decreasing	37.71	-0.010	0.475	0.00458
		Temp	increasing	4.06	0.028		
5cb001	32	Flow	increasing	37.28	0.068	0.895	0.00000
		Temp	increasing	1.61	0.038		
5cc001	30	Flow	increasing	6.47	0.464	0.067	60.48838
		Temp	increasing	0.45	0.050		
5ce001	33	Flow	increasing	0.34	1.859	0.379	0.19425
		Temp	increasing	2.20	0.035		

5ce002	34	Flow	decreasing	8.40	-0.044	-0.012	91.73512
		Temp	increasing	6.91	0.027		
5da007	42	Flow	decreasing	3.43	-0.112	-0.447	0.00301
		Temp	increasing	2.01	0.027		
5db002	41	Flow	increasing	3.19	0.166	0.412	0.01468
		Temp	increasing	4.80	0.023		
5ea001	57	Flow	increasing	0.05	0.063	0.102	26.47718
		Temp	increasing	18.54	0.005		
5hd036	37	Flow	increasing	44.28	0.002	-0.216	5.96517
		Temp	increasing	1.65	0.033		
5jl002	51	Flow	increasing	46.12	0.000	0.252	0.91278
		Temp	increasing	12.10	0.013		
5kb003	37	Flow	decreasing	30.04	-0.014	-0.243	3.41092
		Temp	increasing	1.22	0.031		
5kg002	31	Flow	decreasing	7.67	-0.540	-0.613	0.00013
		Temp	increasing	2.83	0.036		
5lb002	37	Flow	increasing	10.22	0.044	0.105	35.99178
		Temp	increasing	1.22	0.031		
5lc001	38	Flow	decreasing	31.64	-0.087	-0.496	0.00115
		Temp	increasing	1.95	0.026		
5lc004	36	Flow	decreasing	12.35	-0.230	-0.571	0.00009
		Temp	increasing	2.65	0.025		
5ld001	38	Flow	decreasing	19.28	-0.225	-0.587	0.00002
		Temp	increasing	1.95	0.026		
5le004	38	Flow	increasing	35.77	0.028	-0.340	0.26586
		Temp	increasing	1.95	0.026		
5le005	33	Flow	increasing	32.66	0.015	-0.462	0.01564
		Temp	increasing	1.68	0.036		
5le006	32	Flow	increasing	35.46	0.048	-0.117	34.69334
		Temp	increasing	1.61	0.038		
5lg001	38	Flow	increasing	22.91	0.058	-0.010	92.98740
		Temp	increasing	1.95	0.026		
5lh005	41	Flow	decreasing	2.27	-1.607	-0.212	5.06590
		Temp	increasing	4.80	0.023		
5lj005	44	Flow	decreasing	5.28	-0.210	-0.412	0.00799
		Temp	increasing	1.20	0.030		
5lj007	44	Flow	decreasing	21.22	-0.166	-0.070	50.44263
		Temp	increasing	1.20	0.030		
5lj011	34	Flow	increasing	50.00	-0.021	-0.294	1.44438
		Temp	increasing	30.19	0.012		
5lj015	31	Flow	decreasing	36.69	-0.005	-0.413	0.10876
		Temp	increasing	34.17	0.009		
5lj019	38	Flow	increasing	1.30	0.012	0.252	2.60660
		Temp	increasing	2.02	0.030		

5lj027	33	Flow Temp	increasing increasing	21.47 2.20	0.025 0.035	0.136	26.45944
5ll007	33	Flow Temp	decreasing increasing	7.05 2.20	-0.074 0.035	-0.246	4.39808
5ll009	33	Flow Temp	decreasing increasing	19.71 2.20	-0.020 0.035	-0.761	0.00000
5ll013	31	Flow Temp	decreasing increasing	12.39 1.83	-0.010 0.042	-0.209	9.92189
5mc001	47	Flow Temp	decreasing increasing	33.99 2.65	-0.003 0.025	-0.038	70.69254
5md005	44	Flow Temp	increasing increasing	31.05 1.20	0.012 0.030	0.190	6.86727
5me003	39	Flow Temp	increasing increasing	41.85 5.12	0.005 0.025	0.239	3.22623
5me005	32	Flow Temp	increasing increasing	18.19 0.97	0.000 0.040	0.460	0.02179
5mf001	33	Flow Temp	decreasing increasing	24.28 2.20	-0.051 0.035	-0.845	0.00000
5mf008	31	Flow Temp	decreasing increasing	45.94 1.83	-0.007 0.042	0.084	50.74202
5mg001	33	Flow Temp	increasing increasing	15.69 2.20	0.005 0.035	0.572	0.00029
5mg003	31	Flow Temp	decreasing increasing	25.36 6.52	-0.003 0.029	-0.738	0.00000
5mh006	30	Flow Temp	increasing increasing	30.87 2.19	0.000 0.045	-0.347	0.70601
5nf002	47	Flow Temp	decreasing increasing	1.56 10.95	-0.010 0.016	-0.393	0.00972
5nf008	47	Flow Temp	decreasing increasing	0.23 10.95	-0.002 0.016	-0.406	0.00559
5ng010	31	Flow Temp	decreasing increasing	11.70 1.83	-0.011 0.042	-0.966	0.00000
5oa007	33	Flow Temp	decreasing increasing	23.80 2.20	-0.014 0.035	-0.299	1.43605
5oa008	33	Flow Temp	decreasing increasing	2.83 2.20	-0.081 0.035	-0.678	0.00000
5ob006	32	Flow Temp	increasing increasing	43.98 0.93	0.000 0.040	0.281	2.40479
5ob010	33	Flow Temp	decreasing increasing	21.47 2.20	-0.001 0.035	-0.504	0.00376
5od001	75	Flow Temp	increasing increasing	10.84 28.52	0.065 0.003	-0.343	0.00133
5od004	30	Flow Temp	decreasing increasing	29.63 0.66	-0.192 0.050	-0.310	1.60165

5od028	32	Flow	decreasing	12.48	-0.027	0.081	51.65593
		Temp	increasing	2.40	0.036		
5od030	72	Flow	increasing	42.87	0.007	-0.451	0.00000
		Temp	increasing	39.64	0.000		
5od031	53	Flow	increasing	42.40	0.005	-0.753	0.00000
		Temp	decreasing	13.64	-0.011		
5oe004	32	Flow	decreasing	44.20	-0.008	-0.290	1.95346
		Temp	increasing	2.40	0.036		
5oe006	31	Flow	increasing	45.26	0.008	-0.011	93.22754
		Temp	increasing	1.83	0.042		
5of014	32	Flow	decreasing	11.82	-0.015	-0.121	33.05597
		Temp	increasing	2.40	0.036		
5of015	32	Flow	decreasing	19.50	-0.013	-0.415	0.08360
		Temp	increasing	2.40	0.036		
5oj006	32	Flow	decreasing	33.66	-0.018	-0.141	25.63118
		Temp	increasing	2.40	0.036		
5oj008	32	Flow	increasing	26.35	0.013	0.004	97.41269
		Temp	increasing	2.40	0.036		
5pa006	71	Flow	increasing	3.50	0.565	0.269	0.08980
		Temp	increasing	10.19	0.005		
5pb014	78	Flow	increasing	19.05	0.090	0.124	10.94478
		Temp	increasing	5.38	0.006		
5pc010	35	Flow	increasing	20.11	0.089	-0.116	32.71362
		Temp	decreasing	11.09	-0.017		
5pc011	40	Flow	increasing	32.06	0.072	-0.223	4.26338
		Temp	decreasing	23.51	-0.008		
5ph003	50	Flow	decreasing	4.40	-0.338	-0.050	60.98719
		Temp	increasing	5.98	0.018		
5qa001	61	Flow	decreasing	27.52	-0.270	0.168	5.60101
		Temp	increasing	12.23	0.006		
5qa002	71	Flow	increasing	28.57	0.116	0.370	0.00051
		Temp	increasing	10.19	0.005		
5qa004	31	Flow	decreasing	4.79	-1.062	-0.273	3.08855
		Temp	increasing	25.36	0.008		
5qe009	32	Flow	decreasing	7.44	-0.230	-0.410	0.09833
		Temp	increasing	37.89	0.000		
5ra001	32	Flow	decreasing	13.16	-0.125	-0.714	0.00000
		Temp	increasing	1.61	0.038		
5ra002	32	Flow	decreasing	4.58	-0.151	-0.823	0.00000
		Temp	increasing	1.61	0.038		
5rd007	33	Flow	increasing	37.83	0.199	-0.068	57.69818
		Temp	increasing	6.83	0.024		
5rd008	33	Flow	decreasing	45.68	-0.211	-0.383	0.17488
		Temp	increasing	6.83	0.024		

5sa002	50	Flow	decreasing	4.09	-0.061	-0.038	69.42100
		Temp	increasing	5.98	0.018		
5sa004	32	Flow	decreasing	13.16	-0.017	-0.137	27.01493
		Temp	increasing	2.40	0.036		
5sc002	34	Flow	increasing	30.71	0.012	0.515	0.00183
		Temp	increasing	4.00	0.025		
5sd003	31	Flow	increasing	39.94	0.006	0.312	1.37212
		Temp	increasing	0.86	0.042		
5tb002	35	Flow	decreasing	17.43	-0.131	-0.693	0.00000
		Temp	increasing	3.90	0.025		
5uf004	30	Flow	decreasing	26.61	-0.229	-0.223	8.35267
		Temp	increasing	0.07	0.061		
6ad001	32	Flow	decreasing	1.11	-1.199	-0.391	0.16552
		Temp	increasing	1.61	0.038		
6ad006	37	Flow	decreasing	1.18	-0.890	-0.306	0.76283
		Temp	increasing	1.22	0.031		
7af002	38	Flow	increasing	21.05	0.400	0.070	53.78791
		Temp	increasing	1.95	0.026		
7ag003	38	Flow	increasing	5.95	0.202	0.141	21.32721
		Temp	increasing	1.95	0.026		
7bb002	38	Flow	increasing	24.08	0.274	0.249	2.78010
		Temp	increasing	1.95	0.026		
7bf001	33	Flow	increasing	0.69	1.569	0.545	0.00081
		Temp	increasing	1.68	0.036		
7cd001	35	Flow	decreasing	19.71	-0.987	-0.400	0.07175
		Temp	increasing	3.90	0.025		
7da001	35	Flow	increasing	9.10	13.281	0.525	0.00092
		Temp	increasing	3.90	0.025		
7ge001	32	Flow	decreasing	45.48	-0.220	-0.730	0.00000
		Temp	increasing	1.61	0.038		
7gj001	37	Flow	increasing	33.30	3.167	-0.667	0.00000
		Temp	increasing	1.22	0.031		
7hc001	31	Flow	decreasing	43.25	-0.215	0.071	57.48781
		Temp	increasing	0.86	0.042		
11aa26	56	Flow	increasing	21.44	0.000	-0.230	1.22960
		Temp	increasing	17.72	0.008		
11ab82	41	Flow	decreasing	49.09	0.000	0.446	0.00394
		Temp	increasing	3.44	0.027		
11ae08	61	Flow	decreasing	10.10	-0.007	0.009	92.06882
		Temp	increasing	31.59	0.004		
11ae09	36	Flow	increasing	6.70	0.074	-0.192	9.90580
		Temp	increasing	4.06	0.028		

SUMMARY OF RESULTS FOR JULIAN DAY ANALYSIS

STAT. #	YRS.	SERIES	TREND	SL (%)	SLOPE	CORREL.	PROB.(%)
2aa001	69	Flow	decreasing	16.64	-0.057	-0.365	0.00093
		Temp	increasing	6.20	0.006		
2ab008	38	Flow	decreasing	25.66	-0.091	-0.112	32.06221
		Temp	increasing	47.50	0.000		
2bd003	51	Flow	decreasing	0.37	-0.250	0.211	2.88980
		Temp	decreasing	40.68	0.000		
2cf007	31	Flow	decreasing	15.80	-0.231	-0.320	1.13263
		Temp	increasing	25.36	0.008		
4aa001	34	Flow	decreasing	0.08	-1.200	-0.772	0.00000
		Temp	increasing	5.79	0.023		
4ac005	38	Flow	decreasing	0.24	-1.000	0.212	6.10389
		Temp	decreasing	30.75	-0.005		
4jc002	41	Flow	decreasing	11.25	-0.158	-0.461	0.00218
		Temp	decreasing	21.59	-0.007		
4lj001	71	Flow	decreasing	1.50	-0.108	-0.332	0.00422
		Temp	increasing	10.19	0.005		
5aa008	43	Flow	decreasing	32.64	-0.083	-0.043	68.31625
		Temp	increasing	1.36	0.030		
5aa022	47	Flow	increasing	48.17	0.000	0.016	87.61137
		Temp	increasing	1.20	0.027		
5aa023	42	Flow	increasing	48.70	0.000	-0.257	1.66175
		Temp	increasing	1.43	0.033		
5ad003	44	Flow	decreasing	17.87	-0.160	-0.372	0.03705
		Temp	increasing	1.20	0.030		
5ae005	55	Flow	decreasing	4.83	-0.214	0.169	6.84331
		Temp	increasing	22.94	0.006		
5af010	56	Flow	decreasing	0.04	-0.413	0.033	71.84275
		Temp	increasing	17.72	0.008		
5bb001	82	Flow	decreasing	10.21	-0.077	-0.661	0.00000
		Temp	increasing	0.59	0.011		
5bg002	49	Flow	decreasing	19.66	-0.080	-0.614	0.00000
		Temp	increasing	12.72	0.009		
5bj004	57	Flow	decreasing	9.66	-0.148	-0.320	0.04468
		Temp	increasing	14.45	0.009		
5bk001	36	Flow	decreasing	0.30	-0.471	-0.397	0.06611
		Temp	increasing	4.06	0.028		
5cb001	31	Flow	increasing	46.61	0.000	-0.015	90.52954
		Temp	increasing	0.86	0.042		
5cc001	30	Flow	decreasing	3.44	-0.429	-0.531	0.00377
		Temp	increasing	0.45	0.050		

5ce001	33	Flow	decreasing	11.95	-0.200	-0.875	0.00000
		Temp	increasing	2.20	0.035		
5ce002	33	Flow	increasing	46.29	0.000	-0.409	0.08175
		Temp	increasing	2.20	0.035		
5da007	41	Flow	decreasing	0.16	-0.457	-0.324	0.28109
		Temp	increasing	4.80	0.023		
5db002	40	Flow	increasing	34.17	0.125	-0.082	45.58691
		Temp	increasing	10.37	0.016		
5ea001	57	Flow	decreasing	1.45	-0.171	-0.197	3.06545
		Temp	increasing	18.54	0.005		
5eg004	31	Flow	decreasing	38.63	0.000	-0.363	0.40737
		Temp	increasing	1.68	0.040		
5hd036	37	Flow	decreasing	4.71	-0.357	-0.907	0.00000
		Temp	increasing	1.65	0.033		
5jl002	46	Flow	decreasing	17.42	-0.154	-0.314	0.20899
		Temp	increasing	22.71	0.010		
5kb003	37	Flow	decreasing	7.70	-0.200	-0.255	2.61882
		Temp	increasing	1.22	0.031		
5kg002	31	Flow	decreasing	7.67	-0.882	-0.918	0.00000
		Temp	increasing	2.83	0.036		
5lb002	37	Flow	decreasing	0.65	-0.385	-0.547	0.00019
		Temp	increasing	1.22	0.031		
5lb004	35	Flow	decreasing	3.13	-0.292	-0.375	0.15406
		Temp	increasing	4.97	0.023		
5lc001	38	Flow	decreasing	0.17	-0.500	-0.516	0.00050
		Temp	increasing	1.95	0.026		
5lc004	36	Flow	decreasing	35.65	-0.115	-0.613	0.00001
		Temp	increasing	2.65	0.025		
5ld001	38	Flow	decreasing	7.41	-0.286	-0.400	0.04113
		Temp	increasing	1.95	0.026		
5le004	38	Flow	decreasing	24.07	-0.080	-0.169	13.46389
		Temp	increasing	1.95	0.026		
5le005	33	Flow	decreasing	16.83	-0.200	-0.511	0.00287
		Temp	increasing	1.68	0.036		
5le006	31	Flow	decreasing	4.62	-0.333	-0.570	0.00067
		Temp	increasing	0.86	0.042		
5lg001	38	Flow	decreasing	1.14	-0.500	-0.377	0.08636
		Temp	increasing	1.95	0.026		
5lh005	41	Flow	decreasing	0.38	-0.567	-0.415	0.01341
		Temp	increasing	4.80	0.023		
5lj005	44	Flow	decreasing	4.76	-0.240	-0.446	0.00197
		Temp	increasing	1.20	0.030		
5lj007	44	Flow	decreasing	38.85	-0.042	0.224	3.20150
		Temp	increasing	1.20	0.030		

