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DETECTION OF TRENDS IN LOW STREAMFLOWS

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To my parents
Who dedicated their life to my success
And
To my wife and children
Noushin,
Sina and Sadra

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ABSTRACT

A study of trends and variability of low flow characteristics was conducted for the Reference Hydrometric Basin Network (RHBN, established in the mid 1990s, for detection, monitoring, and assessment of climate change in Canada). RHBN stations are characterized by either pristine or stable hydrological conditions, with 20 or more years of good quality record. The 7-, 14-, 21-, and 30-day low-flow indices of RHBN hydrometric stations from the beginning of their records to 2003 were extracted using a moving average procedure, and examined to detect trends in Canadian lowstream flows for different record lengths. Also, the time of occurrence of 7-day low flow index was extracted and tested to detect changes in the timing of summer and winter 7-day low-flows for different record lengths. A modified Mann-Kendall (MK) nonparametric trend test was applied to the time series at a 0.05 significance level. The variance of the S statistic was modified if the absolute value of serial correlation was significant at a 0.1 significance level.

It was found that although the majority of the low flow time series were dominated by slight positive autocorrelations, the timing of winter low-flows was dominated by negative autocorrelation. It was also observed that if the autocorrelation coefficient was insignificant, its impact on acceptance or rejection of the null hypothesis was almost insignificant as well.

Statistical analysis indicated that regardless of record length, the percentages of significant trends for different low flow indices are in a good agreement. The number of significant trends in the quantity of low flows amounts to about 33% of the total tested stations. In 65% of stations with significant trends, low-flows experienced downward trends. On the other hand, low flows experienced a significant increase in 11% of tested stations. Numerical analysis indicated that northern Canada (stations located above latitude 60°N) has undergone a

significant increasing trend in low-flows. A significant downward trend dominated the Atlantic Provinces and southern British Columbia. No evidence of significant trends in the Prairies and eastern Ontario was found.

It was also found that there is a positive relationship between record length and the percentage of detected significant trends in low flows, i.e. the percentage of significant downward trends increased as study period increased whereas the percentage of significant upward trends decreased as study period increased.

Numerical analysis showed that the timing of summer 7-day low flow in 15% of stations experienced significant trends where in 52% of tested stations it shifted toward earlier dates. As record length increased the number of detected significant upward trends decreased. It was found that in the east half of the country (Atlantic Provinces and southern Ontario) summer 7-day low-flow shifted to arrive earlier whereas in the west and northwest (British Columbia, Yukon Territories, and North West Territory) it shifted to arrive later. There were no significant trends in timing of summer low flow in central Canada for longer record length. However, regardless of record length, timing of summer low flows showed a shift toward earlier dates in the higher latitudes while it showed a shift toward later dates in lower latitudes of central Canada.

It was observed that the timing of winter 7-day low flow in 20% of stations experienced significant trends. This percentage of significant trends was greater compared to the summer period. Furthermore, in 74% of the detected significant trends, the date of occurrence of winter 7-day low-flow shifted toward earlier dates. The results of this study indicate that trends in timing of both summer and winter 7-day low-flow experienced a shift toward earlier dates in eastern Canada whereas in western Canada winter trends were downward while summer trends were upward. There was no evidence of significant trends in Central Canada.

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CHAPTER 1

INTRODUCTION

1.1 Problem Statement

Detection of quick or gradual changes in hydrological records, and river discharge in particular, is of substantial scientific and practical importance as an essential process in planning future water resources infrastructure. The assumption of stationary hydrology, i.e. the idea that the past is the key to the future, will have to be revised if the stationarity assumption is not met. Otherwise, systems would be over or under-designed and might not serve their purpose effectively.

Changes in streamflows may be due to a variety of human interventions such as: (a) construction of dams and manmade reservoirs; (b) land-use changes which induce land-cover changes and eventually control the rainfall–runoff relationships; (c) deforestation, urbanization, and reduction of wetlands; (d) water withdrawal from rivers as some rivers run dry due to excessive water abstraction.

Nevertheless, since the climate system and water cycle are closely linked and any change in one of these systems induces a change in another, climate is the most important driver of the hydrological cycle and changes in river discharge. The earth's climate system has changed considerably since the pre-industrial era (IPCC, 2001). The global surface temperature rise of $0.6 \pm 0.2^{\circ}\text{C}$ over the 20th century was greater than during any other century in the last 1000 years, reportedly. Maps of changes in temperature over the last 25 years show considerable warming in the vast majority of grid cells, and minor cooling in a few cells. According to IPCC (2001), most of the warming observed over the last

50 years is attributable to human activities including emissions of greenhouse gases. Based on the various computer models it is predicted that, in average, the temperature of earth will increase between 1.8 and 4.0° Celsius during the 21st century (IPCC, 2007).

In attempts to address the impact of climate variability on hydrological time series, a number of studies have been conducted within North America. These include the works of Anderson *et al.* (1992), Smith and Richman (1993), Lettenmaier *et al.* (1994), Burn (1994), Gan (1998), Yulianti and Burn (1998), Leith and Whitfield (1999), Lins and Slack (1999), Douglas *et al.* (2000), Whitfield and Cannon (2000), Zhang *et al.* (2001), Burn and Elnur (2002), Adamowski and Bocchi (2001), Adamowski and Bougadis (2003), and others. Changes in the hydrological regime that do occur are not expected to be equally distributed throughout the year. For example, increased temperatures in the winter are expected to lead to earlier snowmelt events and a shift in runoff from the spring to late winter with a corresponding decrease in runoff in the summer period (Burn and Elnur, 2002). Previous modelling studies have hypothesized that northern basins will be particularly sensitive to the impacts of climatic change.

According to Olsen *et al.* (1998) the impact of non-stationarity in a random variable is mainly observed in the extremes (Douglas *et al.*, 2000). This impact has been observed in climate records in Canada by a number of researchers: Adamowski and Bocchi (2001), Yue *et al.* (2001), Yue *et al.* (2002), Yue and Pilon (2003), Yue and Wang (2002), etc. One of the fields that has not received sufficient attention of researchers, particularly in Canada, is low flow trend detection. Low flows are usually sustained by depletion of ground water or by surface discharge from upstream bodies of water including lakes, wetlands and glaciers. Low-flows within a year or season may result from different mechanisms. Low-flows in northern cold climates, such as Canada, may occur

due to prolonged winter period when precipitation is primarily in the form of snow, resulting in decreasing flows until the occurrence of the spring freshet. A second period that produces low flows is the warm season when there may be periods of significant evaporation and little precipitation (Wyllen and Woo, 1987). Depending on local climatology and physiography, some basins may produce low flows from predominantly one process or a combination of processes. It is important to understand the processes producing low flows, as these may determine the analytical approaches taken to assess the characteristics and their results. Low-flow statistics computed for periods or durations of prescribed lengths, such as 1, 3, 7, 14, 30, 60, 90, 120, 183, and 365 days may be used to identify trends in the magnitude and timing of low flows as important measures in drought studies, design of water supply systems, estimation of safe surface water withdrawals, classification of streams, potential for waste dilution, regulating waste disposal to streams, etc. Limited analyses have been performed for durations in excess of one year. The analysis of multi-year low flows is important in water supply storage where carry over storage from year to year is required to meet water-supply demands.

The low flow indices for various durations are computed using a moving average for the desired period. A moving average is the lowest arithmetically averaged flow of “d” consecutive days within a given year. These values are usually computed over a hydrological or climatic year rather than a calendar year. The hydrological year is defined to start in a season when the flow is most likely to be high so that yearly low-flow periods are not likely to be partitioned into different years. The specific d-day duration is usually selected based on the agricultural, biological or engineering application, which is usually related to the impact of the risk associated with the duration of low water availability on the system under study.

Many studies have investigated the existence of trends in flood flows but few have performed such analyses in low flows. In most relevant studies trend in maximum and minimum annual river flow has been detected as the higher and lower extremes of stream-flows. In these investigations different factors such as annual minimum daily flow, annual mean daily flow, and annual maximum daily flow have been assessed in different extents ranging from few stations in a small region to the whole country. The results of the studies depending on the methods used and the way the correlation structures have been dealt with varies from similar to, in some cases, contradictory. Since droughts and low flows tend to be longer lasting than floods, data of lower temporal resolution than daily are more likely to be sufficient for low flow studies than they are for flood events. An annual extreme minimum river flow does not contain information on the sequence of low flows. In many practical applications, more meaningful information is obtained by abstracting the minimum flows over a period of several consecutive days of varying lengths. Furthermore, analysis of trends in the quantity of a low flow index (e.g. 7-day) which to a certain extent is a measure of short time drought provides some information regarding changes in low flows in a watershed or in a region; however, it is of practical importance to know whether the direction and magnitude of trends are persistent when the study is extended to the low flow indices of longer periods. No study has been performed to study trends in multiple low flow indices in Canada.

Knowledge of the magnitude, frequency, and trends of low flows in streams is important in drought studies, design of water supply systems, estimation of safe surface water withdrawals, classification of streams, potential for waste dilution, regulating of waste disposal to streams, maintenance of certain in-stream discharges, etc. Low flow frequency indices may be used to calculate pollutant concentrations in estuaries (Lung et al., 1990). Low flows are also important in

riparian ecosystem and salmon migration because of their impact on the availability of habitat (Frenette *et al.* 1984; NMFS/USFWS, 2004). Different low-flow extremes may be used to identify existing and potential water supply problems, to identify historical extreme low-flow periods, and to determine potential water supply deficits (and other consequences) during a repeat of the most severe historical low-flow period (Heicher and Hirschel, 1989).

A significant increase in daily minimum temperature with the largest trend during winter and early spring was reported by Bonsal *et al.* (2001), which suggests a shift in timing of winter low-flows toward earlier dates. A trend toward earlier occurrence of spring snowmelt in some of the more northerly rivers of Canada has been reported by Burn (1994) which was attributed to possible climate change. Zhang *et al.* (2001) studied 11 hydro-climatic variables and found that break-up of river ice and the resulting spring freshet were occurring significantly earlier. However, no research on stream flow data has been conducted to investigate shifts in timing of summer/winter low flows in Canada. Trends and possible changes in timing of low-flow could be seen as potential evidence of climate change and its impact on the hydrologic cycle could eventually lead to shifts in the availability of water across Canada. Infrastructural adjustment to such shifts would be both environmentally and economically costly. Therefore, proper statistical investigation of the existence of such trends is of high practical important.

1.2 Research objectives

The objective of this study is to investigate whether there is any support for change in low stream flows in observational data. By using observations rather than model output, uncertainties inherent in the modelling procedure, such as simplifying assumptions and concepts, are avoided. However, using real data

involves other problems, primarily relating to data quality and quantity. Trend analysis requires long records to distinguish climate change-induced trends from climate variability, preferably in excess of about 50 years (Kundzewicz and Robson, 2000). This study is intended to investigate the variability of low stream flows by testing multiple low flow indices with a resolution lower than mean daily flow.

Analysing a set of time series with different record lengths which may, in some cases, belong to different or even non overlapping periods could lead to misleading interpretations. Therefore, in this study, the time series are categorized and examined based on their periods of records. Considering a common time-period for a group of stations and analysing the detected trends in such a period will strengthen any regional analysis performed on the stations and leads to more realistic interpretation of the results. This will also provide an opportunity to investigate any correlation between the record length and the number of detected significant upward or downward trends for tested variables.

In Canada, there are two distinct summer and winter low-flow periods in each hydrological year. Summer low-flow is more likely to happen in late summer and fall while winter low flow caused by freezing conditions is occurring during the period that stream-flow decreases or stops preceded by decreasing surface and shallow ground water movement in severe climatological situations. No previous investigation has been conducted to investigate trends in timing of low flows in both summer and winter. While low flows in one season may shift toward later or earlier dates, the other season may not be affected or may experience opposite changes. Trend in timing of low-flow occurrence is of substantial interest which might permit discerning natural variability in flow regimes.

The statistical significance of investigated trends is another issue that leads to different inference of the results in trend analysis studies. Violation of the assumption of serial and spatial independence of datasets, as is common in hydrological records, can result in misleading and incorrect interpretations of results obtained from climate and/or stream-flow studies.

The principle objectives of the study can be listed as follows:

- To investigate the existence of trends in low flows for a variety of indices in variable time periods in such a manner that the results can be compared with previous studies focusing on other hydro-climatic variables such as precipitation, temperature, and so on and eventually possible suggestion of interrelation between detected trends and changes in other climate variables.
- To study any existing trend in timing of low flows in both summer and winter low flow periods to verify the effects of reported shifts in spring freshet and winter ice break-up and time of occurrence of minimum low flows in Canada.
- To investigate any correlation between the record length and the number of detected significant trends through categorizing and examining the time series based on their periods of records thereby allowing more realistic interpretation of regional patterns.
- To evaluate the effect of serial correlation on interpretation of detected trends in timing and quantity of low flow time series by applying different procedures to account for serial correlation of the data, thereby allowing

comparisons with the cases that the independence of flow records are assumed.

1.3 Scope of the study

In order to accomplish the objectives of the study, a set of low flow indices including 7-, 14-, 21-, and 30-day low flows over the period of available data are tested to detect trends in the magnitude of low flows. For this study, low-flow data are extracted using a moving average procedure. In addition, to perform statistical analysis for the selected stations regardless of record length, the stations are grouped in three different subsets with minimum record lengths of 30, 40, and 50 years. The data used in this study are from the Reference Hydrometric Basin Network (RHBN) established in the mid 1990s for use in detection, monitoring, and assessment of climate change in Canada (Environment Canada, 1999). Since the observations in the majority of the stations terminate after 2000, the 30-, 40-, and 50-year categories correspond approximately to 1971-2000, 1961-2000, and 1951-2000 time periods, respectively.

In order to investigate the changes in timing of minimum 7-day low flows, the date of occurrence of minimum 7-day low-flows is also extracted for summer and winter periods, whereby each year is divided into summer and winter subsets. These values are computed over a hydrological year (starting on May 1st) so that summer and winter low flow periods are not likely to be partitioned into different years.

The nonparametric Mann–Kendall (MK) statistical test (Mann, 1945; Kendall, 1975) is used to identify monotonic trends in this study. The most important criteria as will be discussed in detail in Chapter three for choosing non-parametric statistical tests is that compared to parametric statistical tests, the non-parametric tests are thought to be more suitable for non-normally distributed data and

censored data, which are frequently encountered in hydro-meteorological time series. The serial independence of a time series is still required in non-parametric tests. The MK test can be used for independent (uncorrelated) data. However, since most hydrologic data exhibit time dependence, the MK test could lead to a rejection of the null hypothesis of no trend while it is actually true. Therefore, modifications must be applied to eliminate the influence of serial correlation on the MK test.

1.4 Study overview

Chapter 1 of this study provides introductory material, the motivation and the objectives of the study.

Chapter 2 is dedicated to literature review of trend detection in hydro-climate variables. A definition of low flows and factors affecting low flows is also presented in this chapter.

Theoretical background and experimental design of this study is presented in Chapter 3. Different methods of trend detection and their strength and drawbacks are discussed in this chapter too. The study area and the data used in this study are also presented in this chapter.

The results of statistical analysis are presented in Chapter 4. Trend detection in different low-flow indices and also trend analysis in timing of summer and winter 7-day low flow in RHBN for different time periods are presented in this chapter. This chapter ends with the results of trend detection in the number of zero events in a selected subset of stations across RHBN.

Chapter 5 is dedicated to concluding remarks of the study. The recommendations for future works are also presented in this chapter.

CHAPTER 2

LITRATURE REVIEW

2.1 Introduction

Low flow may be considered, to many, as the actual flow in a river occurring during the dry season of the year (Smakhtin, 2001). Yet, others may be interested in the effects of changes in the total flow regime of a river on sustainable water yield or riverine and riparian ecology. The latter may recognize ‘low flows’ not only as discharges occurring during a dry season, but as a reduction in various aspects of the overall flow regime. International glossary of hydrology (WMO, 1974) defines low flow as “flow of water in a stream during prolonged dry weather”. This definition does not make a clear distinction between low flows and droughts. Low flow is a seasonal phenomenon, and an integral component of a flow regime of any river. Drought, on the other hand, is a natural event resulting from a less than normal precipitation for an extended period of time (Smakhtin, 2001). Several types of droughts may be defined: meteorological, atmospheric, agricultural, hydrological, and water management (Dracup et al., 1980; Rogers and Armbruster, 1990; Bogardy et al., 1994; Rao and Voeller, 1997).

2.2 Hydrology of low-flow

Low flows are normally from groundwater discharge or surface discharge from lakes, marshes, or melting glaciers (Smakhtin, 2001). Low flows usually occur in the same season each year. In unregulated rivers, low flows are derived from water in long-term storage in the catchment, commonly as shallow groundwater.

The physical characteristics of a catchment: geology, soils and slope have an important natural control on low flows upon which other controls, such as climate or land use, are imposed (Longobardi and Villani, 2006). According to Pyrcce (2004) a variety of the natural factors impact the low-flow regime of the rivers that can be grouped into four general categories: a) physical character of the watershed (drainage area, channel length, basin perimeter, mean elevation, mean latitude, channel slope, mean basin slope, watershed morphology, region), b) meteorological character of the watershed or region (annual precipitation index, average basin winter precipitation, average summer precipitation, average basin temperature), c) geologic character of the watershed or region (area of stratified drift per total stream length, geological index, fraction of the basin underlain by significant sand and gravel aquifers), and d) hydrology of the stream (streamflow recession index). Drainage area is the most important variable, as it is used in seven of the eight regression equations, reportedly.

Generally, the majority of natural gains to streamflow during low-flow periods are from groundwater storage where stream channels intersect the main water table in a draining aquifer. The following conditions must be met in order to have sustainable lowflows: (a) the draining watershed must have sufficient seasonal recharge; (b) the water table must be high enough to be intersected by the stream; and (c) the watershed characteristics such as size and hydraulic properties must be sufficient to sustain flows throughout the dry season. Low flows may also be sustained by drainage of a saturated top soil zone rather than by deeper groundwater (Anderson and Burt, 1980; Smakhtin, 2001).

Low-flows in rivers may also be maintained by lakes which have direct hydraulic connection with the rivers. The adequate water level in a lake should be maintained during the dry season to allow lateral outflow into a stream. In highly seasonal

climates, low flows in different dry seasons (e.g. summer and winter) may be generated by different physical processes. In cold or mountainous regions, in addition to the usual catchment parameters, low flows are subject to the special influences of ice and snow melting (Bowles and Riley, 1976; Gerard, 1981; Collins, 1982; Fountain and Tangborn, 1985; Gurnell, 1993; Hopkinson and Young, 1998; Smakhtin, 2001). The release of water from glacier storage may greatly affect the local hydrology cycle by contributing to streamflow in low-flow periods. The principal influence of glaciers in the context of low flows is similar to that of lakes and includes a decrease in runoff variation and, consequently, more sustained low flows.

Losses to streamflow during dry weather periods may be caused by: (a) direct evaporation from standing or flowing water in a channel, other open water bodies and wetlands; (b) evaporation and transpiration losses from seepage areas; (c) groundwater recharge from streamflow where the water table is below the channel. For large areas in high latitudes, low flows generally decrease with increasing latitude and distance from the balancing effects of the oceans (Janowicz, 1990). This trend is largely controlled by the distribution of permafrost which influences groundwater contributions to winter streamflow. In cold regions, rivers often have their lowest flows in winter due to temporary storage of precipitation as snow. They might also have two distinct low-flow seasons (in winter and summer) controlled by different processes. Winter streamflow is often less than river recharge from an aquifer. The difference may be attributed to the flow losses for ice cover formation in rivers (Kravchenko and Chernykh, 1985). In permafrost zone, these losses may reach the level of 20–30 to 1000% of measured winter flow (Sokolov and Chernaja, 1984; Kravchenko, 1986; Smakhtin, 2001).

Gains and losses to low flows are affected by various anthropogenic activities. These activities introduce a variety of changes to low flows through different

processes. For example, pumping water from the aquifers within the subsurface drainage area noticeably affects the level of water table and therefore the potential of groundwater recharging stream channels. Local reductions in the water table level may affect either hydraulic gradients or the length of channel that intersects the phreatic surface. The effects of groundwater pumping near the head of a perennial river may result in groundwater table depletion through interception of recharge water and induced recharge of the aquifer from the river itself. This leads to considerable environmental degradation of the river habitats, loss of naturally sustained fisheries, and reductions in the general amenity value of the river (Smakhtin, 2001).

Forestation of whole or parts of the basin is another factor that impacts the quantity and timing of low flows. Mature trees generally have a greater water use than other vegetation types (Bosch and Hewlett, 1982; Calder, 1990; Kirby et al., 1991; Whitehead and Calder, 1993; McCulloch and Robinson, 1993). Trees intercept more precipitation and transpiration rates are greater, resulting in higher evaporation rates compared to other vegetation types. The expected impact on the flow regimes would therefore be a general reduction in flows as the forest grows, and increased flows once a forest is clear cut (Johnson, 1997). A study performed by McGuinness and Harrold (1971) in the United States showed that the low and intermediate flows declined in the reforested catchment over the first 15 years of tree growth, where annual runoff reduced by 2 inches in an area with a mean annual precipitation of 37 inches (Johnson, 1997). According to Robinson et al. (1991) lowflows and annual flows were progressively reduced by forest growth in southern Germany. The impact on low flows, reportedly, was greater than that on annual flows because the low flows occurred mostly in the summer when interception and transpiration rates were greatest.

Deforestation of a catchment can theoretically at the same time cause increase or decrease in low flows. For example, reduced evapotranspiration, interception and infiltration rates following deforestation may result in higher soil moisture storage and increased surface runoff, consequently leading to reduced recharge and increased gully erosion. Eventually this may result in lowering the groundwater table and reduced low flows, which originate from groundwater storage (Smakhtin, 2001). In the USA a period of low annual precipitation in the 1950s prompted research into the possibilities of increasing low river flows by felling forests. The performed studies showed that (Hornbeck et al., 1993) a reduction in forest cover of 25% was necessary before any changes were observed. From the long-term catchment study in the United States, clear felling in three catchments increased flows in the year following cutting followed by an unsteady decrease in the following years (Swift and Swank, 1981). The initial increase was again attributed to reduced canopy interception and virtual elimination of transpiration, followed by an increase in both interception and transpiration due to the regrowth of the vegetation.

Climate change is another contributor to changes in low flows particularly in the regions of the globe where snowmelt plays a dominant role in the seasonal patterns of stream-flow. The largest changes in the hydrological cycle due to warming are predicted for the snow-dominated basins of mid- to higher latitudes, because adding or removing snow cover fundamentally changes the snow pack's ability to act as a reservoir for water storage. Studies in various regions of the globe indicate that the stream-flow regime in snowmelt-dominated river basins is most sensitive to wintertime increases in temperature (Barnett et al., 2005). Warming induced changes to evapotranspiration may also affect regional water availability. Even more serious problems may occur in regions that depend heavily on glacial melt water for their main dry season water supply, reportedly. It has been documented

that glaciers are in retreat over most of the world. Unlike the present water supply which is renewed seasonally, with melting the glaciers, no replacement will exist for the water they provide now. Therefore, the natural water in the glaciers has even more importance than seasonal storage in the snow pack (Barnett et al., 2005).

A variety of other factors may affect low flow regime. A general example is the modification of land use over large parts of a catchment which may contribute to changes in the infiltration and/or evaporation characteristics, as well as modifications to the amount of groundwater recharge. One example is catchment urbanisation. In urbanized catchments, low flows have a tendency to decrease due to the effects of urban impervious surfaces upon direct runoff, infiltration and evapotranspiration (Simmons and Reynolds, 1982; Warner, 1984; Ferguson and Suckling, 1990; Smakhtin, 2001).

2.3 Trend detection studies in hydro-climatic time series

The trend analysis of hydrological series is of considerable scientific and practical importance because of the effects of climate variability and also impacts of human activities on water resources. Kundzewicz & Robson (2004) provide general guidelines for the methodology of change detection in time series of hydrological records, giving an overview of preparation of a suitable data set, exploratory analysis, and application of satisfactory statistical tests and interpretation of results. Particular emphasis is made on the use of distribution-free testing, particularly resampling methods, which are well suited to skewed, seasonal and serially correlated hydrological data.

Yue & Pilon (2004) present guidance for selection of a test (from slope-based, rank-based, parametric, non-parametric and bootstrap-based approaches) for non-normally distributed data by comparison of test power. Sensitivity of the power of

the tests to the shape of trend (linear versus nonlinear) has also been examined. Other aspects of detection of trends are dealt with by Radziejewski & Kundzewicz (2004), who examine how strong a change (gradual trend or abrupt jump) must be and how long it must take in order to be detected by different tests. Burn *et al.* (2004) examined the trends and variability of river flow in climate-sensitive northern Canada, where local anthropogenic effects are negligible. The relationships between trends in hydrological variables and both meteorological variables and a large-scale oceanic and atmospheric process were investigated. Their trend detection results suggest increasing winter and spring flows and earlier dates of spring freshets and spring maximum discharges. In a study carried out for Sweden, Lindström & Bergström (2004) analysed river flow for 61 stations over a century. A considerable recent increase in both annual discharge and flood magnitude were found, but it was not exceptional in the context of high flows experienced earlier.

Callède *et al.* (2004) examined the flow of the Amazon at Óbidos, where available information is scarce and loaded with high uncertainty. A slight increase has been found in the nearly century-long series of flow. It has been suggested that the increase in the flow is stronger than in the rainfall, which could be a result of the Amazonian deforestation. The rupture tests indicate a break in 1970, as in other rivers of South America. According to Callède *et al.* (2004), this upward jump looks like a counterpart of a negative jump change observed in Africa at about the same time (L'Hôte *et al.*, 2002; Sambou, 2004). Since the issue of whether the Sahelian drought ended during the 1990s, or is still in progress, is of high practical importance for the region, it has raised strong debate (e.g. Ozer *et al.*, 2003; L'Hôte *et al.*, 2003).

Xiong & Guo (2004) tested the Yangtze flow at Yichang in 1882–2001. No significant trend in the annual maximum flood series was detected, but minimum and mean discharges show decreasing trends. These findings are of practical importance, but cannot serve as a picture of climate change impact due to substantial intervention by direct anthropogenic factors. In order to be able to predict what is going on in ungauged basins (Sivapalan et al., 2003), one has to draw as much information as possible from the available long time series of data for gauged basins. Even though increasing temperatures may lead to an increase in heavy precipitation in the northern hemisphere through a more active hydrological cycle, higher temperatures also mean that evapotranspiration will increase. The effect on river flows, which in the longer term is the difference between precipitation and evapotranspiration, is therefore not clear.

Douglas et al. (2000) and Lins and Slack (1999), using annual minimum 7-day flow and the annual minimum daily flow, found increasing trends in low flows from the midwest towards the northeast of the United States, significant at a 5% level. Lins and Slack (1999) also found that the annual mean streamflow is increasing, whereas floods are neither increasing nor decreasing, leading them to conclude that the United states appears to be getting wetter, but less extreme.

Hisdal et al. (2001) using 600 daily streamflow records in Europe concluded that it is not possible to state that drought conditions in general have become more severe or frequent. Although for the relatively short period of 1962-1990 some regional differences were found, most stations did not show any significant trends. Examples of increasing drought deficit volumes were found in Spain, the eastern part of Eastern Europe and in large parts of the UK, whereas decreasing drought deficit volumes occurred in large parts of Central Europe and in the western part of Eastern Europe (Hisdal et al., 2001).

Trends in the Asia-Pacific region including Oceania and the vast majority of Asia were investigated by Cluis and Laberge (2001) using minimum monthly discharges. Most areas did not exhibit consistent trends. However, in Central and Far-East Asia rivers to the north (between the 50th and 75th parallels) exhibited upward trends whereas more southern stations (around the 45th parallel) showed downward trends. Two low flow indices of annual minimum 7-day and 30-day mean river flow were used to describe the lower end of the flow spectrum.

Adamowski and Bocci (2001), using a geostatistical approach, analysed data from 248 river stations in the reference Hydrometric Basin Network (RHBN) established by Environment Canada. They found that there are significant trends in some regions for different seasons, and their magnitudes vary for different regions and type of variable studied. For some regions and variables no trend was found. For monthly flows, a significant increasing trend was detected for the month of July (Prairie and Pacific regions) and December (Northwest Territories/Nunavut). A decreasing trend was found for annual mean flow (Central, Mountain-north, and Pacific regions). According to the study, the annual maximum daily flow showed a significant decreasing trend for the Central/East, Mountain-North, Pacific, and Northwest Territories/Nunavut and a significant increasing trend for Central and Prairie regions. The annual minimum flow was found to have an increasing significant trend for Western Quebec/Southern Ontario, Mountain-North and Pacific regions, and a decreasing trend for the Central/East region.

Yue et al. (2001) examined annual mean, annual maximum, and annual minimum daily stream flow series at 213 stations in the RHBN. The sites with significant positive and negative trends are illustrated in Fig. 2.1. A circle indicates a station with no significant trend, an upward-pointing triangle indicates a station with

significant upward trend, and a downward-pointing triangle indicates a station with significant downward trend. In this figure some patterns with three distinct bands of trend in annual minimum flow stretching across the country are recognizable. The central band at mid-latitudes shows a predominantly downward trend. The northern band of upward trend in Fig. 2.1, above latitude 58°N, is consistent with the pattern seen in the other data sets, indicating short-term trend and long-term trend in annual minimum flow that are both upward. The southern band of upward trend, below latitude 50°N, is also consistent with the pattern seen in the other two data sets, indicating annual minimum flows are experiencing both short-term and long-term upward trend in that region (Yue et al. 2001).

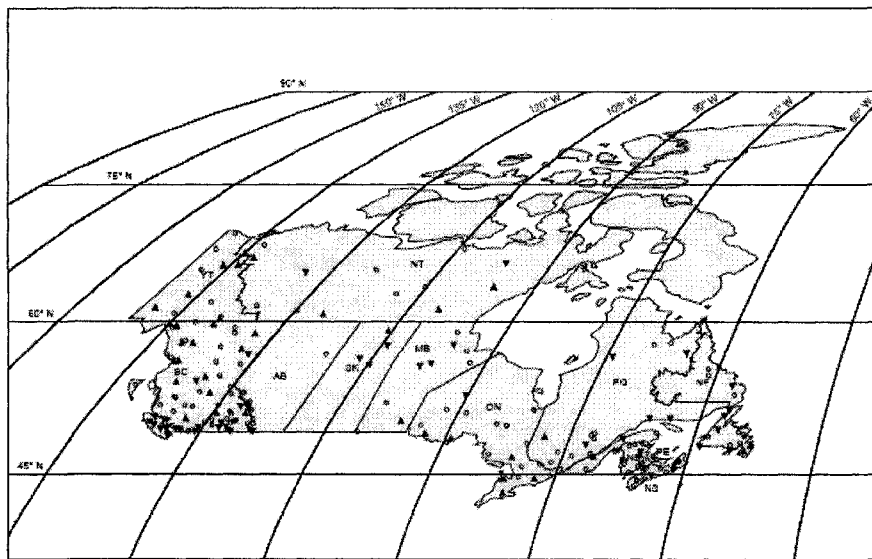


Fig. 2.1. Spatial illustration of significant trends in annual minimum daily flows (Yue et al., 2001).

Yue and Wang (2002) developed a methodology that takes into account both serial and cross-correlation in the assessment of the field significance of trends. The regional average Mann–Kendall (RAMK) statistic was used to represent the regional properties of trends at a regional scale. The method was applied to detect

regional significant trends in river flows in the whole country of Canada, divided into 10 major homogeneous climate regions. Fig. 2.2 lists the names of these climate regions. The method was applied to assess the field significance of trends in three flow regimes, namely annual mean, annual maximum, and annual minimum daily streamflows from 1967 to 1996 in each of ten climatic regions of Canada. The results demonstrate that the proposed method provides a more accurate assessment of the field significance of trends than that without consideration of temporal and spatial correlation (Yue and Wang, 2002). Fig. 2.3 presents the assessment results obtained using this approach with consideration of both serial and cross-correlation at the significance level of 0.10.

Canada	Identifier	Name of subregion
Southern	Southwest	1 Pacific
		2 South BC mountains
		4 Prairie
		5 Northwestern forest
		6 Northeastern forest
	Southeast	7 Great Lakes & St Lawrence
		8 Atlantic
		3 Yukon & northern BC mountains
	Northern	9 Mackenzie
		10 Arctic tundra
11 Arctic mountains		

Fig. 2.2 Climate regions (Yue and Wang, 2002).

Hydrologically, the region of Yukon and northern BC mountains (region 3) is getting wetter, though extreme flood events remain unchanged. The Pacific region, Prairie region, and southeastern Canada, with the exception of the Great Lakes and St Lawrence river basins, are getting drier. Extreme flood events over southern Canada are becoming less intensive, except in the Pacific region (Yue and Wang, 2002).

Canada	Climate region	Mean	Maximum	Minimum	
Southern	Southwest	1	Downward	No	Downward
		2	No	Downward	No
		4	Downward	Downward	No
		5	No	Downward	No
	Southeast	6	No	Downward	Downward
		7	No	Downward	No
		8	No	Downward	Downward
	Northern	3	Upward	No	Upward
		9	No	No	No
		10	No	No	No

Fig. 2.3. Summary of the assessment results (Yue and Wang, 2002).

According to the above, detection of trends in hydro-climatic variables has been performed all over the world in different temporal and spatial scales. In some cases the variability of a hydrological factor has been investigated in a considerably small scale, i.e. as small as a watershed. In other cases the studies have been extended to larger regions in a country and even in some cases in a continent scale. The time period of studied factors also varies from few decades to a century, or in some cases even longer periods. Among various hydro-climate variables, streamflows, because of their direct impact on water resources, are of critical importance. Although some research into the trends in extreme streamflows have been reported, no significant attention has been given to duration of these events. In many practical applications the duration of extreme events, especially in low flow context, has a more critical importance compared to the peak value. For example in agriculture applications, the minimum quantity of available water might be of considerable importance; nevertheless, the duration of this water deficit period plays a key role in producing agricultural products. Another example of the importance of the duration of low stream flow is in fish habitat context. No research has been reported so far on the variability of quantity

and timing of low flows for time periods larger than one day in Canada. This study is intended to look into the changes in quantity and time of occurrence of low-flow events for time periods larger than daily means that are of practical importance for agriculture, industry, navigation and fish habitat.

CHAPTER 3

THEORETICAL BACKGROUND AND DEVELOPEMENT

3.1 Introduction

Statistical measures are used for detection of gradual trends over time. The purpose of trend testing is to determine if the values of a random variable generally increase (or decrease) over some period of time in statistical terms (Helsel and Hirsch, 1992). Generally, two different methods of parametric and nonparametric statistical tests are used to determine whether there is a significant positive or negative trend in a data sample. Linear regression fits a regression line to the series, and the slope describes whether the trend is strong or not. The null hypothesis is that the slope of the line is zero. Because the linear regression is applied directly to the index series, rather than to ranks, it is very good for visual presentation. However, the linear regression method requires the assumption of normal distribution and is very sensitive to outliers in the data. By ranking the observations and applying the nonparametric tests, a more robust measure of trend is obtained.

All statistical tests involve two kinds of errors. These are the so-called type I error (rejecting the null hypothesis when it is true), and the type II error (not rejecting the null hypothesis when it is false) (Fig. 3.1). The significance level or type I

error (α) is the probability of rejecting the null hypothesis when it is true (Fig. 3.1(a)). Significance levels are normally set quite low at values of 0.01, 0.05 or 0.1. The smaller the value of α , the more confidence there is that the null hypothesis is really false when it has been rejected. A type II Error (β) is the probability of accepting a null hypothesis, when it is false. The power of a test is the probability of correctly rejecting the null hypothesis, when it is false, which is equal to $1 - \beta$ (Fig. 3.1(b)).

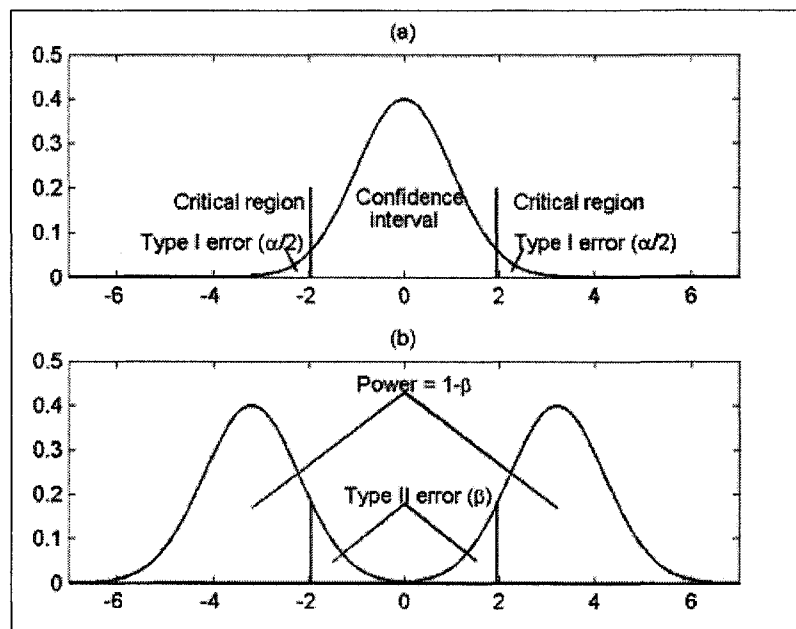


Fig. 3.1 (a) Schematic illustration of the confidence interval, critical regions, and type I error for the two-tailed test; and (b) schematic illustration of the type II error and the power of the test (Yue et al., 2002).

When sampling from a population that represents the case where the null hypothesis is false, the power can be estimated (Yue et al., 2002) by:

$$Power = \frac{N_{rej}}{N} \quad (3.1)$$

Where N is the total number of simulation experiments and N_{rej} is the number of experiments that fall in the critical region.

3.2 Tests for trend detection

The existence of a trend in a hydrological time series is detected by statistical tests. Parametric or non-parametric tests can be used for this purpose.

3.2.1 Parametric T-test

If a time series with a linear trend is represented by:

$$X_i = \beta (i - 1) + e_i \quad (i = 1, 2, 3, \dots, n) \quad (3.2)$$

and let a time series with a shift or jump be given by:

$$Y_i = \begin{cases} e_i & (i = 1, 2, 3, \dots, m) \\ u + e_i & (i = m + 1, m + 2, \dots, n) \end{cases} \quad (3.3)$$

where β is the slope of a linear trend, u is the magnitude of a shift in an initial time series (e_i), and n is the sample size. In order to apply t -test, the series must be normally distributed. The validity of this test to assess the statistical significance of a linear trend or a shift in mean in a time series is on the basis of normality of a time series (e_i) (Hoel, 1954). In order to find out if it follows the normal distribution, the sample data has to be examined prior to applying the t -test. The null hypothesis H_0 that there is no trend, is to be tested against the alternative hypothesis, H_1 , that there is a trend. The parametric test considers the linear regression of the random variable Y on time X . The regression coefficient b_1 (or the Pearson correlation coefficient r) is computed from the data. According to Haan (1977) the t -statistic is defined as:

$$t = \frac{T\sqrt{n-2}}{\sqrt{1-r^2}} = \frac{b_1}{s/\sqrt{SS_x}} \quad (3.4)$$

and follows Student's t distribution with degrees of freedom $n-2$, where n is the sample size, s is the standard deviation of residuals, and SS_x is the sums of squares of the independent variable (time in trend analysis). The hypothesis $H_0: \rho = 0$ (or $\beta_1 = 0$) is tested against the hypothesis $H_1: \rho \neq 0$ (or $\beta_1 \neq 0$) at a chosen level of significance, α , where ρ and β_1 are the population values of the correlation coefficient and regression coefficient, respectively. The hypothesis that there is no trend is rejected when the t value computed by equation (3.4) is greater in absolute value than the critical value $t_{\alpha/2}$. Annual river flow series most likely do not follow the normal distribution. In such cases, nonparametric statistical tests, such as the Mann-Kendall test (Mann, 1945; Kendall, 1975), Spearman's rho test (SR), and the Mann-Whitney test (Mann & Whitney, 1947), are commonly applied to assess the statistical significance of trends.

3.2.2 Mann-Whitney-Pettit (MWP) nonparametric test

Assuming a time series of some hydrological variable, X_1, X_2, \dots, X_T where T is the length of the time series, it is important to know whether the characteristics of the variable of interest before and after time instance t are different. Pettitt (1979) defined a statistic U_t that can be used for change detection as follows:

$$U_{t,T} = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sgn}(x_j - x_i) \quad (1 \leq t \leq T) \quad (3.5)$$

Where

$$\text{sgn}(x_j - x_i) = \begin{cases} 1 & \text{if } x_j - x_i > 0 \\ 0 & \text{if } x_j - x_i = 0 \\ -1 & \text{if } x_j - x_i < 0 \end{cases} \quad (3.6)$$

$$K_T = \max_{1 \leq i \leq T} |U_{i,T}| \quad (3.7)$$

$$K_T^+ = \max_{1 \leq i \leq T} U_{i,T} \quad (3.8)$$

$$K_T^- = \min_{1 \leq i \leq T} U_{i,T} \quad (3.9)$$

Statistics K_T^+ (or K_T^-) can be large if there is a shift down (or up) in level from the beginning of the time series. Similarly, for detection of change in any direction, K_T is expected to be large. It can be shown (Pettitt, 1979) that:

$$P(K_T^+ > k^+) = \exp\left(\frac{-6(k^+)^2}{T^3 + T^2}\right) \quad (3.10)$$

$$P(K_T > k) = 2 \exp\left(\frac{-6k^2}{T^3 + T^2}\right) \quad (3.11)$$

Where k^+ and k are values of the statistics K_T^+ and K_T , respectively. By choosing a level of significance (α), the hypothesis of no change in the time series would be rejected if $P(K_T^+ > k^+)$ or $P(K_T > k)$ is smaller than α . The Mann-Whitney test for detecting a shift in mean or median in hydrological time series has been applied in works of McCuen & James (1972), Lazaro (1976), Lettenmaier (1976), Helsel & Hirsch (1988), Kiely (1999), and Kiely *et al.* (1998).

3.2.3 Spearman Rho (SR) test

Spearman's rho (SR) test is another non-parametric rank-order test. Given a sample data set $\{X_i, i=1, 2, \dots, n\}$, the null hypothesis H_0 of the SR test against trend tests is that all the X_i are independent and identically distributed; the alternative hypothesis is that X_i increases or decreases with i , that is, trend exists. The test statistics is given by (Sneyers, 1990):

$$D = 1 - \frac{6 \sum_{i=1}^n [R(X_i) - i]^2}{n(n^2 - 1)} \quad (3.12)$$

Where $R(X_i)$ is the rank of i^{th} observation (X_i) in the sample of size n . Under the null hypothesis, the distribution of D is asymptotically normal with the mean and variance as follows (Lehmann, 1975; Sneyers, 1990):

$$E(D) = 0 \quad (3.13)$$

$$V(D) = \frac{1}{n-1} \quad (3.14)$$

The P -value of the SR statistic (D) of the observed sample data is estimated using the normal cumulative distribution function (CDF) as its statistics are approximately normally distributed with mean of zero and variance of $V(D)$ for the SR statistic. Using the following standardization:

$$Z_{SR} = \frac{D}{\sqrt{V(D)}} \quad (3.15)$$

The standardized statistic Z_{SR} follows the standard normal distribution ($Z_{SR} \sim N(0,1)$). The P -value of SP statistic (D) of sample data can be estimated using the normal CDF as:

$$p = 0.5 - \Phi(|Z|) \quad (Z=Z_{MK}, Z_{SR}) \quad (3.16)$$

Where

$$\Phi(|Z|) = \frac{1}{\sqrt{2\pi}} \int_0^{|Z|} e^{-t^2/2} dt \quad (3.17)$$

If the P -value is small enough, the trend is quite unlikely to be caused by random chance. The SR test is seldom used in hydrometeorological trend analysis (Yue et al., 2002). Limited examples using the SR test are Lettenmaier (1976), El-Shaarawi et al. (1983), Pilon et al. (1985), Mcleod et al. (1991), and Hipel and Mcleod (1994).