5lj011	34	Flow	decreasing	22.46	-0.125	-0.176	14.22075
		Temp	increasing	30.19	0.012		
5lj015	33	Flow	increasing	30.45	0.077	-0.617	0.00004
		Temp	increasing	40.81	0.004		
5lj019	38	Flow	decreasing	0.24	-0.478	-0.408	0.03084
		Temp	increasing	2.02	0.030		
5lj027	33	Flow	decreasing	24.28	-0.120	-0.280	2.18380
		Temp	increasing	2.20	0.035		
5ll007	33	Flow	decreasing	12.58	-0.214	-0.663	0.00001
		Temp	increasing	2.20	0.035		
5ll009	33	Flow	decreasing	11.64	-0.308	-0.542	0.00094
		Temp	increasing	2.20	0.035		
5ll013	31	Flow	decreasing	12.39	-0.316	-0.755	0.00000
		Temp	increasing	1.83	0.042		
5mc001	47	Flow	decreasing	5.95	-0.190	-0.480	0.00019
		Temp	increasing	2.65	0.025		
5md005	44	Flow	decreasing	4.96	-0.240	-0.776	0.00000
		Temp	increasing	1.20	0.030		
5me003	38	Flow	decreasing	12.37	-0.200	-0.525	0.00035
		Temp	increasing	2.02	0.030		
5me005	32	Flow	decreasing	34.86	-0.083	-0.536	0.00161
		Temp	increasing	0.97	0.040		
5mf001	33	Flow	decreasing	1.39	-0.462	-0.852	0.00000
		Temp	increasing	2.20	0.035		
5mf008	31	Flow	decreasing	0.02	-0.875	-0.583	0.00041
		Temp	increasing	1.83	0.042		
5mg001	33	Flow	decreasing	19.71	-0.222	-0.534	0.00125
		Temp	increasing	2.20	0.035		
5mg003	31	Flow	decreasing	46.61	0.000	-0.355	0.50409
		Temp	increasing	6.52	0.029		
5nf002	46	Flow	decreasing	7.37	-0.188	-0.302	0.30413
		Temp	increasing	10.56	0.018		
5nf008	43	Flow	decreasing	34.93	-0.111	-0.256	1.56270
		Temp	increasing	18.96	0.013		
5ng010	31	Flow	decreasing	5.50	-0.353	-0.609	0.00015
		Temp	increasing	1.83	0.042		
5oa007	33	Flow	decreasing	9.65	-0.278	-0.822	0.00000
		Temp	increasing	2.20	0.035		
5oa008	33	Flow	decreasing	9.39	-0.300	-0.818	0.00000
		Temp	increasing	2.20	0.035		
5ob006	32	Flow	decreasing	5.60	-0.417	-0.633	0.00004
		Temp	increasing	0.93	0.040		
5ob010	33	Flow	decreasing	7.26	-0.312	-0.890	0.00000
		Temp	increasing	2.20	0.035		

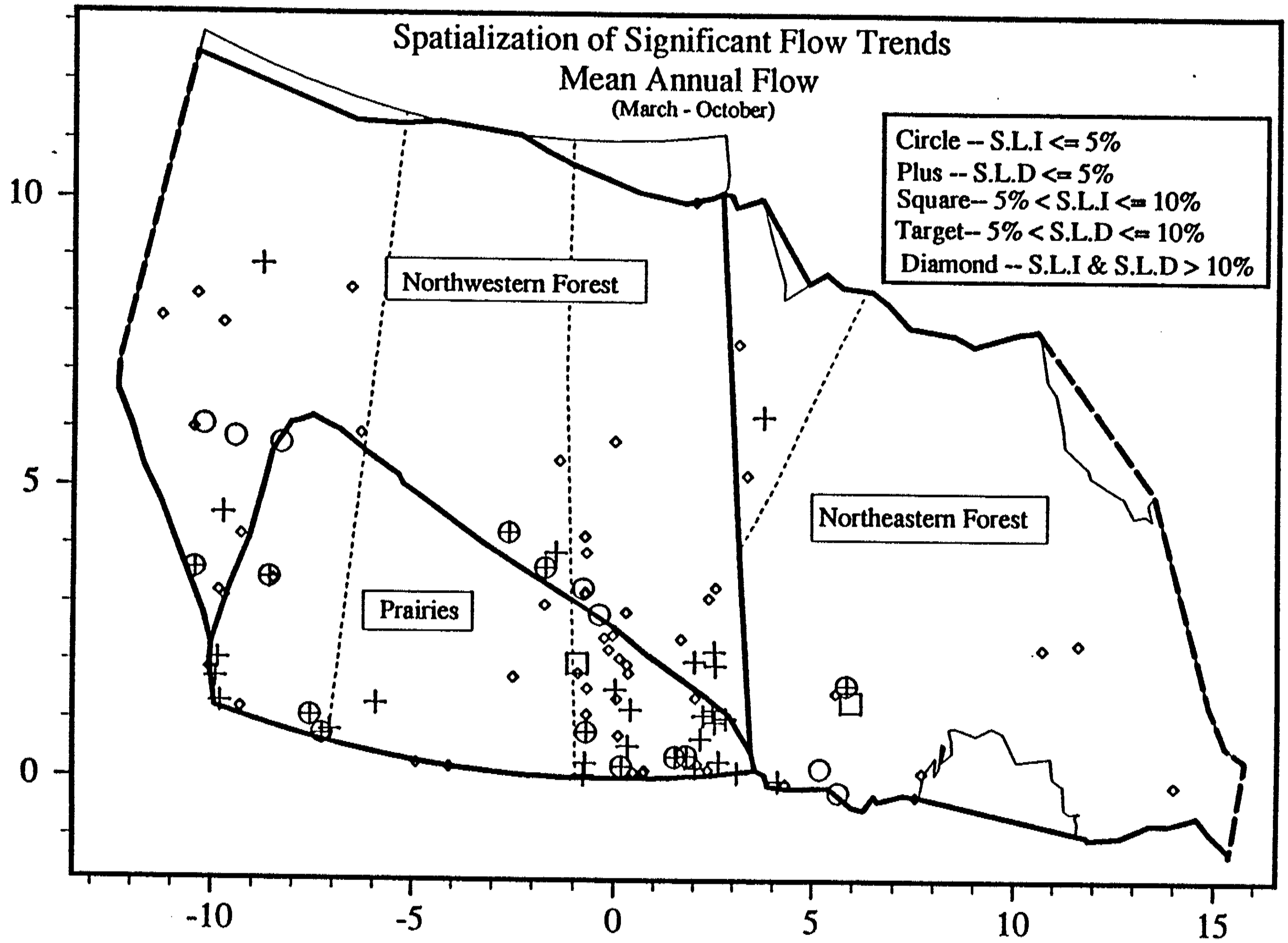
5od001	75	Flow	decreasing	7.88	-0.091	-0.205	0.91122
		Temp	increasing	28.52	0.003		
5od004	30	Flow	decreasing	3.87	-0.607	-0.903	0.00000
		Temp	increasing	0.66	0.050		
5od028	32	Flow	decreasing	4.74	-0.444	-0.242	5.16578
		Temp	increasing	2.40	0.036		
5od030	72	Flow	increasing	38.53	0.024	-0.738	0.00000
		Temp	increasing	39.64	0.000		
5od031	53	Flow	decreasing	42.09	0.000	0.197	3.75700
		Temp	decreasing	13.64	-0.011		
5oe004	32	Flow	decreasing	6.35	-0.294	-0.649	0.00002
		Temp	increasing	2.40	0.036		
5oe006	31	Flow	decreasing	4.78	-0.400	-0.862	0.00000
		Temp	increasing	1.83	0.042		
5of014	32	Flow	decreasing	13.86	-0.300	-0.625	0.00005
		Temp	increasing	2.40	0.036		
5of015	32	Flow	decreasing	11.19	-0.250	-0.746	0.00000
		Temp	increasing	2.40	0.036		
5oj006	32	Flow	decreasing	1.21	-0.333	-0.387	0.18485
		Temp	increasing	2.40	0.036		
5oj008	32	Flow	decreasing	2.30	-0.391	-0.645	0.00002
		Temp	increasing	2.40	0.036		
5oj009	32	Flow	decreasing	1.55	-0.417	-0.621	0.00006
		Temp	increasing	2.40	0.036		
5pa006	69	Flow	decreasing	41.18	0.000	-0.778	0.00000
		Temp	increasing	6.20	0.006		
5pb014	74	Flow	decreasing	4.43	-0.100	0.320	0.00564
		Temp	increasing	3.23	0.008		
5pc010	35	Flow	decreasing	38.27	-0.080	-0.499	0.00247
		Temp	decreasing	11.09	-0.017		
5pc011	40	Flow	decreasing	2.80	-0.375	-0.192	8.05238
		Temp	decreasing	23.51	-0.008		
5ph003	50	Flow	decreasing	22.57	-0.100	-0.703	0.00000
		Temp	increasing	5.98	0.018		
5pj001	32	Flow	decreasing	1.68	-0.737	-0.411	0.09391
		Temp	increasing	1.61	0.038		
5qa001	60	Flow	increasing	25.56	0.059	0.456	0.00003
		Temp	increasing	6.94	0.009		
5qa002	70	Flow	increasing	35.38	0.019	0.330	0.00543
		Temp	increasing	5.86	0.006		
5qa004	30	Flow	decreasing	1.61	-0.652	-0.692	0.00001
		Temp	increasing	14.63	0.014		
5qe009	32	Flow	decreasing	8.16	-0.250	0.498	0.00608
		Temp	increasing	37.89	0.000		

5ra001	32	Flow	decreasing	1.06	-0.500	-0.569	0.00048
		Temp	increasing	1.61	0.038		
5ra002	32	Flow	decreasing	2.05	-0.333	-0.573	0.00041
		Temp	increasing	1.61	0.038		
5rd007	34	Flow	decreasing	98.98	-1.762	-0.130	27.91707
		Temp	increasing	4.00	0.025		
5rd008	34	Flow	decreasing	0.03	-1.833	-0.376	0.17603
		Temp	increasing	4.00	0.025		
5sa002	50	Flow	decreasing	8.38	-0.171	-0.647	0.00000
		Temp	increasing	5.98	0.018		
5sa004	32	Flow	decreasing	22.28	-0.182	-0.738	0.00000
		Temp	increasing	2.40	0.036		
5sb002	31	Flow	decreasing	1.68	-0.421	-0.531	0.00269
		Temp	increasing	2.32	0.033		
5sc002	33	Flow	decreasing	3.73	-0.259	-0.561	0.00045
		Temp	increasing	1.68	0.036		
5sd003	31	Flow	decreasing	0.95	-0.429	-0.467	0.02258
		Temp	increasing	0.86	0.042		
5sd004	31	Flow	decreasing	0.99	-0.375	-0.527	0.00313
		Temp	increasing	0.86	0.042		
5tb002	34	Flow	increasing	9.11	0.625	-0.112	35.03350
		Temp	increasing	4.00	0.025		
5uf004	30	Flow	decreasing	18.13	-0.400	-0.361	0.50938
		Temp	increasing	0.02	0.064		
6ad001	32	Flow	decreasing	0.21	-0.500	-0.879	0.00000
		Temp	increasing	1.61	0.038		
6ad006	36	Flow	decreasing	4.43	-0.212	-0.349	0.27301
		Temp	increasing	2.65	0.025		
7af002	37	Flow	increasing	40.19	0.059	0.171	13.59635
		Temp	increasing	1.22	0.031		
7ag003	37	Flow	increasing	25.65	0.150	-0.378	0.09811
		Temp	increasing	1.22	0.031		
7bb002	37	Flow	decreasing	18.69	-0.222	-0.688	0.00000
		Temp	increasing	1.22	0.031		
7bf001	33	Flow	decreasing	0.17	-0.609	-0.492	0.00561
		Temp	increasing	1.68	0.036		
7cd001	33	Flow	decreasing	3.36	-0.375	-0.409	0.08175
		Temp	increasing	3.85	0.026		
7da001	34	Flow	decreasing	0.89	-0.571	-0.176	14.22075
		Temp	increasing	4.00	0.025		
7ge001	31	Flow	decreasing	0.59	-0.792	-0.372	0.32781
		Temp	increasing	0.86	0.042		
7gj001	36	Flow	increasing	18.79	0.235	0.413	0.03980
		Temp	increasing	2.65	0.025		

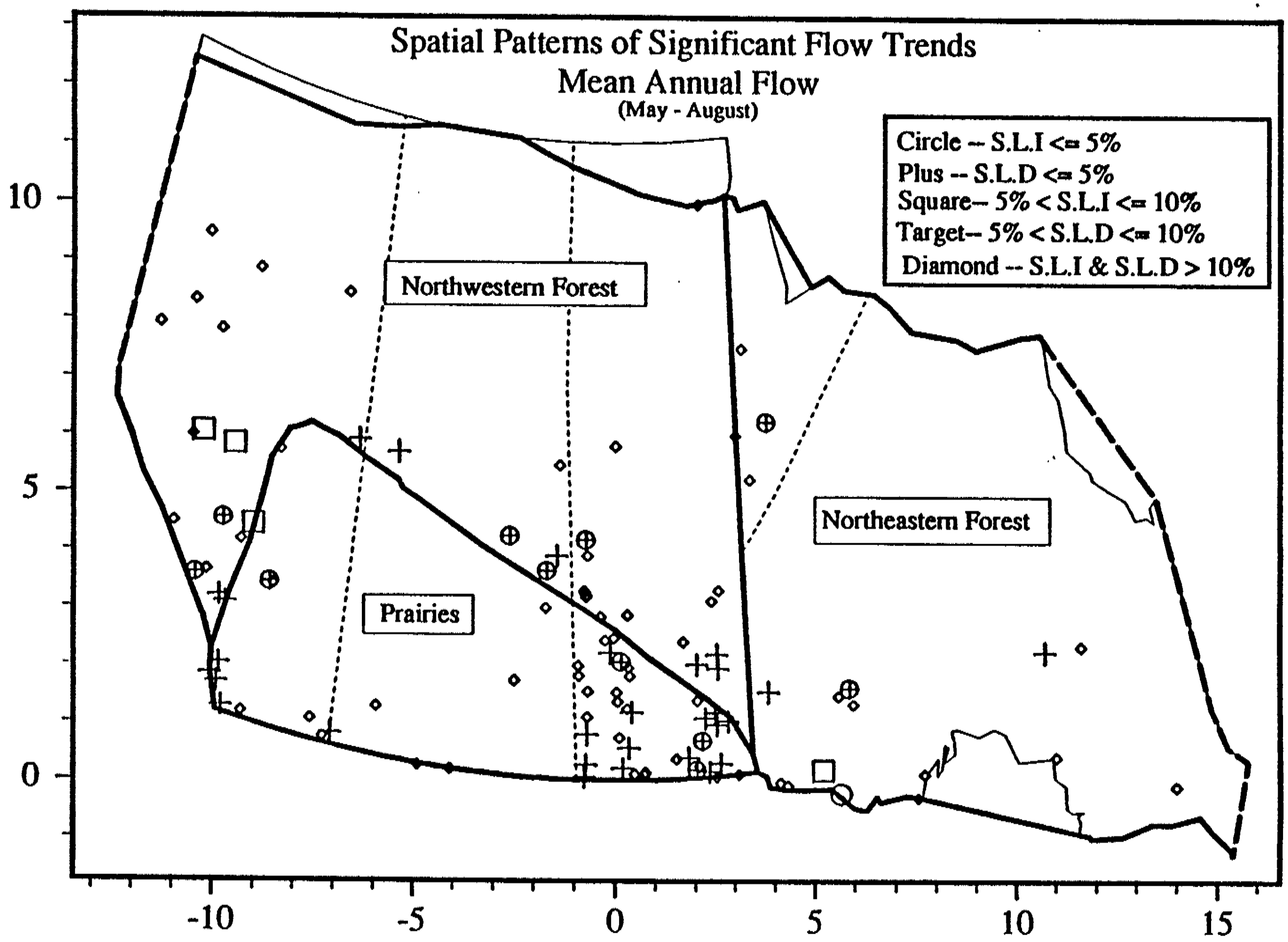
7hc001	31	Flow	decreasing	0.59	−0.500	−0.725	0.00000
		Temp	increasing	0.86	0.042		
11aa26	55	Flow	decreasing	3.15	−0.250	−0.295	0.14689
		Temp	increasing	24.75	0.006		
11ab82	41	Flow	decreasing	0.50	−0.571	−0.578	0.00001
		Temp	increasing	3.44	0.027		
11ae08	61	Flow	increasing	24.10	0.062	−0.281	0.13811
		Temp	increasing	31.59	0.004		
11ae09	35	Flow	decreasing	23.45	−0.154	−0.597	0.00005
		Temp	increasing	5.58	0.025		

APPENDIX C: Regionalization Maps for Trend Results

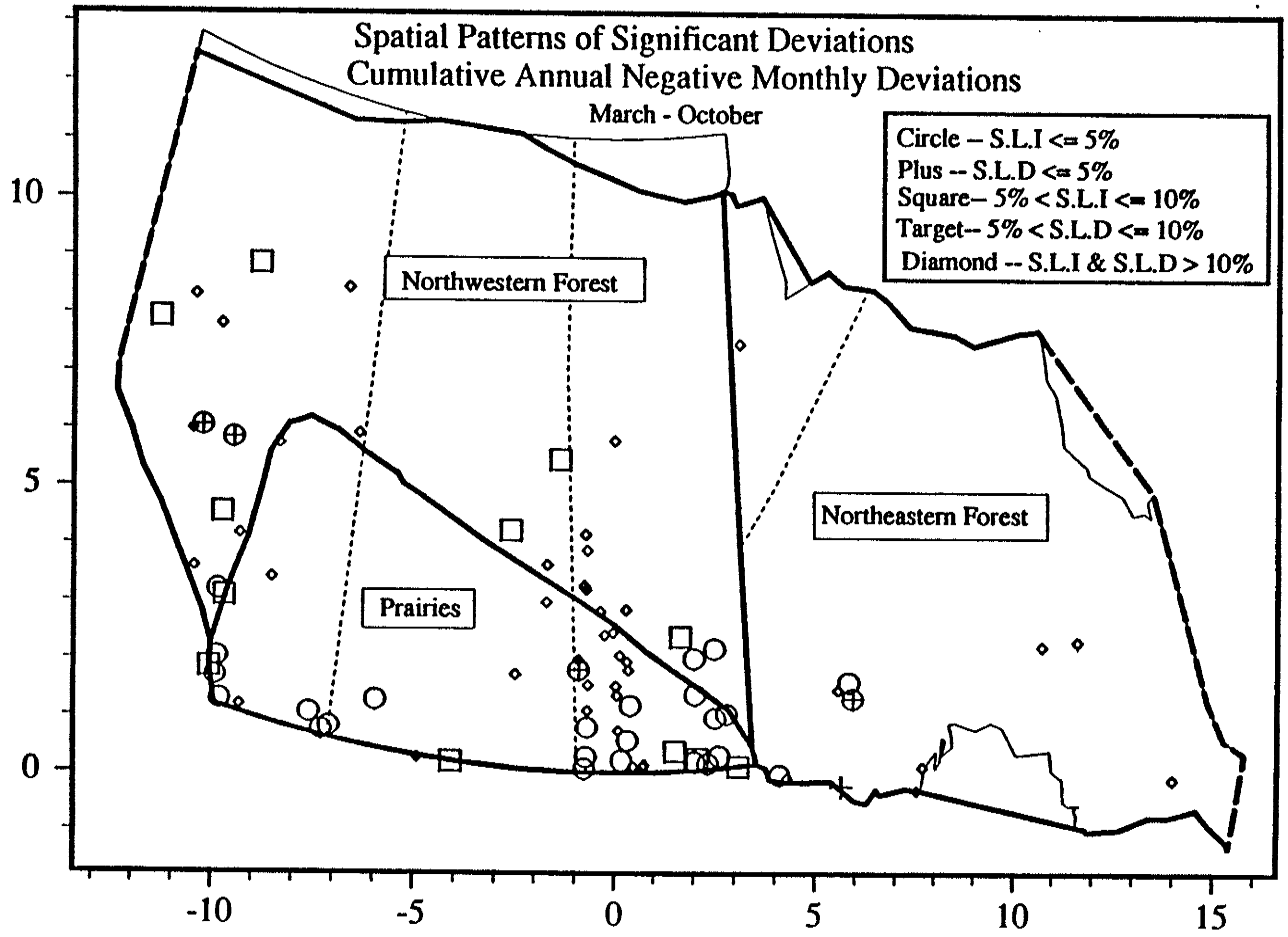
C-1: Mean Annual Flow
C-2: CND
C-3: Mean Seasonal Flow
C-4: Mean Monthly Flow
C-5: Extreme Annual Flow
C-6: Maximum Summer Precipitation Event
C-7: Julian Day of Spring Melt


Spatialization of Significant Flow Trends
Mean Annual Flow
(March - October)
Circle -- S.L.I <= 5%
Plus -- S.L.D <= 5%
Square-- 5% < S.L.I <= 10%
Target-- 5% < S.L.D <= 10%
Diamond -- S.L.I & S.L.D > 10%
Northwestern Forest
Northeastern Forest
Prairies
10
5
0
-10
-5
0
5
10
15

Regionalization Analysis



Regionalization Analysis



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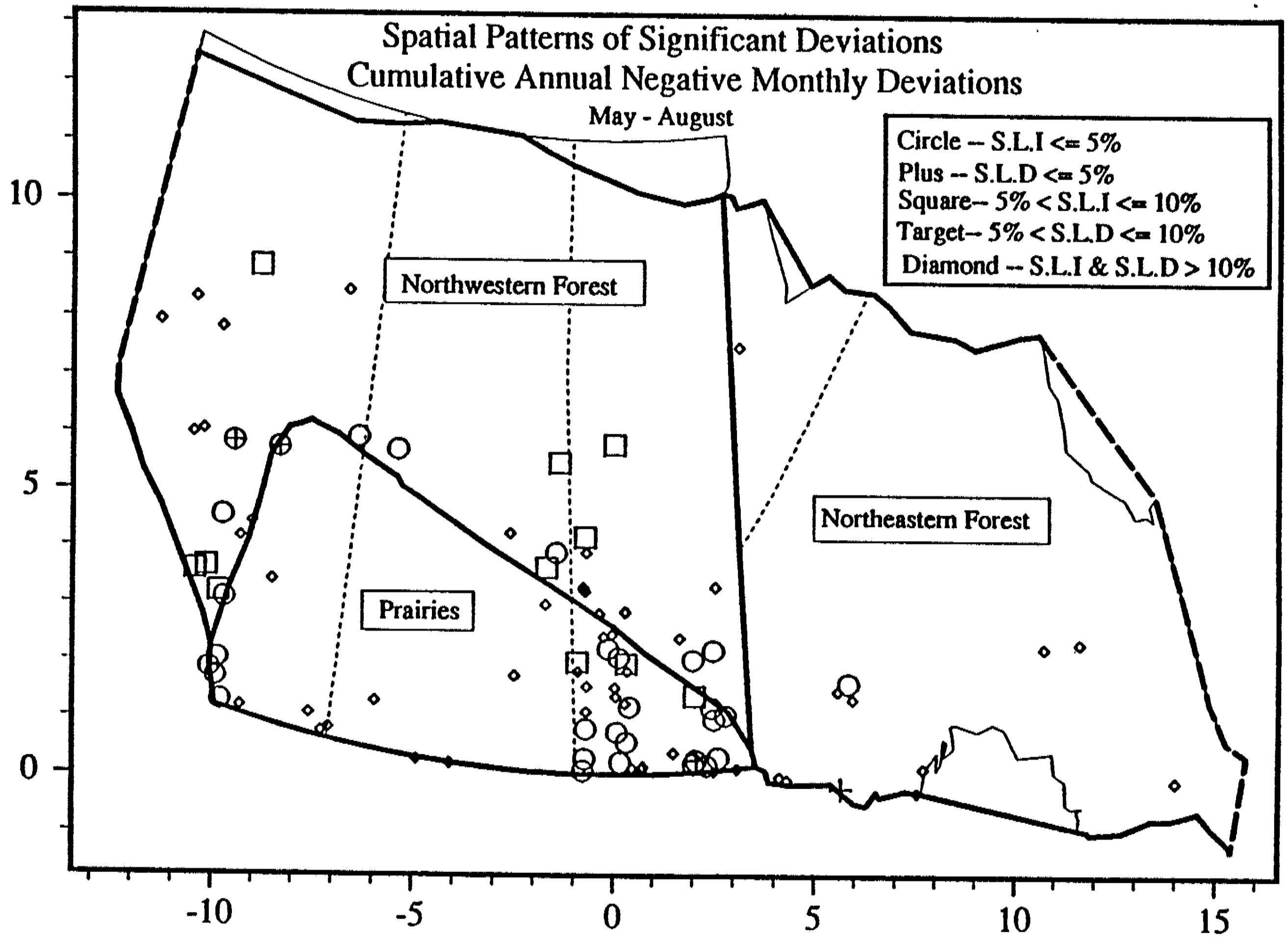

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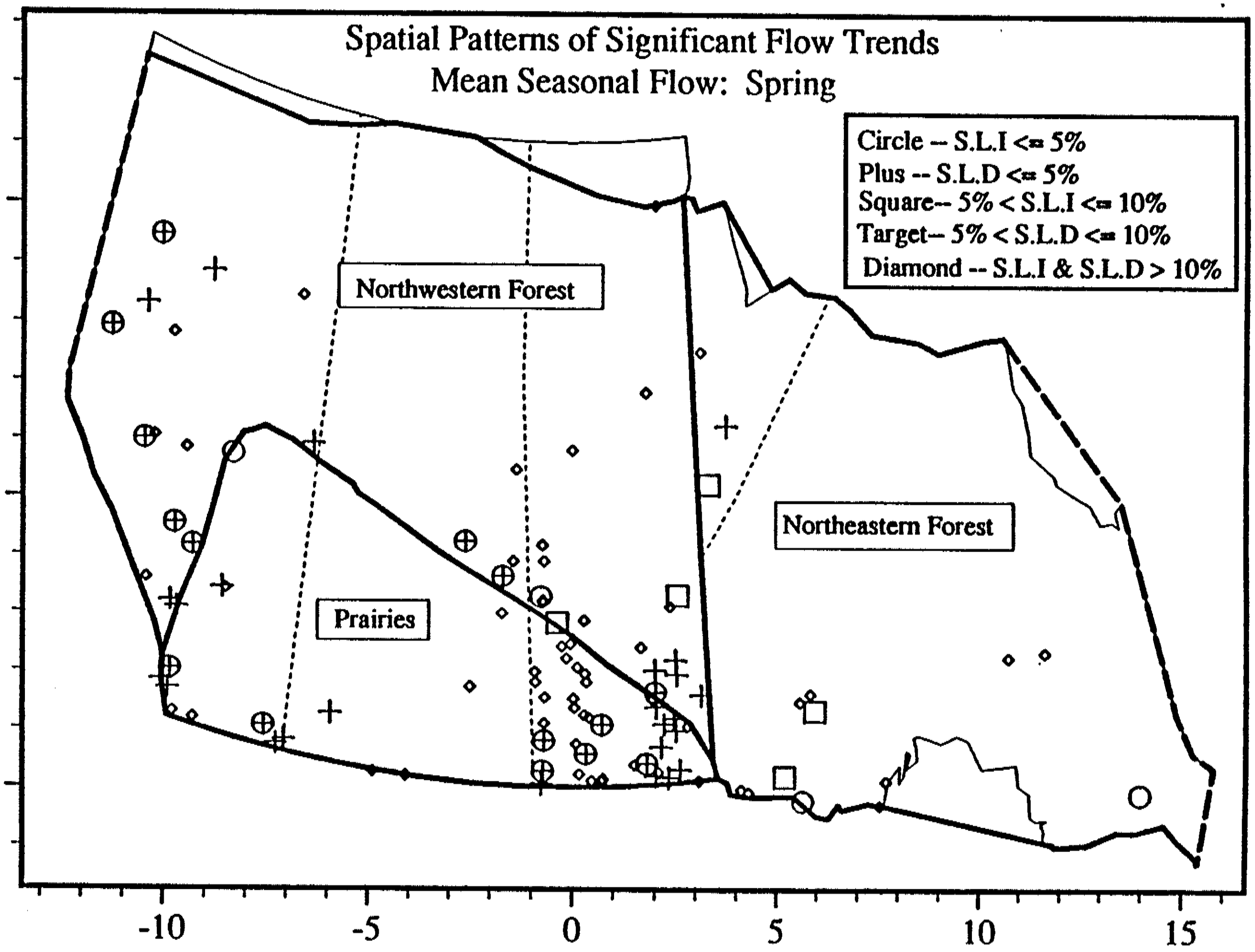

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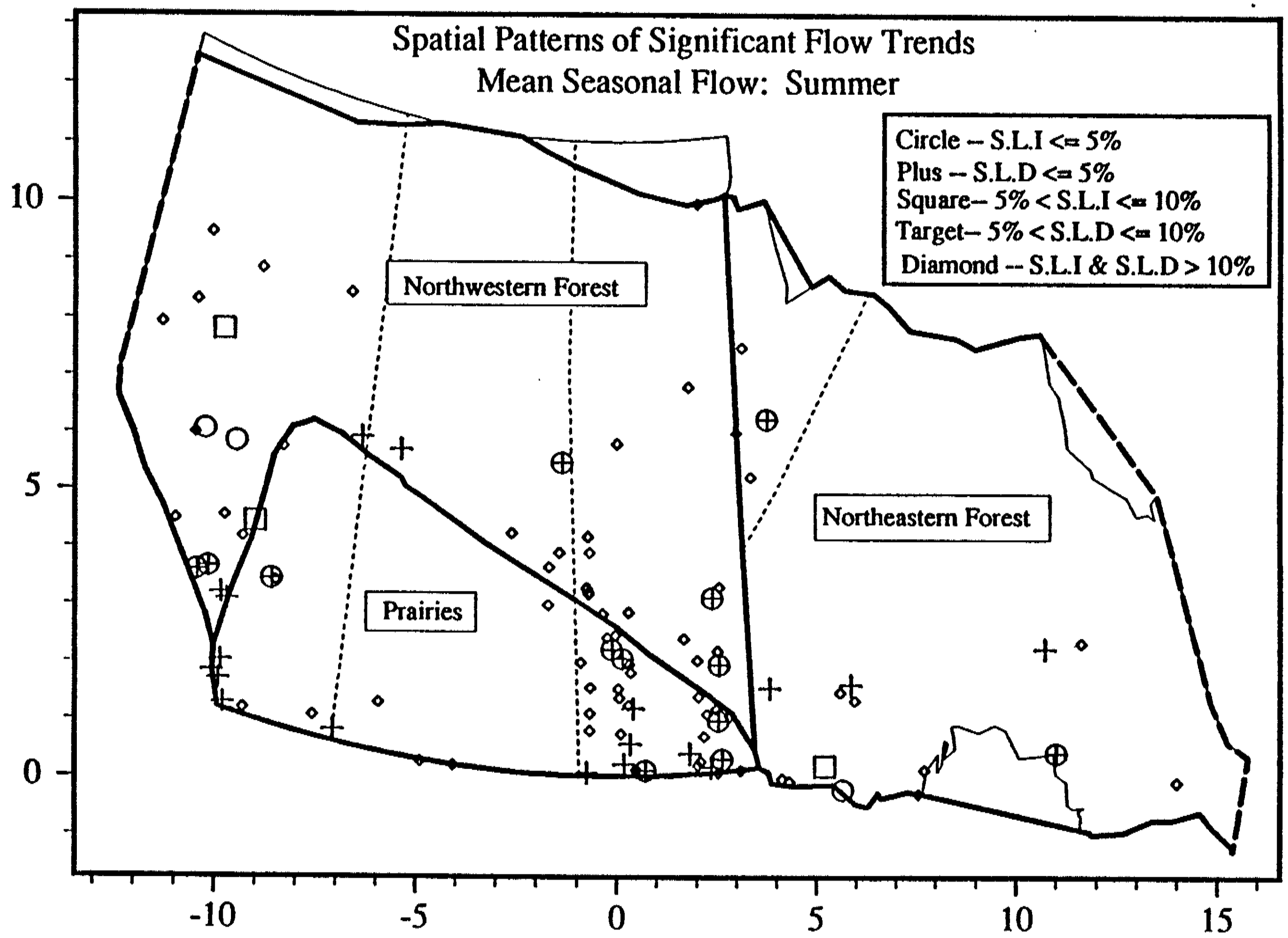

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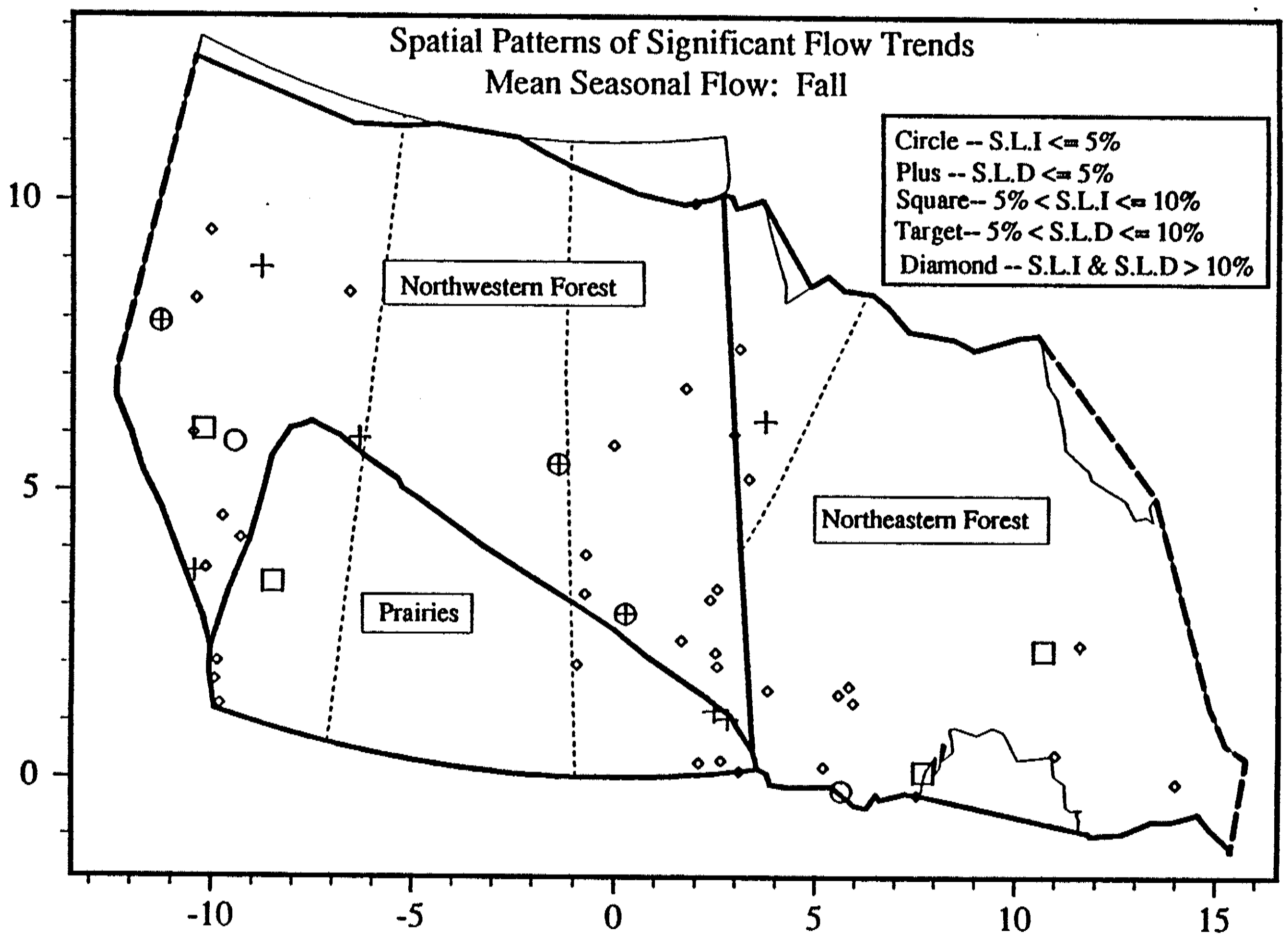