3.2.4 Mann-Kendall (MK) test

In the past decades, increased public concern over environmental degradation has led to the popular use of the nonparametric Mann-Kendall (MK) statistical test (Mann, 1945; Kendall, 1975) to identify whether or not significant trends exist in hydro-meteorological time series such as streamflow, precipitation, and temperature (e.g., Hirsch et al., 1982; van Belle and Hughes, 1984; Cailas et al., 1986; Hipel et al., 1988; Taylor and Loftis, 1989; Zetterqvist, 1991; Yu et al., 1993). The null and the alternative hypothesis of the MK test are:

$$\begin{aligned} H_0 & : \text{Prob } [x_j > x_i] = 0.5 \quad \text{where } j > i \\ H_A & : \text{Prob } [x_j > x_i] \neq 0.5 \quad (\text{two sided test}) \end{aligned} \quad (3.18)$$

The Mann-Kendall test statistic S is calculated using the formula (Yue et al., 2002):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sgn}(x_j - x_i) \quad (3.19)$$

Where x_j and x_i are the data values in years j and i , respectively, with $j > i$, and $\text{sgn}(x_j - x_i)$ is the sign function as:

$$\text{sgn}(x_j - x_i) = \begin{cases} 1 & \text{if } x_j - x_i > 0 \\ 0 & \text{if } x_j - x_i = 0 \\ -1 & \text{if } x_j - x_i < 0 \end{cases} \quad (3.20)$$

The distribution of MK S statistic can be approximated well by a normal distribution for large n , with mean (μ_s) and standard deviation (σ_s) given by:

$$\mu_s = 0 \quad (3.21)$$

$$\sigma_s = \sqrt{\frac{n(n-1)(2n+5) - \sum_{i=1}^m t_i(i)(i-1)(2i+5)}{18}} \quad (3.22)$$

Equation (3.22) estimates the standard deviation of S statistic with the correction for ties in data (t_i denotes the number of ties of extent i). For n larger than 10, the standard normal test statistic Z_S for hypothesis testing is:

$$Z_s = \begin{cases} \frac{S-1}{\sigma_s} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sigma_s} & \text{if } S < 0 \end{cases} \quad (3.23)$$

Z_s has a standard normal distribution (Kendall, 1962). Local (at-site) significance levels (p-values) for each trend test can be obtained from (Douglas et al., 2000):

$$p = 2 [1 - \Phi(|Z_s|)] \quad (3.24)$$

Where

$$\Phi(|Z_s|) = \frac{1}{\sqrt{2\pi}} \int_0^{|z|} e^{-\frac{t^2}{2}} dt \quad (3.25)$$

If the P value is small enough, the trend is quite unlikely to be caused by random sampling. At the significance level of 0.05, if $p \leq 0.05$, then the existing trend is assessed to be statistically significant. The examples using the Mann-Kendall test for detecting monotonic trends in hydrological time series may be found in Hirsch & Slack (1984), Burn (1994), Lettenmaier *et al.* (1994), Gan (1998), Lins & Slack (1999), Douglas *et al.* (2000), Zhang *et al.* (2000, 2001), Yue *et al.* (2002), Burn & Hag Elnur (2002), Adamowski and Bougadis (2003), and others.

3.3 Comparison of power of the tests

Parametric tests assume that the random variable is normally distributed and have homogeneous variance. Non-parametric tests make no assumption for probability distribution. The t-test for trend detection is based on linear regression, and therefore checks only for a linear trend. There is no such restriction for the nonparametric tests such as Mann- Kendall test. The Mann-Kendall test is expected to be less affected by the outliers because its statistic is based on the sign of differences, not directly on the values of the random variable. In general, parametric tests are more powerful for given n when the variable is normally distributed, but much less powerful when it is not, compared with the non-parametric tests (Hirsch et al., 1991). The power of a test can be determined only when the true condition is known. In a trend test, this requires knowledge of the

trend. The probability of the rejection of a given trend (probability of type II error, β) can be computed for a chosen level of significance, α . In fact α is the probability of type I error, or the probability of detecting a trend when no trend exists. The power is defined as $1-\beta$.

Yue et al. (2002) examined the power of different tests and found that the power of the Mann-Kendall test is quite different for different distribution types when a trend exists. The GEV3 distribution (type 3 generalized extreme values) has the highest power while the lognormal distribution has the lowest power. This is an interesting result showing that the power of the Mann-Kendall trend test is dependent on the distribution type, in contrast to common thinking that this test is rank-based and therefore distribution free. The power of the test is also dependent on the shape parameter of the probability distribution, such that it increases with the coefficient of skewness for the generalized extreme value and Pearson type 3 distributions. The results of Yue et al. (2002) for the lognormal distribution are not in agreement with those of the other distributions that have roughly the same value of the coefficient of skewness.

Önöz and Bayazit (2003) investigated the power of the t-test for trend analysis and compared its power with the power of the Mann-Kendall test. For this purpose, a Monte Carlo simulation was performed similar to that of Yue et al. (2002) described above. Generated samples had various probability distributions such as normal (N), lognormal (LN), Gumbel, generalized extreme value (GEV), and Pearson type 3 (P3). Linear trends were superimposed onto each of the generated series and t-test was applied to each series at the level of significance $\alpha = 0.05$. Fig. 3.2 shows the power of the t-test for various distributions as a function of the slope of the trend. The power increases with the absolute value of the slope, and is nearly the same for the equal positive and negative slopes. It is seen that the power

increases with the coefficient of skewness of the distribution. The normal distribution has the lowest power. The lognormal, Gumbel, generalized extreme value and Pearson type 3 distributions that have a skew coefficient of about $C_s = 1.5$ lead to values of the power that are close to each other. The power of the test is highest for the generalized extreme value distribution with $k = -0.3$ ($C_s = 13.5$).

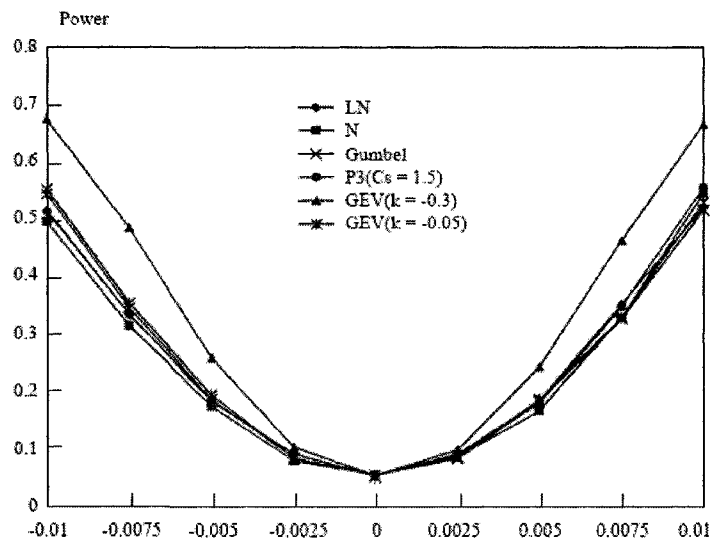


Fig. 3.2 .Power of the t test for trend detection as a function of the slope of the trend for various probability distributions (Önöz and Bayazit, 2003).

Fig. 3.3 shows the ratio of the power of the t -test to that of the Mann-Kendall test for various probability distributions as function of the slope of the trend (Önöz and Bayazit, 2003). It can be seen that this ratio is slightly above one for the normal distribution, implying that t -test is more powerful than the Mann-Kendall test in this case. For all other (non-normal) distributions, the ratio is significantly less than one. For skewed distributions, the Mann-Kendall test is more powerful, especially when the coefficient of skewness is high (Önöz and Bayazit 2003). The MK and SR non-parametric tests have been compared by some authors (e.g. Daniel, 1978 and Yue et. al., 2002). These studies have found that there is no

significant reason for choosing one over the other. Nevertheless, Daniel (1978) pointed out that the distribution of S (MK) approaches normality more rapidly than does D (SR) and S provides an unbiased estimate of the population parameter, which D does not, and therefore, S is more interpretable.

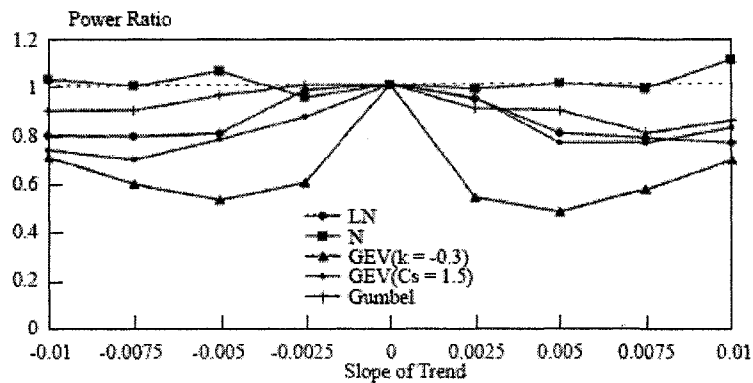


Fig. 3.3. Ratio of the power of the t-test to the power of the Mann-Kendall test as a function of the slope of the trend for various probability distributions (Önöz and Bayazit 2003).

The rank-based non-parametric Mann-Kendall (MK) statistical test has been frequently used to quantify the significance of trends in hydro-meteorological time series such as water quality, streamflow, temperature, and precipitation. Furthermore, the comparison made by different researchers supports the superiority of Mann-Kendall test over other parametric and nonparametric tests when dealing with hydro-climatic variables. The main reason for using non-parametric statistical test is that compared with parametric statistical tests, the non-parametric tests are thought to be more suitable for non-normally distributed data and censored data, which are frequently encountered in hydro-meteorological time series. Moreover, among nonparametric tests, Mann-Kendall (MK) test due to unbiased estimation of population parameters is preferred to other tests and as such is used in this study to investigate trends in quantity and timing of low-flows in Canadian streamflows. The serial independence of a time series is still required

in non-parametric tests. Therefore some modifications are required to account for the impact of autocorrelation on MK test.

3.4 Effects of nonstationarity on the MK test

Hydrological time series may frequently display statistically significant serial correlation. In such cases the existence of serial correlation will increase the probability that the MK test detects a significant trend. This leads to a disproportionate rejection of the null hypothesis, whereas the null hypothesis is actually true. The fitted probability density functions of the MK statistics (S) of the simulated series for different correlation coefficients by Yue and Wang (2002) is shown in Fig. 3.4. It is evident that the existence of positive serial correlation in a time series does not alter the normality of the MK statistic S or the location of the centre of the distribution or the mean of S . However, it can be seen that the presence of positive serial correlation changes the scattering of the distribution. That is, the variance of S increases as the magnitude of serial correlation increases. For a time series with negative serial correlation, opposite to the positive case, the existence of negative serial correlation decreases the variance of the MK statistic (Yue and Wang, 2002).

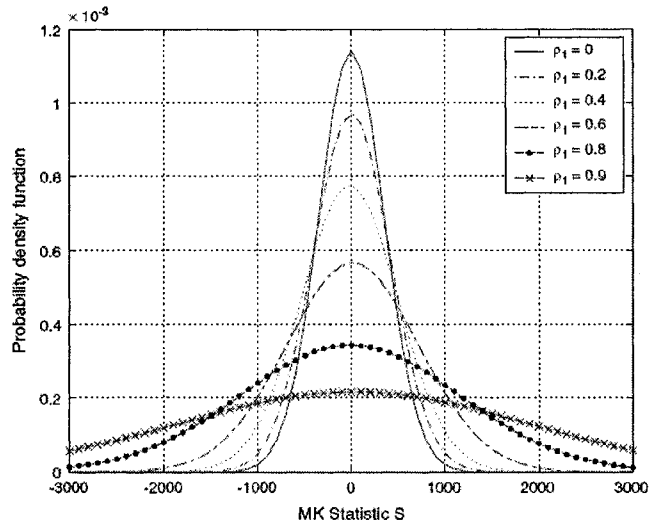


Fig. 3.4. Effect of positive serial correlation on the M K statistic (Yue et al., 2002).

3.5 Modifications on Mann-Kendall (MK) test

As explained before, positive serial correlation within a time series inflates the variance of the estimated mean, and a time series contains less information about the mean than a random series. In other words, the effective number of independent samples (Effective Sample Size, ESS) of a serially correlated series is less than its actual number of samples (Actual Sample Size, ASS). Positive serial correlation increases the variance (σ_s) of the MK statistic and hence increases the possibility of rejecting the null hypothesis of no trend, when it is true. In contrast, negative serial correlation shrinks the variance of the MK statistic and hence results in underestimation of significant trends and consequently accepting the null hypothesis of no trend when it is false (Yue and Wang, 2002a). The variance of the MK test must be customized in order to account for any existing autocorrelation. Lettenmaier (1976) modified variance of the MK statistics ($Var^*(S)$) using the following approximation:

$$Var^*(S) = \frac{n}{n^*} Var(S) = \eta^s Var(S) \quad (3.26)$$

Where, $Var(S)$ is the variance of the actual sample, n is the ASS of the actual sample data, n^* is the ESS, and η^s is the correction factor for serial correlation. Effective sample size (n^*) is computed as (Yue and Wang, 2002):

$$n^* = \frac{n}{1 + \frac{2}{n} \sum_{j=1}^{n-1} (n-j) \rho_j} \quad (3.27)$$

Where ρ_j is the lag- j serial correlation coefficient. For sample data, ρ_j is replaced by r_j and is computed by the following formula (Salas *et al.*, 1980; Yue *et al.*, 2002):

$$r_j = \frac{\frac{1}{n-j} \sum_{i=1}^{n-j} (X_i - \bar{X})(X_{i+j} - \bar{X})}{\frac{1}{n} \sum_{i=1}^n (X_i - \bar{X})^2} \quad (3.28)$$

Where

$$\bar{X} = \frac{1}{n} \sum_{i=1}^n X_i \quad (3.29)$$

Hence the correction factor can be given by:

$$\eta^s = \left\{ \begin{array}{ll} 1 + \frac{2}{n} \sum_{j=1}^{n-1} (n-j) \rho_j & \text{for } j > 1 \\ 1 + 2 \frac{\rho_1^{n+1} - n\rho_1^2 + (n-1)\rho_1}{n(\rho_1 - 1)^2} & \text{for } j = 1 \end{array} \right\} \quad (3.30)$$

The modified standard MK statistic then can be defined as:

$$Z^* = \frac{Z}{\sqrt{\eta'}} \quad (3.31)$$

Equation (3.31) accounts for the effect of serial correlation on the MK test statistic at a site. To determine if observed sample data are statistically correlated, the significance of the lag-1 serial correlation at the significance level of α of the two-tailed test is assessed using a confidence interval defined by the following equation (Anderson, 1942; Yevjevich, 1972; Salas *et al.*, 1980; Yue *et al.*, 2002):

$$\frac{-1 - 1.645\sqrt{n-2}}{n-1} \leq r_1 \leq \frac{-1 + 1.645\sqrt{n-2}}{n-1} \quad (3.32)$$

If the lag-1 serial correlation computed by Equation (3.28) falls within the confidence interval given by Equation (3.32), the sample data are assumed to be serially independent. Otherwise the sample data are considered to be significantly serially correlated and the MK test is corrected to account for serial correlation.

3.6 Experimental Design

3.6.1 Data used in the study

Water Survey of Canada (WSC) collects streamflow and water level data at 2,423 hydrometric gauging stations across Canada. Meteorological Service of Canada (MSC) has identified a national hydrological network that can be used to recognize and document the effects of a changing climate on Canada's water resources. Such information is essential for water planning and management and infrastructure design at local, regional and national scales (the Environment Canada website, 2007). The data used in this study are from the Reference Hydrometric basin network (RHBN). Established in mid 90s, the Reference Hydrometric Basin Network (RHBN) was a 250-station sub-set of Canada's

national hydrometric network of plus 2400 active stations, identified by a national group of hydrological experts for use in the detection, monitoring, and assessment of climate change (Harvey et al., 1999; Pilon and Kuylenstierna, 2000).

Presently, after some modifications, RHBN consists of 225 streamflow stations and 4 Lake water level stations. RHBN basins are currently being monitored, and are characterized by either pristine or stable hydrological conditions, with 20 or more years of good quality record. The RHBN, as illustrated in Fig. 3.5, covers most of Canada's major hydrologic regions, although there are gaps in some regions of the country and there are no RHBN stations north of 70 degrees latitude. Hydrometric stations within the RHBN are of particular importance for studies aimed to climate variability and change; however, analysis of the characteristics of stations indicates certain limitations. The network tends to be composed of large basins in the north and smaller basins in the south, with certain provinces having large gaps in spatial coverage. This underscores the need to supplement the current network to allow smaller basins to be brought on-line in the North and to fill major geographic gaps (Harvey et al., 1999; Pilon and Kuylenstierna, 2000).

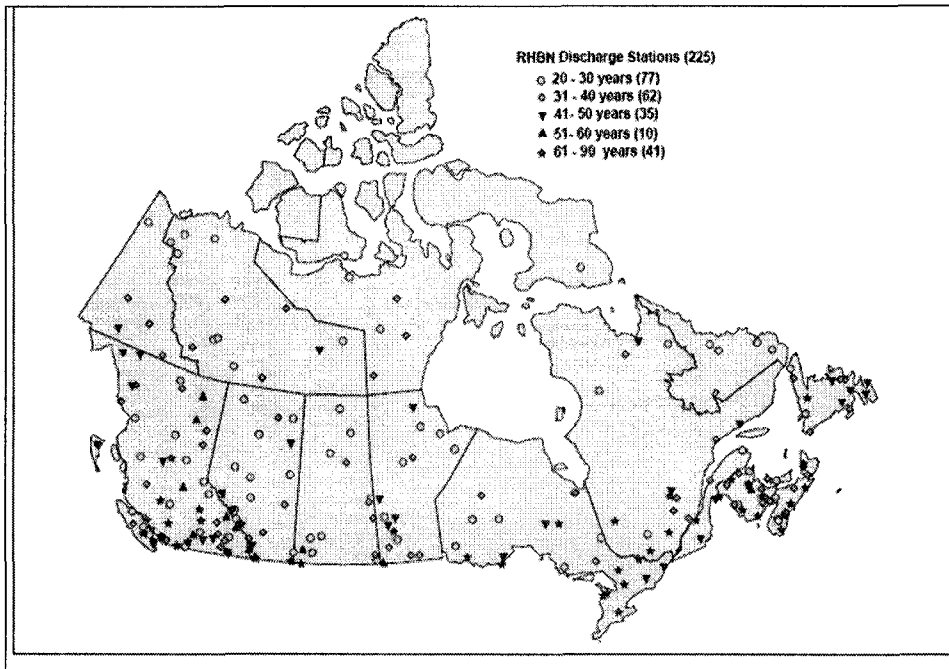


Fig. 3.5 Distribution of RHBN stations across Canada (Yuzyk, 2001).

3.6.2 Extracting low flow time series

3.6.2.1 Data extracted for trend detection in quantity of low flows

To investigate trends in the quantity of different low-flow indices and whether a trend in a short low-flow period can be interpreted as trend in longer low-flow periods as well, it was decided to extract and test low flow indices of 7-, 14-, 21-, and 30-days for the RHBN network. Considering 225 streamflow stations in RHBN network with an average of 40 years of record length, more than 9000 mean daily flow time series were inspected to verify the quality and the quantity of the available records. After applying some filtering processes in terms of completeness and record length of the time series, 212 out of 229 stations from the beginning of their observations to 2003 were selected to perform trend detection analysis in Canadian streamflows. The excluded stations are the lake

level stations (4 stations) plus 13 other stations that due to high number of missing data were eliminated from the data set.

The minimum and maximum years of records after consideration of the number of missing data, were 16 and 92 years, respectively. The last year of records for the whole network is 2003 yet in some stations the records may terminate one or more years before 2003 due to the lack of observation or high number of missing data for the last years. The longest record belongs to a hydrometric station in Alberta (05BB001) with 92 years of record. The shortest record belongs to a hydrometric station in British Columbia (08HB025) with 16 years of record. It should be noted that RHBN stations have at least 20 years of records; however, in this study, some years have been eliminated from the time series due to high number of missing data.

For each station the time series were reorganized in a way that calculation and extraction of 7-, 14-, 21-, and 30-day annual low-flow indices was facilitated. Considering different record length for the selected stations, overall, a sum of 8821 time series constitute the final database for the study. Four new time series of 7-, 14-, 21-, and 30-day low flow indices were created for the selected stations. The new data set consisted of 35284 time series which was used for detection of trends in the quantity of low-flows in Canadian stream flows. It was decided not to estimate the missing data to avoid the uncertainties involved in interpolations. That is, the minimum low flows were extracted using available data and trend detection in low-flows was performed ignoring the days with no records.

It is noteworthy that the average daily flows recorded in hydrometric sites are the mean daily stream flows measured, derived, or computed under different circumstances which might be associated with some measurement errors. For example, observations are not available in certain periods of winter in some

stations due to different difficulties such as freezing situations and limited access to the hydrometric stations. The available data in some stations in these periods are based on some calculations considering different factors including backwater rather than direct measurements which involves a certain level of uncertainties; however, the errors and reliability of the gauge measurements were not investigated in this study.

The low-flow indices were extracted using a moving average procedure. A moving average is the lowest arithmetically averaged flow of duration “d” of consecutive days within a given year. A list of the stations along with other specifications of the sites used in this part of the study is presented in Table 3.1. In this table column (2) presents the region code based on the eco-zones and column (4) is the station ID used in RHBN. Latitude, longitude, and the drainage area of each station are presented in columns 5, 6, and 7, respectively. Columns 8 and 9, respectively, present the last year of record and record length (in years) for each station. In some cases there might be a small difference between the last year of record reported by the RHBN and the last year of records used in this study due to the fact that the last year, or in some cases the last years, of the observations encountered some missing data and therefore were eliminated from the sample data before applying the tests. Fig. 3.6 illustrates the starting and ending dates of the time series for studied stations.

3.6.2.2 Extracted time series for detection of trend in timing of low flows

In order to investigate the changes in timing of minimum 7-day events, the date of occurrence of minimum 7-day low-flows was extracted for summer and winter periods, whereby each year was divided into summer and winter time periods. In order to ensure that a period of summer or winter low-flow is not split to two parts, the starting and ending dates for each study year were defined so that it

practically matches the local situations of the low flows. That is, in this study, each hydrological year starts on May 1st and ends on April 31st of the following calendar year. Also, the summer portion of the year starts on May 1st and ends on October 30th whereas the winter portion starts on November 1st and ends on April 30th of the following year. The date of occurrence of the minimum summer or winter low flows were calculated in a way that smaller numbers indicate earlier dates while larger numbers mean later dates in timing of low-flows. When a calendar year changes in a winter period, the calculations are modified to account for the changes due to starting the new calendar year.

Since some stations are not being observed in winter, the number of stations studied for summer low flow dates may not correspond to the number of stations for winter 7-day low flow. In this part of the study 193 stations were used to perform trend detection in timing of winter 7-day low flows whereas 201 stations were tested to detect changes in timing of 7-day low-flow in the summer portion of the year for this analysis. The list of stations used for trend detection in timing of summer and winter low-flow are the same as presented in Table 3.1 except the stations eliminated due to low quality of time series in summer or winter portions of the year.

Table 3.1.Stations used in detection of trends in low-flows.

No. (1)	Region Code (2)	Province/ Territory (3)	Station ID (4)	Latitude (5)	Longitude (6)	Drainage Area(km ²) (7)	Last year of Record (8)	Record Length(year) (9)
1	7	ME	01AD002	47.257	-68.593	14700	2002	75
2	7	NB	01AD003	47.207	-68.957	1350	2002	51
3	7	NB	01AJ004	46.438	-67.745	484	2002	36
4	7	NB	01AJ010	46.341	-67.466	350	2002	30
5	7	NB	01AK001	45.945	-67.322	234	2002	60
6	7	NB	01AP002	46.072	-65.367	668	2002	41
7	7	NB	01AP004	45.702	-65.601	1100	2002	41
8	7	NB	01AQ001	45.170	-66.467	239	2002	84
9	7	NB	01BC001	47.667	-67.484	3160	2002	41
10	7	NB	01BE001	47.832	-66.882	2270	2002	60
11	6	QC	01BH005	48.980	-64.699	645	2001	31
12	7	NB	01BJ003	47.898	-66.030	510	2002	39
13	7	NB	01BL002	47.706	-65.155	173	2002	34
14	7	NB	01BO001	46.736	-65.827	5050	2002	42
15	7	NB	01BP001	46.936	-65.907	1340	2002	52
16	7	NB	01BQ001	47.095	-65.837	948	2002	42
17	7	NB	01BS001	46.444	-65.065	166	2002	39
18	7	NB	01BU002	45.944	-65.170	391	2002	42
19	7	NB	01BV006	45.559	-65.017	130	2002	39
20	7	PE	01CA003	46.744	-64.186	46.8	2002	41
21	7	PE	01CB004	46.393	-63.660	45.4	2002	31
22	7	NS	01DG003	44.852	-63.665	96.9	2002	81
23	7	NS	01DL001	45.586	-64.451	63.2	2002	31
24	7	NS	01DP004	45.497	-62.781	92.2	2002	36
25	7	NS	01EC001	43.838	-65.370	495	2002	74
26	7	NS	01ED005	44.333	-65.204	723	2000	32
27	7	NS	01ED007	44.437	-65.223	295	2002	34
28	7	NS	01EF001	44.447	-64.592	1250	2002	87
29	7	NS	01EG002	44.564	-64.352	370	2002	31
30	7	NS	01EO001	45.173	-61.982	1350	2002	87
31	7	NS	01FA001	45.721	-61.286	193	2002	37
32	7	NS	01FB001	46.369	-60.977	368	2002	81
33	7	NS	01FB003	46.223	-61.137	357	2002	84
34	5	MN	02AA001	48.012	-89.616	1550	1999	76
35	5	ON	02AB008	48.382	-89.308	187	2003	49
36	5	ON	02BF002	46.860	-83.972	1160	2003	36
37	5	ON	02CF008	46.610	-81.033	179	2003	27
38	5	ON	02EA005	45.669	-79.379	321	2003	88
39	5	ON	02EC002	44.713	-79.282	1520	2003	88
40	5	ON	02FB007	44.523	-80.931	181	2003	42
41	5	ON	02FC001	44.456	-81.327	3960	2003	89
42	5	ON	02GA010	43.191	-80.455	1030	2003	55
43	5	ON	02HL004	44.549	-77.329	712	2003	48
44	5	ON	02JC008	47.889	-79.879	1780	2003	33
45	5	ON	02KB001	45.888	-77.308	4120	2003	88
46	5	ON	02LB007	44.842	-75.544	246	2003	54
47	6	QC	02LG005	47.084	-75.754	6840	2001	25
48	6	QC	02LH004	46.078	-76.069	1290	2001	25
49	6	QC	02NE011	47.767	-72.737	1570	2000	35
50	6	QC	02NF003	46.686	-73.914	1390	2001	58
51	6	QC	02OE027	45.467	-71.655	642	2001	47
52	6	QC	02PB006	46.972	-71.854	642	2001	35
53	6	QC	02PJ007	46.659	-71.289	709	2001	75

Table 3.1(Continued). Stations used in detection of trends in low-flows.

No. (1)	Region Code (2)	Province/Territory (3)	Station ID (4)	Latitude (5)	Longitude (6)	Drainage Area(km ²) (7)	Last year of Record (8)	Record Length(year) (9)
54	6	OC	02OA002	48.413	-68.556	1610	2001	38
55	6	OC	02RD002	48.899	-72.212	9320	2001	38
56	6	OC	02RF001	48.686	-72.488	15300	2001	36
57	6	OC	02RG005	48.375	-71.994	2280	2001	23
58	6	OC	02UC002	50.350	-66.190	19000	2001	31
59	6	OC	02VC001	50.308	-63.623	13000	2001	44
60	7	NF	02YA001	51.138	-56.792	306	2002	27
61	7	NF	02YC001	50.608	-57.151	624	2002	43
62	7	NF	02YJ001	48.575	-58.363	640	2002	34
63	7	NF	02YL001	49.241	-57.363	2110	2002	63
64	7	NF	02YO001	49.015	-54.854	4450	2002	53
65	7	NF	02YR001	48.808	-54.224	275	2002	43
66	7	NF	02YS003	48.607	-53.981	36.7	2002	35
67	7	NF	02ZB001	47.6139	-59.0092	205	2002	40
68	7	NF	02ZF001	47.747	-55.442	1170	2002	49
69	7	NF	02ZG001	47.214	-55.329	205	2002	44
70	7	NF	02ZH001	47.947	-54.286	764	2002	50
71	7	NF	02ZK001	47.225	-53.568	301	2002	53
72	7	NF	02ZM006	47.635	-52.837	3.63	2002	49
73	6	OC	03FA003	56.455	-74.239	8390	1999	20
74	6	OC	03KC004	57.6706	-69.6144	42700	1999	36
75	6	OC	03MB002	57.883	-67.583	29800	1999	36
76	7	NF	03NF001	55.233	-61.299	7570	2002	24
77	7	NF	03NG001	54.624	-60.977	8930	2002	16
78	7	NF	03OC001	53.534	-57.495	10900	2002	36
79	7	NF	03OC002	52.649	-56.871	2310	2002	25
80	4	MB	04AD002	55.8500	-92.0986	65500	2003	44
81	5	ON	04DA001	52.581	-90.189	5960	2003	28
82	5	ON	04GA002	51.167	-91.597	5390	2003	30
83	5	ON	04GB004	50.867	-88.931	11200	2003	30
84	5	ON	04JC002	49.779	-84.53	2410	2003	53
85	5	ON	04KA001	51.15	-80.867	4250	2003	33
86	5	ON	04LJ001	49.617	-83.263	8940	2003	83
87	5	ON	04MF001	51.083	-80.767	6680	2003	37
88	6	OC	04NA001	48.601	-78.109	3680	2001	65
89	3	AB	05AA008	49.597	-114.409	404	2003	37
90	3	AB	05AA023	49.814	-114.183	1440	2003	54
91	3	AB	05AD003	49.114	-113.839	614	2003	56
92	3	AB	05AD005	49.1	-113.697	319	2003	92
93	3	AB	05BA002	51.434	-116.172	306	2003	19
94	3	AB	05BB001	51.175	-115.569	2210	2003	91
95	3	AB	05BL022	50.284	-114.59	166	2003	32
96	3	AB	05DA007	51.884	-116.688	249	2003	37
97	3	AB	05DA009	52.002	-116.469	1920	2003	33
98	3	AB	05DA010	51.8	-116.583	20.7	2003	29
99	3	AB	05DE007	52.93	-115.006	551	2003	32
100	3	AB	05FB002	52.7077	-111.3100	3500	2003	39
101	4	MB	05LD001	53.154	-101.108	3350	2003	47
102	4	MB	05LG004	52.031	-100.65	223	2003	36
103	4	MB	05LH005	51.853	-99.547	55000	2003	45
104	4	MB	05LJ005	51.051	-99.788	341	2003	48
105	4	MB	05LJ005	51.051	-99.788	341	2003	48
106	5	ON	05PB014	48.85	-92.725	4870	2003	81

Table 3.1(Continued). Stations used in detection of trends in low-

No. (1)	Region Code (2)	Province/Territory (3)	Station ID (4)	Latitude (5)	Longitude (6)	Drainage Area(km ²) (7)	Last year of Record (8)	Record Length(year) (9)
107	4	MB	05SA002	50.09	-96.429	1610	2003	38
108	4	MB	05TD001	55.7431	-97.0000	15400	2003	32
109	4	MB	05TG002	55.489	-98.186	883	2003	30
110	4	MB	05UH002	57.026	-93.448	2180	2003	27
111	3	AB	06AB002	54.713	-111.001	725	2003	25
112	8	SK	06BD001	56.244	-106.561	3680	2003	32
113	8	SK	06CD002	55.646	-104.735	119000	2003	37
114	8	SK	06DA004	58.481	-103.281	16400	2003	33
115	4	MB	06FB002	57.653	-95.664	4250	2003	30
116	4	MB	06GD001	58.892	-96.275	48100	2003	48
117	9	NU	06JB001	63.591	-105.154	5770	2002	19
118	9	NU	06KC003	64.264	-99.594	67300	2003	27
119	9	NU	06LA001	61.254	-100.974	21400	2003	32
120	9	NU	06LC001	63.653	-95.852	70000	2003	30
121	3	AB	07AA001	52.864	-118.106	630	2003	28
122	3	AB	07AA002	52.91	-118.057	3880	2003	33
123	3	AB	07AH002	54.228	-115.333	424	2003	28
124	3	AB	07CD001	56.685	-111.254	30800	2003	46
125	3	AB	07DD002	58.363	-111.237	2700	2003	33
126	2	BC	07EA002	57.4500	-125.6375	2410.00	2003	20
127	2	BC	07EC002	55.919	-124.564	5490	2003	28
128	2	BC	07EE009	54.529	-122.6	311	2003	28
129	2	BC	07FB001	55.72	-121.208	12100	2003	39
130	2	BC	07FC003	56.677	-121.221	1750	2003	32
131	3	AB	07GG001	54.751	-117.206	1040	2003	33
132	3	AB	07JC001	57.0778	-115.0917	491	2003	28
133	3	AB	07KE001	58.322	-113.068	9860	2003	19
134	8	SK	07LE002	59.147	-105.539	50700	2003	35
135	9	NT	07OB001	60.745	-115.86	47900	2003	40
136	3	AB	07OB003	59.149	-117.634	36900	2003	29
137	9	NT	07RD001	62.897	-108.471	26600	2003	35
138	2	BC	08CC001	57.9000	-129.7040	3550.00	2002	32
139	2	BC	08CD001	58.072	-130.824	3600	2003	37
140	2	BC	08CE001	57.901	-131.154	29300	2003	39
141	2	BC	08CG001	56.739	-131.674	9350	2003	39
142	2	BC	08DA005	56.11	-129.476	221	2003	33
143	2	BC	08DC006	56.043	-129.925	350	2003	31
144	2	BC	08DD001	56.351	-130.692	1480	2003	29
145	2	BC	08ED001	53.931	-127.453	741	2003	31
146	2	BC	08FA002	51.679	-127.179	3900	2003	38
147	2	BC	08FB006	52.361	-126.003	2430	2003	31
148	2	BC	08FB007	52.422	-126.159	3720	2003	31
149	2	BC	08GA010	49.396	-123.144	172	2003	87
150	2	BC	08GA061	49.356	-123.098	3.63	2003	30
151	2	BC	08GD004	50.984	-124.917	5720	2003	31
152	2	BC	08HA001	48.879	-123.702	355	2003	29
153	2	BC	08HA003	48.728	-123.67	209	2003	44
154	2	BC	08HB002	49.317	-124.283	324	2003	24
155	2	BC	08HB008	49.29	-124.91	347	2003	62
156	2	BC	08HB025	49.693	-125.085	86	2003	16
157	2	BC	08HC002	49.709	-126.098	185	2003	19
158	2	BC	08HE006	50.098	-126.842	178	2003	37
159	2	BC	08HF004	50.437	-126.574	360	2003	27

Table 3.1(Continued). Stations used in detection of trends in low-flows.

No. (1)	Region Code (2)	Province/Territory (3)	Station ID (4)	Latitude (5)	Longitude (6)	Drainage Area (km ²) (7)	Last year of Record (8)	Record Length(year) (9)
160	2	BC	08JB002	54.009	-125.005	3600	2003	53
161	2	BC	08JE001	54.418	-124.275	14600	2003	53
162	2	BC	08KA009	53.445	-120.219	252	2003	32
163	2	BC	08KH006	52.844	-122.224	11500	2003	58
164	2	BC	08LA001	51.656	-120.065	10200	2003	53
165	2	BC	08LD001	50.938	-119.654	3080	2003	44
166	2	BC	08LG016	49.974	-120.135	87	2003	31
167	2	BC	08MA002	51.625	-124.142	2110	2003	35
168	2	BC	08MB006	51.523	-123.114	1020	2003	29
169	2	BC	08MG005	50.336	-122.799	2160	2003	74
170	2	BC	08MH006	49.243	-122.578	37.3	2003	43
171	2	BC	08MH016	49.084	-121.457	329	2003	45
172	2	BC	08NB005	51.483	-117.179	9710	2003	56
173	2	BC	08NC004	52.728	-119.408	298	2003	31
174	2	BC	08ND013	51.014	-118.083	1170	2003	38
175	2	BC	08NE006	50.278	-117.748	337	2003	33
176	2	BC	08NE077	49.908	-118.125	201	2003	53
177	2	BC	08NE077	49.908	-118.125	201	2000	53
178	2	BC	08NE087	49.4250	-118.041	80.50	2002	39
179	2	BC	08NF001	50.886	-116.043	420	2003	43
180	2	BC	08NH005	49.908	-116.952	453	2003	39
181	2	BC	08NH016	49.203	-116.532	57	2003	24
182	2	BC	08NH084	49.159	-116.451	78.7	2003	33
183	2	BC	08NH115	49.104	-116.426	6.22	2003	39
184	2	BC	08NH130	50.081	-116.785	461	2003	30
185	2	BC	08NH131	50.158	-116.575	118	2003	30
186	2	BC	08NJ130	49.501	-117.26	9.07	2003	37
187	2	BC	08NL007	49.46	-120.502	1850	2003	59
188	2	BC	08NL070	49.1	-120.665	407	2003	29
189	2	BC	08NM174	50.212	-119.539	112	2003	33
190	2	BC	08NN015	49.704	-119.092	230	2003	38
191	2	BC	08OA002	53.614	-132.21	477	2003	31
192	2	BC	09AA006	59.599	-133.813	6810	2003	49
193	2	YT	09AA015	59.4319	-134.2055	269.00	2003	30
194	2	YT	09AC001	60.852	-135.739	6990	2003	54
195	2	BC	09AE003	59.931	-131.768	3320	2003	40
196	2	YT	09BA001	61.994	-132.378	7250	2003	39
197	2	YT	09BC001	62.83	-136.581	49000	2003	44
198	2	YT	09FC001	67.634	-139.696	13900	2003	24
199	2	YT	10AB001	60.474	-129.119	12800	2003	39
200	2	BC	10BE004	58.856	-125.381	2570	2003	37
201	2	BC	10BE007	59.335	-125.936	1190	2003	29
202	2	BC	10BE007	59.335	-125.936	1190	2003	29
203	2	BC	10CB001	57.234	-122.694	2160	2003	38
204	2	BC	10CD001	58.788	-122.659	20300	2003	39
205	9	NT	10EB001	61.636	-125.812	14600	2003	31
206	9	NT	10FA002	61.14	-119.836	9270	2003	33
207	9	NT	10GA001	62.48	-123.433	9820	2003	21
208	9	NT	10GB006	62.651	-122.899	20200	2003	21
209	9	NT	10LA002	66.789	-133.079	18600	2003	27
210	9	NT	10MC002	67.236	-134.908	70600	2003	26
211	9	NT	10NC001	68.632	-128.413	56200	2003	27
212	9	NU	10PB001	65.414	-114.008	19300	2003	33

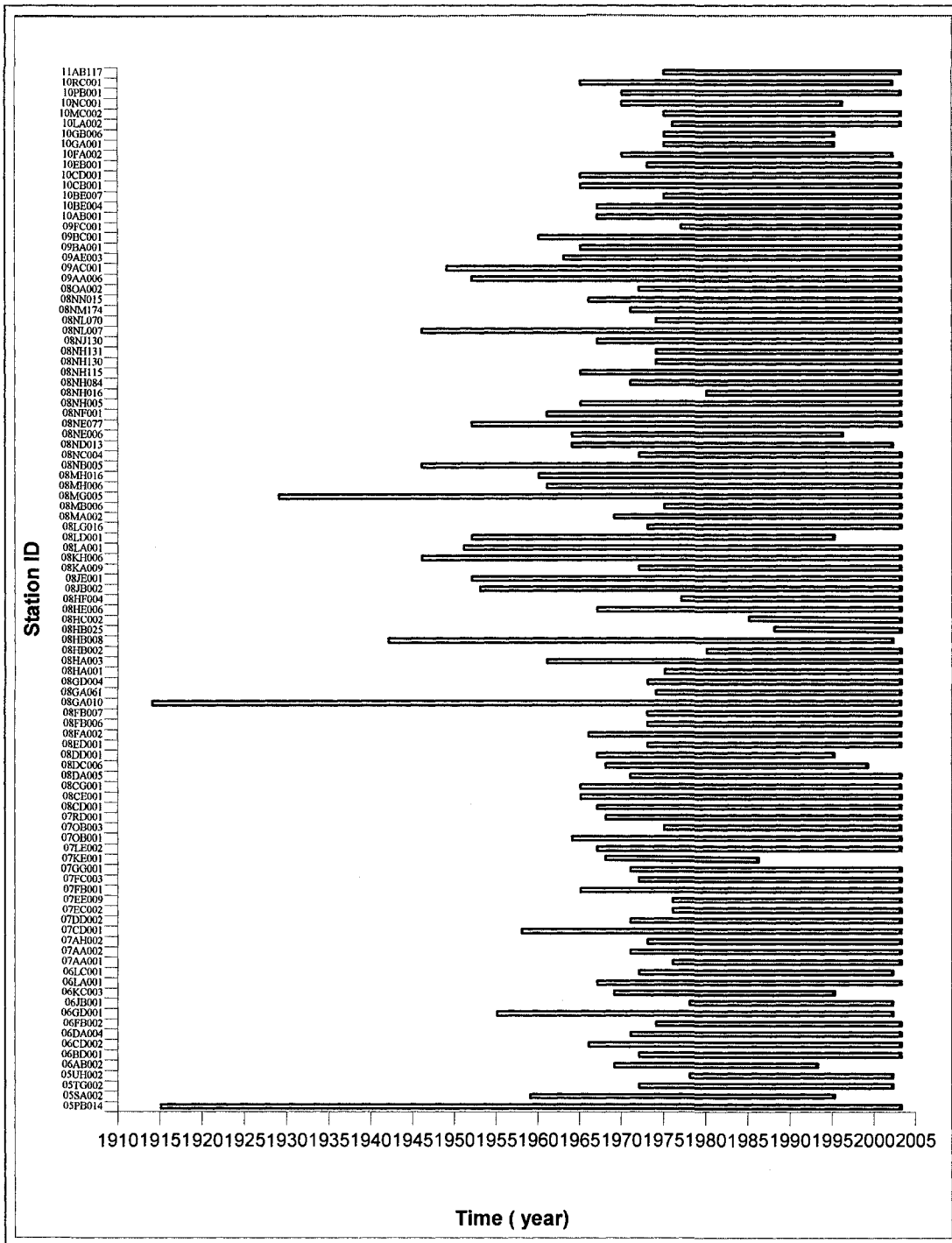


Fig. 3.6. Starting and ending dates of the time series used in the study.

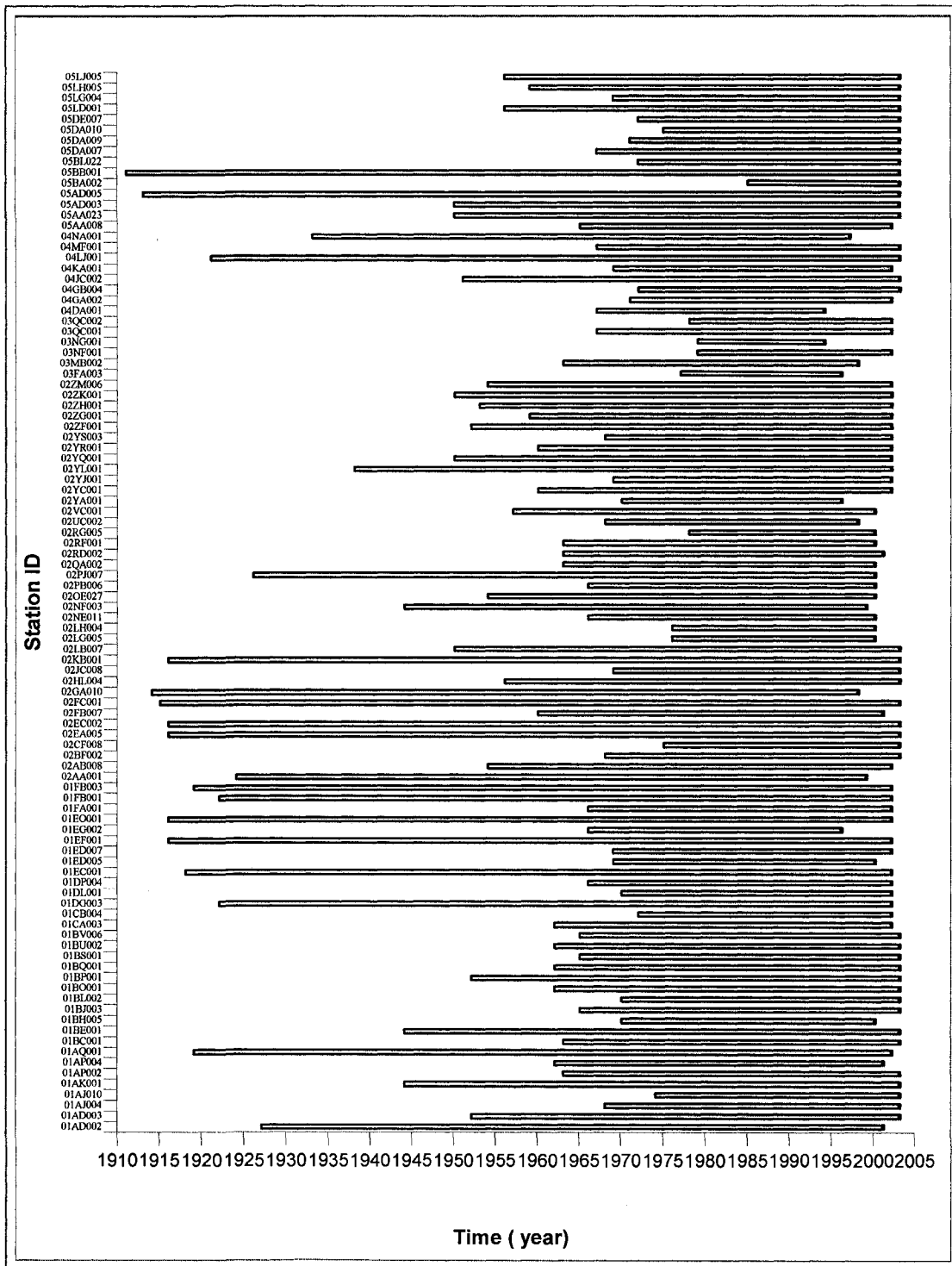


Fig. 3.6 (Continued). Starting and ending dates of the time series used in the study.

3.6.3 Application of Mann-Kendall (MK) test

The nonparametric Mann-Kendall test was applied to extracted low flow time series in order to detect any monotonic trend in quantity and timing of low flows during the period of available records. The S statistic of the test was calculated for each time series using the sign function as described in previous sections. Assuming the normality of the distribution of S statistic, the expectation of S statistic (μ) was set to zero. The variance of the test statistic (σ) which depending on the size of the time series could take a small to a quite large value was calculated for each sample data series. The standard normal variate (Z) was estimated based on the mean and the standard deviation of the time series. Based on the sign of the standard normal variate, one can find out the direction of trends in the tested time series, i.e. if the standard normal variate has a positive sign it means that the time series has experienced an upward trend whereas a negative standard normal variate indicates a downward trend in the tested time series. A standard normal variate equal to zero shows no trend for the time series in the tested record period. The next step after calculating standard normal variates and finding upward, downward, or no trends for each station is to investigate whether the detected trends are statistically meaningful. In other words, it is likely that any time series will show a slight but not considerable increasing or decreasing rate in a certain period; however, this increase or decrease has to be in a certain statistical range to be considered as a statistical significant trend. The estimated standard variate (Z) is associated with a so-called p -value which can be calculated or extracted from normal distribution tables or graphs for each time series. The next step is to determine whether the estimated p -values are statistically significant. This could be done by defining a significance level for the estimated standard normal variates (Z). Defined significance level is in fact the type I error or the risk associated to the rejection of the null hypothesis of no trend where it is true. If the

estimated p -values are smaller than the defined significance level, the detected trend is not likely to occur by chance. On the other hand, if the estimated p -values are larger than the assigned significance level, it implies that the detected trends are likely to occur by chance and the impact of external drivers has not been significant in causing the trends. The most common significance level used in trend detection studies is 0.05. In this study, therefore, it was decided to test the statistical significance of trends in a 0.05 significance level. That is, p -value associated with each detected trend was tested against the defined significance level in order to verify its significance.

Another issue in verifying the significance of a detected trend that has to be addressed is the impact of serial correlation on the time series. Some time series, as discussed before, may display statistically significant serial correlation which will increase the probability that the MK test detects a significant trend and this leads to a disproportionate rejection of the null hypothesis of no trend, whereas the null hypothesis is actually true. In fact, the presence of positive serial correlation changes the scattering of the distribution and the variance of S statistic increases as the magnitude of serial correlation increases. For a time series with negative serial correlation, opposite to the positive case, the existence of negative serial correlation decreases the variance of the MK statistic. In order to reduce the impact of autocorrelation on detection of trends, the variance of the MK test is modified and a corrected standard normal variate (Z^*) is introduced. The correction factor, as discussed before, is a function of serial correlation coefficient (lag-1 autocorrelation in this study) and the number of sample data. The correction coefficient of variance is calculated for each time series and the original estimated variance is modified using this coefficient and then the corrected standard normal variate (Z^*) is calculated for the time series. To assess the impact of serial correlation on the number of detected significant trends, the

test is applied before and after modifications on the variance of the S statistic. Then the differences in the number of detected trends before and after applying modifications are discussed.

3.6.4 Experimental procedure of the study

The study starts with selection of some representative stations across RHBN network in order to perform an exploratory data analysis. This part of the study is intended to obtain a general picture of the magnitude and direction of trends along with an estimation of different order autocorrelations in the low flow time series. Then the study is extended to the whole network to detect trends in timing and also quantity of low flows. Trend in timing of summer and winter low flows is investigated for a 7-day low flow index using MK test regardless of record length, and also in three groups of stations with the minimum of 30- 40-, and 50-years of records. The same procedure is applied to investigate trends in quantity of low flows; however, besides 7-day low flow, trend detection is extended to study changes in 14-, 21-, and 30-day low flow indices. A study of trends in the number of zero events in a few stations with a great number of zero mean daily flows is also performed. The study terminates with the conclusion and the recommendations for future work. Fig. 3.7 shows the flow chart of the experimental design.

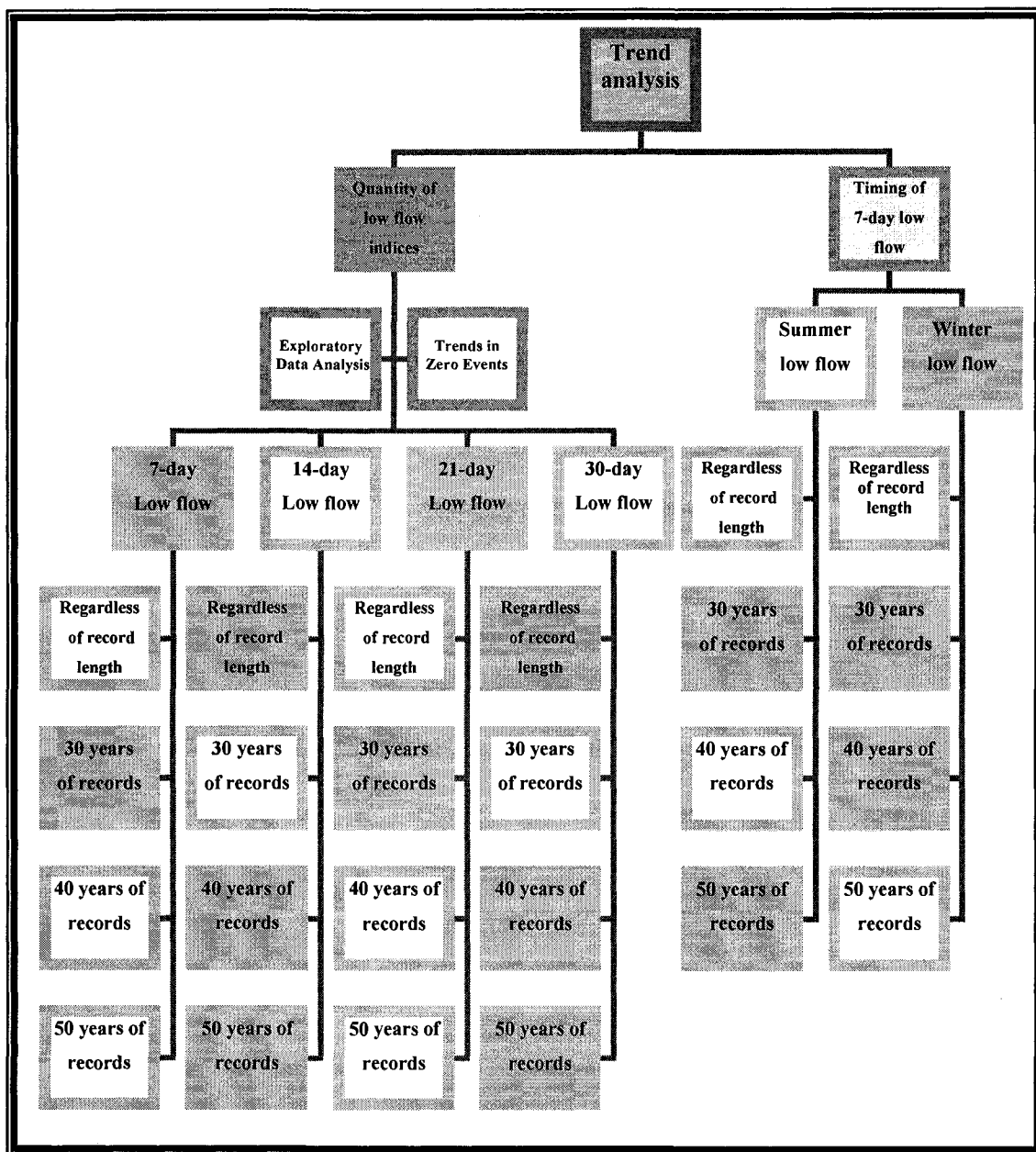


Fig. 3.7. Flowchart of the experimental design.

CHAPTER 4

STATISTICAL ANALYSIS

4.1. Exploratory data analysis

In order to have a general picture of the amount and direction of the trends, an exploratory data analysis was performed on the time series at a number of selected stations and a linear regression was applied to each time series. A trend line was fitted to each data set and the p values of corresponding slopes were estimated. Although due to the assumption of normality of data sets, which is not the case for hydrological records, normal regression is not a recommended measure to evaluate the trends, it is beneficial to make use of it as the first step in exploring qualitative trends. Fig. 4.1 illustrates examples of decreasing, stationary, and increasing trends in stations 08MH016 (BC), 02EA005 (Ontario), 02RF001 (Quebec), and 01EF001 (Nova Scotia), respectively. Despite the dispersion of the data over the observational periods, the fitted trend line for the majority of the selected stations had an increasing or decreasing direction. However, the absolute value of the slope of the trend lines was varying from small values close to zero to significant values in some stations. The specification of selected stations and the values of estimated trends using normal regression are presented in Table 4.1.

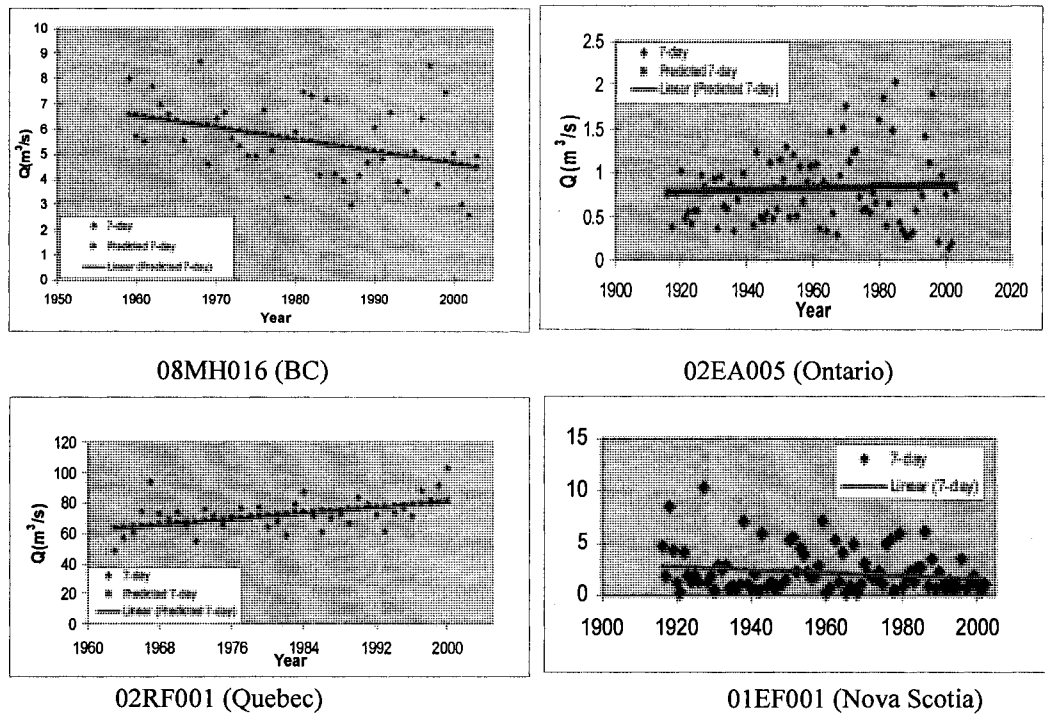


Fig. 4.1. Some examples of exploratory trend detection using normal regression.

For the selected stations, serial correlations of various orders were calculated. As an example, Figure 4.2 shows autocorrelation for different lags in station 02RF001 (Quebec). As it can be seen from this figure, lag one autocorrelation is significant and as such it was taken into account in trend assessments in this study. The calculated autocorrelations for the selected stations are presented in column (5) of Table 4.1. In column (6) of this table, the significance/insignificance of estimated serial correlation at a 0.1 significance level is presented. The word "TRUE" indicates an insignificant autocorrelation whereas the word "FALSE" shows that the absolute value of estimated autocorrelations exceed the lower or upper limit of the 80% confidence interval.

Table 4.1. Estimated trends and autocorrelations for selected stations

No. (1)	Province (2)	Station ID (3)	Trend (m ³ /s/year) (4)	Serial Correlation (5)	Autocorrelation significance (6)
1	NB	01AD002	-0.00008	0.069	TRUE
2	NB	01AD003	-0.00002	-0.03	TRUE
3	NB	01AK001	-0.00001	-0.045	TRUE
4	NB	01AQ001	0.00000	0.17	FALSE
5	NB	01BE001	-0.00002	0.05	TRUE
6	NB	01BP001	0.00005	0.03	TRUE
7	PE	01CA003	0.00000	0.114	TRUE
8	NS	01DG003	0.00000	-0.069	TRUE
9	NS	01EF001	-0.00004	-0.133	TRUE
10	NS	01EO001	0.00000	-0.136	TRUE
11	ON	02AB008	0.00000	0.207	TRUE
12	ON	02EA005	0.00000	0.177	FALSE
13	ON	02EC002	-0.00002	0.290	FALSE
14	ON	02FC001	0.00003	-0.093	TRUE
15	ON	02KB001	-0.00014	0.181	FALSE
16	ON	02LB007	0.00000	-0.064	TRUE
17	QC	02OE027	-0.00003	0.246	FALSE
18	QC	02PJ007	0.00002	0.35	FALSE
19	QC	02RD002	0.00050	0.11	TRUE
20	QC	02RF001	0.00130	0.159	TRUE
21	NF	02YL001	-0.00660	-0.0432	TRUE
22	NF	02YQ001	0.06230	-0.0317	TRUE
23	NF	02ZF001	-0.07180	0.203	TRUE
24	NF	02ZK001	0.00310	0.091	TRUE
25	ON	04JC002	0.00002	0.039	TRUE
26	ON	04LJ001	-0.00005	-0.018	TRUE
27	AB	05AA023	-0.00002	0.3653	FALSE
28	AB	05AD003	-0.00004	0.147	TRUE
29	AB	05AD005	-0.00001	0.155	TRUE
30	AB	05BB001	0.00002	0.310	FALSE
31	AB	05DE007	-0.00110	-0.048	TRUE
32	AB	05FB002	-0.00300	-0.052	TRUE
33	MB	05LH005	0.00004	0.325	FALSE
34	ON	05PB014	0.00008	0.342	FALSE
35	MB	05TD001	-0.00040	0.460	FALSE
36	SK	06BD001	-0.00016	0.2951	FALSE
37	SK	06CD002	-0.00772	0.698	FALSE
38	NT	07OB001	0.00017	0.383	FALSE
39	NT	07RD001	0.00069	0.416	FALSE
40	BC	08HA003	-0.00001	0.0987	TRUE
41	BC	08HB008	-0.00016	0.3192	FALSE
42	BC	08JB002	-0.00009	0.1592	TRUE
43	BC	08JE001	0.00030	-0.0005	TRUE
44	BC	08MH016	-0.00013	0.1513	TRUE
45	BC	08NB005	-0.00019	0.1142	TRUE
46	BC	08NE077	0.00000	0.1319	TRUE
47	BC	08NL007	-0.00004	0.3366	FALSE
48	BC	09AA006	0.00022	0.3251	FALSE
49	YT	09AC001	0.00010	0.14	TRUE
50	YT	09BA001	0.00012	0.077	TRUE
51	YT	09BC001	0.00033	0.236	FALSE
52	YT	10AB001	0.00013	0.36	FALSE
53	NT	10FA002	0.00016	0.5934	FALSE
54	NU	10PB001	0.00071	0.4544	FALSE
55	NU	10QD001	0.00000	0	TRUE
56	NU	10RC001	-0.00050	0.4405	FALSE
57	NU	10TF001	0.00000	0	TRUE

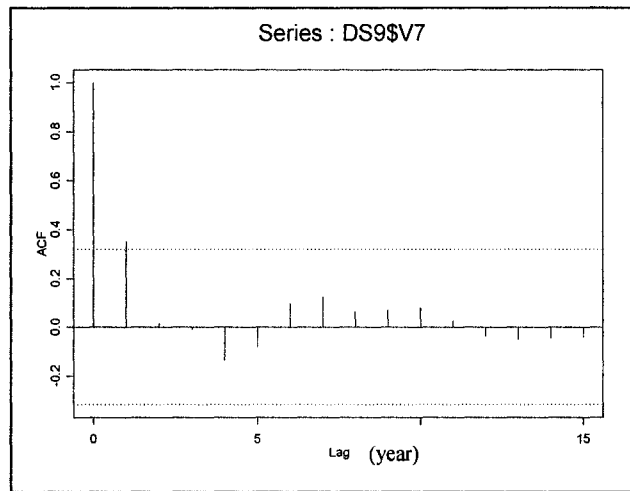


Fig. 4.2. Autocorrelations for different lags for station 02RF001 (Quebec).

Trends and also shifts in timing of 7-day low-flows in summer and winter portions of the year were analyzed using Mann-Kendall test for the selected stations across the country. It was revealed that a number of stations were experiencing statistically significant upward or downward trends in the quantity and timing of 7-day low-flows. Also, mapped results showed that some regional patterns existed in the direction of the trends in both quantity and timing of 7-day low-flows (Adamowski and Ehsanzadeh, 2007; Ehsanzadeh and Adamowski, 2007).

4.2 Trends in the timing of 7-day low flows in RHBN

4.2.1 Data

In this part of the study 193 stations were used to perform trend detection in timing of winter 7-day low flows whereas 201 stations were tested to detect changes in timing of 7-day low-flow in the summer portion of the year. The minimum and maximum years of records were 16 and 92, respectively. The list of stations studied for timing of summer and winter low-flow is presented in Table

3.1. The date of occurrence of the minimum summer and winter low flows were calculated in a way that smaller numbers indicate earlier dates while larger numbers mean later dates in timing of low-flows. When a calendar year changes in a winter period, the calculations are modified to account for the changes due to starting the new calendar year. Fig. 4.3 illustrates the distribution of stations with the specified minimum record length for each station. It can be seen that the stations with shorter record lengths are located in Central Canada (Prairies) and Northern Canada whereas stations with longer record lengths are concentrated in the southern parts of the country and more specifically in Atlantic and Pacific provinces.

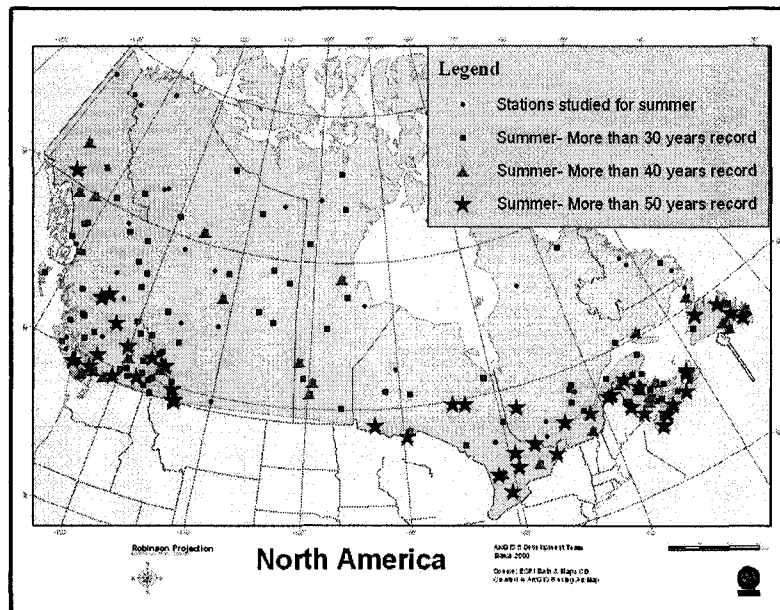


Fig. 4.3 Studied stations categorized based on their record length.

4.2.2 Trends in timing of summer 7-day low flows

To study trend in timing of 7-day low-flows in summer portion of the year, 201 out of 225 stations (RHBN) were selected based on the completeness of the time

series. Observations in only 2 stations terminate in 1999 and in the rest of the stations the sample data end between 2000 and 2003 with the majority ending in 2003. Fig. 4.4 shows the spatial distribution of the selected stations to perform trend detection on timing of summer 7-day low flow across Canada. It can be seen that the majority of the stations are concentrated in west and east parts of the country while north and central Canada have a poor coverage.

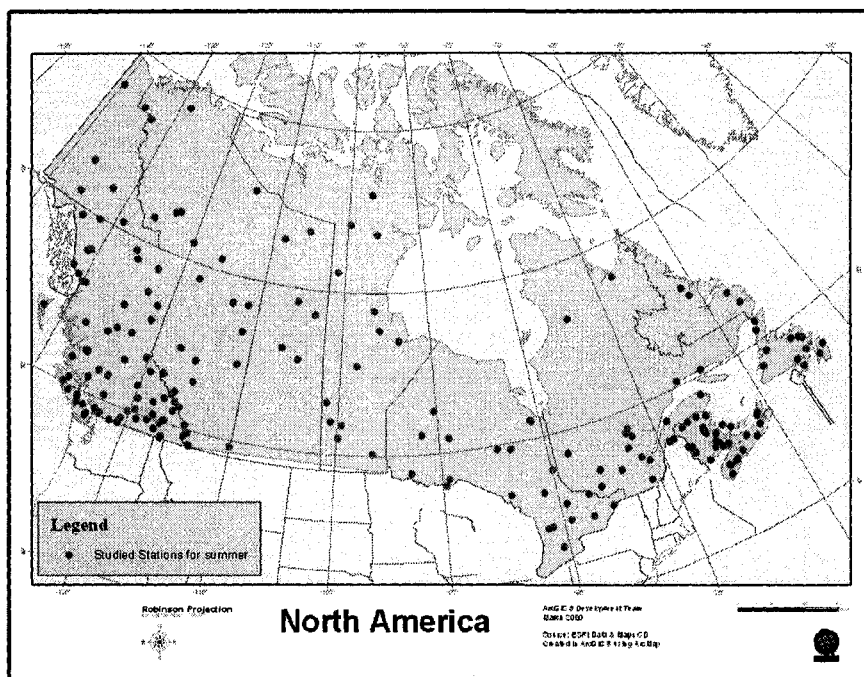


Fig. 4.4 Selected stations for detection of trend in timing of 7-day low-flows.

4.2.2.1 Autocorrelations

Lag-1 serial correlation coefficient of timing of summer 7-day data was estimated and its significance was tested at a 0.1 significance level. Autocorrelation, significance/ insignificance, upper limit, and lower limit for tested stations are presented in Table A-1 (appendix A). In column (5) of this table, the number “1”

indicates an insignificant autocorrelation whereas a “0” sign indicates a significant autocorrelation.

At a 0.1 significance level, 22 out of 201 stations showed significant autocorrelation while in the rest of the network (179 sites) autocorrelation was insignificant. That is, at defined significance level, only 11% of the sites had statistically significant serial correlations. Fig.4.5 shows the location of significant/insignificant autocorrelations throughout the network. It can be seen in this figure that the stations with significant autocorrelation are distributed across the country without any specific pattern.

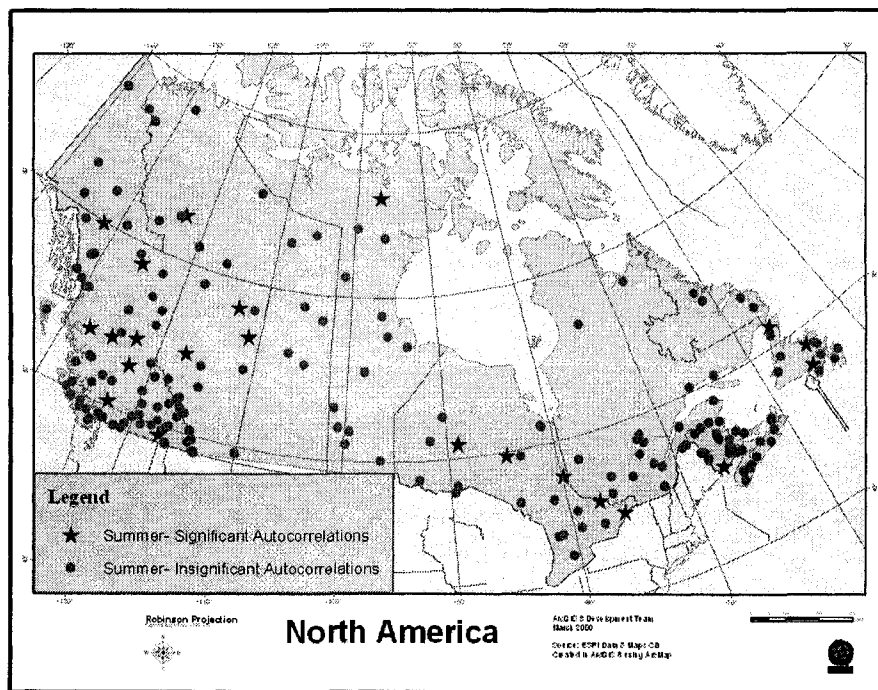


Fig. 4.5. Significant / insignificant autocorrelations in timing of summer 7-day low-flows.

On the other hand, 108 out of 201 stations (54%) showed positive autocorrelation while 92 stations (46%) had negative autocorrelation. The location of positive and negative autocorrelations presented in Fig. 4.6 shows that there is a balance

between the number of positive and negative autocorrelations and no regional pattern can be seen throughout the whole network.

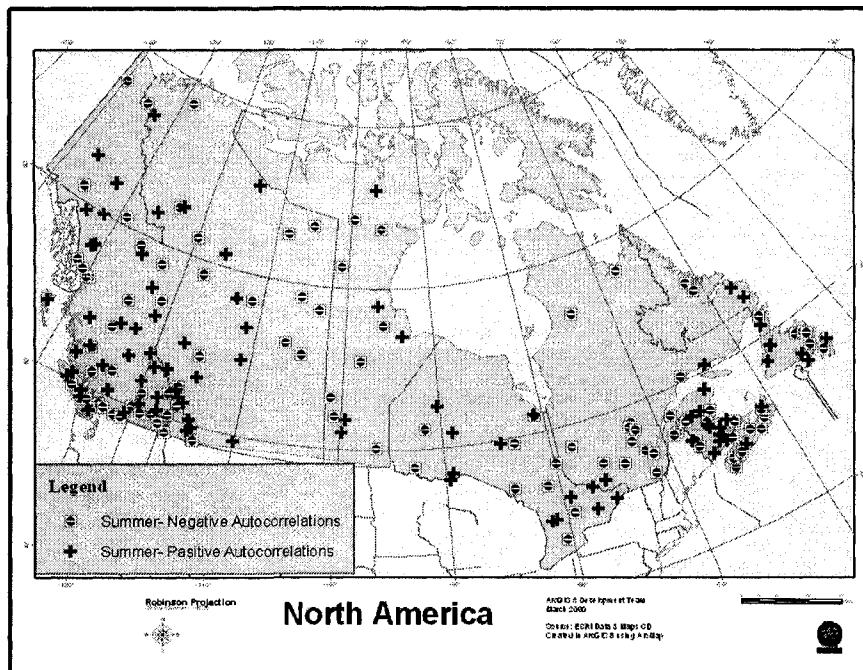


Fig. 4.6. Positive and negative autocorrelations in timing of summer low-flows.

4.2.2.2 Analysis of summer 7-day low-flow regardless of record length

The time of occurrence of the minimum 7-day low-flows of 201 stations in the summer period was tested to detect any monotonic trend regardless of record length and regardless of the time of starting or ending of observations. The results of trend detection in timing of summer 7-day low flow are presented in the appendix A (Table A-2). The record length, S statistic, standard normal variate, and p -values of detected trends before and after correction for autocorrelation are presented in columns 3 to 7 of Table A-2, respectively. A summary of results is presented in Table 4.2. In this table upward and downward trends represent shifts in timing of low flows toward later and earlier dates, respectively.

Table 4.2. Trends in timing of summer 7-day low-flow regardless of record length.

Test Applied	Number of stations	Upward trends	Downward trends	Significant trends at 0.05 significance level		
				Total	Upward	Downward
Original MK Test	201	105	96	31 (15%)	15 (48%)	16 (52%)
Modified MK Test (No Confidence Interval)	201	105	96	30 (15%)	14 (47%)	16 (53%)
Modified MK test (significance level at 0.1)	201	105	96	31(15%)	15 (48%)	16 (52%)

Table 4.2 shows that regardless of statistical significance, all stations have either upward or downward trends. At a 0.05 significance level, 31 out of 201 stations (15%) showed significant upward or downward trends (the second row of Table 4.2). Out of 31 significant trends, 15 time series showed increasing trends while other 16 stations exhibited decreasing trends. After removing any existing autocorrelation, it was found that the number of significant trends did not change substantially where it decreased from 31 to 30 stations (the third row of Table 4.2). The insignificant difference in the results before and after applying the modifications on Mann-Kendall test showed that the presence of autocorrelation did not have a considerable impact on the acceptance or rejection of the null hypothesis of no trend in the timing of summer 7-day low-flows.

In order to remove the impact of serial correlation with a minimum impact on the existing trends, it was decided to remove serial correlation only if its absolute value exceeds a certain confidence interval. In light of this, and as a third procedure, the original MK test was applied to the stations with insignificant autocorrelation while the stations with significant serial correlation were tested using modified MK test. The results from this procedure are presented in the last row of Table 4.2. Out of 201 stations 31 stations (the same number when using original MK test) showed significant trends where 15 stations experienced increasing trends and the rest (16 stations) experienced decreasing trends. A

closer look at the results reveals that in this part of the study, the modification on the MK test did not have significant impact on the number of identified trends.

Despite the fact that consideration of a significance level for autocorrelations and correcting the MK test did not noticeably affect the rate of acceptance/rejection of the null hypothesis, it was decided to use the corrected MK test if stations had significant autocorrelation. This could be considered a compromise between applying the original MK test without any consideration of serial correlation and applying the modified MK test that removes any autocorrelation which may also remove a portion of existing trend. This is the rationale behind choosing this procedure to detect trends in timing of summer 7-day low flow for different record length presented in the following subsections.

The location of general upward and downward trends in timing of summer 7-day low-flows is shown in Fig. 4.7. It can be seen that there are variations in concentration of upward or downward trends in different parts of the network. Almost all of the stations located in the Yukon experienced upward trends while the majority of the stations in Ontario experienced downward trends. Fig. 4.8 shows the spatial distribution of stations with significant upward/downward trends. In this figure (compared to Fig. 4.7) some more distinguishable patterns can be located, i.e. the timing of summer 7-day low-flow in almost all of the stations located in western Canada experienced a significant shift toward later dates, while there is no clear pattern of shifting toward earlier or later dates in other parts of the country.

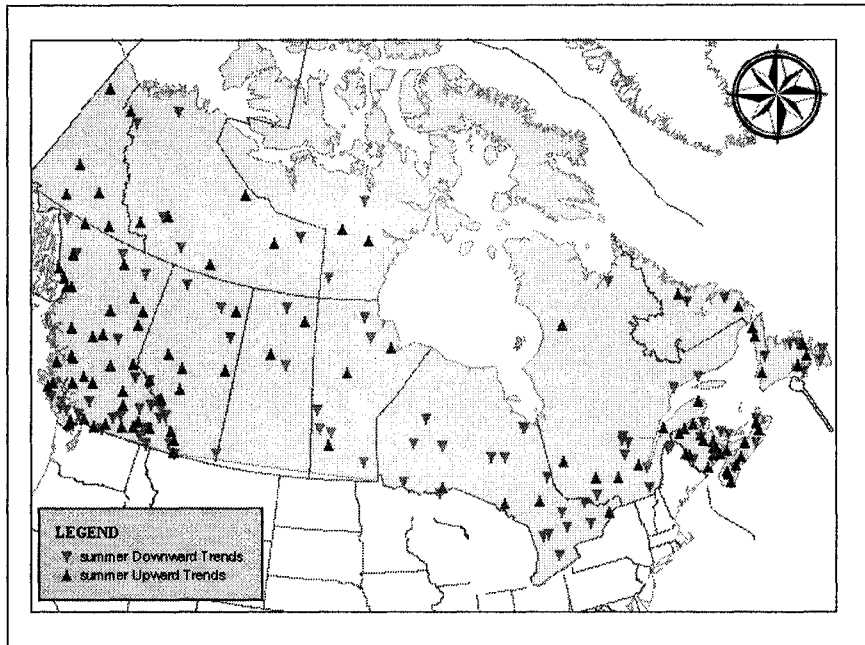


Fig. 4.7. Upward and downward trends in timing of summer 7-day low-flows.

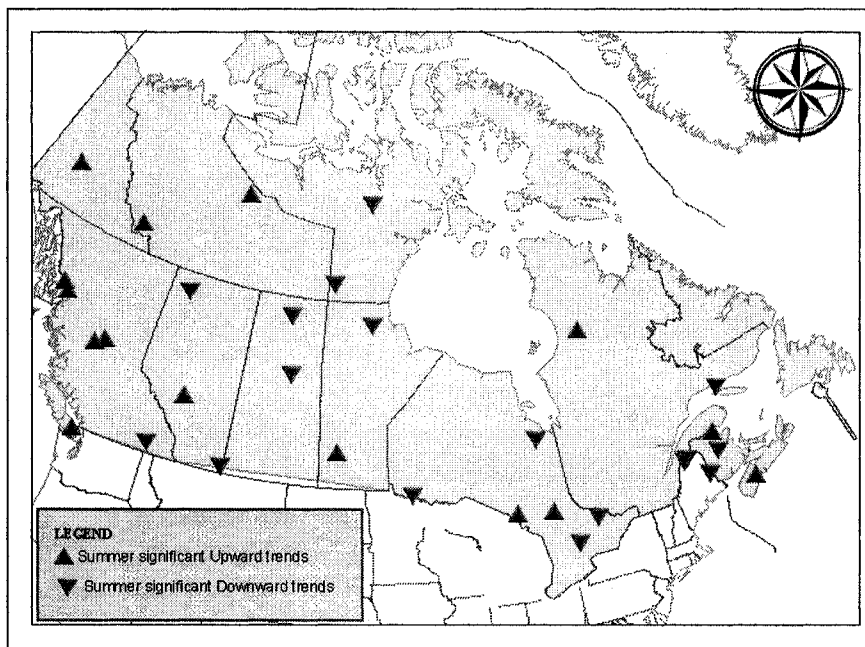


Fig. 4.8. Significant upward/downward trends in timing of summer 7-day low flows.

4.2.2.3 Analysis of summer low-flow in stations with at least 30 years of record

Out of 201 studied stations, 153 stations had equal or more than 30 years of observations. Fig. 4.9 shows the location of selected stations. It can be seen that the selected stations are not located in a specific part of the country and are scattered throughout the network.

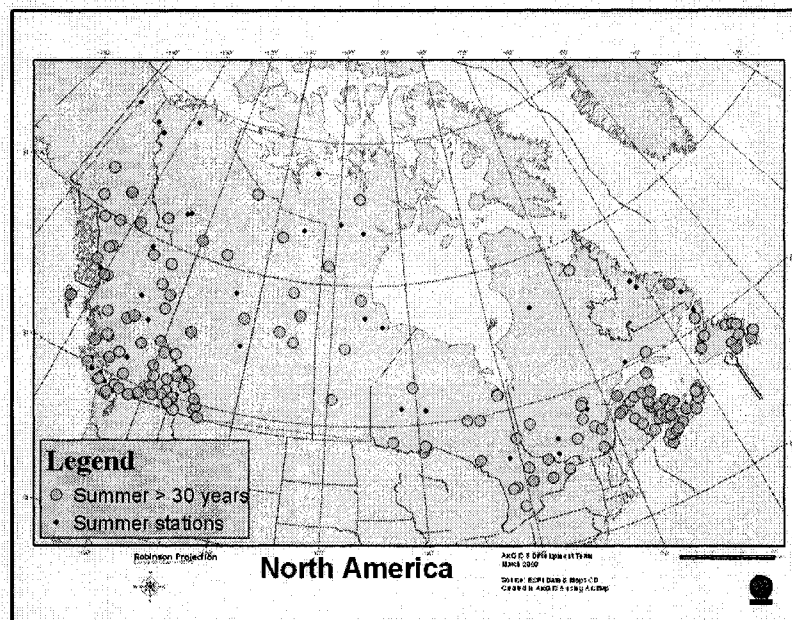


Fig. 4.9. Distribution of stations with at least 30 years of record length.

It was found that 83 out of 153 stations (54%) had decreasing trends while 70 stations showed increasing trends. There is a slight increase in the number of downward trends compared to the previous case where all stations were tested regardless of record length. At a 0.05 significance level, 27 out of 153 stations (18%) had significant upward or downward trends. This percentage, too, is larger compared to the previous case (see 4.2.2.2.2). Furthermore, in 16 out of 27 stations (59%) timing of minimum summer 7-day low-flow was shifting toward earlier dates while the rest (11 stations) shifted toward later dates. Fig. 4.10 shows

the distribution of significant upward/downward trends in the stations with more than 30 years of observations.

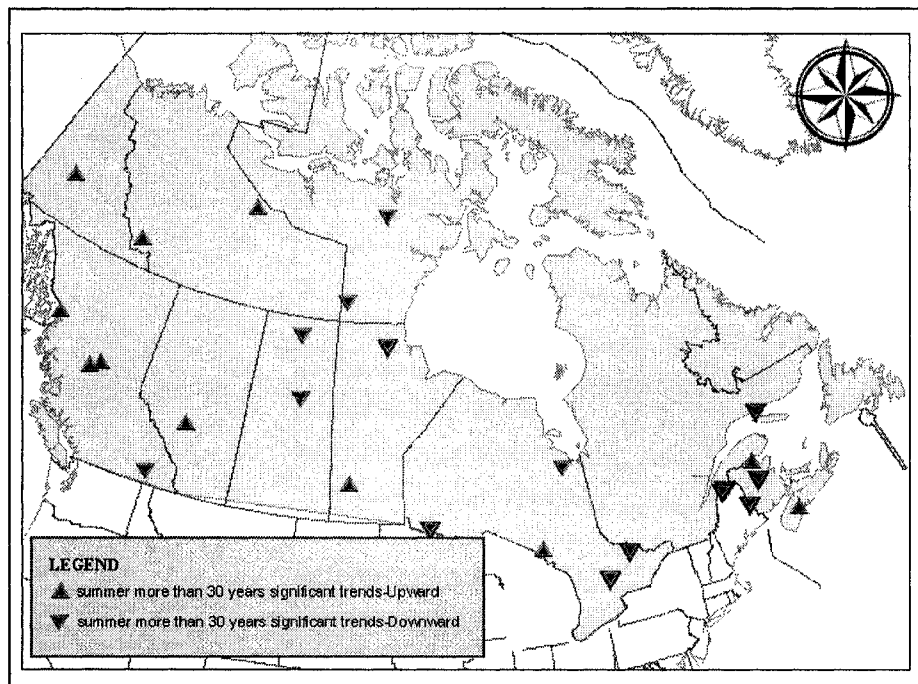


Fig. 4.10. Significant upward/downward trends (more than 30 years of records)

The patterns in the location of significant upward/downward trends are similar to the ones in trend analysis regardless of record length with fewer but clearer presence of significant upward trends in west and northwest of Canada.

4.2.2.4 Analysis of summer low-flow in stations with at least 40 years of record

In this part of the study 75 out of 201 stations were selected to perform trend analysis in summer low flows. Fig. 4.11 illustrates the geographical distribution of stations with at least 40 years of observations.

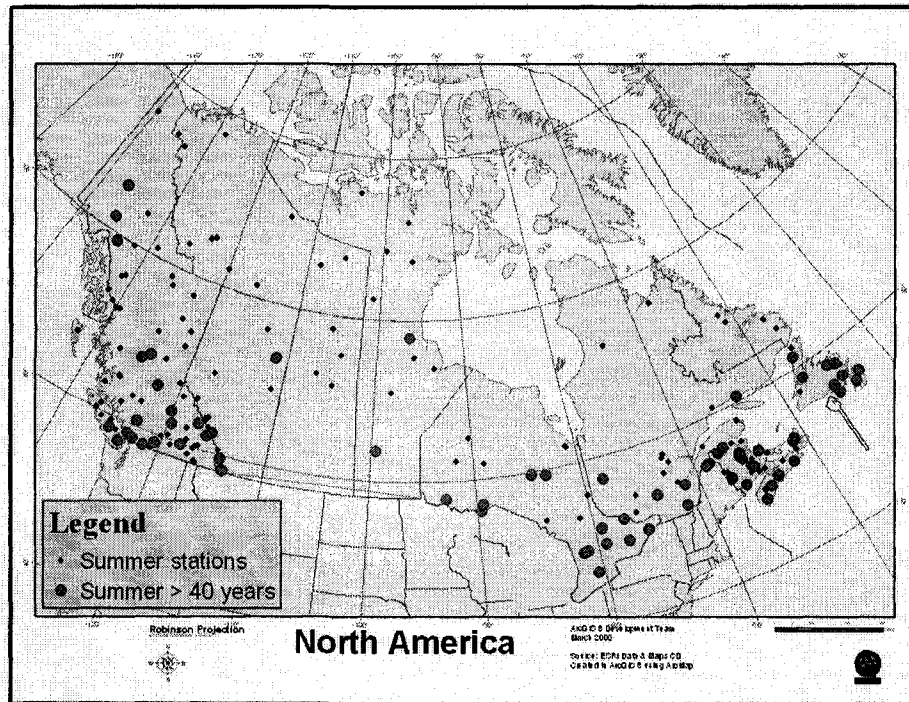


Fig. 4.11. Stations with at least 40 years of record length.

Out of 75 stations, 35 stations (45%) showed upward trends while 40 stations experienced downward trends. At a 0.05 significance level, 13 stations (18%) had significant trends where only 4 stations had upward trends and the rest (9 stations) experienced downward trends. The ratio of downward to upward trends shows an increase compared to the 30-year case (see 4.2.2.3). The location of stations with significant upward and downward trends is shown in Fig. 4.12. It can be seen that while there is no pattern in central Canada, there are stronger patterns of upward trends in the west and more uniform downward trends in eastern Canada compared to the stations with 30 years of record.