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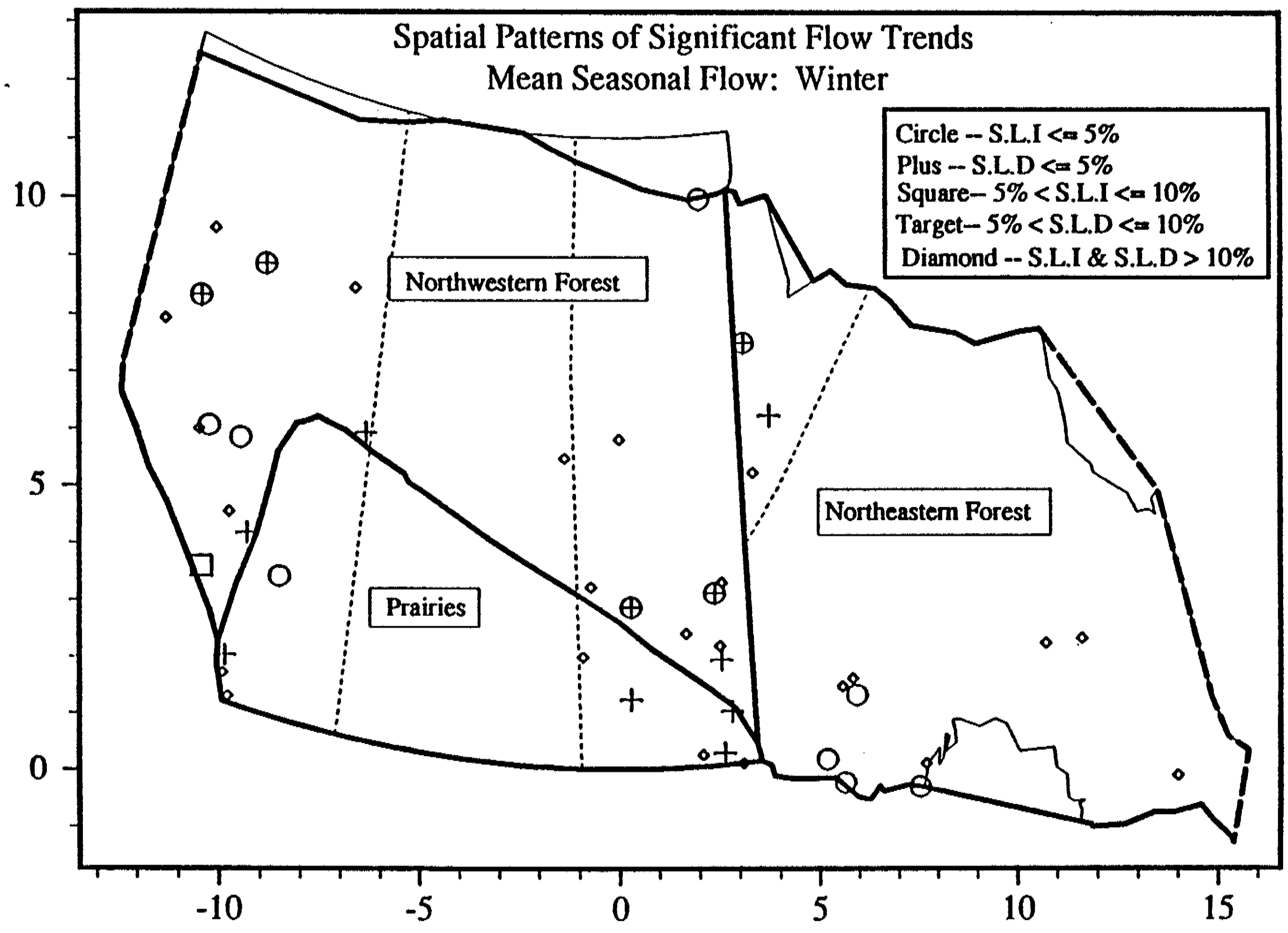

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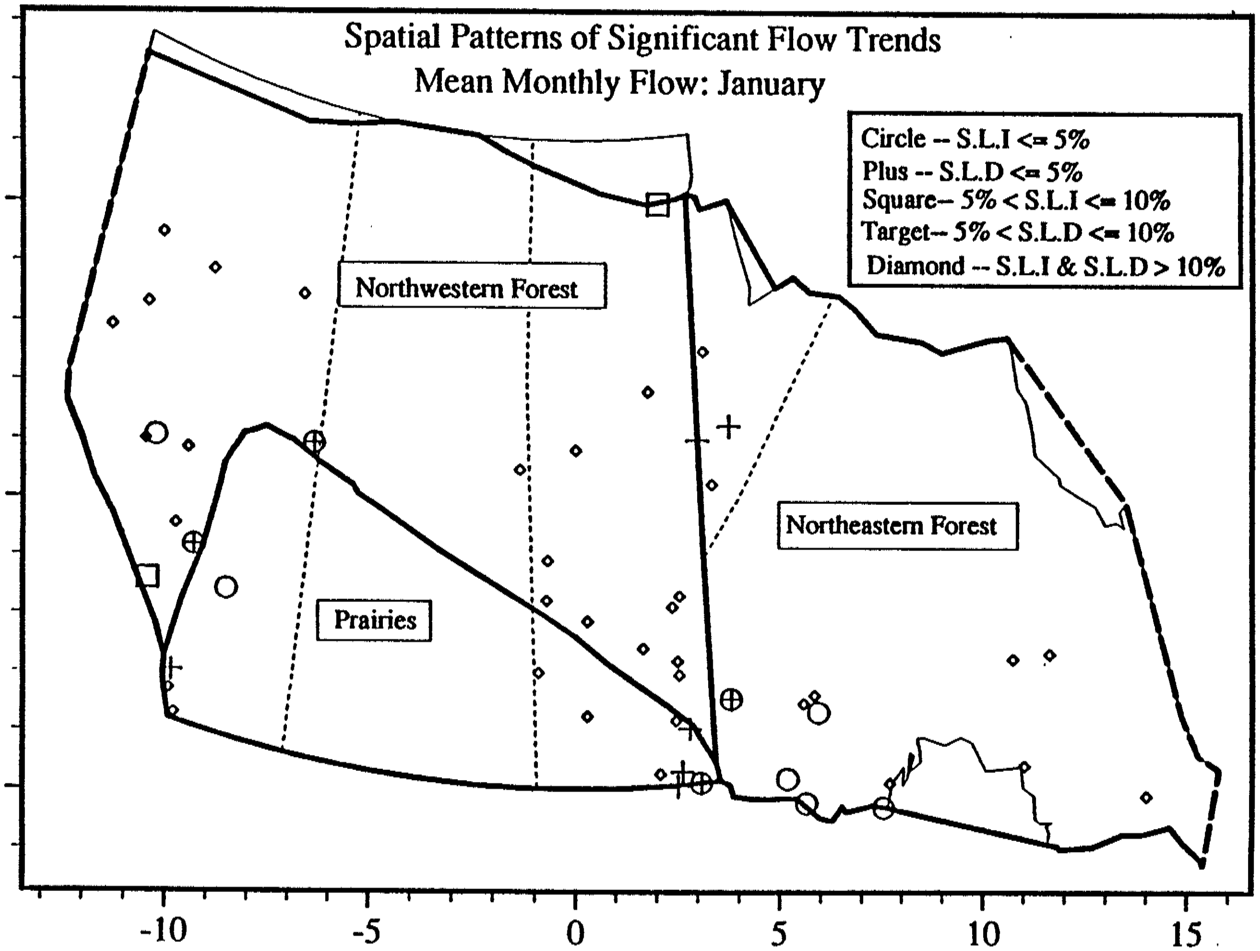

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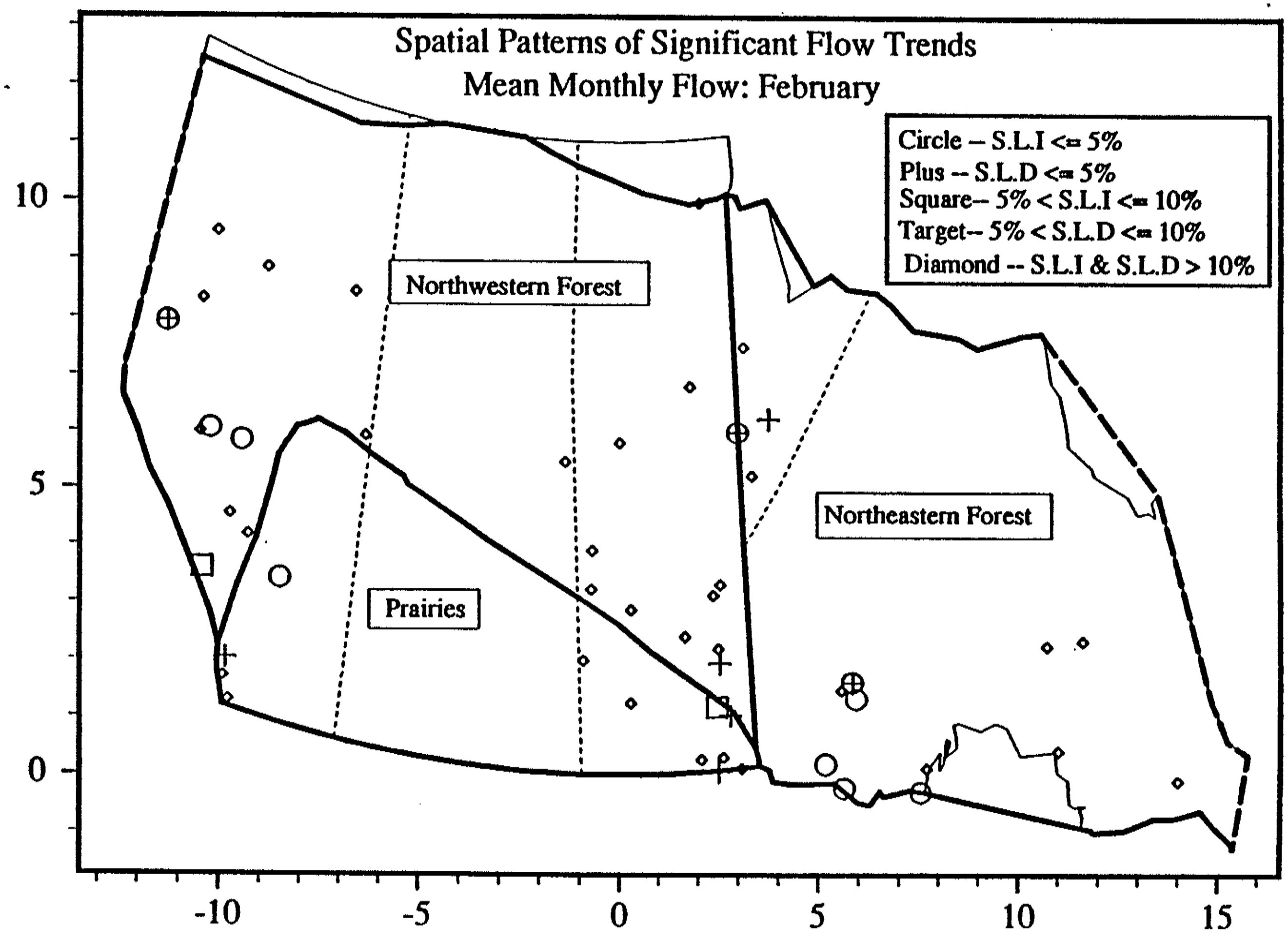

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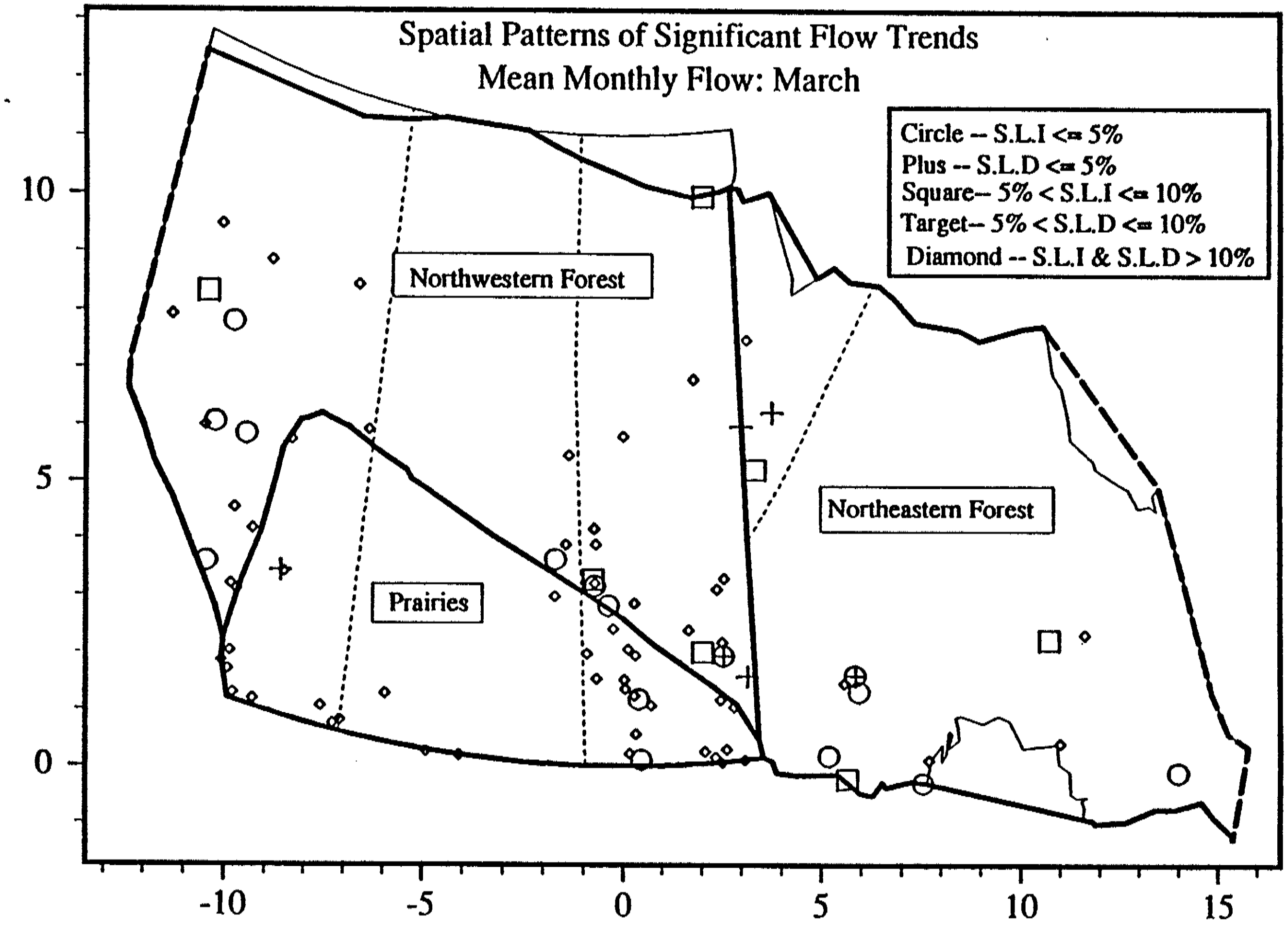

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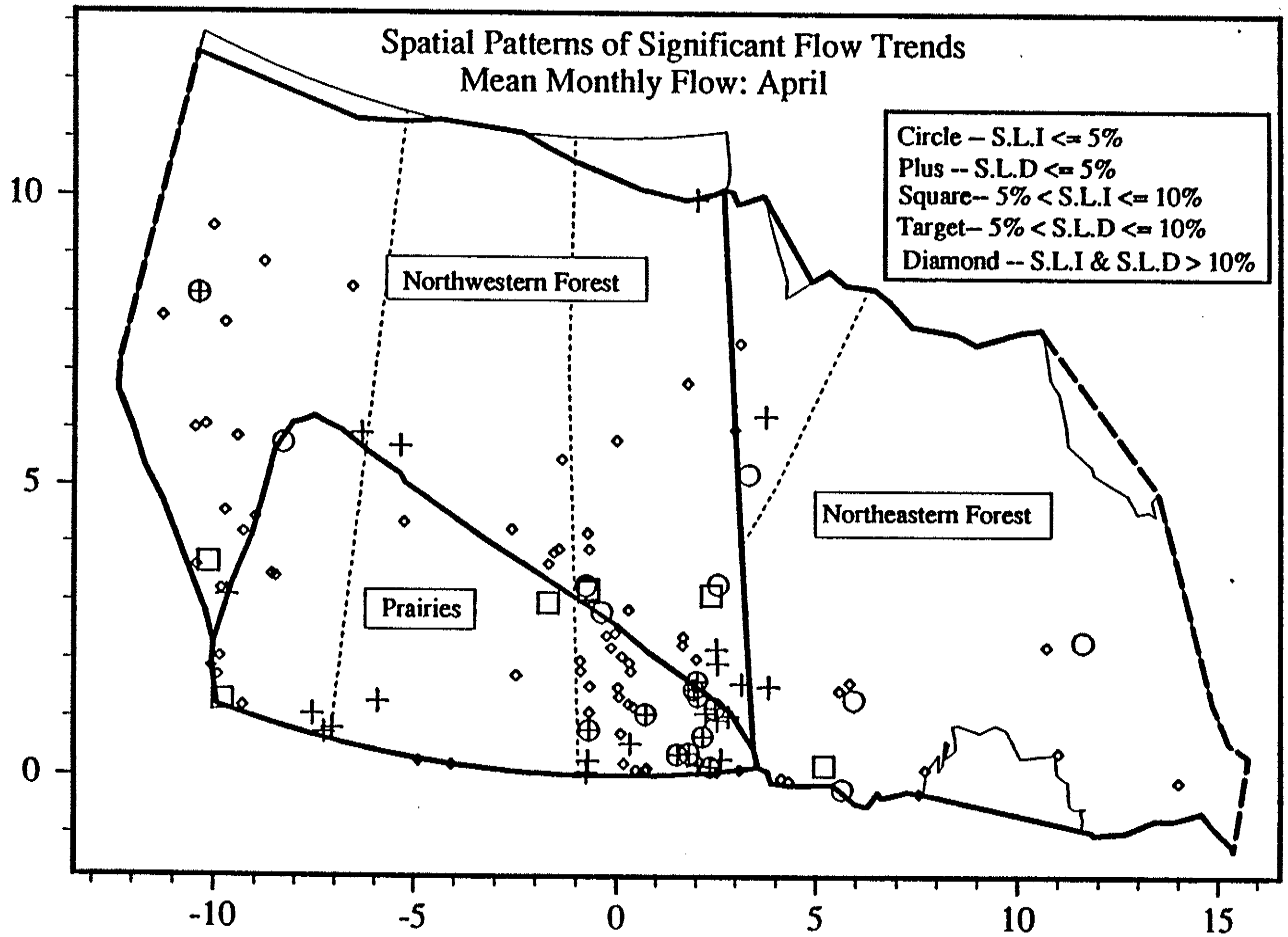

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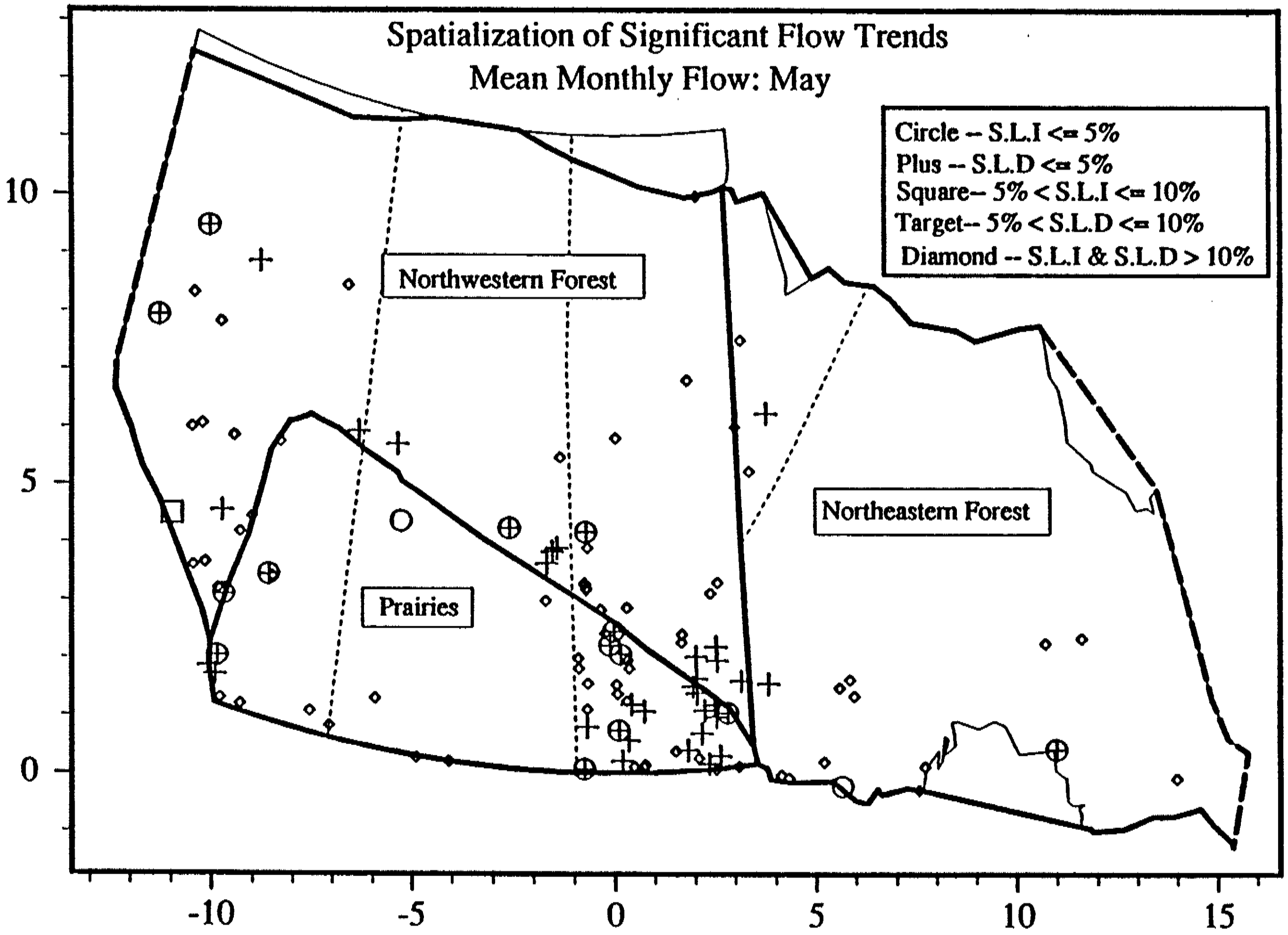

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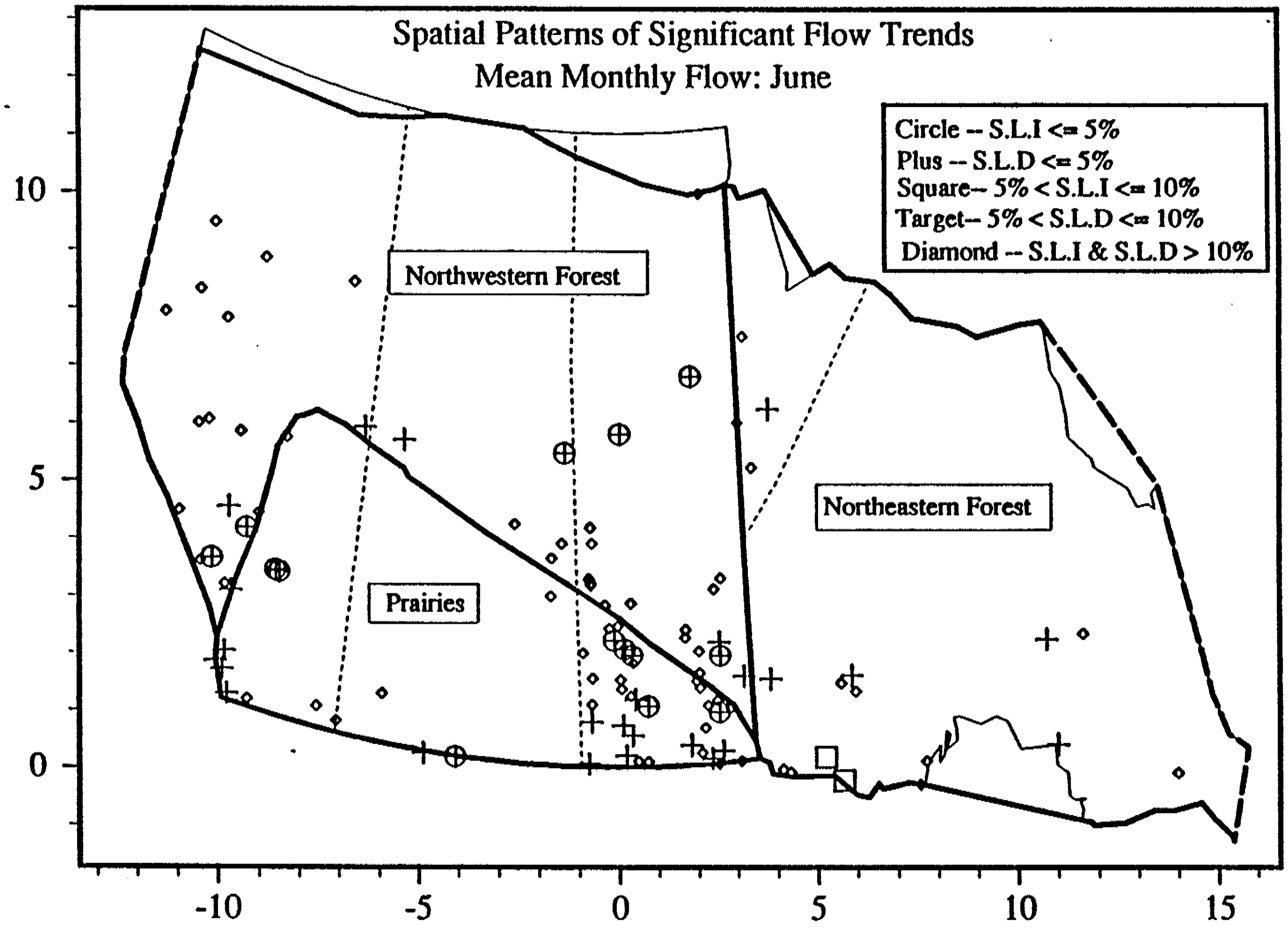

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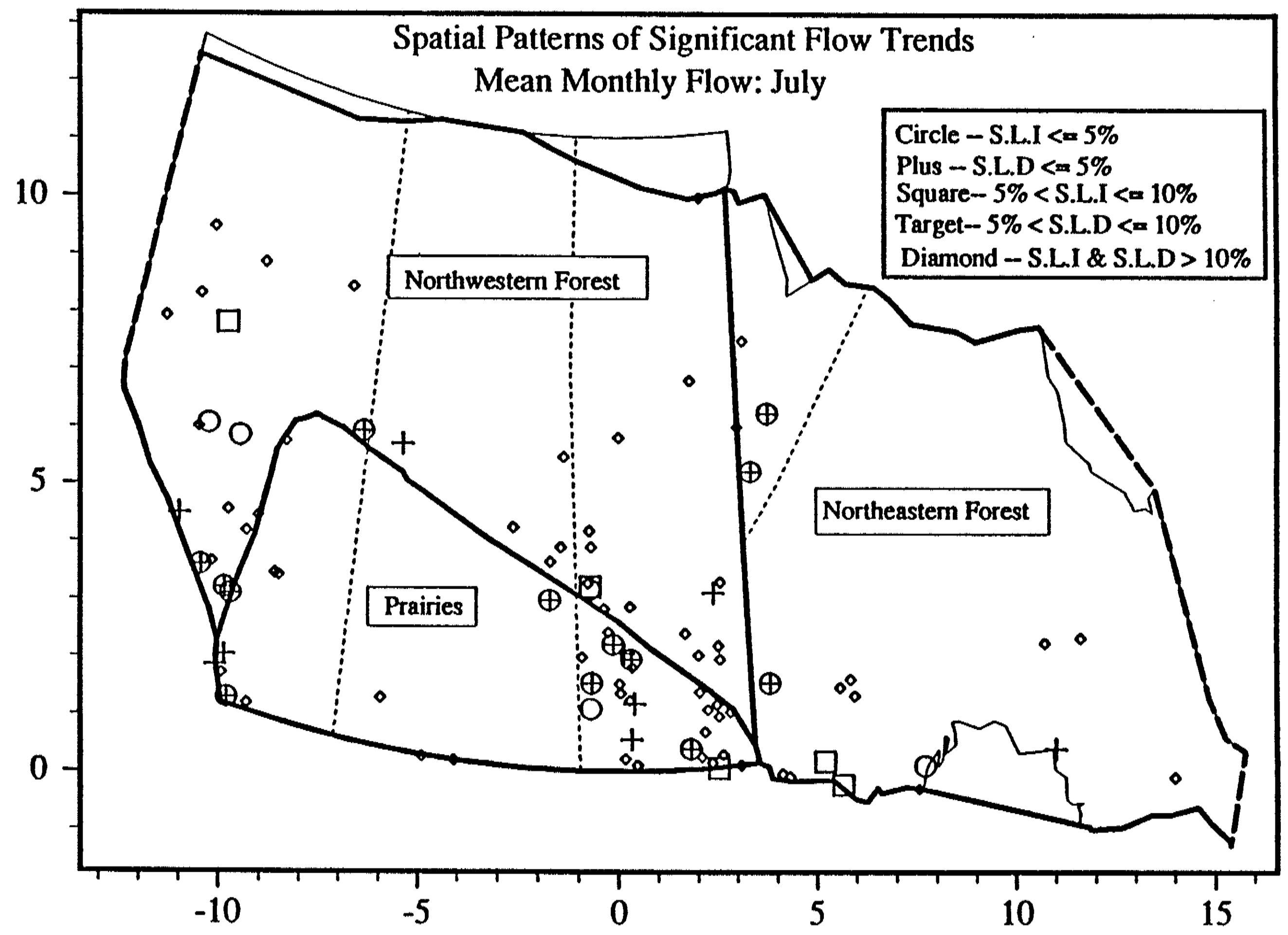

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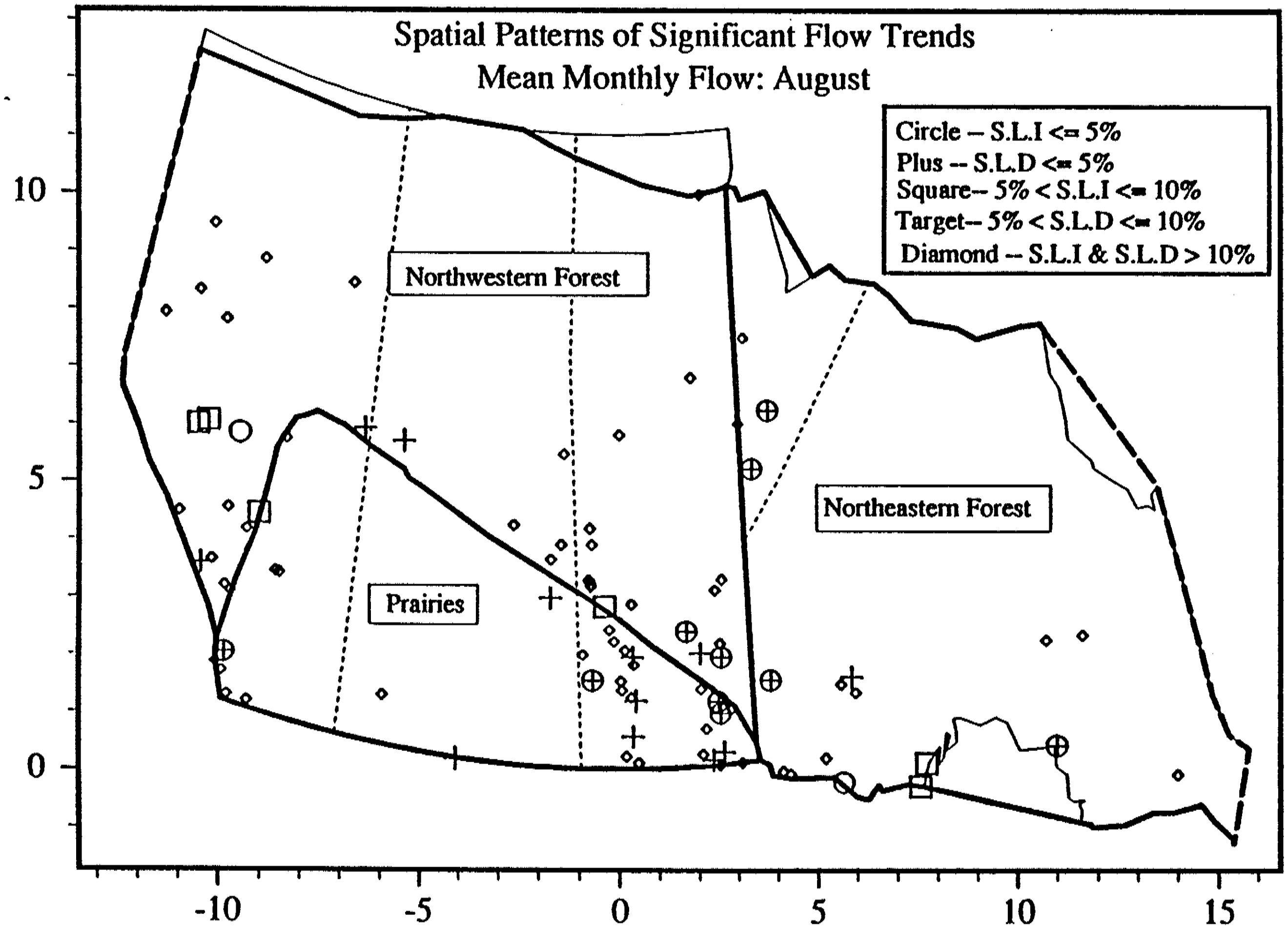