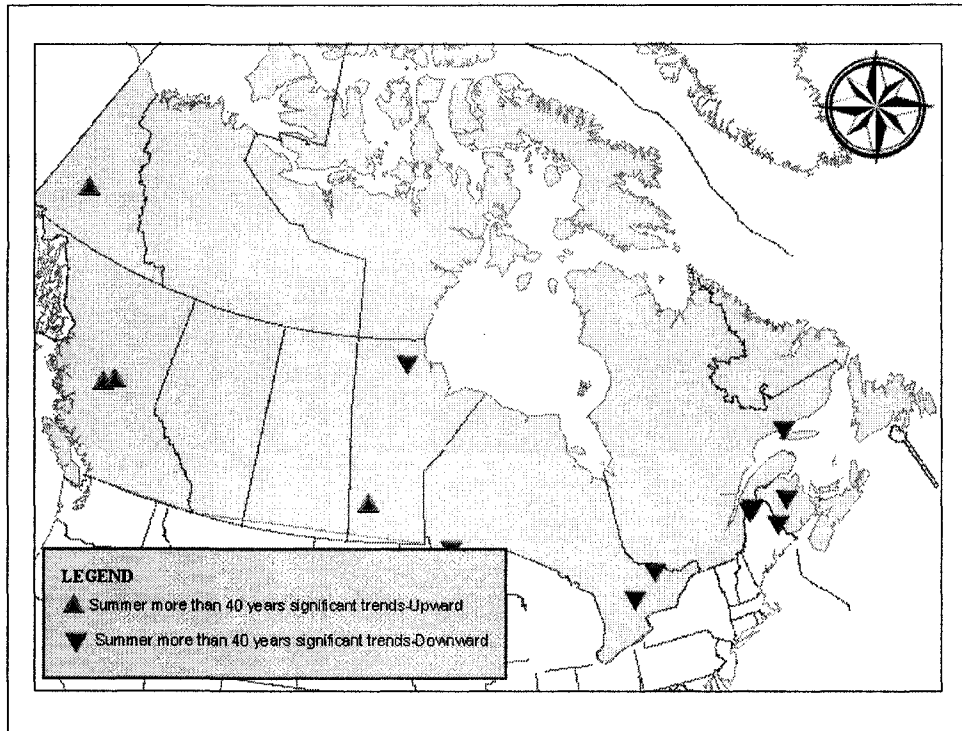


Fig. 4.12. Significant upward/downward trends (more than 40 years of records).

4.2.2.5 Analysis of summer low-flow in stations with at least 50 years of record

Out of 201 stations, 44 stations had at least 50 years of records and were selected for this part of the study. The location of the selected stations is shown in Fig. 4.13. As it can be seen in this figure the stations located in the central Canada in previous subsection of the study are not present due to the shortness of the record length. The selected stations are located in parts of Pacific Provinces in the west, Atlantic Provinces in the east, and also Southern Ontario. Out of 44 selected stations, 18 stations showed upward trends whereas 26 stations showed downward trends. At a 0.05 significance level, 9 out of 44 stations (20%) had significant upward or downward trends. This again shows an increase in the percentage of significant trends compared to other cases dealing with shorter record lengths. It

was observed that in 78% of significant trends (7 stations) the time of occurrence of summer 7-day low-flow was shifted toward earlier dates.

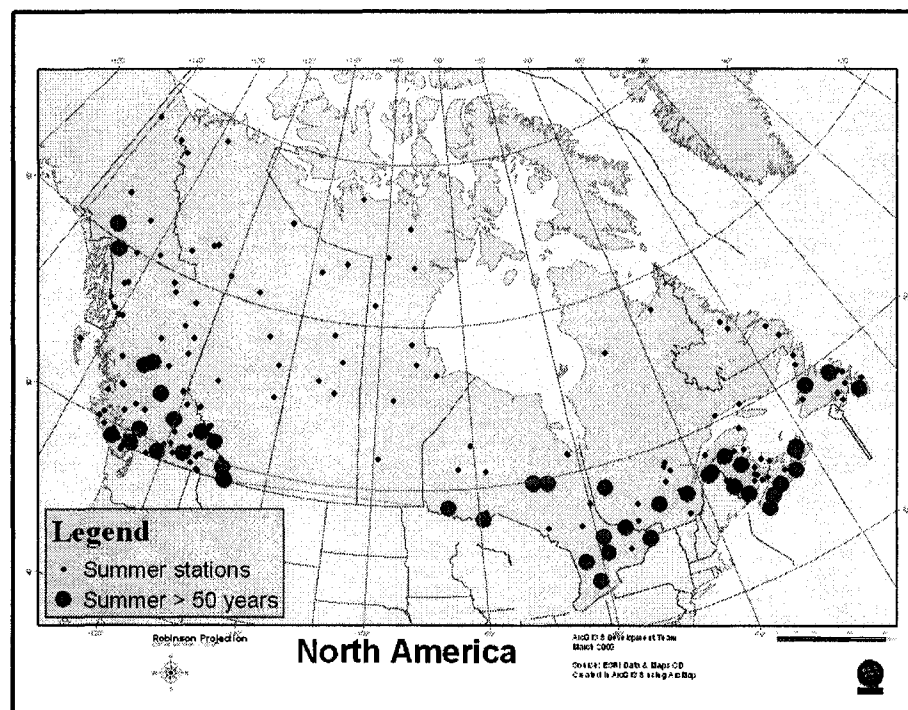


Fig. 4.13. Stations with at least 50 years of record length.

The location of stations with at least 50 years of observations experiencing significant upward or downward trends is shown in Fig. 4.14. It can be seen that the only two stations with significant upward trends are located in central British Columbia. However, the stations with a significant downward trend cover larger areas along the southern border of the country stretching from Atlantic Provinces to eastern Ontario.

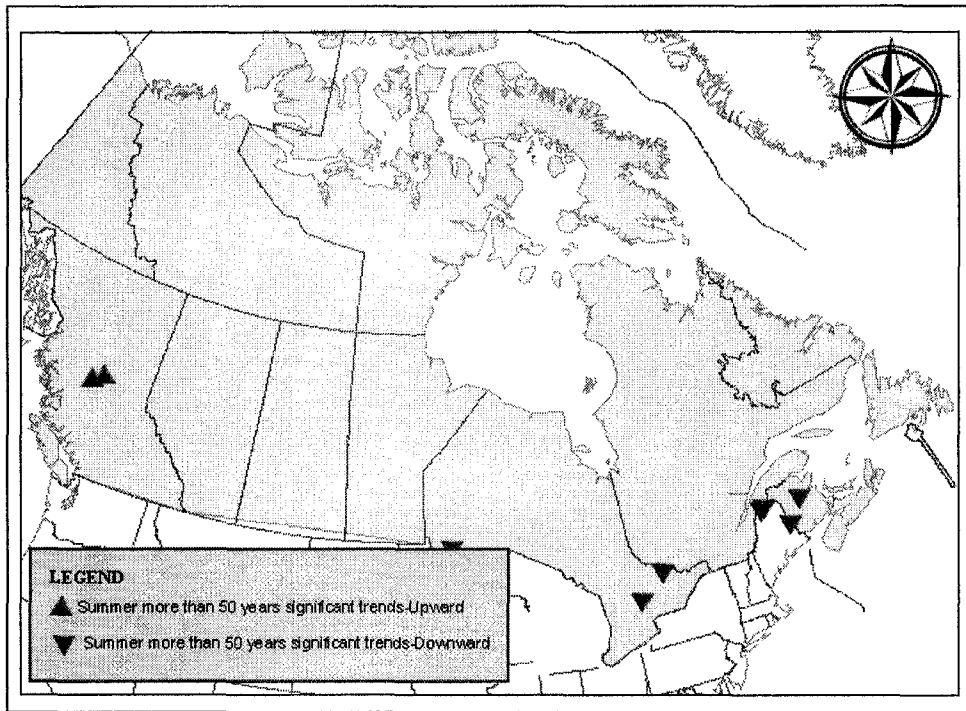


Fig. 4.14. Significant upward/downward trends (more than 50 years of records).

4.2.2.6 Comparison of trends for different time periods

As pointed out at the beginning of this chapter, one of the objectives of defining record lengths criteria and grouping the stations based on specific time periods was to facilitate the investigation of any linkage between the length of the observed sample data and the number of identified significant trends. As such, the results obtained from different subsections of trend detection in timing of summer 7-day low-flow are compared in Table 4.3. This Table shows that a certain level of correlation between the record length and the percentage of significant trends is recognizable. For example, the percentage of significant upward trends decreases from 45 to 22 percent when the record length increases from a minimum of 16 years (trend analysis regardless of record length) to a minimum of 50 years of

observations. On the other hand, a similar trend but in the opposite direction exists for the percentage of downward trends where significant downward trends increases from 54 to 78 percent as record length increases.

Table 4.3. Comparing the trends in timing of summer low-flow for different record lengths.

Variable	Total Record Length		Stations with at least 30 years of record		Stations with at least 40 years of record		Stations with at least 50 years of record	
	station	Percent	Station	Percent	station	Percent	station	Percent
Number of Stations	201		153		73		43	
Upward Trends	105	52 %	83	54 %	33	45 %	17	39%
Downward Trends	96	48 %	70	46 %	40	55 %	26	60%
Significant Trends (5% significance)	31	16 %	27	18 %	13	18 %	9	21%
Significant Upward Trends	15	45% ↑	11	41% ↑	4	31% ↑	2	22% ↑
Significant Downward Trends	16	54% ↓	16	59% ↓	9	69% ↓	7	78% ↓

It can be stated that if all stations are tested regardless of their record length, there is no significant difference between the percentage of upward and downward trends. However, when the stations are grouped based on the record length, the difference between percentage of upward and downward trends increases as the record length increases (the number of tested stations decreases) at the same time. The difference between the percentage of upward and downward trends is 56% for the stations with at least 50 years of record length. The location of significant upward/downward trends in timing of summer 7-day low-flows for different record lengths is shown in Fig. 4.15.

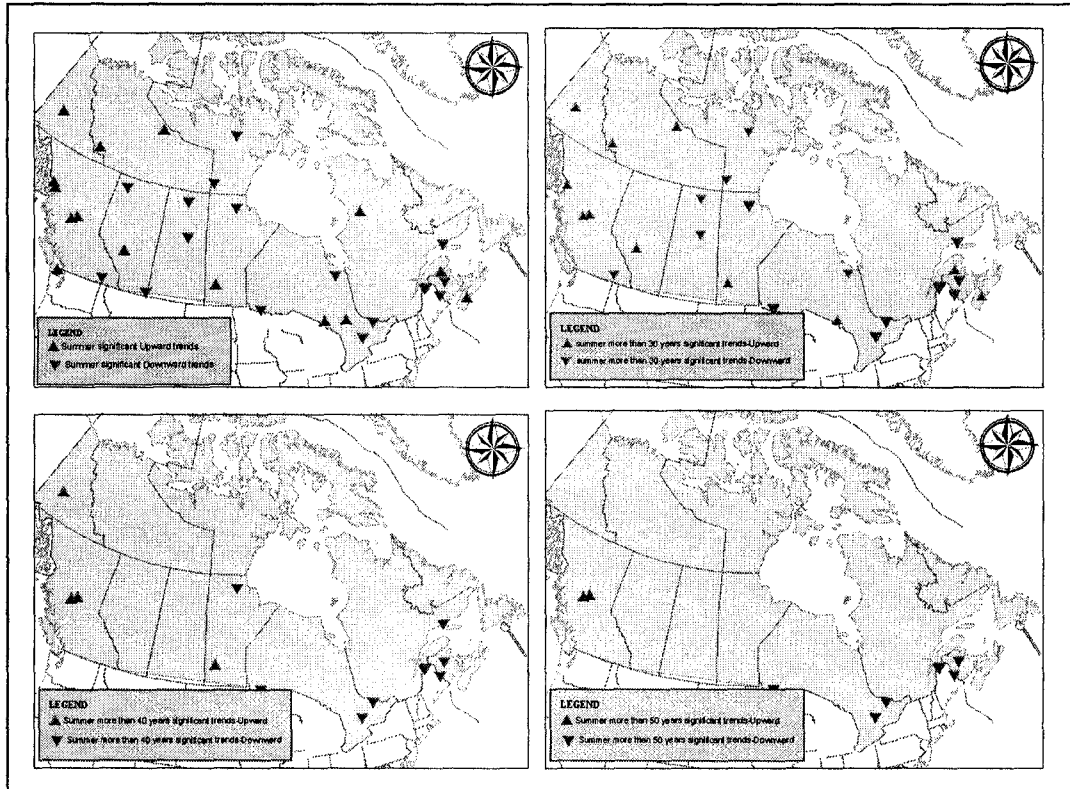


Fig. 4.15. Significant trends in the timing of summer 7-day low-flows for different record lengths.

By examining the sites across Canada (Fig.4.15), it can be seen that regardless of the record length, minimum summer 7-day low-flow in the east half of the country (Atlantic Provinces and southern Ontario) has significantly shifted toward earlier dates whereas it shifted toward later dates in the west and northwest regions (British Columbia, Yukon Territories, and North West Territory). The shift in the timing of summer low-flow toward earlier dates in eastern Canada can be attributed to shift in the timing of river ice-break observed by other researchers (Zhang *et al.*, 2001). An early occurrence of spring freshet can introduce a shift in spring and summer river flow which in turn leads to earlier summer low flows in late summer or early fall. It can be hypothesized that the complex interrelation between hydro-climatic variables

results in a shift in the timing of low flows toward later dates in the west and northwest of Canada. If the early freshet coincides with a prolonged freshet period resulting in a long lasting high flow in the summer period, the summer low flows can, consequently, shift toward later dates in these regions.

In central Canada there is a combination of upward and downward trends; however, downward trends are more evident in higher latitudes of this region while upward trends are dominant in southern areas of central Canada. For stations with at least 30 years of records, the spatial distribution of upward and downward trends follows the same patterns described for trend detection regardless of record length. The map of stations with at least 40 years of record length shows three distinctive regions across the country. In eastern Canada (Atlantic Provinces and eastern Ontario) the timing of summer 7-day low-flow shifted toward earlier dates. In central Canada (more specifically Manitoba) the available stations show the same pattern as before, i.e. higher latitudes show a shift toward earlier dates whereas lower latitudes show a shift toward later dates in timing of summer 7-day low-flows. In western Canada (British Columbia and Yukon Territory) the stations show a shift toward later dates.

In the case of stations with at least 50 years of record length, there are no significant upward or downward trends in central Canada. In eastern Canada, there exists a pattern of significant downward trends in Atlantic Provinces and also southern Ontario. The stations with significant trends in western Canada (British Columbia) show a shift toward later dates in timing of summer low flows.

4.2.3 Trends in timing of winter 7-day low flow

The number of stations tested for detection of trends in winter 7-day low-flow was less than the stations used in the summer study due to the fact that some stations did not have observations for the winter periods. As a result 192 out of

225 stations were selected to perform trend detection in timing of low flows in winter. The stations are the same as the ones used for the summer study except 9 stations that are excluded for this part of the study (see Table 3.1).

4.2.3.1 Autocorrelations

Lag-1 serial correlation coefficients for the timing of winter 7-day low-flows were estimated and lower and upper limits for an 80% confidence interval were calculated. Estimated autocorrelations were tested to identify stations with significant/insignificant serial correlations and the results are presented in columns 4 to 7 of Table A-3, respectively. In columns (5) the word “TRUE” indicates an insignificant autocorrelation and the word “FALSE” indicates a significant autocorrelation. Table A-3 shows that 29 out of 192 sites (15%) had significant autocorrelations at a 0.1 significance level while the rest of the stations (163 sites) had no significant autocorrelations. The location of significant and insignificant autocorrelations is illustrated in Fig. 4.16. As it can be seen, there is no evidence of any pattern or clustering in the location of significant or insignificant autocorrelations for timing of winter 7-day low flows throughout the network.

It was observed that 83 out of 192 stations had positive autocorrelation and the rest of the network (109 stations) was dominated by negative autocorrelation. The locations of positive and negative autocorrelations are shown in Fig. 4.17. Although positive and negative autocorrelations are spread all over the country, eastern Canada (Atlantic Provinces, Quebec, and eastern Ontario) is slightly dominated by negative autocorrelations.

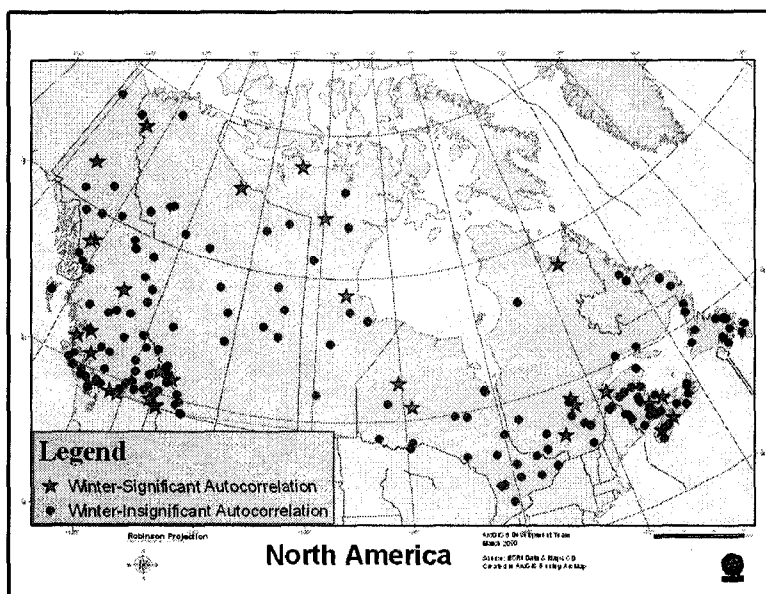


Fig. 4.16. Significant/insignificant autocorrelations in timing of winter 7-day low-flow.

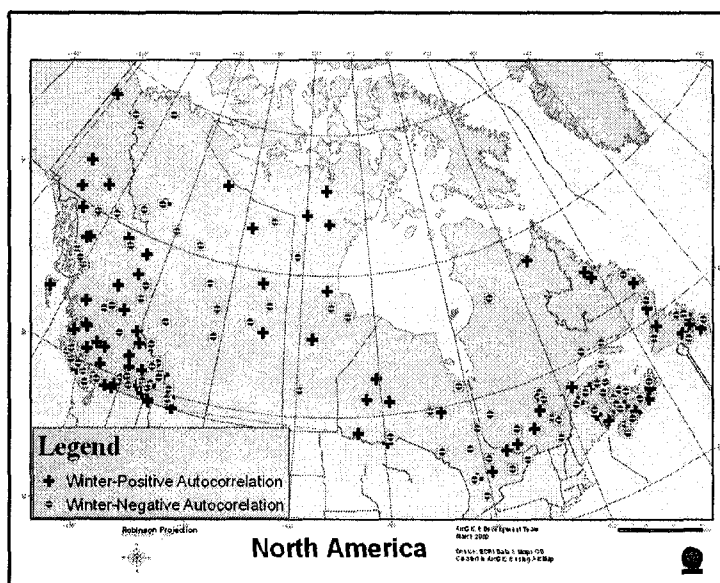


Fig. 4.17. Positive/negative autocorrelation in timing of winter 7-day low-flow time series.

4.2.3.2 Analysis of winter low-flow regardless of record length

The time of occurrence of the minimum 7-day low-flows of 192 stations in the winter period was tested to detect any monotonic trend regardless of record length. The record length, S statistic, standard normal variate, and also p -values before and after correction for autocorrelation for the investigated stations are presented in columns 3 to 7 of Table A-4, respectively. Also a summary of the results for three different procedures is presented in table 4.4.

Table 4.4. Trends in timing of winter 7-day low-flow regardless of record length.

Test Applied	Number of stations	Upward Trends	Downward trends	Significant trends at 0.05 significance level		
				Total	Downward	Upward
Original MK Test	192	75	117	38 (20%)	29 (76%)	9
Modified MK Test (No Confidence Interval)	192	75	117	42 (22%)	32 (76%)	10
Modified MK test (Confidence level at 0.9)	192	75	117	35 (18%)	26 (74%)	9

The results show that all stations experienced either upward or downward trends where 75 stations showed upward trends and 117 stations showed downward trends. Based on original MK test (no correction for autocorrelations) at a 0.05 significance level, 38 out of 192 stations (20%) showed significant upward or downward trends (first row of Table 4.4). This percentage of significant trends shows an increase in the number of significant trends in winter 7-day low-flows compared to the summer period (see 4.2.2.2.2). Out of 38 significant trends, 9 stations showed increasing trends whereas remaining 29 stations (76%) had decreasing trends.

To account for serial correlation and as a second procedure, the variance of the MK test was corrected and the modified MK test was applied to all time series. It

was found that the number of significant trends increased as autocorrelation was removed from the time series; i.e. 42 out of 192 stations showed significant trends where 32 stations (76%) had decreasing trends and 10 stations had increasing trends. This suggests that presence of autocorrelation shrank the variance of the MK test and resulted in acceptance of the null hypothesis of no trend when it was false. One should recall that the number of negative autocorrelations was larger than the number of positive autocorrelations for timing of winter low-flows and this domination of negative autocorrelation justifies its unexpected impact on increasing the number of detected significant trends. As a third procedure, serial correlations were removed only if they exceeded an 80% confidence interval. Last row of Table 4.4 presents the results obtained from this procedure. Out of 192 stations, 35 stations (18%) showed significant trends where in 26 stations (74%) winter low flows experienced a shift toward earlier dates and in 9 stations (26%) this shift was toward later dates. This decrease in the number of significant trends reveals that the removal of significant serial correlations had more impact on stations with positive autocorrelation compared to the stations with negative autocorrelations (significant autocorrelations in 22 out of 29 stations were positive and therefore correction of the variance of the test led to a decrease in the number of significant trends).

Fig. 4.18 shows the spatial distribution of significant upward and downward trends. It can be seen that almost all of the stations with significant trends located in eastern Canada (Atlantic Provinces) experienced a shift toward earlier dates in the timing of minimum winter low-flow. There is no evidence of significant trends in Prairies where there is almost no significant trend in Alberta and Saskatchewan for timing of winter low-flows. There is a balance between the number of upward and downward trends in northern Canada whereas the majority of significant trends in British Columbia are downward.

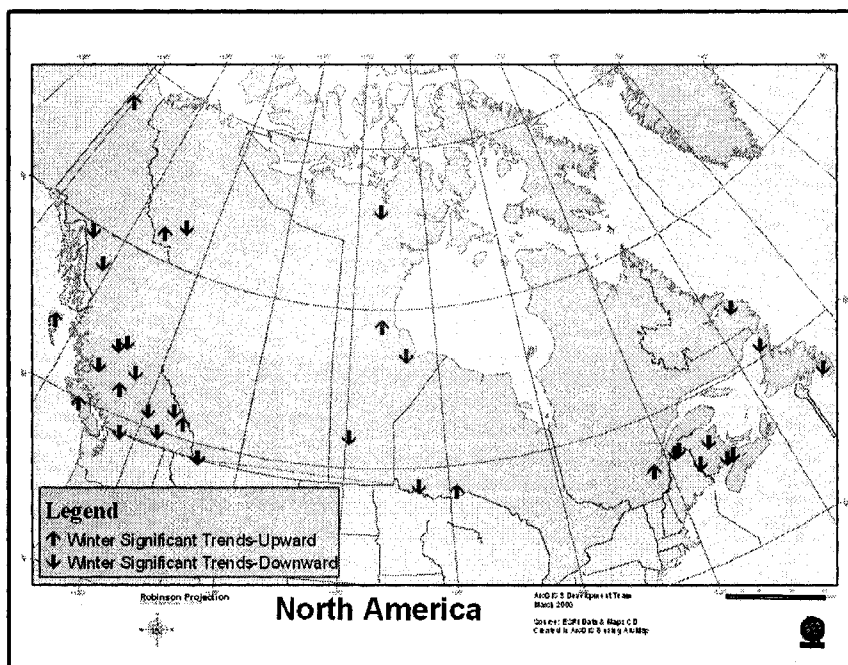


Fig. 4.18. Significant upward/downward trends in timing of winter 7-day low-flows.

4.2.3.3 Analysis of winter low-flow in stations with at least 30 years of record

Out of 192 stations, 148 stations had equal or more than 30 years of observations. The stations with at least 30 years of record length are mostly the same stations for the summer period. According to MK test 95 stations experienced downward trends and in 53 stations the date of occurrence of winter 7-day low flow was shifting toward later dates.

The number of downward trends shows a slight increase compared to the case that the whole sample data regardless of record length were examined. At a 0.05 significance level, 30 stations (20%) showed statistically significant trends where 24 stations (80%) experienced downward trends and 6 stations (20%) experienced upward trends in the time of occurrence of winter 7-day low-flow. The percentage of significant downward trends again shows an increase compared to trend

detection regardless of record length (see 4.2.3.2). The distributions of significant upward and downward trends are illustrated in Fig. 4.19.

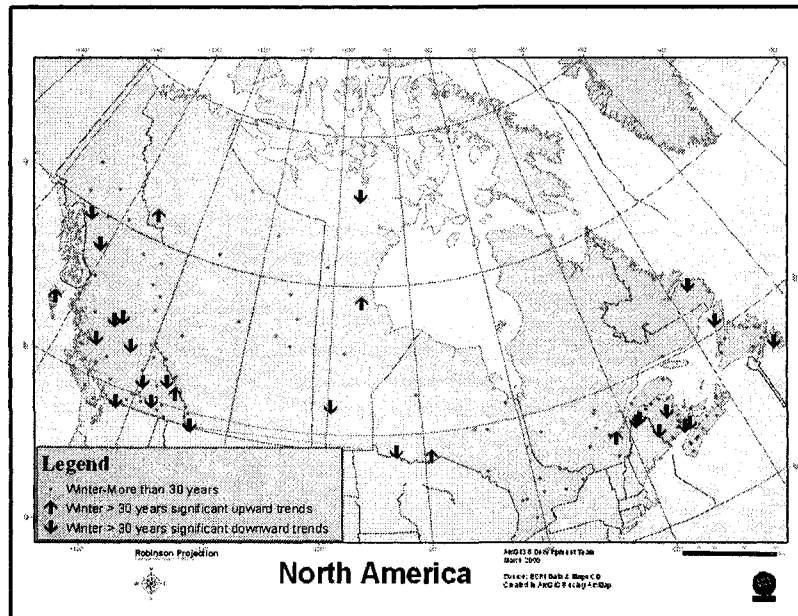


Fig. 4.19. Significant upward/downward trends in winter 7-day low-flows (more than 30 years).

Fig. 4.19 shows that there exist some recognizable patterns in significant trends. The majority of stations with significant trends located in both coasts (Pacific and Atlantic) show a shift toward earlier dates in the timing of winter 7-day low-flow. On the other hand, there is no evidence of significant upward or downward trends in the North and Central Canada.

4.2.3.4 Analysis of winter low-flow in stations with at least 40 years of record

For this part of the study 70 out of 192 stations were selected. Based on MK test 45 stations (64%) had general decreasing trends while 25 stations showed increasing trends. At a 0.05 significance level, 22 stations (31%) showed significant increasing or decreasing trends where in 82% of significant trends (18

stations) the date of occurrence of winter 7-day low flow shifted toward earlier dates. This percentage of significant downward trends shows again a slight increase compared to summer (see 4.2.3.3). The geographical distribution of stations with significant upward/downward trends is shown in Fig. 4.20.

Compared to the case of stations with 30 years of records (Fig. 4.19), patterns in significant upward and downward trends are clearer where in almost all of the stations located in west and east coasts the time of occurrence of winter 7-day low-flow shifted toward earlier dates (see Fig. 4.20). Also, few but balanced numbers of significant upward and downward trends exist in eastern Ontario and Prairies.

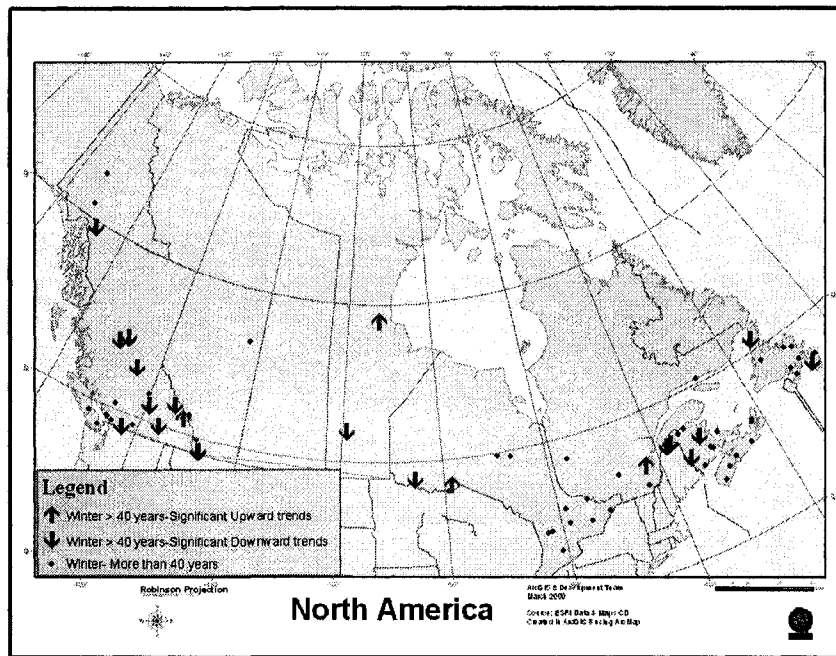


Fig. 4.20. Significant trends in timing of winter 7-day low-flows (more than 40 years).

4.2.3.5 Analysis of winter low-flow in stations with at least 50 years of record

Out of 192 stations, 44 stations had a minimum of 50 years of observations. Fig. 4.21 shows that there are no stations with 50 or more years of records in central Canada (Saskatchewan, Manitoba) and northern Canada (Yukon, Nunavut). At a 0.05 significance level, 15 stations (34%) showed a significant change in timing of winter 7-day low-flows. In 93% of stations with significant trends (14 stations) the time of occurrence of winter low-flow experienced a shift toward earlier dates whereas in only 1 station minimum winter 7-day low flow was occurring later. Fig 4.22 shows the distribution of significant upward/downward trends. This figure shows the same patterns as Fig. 4.21 (stations with 40 years of record length) except that patterns in decreasing trends in east and west coasts are more evident and there is a lack of stations/patterns in central and northern Canada.

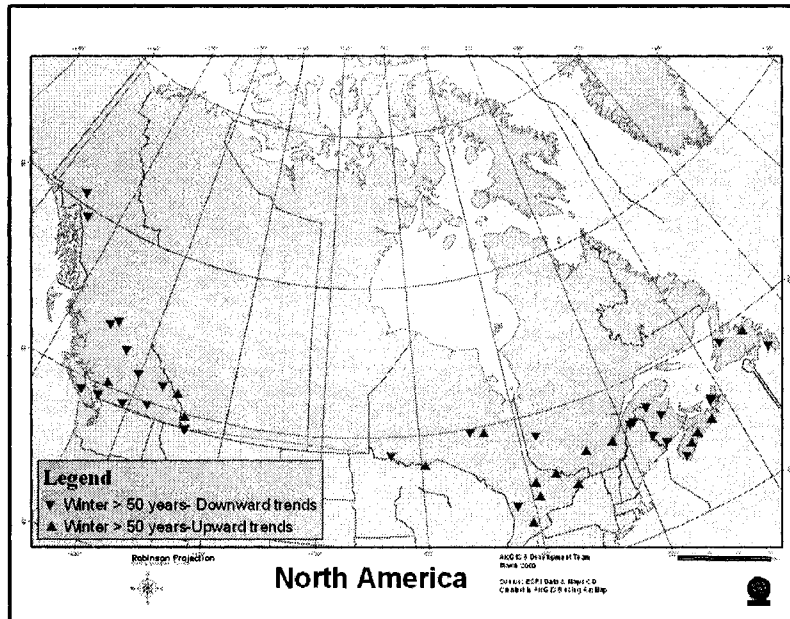


Fig. 4.21. Upward/downward trends in timing of winter low-flows (more than 50 years).

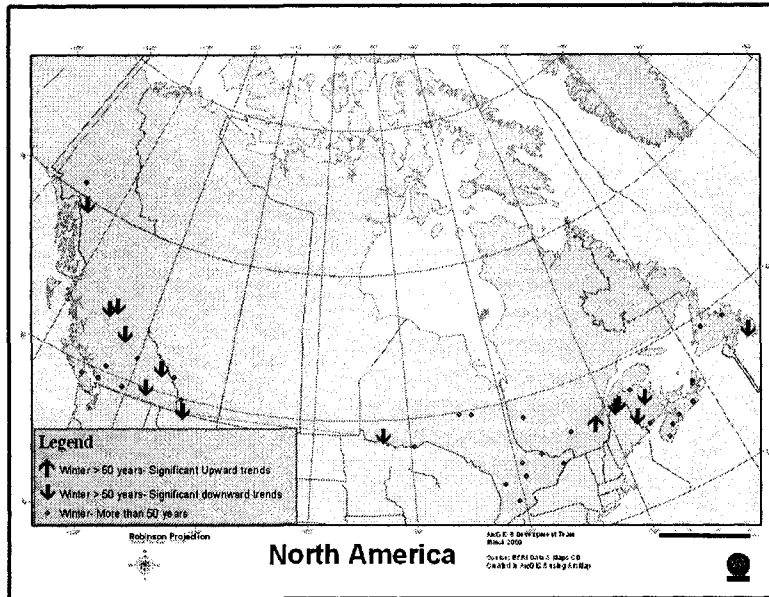


Fig. 4.22. Significant trends in timing of winter low-flows (more than 50 years).

4.2.3.6 Comparing trends in timing of winter low-flows for different record lengths

The results from different sections of trend study in timing of winter 7-day low-flows for different record lengths are summarized in Table 4.5.

Table 4.5 Summary of trend detection in timing of winter 7-day low-flows.

Variable	All stations		Stations with at least 30 years of record		Stations with at least 40 years of record		Stations with at least 50 years of record	
	Station	Percentage	Station	Percentage	Station	Percentage	Station	Percentage
Number of Stations	193		148		70		44	
Upward Trends	75	39%	53	36%	25	36%	16	36%
Downward Trends	118	61%	95	64%	45	64%	28	64%
Significant Trends	36	19%	30	20%	22	31%	15	34%
Significant Upward Trends	9	25% ↑	6	20% ↑	4	18% ↑	1	7% ↑
Significant Downward Trends	27	75% ↓	24	80% ↓	18	82% ↓	14	93% ↓

Table 4.5 indicates that the ratio of the number of significant trends to the total number of tested stations increases as the record length criteria increases (the number of tested stations decreases as the record length criteria increases). For example, when all stations regardless of the record length are tested, 19% of the stations are identified having significant trends by MK test; however, for the stations with at least 50 years of records, the percentage of significant trends in timing of winter low flows increases to 34%. This shows that there is a positive relationship between the record length and the percentage of significant trends, i.e. trends are more likely to be significant in longer periods rather than shorter periods.

It should be noted that while this linkage is positive for total and downward trends, it is in the opposite direction for upward trends. That is, any increase in the record length criteria increases the percentage of significant downward trends whereas it decreases the percentage of significant upward trends.

Table 4.5 shows that if all stations are tested for trend regardless of their period of record, the difference between the percentage of upward and downward significant trends is 50 percent; however, if the stations are categorized based on the record length this difference increases as the record length increases with a maximum of 86% for the stations with at least 50 years of record where all but one of detected significant trends are downward. Furthermore, the percentage of significant downward trends increases from 75% to 93% as the record length criteria increases from 16 to 50 years. The increase in the percentage of significant downward trends and at the same time reduced percentage of significant upward trends in longer time periods could also be due to the fact that the stations with significant upward trends are located in the regions that generally

have shorter record lengths and therefore they are excluded from the analysis when trend analysis is performed on the subsets with longer record lengths.

It can be concluded that the downward trends in the time of occurrence of minimum winter 7-day low-flow are dominant and more significant in stations with longer record length. Fig. 4.23 compares the spatial distribution of significant trends in timing of winter 7-day low-flows for different periods of records across Canada. It can be seen from Fig. 4.23 that there are dominant downward trends in timing of winter 7-day low flow across Canada. Significant downward trends are concentrated in Atlantic Provinces, southern Canada stretching from east to west, and also entire British Columbia. These findings support those of Zhang *et al.* (2001) who found that break-up of river ice and the resulting spring high flow season in Canada was occurring significantly earlier.

Bonsal *et al.* (2001) reported a significant increase in daily minimum temperature with the largest trend during winter and early spring which also suggests a shift in timing of winter low-flows toward earlier dates. Burn and Elnur (2002) observed that the Yukon and North British Columbia mountains climate regions are sensitive in the variables related to timing of events. The timing of river freezing up and river ice break in these regions shifted to earlier dates, reportedly.

A general lack of significant trends in Central Canada and Prairies (Manitoba, Saskatchewan, and Alberta) is evident which does not support the results of other studies performed on other variables such as maximum and minimum daily flow (i.e., Yue *et al.*, 2001, Yue and Pilon, 2003). The lack of significant trends in low-flows in central Canada also does not support the temperature increase observed by Yulianti and Burn (1998) in this region which could be reflected in changes in hydrological variables such as low flows.

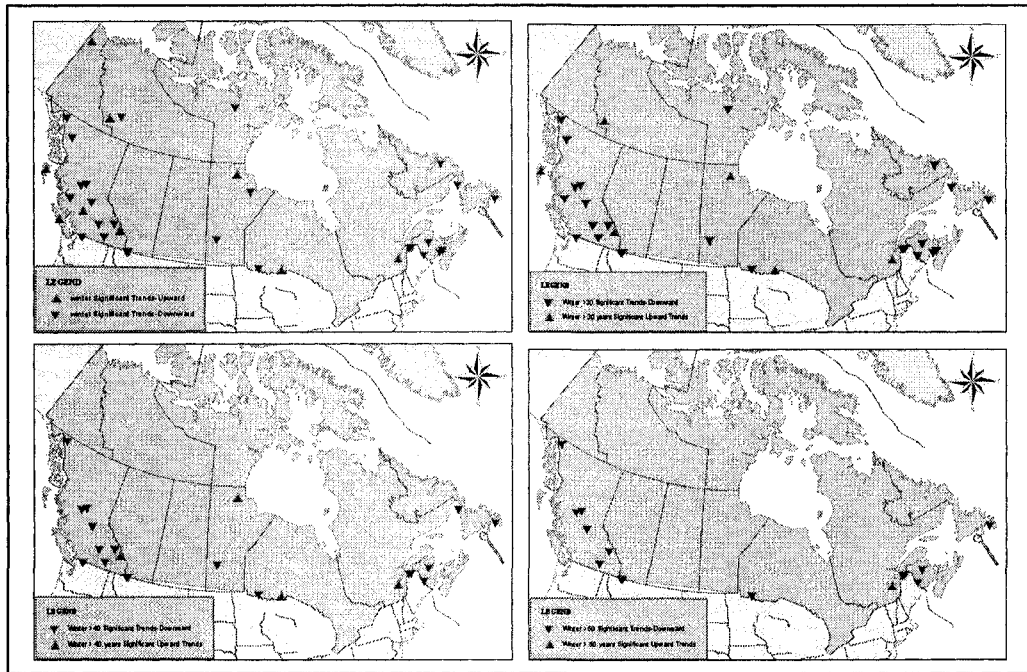


Fig. 4.23. Significant upward/downward trends for different time periods.

It can be seen that no station is available in the northern parts of the country as the record length increases. The long record stations are located in southern Canada particularly close to east and west coasts. The number of significant decreasing trends shows a certain level of persistency in time, i.e. a band of significant downward trends stretches from southern British Columbia to Atlantic Provinces almost independent of the record length. Comparing figures 4.23 and 4.15 reveals that the direction of the detected significant trends in timing of summer and winter 7-day low-flow are in a good agreement in eastern Canada; however, in western Canada, winter trends are downward whereas summer trends are in the opposite direction.

4.3 Analysis of trends in the quantity of low flows in RHBN

4.3.1 Introduction

In this part of the study 212 stations were tested to study trend in low-flow indices. The statistical analysis was performed on the stations regardless of record length. Also, in order to investigate any correlation between the record length and the number of detected trends, stations were grouped in three different subsets with minimum record lengths of 30, 40, and 50 years. List of the stations along with other specifications of the sites used in this part of the study are presented in Table 3.1.

4.3.2 Autocorrelations in low flow indices

Lag-1 autocorrelation of 7-, 14-, 21-, and 30-day low-flow time series for 212 stations across the network were estimated. Statistical significance of autocorrelations was tested using upper and lower limits based on an 80% confidence interval and the results are presented in tables A-5, A-6, A-7, and A-8 of appendix A. The word “TRUE” in Column (5) represents an insignificant autocorrelation whereas the word “FALSE” indicates a significant autocorrelation. The lower limits and upper limits based on an 80% confidence interval are given in columns (6) and (7), respectively. A summary of estimated serial correlations for different low flow indices is presented in Table 4.6.

Table 4.6. The summary of estimated autocorrelations for different indices.

Low flow Index	Number of stations	Positive Autocorrelations	Negative Autocorrelations	Significant Autocorrelations
7-day	212	167 (79%)	45 (21%)	74 (35%)
14-day	212	163(77%)	50 (23%)	71 (33%)
21-day	212	160 (75%)	52 (25%)	69 (32%)
30-day	212	158 (74%)	54 (24%)	63 (30%)

Table 4.6 shows that one third of the tested stations had significant autocorrelations with over 75% of stations having positive autocorrelations. It can be seen that the number of positive and negative autocorrelations as well as the number of significant autocorrelations are in close agreement for different low flow indices.

As an example, Fig. 4.24 shows the distribution of positive and negative autocorrelations for 7-day low flows. It can be seen that although the positive and negative autocorrelations are distributed all over the country, all stations located above latitude 60°N have positive autocorrelations. This is also true for stations located in northern areas of Prairies.

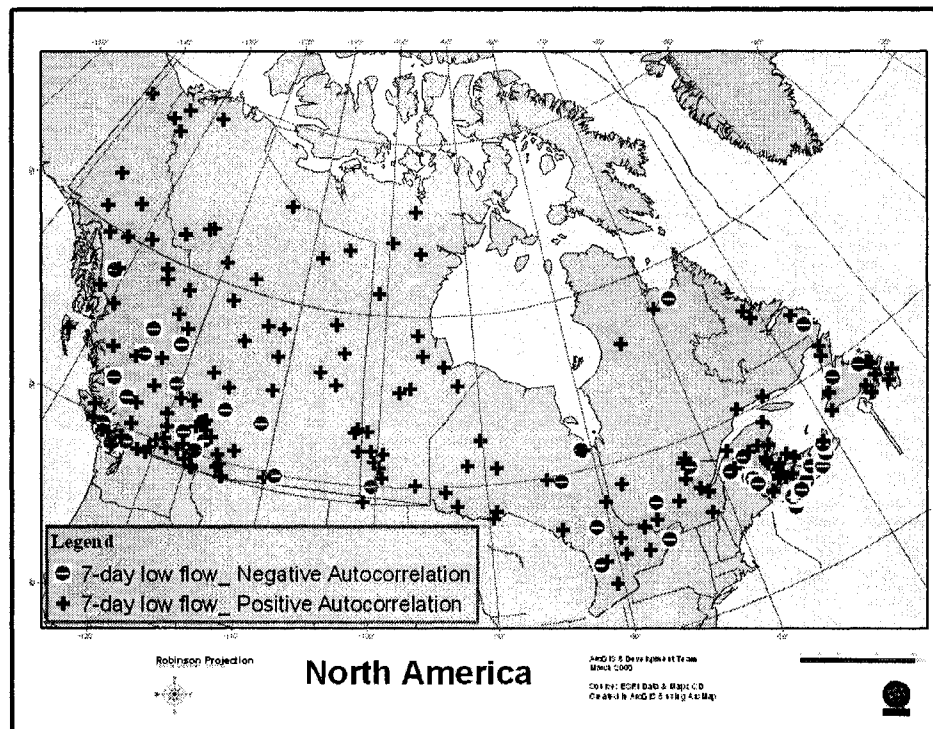


Fig. 4.24. Positive and negative autocorrelations in 7-day low flows.