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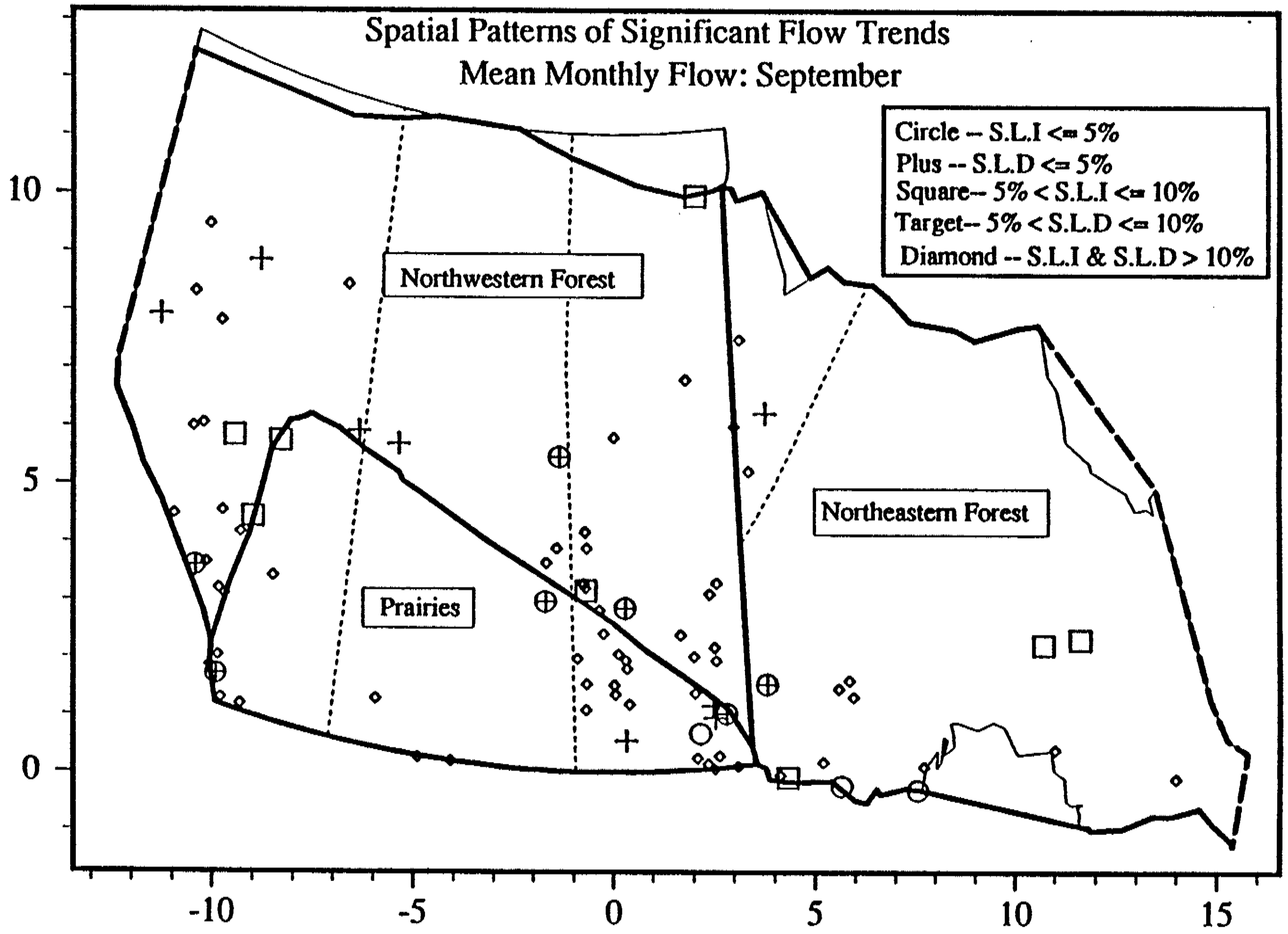
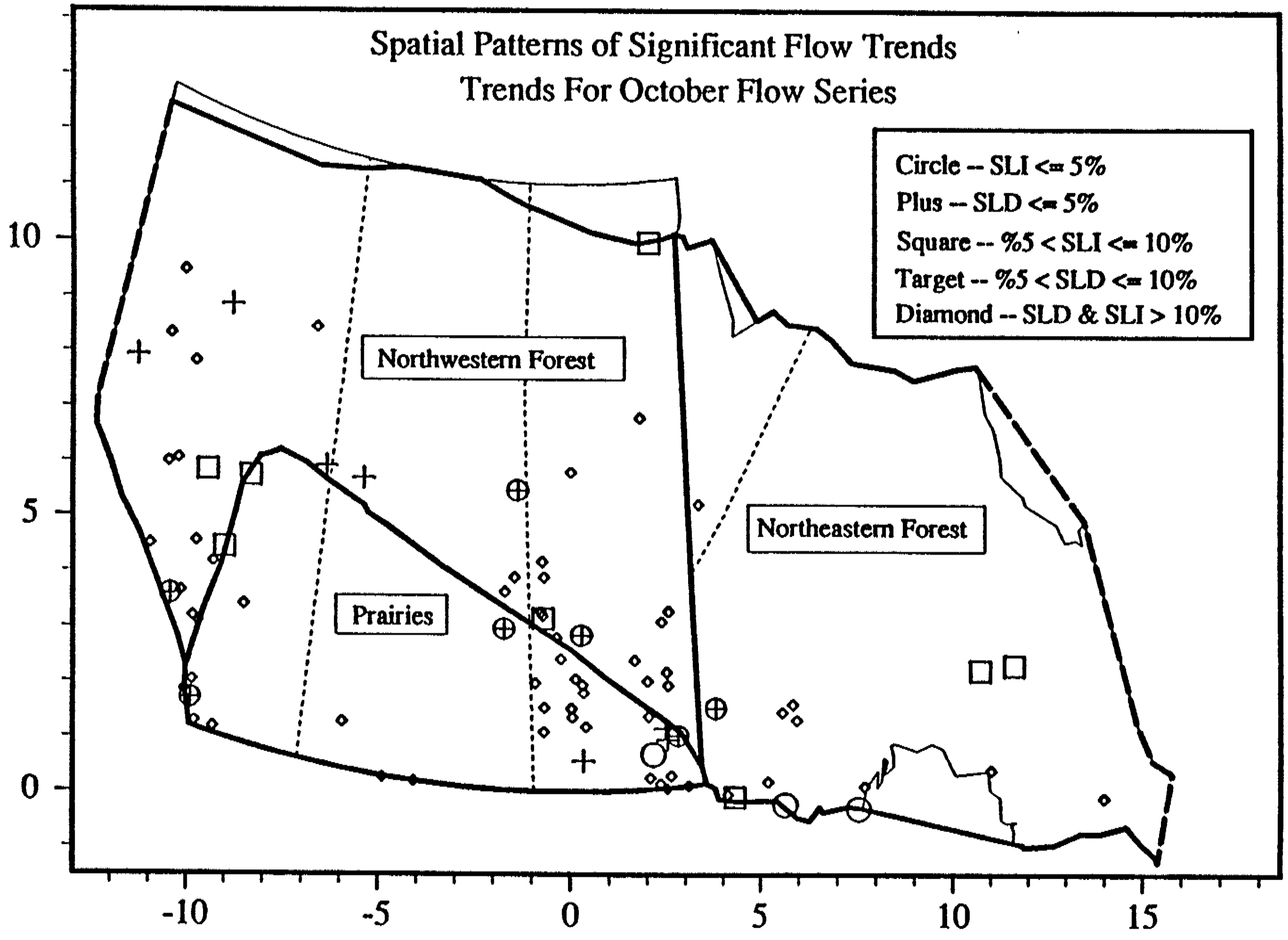
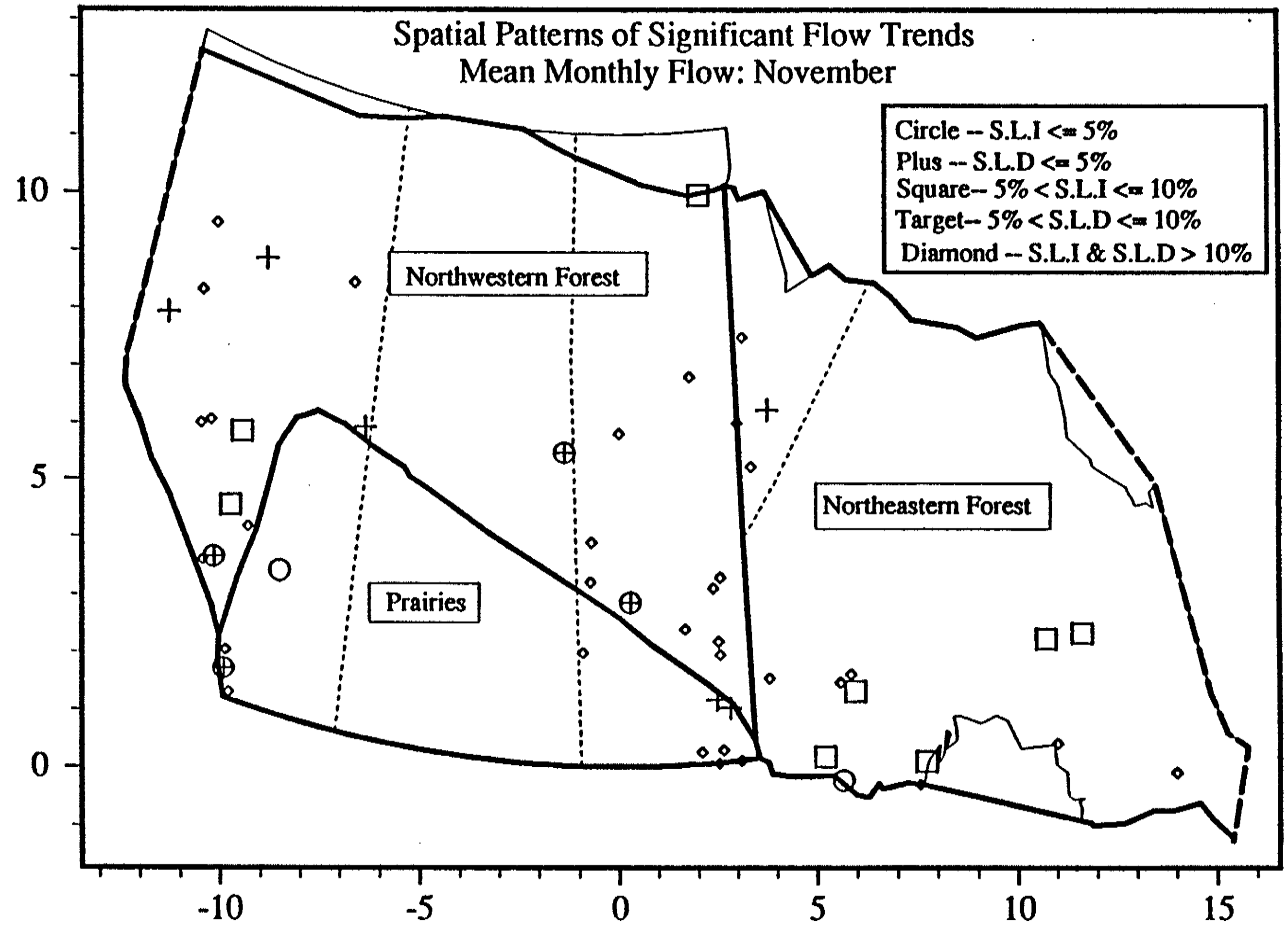


Spatial Patterns of Significant Flow Trends
Mean Monthly Flow: September

Regionalization Analysis


Spatial Patterns of Significant Flow Trends
Trends For October Flow Series

Regionalization Analysis



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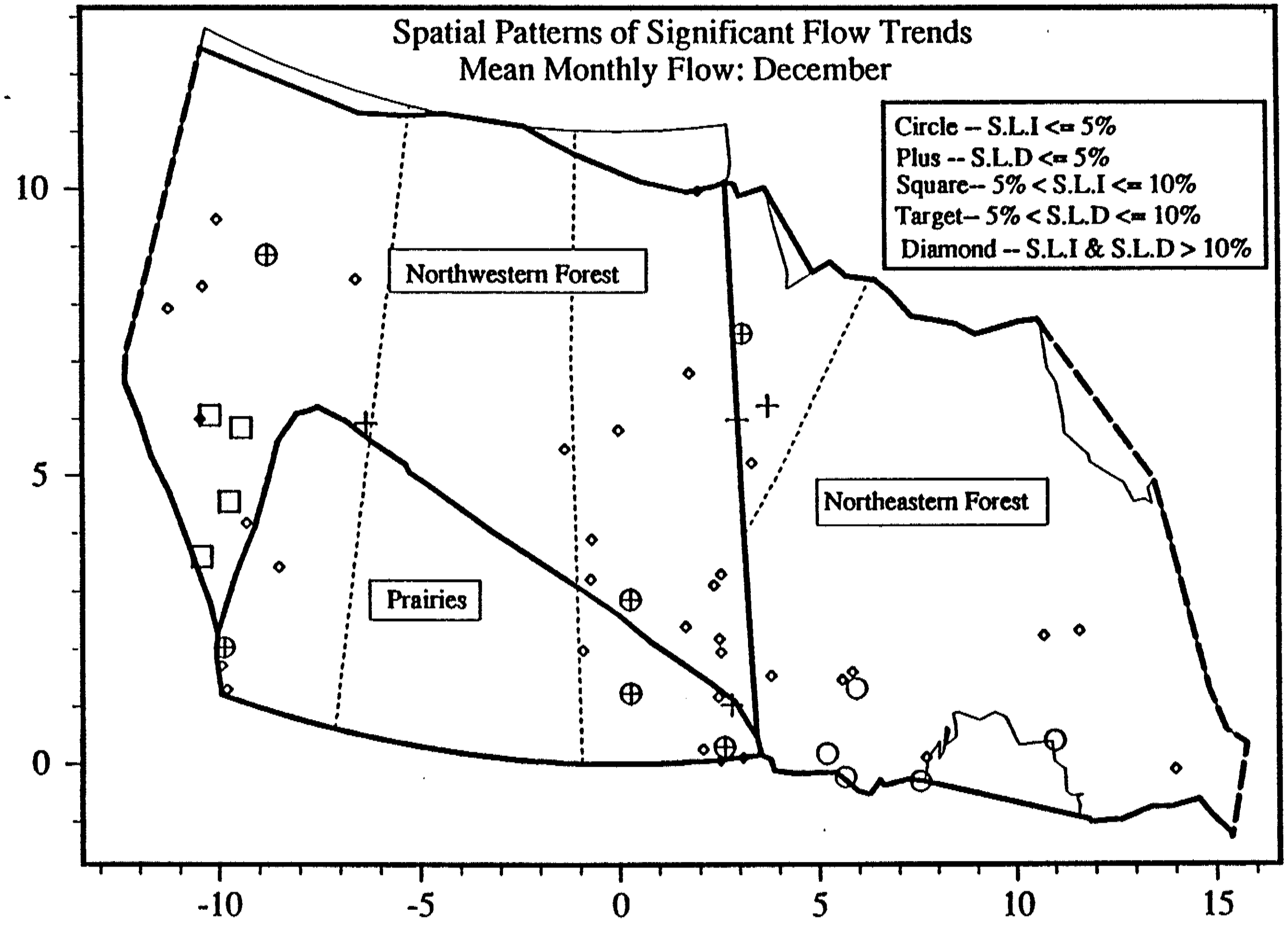

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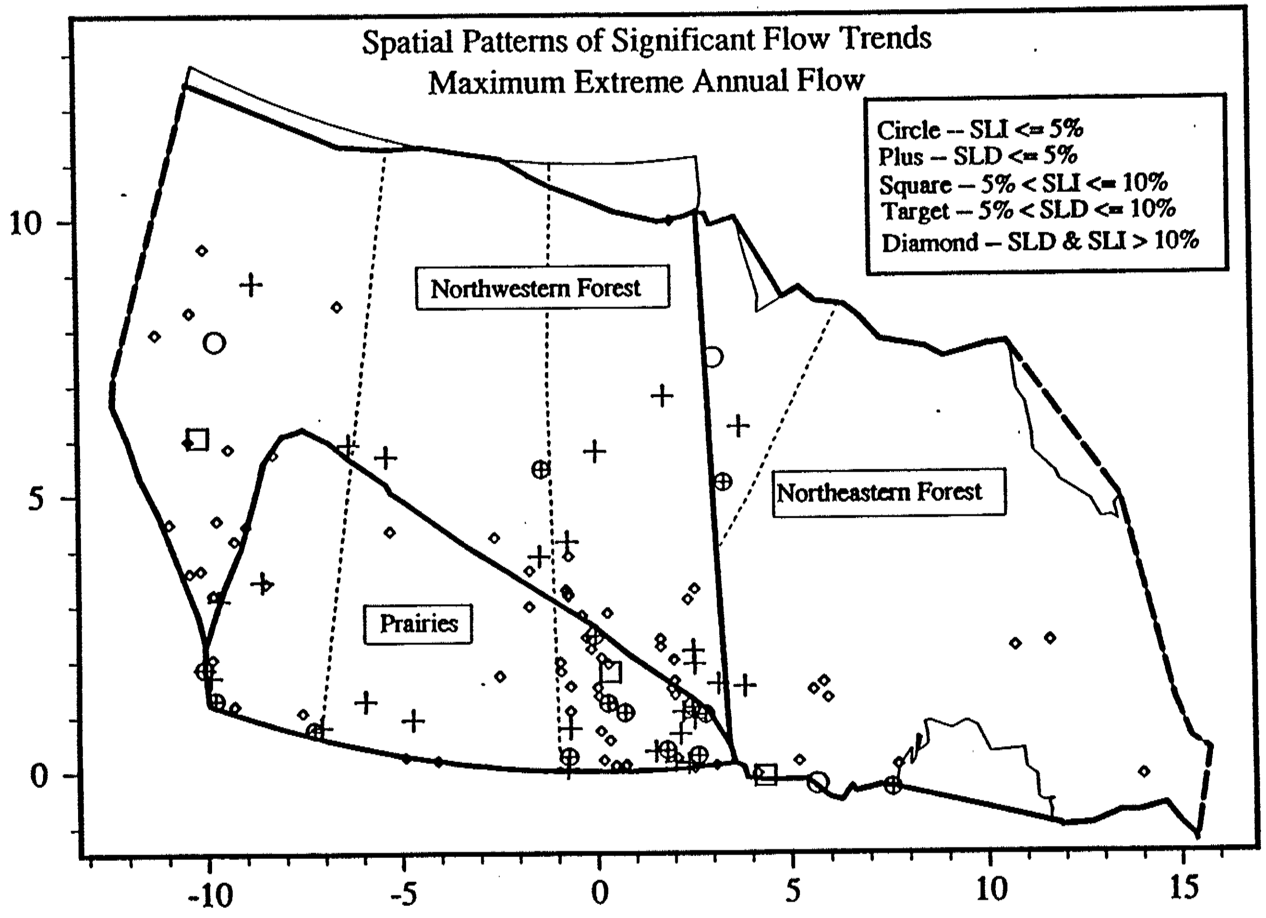

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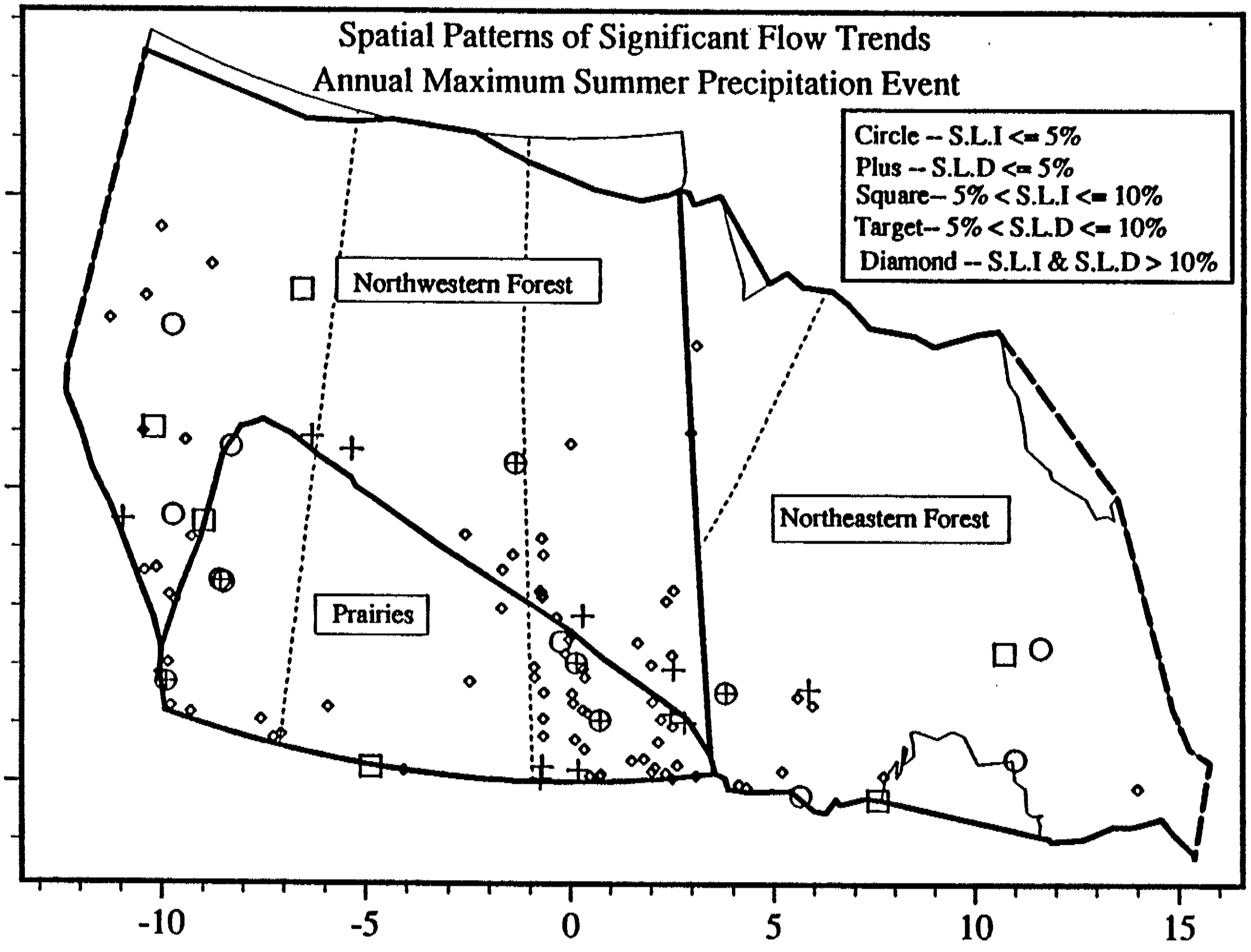