Fig. 4.25 shows significant and insignificant autocorrelations for 7-day low-flows across Canada and indicates that stations above 60°N are mostly affected by significant autocorrelations. While the majority of autocorrelations in Atlantic Provinces are insignificant, there is no evidence of domination of either significant or insignificant autocorrelations in central Canada and British Columbia.

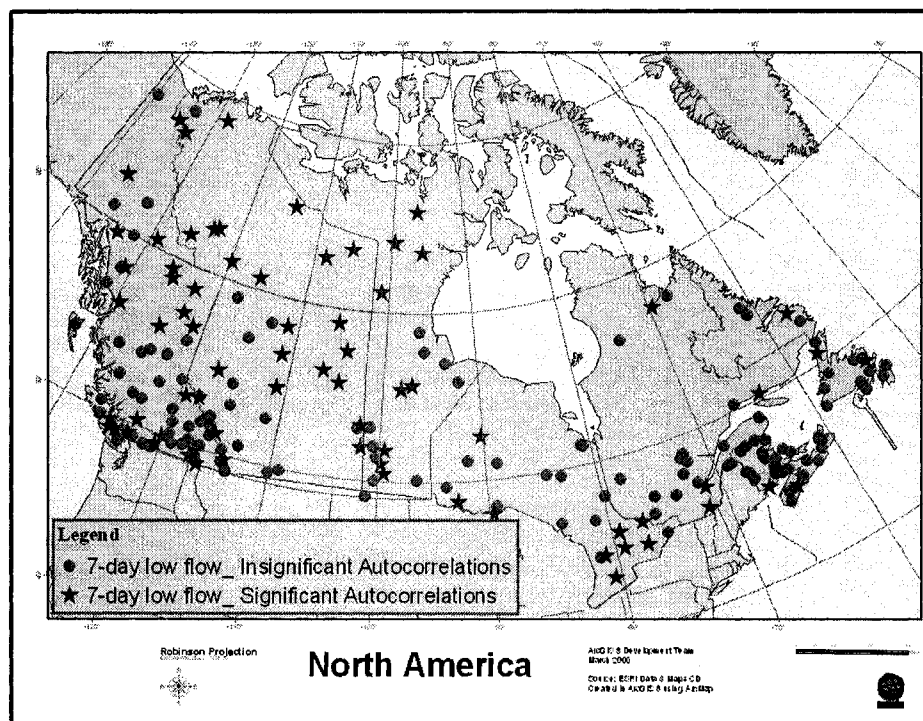


Fig. 4.25. Significant/insignificant autocorrelations in 7-day low-flows.

4.3.3 Analysis of trends in low-flows regardless of record length

In this part of the study the time series of different low flow indices were tested to detect any trend regardless of record length. The list of the tested stations and

their record lengths along with the time period of observations are presented in Table 3.1. Low flow index of 7-, 14-, 21-, and 30-day of 212 stations were estimated using a moving average window. Overall, 32884 time series were extracted and tested for this part of the study. The rank-based non-parametric Mann-Kendall (MK) statistical test was applied to detect any increasing or decreasing trends at a 0.05 significance level. The results of numerical analysis are presented in Tables, A-9, A-10, A-11, and A-12 of appendix A. A summary of results for trend detection in different low flow indices is presented in Table 4.7.

Table 4.7. Trend detection results for different low flow indices.

Low flow Index	Number of stations	Upward trends	Downward trends	Significant trends at 0.05 significance level		
				Total	Upward	Downward
7-day	212	98	114	69 (32%)	24 (35%)	45 (65%)
14-day	212	102	110	67 (32%)	26 (39%)	41 (61%)
21-day	212	108	104	70 (33%)	28 (40%)	42 (60%)
30-day	212	105	107	67 (32%)	27 (40%)	40 (60%)

Table 4.7 shows that the numbers of significant trends in the quantity of different low flow indices are in a good agreement and it amounts to 32 to 33% for tested indices. This suggests an overall change in the quantity of low flows in Canadian low-streamflows. The quantity of low flows has significantly decreased in over 60% of the stations with significant trends. On the other hand, the low flows experienced a significant increase in almost 40% of stations with significant trends. The percentage of significant downward/upward trends is slightly different for different low flow indices which can be interpreted as an indication of the variability of changes in different durations of low flows.

Fig. 4.26 shows the location of significant upward and downward trends in different low-flows. It can be seen that there is no significant difference in

existing patterns for different studied low flow indices. It can be also seen that the significant upward and downward trends in low flow indices are not evenly distributed across Canada. For example, the stations in some parts of the country (Atlantic Provinces) have experienced a decreasing trend in the quantity of low flows. This is also true, but in the opposite direction, for some other parts of the country such as areas above 60°N where all stations experienced an increase in the quantity of low stream flow. In Ontario and central Canada, however, there is no clear pattern of upward or downward trends. There is also a domination of downward trends in southern British Columbia.

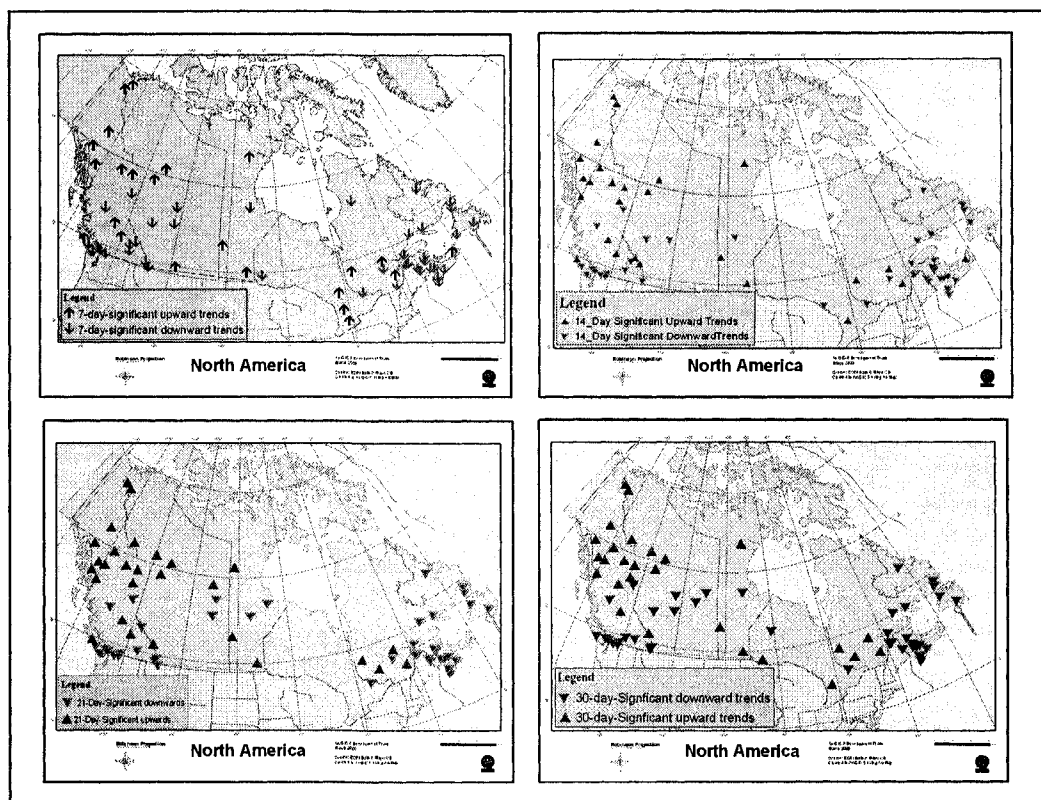


Fig. 4.26. Significant upward/downward trends in studied low-flows.

4.3.4 Trend in low-flows considering record length

In addition to perform the statistical analysis for the selected stations regardless of record length, the stations were grouped in three different subsets with minimum record lengths of 30, 40, and 50 years and were tested to detect any monotonic trends considering their record length.

4.3.4.1 Trend in stations with at least 30 years of record length

Out of 212 stations, 171 stations (80%) had equal or more than 30 years of available records. Fig. 4.27 shows the location of selected stations that are scattered throughout the network.

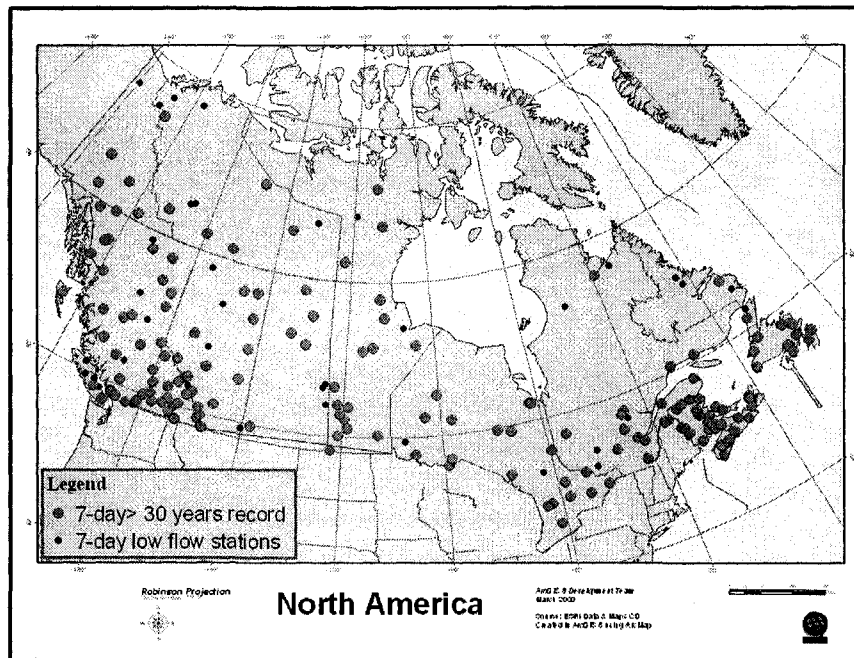


Fig. 4.27. Spatial distribution of stations with at least 30 years of record.

Low flow indices of 7-, 14-, 21-, and 30-day for these stations were tested for trends and the results are presented in Table 4.8.

Table 4.8. Summary of trend detection results in stations with at least 30 years of record.

Index	Number of stations	Significant trends	Significant upward trends	Significant downward trends
7-day	171	58 (34%)	19 (33%)	39 (67%)
14-day	171	59 (34%)	22 (37%)	37 (63%)
21-day	171	62 (36%)	24 (39%)	38 (61%)
30-day	171	58 (34%)	23 (39%)	36 (61%)

The results are in a close agreement with those of trend analysis regardless of record length with the slight increase in the percentage of significant trends from an average of 32% to an average of 34% for different low flow indices. Moreover, the percentage of significant downward trends experienced a slight increase of 2% compared to the results obtained where all stations were tested regardless of record length. Fig. 4.28 shows spatial distribution of significant upward and downward trends in stations with at least 30 years of records for different low flow indices. It can be seen that, similar to the whole record length study, there are a few noticeable patterns in the distribution of significant upward and downward trends. Atlantic Provinces are dominated by significant downward trends whereas northern Canada is dominated by upward trends. Furthermore, all of the stations located in southern British Columbia experienced downward trends while in northern British Columbia the significant trends are upward. Stations located in the central parts of this province experienced both upward and downward significant trends. There is no pattern in significant upward and downward trends in central Canada (Prairies).

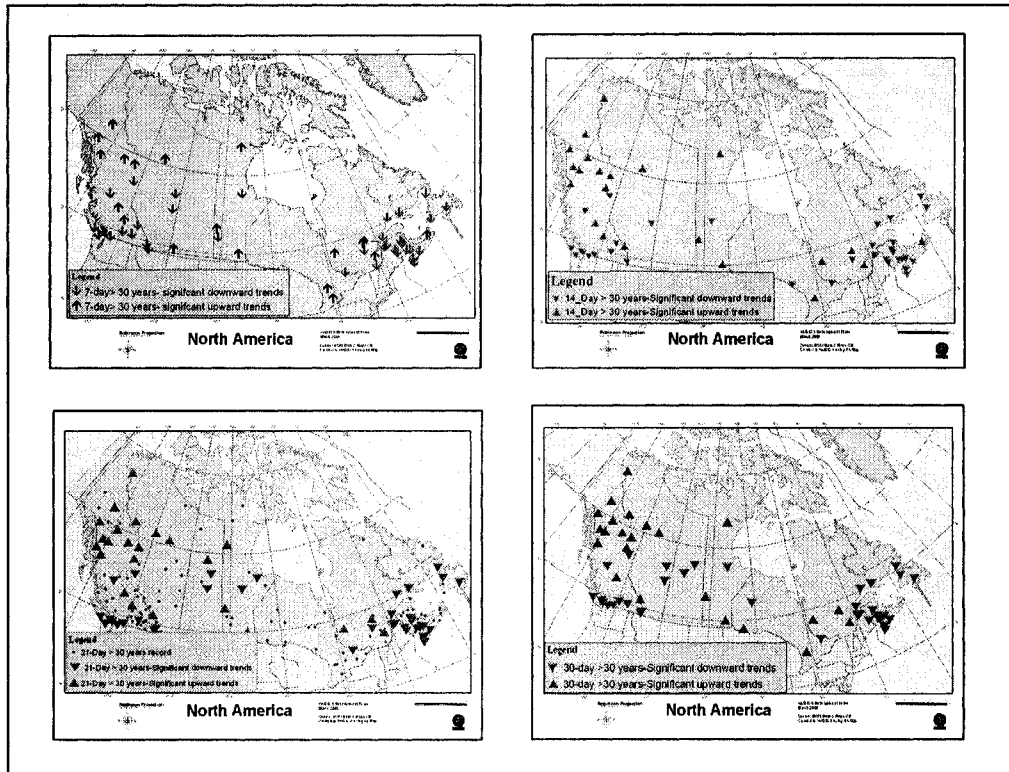


Fig. 4.28. Significant upward/downward trends in stations with at least 30 years of record.

4.3.4.2 Trend in stations with at least 40 years of record

Out of 212 stations, 81 stations (38%) had at least 40 years of records. Fig. 4.35 shows the location of these stations which are mostly located in southern borders of the country, and only few stations are located above latitude 60°N. The summary of results of trend detection for different low flow indices is presented in Table 4.9. This table shows that the percentage of significant trends increases from 34 to 40% when the minimum record length increases from 30 to 40 years. Therefore, it can be stated that the trends regardless of duration of the low flow index are more detectable in stations with longer record length compared to the stations with shorter record length.

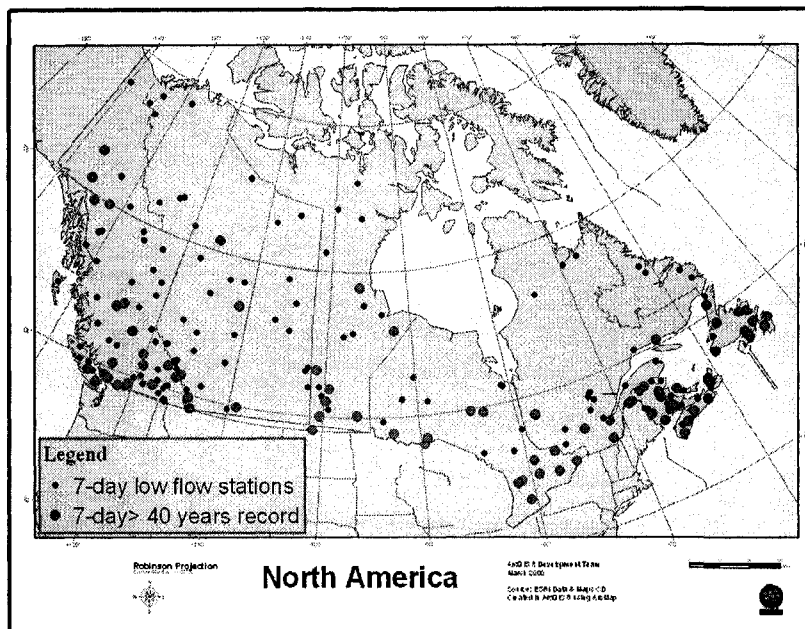


Fig. 4.29. Location of stations with at least 40 years of record.

Table 4.9. Summary of results for trend analysis in stations with at least 40 years of record.

Index	Number of stations	Upward trends	Downward trends	Significant trends	Significant upward trends	Significant downward trends
7-day	81	33	48	36 (44%)	12 (33%)	24 (67%)
14-day	81	35	46	32 (40%)	11 (34%)	21 (66%)
21-day	81	35	46	32 (40%)	10 (31%)	22 (69%)
30-day	81	34	45	30 (37%)	10 (33%)	20 (67%)

The percentage of significant trends is the highest for 7-day low flows (44%) and lowest for 30-day low –flows (37%). However, there is no difference in the percentage of upward and downward significant trends for different low flow indices. The percentage of significant downward trends has a slight increase (6%) for the stations with at least 40 years of records compared to the stations with a minimum of 30 years of record.

Fig.4.30 shows the location of significant upward and downward trends for different low flow indices. A comparison between figures 4.30 and 4.28 reveals that there are some similarities as well as differences between the patterns of significant upward and downward trends for stations with at least 40 years of records compared to the stations with at least 30 years of records. The number of significant upward trends in northern Canada has decreased significantly for the stations with at least 40 years of records. On the other hand, there is a lack of significant downward trends in central Canada and eastern Ontario where almost all of the significant trends in central Canada (Prairies) are upward. As for the similarities, the pattern of significant trends in Atlantic Provinces does not experience any changes as the record length increases from 30 to 40 years.

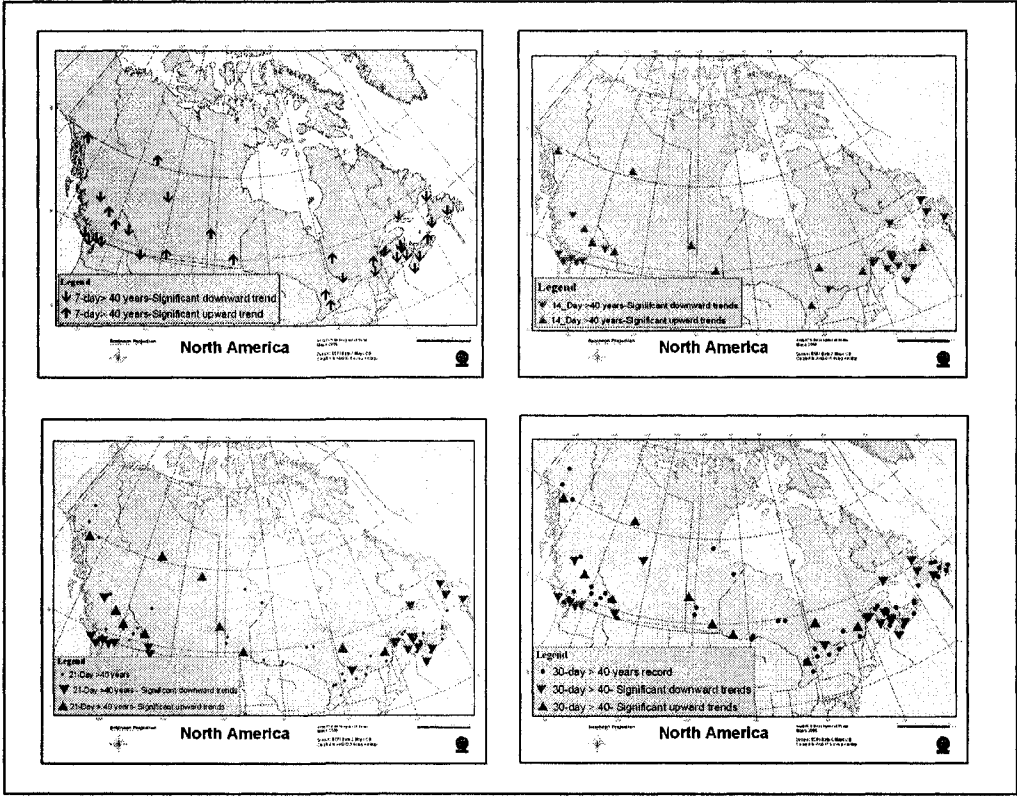


Fig. 4.30. Significant upward/downward trends (stations with at least 40 years of records).

4.3.4.3 Trend in stations with at least 50 years of record length

Considering low-flow observations with at least 50 years of data, there are only 44 such stations. Fig. 4.31 shows the location of selected stations for 21-day low-flow index (the stations are the same for different low-flow indices). It can be seen that there is almost no station with at least 50 years of record in central and Northern Canada. The stations are divided into the east subset close to the southern border of the country and west subset mostly located in British Columbia stretching from south to north of this province.

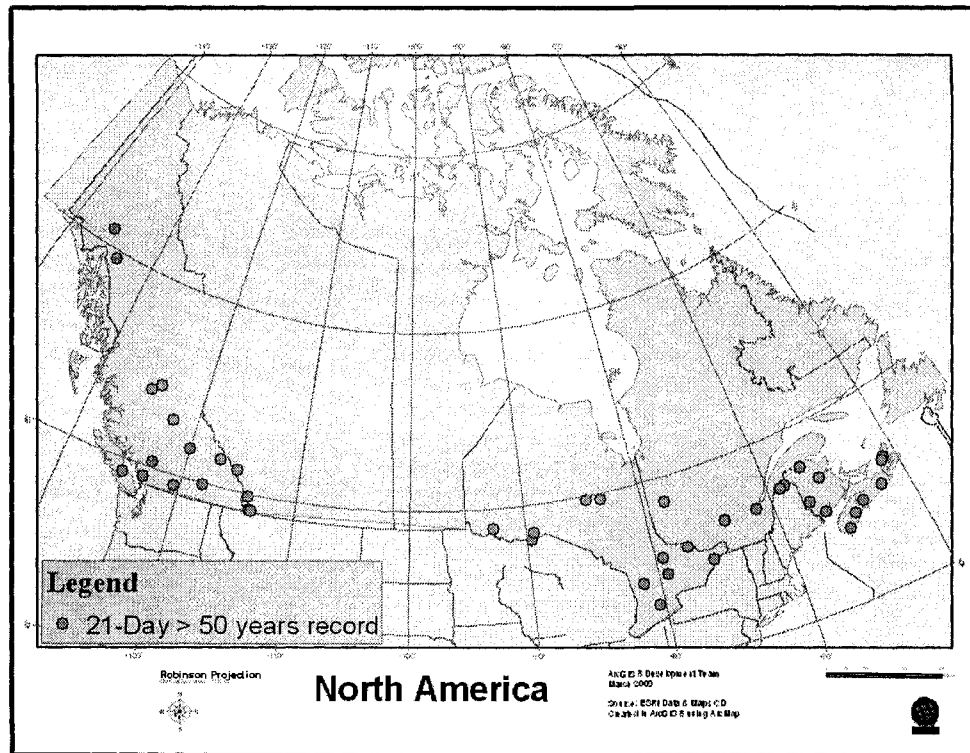


Fig. 4.31. Spatial distribution of stations with at least 50 years of record length.

Table 4.10 compares the results of trend analysis in the stations with at least 50 years of record for different low flow indices.

Table 4.10. Summary of results for trend analysis in stations with at least 50 years of record.

Index	Number of stations	Upward trends	Downward trends	Significant trends	Significant upward trends	Significant downward trends
7-day	44	20	24 (45%)	19 (42%)	7	12 (63%)
14-day	44	20	24 (54%)	18 (41%)	7	11 (61%)
21-day	44	20	24 (54%)	18 (41%)	6	12 (67%)
30-day	44	21	23 (52%)	17 (39%)	6	11 (65%)

Table 4.10 shows that in average 41% of the stations with 50 years of records have significant trends in low flow indices at a 0.05 significance level. This percentage is the same as the percentage of significant trends in stations with at least 40 years of record (see 4.3.4.2). However, the percentage of significant downward trend shows a slight decrease where it decreased from 67% for stations with at least 40 years of records to an average of 63% in the present case. Fig. 4.32 shows the distribution of significant upward and downward trends. It can be seen that the majority of the significant trends are located in British Columbia with a combination of upward and downward trends, and also in Atlantic Provinces with a domination of downward trends. There are no significant trends in eastern Ontario and no data are available for Northern Canada and the Prairies.

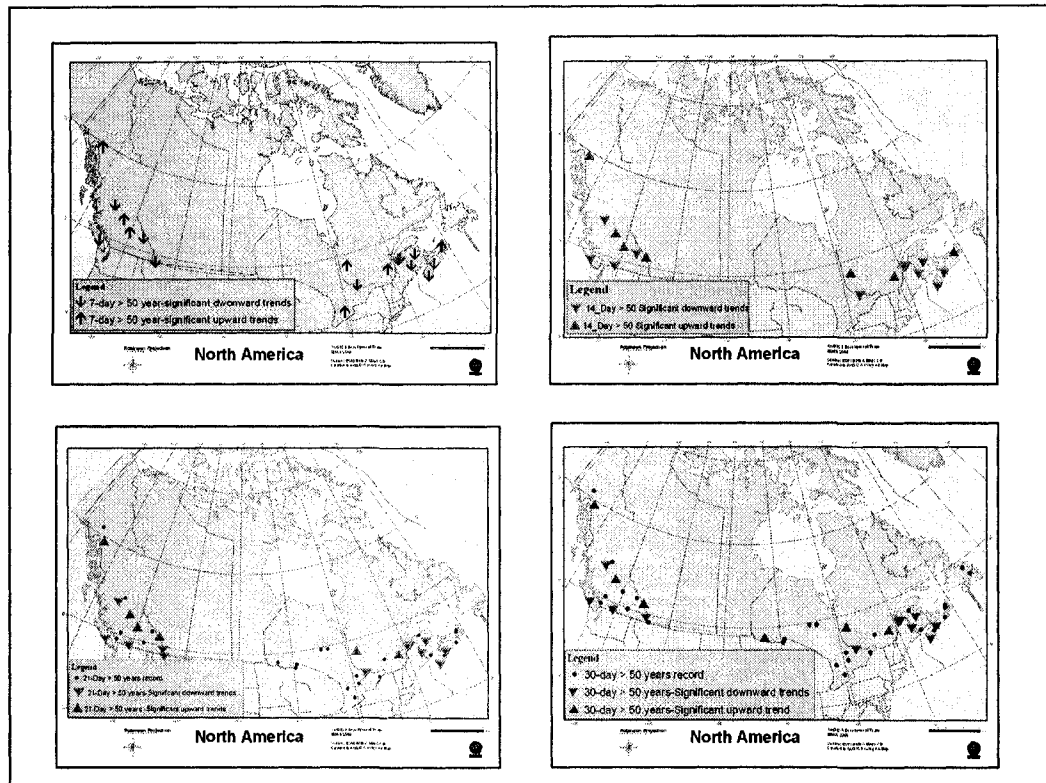


Fig. 4.32. Significant upward/downward trends (stations with at least 50 years of records).

Numerical analysis performed on 7-, 14-, 21-, and 30-day low flow indices indicates that in more than 1/3 of stations the low flows are experiencing significant trends. In 2/3 of stations with significant trends the quantity of low flows are decreasing and in 1/3 of these stations the discharge is increasing. There is a correlation between the record length and the percentage of significant trends where it increases from 32 to 41% as the minimum record length increases from 16 to 50 years. However, the percentages of significant upward and downward trends do not undergo substantial changes as the record length increases.

Mapped results show that there exists a band of significant upward trends across northern Canada, where almost all of the stations located above latitude 60°N show increasing trends in low-flow quantities. These results are similar to those of Yue *et al.* (2001) and Yue and Pilon (2003) who found a band of upward trends in minimum daily flow that stretched from northern B.C. and the Yukon through the Northwest Territories and into Nunavut. This increase in low flows can be attributed to precipitation increase reported by Zhang *et al.* (2000) who suggested an overall increase in annual precipitation during the second half of twentieth century over Canada with the strongest increasing trends in northern Canada. They also observed that in northern Canada temperature increases have mostly occurred in periods below freezing conditions creating warmer conditions for more evaporation and consequently higher precipitations in these regions which could lead to an increase in low-flows.

It was also found that significant downward trends exist in tested low-flows in some stations located in Atlantic Provinces (Nova Scotia, New Brunswick, and Prince Edward Island) and southern British Columbia. These results are in agreement with Yue and Pilon (2003) who showed that minimum daily flow significantly decreased in the regions of southern British Columbia and Atlantic Provinces. Burn and Elnur (2002) observed that the annual flow and the monthly flow from May to October decreased in the Pacific climate region implying a decrease in water availability in this region. They also found that the Southern British Columbia climate region had decreasing monthly flows in February and June-October period which is supported by observed downward trends in this region in this study.

Observed downward trends in the southeast of Canada do not support the results of Douglas *et al.* (2000) who tested 7-day low flows throughout the United States and reported significant upward trends in the Midwest towards the Northeast of

the United States (close to the southeast of Canada) in 7-day low flows. They attributed the observed increase in low flows to increase in the basin storage resulting from increase in annual precipitation reported by other studies in these regions.

Zhang *et al.* (2000) suggested an increase in annual mean temperatures over southern Canada in twentieth century and Davis *et al.* (1999) found that, in Canada, the snowfall-temperature relationship is positive in high latitudes but is negative in southern Canada and also east and west coasts. The observed downward trends in low flows in southern Canada and also east and west coasts can be attributed to the reported increase in annual mean temperatures and the observed negative snowfall-temperature relationship in these regions.

There was no evidence of trends in low-flow in Manitoba, Saskatchewan, Alberta, and eastern Ontario, which does not support the results of other studies performed on other variables such as maximum and minimum daily flow (i.e., Yue *et al.*, 2001, Yue and Pilon, 2003). The lack of significant trends in low-flows in central Canada also does not support the temperature increase observed by Yulianti and Burn (1998) in this region which could be reflected in changes in hydrological variables such as low flows.

The spatial differences can be attributed to spatial differences in hydro-climatic contributors such as precipitation and temperature. The watershed characteristics could also contribute to observed differences as they may respond differently to the changes in climatic variables. Decreasing river flows in southern Canada particularly in low-flow season impacts aquatic ecosystems. It could also introduce changes to patterns of erosion, transport and deposition of sediments and this eventually changes the characteristics of channel and floodplain. Reduction of low-flow could also lead to a decrease in water availability for

irrigation, domestic and industrial use, recreation uses, navigation, wastewater assimilation, and hydropower generation.

4.4 Trends in the number of zero events

In stations with zero low flows for the whole or a part of the record period, some restraints are introduced in statistical analysis of trends, i.e. the application of MK test is difficult and it may produce unreliable results. Also, the estimation of autocorrelation is not possible with so many zero numbers in the time series. Therefore, the stations with described characteristics were excluded from trend detection in low flows. However, this created a motivation to investigate trends in the number of zero events over the time period of available observations. That is, the stations with zero values for the whole record period or the stations that mean daily flow for the majority of the record period was zero were tested to detect any trend in the number of zero events. This resulted in selection of 15 stations across Canada. The list of the stations studied in this part of the study along with their other specifications is presented in Table 4.11.

Table 4.11. Stations selected for trend detection in the number of zero events.

No.	Station ID	Province/ Territory	latitude	longitude	Drainage Area (km ²)	Last year of Record	Record Length (year)
1	05BM014	AB	50.7638	-113.233	775	2003	33
2	05HA003	SK	49.89861	-109.106	253	2003	33
3	05LE011	SK	51.96889	-101.914	180	2003	22
4	05LL027	MB	50.47667	-99.4758	9.09	2003	28
5	05MG004	MB	50.025	-100.393	1150	2003	42
6	05NF002	MB	49.05944	-101.049	3210	2003	57
7	05NF006	SK	49.22139	-101.719	748	2003	29
8	05NF010	SK	49.584	-101.848	348	2003	32
9	05OF014	MB	49.355	-97.42	617	2003	44
10	05OF017	MB	49.38056	-98.2486	75.1	2003	40
11	05PD023	ON	49.65778	-93.7267	3.9	2003	20
12	10LC007	NT	68.08917	-133.484	625	2003	20
13	10QD001	NU	67.71167	-104.141	16900	2003	29
14	10TF001	NU	69.1311	-104.991	1490	2003	26
15	11AA026	AB	49.108	-110.023	456	2003	68

The distribution of the selected stations is illustrated in Fig. 4.33. It can be seen that the stations with large numbers of zero events are located in southern parts of prairies and western Ontario, and also Northern Territories. For these stations the number of zero events for each year of observation was calculated and the new time series of number of zero events per year for the whole record length of each station was created. The independency of the new time series was tested by calculating autocorrelation coefficients for each time series and the upper and lower limits of insignificant serial correlations were calculated based on an 80% confidence interval. Table 4.12 presents the results of autocorrelation analysis for the selected stations.

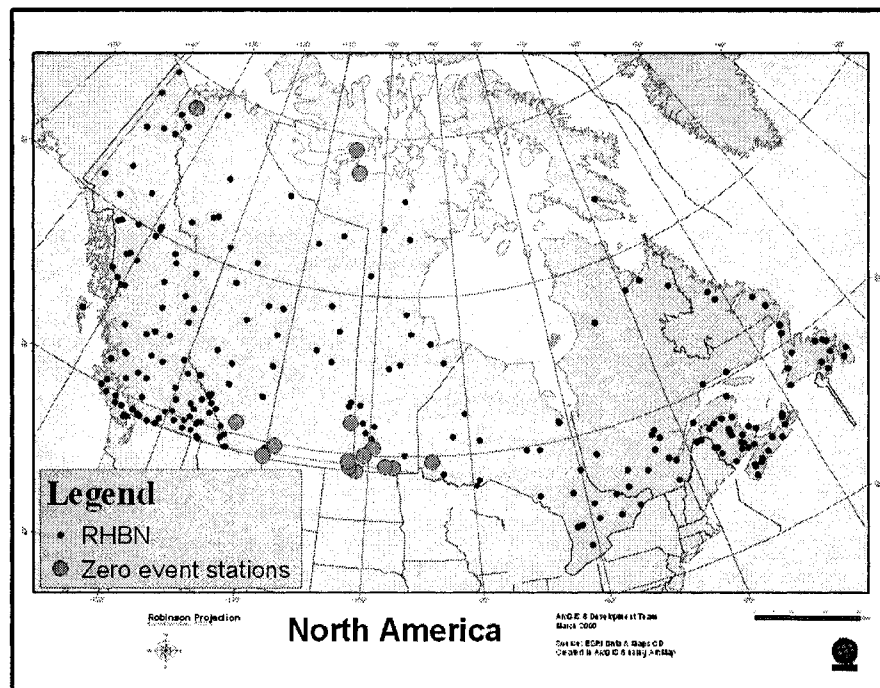


Fig. 4.33. Distribution of selected stations for trend detection in the number of zero events.

Table 4.12. Estimated autocorrelations in the number of zero events.

No. (1)	Province/Territory (2)	Station ID (3)	Autocorrelation (4)	Significant/Insignificant (5)	Upper Limit (6)	Lower limit (7)
1	ME	01AD002	0.53	FALSE	0.228441	0.410
2	NB	01AD003	0.159	TRUE	0.265289	0.395
3	NB	01AJ004	0.39	FALSE	-0.97324	0.165
4	NB	01AJ010	0.25	TRUE	-1.86959	0.031
5	NB	01AK001	0.67	FALSE	-0.89836	0.184
6	NB	01AP002	0.777	FALSE	0.826354	0.204
7	NB	01AP004	0.6	FALSE	-0.39761	0.345
8	NB	01AQ001	0.35	FALSE	1.310465	0.095
9	NB	01BC001	0.417	FALSE	-1.22078	0.111
10	NB	01BE001	0.5	FALSE	-0.97837	0.164
11	QC	01BH005	0.51	FALSE	1.245	0.107
12	NB	01BJ003	0.47	FALSE	-1.34649	0.089
13	NB	01BL002	0.43	FALSE	1.45979	0.072
14	NB	01BO001	0.656	FALSE	0.978622	0.164
15	NB	01BP001	0.028	TRUE	-0.13903	0.445

It was found that 12 out of 15 stations had significant autocorrelations at a 0.1 significance level and autocorrelations in only 3 stations were not significant. The trend in the number of zero events at selected stations was investigated using Mann-Kendall test. Table 4.13 presents the results of trend detection for the selected stations. In this table, columns (5) and (6) present p -values before and after modifications to account for autocorrelations. Based on the MK test, 7 stations experienced upward trends and 8 stations experienced downward trends. At a 0.5 significance level, 10 out of 15 stations showed significant upward or downward trends; however, due to the high level of serial correlations, only one station shows significant trends at a 0.05 significance level after MK test was corrected to account for autocorrelations (column (7)).

Table 4.13. Trend detection results for the number of zero events in selected stations.

No. (1)	Station ID (2)	Record length (years) (3)	S statistic (4)	Z (5)	P (6)	P* (7)
1	05BM014	33	27	0.402855	0.344	0.410
2	05HA003	33	21	0.309888	0.378	0.395
3	05LE011	22	-50	-1.3817	0.084	0.165
4	05LL027	28	-120	-2.35103	0.009	0.031
5	05MG004	42	-180	-1.93989	0.026	0.184
6	05NF002	57	328	2.251019	0.012	0.204
7	05NF006	29	-40	-0.73156	0.232	0.345
8	05NF010	32	116	1.864892	0.031	0.095
9	05OF014	44	-185	-1.86102	0.031	0.111
10	05OF017	40	-142	-1.6428	0.050	0.164
11	05PD023	20	66	2.108878	0.017	0.107
12	10LC007	20	-66	-2.10888	0.017	0.089
13	10QD001	29	122	2.269725	0.012	0.072
14	10TF001	26	94	2.049864	0.020	0.164
15	11AA026	68	-26	-0.13234	0.447	0.445

Fig. 4.34 illustrates the spatial distribution of significant/insignificant upward and downward trends. It can be seen that there is no evidence of patterns in the distribution of upward and downward trends in the number of zero events in the selected stations. The only station with significant downward trend is located in Manitoba (station 05LL027).

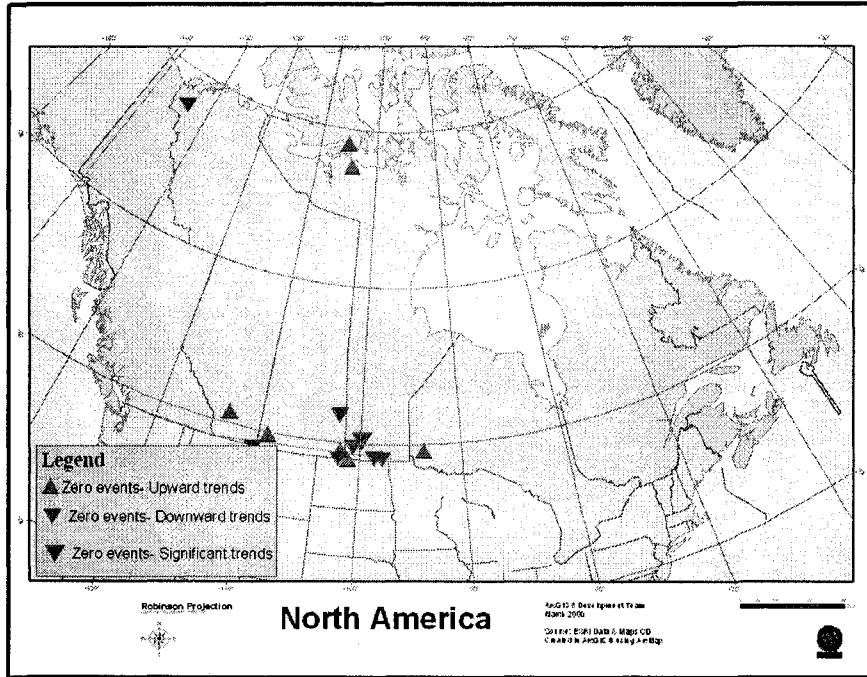


Fig. 4.34. Significant/insignificant trends in zero stations.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The objective of this study was to investigate whether there is any support for changes in river flow in observational data across Canada. The focus of the study was to investigate the existence of trends in quantity of low flows for a variety of indices for different time periods, to study trends in timing of low flows in both summer and winter portion of the year, and to assess the effects of serial correlation on interpretation of detected trends in timing and quantity of low flow time series.

The data used in this study were from the Reference Hydrometric basin network (RHBN). Overall, more than 9000 time series of daily mean flow were used to perform trend analysis in Canadian streamflows. The Mann-Kendall (MK) nonparametric test was applied to assess the existence of significant trends as well as changes in timing of low-flows at a 0.05 significance level.

Low flow indices of 7-, 14-, 21-, and 30-days for the whole subset of stations in RHBN network were extracted and tested for trends regardless of record length. Also to study the interrelation between the existing trends and the period of records, stations were grouped in three subsets with at least 30, 40, and 50 years of records and trends were detected considering different record lengths.

Furthermore, the time of occurrence of minimum 7-day low flows were extracted on a summer and winter basis and shifts in timing of low flows toward earlier and/or later dates were investigated. The quantity and timing of low-flows were extracted using a moving average procedure. These values were computed over a hydrological year (starting on May 1st) so that yearly low-flow periods were not likely to be partitioned into different years. An exploratory data analysis was performed on the time series at a number of selected stations and trends in these stations were estimated using a linear regression. It was observed that almost all of the stations showed some degree of upward and downward trends.

Various orders of serial correlations were calculated and it was found that the lag one autocorrelation was significantly larger than other autocorrelations and as such lag-1 serial correlation coefficient was taken into account in trend assessments in this study. It was found that although the majority of low flow indices were slightly dominated by positive autocorrelations, the timing of winter low-flows was slightly dominated by negative autocorrelation which had an inverse impact on the number of identified significant trends, i.e. modification on the MK test resulted in an increase in the rate of rejection of the null hypothesis.

One third of the tested stations for trend in the quantity of low flows had significant autocorrelations with over 75% of stations having positive autocorrelations. The number of positive and negative autocorrelations as well as the number of significant autocorrelations was in close agreement for different low flow indices. Most of the stations above latitude 60°N had positive autocorrelations; however, positive and negative autocorrelations in low flow time series were almost evenly distributed across other parts of the country. Although it has been reported that autocorrelation results in the rejection of the null hypothesis while it is true, the results showed that this is the case only if the existing autocorrelation is statistically significant. That is, if the autocorrelation

coefficient was insignificant, its impact on acceptance or rejection of the null hypothesis was almost insignificant as well. Thus, in this study, serial correlations were removed only if they were significant at a 0.1 significance level. Also it was found that serial correlation was significant in (15%) of stations for the timing of winter low flows and the site significance of the trends for the majority of the time series was not affected by autocorrelation. There was no evidence of any pattern or clustering in the location of significant or insignificant autocorrelations for timing of winter 7-day low flows throughout the network. At defined significance level, only 11% of the sites had statistically significant serial correlations in timing of summer 7-day low-flows. The stations with significant autocorrelation are distributed across the country without any specific pattern.

Numerical analysis performed on 7-, 14-, 21-, and 30-day low flow indices indicated that regardless of record length, the percentages of significant trends for different low flow indices are in a good agreement. The number of significant trends in the quantity of low flows amounts to about 33% of the total tested time series. The consistency of this percentage for different low flow indices suggests an overall variability in low flows in Canadian low streamflows. In 65% of stations with significant trends the low-flows experienced downward trends. On the other hand, low flows experienced a significant increase in 11% of tested stations. There was a slight decrease in the percentage of significant downward trends for longer low flow indices (21-, and 30-day low flows). It can be stated, therefore, that shorter low flow indices (i.e. 7-day) have experienced slightly stronger changes compared to the longer duration low flows.

The observed patterns revealed that the stations with significant trends in low flow indices are not evenly distributed across Canada. There exists a band of significant upward trends across northern Canada, where almost all of the stations located above latitude 60°N show increasing trends in low-flow quantities. It was

also found that significant downward trends exist in tested low-flows in some stations located in Atlantic Provinces (Nova Scotia, New Brunswick, and Prince Edward Island) and southern British Columbia. There was no evidence of trends in low-flow in Manitoba, Saskatchewan, Alberta, and eastern Ontario.

It was also found that there is a positive relationship between record length and the percentage of detected significant trends in the quantity of low flows. Increasing the record length had opposite impacts on the number of significant upward and downward trends. The percentage of significant downward trends increased as record length increased whereas the percentage of significant upward trends decreased as record length increased. For stations with more than 50 years of observations almost all significant trends were downward. It was observed that the stations with longer records are located in areas with dominant downward trends whereas the majority of the stations with shorter records are located in regions with dominant upward trends. This was the principal reason of difference in the percentage of significant upward and downward trends for different record lengths. The number of decreasing significant trends shows a persistency in time. That is, a band of significant downward trends stretches from southern British Columbia to Atlantic Provinces almost independent from the record length.

Numerical analysis showed that in the east half of the country (Atlantic Provinces and southern Ontario) summer 7-day low-flow significantly shifted to arrive earlier whereas in the west and northwest (British Columbia, Yukon Territories, and North West Territory) it shifted to arrive later. As record length increases the number of significant upward trends in the timing of summer low flow decreases. For record lengths longer than 50 years, all significant trends in timing of summer 7-day low-flows were downward. There were no significant upward or downward trends in central Canada for longer record lengths. However, in shorter

record lengths, higher latitudes of this region showed a shift toward earlier dates while lower latitudes showed a shift toward later dates. It can be stated that upward trends in timing of summer 7-day low-flow were more visible in shorter record lengths whereas significant downward trends were observed in both longer and shorter record periods.

It was observed that regardless of time period, the number of significant trends in timing of winter 7-day low flow had a 25% increase compared to the summer portion of the year. Furthermore, in 74% of the detected significant trends, the date of occurrence of winter 7-day low-flow shifted towards earlier dates. Mapped results indicate a domination of significant downward trends in eastern Canada (Atlantic Provinces), a lack of significant trends in central Canada, and a balance between the number of upward and downward trends in the west areas of the country. The results of this study indicate that trends in timing of both summer and winter 7-day minimum low flow experienced a shift toward earlier dates in eastern Canada whereas in western Canada winter trends were downward while summer trends were upward for timing of 7-day low-flows.

The variability and trend in the number of zero events in some stations with high numbers of zero mean daily flow was investigated using Mann-Kendall test. It was revealed that there was a balance between the number of upward and downward trends. At a 0.05 significance level, 10 out of 15 stations showed significant upward or downward trends; however, due to the high level of serial correlations, only one station showed significant trends after MK test was corrected to account for autocorrelations. Furthermore, there was no evidence of patterns in the distribution of upward and downward trends in the number of zero events throughout the country.

In conclusion, the majority of the results in this study are in agreement with other studies testing other hydro-climatic variables. Nevertheless, there are some discrepancies with the results of other studies (no evidence of trends in central Canada while some trends in other hydro-climatic variables have been reported by other researchers in this region).

Observed trends in low-flows can introduce changes in water supply and quality for domestic, irrigation, recreational, commercial, and industrial uses. Changes in the quantity and timing of low flows can also impact aquatic ecosystems, navigation, and wastewater assimilation.

5.2 Recommendations for future work

Further research into the attribution of the observed trends in quantity and timing of low-flow would be useful. Analysis of interrelationships between other climate variables such as precipitation, temperature, and evapotranspiration with similar temporal and spatial resolution could provide a better understanding of causes and effects of trends in climate parameters over Canada. The conceptual model of Water Balance which makes use of continuous functions of relative storage to represent surface outflow, subsurface outflow, and evapotranspiration is a recommendable approach to investigate this interrelationship. In this approach, the mass balance is represented by a differential equation, and all storage functions are included in a single mass balance. All components of discharge and infiltration are dependent upon the state variables related to the hydrological cycle (Hailemariam, 1999). The surface water balance for a domain is estimated through consideration of the balance of precipitation (P) and evapotranspiration (E) with basin runoff (R , the water leaving the domain, primarily by river channels) and is defined as (Strong *et al.*, 2001):

$$\langle P - E \rangle = \langle R \rangle + \langle \Delta S / \Delta t \rangle$$

Where $\Delta S / \Delta t$ is the rate of change of surface water storage. The variables P , E , and S are areal averages of distributed values and the brackets $\langle \rangle$ indicate spatial averaging over the entire basin for some time interval t , whereas R is a point value integrated in time (Strong *et al.*, 2001). The model contains different parameters such as baseflow, direct runoff, surface runoff, subsurface runoff, and maximum catchment water holding capacity. Different time periods can be used depending on the data availability and basin characteristics.

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Appendix A

The results of trend detection in quantity and timing of low flows performed in this study are presented in Table A-1 through A-12.

Table A-1. Serial correlations for timing of summer 7-day low-flow.

No. (1)	Province/Territory (2)	Station ID (3)	Serial correlation (4)	Significance/Insignificance (5)	Upper Limit (6)	Lower limit (7)
1	ME	01AD002	-0.1264	1	-0.2034	0.1764
2	NB	01AD003	-0.2438	1	-0.2503	0.2103
3	NB	01AJ004	0.0091	1	-0.3026	0.2455
4	NB	01AJ010	-0.0630	1	-0.3346	0.2657
5	NB	01AK001	-0.0624	1	-0.2293	0.1954
6	NB	01AP002	0.1107	1	-0.2818	0.2318
7	NB	01AP004	0.0653	1	-0.2818	0.2318
8	NB	01AQ001	0.2044	0	-0.1915	0.1674
9	NB	01BC001	-0.0558	1	-0.2818	0.2318
10	NB	01BE001	0.0227	1	-0.2293	0.1954
11	QC	01BH005	0.1503	1	-0.3286	0.2620
12	NB	01BJ003	0.2035	1	-0.2896	0.2370
13	NB	01BL002	-0.0697	1	-0.3123	0.2517
14	NB	01BO001	0.1289	1	-0.2781	0.2294
15	NB	01BP001	0.1412	1	-0.2477	0.2085
16	NB	01BQ001	-0.0752	1	-0.2781	0.2294
17	NB	01BS001	0.0427	1	-0.2896	0.2370
18	NB	01BU002	0.1602	1	-0.2781	0.2294
19	NB	01BV006	0.0258	1	-0.2896	0.2370
20	PE	01CA003	0.1485	1	-0.2818	0.2318
21	PE	01CB004	-0.1742	1	-0.3286	0.2620
22	NS	01DG003	0.0060	1	-0.1953	0.1703
23	NS	01DL001	-0.0512	1	-0.3286	0.2620
24	NS	01DP004	-0.1049	1	-0.3026	0.2455
25	NS	01EC001	-0.1262	1	-0.2049	0.1775
26	NS	01ED005	-0.1048	1	-0.3229	0.2584
27	NS	01ED007	-0.1164	1	-0.3123	0.2517
28	NS	01EF001	-0.0543	1	-0.1880	0.1647
29	NS	01EG002	-0.1937	1	-0.3286	0.2620
30	NS	01EQ001	-0.0109	1	-0.1880	0.1647
31	NS	01FA001	-0.0007	1	-0.2981	0.2426
32	NS	01FB001	0.1183	1	-0.1953	0.1703
33	NS	01FB003	-0.0504	1	-0.1915	0.1674
34	MN	02AA001	0.0927	1	-0.2020	0.1753
35	ON	02AB008	0.0061	1	-0.2558	0.2141
36	ON	02BF002	-0.0020	1	-0.3026	0.2455
37	ON	02CF008	-0.2325	1	-0.3548	0.2779
38	ON	02EA005	0.0534	1	-0.1868	0.1639
39	ON	02EC002	-0.0627	1	-0.1868	0.1639
40	ON	02FB007	0.0962	1	-0.2781	0.2294
41	ON	02FC001	0.0010	1	-0.1857	0.1630
42	ON	02GA010	-0.1681	1	-0.2403	0.2033
43	ON	02HL004	0.1128	1	-0.2587	0.2161
44	ON	02JC008	-0.3412	0	-0.3175	0.2550
45	ON	02KB001	0.2232	0	-0.1868	0.1639
46	ON	02LB007	0.2481	0	-0.2427	0.2049
47	QC	02LG005	-0.3398	1	-0.3704	0.2870
48	QC	02LH004	0.0789	1	-0.3704	0.2870
49	QC	02NE011	-0.1414	1	-0.3073	0.2485
50	QC	02NF003	-0.0795	1	-0.2335	0.1984

Table A-1 (continued). Serial correlations for timing of summer 7-day low-flow.

No. (1)	Province/Territory (2)	Station ID (3)	Serial correlation (4)	Significance/Insignificance (5)	Upper Limit (6)	Lower limit (7)
51	QC	02OE027	-0.0585	1	-0.2616	0.2182
52	QC	02PB006	-0.1907	1	-0.3073	0.2485
53	QC	02PJ007	-0.0151	1	-0.2034	0.1764
54	QC	02QA002	-0.2084	1	-0.2938	0.2397
55	QC	02RD002	-0.0481	1	-0.2938	0.2397
56	QC	02RF001	-0.1473	1	-0.3026	0.2455
57	QC	02RG005	-0.2098	1	-0.3881	0.2972
58	QC	02UC002	-0.1759	1	-0.3286	0.2620
59	QC	02VC001	0.0467	1	-0.2712	0.2247
60	NF	02YA001	-0.3609	0	-0.3548	0.2779
61	NF	02YC001	0.0360	1	-0.2746	0.2270
62	NF	02YJ001	0.0363	1	-0.3123	0.2517
63	NF	02YL001	0.0365	1	-0.2234	0.1911
64	NF	02YQ001	-0.3717	0	-0.2451	0.2067
65	NF	02YR001	-0.2105	1	-0.2746	0.2270
66	NF	02YS003	-0.2106	1	-0.3073	0.2485
67	NF	02ZF001	0.2319	0	-0.2558	0.2141
68	NF	02ZG001	0.0631	1	-0.2712	0.2247
69	NF	02ZH001	-0.0605	1	-0.2530	0.2122
70	NF	02ZK001	-0.2345	1	-0.2451	0.2067
71	NF	02ZM006	0.1230	1	-0.2558	0.2141
72	QC	03FA003	-0.2161	1	-0.4200	0.3147
73	QC	03MB002	-0.0479	1	-0.3026	0.2455
74	NF	03NF001	-0.0813	1	-0.3789	0.2920
75	NF	03NG001	-0.1509	1	-0.4770	0.3437
76	NF	03QC001	0.1751	1	-0.3026	0.2455
77	NF	03QC002	0.0005	1	-0.3704	0.2870
78	ON	04DA001	0.0979	1	-0.3477	0.2736
79	ON	04GA002	-0.2578	1	-0.3346	0.2657
80	ON	04GB004	0.3968	0	-0.3346	0.2657
81	ON	04JC002	0.2817	0	-0.2451	0.2067
82	ON	04KA001	0.2354	1	-0.3175	0.2550
83	ON	04LJ001	-0.0444	1	-0.1927	0.1684
84	ON	04MF001	-0.0752	1	-0.2981	0.2426
85	QC	04NA001	-0.0929	1	-0.2196	0.1884
86	AB	05AA008	0.2127	1	-0.2981	0.2426
87	AB	05AA023	0.0951	1	-0.2427	0.2049
88	AB	05AD003	-0.0609	1	-0.2380	0.2016
89	AB	05AD005	-0.0526	1	-0.1825	0.1605
90	AB	05BA002	0.1549	1	-0.4324	0.3213
91	AB	05BB001	0.0760	1	-0.1835	0.1613
92	AB	05BL022	0.2298	1	-0.3229	0.2584
93	AB	05DA007	-0.0484	1	-0.2981	0.2426
94	AB	05DA009	0.0000	1	-0.3175	0.2550
95	AB	05DA010	0.0902	1	-0.3410	0.2696
96	AB	05DE007	0.0162	1	-0.3229	0.2584
97	MB	05LD001	-0.1744	1	-0.2616	0.2182
98	MB	05LG004	-0.0196	1	-0.3026	0.2455
99	MB	05LH005	0.0037	1	-0.2679	0.2224
100	MB	05LJ005	0.1735	1	-0.2587	0.2161

Table A-1 (continued). Serial correlations for timing of summer 7-day low-flow.

No. (1)	Province/Territory (2)	Station ID (3)	Serial correlation (4)	Significance/Insignificance (5)	Upper Limit (6)	Lower limit (7)
101	ON	05PB014	-0.1811	1	-0.1953	0.1703
102	MB	05SA002	-0.0216	1	-0.2938	0.2397
103	MB	05TG002	-0.2215	1	-0.3346	0.2657
104	MB	05UH002	0.1305	1	-0.3548	0.2779
105	AB	06AB002	0.2519	1	-0.3704	0.2870
106	SK	06BD001	-0.0315	1	-0.3229	0.2584
107	SK	06CD002	-0.0220	1	-0.2981	0.2426
108	SK	06DA004	-0.0631	1	-0.3175	0.2550
109	MB	06FB002	-0.0857	1	-0.3346	0.2657
110	MB	06GD001	0.0516	1	-0.2587	0.2161
111	NU	06JB001	-0.0804	1	-0.4324	0.3213
112	NU	06KC003	-0.0697	1	-0.3548	0.2779
113	NU	06LA001	-0.0959	1	-0.3229	0.2584
114	NU	06LC001	-0.1593	1	-0.3346	0.2657
115	AB	07AA001	0.2385	1	-0.3477	0.2736
116	AB	07AA002	0.2520	1	-0.3175	0.2550
117	AB	07AH002	-0.0522	1	-0.3477	0.2736
118	AB	07CD001	0.5387	0	-0.2647	0.2203
119	AB	07DD002	-0.0795	1	-0.3175	0.2550
120	BC	07EC002	-0.3003	1	-0.3477	0.2736
121	BC	07EE009	0.3033	0	-0.3477	0.2736
122	BC	07FB001	0.0744	1	-0.2896	0.2370
123	BC	07FC003	-0.0072	1	-0.3229	0.2584
124	AB	07GG001	0.3824	0	-0.3175	0.2550
125	AB	07KE001	0.4969	0	-0.4324	0.3213
126	SK	07LE002	-0.1270	1	-0.3073	0.2485
127	NT	07OB001	0.0567	1	-0.2857	0.2344
128	AB	07OB003	0.1322	1	-0.3410	0.2696
129	NT	07RD001	-0.0413	1	-0.3073	0.2485
130	BC	08CD001	0.1711	1	-0.2981	0.2426
131	BC	08CE001	0.1919	1	-0.2896	0.2370
132	BC	08CG001	-0.1979	1	-0.2896	0.2370
133	BC	08DA005	-0.1855	1	-0.3175	0.2550
134	BC	08DC006	-0.0555	1	-0.3286	0.2620
135	BC	08DD001	-0.2251	1	-0.3410	0.2696
136	BC	08ED001	0.3156	0	-0.3286	0.2620
137	BC	08FA002	0.0864	1	-0.2938	0.2397
138	BC	08FB006	-0.0783	1	-0.3286	0.2620
139	BC	08FB007	0.1198	1	-0.3286	0.2620
140	BC	08GA010	-0.0293	1	-0.1880	0.1647
141	BC	08GA061	-0.1593	1	-0.3346	0.2657
142	BC	08GD004	-0.2362	1	-0.3286	0.2620
143	BC	08HA001	-0.0495	1	-0.3410	0.2696
144	BC	08HA003	0.1384	1	-0.2712	0.2247
145	BC	08HB002	-0.2760	1	-0.3789	0.2920
146	BC	08HB008	0.1717	1	-0.2253	0.1925
147	BC	08HB025	0.0170	1	-0.4770	0.3437
148	BC	08HC002	-0.1917	1	-0.4324	0.3213
149	BC	08HE006	0.0674	1	-0.2981	0.2426
150	BC	08HF004	0.1988	1	-0.3548	0.2779

Table A-1 (continued). Serial correlations for timing of summer 7-day low-flow.

No. (1)	Province/Territory (2)	Station ID (3)	Serial correlation (4)	Significance/Insignificance (5)	Upper Limit (6)	Lower limit (7)
151	BC	08JB002	-0.2852	0	-0.2451	0.2067
152	BC	08JE001	0.0977	1	-0.2451	0.2067
153	BC	08KA009	0.0615	1	-0.3229	0.2584
154	BC	08KH006	0.2338	0	-0.2335	0.1984
155	BC	08LA001	0.1134	1	-0.2451	0.2067
156	BC	08LD001	-0.0750	1	-0.2712	0.2247
157	BC	08LG016	-0.1861	1	-0.3286	0.2620
158	BC	08MA002	0.2316	1	-0.3073	0.2485
159	BC	08MB006	-0.1980	1	-0.3410	0.2696
160	BC	08MG005	0.2207	0	-0.2049	0.1775
161	BC	08MH006	-0.2092	1	-0.2746	0.2270
162	BC	08MH016	-0.0286	1	-0.2679	0.2224
163	BC	08NB005	-0.0233	1	-0.2380	0.2016
164	BC	08NC004	0.0856	1	-0.3286	0.2620
165	BC	08ND013	0.0355	1	-0.2938	0.2397
166	BC	08NE006	0.1244	1	-0.3175	0.2550
167	BC	08NE077	-0.0295	1	-0.2451	0.2067
168	BC	08NF001	-0.0852	1	-0.2746	0.2270
169	BC	08NH005	-0.1434	1	-0.2896	0.2370
170	BC	08NH016	-0.1517	1	-0.3789	0.2920
171	BC	08NH084	-0.2521	1	-0.3175	0.2550
172	BC	08NH115	-0.0014	1	-0.2896	0.2370
173	BC	08NH130	-0.0713	1	-0.3346	0.2657
174	BC	08NH131	-0.1273	1	-0.3346	0.2657
175	BC	08NJ130	-0.3460	0	-0.2981	0.2426
176	BC	08NL007	0.1327	1	-0.2314	0.1969
177	BC	08NL070	-0.0445	1	-0.3410	0.2696
178	BC	08NM174	0.1785	1	-0.3175	0.2550
179	BC	08NN015	-0.0687	1	-0.2938	0.2397
180	BC	08OA002	0.1232	1	-0.3286	0.2620
181	BC	09AA006	0.0008	1	-0.2558	0.2141
182	YT	09AC001	-0.1079	1	-0.2427	0.2049
183	BC	09AE003	0.3810	0	-0.2857	0.2344
184	YT	09BA001	0.1568	1	-0.2896	0.2370
185	YT	09BC001	0.0917	1	-0.2712	0.2247
186	YT	09FC001	-0.0941	1	-0.3789	0.2920
187	YT	10AB001	-0.0918	1	-0.2896	0.2370
188	BC	10BE004	0.2571	0	-0.2981	0.2426
189	BC	10BE007	-0.0543	1	-0.3410	0.2696
190	BC	10CB001	0.1476	1	-0.2938	0.2397
191	BC	10CD001	-0.1056	1	-0.2896	0.2370
192	NT	10EB001	0.0745	1	-0.3286	0.2620
193	NT	10FA002	-0.1343	1	-0.3175	0.2550
194	NT	10GA001	-0.0782	1	-0.4085	0.3085
195	NT	10GB006	0.4017	0	-0.4085	0.3085
196	NT	10LA002	0.1567	1	-0.3548	0.2779
197	NT	10MC002	-0.0488	1	-0.3624	0.2824
198	NT	10NC001	-0.0921	1	-0.3548	0.2779
199	NU	10PB001	0.1914	1	-0.3175	0.2550
200	NU	10RC001	0.3510	0	-0.3073	0.2485
201	SK	11AB117	0.0081	1	-0.3410	0.2696

Table A-2. Trend detection in timing of summer 7-day low flows.

No. (1)	Station ID (2)	Record Length (3)	S statistic (4)	Z (5)	P (6)	P* (7)
1	01AD002	75	-657	-3.0007	0.0013	0.0003
2	01AD003	51	-271	-2.1930	0.0142	0.0027
3	01AJ004	36	16	0.2316	0.4084	0.4092
4	01AJ010	30	63	1.1418	0.1268	0.1124
5	01AK001	60	-366	-2.3279	0.0100	0.0068
6	01AP002	41	53	0.6065	0.2721	0.2930
7	01AP004	41	28	0.3257	0.3723	0.3794
8	01AQ001	84	222	0.8615	0.1945	0.2404
9	01BC001	41	87	0.9884	0.1615	0.1492
10	01BE001	60	35	0.2296	0.4092	0.4109
11	01BH005	31	8	0.1530	0.4392	0.4474
12	01BJ003	39	144	1.7540	0.0397	0.0749
13	01BL002	34	-38	-0.5485	0.2917	0.2786
14	01BO001	42	71	0.7803	0.2176	0.2461
15	01BP001	52	-239	-1.8781	0.0302	0.0510
16	01BQ001	42	105	1.1488	0.1253	0.1093
17	01BS001	39	25	0.3145	0.3766	0.3814
18	01BU002	42	11	0.1300	0.4483	0.4558
19	01BV006	39	106	1.2944	0.0978	0.1033
20	01CA003	41	-21	-0.2246	0.4111	0.4231
21	01CB004	31	-35	-0.5439	0.2933	0.2604
22	01DG003	81	33	0.1387	0.4449	0.4452
23	01DL001	31	84	1.4447	0.0743	0.0638
24	01DP004	36	11	0.1362	0.4458	0.4403
25	01EC001	74	-359	0.2893	0.3862	0.3619
26	01ED005	32	0	0.0162	0.4935	0.4929
27	01ED007	34	81	1.2156	0.1121	0.0859
28	01EF001	87	-300	-1.0962	0.1365	0.1247
29	01EG002	31	98	1.6826	0.0462	0.0213
30	01EO001	87	-170	-0.6196	0.2678	0.2657
31	01FA001	37	92	1.1902	0.1170	0.1168
32	01FB001	81	-15	-0.0653	0.4740	0.4747
33	01FB003	84	98	0.3747	0.3539	0.3452
34	02AA001	76	-175	-0.7893	0.2150	0.2351
35	02AB008	49	95	0.8103	0.2089	0.2103
36	02BF002	36	133	1.7980	0.0361	0.0358
37	02CF008	27	92	1.8971	0.0289	0.0087
38	02EA005	88	-71	-0.2523	0.4004	0.4051
39	02EC002	88	-460	-1.6543	0.0490	0.0396
40	02FB007	42	-110	-1.2030	0.1145	0.1367
41	02FC001	89	-324	-1.1447	0.1262	0.1264
42	02GA010	55	-28	-0.2105	0.4166	0.4018
43	02HL004	48	-153	-1.3688	0.0855	0.1096
44	02JC008	33	-18	-0.2944	0.3842	0.3392
45	02KB001	88	-1117	-4.0222	0.0000	0.0006
46	02LB007	54	81	0.5968	0.2753	0.3211
47	02LG005	25	32	0.7240	0.2345	0.1548
48	02LH004	25	-49	-1.1210	0.1311	0.1496
49	02NE011	35	-43	-0.5965	0.2754	0.2470
50	02NF003	58	42	0.2884	0.3865	0.3775

Table A-2 (continued). Trend detection in timing of summer 7-day low flow

No. (1)	Station ID (2)	Record Length (3)	S statistic (4)	Z (5)	P (6)	P* (7)
51	02OE027	47	-52	-0.4677	0.3200	0.3099
52	02PB006	35	6	0.0710	0.4717	0.4659
53	02PJ007	75	-56	-0.2516	0.4007	0.3992
54	02QA002	38	97	1.2320	0.1090	0.0667
55	02RD002	38	-61	-0.7543	0.2253	0.2142
56	02RF001	36	-9	-0.1362	0.4458	0.4373
57	02RG005	23	-40	-1.0828	0.1394	0.0922
58	02UC002	31	-6	-0.0850	0.4661	0.4600
59	02VC001	44	-178	-1.7902	0.0367	0.0441
60	02YA001	27	8	0.1876	0.4256	0.3938
61	02YC001	43	118	1.2454	0.1065	0.1146
62	02YJ001	34	77	1.1563	0.1238	0.1307
63	02YL001	63	-52	-0.3025	0.3811	0.3852
64	02YQ001	53	-139	-1.0586	0.1449	0.0607
65	02YR001	43	-13	-0.1465	0.4418	0.4291
66	02YS003	35	68	0.9799	0.1636	0.1141
67	02ZF001	49	83	0.7241	0.2345	0.2824
68	02ZG001	44	-25	-0.2427	0.4041	0.4095
69	02ZH001	50	27	0.2342	0.4074	0.4019
70	02ZK001	53	-125	-0.9512	0.1708	0.1157
71	02ZM006	49	-91	-0.7930	0.2139	0.2412
72	03FA003	20	56	1.8493	0.0322	0.0111
73	03MB002	36	-19	-0.2452	0.4032	0.3986
74	03NF001	24	5	0.0992	0.4605	0.4573
75	03NG001	16	-7	-0.2701	0.3935	0.3778
76	03QC001	36	-2	-0.0136	0.4946	0.4954
77	03QC002	25	7	0.1868	0.4259	0.4262
78	04DA001	28	-4	-0.0988	0.4607	0.4642
79	04GA002	30	-1	-0.0357	0.4858	0.4816
80	04GB004	30	-87	-1.5700	0.0582	0.1481
81	04JC002	53	-114	-0.8821	0.1889	0.2529
82	04KA001	33	-179	-2.7890	0.0026	0.0131
83	04LJ001	83	-159	-0.6214	0.2672	0.2590
84	04MF001	37	-84	-1.1117	0.1331	0.1158
85	04NA001	65	198	1.1153	0.1324	0.1114
86	05AA008	37	-51	-0.6801	0.2482	0.2856
87	05AA023	54	19	1.3130	0.0946	0.1159
88	05AD003	56	-326	1.0036	0.1578	0.1435
89	05AD005	92	-518	-1.6435	0.0501	0.0421
90	05BA002	19	-38	-1.3644	0.0862	0.0966
91	05BB001	91	163	-0.7420	0.2290	0.2457
92	05BL022	32	51	0.8108	0.2087	0.1668
93	05DA007	37	30	0.3793	0.3522	0.2836
94	05DA009	33	19	0.2789	0.3902	0.3804
95	05DA010	29	-86	-1.6320	0.0513	0.0527
96	05DE007	32	128	2.0595	0.0197	0.0195
97	05LD001	47	-18	-0.1742	0.4308	0.4184
98	05LG004	36	-40	-0.5312	0.2976	0.2940
99	05LH005	45	-42	-0.4206	0.3370	0.3375
100	05LJ005	48	284	2.5153	0.0059	0.0170

Table A-2 (continued). Trend detection in timing of summer 7-day low flows.

No. (1)	Station ID (2)	Record Length (3)	S statistic (4)	Z (5)	P (6)	P* (7)
101	05PB014	81	-544	-2.2227	0.0131	0.0039
102	05SA002	38	-52	-0.6663	0.2526	0.2484
103	05TG002	30	22	0.3747	0.3540	0.3210
104	05UH002	27	32	0.6463	0.2591	0.2844
105	06AB002	25	23	0.5138	0.3037	0.3122
106	06BD001	32	16	0.2757	0.2838	0.3883
107	06CD002	37	-12	-0.1439	-0.1494	0.4406
108	06DA004	33	5	0.0930	0.0988	0.4606
109	06FB002	30	-46	-0.8028	0.2110	0.1928
110	06GD001	48	-210	-1.8754	0.0304	0.0371
111	06JB001	19	0	-0.0350	0.4860	0.4849
112	06KC003	27	64	1.3134	0.0945	0.0800
113	06LA001	32	-148	-2.4163	0.0078	0.0042
114	06LC001	30	3	0.0357	0.4858	0.4834
115	07AA001	28	-40	-0.8100	0.2090	0.1954
116	07AA002	33	28	0.4183	0.3378	0.3035
117	07AH002	28	22	0.4149	0.3391	0.3347
118	07CD001	46	-36	-0.3503	0.3630	0.3656
119	07DD002	33	43	0.6508	0.2576	0.2256
120	07EC002	28	54	1.0471	0.1475	0.0792
121	07EE009	28	-22	-0.4544	0.3248	0.3679
122	07FB001	39	134	1.6089	0.0538	0.0665
123	07FC003	32	69	1.1027	0.1351	0.1335
124	07GG001	33	99	1.5185	0.0645	0.1015
125	07KE001	19	-6	-0.2449	0.4033	0.4167
126	07LE002	35	-49	-0.6817	0.2481	0.2202
127	07OB001	40	104	1.2001	0.1151	0.1277
128	07OB003	29	-91	-1.7257	0.0422	0.0240
129	07RD001	35	52	0.7243	0.2344	0.2255
130	08CD001	37	-117	-1.5433	0.0614	0.0958
131	08CE001	39	64	0.7621	0.2230	0.2637
132	08CG001	39	35	0.4113	0.3404	0.3082
133	08DA005	33	13	0.1859	0.4262	0.4122
134	08DC006	31	99	1.6656	0.0479	0.0402
135	08DD001	29	91	1.6882	0.0457	0.0181
136	08ED001	31	68	1.1388	0.1274	0.2016
137	08FA002	38	57	0.7040	0.2407	0.2587
138	08FB006	31	52	0.8668	0.1930	0.1768
139	08FB007	31	20	0.3229	0.3734	0.3869
140	08GA010	87	-223	-0.8212	0.2058	0.1988
141	08GA061	30	-6	-0.1249	0.4503	0.4420
142	08GD004	31	4	0.0510	0.4797	0.4745
143	08HA001	29	91	1.6882	0.0457	0.0384
144	08HA003	44	10	0.1113	0.4557	0.4613
145	08HB002	24	-23	-0.5953	0.2758	0.2166
146	08HB008	62	-81	-0.4859	0.3135	0.3407
147	08HB025	16	-28	-1.3057	0.0958	0.0994
148	08HC002	19	-5	-0.2099	0.4169	0.4006
149	08HE006	37	29	0.3662	0.3571	0.3658
150	08HF004	27	54	1.1049	0.1346	0.1838

Table A-2 (continued). Trend detection in timing of summer 7-day low flows.

No. (1)	Station ID (2)	Record Length (3)	S statistic (4)	Z (5)	P (6)	P* (7)
151	08JB002	53	179	1.3807	0.0837	0.0329
152	08JE001	53	328	2.5083	0.0061	0.0114
153	08KA009	32	23	0.3568	0.3606	0.3682
154	08KH006	58	176	1.1739	0.1202	0.1755
155	08LA001	53	113	0.8591	0.1951	0.2204
156	08LD001	44	66	0.6574	0.2555	0.2396
157	08LG016	31	-12	-0.2210	0.4126	0.3955
158	08MA002	35	39	0.5397	0.2947	0.3336
159	08MB006	29	8	0.1313	0.4478	0.4366
160	08MG005	74	-3	-0.0187	0.4926	0.4940
161	08MH006	43	33	0.3349	0.3689	0.3400
162	08MH016	45	79	0.7826	0.2169	0.2104
163	08NB005	56	-43	-0.2968	0.3833	0.3807
164	08NC004	31	-67	-1.1558	0.1239	0.1436
165	08ND013	38	-96	-1.2195	0.1113	0.1181
166	08NE006	33	65	0.9916	0.1607	0.1888
167	08NE077	53	95	0.7364	0.2307	0.1619
168	08NF001	43	-64	-0.6803	0.2482	0.2310
169	08NH005	39	-166	-2.0202	0.0217	0.0102
170	08NH016	24	-47	-1.1906	0.1169	0.0844
171	08NH084	33	-61	-0.9607	0.1684	0.1625
172	08NH115	39	-17	-0.2177	0.4138	0.4137
173	08NH130	30	-59	-1.0705	0.1422	0.1260
174	08NH131	30	33	0.5709	0.2840	0.2592
175	08NJ130	37	-24	-0.3270	0.3718	0.3205
176	08NL007	59	216	1.4191	0.0779	0.1067
177	08NL070	29	-53	-1.0129	0.1555	0.1462
178	08NM174	33	-12	-0.2014	0.4202	0.4330
179	08NN015	38	51	0.6286	0.2648	0.2505
180	08OA002	31	-132	-2.2605	0.0119	0.0224
181	09AA006	49	-132	-1.1292	0.1294	0.1313
182	09AC001	54	134	0.9922	0.1605	0.1368
183	09AE003	40	163	1.8875	0.0295	0.1004
184	09BA001	39	111	1.3307	0.0917	0.1277
185	09BC001	44	259	2.6095	0.0045	0.0084
186	09FC001	24	61	1.4883	0.0683	0.0517
187	10AB001	39	81	0.9677	0.1666	0.1453
188	10BE004	37	46	0.5885	0.2781	0.3242
189	10BE007	29	-44	-0.8441	0.1993	0.1878
190	10CB001	38	69	0.8549	0.1963	0.2296
191	10CD001	39	-83	-1.0161	0.1548	0.1313
192	10EB001	31	147	2.4815	0.0065	0.0102
193	10FA002	33	-9	-0.1549	0.4384	0.4302
194	10GA001	21	-20	-0.6341	0.2630	0.2473
195	10GB006	21	18	0.5133	0.3039	0.3654
196	10LA002	27	-76	-1.6052	0.0542	0.0838
197	10MC002	26	15	0.3086	0.3788	0.3732
198	10NC001	27	-40	-0.8130	0.2081	0.1876
199	10PB001	33	148	2.2777	0.0114	0.0293
200	10RC001	35	-255	-3.6072	0.0002	0.0057
201	11AB117	29	-101	-1.87	0.030	0.0313

Table A-3. Serial correlation coefficients for timing of winter 7-day low-flow time series.

No. (1)	Province/Territory (2)	Station ID (3)	Autocorrelation (4)	Sig. /Insig. (5)	Upper Limit (6)	Lower limit (7)
1	ME	01AD002	0.0254	TRUE	-0.20061	0.174291
2	NB	01AD003	-0.1548	TRUE	-0.2503	0.2103
3	NB	01AJ004	-0.2	TRUE	-0.30263	0.245483
4	NB	01AJ010	-0.2147	TRUE	-0.33464	0.265673
5	NB	01AK001	0.0049	TRUE	-0.22929	0.195389
6	NB	01AP002	-0.0875	TRUE	-0.28183	0.231826
7	NB	01AP004	-0.0562	TRUE	-0.28565	0.234371
8	NB	01AQ001	0.1491	TRUE	-0.19152	0.167423
9	NB	01BC001	-0.1359	TRUE	-0.28183	0.231826
10	NB	01BE001	0.0713	TRUE	-0.22929	0.195389
11	QC	01BH005	-0.2707	TRUE	-0.32862	0.261953
12	NB	01BJ003	-0.1777	TRUE	-0.28964	0.237004
13	NB	01BL002	-0.1266	TRUE	-0.31229	0.251683
14	NB	01BO001	-0.2352	TRUE	-0.27814	0.229363
15	NB	01BP001	-0.1761	TRUE	-0.24768	0.208469
16	NB	01BQ001	-0.1717	TRUE	-0.27814	0.229363
17	NB	01BS001	-0.2974	FALSE	-0.28964	0.237004
18	NB	01BU002	-0.1272	TRUE	-0.27814	0.229363
19	NB	01BV006	-0.0529	TRUE	-0.28964	0.237004
20	PE	01CA003	-0.2484	TRUE	-0.28183	0.231826
21	PE	01CB004	-0.3321	FALSE	-0.32862	0.261953
22	NS	01DG003	0.1738	FALSE	-0.19526	0.170263
23	NS	01DL001	0.0978	TRUE	-0.32862	0.261953
24	NS	01DP004	-0.0982	TRUE	-0.30735	0.248524
25	NS	01EC001	-0.0467	TRUE	-0.20491	0.177511
26	NS	01ED005	-0.3006	TRUE	-0.3229	0.258388
27	NS	01ED007	-0.4949	FALSE	-0.31229	0.251683
28	NS	01EF001	-0.1008	TRUE	-0.18798	0.164723
29	NS	01EG002	-0.127	TRUE	-0.32862	0.261953
30	NS	01EO001	0.0945	TRUE	-0.18914	0.165608
31	NS	01FA001	0.1294	TRUE	-0.29811	0.242554
32	NS	01FB001	-0.0213	TRUE	-0.19526	0.170263
33	NS	01FB003	-0.002	TRUE	-0.19152	0.167423
34	MN	02AA001	0.1136	TRUE	-0.20201	0.175344
35	ON	02AB008	-0.1547	TRUE	-0.253	0.212182
36	ON	02BF002	-0.0933	TRUE	-0.30263	0.245483
37	ON	02CF008	-0.0679	TRUE	-0.35481	0.277885
38	ON	02EA005	-0.1535	TRUE	-0.18684	0.163852
39	ON	02EC002	0.1429	TRUE	-0.18684	0.163852
40	ON	02FB007	0.223	TRUE	-0.2746	0.22698
41	ON	02FC001	-0.0927	TRUE	-0.18572	0.162995
42	ON	02GA010	-0.1023	TRUE	-0.23797	0.201604
43	ON	02HL004	-0.0688	TRUE	-0.25866	0.216105
44	ON	02JC008	-0.2266	TRUE	-0.31747	0.254968
45	ON	02KB001	0.0406	TRUE	-0.18684	0.163852
46	ON	02LB007	-0.0977	TRUE	-0.24268	0.204948
47	QC	02LG005	-0.1544	TRUE	-0.37038	0.287048
48	QC	02LH004	0.14	TRUE	-0.37038	0.287048
49	QC	02NE011	0.0513	TRUE	-0.30735	0.248524
50	QC	02NF003	0.2815	FALSE	-0.23571	0.199994

Table A-3 (continued). Serial correlations for timing of winter 7-day low-flow time series.

No. (1)	Province/ Territory (2)	Station ID (3)	Autocorrelation (4)	Sig/Insig. (5)	Upper Limit (6)	Lower limit (7)
51	QC	02OE027	-0.0213	TRUE	-0.26163	0.218152
52	QC	02PB006	-0.1128	TRUE	-0.30735	0.248524
53	QC	02PJ007	-0.0517	TRUE	-0.20491	0.177511
54	QC	02QA002	0.271	FALSE	-0.29378	0.23973
55	QC	02RD002	-0.2945	FALSE	-0.29378	0.23973
56	QC	02RF001	-0.2022	TRUE	-0.29378	0.23973
57	QC	02RG005	-0.4033	FALSE	-0.38811	0.297197
58	QC	02UC002	-0.0492	TRUE	-0.34099	0.26956
59	QC	02VC001	-0.2153	TRUE	-0.27118	0.22467
60	NF	02YA001	-0.0503	TRUE	-0.35481	0.277885
61	NF	02YC001	0.0379	TRUE	-0.2746	0.22698
62	NF	02YJ001	-0.1004	TRUE	-0.31229	0.251683
63	NF	02YL001	0.0425	TRUE	-0.22335	0.191095
64	NF	02YQ001	-0.2074	TRUE	-0.24768	0.208469
65	NF	02YR001	-0.206	TRUE	-0.2746	0.22698
66	NF	02YS003	0.0379	TRUE	-0.30735	0.248524
67	NF	02ZF001	0.1077	TRUE	-0.25578	0.214116
68	NF	02ZG001	-0.2607	TRUE	-0.27118	0.22467
69	NF	02ZH001	0.0154	TRUE	-0.253	0.212182
70	NF	02ZK001	0.0123	TRUE	-0.24515	0.206686
71	NF	02ZM006	-0.2042	TRUE	-0.25578	0.214116
72	QC	03FA003	-0.0021	TRUE	-0.41995	0.314692
73	QC	03MB002	0.2895	FALSE	-0.30263	0.245483
74	NF	03NF001	0.0198	TRUE	-0.37894	0.291988
75	NF	03NG001	0.0052	TRUE	-0.477	0.343668
76	NF	03QC001	-0.0295	TRUE	-0.30263	0.245483
77	NF	03QC002	0.1544	TRUE	-0.37038	0.287048
78	ON	04DA001	0.5988	FALSE	-0.29811	0.242554
79	ON	04GA002	0.0554	TRUE	-0.33464	0.265673
80	ON	04GB004	0.4239	FALSE	-0.33464	0.265673
81	ON	04JC002	-0.1454	TRUE	-0.24515	0.206686
82	ON	04KA001	-0.1702	TRUE	-0.31229	0.251683
83	ON	04LJ001	0.1078	TRUE	-0.19274	0.168354
84	ON	04MF001	-0.1602	TRUE	-0.29811	0.242554
85	QC	04NA001	-0.0555	TRUE	-0.21964	0.188387
86	AB	05AA008	-0.0599	TRUE	-0.29378	0.23973
87	AB	05AA023	0.0281	TRUE	-0.24268	0.204948
88	AB	05AD003	0.1272	TRUE	-0.23797	0.201604
89	AB	05AD005	0.0448	TRUE	-0.18248	0.160504
90	AB	05BA002	-0.1602	TRUE	-0.43236	0.32125
91	AB	05BB001	0.2465	FALSE	-0.18354	0.161321
92	AB	05BL022	-0.0094	TRUE	-0.3229	0.258388
93	AB	05DA007	-0.1759	TRUE	-0.29811	0.242554
94	AB	05DA009	-0.1662	TRUE	-0.31747	0.254968
95	AB	05DA010	-0.0213	TRUE	-0.34099	0.26956
96	MB	05LH005	-0.0243	TRUE	-0.26789	0.222432
97	ON	05PB014	0.1595	TRUE	-0.19399	0.1693
98	MB	05TG002	0.0114	TRUE	-0.32862	0.261953
99	MB	05UH002	-0.0795	TRUE	-0.3477	0.273625
100	AB	06AB002	-0.16	TRUE	-0.37038	0.287048

Table A-3 (continued). Serial correlations for timing of winter 7-day low-flow time series.

No. (1)	Province/Territory (2)	Station ID (3)	Autocorrelation(4)	Sig/Insig. (5)	Upper Limit (6)	Lower limit (7)
101	SK	06BD001	-0.1623	TRUE	-0.3229	0.258388
102	SK	06CD002	0.0051	TRUE	-0.29811	0.242554
103	SK	06DA004	-0.0309	TRUE	-0.31747	0.254968
104	MB	06FB002	-0.0465	TRUE	-0.33464	0.265673
105	MB	06GD001	0.6612	FALSE	-0.25866	0.216105
106	NU	06JB001	-0.0561	TRUE	-0.43236	0.32125
107	NU	06KC003	0.63	FALSE	-0.35481	0.277885
108	NU	06LA001	-0.0688	TRUE	-0.3229	0.258388
109	NU	06LC001	0.1729	TRUE	-0.33464	0.265673
110	AB	07AA001	0.0027	TRUE	-0.3477	0.273625
111	AB	07AA002	-0.1819	TRUE	-0.31747	0.254968
112	AB	07CD001	-0.1441	TRUE	-0.2647	0.22026
113	BC	07EC002	0.4082	FALSE	-0.3477	0.273625
114	BC	07EE009	0.2191	TRUE	-0.3477	0.273625
115	BC	07FB001	-0.2419	TRUE	-0.28964	0.237004
116	BC	07FC003	-0.197	TRUE	-0.3229	0.258388
117	AB	07GG001	-0.0191	TRUE	-0.31747	0.254968
118	AB	07KE001	-0.0678	TRUE	-0.43236	0.32125
119	SK	07LE002	0.1016	TRUE	-0.30735	0.248524
120	NT	07OB001	-0.1972	TRUE	-0.28565	0.234371
121	NT	07RD001	0.0351	TRUE	-0.30735	0.248524
122	BC	08CD001	0.3434	FALSE	-0.29811	0.242554
123	BC	08CE001	0.4922	FALSE	-0.28964	0.237004
124	BC	08CG001	-0.1489	TRUE	-0.28964	0.237004
125	BC	08DA005	-0.1295	TRUE	-0.31747	0.254968
126	BC	08DC006	-0.0299	TRUE	-0.3229	0.258388
127	BC	08DD001	-0.1173	TRUE	-0.34099	0.26956
128	BC	08ED001	0.2511	TRUE	-0.32862	0.261953
129	BC	08FA002	0.3149	FALSE	-0.29378	0.23973
130	BC	08FB006	0.3139	FALSE	-0.32862	0.261953
131	BC	08FB007	0.0155	TRUE	-0.32862	0.261953
132	BC	08GA010	-0.1266	TRUE	-0.18798	0.164723
133	BC	08GA061	-0.2372	TRUE	-0.33464	0.265673
134	BC	08GD004	0.5033	FALSE	-0.32862	0.261953
135	BC	08HA001	-0.2849	TRUE	-0.34099	0.26956
136	BC	08HA003	-0.1562	TRUE	-0.27118	0.22467
137	BC	08HB002	-0.3489	TRUE	-0.37894	0.291988
138	BC	08HB008	0.023	TRUE	-0.22528	0.192494
139	BC	08HB025	-0.1154	TRUE	-0.477	0.343668
140	BC	08HC002	-0.0533	TRUE	-0.43236	0.32125
141	BC	08HE006	-0.188	TRUE	-0.29811	0.242554
142	BC	08HF004	-0.0774	TRUE	-0.35481	0.277885
143	BC	08JB002	-0.1643	TRUE	-0.24768	0.208469
144	BC	08JE001	-0.0215	TRUE	-0.24515	
145	BC	08KA009	0.0984	TRUE	-0.3229	0.258388
146	BC	08KH006	-0.1309	TRUE	-0.23351	0.198422
147	BC	08LA001	0.1963	TRUE	-0.24515	0.206686
148	BC	08LD001	0.0365	TRUE	-0.27118	0.22467
149	BC	08LG016	-0.0494	TRUE	-0.32862	0.261953
150	BC	08MA002	0.1815	TRUE	-0.30735	0.248524

Table A-3 (continued). Serial correlations for timing of winter 7-day low-flow time series.