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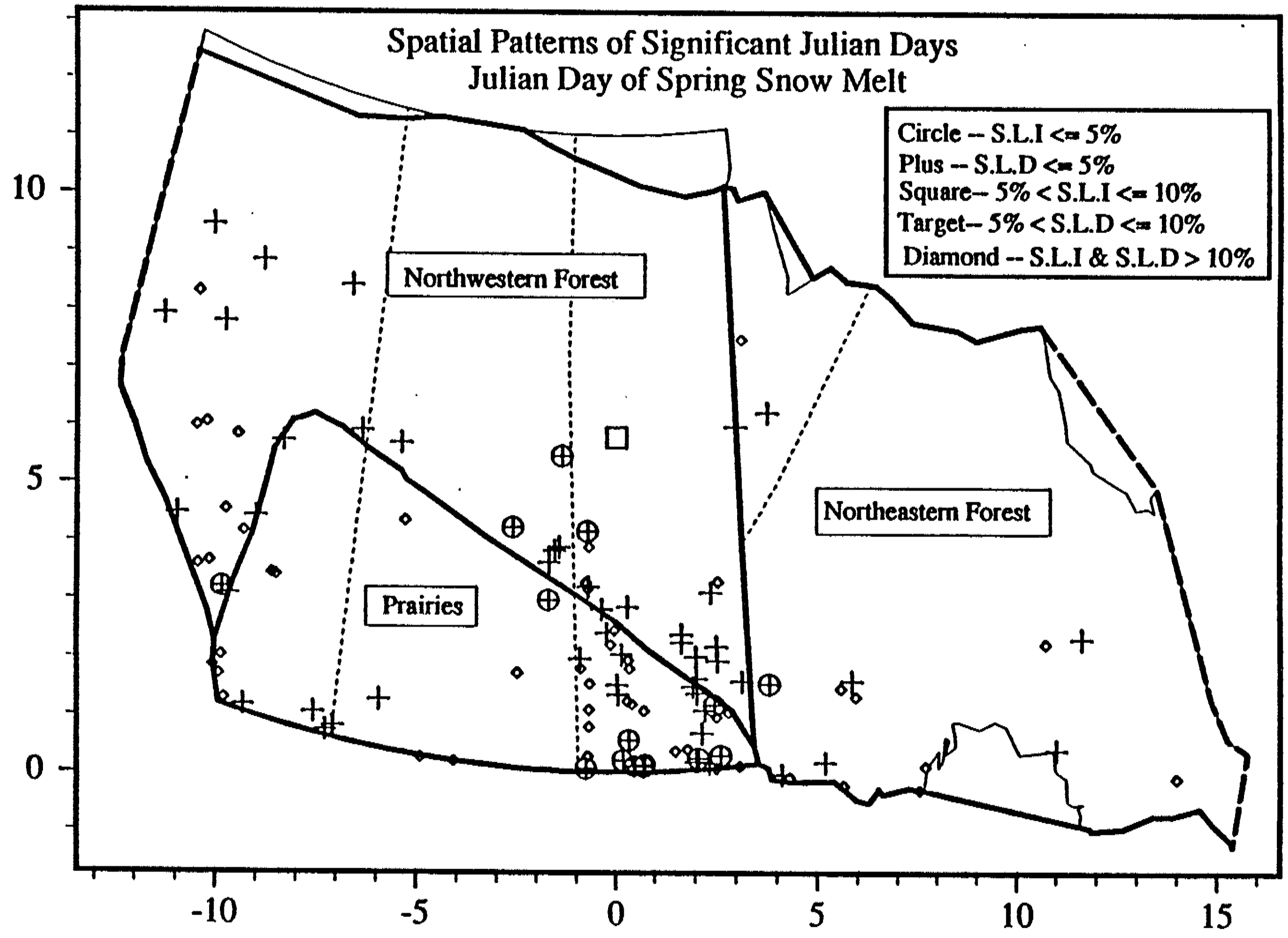


APPENDIX D: Regionalization Maps for Behavioral Responses

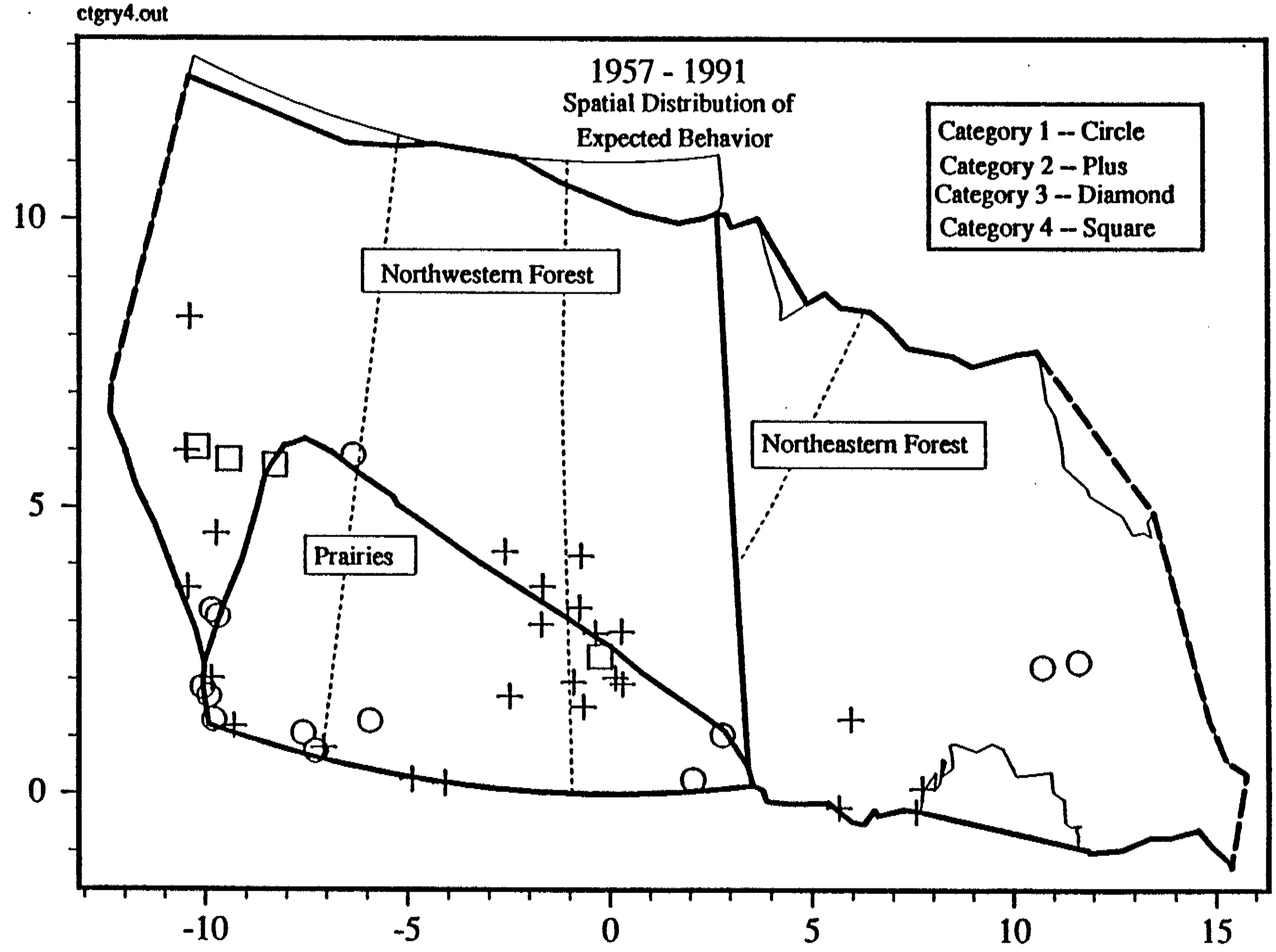
D-a: All Variables Considered Together

- D-a-1: Year boundary (1957-91)
- D-a-2: No Year Range Boundary

D-b: Separate Variable Analysis (No Year Range)

- D-b-1: Mean Annual Flow
- D-b-2: CND
- D-b-3: Extreme Annual Flow
- D-b-4: Maximum Summer Precipitation Event
- D-b-5: Julian Day of Spring Melt

Regionalization Analysis



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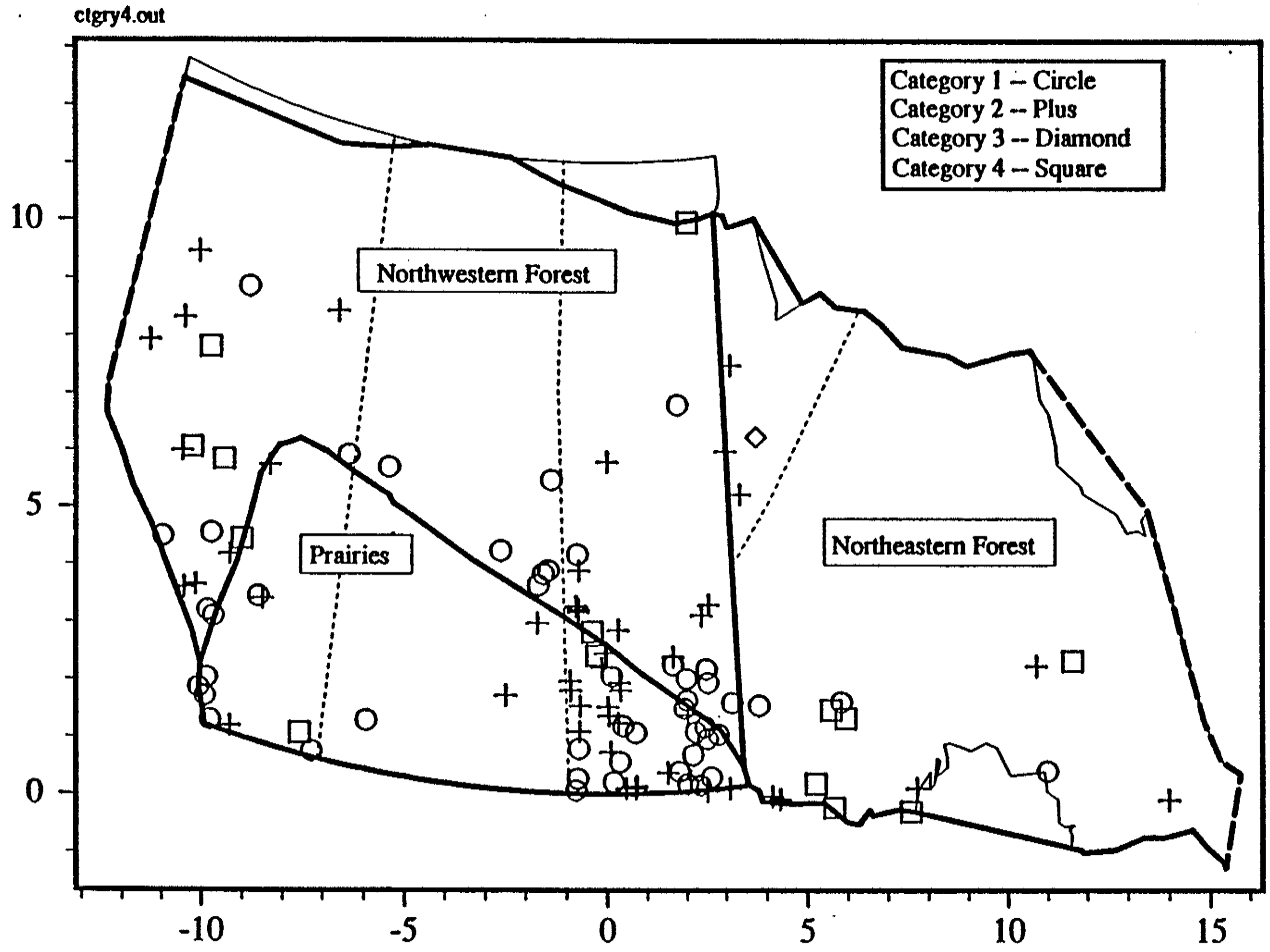

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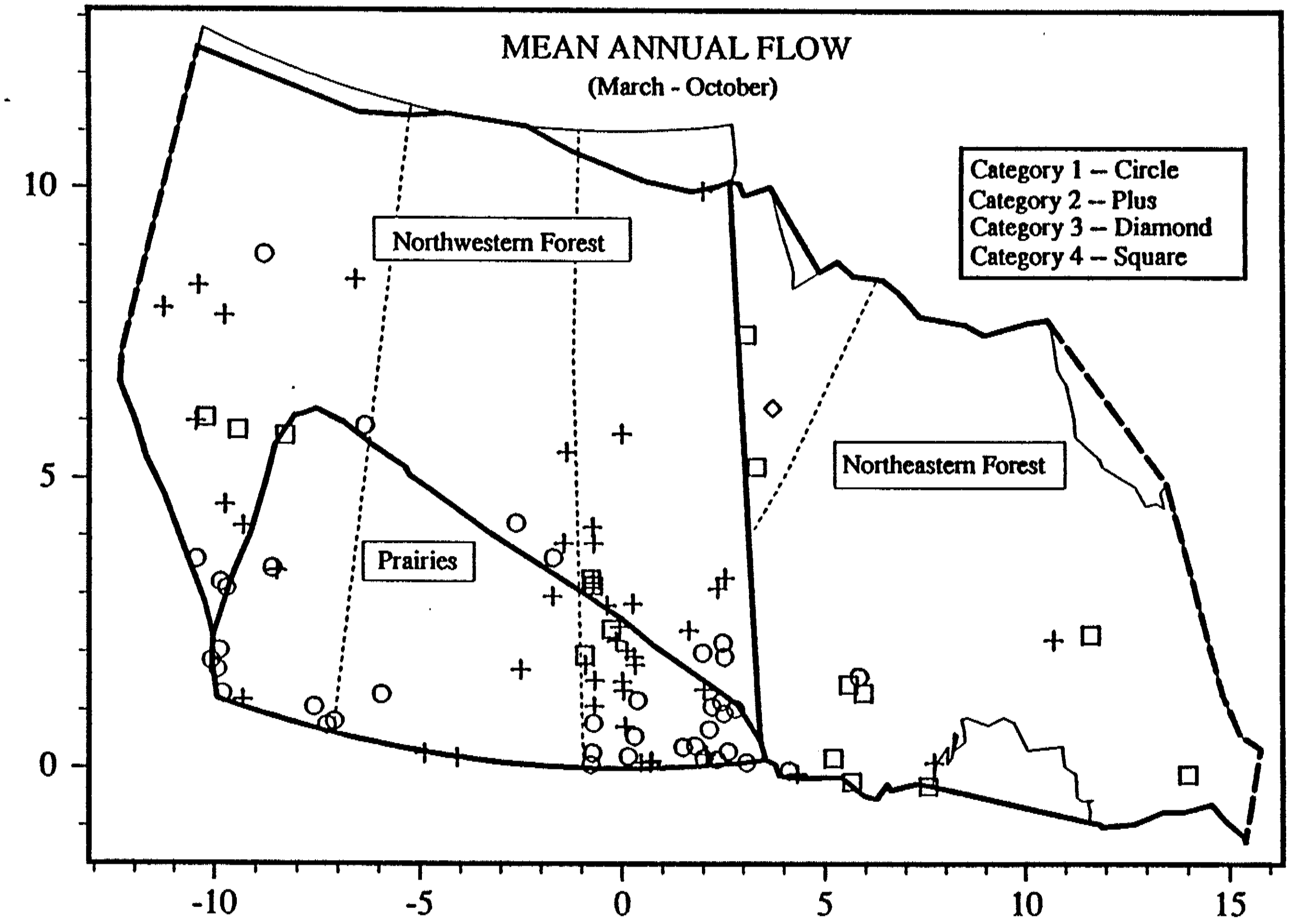