No. (1)	Province/ Territory (2)	Station ID (3)	Autocorrelation (4)	Sig/Insig. (5)	Upper Limit (6)	Lower limit (7)
151	BC	08MB006	0.0134	TRUE	-0.34099	0.26956
152	BC	08MG005	0.0229	TRUE	-0.20491	0.177511
153	BC	08MH006	-0.089	TRUE	-0.2746	0.22698
154	BC	08MH016	0.2344	FALSE	-0.26789	0.222432
155	BC	08NB005	-0.2424	FALSE	-0.23797	0.201604
156	BC	08NC004	0.0543	TRUE	-0.32862	0.261953
157	BC	08ND013	0.0545	TRUE	-0.29378	0.23973
158	BC	08NE006	-0.2667	TRUE	-0.31747	0.254968
159	BC	08NE077	0.1342	TRUE	-0.24515	0.206686
160	BC	08NF001	-0.1133	TRUE	-0.2746	0.22698
161	BC	08NH005	-0.0079	TRUE	-0.28964	0.237004
162	BC	08NH016	0.3064	FALSE	-0.37894	0.291988
163	BC	08NH084	0.0432	TRUE	-0.31747	0.254968
164	BC	08NH115	0.3481	FALSE	-0.28964	0.237004
165	BC	08NH130	0.0058	TRUE	-0.33464	0.265673
166	BC	08NH131	0.0483	TRUE	-0.33464	0.265673
167	BC	08NJ130	0.3806	FALSE	-0.29811	0.242554
168	BC	08NL007	0.0766	TRUE	-0.23137	0.196888
169	BC	08NL070	0.3263	FALSE	-0.34099	0.26956
170	BC	08NM174	-0.0175	TRUE	-0.31747	0.254968
171	BC	08NN015	-0.1033	TRUE	-0.29378	0.23973
172	BC	08OA002	0.2449	TRUE	-0.32862	0.261953
173	BC	09AA006	0.0972	TRUE	-0.2503	0.2103
174	YT	09AC001	0.054	TRUE	-0.24268	0.204948
175	BC	09AE003	-0.0386	TRUE	-0.28565	0.234371
176	YT	09BA001	0.2196	TRUE	-0.29378	0.23973
177	YT	09BC001	0.2992	FALSE	-0.27118	0.22467
178	YT	09FC001	0.0301	TRUE	-0.37894	0.291988
179	YT	10AB001	-0.071	TRUE	-0.28964	0.237004
180	BC	10BE004	-0.1059	TRUE	-0.29811	0.242554
181	BC	10BE007	0.0258	TRUE	-0.34099	0.26956
182	BC	10CB001	0.0662	TRUE	-0.28964	0.237004
183	BC	10CD001	0.0346	TRUE	-0.28964	0.237004
184	NT	10EB001	-0.0251	TRUE	-0.32862	0.261953
185	NT	10FA002	-0.0076	TRUE	-0.31747	0.254968
186	NT	10GA001	-0.0158	TRUE	-0.40852	0.308519
187	NT	10GB006	0.2853	TRUE	-0.40852	0.308519
188	NT	10LA002	-0.3905	FALSE	-0.35481	0.277885
189	NT	10MC002	-0.2412	TRUE	-0.36235	0.282353
190	NT	10NC001	-0.0013	TRUE	-0.35481	0.277885
191	NU	10PB001	0.6868	FALSE	-0.30263	0.245483
192	NU	10RC001	0.0486	TRUE	-0.30735	0.248524

Table A-4. Estimated statistics for timing of winter 7-day low-flow.

No. (1)	Station ID (2)	Record Length(year) (3)	MK S statistic (4)	Z (5)	P (6)	P* (7)
1	01AD002	77	-767	-3.369	0.000	-3.287
2	01AD003	51	-271	-2.193	0.014	-2.543
3	01AJ004	36	69	0.953	0.170	1.161
4	01AJ010	30	38	0.696	0.243	0.855
5	01AK001	60	-381	-2.424	0.008	-2.412
6	01AP002	41	-103	-1.146	0.126	-1.239
7	01AP004	40	-57	-0.652	0.257	-0.685
8	01AQ001	84	-162	-0.622	0.267	-0.536
9	01BC001	41	-6	-0.056	0.478	-0.064
10	01BE001	60	-20	-0.121	0.452	-0.113
11	01BH005	31	23	0.408	0.342	0.533
12	01BJ003	39	-65	-0.774	0.219	-0.915
13	01BL002	34	-23	-0.326	0.372	-0.370
14	01BO001	42	-38	-0.401	0.344	-0.504
15	01BP001	52	-239	-1.878	0.030	-2.236
16	01BQ001	42	-40	-0.423	0.336	-0.500
17	01BS001	39	-24	-0.278	0.390	-0.372
18	01BU002	42	-11	-0.108	0.457	-0.123
19	01BV006	39	-142	-1.706	0.044	-1.791
20	01CA003	41	26	0.303	0.381	0.385
21	01CB004	31	-35	-0.306	0.380	-0.426
22	01DG003	81	-180	0.233	0.233	0.270
23	01DL001	31	-154	-2.600	0.005	-2.466
24	01DP004	35	-86	-1.236	0.108	-1.458
25	01EC001	74	-359	-0.014	0.494	-0.017
26	01ED005	32	-38	-0.600	0.274	-0.707
27	01ED007	34	-13	-0.178	0.429	-0.179
28	01EF001	87	-319	0.122	0.122	0.099
29	01EG002	31	0	0.017	0.493	0.024
30	01EO001	86	-196	0.234	0.234	0.253
31	01FA001	37	-33	-0.445	0.328	-0.482
32	01FB001	81	305	-0.665	0.253	-0.645
33	01FB003	84	-41	-0.162	0.436	-0.173
34	02AA001	76	263	1.175	0.120	1.054
35	02AB008	50	416	3.471	0.000	4.025
36	02BF002	36	112	1.512	0.065	1.651
37	02CF008	27	-28	-0.605	0.273	-0.646
38	02EA005	88	68	0.241	0.405	0.280
39	02EC002	88	397	1.434	0.076	1.248
40	02FB007	43	-35	-0.377	0.353	-0.303
41	02FC001	89	-9	-0.028	0.489	-0.031
42	02GA010	56	121	0.848	0.198	0.936
43	02HL004	48	89	0.782	0.217	0.838
44	02JC008	33	-60	-0.945	0.172	-1.186
45	02KB001	88	397	1.434	0.076	1.379
46	02LB007	54	52	0.380	0.352	0.420
47	02LG005	25	2	0.023	0.491	0.027
48	02LH004	25	23	0.561	0.288	0.490
49	02NE011	35	-47	-0.653	0.257	-0.622
50	02NF003	57	155	1.074	0.141	0.810

Table A-4 (continued). Estimated statistics for timing of winter 7-day low-flow.

No. (1)	Station ID (2)	Record Length(year) (3)	MK S statistic (4)	Z (5)	P (6)	P* (7)
51	02OE027	47	62	0.578	0.282	0.589
52	02PB006	35	-100	-1.434	0.076	-1.597
53	02PJ007	74	443	2.063	0.020	2.167
54	02QA002	38	-161	-2.012	0.022	-1.537
55	02RD002	38	-37	-0.453	0.325	-0.605
56	02RF001	38	-50	-0.616	0.269	-0.750
57	02RG005	23	-9	-0.264	0.396	-0.395
58	02UC002	29	3	0.075	0.470	0.079
59	02VC001	44	20	0.212	0.416	0.262
60	02YA001	27	-1	0.000	0.500	0.000
61	02YC001	43	-177	-1.842	0.033	-1.775
62	02YJ001	34	-105	-1.542	0.062	-1.699
63	02YL001	63	-106	-0.623	0.267	-0.599
64	02YQ001	52	137	1.089	0.138	1.328
65	02YR001	43	-17	-0.188	0.425	-0.230
66	02YS003	35	25	0.369	0.356	0.355
67	02ZF001	49	-75	-0.638	0.262	-0.572
68	02ZG001	44	-23	-0.223	0.412	-0.289
69	02ZH001	50	-38	-0.309	0.378	-0.305
70	02ZK001	53	-308	-2.355	0.009	-2.327
71	02ZM006	49	29	0.241	0.405	0.294
72	03FA003	20	-1	0.000	0.500	0.000
73	03MB002	36	9	0.136	0.446	0.102
74	03NF001	24	-53	-1.339	0.090	-1.314
75	03NG001	16	16	0.765	0.222	0.762
76	03QC001	36	-132	-1.784	0.037	-1.837
77	03QC002	25	-62	-1.425	0.077	-1.232
78	04DA001	37	-232	-3.047	0.001	-1.564
79	04GA002	30	-77	-1.392	0.082	-1.326
80	04GB004	30	-85	-1.534	0.062	-0.998
81	04JC002	53	-32	-0.253	0.400	-0.292
82	04KA001	34	4	0.044	0.482	0.053
83	04LJ001	83	336	1.325	0.093	1.188
84	04MF001	37	-51	-0.680	0.248	-0.796
85	04NA001	65	-81	-0.464	0.321	-0.488
86	05AA008	38	42	0.515	0.303	0.546
87	05AA023	54	19	0.134	0.447	0.131
88	05AD003	56	-326	-2.297	0.011	-2.026
89	05AD005	92	-518	-1.744	0.041	-1.676
90	05BA002	19	29	0.980	0.164	1.023
91	05BB001	91	163	0.555	0.289	0.431
92	05BL022	32	74	1.184	0.118	1.194
93	05DA007	37	-28	-0.379	0.352	-0.448
94	05DA009	33	12	0.170	0.432	0.199
95	05DA010	29	14	0.244	0.404	0.249
96	05LH005	45	-186	-1.829	0.034	-1.865
97	05PB014	82	-722	-2.895	0.002	-2.469
98	05TG002	31	-57	-0.986	0.162	-0.976
99	05UH002	28	-106	-2.114	0.017	-2.284
100	06AB002	25	7	0.140	0.444	0.164

Table A-4 (continued). Estimated statistics for timing of winter 7-day low-flow.

No. (1)	Station ID (2)	Record Length(year) (3)	MK S statistic (4)	Z (5)	P (6)	P* (7)
101	06BD001	32	-89	-1.43	0.077	0.048
102	06CD002	37	-58	-0.75	0.228	0.229
103	06DA004	33	-42	-0.64	0.263	0.256
104	06FB002	30	-43	-0.75	0.227	0.217
105	06GD001	48	578	5.13	0.000	0.009
106	06JB001	19	-11	-0.42	0.337	0.329
107	06KC003	27	72	1.48	0.069	0.231
108	06LA001	32	76	1.22	0.112	0.097
109	06LC001	30	-75	-1.36	0.088	0.125
110	07AA001	28	23	0.43	0.332	0.332
111	07AA002	33	-91	-1.43	0.077	0.045
112	07CD001	46	-63	-0.61	0.272	0.243
113	07EC002	28	79	1.54	0.062	0.153
114	07EE009	28	23	0.43	0.332	0.361
115	07FB001	39	25	0.29	0.386	0.356
116	07FC003	32	-77	-1.26	0.103	0.062
117	07GG001	33	-62	-0.98	0.164	0.160
118	07KE001	19	-23	-0.84	0.201	0.187
119	07LE002	35	-55	-0.77	0.222	0.243
120	07OB001	40	-52	-0.62	0.268	0.227
121	07RD001	35	39	0.54	0.295	0.300
122	08CD001	37	-202	-2.66	0.004	0.030
123	08CE001	39	-189	-2.30	0.011	0.086
124	08CG001	39	37	0.44	0.332	0.354
125	08DA005	33	-16	-0.26	0.396	0.382
126	08DC006	32	-28	-0.47	0.319	0.314
127	08DD001	29	-1	-0.04	0.485	0.483
128	08ED001	31	-15	-0.27	0.393	0.416
129	08FA002	38	102	1.27	0.102	0.176
130	08FB006	31	-150	-2.57	0.005	0.030
131	08FB007	31	-61	-1.05	0.146	0.150
132	08GA010	87	-163	-0.60	0.274	0.248
133	08GA061	30	-19	-0.36	0.361	0.327
134	08GD004	31	67	1.12	0.131	0.254
135	08HA001	29	-69	-1.31	0.095	0.042
136	08HA003	44	-105	-1.05	0.146	0.110
137	08HB002	24	12	0.27	0.392	0.351
138	08HB008	62	-38	-0.22	0.411	0.413
139	08HB025	16	9	0.36	0.359	0.345
140	08HC002	19	56	1.92	0.027	0.022
141	08HE006	37	-12	-0.17	0.432	0.419
142	08HF004	27	18	0.35	0.362	0.352
143	08JB002	52	-238	-1.87	0.031	0.014
144	08JE001	53	-317	-2.42	0.008	0.007
145	08KA009	32	-46	-0.76	0.223	0.245
146	08KH006	58	-271	-1.82	0.034	0.019
147	08LA001	53	-201	-1.55	0.061	0.100
148	08LD001	44	-317	-3.22	0.001	0.001
149	08LG016	31	14	0.22	0.413	0.408
150	08MA002	35	69	0.97	0.167	0.209

Table A-4 (continued). Estimated statistics for timing of winter 7-day low-flow.

No. (1)	Station ID (2)	Record Length(year) (3)	MK S statistic (4)	Z (5)	P (6)	P* (7)
151	08MB006	29	137	2.55	0.005	0.006
152	08MG005	74	124	0.57	0.283	0.287
153	08MH006	43	-94	-0.99	0.160	0.139
154	08MH016	45	-295	-2.88	0.002	0.011
155	08NB005	56	-238	-1.68	0.047	0.017
156	08NC004	31	-39	-0.68	0.248	0.259
157	08ND013	38	-73	-0.93	0.176	-0.886
158	08NE006	33	17	0.25	0.402	0.373
159	08NE077	53	-332	-2.54	0.006	0.013
160	08NF001	43	171	1.78	0.038	0.024
161	08NH005	39	77	0.92	0.179	0.177
162	08NH016	24	-18	-0.47	0.319	0.363
163	08NH084	33	46	0.70	0.243	0.251
164	08NH115	39	-92	-1.13	0.130	0.215
165	08NH130	30	-42	-0.77	0.221	0.223
166	08NH131	30	-11	-0.21	0.415	0.419
167	08NJ130	37	-94	-1.24	0.107	0.200
168	08NL007	59	-116	-0.75	0.226	0.243
169	08NL070	29	-46	-0.88	0.189	0.261
170	08NM174	33	-91	-1.43	0.077	0.075
171	08NN015	38	53	0.65	0.257	0.236
172	08OA002	31	182	3.08	0.001	0.008
173	09AA006	51	-408	-3.31	0.000	0.001
174	09AC001	54	-27	-0.19	0.423	0.427
175	09AE003	40	-55	-0.65	0.257	0.249
176	09BA001	38	10	0.11	0.455	0.464
177	09BC001	44	160	1.61	0.054	0.117
178	09FC001	24	79	1.93	0.027	0.030
179	10AB001	39	-38	-0.45	0.327	0.316
180	10BE004	37	16	0.20	0.422	0.414
181	10BE007	29	58	1.07	0.142	0.148
182	10CB001	39	-15	-0.19	0.423	0.428
183	10CD001	39	-16	-0.21	0.419	0.422
184	10EB001	31	131	2.21	0.014	0.012
185	10FA002	33	95	1.46	0.073	0.071
186	10GA001	21	-55	-1.69	0.045	0.043
187	10GB006	21	6	0.15	0.440	0.454
188	10LA002	27	47	0.96	0.169	0.077
189	10MC002	26	35	0.75	0.227	0.172
190	10NC001	27	-69	-1.42	0.078	0.078
191	10PB001	36	13	0.16	0.435	0.471
192	10RC001	35	-134	-1.89	0.029	0.036

Table A-5. Autocorrelations in the quantity of 7-day low-flow time series.

No. (1)	Province/Territory (2)	Station ID (3)	Autocorrelation (4)	Sig/Insig. (5)	Lower Limit (6)	Upper limit (7)
1	ME	01AD002	0.069	TRUE	-0.201	0.174
2	NB	01AD003	-0.030	TRUE	-0.250	0.210
3	NB	01AJ004	-0.261	TRUE	-0.303	0.245
4	NB	01AJ010	-0.033	TRUE	-0.335	0.266
5	NB	01AK001	-0.045	TRUE	-0.229	0.195
6	NB	01AP002	-0.046	TRUE	-0.282	0.232
7	NB	01AP004	0.037	TRUE	-0.282	0.232
8	NB	01AQ001	0.170	FALSE	-0.192	0.167
9	NB	01BC001	-0.153	TRUE	-0.282	0.232
10	NB	01BE001	0.050	TRUE	-0.229	0.195
11	QC	01BH005	0.108	TRUE	-0.329	0.262
12	NB	01BJ003	0.046	TRUE	-0.290	0.237
13	NB	01BL002	0.210	TRUE	-0.312	0.252
14	NB	01BO001	0.115	TRUE	-0.278	0.229
15	NB	01BP001	0.030	TRUE	-0.248	0.208
16	NB	01BQ001	0.121	TRUE	-0.278	0.229
17	NB	01BS001	0.023	TRUE	-0.290	0.237
18	NB	01BU002	0.231	FALSE	-0.278	0.229
19	NB	01BV006	0.123	TRUE	-0.290	0.237
20	PE	01CA003	0.114	TRUE	-0.282	0.232
21	PE	01CB004	0.117	TRUE	-0.329	0.262
22	NS	01DG003	-0.069	TRUE	-0.195	0.170
23	NS	01DL001	0.056	TRUE	-0.329	0.262
24	NS	01DP004	-0.169	TRUE	-0.303	0.245
25	NS	01EC001	-0.201	TRUE	-0.205	0.178
26	NS	01ED005	-0.168	TRUE	-0.323	0.258
27	NS	01ED007	-0.007	TRUE	-0.312	0.252
28	NS	01EF001	-0.133	TRUE	-0.188	0.165
29	NS	01EG002	-0.344	FALSE	-0.329	0.262
30	NS	01EO001	-0.136	TRUE	-0.188	0.165
31	NS	01FA001	-0.083	TRUE	-0.298	0.243
32	NS	01FB001	0.033	TRUE	-0.195	0.170
33	NS	01FB003	-0.062	TRUE	-0.192	0.167
34	MN	02AA001	0.223	FALSE	-0.202	0.175
35	ON	02AB008	0.207	TRUE	-0.253	0.212
36	ON	02BF002	0.206	TRUE	-0.303	0.245
37	ON	02CF008	-0.188	TRUE	-0.355	0.278
38	ON	02EA005	0.177	FALSE	-0.187	0.164
39	ON	02EC002	0.290	FALSE	-0.187	0.164
40	ON	02FB007	0.470	FALSE	-0.271	0.225
41	ON	02FC001	-0.093	TRUE	-0.186	0.163
42	ON	02GA010	0.335	FALSE	-0.229	0.195
43	ON	02HL004	0.231	FALSE	-0.259	0.216
44	ON	02JC008	0.100	TRUE	-0.317	0.255
45	ON	02KB001	0.181	FALSE	-0.187	0.164
46	ON	02LB007	-0.064	TRUE	-0.243	0.205
47	QC	02LG005	-0.216	TRUE	-0.370	0.287
48	QC	02LH004	0.014	TRUE	-0.370	0.287
49	QC	02NE011	0.051	TRUE	-0.307	0.249
50	QC	02NF003	0.029	TRUE	-0.234	0.198
51	QC	02OE027	0.246	FALSE	-0.262	0.218
52	QC	02PB006	0.178	TRUE	-0.307	0.249
53	QC	02PJ007	0.350	FALSE	-0.203	0.176

Table A-5 (continued). Autocorrelations in the quantity of 7-day low-flow time series.

No. (1)	Province/ Territory (2)	Station ID (3)	Autocorrelation (4)	Sig/Insig. (5)	Lower Limit (6)	Upper limit (7)
54	QC	02QA002	0.182	TRUE	-0.294	0.240
55	QC	02RD002	0.110	TRUE	-0.290	0.237
56	QC	02RF001	0.159	TRUE	-0.294	0.240
57	QC	02RG005	-0.231	TRUE	-0.388	0.297
58	QC	02UC002	0.170	TRUE	-0.329	0.262
59	QC	02VC001	0.259	FALSE	-0.271	0.225
60	NF	02YA001	0.230	TRUE	-0.355	0.278
61	NF	02YC001	0.320	FALSE	-0.275	0.227
62	NF	02YJ001	0.220	TRUE	-0.312	0.252
63	NF	02YL001	-0.043	TRUE	-0.259	0.216
64	NF	02YQ001	-0.032	TRUE	-0.245	0.207
65	NF	02YR001	0.186	TRUE	-0.275	0.227
66	NF	02YS003	0.354	FALSE	-0.307	0.249
67	NF	02ZB001	0.009	TRUE	-0.286	0.234
68	NF	02ZF001	0.203	TRUE	-0.259	0.216
69	NF	02ZG001	0.182	TRUE	-0.271	0.225
70	NF	02ZH001	0.127	TRUE	-0.253	0.212
71	NF	02ZK001	0.091	TRUE	-0.262	0.218
72	NF	02ZM006	0.107	TRUE	-0.256	0.214
73	QC	03FA003	0.227	TRUE	-0.446	0.328
74	QC	03KC004	0.506	FALSE	-0.303	0.245
75	QC	03MB002	-0.069	TRUE	-0.370	0.287
76	NF	03NF001	0.141	TRUE	-0.379	0.292
77	NF	03NG001	0.227	TRUE	-0.446	0.328
78	NF	03QC001	0.506	FALSE	-0.303	0.245
79	NF	03QC002	-0.069	TRUE	-0.370	0.287
80	MB	04AD002	0.207	TRUE	-0.271	0.225
81	ON	04DA001	0.293	FALSE	-0.298	0.243
82	ON	04GA002	0.105	TRUE	-0.335	0.266
83	ON	04GB004	0.105	TRUE	-0.335	0.266
84	ON	04JC002	0.039	TRUE	-0.245	0.207
85	ON	04KA001	-0.073	TRUE	-0.312	0.252
86	ON	04LJ001	-0.018	TRUE	-0.193	0.168
87	ON	04MF001	0.124	TRUE	-0.298	0.243
88	QC	04NA001	0.101	TRUE	-0.220	0.188
89	AB	05AA008	0.213	TRUE	-0.294	0.240
90	AB	05AA023	0.365	FALSE	-0.243	0.205
91	AB	05AD003	0.147	TRUE	-0.238	0.202
92	AB	05AD005	0.155	TRUE	-0.182	0.161
93	AB	05BA002	0.090	TRUE	-0.432	0.321
94	AB	05BB001	0.310	FALSE	-0.182	0.161
95	AB	05BL022	0.159	TRUE	-0.323	0.258
96	AB	05DA007	-0.080	TRUE	-0.298	0.243
97	AB	05DA009	0.016	TRUE	-0.317	0.255
98	AB	05DA010	0.252	TRUE	-0.341	0.270
99	AB	05DE007	-0.048	TRUE	-0.323	0.258
100	AB	05FB002	-0.052	TRUE	-0.290	0.237
101	MB	05LD001	0.073	TRUE	-0.262	0.218
102	SK	05LD003	0.004	TRUE	-0.388	0.297
103	MB	05LG004	0.181	TRUE	-0.303	0.245
104	MB	05LH00	0.325	FALSE	-0.268	0.222
105	MB	05LJ005	0.493	FALSE	-0.259	0.216
106	ON	05PB014	0.342	FALSE	-0.194	0.169

Table A-5 (continued). Autocorrelations in the quantity of 7-day low-flow time series.

No. (1)	Province/ Territory (2)	Station ID (3)	Autocorrelation (4)	Sig/Insig (5)	Lower Limit (6)	Upper limit (7)
107	MB	05SA002	0.109	TRUE	-0.265	0.220
108	MB	05TD001	0.460	FALSE	-0.323	0.258
109	MB	05TG002	0.331	FALSE	-0.329	0.262
110	MB	05UH002	0.194	TRUE	-0.348	0.274
111	AB	06AB002	0.539	FALSE	-0.307	0.249
112	SK	06BD001	0.295	FALSE	-0.323	0.258
113	SK	06CD002	0.698	FALSE	-0.290	0.237
114	SK	06DA004	0.573	FALSE	-0.317	0.255
115	MB	06FB002	0.080	TRUE	-0.335	0.266
116	MB	06GD001	0.132	TRUE	-0.256	0.214
117	NU	06JB001	0.411	FALSE	-0.432	0.321
118	NU	06KC003	0.739	FALSE	-0.355	0.278
119	NU	06LA001	0.536	FALSE	-0.323	0.258
120	NU	06LC001	0.269	FALSE	-0.329	0.262
121	AB	07AA001	0.382	FALSE	-0.348	0.274
122	AB	07AA002	0.132	TRUE	-0.317	0.255
123	AB	07AH002	0.252	TRUE	-0.348	0.274
124	AB	07CD001	0.239	FALSE	-0.265	0.220
125	AB	07DD002	0.497	FALSE	-0.317	0.255
126	BC	07EA002	-0.256	TRUE	-0.420	0.315
127	BC	07FC002	-0.402	FALSE	-0.348	0.274
128	BC	07EE009	0.206	TRUE	-0.348	0.274
129	BC	07FB001	-0.022	TRUE	-0.290	0.237
130	BC	07FC003	0.571	FALSE	-0.323	0.258
131	AB	07GG001	0.434	FALSE	-0.317	0.255
132	AB	07JC001	0.230	TRUE	-0.348	0.274
133	AB	07KE001	0.152	TRUE	-0.303	0.245
134	SK	07LE002	0.331	FALSE	-0.307	0.249
135	NT	07OB001	0.383	FALSE	-0.286	0.234
136	AB	07OB003	0.054	TRUE	-0.341	0.270
137	NT	07RD001	0.416	FALSE	-0.307	0.249
138	BC	08CC001	0.022	TRUE	-0.323	0.258
139	BC	08CD001	0.251	FALSE	-0.298	0.243
140	BC	08CE001	-0.103	TRUE	-0.290	0.237
141	BC	08CG001	0.128	TRUE	-0.290	0.237
142	BC	08DA005	0.373	FALSE	-0.317	0.255
143	BC	08DC006	0.414	FALSE	-0.323	0.258
144	BC	08DD001	0.195	TRUE	-0.341	0.270
145	BC	08ED001	0.201	TRUE	-0.329	0.262
146	BC	08FA002	-0.128	TRUE	-0.294	0.240
147	BC	08FB006	-0.053	TRUE	-0.329	0.262
148	BC	08FB007	0.157	TRUE	-0.329	0.262
149	BC	08GA010	0.322	FALSE	-0.188	0.165
150	BC	08GA061	0.081	TRUE	-0.335	0.266
151	BC	08GD004	0.157	TRUE	-0.329	0.262
152	BC	08HA001	-0.050	TRUE	-0.341	0.270
153	BC	08HA003	0.099	TRUE	-0.271	0.225
154	BC	08HB002	0.495	FALSE	-0.379	0.292
155	BC	08HB008	0.319	FALSE	-0.223	0.191
156	BC	08HB025	-0.597	FALSE	-0.477	0.344
157	BC	08HC002	0.010	TRUE	-0.432	0.321
158	BC	08HF004	0.249	FALS	-0.298	0.243
159	BC	08JB002	0.210	TRUE	-0.355	0.278

Table A-5 (continued). Autocorrelations in the quantity of 7-day low-flow time series.

No. (1)	Province/ Territory (2)	Station ID (3)	Autocorrelation (4)	Sig/Insig. (5)	Lower Limit (6)	Upper limit (7)
160	BC	08JB002	0.159	TRUE	-0.245	0.207
161	BC	08JE001	-0.001	TRUE	-0.245	0.207
162	BC	08KA009	-0.077	TRUE	-0.323	0.258
163	BC	08KH006	0.105	TRUE	-0.234	0.198
164	BC	08LA001	0.074	TRUE	-0.245	0.207
165	BC	08LD001	0.066	TRUE	-0.271	0.225
166	BC	08LG016	0.270	FALSE	-0.329	0.262
167	BC	08MA002	-0.044	TRUE	-0.307	0.249
168	BC	08MB006	0.195	TRUE	-0.341	0.270
169	BC	08MG005	0.263	FALSE	-0.205	0.178
170	BC	08MH006	-0.066	TRUE	-0.275	0.227
171	BC	08MH016	0.151	TRUE	-0.268	0.222
172	BC	08NB005	0.114	TRUE	-0.238	0.202
173	BC	08NC004	0.384	FALSE	-0.329	0.262
174	BC	08ND013	-0.256	TRUE	-0.290	0.237
175	BC	08NE001	-0.010	TRUE	-0.271	0.225
176	BC	08NE006	0.025	TRUE	-0.317	0.255
177	BC	08NE077	0.132	TRUE	-0.245	0.207
178	BC	08NE087	0.497	FALSE	-0.290	0.237
179	BC	08NF001	-0.041	TRUE	-0.275	0.227
180	BC	08NH005	0.352	FALSE	-0.290	0.237
181	BC	08NH016	0.152	TRUE	-0.379	0.292
182	BC	08NH084	0.206	TRUE	-0.317	0.255
183	BC	08NH115	0.507	FALSE	-0.290	0.237
184	BC	08NH130	0.076	TRUE	-0.335	0.266
185	BC	08NH131	-0.167	TRUE	-0.335	0.266
186	BC	08NJ130	0.421	FALSE	-0.298	0.243
187	BC	08NL007	0.337	FALSE	-0.231	0.197
188	BC	08NL070	0.126	TRUE	-0.341	0.270
189	BC	08NM174	0.119	TRUE	-0.317	0.255
190	BC	08NN015	0.101	TRUE	-0.294	0.240
191	BC	08OA002	0.106	TRUE	-0.329	0.262
192	BC	09AA006	0.325	FALSE	-0.250	0.210
193	YT	09AA015	0.019	TRUE	-0.335	0.266
194	YT	09AC001	0.140	TRUE	-0.243	0.205
195	BC	09AE003	0.101	TRUE	-0.286	0.234
196	YT	09BA001	0.077	TRUE	-0.290	0.237
197	YT	09BC001	0.236	FALSE	-0.271	0.225
198	YT	09FC001	0.211	TRUE	-0.379	0.292
199	YT	10AB001	0.360	FALSE	-0.290	0.237
200	BC	10AC004	0.121	TRUE	-0.329	0.262
201	BC	10BE004	0.288	FALSE	-0.298	0.243
202	BC	10BE007	0.363	FALSE	-0.341	0.270
203	BC	10CB001	0.360	FALSE	-0.290	0.237
204	BC	10CD001	0.393	FALSE	-0.290	0.237
205	NT	10EB001	0.658	FALSE	-0.329	0.262
206	NT	10FA002	0.593	FALSE	-0.312	0.252
207	NT	10GA001	0.538	FALSE	-0.409	0.309
208	NT	10GB006	0.524	FALSE	-0.409	0.309
209	NT	10LA002	0.586	FALSE	-0.317	0.255
210	NT	10MC002	0.413	FALSE	-0.362	0.282
211	NT	10NC001	0.404	FALSE	-0.355	0.278
212	NU	10PB001	0.454	FALSE	-0.329	0.262

Table A-6. Serial correlation estimations for 14-day low-flow time series.

No. (1)	Province/Territory (2)	Station ID (3)	Autocorrelation (4)	Sig/Insig. (5)	Lower Limit (6)	Upper limit (7)
1	ME	01AD002	0.074	TRUE	-0.201	0.174
2	NB	01AD003	-0.052	TRUE	-0.250	0.210
3	NB	01AJ004	-0.261	TRUE	-0.303	0.245
4	NB	01AJ010	-0.099	TRUE	-0.335	0.266
5	NB	01AK001	-0.062	TRUE	-0.229	0.195
6	NB	01AP002	-0.112	TRUE	-0.282	0.232
7	NB	01AP004	0.076	TRUE	-0.282	0.232
8	NB	01AQ001	0.075	TRUE	-0.192	0.167
9	NB	01BC001	-0.175	TRUE	-0.282	0.232
10	NB	01BE001	0.044	TRUE	-0.229	0.195
11	QC	01BH005	0.067	TRUE	-0.329	0.262
12	NB	01BJ003	0.030	TRUE	-0.290	0.237
13	NB	01BL002	0.172	TRUE	-0.312	0.252
14	NB	01BO001	0.055	TRUE	-0.278	0.229
15	NB	01BP001	0.087	TRUE	-0.248	0.208
16	NB	01BQ001	0.003	TRUE	-0.278	0.229
17	NB	01BS001	-0.012	TRUE	-0.290	0.237
18	NB	01BU002	0.114	TRUE	-0.278	0.229
19	NB	01BV006	0.112	TRUE	-0.290	0.237
20	PE	01CA003	0.089	TRUE	-0.282	0.232
21	PE	01CB004	0.142	TRUE	-0.329	0.262
22	NS	01DG003	-0.165	TRUE	-0.195	0.170
23	NS	01DL001	0.043	TRUE	-0.329	0.262
24	NS	01DP004	-0.218	TRUE	-0.303	0.245
25	NS	01EC001	-0.222	FALSE	-0.205	0.178
26	NS	01ED005	-0.199	TRUE	-0.323	0.258
27	NS	01ED007	-0.030	TRUE	-0.312	0.252
28	NS	01EF001	-0.107	TRUE	-0.188	0.165
29	NS	01EG002	-0.340	FALSE	-0.329	0.262
30	NS	01EO001	-0.185	TRUE	-0.188	0.165
31	NS	01FA001	-0.151	TRUE	-0.298	0.243
32	NS	01FB001	-0.030	TRUE	-0.195	0.170
33	NS	01FB003	-0.068	TRUE	-0.192	0.167
34	MN	02AA001	0.230	FALSE	-0.202	0.175
35	ON	02AB008	0.162	TRUE	-0.253	0.212
36	ON	02BF002	0.233	TRUE	-0.303	0.245
37	ON	02CF008	-0.174	TRUE	-0.355	0.278
38	ON	02EA005	0.168	FALSE	-0.187	0.164
39	ON	02EC002	0.232	FALSE	-0.187	0.164
40	ON	02FB007	0.416	FALSE	-0.271	0.225
41	ON	02FC001	-0.098	TRUE	-0.186	0.163
42	ON	02GA010	0.346	FALSE	-0.229	0.195
43	ON	02HL004	0.184	TRUE	-0.259	0.216
44	ON	02JC008	0.025	TRUE	-0.317	0.255
45	ON	02KB001	0.196	FALSE	-0.187	0.164
46	ON	02LB007	-0.063	TRUE	-0.243	0.205
47	QC	02LG005	-0.145	TRUE	-0.370	0.287
48	QC	02LH004	-0.025	TRUE	-0.370	0.287
49	QC	02NE011	-0.006	TRUE	-0.307	0.249
50	QC	02NF003	0.082	TRUE	-0.234	0.198
51	QC	02OE02	0.079	TRUE	-0.262	0.218
52	QC	02PB00	0.162	TRUE	-0.307	0.249
53	QC	02PJ007	0.188	FALSE	-0.203	0.176

Table A-6 (continued). Serial correlation estimations for 14-day low-flow time series.

No. (1)	Province/ Territory (2)	Station ID (3)	Autocorrelation (4)	Sig/Insig. (5)	Lower Limit (6)	Upper limit (7)
54	QC	02QA002	0.167	TRUE	-0.294	0.240
55	QC	02RD002	0.231	TRUE	-0.290	0.237
56	QC	02RF001	0.346	FALSE	-0.294	0.240
57	QC	02RG005	-0.215	TRUE	-0.388	0.297
58	QC	02UC002	0.163	TRUE	-0.329	0.262
59	QC	02VC001	0.227	FALSE	-0.271	0.225
60	NF	02YA001	0.200	TRUE	-0.355	0.278
61	NF	02YC001	0.283	FALSE	-0.275	0.227
62	NF	02YJ001	0.198	TRUE	-0.312	0.252
63	NF	02YL001	0.052	TRUE	-0.259	0.216
64	NF	02YQ001	0.005	TRUE	-0.248	0.208
65	NF	02YR001	0.178	TRUE	-0.275	0.227
66	NF	02YS003	0.283	FALSE	-0.307	0.249
67	NF	02ZB001	0.067	TRUE	-0.286	0.234
68	NF	02ZF001	0.189	TRUE	-0.259	0.216
69	NF	02ZG001	0.169	TRUE	-0.271	0.225
70	NF	02ZH001	0.068	TRUE	-0.253	0.212
71	NF	02ZK001	0.050	TRUE	-0.262	0.218
72	NF	02ZM006	0.095	TRUE	-0.256	0.214
73	QC	03FA003	0.285	TRUE	-0.420	0.315
74	QC	03KC004	-0.006	TRUE	-0.461	0.336
75	QC	03MB002	0.061	TRUE	-0.303	0.245
76	NF	03NF001	0.163	TRUE	-0.379	0.292
77	NF	03NG001	0.231	TRUE	-0.446	0.328
78	NF	03QC001	0.497	FALSE	-0.303	0.245
79	NF	03QC002	-0.058	TRUE	-0.370	0.287
80	MB	04AD002	0.210	TRUE	-0.271	0.225
81	ON	04DA001	0.278	FALSE	-0.298	0.243
82	ON	04GA002	0.099	TRUE	-0.335	0.266
83	ON	04GB004	0.108	TRUE	-0.335	0.266
84	ON	04JC002	0.040	TRUE	-0.245	0.207
85	ON	04KA001	-0.082	TRUE	-0.312	0.252
86	ON	04LJ001	-0.004	TRUE	-0.193	0.168
87	ON	04MF001	0.098	TRUE	-0.298	0.243
88	QC	04NA001	0.119	TRUE	-0.220	0.188
89	AB	05AA008	0.189	TRUE	-0.294	0.240
90	AB	05AA023	0.234	FALSE	-0.243	0.205
91	AB	05AD003	0.166	TRUE	-0.240	0.203
92	AB	05AD005	0.112	TRUE	-0.182	0.161
93	AB	05BA002	-0.028	TRUE	-0.432	0.321
94	AB	05BB001	0.263	FALSE	-0.182	0.161
95	AB	05BL022	0.219	TRUE	-0.323	0.258
96	AB	05DA007	-0.096	TRUE	-0.298	0.243
97	AB	05DA009	-0.102	TRUE	-0.317	0.255
98	AB	05DA010	0.199	TRUE	-0.341	0.270
99	AB	05DE007	-0.162	TRUE	-0.323	0.258
100	AB	05FB002	0.048	TRUE	-0.290	0.237
101	MB	05LD001	0.176	TRUE	-0.262	0.218
102	SK	05LD003	-0.058	TRUE	-0.388	0.297
103	MB	05LG004	0.231	TRUE	-0.303	0.245
104	MB	05LH005	0.340	FALSE	-0.268	0.222
105	MB	05LJ005	0.422	FALSE	-0.259	0.216
106	ON	05PB014	0.326	FALSE	-0.195	0.170

Table A-6 (continued). Serial correlation estimations for 14-day low-flow time series.

No. (1)	Province/Territory (2)	Station ID (3)	Autocorrelation (4)	Sig/Insig. (5)	Lower Limit (6)	Upper limit (7)
107	MB	05SA002	0.169	TRUE	-0.265	0.220
108	MB	05TG002	0.272	FALSE	-0.329	0.262
109	MB	05UH002	0.197	TRUE	-0.348	0.274
110	AB	06AB002	0.540	FALSE	-0.307	0.249
111	SK	06BD001	0.269	FALSE	-0.323	0.258
112	SK	06CD002	0.703	FALSE	-0.290	0.237
113	SK	06DA004	0.550	FALSE	-0.317	0.255
114	MB	06FB002	0.064	TRUE	-0.335	0.266
115	MB	06GD001	0.130	TRUE	-0.256	0.214
116	NU	06JB001	0.382	FALSE	-0.432	0.321
117	NU	06KC003	0.735	FALSE	-0.355	0.278
118	NU	06LA001	0.527	FALSE	-0.323	0.258
119	NU	06LC001	0.221	TRUE	-0.329	0.262
120	AB	07AA001	0.351	FALSE	-0.348	0.274
121	AB	07AA002	0.084	TRUE	-0.317	0.255
122	AB	07AH002	0.219	TRUE	-0.348	0.274
123	AB	07CD001	0.267	FALSE	-0.265	0.220
124	AB	07DD002	0.511	FALSE	-0.317	0.255
125	BC	07EA002	-0.282	TRUE	-0.420	0.315
126	BC	07EC002	-0.403	FALSE	-0.348	0.274
127	BC	07EE009	0.232	TRUE	-0.348	0.274
128	BC	07FB001	-0.088	TRUE	-0.290	0.237
129	BC	07FC003	0.470	FALSE	-0.323	0.258
130	AB	07GG001	0.416	FALSE	-0.317	0.255
131	AB	07JC001	0.115	TRUE	-0.348	0.274
132	AB	07KE001	0.150	TRUE	-0.303	0.245
133	SK	07LE002	0.323	FALSE	-0.307	0.249
134	NT	07OB001	0.382	FALSE	-0.286	0.234
135	AB	07OB003	0.053	TRUE	-0.341	0.270
136	NT	07RD001	0.411	FALSE	-0.307	0.249
137	BC	08CC001	0.024	TRUE	-0.323	0.258
138	BC	08CD001	0.279	FALSE	-0.298	0.243
139	BC	08CE001	-0.086	TRUE	-0.290	0.237
140	BC	08CG001	0.097	TRUE	-0.290	0.237
141	BC	08DA005	0.355	FALSE	-0.317	0.255
142	BC	08DC006	0.321	FALSE	-0.323	0.258
143	BC	08DD001	0.164	TRUE	-0.341	0.270
144	BC	08ED001	0.173	TRUE	-0.329	0.262
145	BC	08FA002	-0.094	TRUE	-0.294	0.240
146	BC	08FB006	-0.071	TRUE	-0.329	0.262
147	BC	08FB007	0.165	TRUE	-0.329	0.262
148	BC	08GA010	0.317	FALSE	-0.188	0.165
149	BC	08GA061	0.113	TRUE	-0.335	0.266
150	BC	08GD004	0.090	TRUE	-0.329	0.262
151	BC	08HA001	-0.059	TRUE	-0.341	0.270
152	BC	08HA003	0.059	TRUE	-0.271	0.225
153	BC	08HB002	0.446	FALSE	-0.379	0.292
154	BC	08HB008	0.281	FALSE	-0.223	0.191
155	BC	08HB025	-0.601	FALSE	-0.477	0.344
156	BC	08HC002	0.148	TRUE	-0.432	0.321
157	BC	08HE006	0.256	FALSE	-0.298	0.243
158	BC	08HF004	0.195	TRUE	-0.355	0.278
159	BC	08JB002	0.164	TRUE	-0.245	0.207

Table A-6 (continued). Serial correlation estimations for 14-day low-flow time series.