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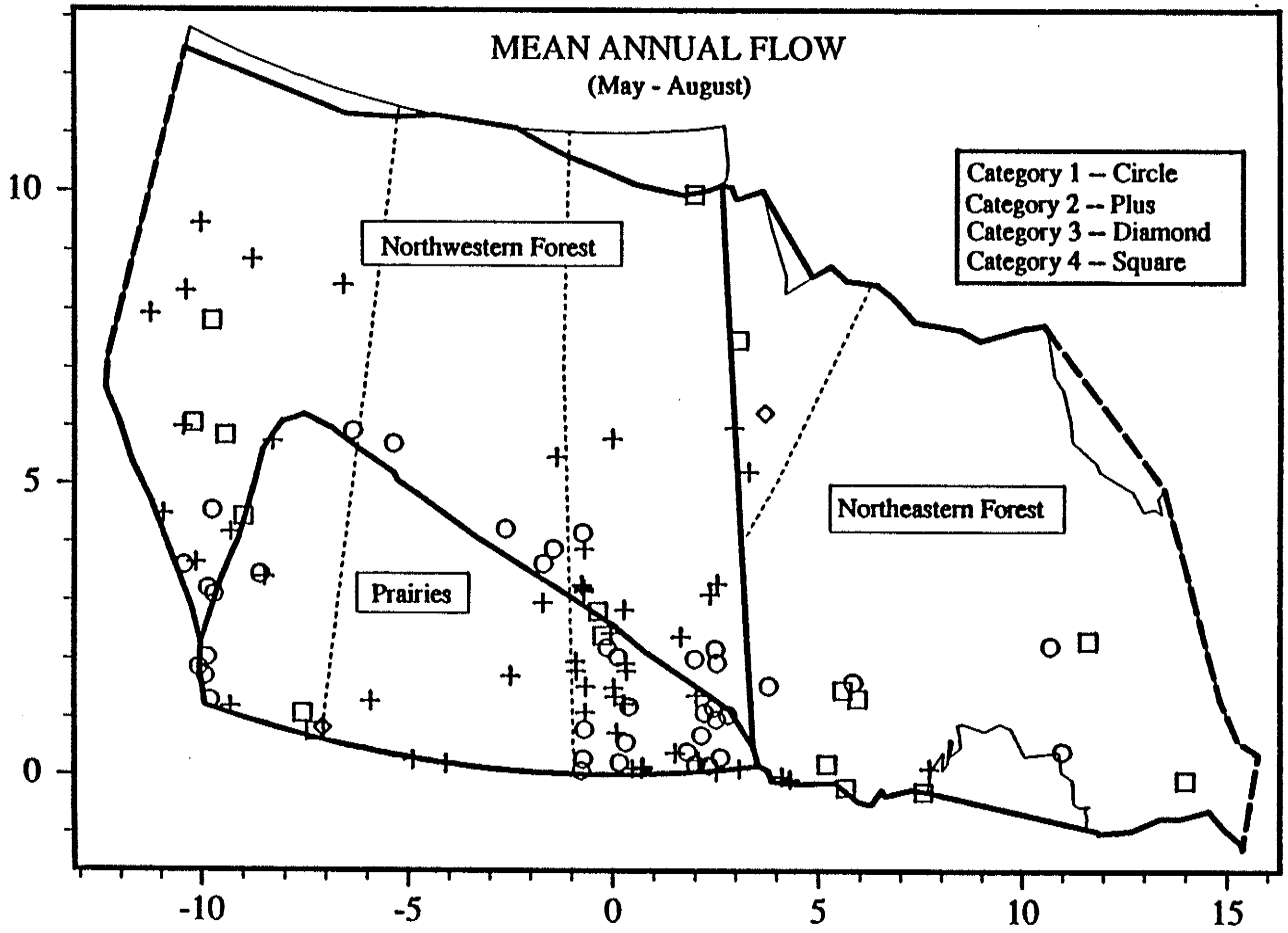

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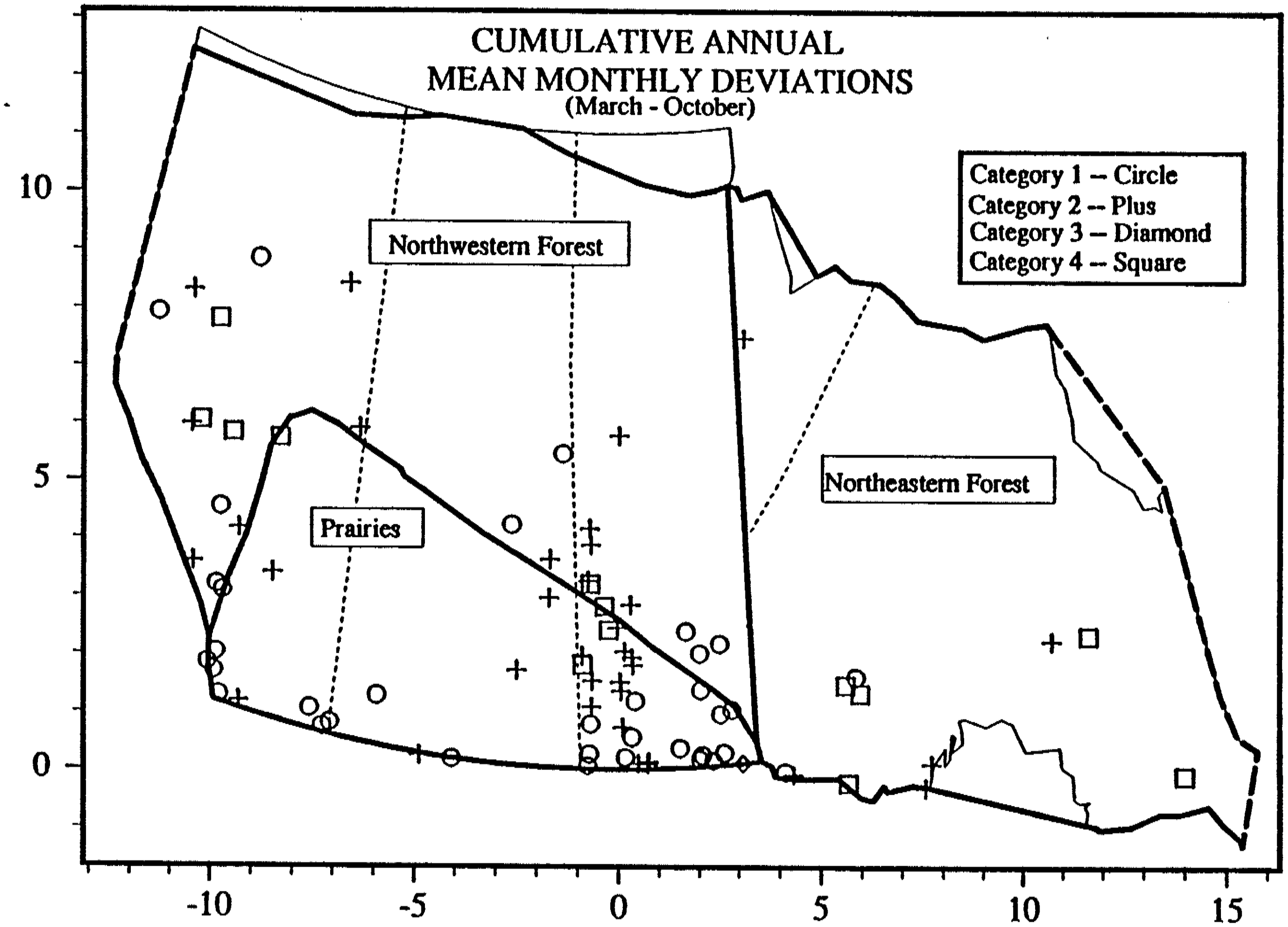

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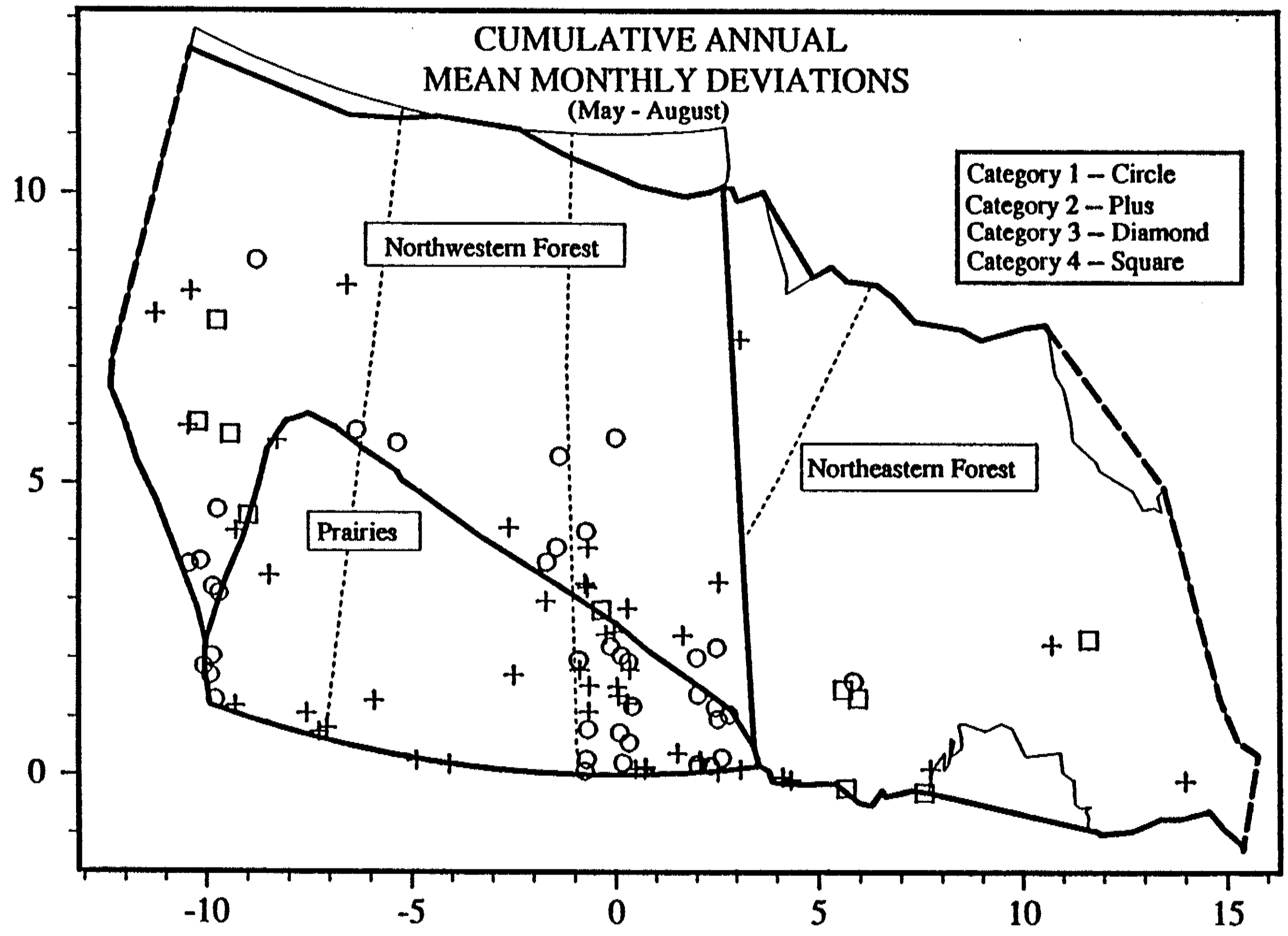

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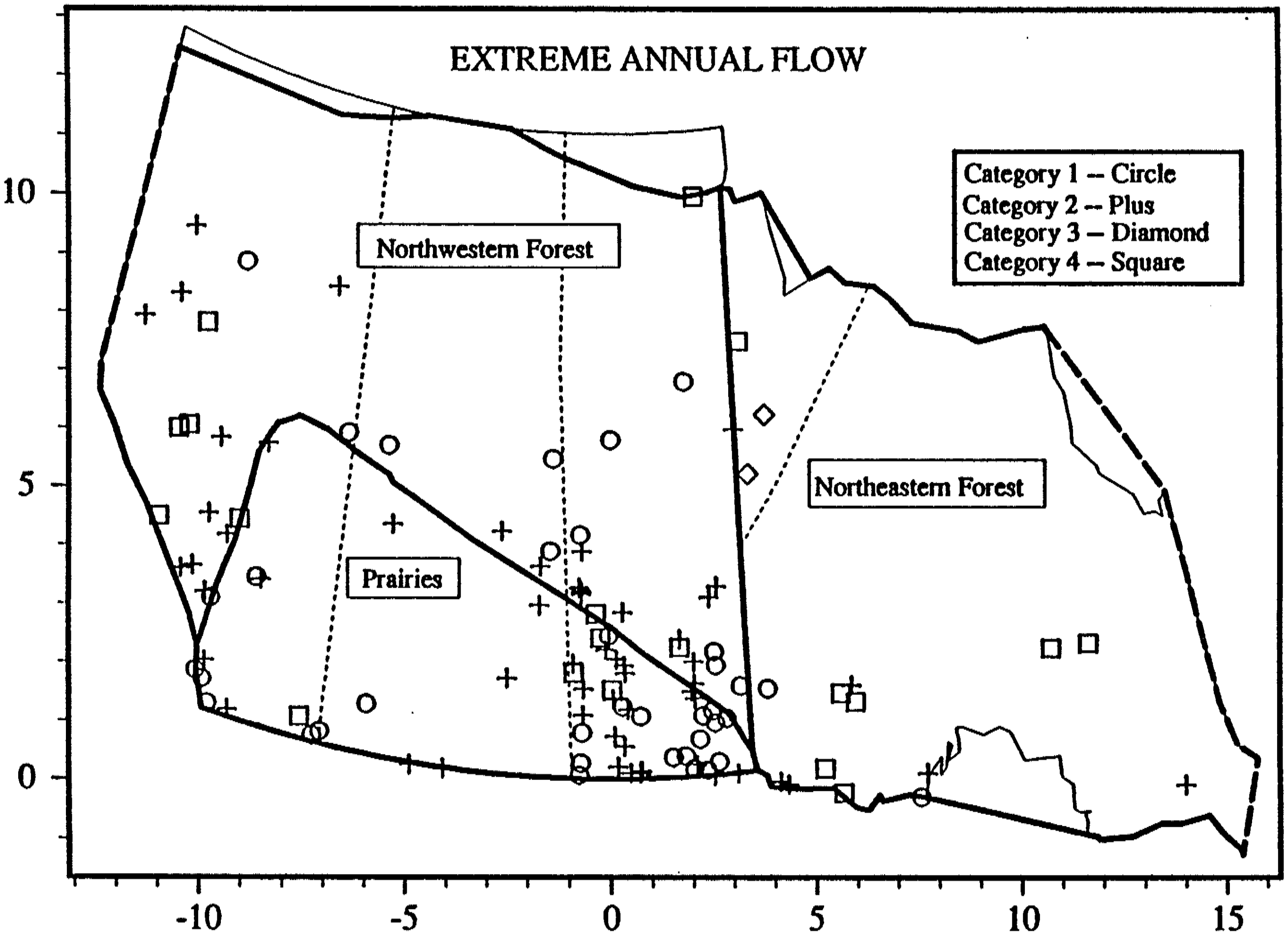

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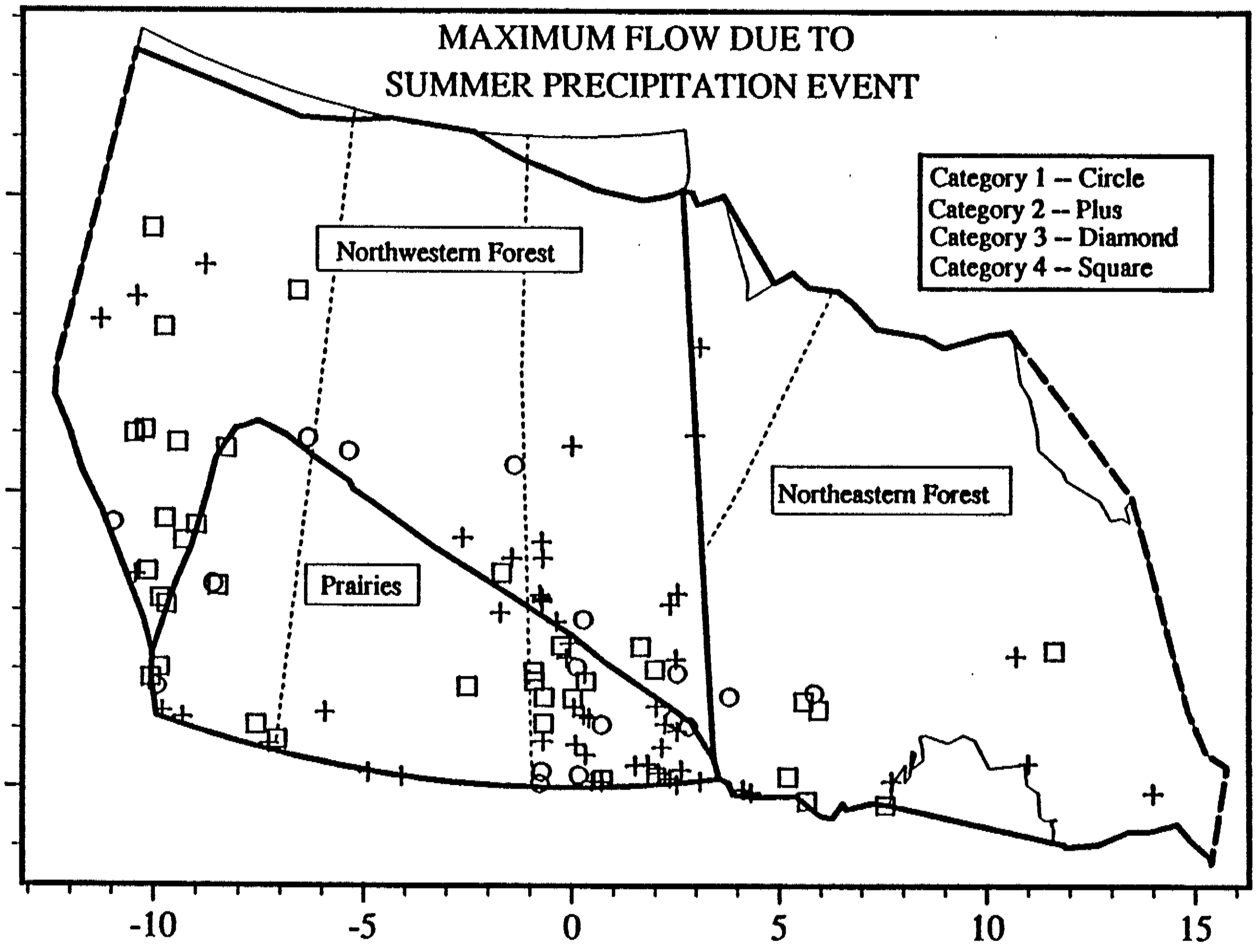

Regionalization Analysis