No. (1)	Province/Territory (2)	Station ID (3)	Autocorrelation (4)	Sig/Insig. (5)	Lower Limit (6)	Upper limit (7)
160	BC	08JE001	-0.025	TRUE	-0.245	0.207
161	BC	08KA009	-0.047	TRUE	-0.323	0.258
162	BC	08KH006	0.089	TRUE	-0.234	0.198
163	BC	08LA001	0.080	TRUE	-0.245	0.207
164	BC	08LD001	0.066	TRUE	-0.271	0.225
165	BC	08LG016	0.336	FALSE	-0.329	0.262
166	BC	08MA002	-0.036	TRUE	-0.307	0.249
167	BC	08MB006	0.197	TRUE	-0.341	0.270
168	BC	08MG005	0.265	FALSE	-0.205	0.178
169	BC	08MH006	-0.104	TRUE	-0.275	0.227
170	BC	08MH016	0.134	TRUE	-0.268	0.222
171	BC	08NB005	0.107	TRUE	-0.238	0.202
172	BC	08NC004	0.366	FALSE	-0.329	0.262
173	BC	08ND013	-0.316	FALSE	-0.290	0.237
174	BC	08NE001	-0.021	TRUE	-0.275	0.227
175	BC	08NE006	0.094	TRUE	-0.317	0.255
176	BC	08NE077	0.108	TRUE	-0.245	0.207
177	BC	08NE087	0.515	FALSE	-0.290	0.237
178	BC	08NF001	-0.085	TRUE	-0.275	0.227
179	BC	08NH005	0.304	FALSE	-0.290	0.237
180	BC	08NH016	0.242	TRUE	-0.379	0.292
181	BC	08NH084	0.283	FALSE	-0.317	0.255
182	BC	08NH115	0.522	FALSE	-0.290	0.237
183	BC	08NH130	0.093	TRUE	-0.335	0.266
184	BC	08NH131	-0.190	TRUE	-0.335	0.266
185	BC	08NJ130	0.399	FALSE	-0.298	0.243
186	BC	08NL007	0.364	FALSE	-0.231	0.197
187	BC	08NL070	0.117	TRUE	-0.341	0.270
188	BC	08NM174	0.192	TRUE	-0.317	0.255
189	BC	08NN015	0.115	TRUE	-0.294	0.240
190	BC	08OA002	0.164	TRUE	-0.329	0.262
191	BC	09AA006	0.329	FALSE	-0.250	0.210
192	YT	09AA015	0.020	TRUE	-0.335	0.266
193	YT	09AC001	0.151	TRUE	-0.243	0.205
194	BC	09AE003	0.116	TRUE	-0.286	0.234
195	YT	09BA001	0.066	TRUE	-0.290	0.237
196	YT	09BC001	0.228	FALSE	-0.275	0.227
197	YT	09FC001	0.193	TRUE	-0.379	0.292
198	YT	10AB001	0.361	FALSE	-0.290	0.237
199	BC	10AC004	0.126	TRUE	-0.329	0.262
200	BC	10BE004	0.281	FALSE	-0.298	0.243
201	BC	10BE007	0.366	FALSE	-0.341	0.270
202	BC	10CB001	0.355	FALSE	-0.290	0.237
203	BC	10CD001	0.394	FALSE	-0.290	0.237
204	NT	10EB001	0.659	FALSE	-0.329	0.262
205	NT	10FA002	0.577	FALSE	-0.317	0.255
206	NT	10GA001	0.541	FALSE	-0.409	0.309
207	NT	10GB006	0.525	FALSE	-0.409	0.309
208	NT	10LA002	0.574	FALSE	-0.317	0.255
209	NT	10MC002	0.406	FALSE	-0.362	0.282
210	NT	10NC001	0.390	FALSE	-0.355	0.278
211	NU	10PB001	0.473	FALSE	-0.329	0.262
212	NU	10RC001	0.441	FALSE	-0.303	0.245

Table.A.7. Autocorrelation estimations for 21-day low-flow time series.

No. (1)	Province/Territory (2)	Station ID (3)	Autocorrelation (4)	Sig/Insig. (5)	Lower Limit (6)	Upper limit (7)
1	ME	01AD002	0.0737	TRUE	-0.20061	0.174291
2	NB	01AD003	-0.0521	TRUE	-0.2503	0.2103
3	NB	01AJ004	-0.247	TRUE	-0.30263	0.245483
4	NB	01AJ010	-0.1902	TRUE	-0.33464	0.265673
5	NB	01AK001	-0.062	TRUE	-0.22929	0.195389
6	NB	01AP002	-0.0959	TRUE	-0.28183	0.231826
7	NB	01AP004	0.1027	TRUE	-0.28183	0.231826
8	NB	01AQ001	0.0753	TRUE	-0.19152	0.167423
9	NB	01BC001	-0.2087	TRUE	-0.28183	0.231826
10	NB	01BE001	0.0436	TRUE	-0.22929	0.195389
11	QC	01BH005	0.04	TRUE	-0.32862	0.261953
12	NB	01BJ003	0.0225	TRUE	-0.28964	0.237004
13	NB	01BL002	0.1568	TRUE	-0.31229	0.251683
14	NB	01BO001	0.0117	TRUE	-0.27814	0.229363
15	NB	01BP001	0.0874	TRUE	-0.24768	0.208469
16	NB	01BQ001	-0.0607	TRUE	-0.27814	0.229363
17	NB	01BS001	-0.0053	TRUE	-0.28964	0.237004
18	NB	01BU002	0.1538	TRUE	-0.27814	0.229363
19	NB	01BV006	0.1045	TRUE	-0.28964	0.237004
20	PE	01CA003	0.0912	TRUE	-0.28183	0.231826
21	PE	01CB004	0.0604	TRUE	-0.32862	0.261953
22	NS	01DG003	-0.1937	TRUE	-0.19526	0.170263
23	NS	01DL001	-0.09	TRUE	-0.32862	0.261953
24	NS	01DP004	-0.2368	TRUE	-0.30263	0.245483
25	NS	01EC001	-0.2226	FALSE	-0.20491	0.177511
26	NS	01ED005	-0.227	TRUE	-0.3229	0.258388
27	NS	01ED007	-0.0288	TRUE	-0.31229	0.251683
28	NS	01EF001	-0.1277	TRUE	-0.18798	0.164723
29	NS	01EG002	-0.33	FALSE	-0.32862	0.261953
30	NS	01EO001	-0.1795	TRUE	-0.18798	0.164723
31	NS	01FA001	-0.1677	TRUE	-0.29811	0.242554
32	NS	01FB001	0.0219	TRUE	-0.19526	0.170263
33	NS	01FB003	-0.0615	TRUE	-0.19152	0.167423
34	MN	02AA001	0.248	FALSE	-0.20201	0.175344
35	ON	02AB008	0.1362	TRUE	-0.253	0.212182
36	ON	02BF002	0.2756	FALSE	-0.30263	0.245483
37	ON	02CF008	-0.104	TRUE	-0.35481	0.277885
38	ON	02EA005	0.1506	TRUE	-0.18684	0.163852
39	ON	02EC002	0.2069	FALSE	-0.18684	0.163852
40	ON	02FB007	0.3807	FALSE	-0.27118	0.22467
41	ON	02FC001	-0.0616	TRUE	-0.18572	0.162995
42	ON	02GA010	0.3625	FALSE	-0.22929	0.195389
43	ON	02HL004	0.1696	TRUE	-0.25866	0.216105
44	ON	02JC008	-0.0931	TRUE	-0.31747	0.254968
45	ON	02KB001	0.1868	FALSE	-0.18684	0.163852
46	ON	02LB007	-0.0711	TRUE	-0.24268	0.204948
47	QC	02LG005	-0.0653	TRUE	-0.37038	0.287048
48	QC	02LH004	-0.0609	TRUE	-0.37038	0.287048
49	QC	02NE011	-0.1203	TRUE	-0.30735	0.248524
50	QC	02NF003	0.0739	TRUE	-0.23351	0.198422
51	QC	02OE027	0.0409	TRUE	-0.26163	0.218152
52	QC	02PB006	0.1954	TRUE	-0.30735	0.248524
53	QC	02PJ007	0.2239	FALSE	-0.20344	0.176417

Table A.7 (continued). Autocorrelation estimations for 21-day low-flow time series.

No. (1)	Province/Territory (2)	Station ID (3)	Autocorrelation (4)	Sig/Insig. (5)	Lower Limit (6)	Upper limit (7)
54	OC	02QA002	0.0781	TRUE	-0.29378	0.23973
55	OC	02RD002	0.1163	TRUE	-0.28964	0.237004
56	OC	02RF001	0.3424	FALSE	-0.29378	0.23973
57	OC	02RG005	-0.1693	TRUE	-0.38811	0.297197
58	OC	02UC002	0.1452	TRUE	-0.32862	0.261953
59	OC	02VC001	0.1765	TRUE	-0.27118	0.22467
60	NE	02YA001	0.1718	TRUE	-0.35481	0.277885
61	NE	02YC001	0.2483	FALSE	-0.2746	0.22698
62	NE	02YI001	0.1653	TRUE	-0.31229	0.251683
63	NE	02YL001	0.0463	TRUE	-0.25866	0.216105
64	NE	02YO001	0.0143	TRUE	-0.24768	0.208469
65	NE	02YR001	0.1583	TRUE	-0.2746	0.22698
66	NE	02YS003	0.1802	TRUE	-0.30735	0.248524
67	NE	02ZB001	0.1464	TRUE	-0.28565	0.234371
68	NE	02ZF001	0.1739	TRUE	-0.25866	0.216105
69	NE	02ZG001	0.1806	TRUE	-0.27118	0.22467
70	NE	02ZH001	0.0778	TRUE	-0.253	0.212182
71	NE	02ZK001	0.0544	TRUE	-0.26163	0.218152
72	NE	02ZM006	0.1188	TRUE	-0.25578	0.214116
73	OC	03FA003	0.2676	TRUE	-0.41995	0.314692
74	OC	03KC004	0.0071	TRUE	-0.46069	0.335691
75	OC	03MB002	0.0529	TRUE	-0.30263	0.245483
76	NE	03NF001	0.1878	TRUE	-0.37894	0.291988
77	NE	03NG001	0.2333	TRUE	-0.44588	0.328235
78	NE	03OC001	0.4893	FALSE	-0.30263	0.245483
79	NE	03OC002	-0.0482	TRUE	-0.37038	0.287048
80	MB	04AD002	0.2207	TRUE	-0.27118	0.22467
81	ON	04DA001	0.2551	FALSE	-0.29811	0.242554
82	ON	04GA002	0.1009	TRUE	-0.33464	0.265673
83	ON	04GB004	0.1097	TRUE	-0.33464	0.265673
84	ON	04JC002	0.0481	TRUE	-0.24515	0.206686
85	ON	04KA001	-0.0967	TRUE	-0.31229	0.251683
86	ON	04LJ001	0.0197	TRUE	-0.19274	0.168354
87	ON	04MF001	0.0798	TRUE	-0.29811	0.242554
88	OC	04NA001	0.1089	TRUE	-0.21964	0.188387
89	AB	05AA008	0.1393	TRUE	-0.29378	0.23973
90	AB	05AA023	0.1858	TRUE	-0.24268	0.204948
91	AB	05AD003	0.1342	TRUE	-0.24029	0.203255
92	AB	05AD005	0.1224	TRUE	-0.18248	0.160504
93	AB	05BA002	-0.068	TRUE	-0.43236	0.32125
94	AB	05BB001	0.2476	FALSE	-0.18248	0.160504
95	AB	05BL022	0.247	TRUE	-0.3229	0.258388
96	AB	05DA007	-0.0732	TRUE	-0.29811	0.242554
97	AB	05DA009	-0.0416	TRUE	-0.31747	0.254968
98	AB	05DA010	0.3554	FALSE	-0.34099	0.26956
99	AB	05DE007	-0.1817	TRUE	-0.3229	0.258388
100	AB	05FB002	0.2585	FALSE	-0.28964	0.237004
101	MB	05LD001	0.1676	TRUE	-0.26163	0.218152
102	SK	05LD003	-0.0891	TRUE	-0.38811	0.297197
103	MB	05LG004	0.1881	TRUE	-0.30263	0.245483
104	MB	05LH005	0.3384	FALSE	-0.26789	0.222432
105	MB	05LJ005	0.3987	FALSE	-0.25866	0.216105
106	ON	05PB014	0.3186	FALSE	-0.19526	0.170263

Table A.7 (continued). Autocorrelation estimations for 21-day low-flow time series.

No. (1)	Province/ Territory (2)	Station ID (3)	Autocorrelation (4)	Sig/Insig. (5)	Lower Limit (6)	Upper limit (7)
107	MB	05SA002	0.4329	FALSE	-0.2647	0.22026
108	MB	05TG002	0.2319	TRUE	-0.3477	0.273625
109	MB	05UH002	0.5432	FALSE	-0.30735	0.248524
110	AB	06AB002	0.2683	FALSE	-0.3229	0.258388
111	SK	06BD001	0.7085	FALSE	-0.28964	0.237004
112	SK	06CD002	0.5348	FALSE	-0.31747	0.254968
113	SK	06DA004	0.0532	TRUE	-0.33464	0.265673
114	MB	06FB002	0.1241	TRUE	-0.25578	0.214116
115	MB	06GD001	0.3662	FALSE	-0.43236	0.32125
116	NU	06JB001	0.7287	FALSE	-0.35481	0.277885
117	NU	06KC003	0.5162	FALSE	-0.3229	0.258388
118	NU	06LA001	0.1663	TRUE	-0.32862	0.261953
119	NU	06LC001	0.3684	FALSE	-0.3477	0.273625
120	AB	07AA001	0.1517	TRUE	-0.31747	0.254968
121	AB	07AA002	0.1257	TRUE	-0.3477	0.273625
122	AB	07AH002	0.2509	FALSE	-0.2647	0.22026
123	AB	07CD001	0.5324	FALSE	-0.31747	0.254968
124	AB	07DD002	-0.2922	TRUE	-0.41995	0.314692
125	BC	07EA002	-0.3868	FALSE	-0.3477	0.273625
126	BC	07EC002	0.2201	TRUE	-0.3477	0.273625
127	BC	07EE009	-0.087	TRUE	-0.28964	0.237004
128	BC	07FB001	0.4491	FALSE	-0.3229	0.258388
129	BC	07FC003	0.4006	FALSE	-0.31747	0.254968
130	AB	07GG001	0.1096	TRUE	-0.3477	0.273625
131	AB	07JC001	0.1532	TRUE	-0.30263	0.245483
132	AB	07KE001	0.3138	FALSE	-0.30735	0.248524
133	SK	07LE002	0.3731	FALSE	-0.28565	0.234371
134	NT	07OB001	0.3728	FALSE	-0.28565	0.234371
135	AB	07OB003	0.0509	TRUE	-0.34099	0.26956
136	NT	07RD001	0.412	FALSE	-0.30735	0.248524
137	BC	08CC001	0.008	TRUE	-0.3229	0.258388
138	BC	08CD001	0.779	FALSE	-0.29811	0.242554
139	BC	08CE001	-0.0846	TRUE	-0.28964	0.237004
140	BC	08CG001	0.0753	TRUE	-0.28964	0.237004
141	BC	08DA005	0.3491	FALSE	-0.31747	0.254968
142	BC	08DC006	0.2416	TRUE	-0.3229	0.258388
143	BC	08DD001	0.0718	TRUE	-0.34099	0.26956
144	BC	08ED001	0.1572	TRUE	-0.32862	0.261953
145	BC	08FA002	-0.0511	TRUE	-0.29378	0.23973
146	BC	08FB006	-0.0773	TRUE	-0.32862	0.261953
147	BC	08FB007	0.1795	TRUE	-0.32862	0.261953
148	BC	08GA010	0.2804	FALSE	-0.18798	0.164723
149	BC	08GA061	0.0293	TRUE	-0.33464	0.265673
150	BC	08GD004	0.0652	TRUE	-0.32862	0.261953
151	BC	08HA001	-0.0732	TRUE	-0.34099	0.26956
152	BC	08HA003	-0.0212	TRUE	-0.27118	0.22467
153	BC	08HB002	0.3876	FALSE	-0.37894	0.291988
154	BC	08HB008	0.2439	FALSE	-0.22335	0.191095
155	BC	08HB025	-0.5257	FALSE	-0.477	0.343668
156	BC	08HC002	0.114	TRUE	-0.43236	0.32125
157	BC	08HE006	0.3308	FALSE	-0.29811	0.242554
158	BC	08HF004	0.1689	TRUE	-0.35481	0.277885
159	BC	08JB002	0.1685	TRUE	-0.24515	0.206686

Table A.7 (continued). Autocorrelation estimations for 21-day low-flow time series.

No. (1)	Province/ Territory (2)	Station ID (3)	Autocorrelation (4)	Sig/Insig. (5)	Lower Limit (6)	Upper limit (7)
160	BC	08JE001	-0.0353	TRUE	-0.24515	0.206686
161	BC	08KA009	-0.07	TRUE	-0.3229	0.258388
162	BC	08KH006	0.0705	TRUE	-0.23351	0.198422
163	BC	08LA001	0.0815	TRUE	-0.24515	0.206686
164	BC	08LD001	0.0741	TRUE	-0.27118	0.22467
165	BC	08LG016	0.3301	FALSE	-0.32862	0.261953
166	BC	08MA002	-0.01	TRUE	-0.30735	0.248524
167	BC	08MB006	0.235	TRUE	-0.34099	0.26956
168	BC	08MG005	0.258	FALSE	-0.20491	0.177511
169	BC	08MH006	-0.0842	TRUE	-0.2746	0.22698
170	BC	08MH016	0.091	TRUE	-0.26789	0.222432
171	BC	08NB005	0.0851	TRUE	-0.23797	0.201604
172	BC	08NC004	0.3438	FALSE	-0.32862	0.261953
173	BC	08ND013	-0.3441	FALSE	-0.28964	0.237004
174	BC	08NE001	-0.0032	TRUE	-0.2746	0.22698
175	BC	08NE006	0.0604	TRUE	-0.31747	0.254968
176	BC	08NE077	-0.1236	TRUE	-0.24515	0.206686
177	BC	08NE087	0.5214	FALSE	-0.28964	0.237004
178	BC	08NF001	-0.0808	TRUE	-0.2746	0.22698
179	BC	08NH005	0.2331	TRUE	-0.28964	0.237004
180	BC	08NH016	0.2342	TRUE	-0.37894	0.291988
181	BC	08NH084	0.3243	FALSE	-0.31747	0.254968
182	BC	08NH115	0.5191	FALSE	-0.28964	0.237004
183	BC	08NH130	0.0947	TRUE	-0.33464	0.265673
184	BC	08NH131	-0.1896	TRUE	-0.33464	0.265673
185	BC	08NJ130	0.383	FALSE	-0.29811	0.242554
186	BC	08NL007	0.3958	FALSE	-0.23137	0.196888
187	BC	08NL070	0.1688	TRUE	-0.34099	0.26956
188	BC	08NM174	0.2229	TRUE	-0.31747	0.254968
189	BC	08NN015	0.1233	TRUE	-0.29378	0.23973
190	BC	08OA002	0.203	TRUE	-0.32862	0.261953
191	BC	09AA006	0.3325	FALSE	-0.2503	0.2103
192	YT	09AA015	0.0185	TRUE	-0.33464	0.265673
193	YT	09AC001	0.1487	TRUE	-0.24268	0.204948
194	BC	09AE003	0.1175	TRUE	-0.28565	0.234371
195	YT	09BA001	0.0575	TRUE	-0.28964	0.237004
196	YT	09BC001	0.2311	FALSE	-0.2746	0.22698
197	YT	10AB001	0.3552	FALSE	-0.28964	0.237004
198	BC	10AC004	0.1174	TRUE	-0.32862	0.261953
199	BC	10BE004	0.2694	FALSE	-0.29811	0.242554
200	BC	10BE007	0.3672	FALSE	-0.34099	0.26956
201	BC	10CB001	0.3384	FALSE	-0.28964	0.237004
202	BC	10CD001	0.3879	FALSE	-0.28964	0.237004
203	NT	10EB001	0.625	FALSE	-0.32862	0.261953
204	NT	10FA002	0.56	FALSE	-0.31229	0.251683
205	NT	10GA001	0.5391	FALSE	-0.40852	0.308519
206	NT	10GB006	0.5242	FALSE	-0.40852	0.308519
207	NT	10LA002	0.5593	FALSE	-0.31747	0.254968
208	NT	10MC002	0.3963	FALSE	-0.36235	0.282353
209	NT	10NC001	0.3747	FALSE	-0.35481	0.277885
210	NU	10PB001	0.4838	FALSE	-0.32862	0.261953
211	NU	10RC001	0.4405	FALSE	-0.30263	0.245483
212	SK	11AB117	0.201	TRUE	-0.34099	0.26956

Table A.8. Autocorrelations in 30-day low-flow time series.

No. (1)	Province/Territory (2)	Station ID (3)	Autocorrelation (4)	Sig/Insig. (5)	Lower Limit (6)	Upper limit (7)
1	ME	01AD002	0.067	TRUE	-0.20061	0.174291
2	NB	01AD003	-0.0846	TRUE	-0.2503	0.2103
3	NB	01AJ004	-0.2702	TRUE	-0.30263	0.245483
4	NB	01AJ010	-0.1821	TRUE	-0.33464	0.265673
5	NB	01AK001	-0.065	TRUE	-0.22929	0.195389
6	NB	01AP002	-0.0503	TRUE	-0.28183	0.231826
7	NB	01AP004	0.1138	TRUE	-0.28183	0.231826
8	NB	01AQ001	0.0627	TRUE	-0.19152	0.167423
9	NB	01BC001	-0.2342	TRUE	-0.28183	0.231826
10	NB	01BE001	0.0044	TRUE	-0.22929	0.195389
11	QC	01BH005	0.0186	TRUE	-0.32862	0.261953
12	NB	01BJ003	-0.0153	TRUE	-0.28964	0.237004
13	NB	01BL002	0.0933	TRUE	-0.31229	0.251683
14	NB	01BO001	-0.0018	TRUE	-0.27814	0.229363
15	NB	01BP001	0.0512	TRUE	-0.24768	0.208469
16	NB	01BQ001	-0.0783	TRUE	-0.27814	0.229363
17	NB	01BS001	0.0241	TRUE	-0.28964	0.237004
18	NB	01BU002	0.1167	TRUE	-0.27814	0.229363
19	NB	01BV006	0.071	TRUE	-0.28964	0.237004
20	PE	01CA003	0.0687	TRUE	-0.28183	0.231826
21	PE	01CB004	0.0038	TRUE	-0.32862	0.261953
22	NS	01DG003	-0.145	TRUE	-0.19526	0.170263
23	NS	01DL001	-0.1229	TRUE	-0.32862	0.261953
24	NS	01DP004	-0.1861	TRUE	-0.30263	0.245483
25	NS	01EC001	-0.2363	FALSE	-0.20491	0.177511
26	NS	01ED005	-0.2666	TRUE	-0.3229	0.258388
27	NS	01ED007	-0.0732	TRUE	-0.31229	0.251683
28	NS	01EF001	-0.1542	TRUE	-0.18798	0.164723
29	NS	01EG002	-0.3191	TRUE	-0.32862	0.261953
30	NS	01EO001	-0.1289	TRUE	-0.18798	0.164723
31	NS	01FA001	-0.1761	TRUE	-0.29811	0.242554
32	NS	01FB001	0.0219	TRUE	-0.19526	0.170263
33	NS	01FB003	-0.0541	TRUE	-0.19152	0.167423
34	MN	02AA001	0.2524	FALSE	-0.20201	0.175344
35	ON	02AB008	0.1944	TRUE	-0.253	0.212182
36	ON	02BF002	0.2835	FALSE	-0.30263	0.245483
37	ON	02CF008	-0.0431	TRUE	-0.35481	0.277885
38	ON	02EA005	0.1534	TRUE	-0.18684	0.163852
39	ON	02EC002	0.1544	TRUE	-0.18684	0.163852
40	ON	02FB007	0.3497	FALSE	-0.27118	0.22467
41	ON	02FC001	-0.0327	TRUE	-0.18572	0.162995
42	ON	02GA010	0.3243	FALSE	-0.22929	0.195389
43	ON	02HL004	0.1486	TRUE	-0.25866	0.216105
44	ON	02JC008	-0.1249	TRUE	-0.31747	0.254968
45	ON	02KB001	0.1834	FALSE	-0.18684	0.163852
46	ON	02LB007	-0.0832	TRUE	-0.24268	0.204948
47	QC	02LG005	-0.0468	TRUE	-0.37038	0.287048
48	QC	02LH004	-0.0365	TRUE	-0.37038	0.287048
49	QC	02NE011	-0.1487	TRUE	-0.30735	0.248524
50	QC	02NF003	0.0581	TRUE	-0.23351	0.198422
51	QC	02OE027	-0.1249	TRUE	-0.26163	0.218152
52	QC	02PB006	0.1487	TRUE	-0.30735	0.248524
53	QC	02PJ007	0.1498	TRUE	-0.20344	0.176417

Table A.8 (continued). Autocorrelations in 30-day low-flow time series.

No. (1)	Province/Territory (2)	Station ID (3)	Autocorrelation (4)	Sig/Insig. (5)	Lower Limit (6)	Upper limit (7)
54	QC	02QA002	-0.0518	TRUE	-0.29378	0.23973
55	QC	02RD002	0.0483	TRUE	-0.28964	0.237004
56	QC	02RF001	0.336	FALSE	-0.29378	0.23973
57	QC	02RG005	-0.1581	TRUE	-0.38811	0.297197
58	QC	02UC002	0.1256	TRUE	-0.32862	0.261953
59	QC	02VC001	0.1827	TRUE	-0.27118	0.22467
60	NF	02YC001	0.1662	TRUE	-0.2746	0.22698
61	NF	02YJ001	0.1403	TRUE	-0.31229	0.251683
62	NF	02YL001	0.0141	TRUE	-0.25866	0.216105
63	NF	02YQ001	0.0393	TRUE	-0.24768	0.208469
64	NF	02YR001	0.1549	TRUE	-0.2746	0.22698
65	NF	02YS003	0.0042	TRUE	-0.30735	0.248524
66	NF	02ZB001	0.0843	TRUE	-0.28565	0.234371
67	NF	02ZF001	0.1352	TRUE	-0.25866	0.216105
68	NF	02ZG001	0.1804	TRUE	-0.27118	0.22467
69	NF	02ZH001	0.0186	TRUE	-0.253	0.212182
70	NF	02ZK001	0.103	TRUE	-0.26163	0.218152
71	NF	02ZM006	0.0259	TRUE	-0.25578	0.214116
72	QC	03FA003	0.2459	TRUE	-0.41995	0.314692
73	QC	03KC004	0.0265	TRUE	-0.46069	0.335691
74	QC	03MB002	0.041	TRUE	-0.30263	0.245483
75	NF	03NF001	0.2191	TRUE	-0.37894	0.291988
76	NF	03QC001	0.4808	FALSE	-0.30263	0.245483
77	NF	03QC002	-0.0549	TRUE	-0.37038	0.287048
78	MB	04AD002	0.2061	TRUE	-0.27118	0.22467
79	ON	04DA001	0.2425	TRUE	-0.29811	0.242554
80	ON	04GA002	0.1021	TRUE	-0.33464	0.265673
81	ON	04GB004	0.105	TRUE	-0.33464	0.265673
82	ON	04JC002	0.0464	TRUE	-0.24515	0.206686
83	ON	04KA001	-0.1084	TRUE	-0.31229	0.251683
84	ON	04LJ001	0.0462	TRUE	-0.19274	0.168354
85	ON	04MF001	0.0532	TRUE	-0.29811	0.242554
86	QC	04NA001	0.1078	TRUE	-0.21964	0.188387
87	AB	05AA008	0.1271	TRUE	-0.29378	0.23973
88	AB	05AA023	0.112	TRUE	-0.24268	0.204948
89	AB	05AD003	0.0136	TRUE	-0.23797	0.201604
90	AB	05AD005	0.084	TRUE	-0.18248	0.160504
91	AB	05BA002	-0.048	TRUE	-0.43236	0.32125
92	AB	05BB001	0.2635	FALSE	-0.18248	0.160504
93	AB	05BL022	0.2135	TRUE	-0.3229	0.258388
94	AB	05DA007	-0.0811	TRUE	-0.29811	0.242554
95	AB	05DA009	-0.0461	TRUE	-0.31747	0.254968
96	AB	05DA010	0.4256	FALSE	-0.34099	0.26956
97	AB	05DE007	0.192	TRUE	-0.3229	0.258388
98	AB	05FB002	0.3624	FALSE	-0.28964	0.237004
99	MB	05LD001	0.1191	TRUE	-0.26163	0.218152
100	SK	05LD003	-0.0839	TRUE	-0.38811	0.297197
101	MB	05LG004	0.2814	FALSE	-0.30263	0.245483
102	MB	05LH005	0.3376	FALSE	-0.26789	0.222432
103	MB	05LJ005	0.2739	FALSE	-0.25866	0.216105
104	ON	05PB014	0.3129	FALSE	-0.19399	0.1693
105	MB	05SA002	0.5765	FALSE	-0.2647	0.22026
106	MB	05TD001	0.2013	TRUE	-0.32862	0.261953

Table A.8 (continued). Autocorrelations in 30-day low-flow time series.

No. (1)	Province/ Territory (2)	Station ID (3)	Autocorrelation (4)	Sig/Insig. (5)	Lower Limit (6)	Upper limit (7)
107	MB	05TG002	0.2973	FALSE	-0.3477	0.273625
108	MB	05UH002	0.2973	FALSE	-0.3477	0.273625
109	AB	06AB002	0.5508	FALSE	-0.30735	0.248524
110	SK	06BD001	0.2329	TRUE	-0.3229	0.258388
111	SK	06CD002	0.707	FALSE	-0.28964	0.237004
112	SK	06DA004	0.5253	FALSE	-0.31747	0.254968
113	MB	06FB002	0.0244	TRUE	-0.33464	0.265673
114	MB	06GD001	0.1146	TRUE	-0.25578	0.214116
115	NU	06JB001	0.3295	FALSE	-0.43236	0.32125
116	NU	06KC003	0.7185	FALSE	-0.35481	0.277885
117	NU	06LA001	0.5071	FALSE	-0.3229	0.258388
118	NU	06LC001	0.1069	TRUE	-0.32862	0.261953
119	AB	07AA001	0.3802	FALSE	-0.3477	0.273625
120	AB	07AA002	0.1079	TRUE	-0.31747	0.254968
121	AB	07AH002	0.1173	TRUE	-0.3477	0.273625
122	AB	07CD001	0.1931	TRUE	-0.2647	0.22026
123	AB	07DD002	0.564	FALSE	-0.31747	0.254968
124	BC	07EA002	-0.3198	TRUE	-0.41995	0.314692
125	BC	07EC002	-0.3876	FALSE	-0.3477	0.273625
126	BC	07EE009	0.2417	TRUE	-0.3477	0.273625
127	BC	07FB001	-0.1476	TRUE	-0.28964	0.237004
128	BC	07FC003	0.4234	FALSE	-0.3229	0.258388
129	AB	07GG001	0.4066	FALSE	-0.31747	0.254968
130	AB	07JC001	0.2684	TRUE	-0.3477	0.273625
131	AB	07KE001	0.2946	FALSE	-0.30263	0.245483
132	SK	07LE002	0.3015	FALSE	-0.30735	0.248524
133	NT	07OB001	0.3671	FALSE	-0.28565	0.234371
134	AB	07OB003	0.0506	TRUE	-0.34099	0.26956
135	NT	07RD001	0.4121	FALSE	-0.30735	0.248524
136	BC	08CC001	-0.0155	TRUE	-0.3229	0.258388
137	BC	08CD001	0.2789	FALSE	-0.29811	0.242554
138	BC	08CE001	-0.0559	TRUE	-0.28964	0.237004
139	BC	08CG001	0.1141	TRUE	-0.28964	0.237004
140	BC	08DA005	0.3174	FALSE	-0.31747	0.254968
141	BC	08DC006	0.2026	TRUE	-0.3229	0.258388
142	BC	08DD001	-0.0762	TRUE	-0.34099	0.26956
143	BC	08ED001	0.1511	TRUE	-0.32862	0.261953
144	BC	08FA002	0.0408	TRUE	-0.29378	0.23973
145	BC	08FB006	-0.1066	TRUE	-0.32862	0.261953
146	BC	08FB007	0.1839	TRUE	-0.32862	0.261953
147	BC	08GA010	0.2856	FALSE	-0.18798	0.164723
148	BC	08GA061	0.1543	TRUE	-0.33464	0.265673
149	BC	08GD004	0.0938	TRUE	-0.32862	0.261953
150	BC	08HA001	-0.0677	TRUE	-0.34099	0.26956
151	BC	08HA003	-0.0658	TRUE	-0.27118	0.22467
152	BC	08HB002	0.3911	FALSE	-0.37894	0.291988
153	BC	08HB008	0.2196	FALSE	-0.22335	0.191095
154	BC	08HB025	-0.4134	TRUE	-0.477	0.343668
155	BC	08HC002	0.0392	TRUE	-0.43236	0.32125
156	BC	08HE006	0.369	FALSE	-0.29811	0.242554
157	BC	08HF004	0.1577	TRUE	-0.35481	0.277885
158	BC	08JB00	0.1635	TRUE	-0.24515	0.206686
159	BC	08JE00	-0.0375	TRUE	-0.24515	0.206686

Table A.8 (continued). Autocorrelations in 30-day low-flow time series.

No. (1)	Province/Territory (2)	Station ID (3)	Autocorrelation (4)	Sig/Insig. (5)	Lower Limit (6)	Upper limit (7)
160	BC	08KA009	-0.1018	TRUE	-0.3229	0.258388
161	BC	08KH006	0.034	TRUE	-0.23351	0.198422
162	BC	08LA001	0.0581	TRUE	-0.24515	0.206686
163	BC	08LD001	0.0779	TRUE	-0.27118	0.22467
164	BC	08LG016	0.356	FALSE	-0.32862	0.261953
165	BC	08MA002	-0.0096	TRUE	-0.30735	0.248524
166	BC	08MB006	0.2765	FALSE	-0.34099	0.26956
167	BC	08MG005	0.2083	FALSE	-0.20491	0.177511
168	BC	08MH006	-0.1189	TRUE	-0.2746	0.22698
169	BC	08MH016	0.0614	TRUE	-0.26789	0.222432
170	BC	08NB005	0.0563	TRUE	-0.23797	0.201604
171	BC	08NC004	0.1795	TRUE	-0.32862	0.261953
172	BC	08ND013	-0.3491	FALSE	-0.28964	0.237004
173	BC	08NE001	-0.009	TRUE	-0.2746	0.22698
174	BC	08NE006	0.0112	TRUE	-0.31747	0.254968
175	BC	08NE077	-0.1232	TRUE	-0.24515	0.206686
176	BC	08NE087	0.5129	FALSE	-0.28964	0.237004
177	BC	08NF001	-0.0452	TRUE	-0.2746	0.22698
178	BC	08NH005	0.2137	TRUE	-0.28964	0.237004
179	BC	08NH016	0.2025	TRUE	-0.37894	0.291988
180	BC	08NH084	0.2914	FALSE	-0.31747	0.254968
181	BC	08NH115	0.5101	FALSE	-0.28964	0.237004
182	BC	08NH130	0.099	TRUE	-0.33464	0.265673
183	BC	08NH131	-0.1903	TRUE	-0.33464	0.265673
184	BC	08NJ130	0.3719	FALSE	-0.29811	0.242554
185	BC	08NL007	0.4231	FALSE	-0.23137	0.196888
186	BC	08NL070	-0.0712	TRUE	-0.34099	0.26956
187	BC	08NM174	0.1564	TRUE	-0.31747	0.254968
188	BC	08NN015	0.1358	TRUE	-0.29378	0.23973
189	BC	08OA002	0.2359	TRUE	-0.32862	0.261953
190	BC	09AA006	0.3489	FALSE	-0.2503	0.2103
191	YT	09AA015	0.0239	TRUE	-0.33464	0.265673
192	YT	09AC001	0.1537	TRUE	-0.24268	0.204948
193	BC	09AE003	0.1159	TRUE	-0.28565	0.234371
194	YT	09BA001	0.0593	TRUE	-0.28964	0.237004
195	YT	09BC001	0.2401	FALSE	-0.2746	0.22698
196	YT	09FC001	0.1749	TRUE	-0.37894	0.291988
197	YT	10AB001	0.3543	FALSE	-0.28964	0.237004
198	BC	10AC004	0.0979	TRUE	-0.32862	0.261953
199	BC	10BE004	0.2993	FALSE	-0.29811	0.242554
200	BC	10BE007	0.3634	FALSE	-0.34099	0.26956
201	BC	10CB001	0.3269	FALSE	-0.28964	0.237004
202	BC	10CD001	0.384	FALSE	-0.28964	0.237004
203	NT	10EB001	0.5708	FALSE	-0.32862	0.261953
204	NT	10FA002	0.487	FALSE	-0.31747	0.254968
205	NT	10GA001	0.5243	FALSE	-0.40852	0.308519
206	NT	10GB006	0.5199	FALSE	-0.40852	0.308519
207	NT	10LA002	0.5409	FALSE	-0.31747	0.254968
208	NT	10MC002	0.3773	FALSE	-0.36235	0.282353
209	NT	10NC001	0.3546	FALSE	-0.35481	0.277885
210	NU	10PB001	0.4862	FALSE	-0.32862	0.261953
211	NU	10RC001	0.4405	FALSE	-0.30263	0.245483
212	SK	11AB117	0.318	FALSE	-0.34099	0.26956

Table A-9. Estimated statistics for 7-day low-flow.

No. (1)	Station ID (2)	S (3)	Z (4)	P (5)	ACF (6)	P* (7)
1	01AD002	-924	-4.060	0.000	0.069	0.000
2	01AD003	-271	-2.193	0.014	-0.03	0.018
3	01AJ004	-57	-0.763	0.223	-0.2611	0.161
4	01AJ010	-141	-2.498	0.006	-0.0329	0.005
5	01AK001	-375	-2.385	0.009	-0.045	0.007
6	01AP002	-104	-1.157	0.124	-0.0455	0.113
7	01AP004	-185	-2.067	0.019	0.0367	0.023
8	01AQ001	-35	-0.131	0.448	0.17	0.449
9	01BC001	-98	-1.089	0.138	-0.1528	0.103
10	01BE001	-34	-0.210	0.417	0.05	0.422
11	01BH005	-42	-0.697	0.243	0.1082	0.265
12	01BJ003	-113	-1.355	0.088	0.0458	0.097
13	01BL002	-99	-1.453	0.073	0.2104	0.119
14	01BO001	-199	-2.146	0.016	0.1152	0.028
15	01BP001	-239	-1.878	0.030	0.03	0.056
16	01BQ001	-275	-2.969	0.001	0.1208	0.004
17	01BS001	-29	-0.339	0.367	0.0225	0.370
18	01BU002	-135	-1.452	0.073	0.2312	0.124
19	01BV006	-235	-2.831	0.002	0.1234	0.006
20	01CA003	-57	-0.629	0.265	0.114	0.287
21	01CB004	-35	-0.578	0.282	0.1168	0.303
22	01DG003	-562	-2.288	0.011	-0.069	0.004
23	01DL001	-89	-1.496	0.067	0.0559	0.078
24	01DP004	46	0.613	0.270	-0.1689	0.235
25	01EC001	-359	-1.680	0.046	-0.2013	0.020
26	01ED005	-170	-2.741	0.003	-0.1681	0.001
27	01ED007	-207	-3.054	0.001	-0.0073	0.001
28	01EF001	-356	-1.301	0.097	-0.133	0.076
29	01EG002	-24	-0.391	0.348	-0.3435	0.391
30	01EO001	-76	-0.275	0.392	-0.136	0.376
31	01FA001	12	0.144	0.443	-0.0834	0.438
32	01FB001	305	1.240	0.108	0.0327	0.114
33	01FB003	441	1.700	0.045	-0.062	0.035
34	02AA001	266	1.188	0.117	0.223	0.171
35	02AB008	83	0.686	0.246	0.207	0.288
36	02BF002	-110	-1.512	0.065	0.206	0.109
37	02CF008	82	1.689	0.046	-0.188	0.021
38	02EA005	97	0.346	0.365	0.177	0.386
39	02EC002	-501	-1.802	0.036	0.290	0.090
40	02FB007	290	2.923	0.002	0.470	0.038
41	02FC001	228	0.804	0.211	-0.093	0.190
42	02GA010	403	2.564	0.005	0.335	0.034
43	02HL004	154	1.360	0.087	0.231	0.066
44	02JC008	71	1.085	0.139	0.100	0.163
45	02KB001	-755	-2.717	0.003	0.181	0.012
46	02LB007	83	0.612	0.270	-0.064	0.257
47	02LG005	45	1.028	0.152	-0.2157	0.103
48	02LH004	-22	-0.490	0.312	0.0141	0.314
49	02NE011	-193	-2.727	0.003	0.0509	0.005
50	02NF003	-59	-0.389	0.349	0.0293	0.353
51	02OE027	-227	-2.073	0.019	0.246	0.031
52	02PB006	44	0.611	0.271	0.1783	0.304
53	02PJ007	894	4.085	0.000	0.35	0.000

Table A-9 (continued). Estimated statistics for 7-day low-flow.

No. (1)	Station ID (2)	S (3)	Z (4)	P (5)	ACF (6)	P* (7)
54	02QA002	-287	-3.596	0.000	0.1819	0.001
55	02RD002	141	1.718	0.043	0.11	0.089
56	02RF001	228	2.854	0.002	0.159	0.023
57	02RG005	35	0.898	0.185	-0.2312	0.130
58	02UC002	-186	-3.144	0.001	0.1698	0.004
59	02VC001	-218	-2.195	0.014	0.2588	0.044
60	02YA001	-119	-2.460	0.007	0.2298	0.025
61	02YC001	-228	-2.376	0.009	0.3201	0.043
62	02YJ001	-77	-1.127	0.130	0.2201	0.182
63	02YL001	-101	-0.889	0.187	-0.0432	0.178
64	02YQ001	110	0.836	0.202	-0.0317	0.195
65	02YR001	49	0.502	0.308	0.1864	0.338
66	02YS003	-152	-2.144	0.016	0.3544	0.067
67	02ZB001	-160	-1.853	0.032	0.0092	0.033
68	02ZF001	-295	-2.613	0.004	0.203	0.016
69	02ZG001	-116	-1.163	0.122	0.1822	0.166
70	02ZH001	-16	-0.125	0.450	0.1274	0.456
71	02ZK001	3	0.018	0.493	0.091	0.493
72	02ZM006	91	0.776	0.219	0.1068	0.242
73	03FA003	-59	-2.197	0.014	0.2273	0.038
74	03KC004	-105	-1.417	0.078	0.5059	0.204
75	03MB002	-8	-0.163	0.435	-0.0693	0.431
76	03NF001	9	0.198	0.421	0.1409	0.431
77	03NG001	-59	-2.197	0.014	0.2273	0.038
78	03QC001	-105	-1.417	0.078	0.5059	0.204
79	03QC002	-8	-0.163	0.435	-0.0693	0.431
80	04AD002	-133	-1.335	0.091	0.207	0.135
81	04DA001	-132	-1.739	0.041	0.293	0.097
82	04GA002	-6	-0.125	0.450	0.105	0.455
83	04GB004	7	0.107	0.457	0.105	0.461
84	04JC002	49	0.368	0.356	0.039	0.362
85	04KA001	74	1.082	0.140	-0.073	0.123
86	04LJ001	-261	-1.023	0.153	-0.018	0.149
87	04MF001	-31	-0.419	0.338	0.124	0.355
88	04NA001	517	2.921	0.002	0.1011	0.004
89	05AA008	-174	-2.200	0.014	0.213	0.037
90	05AA023	-200	-1.485	0.069	0.3653	0.152
91	05AD003	-345	-2.497	0.006	0.147	0.015
92	05AD005	-594	-2.007	0.022	0.155	0.043
93	05BA002	-33	-1.190	0.117	0.090	0.137
94	05BB001	493	1.687	0.046	0.310	0.110
95	05BL022	-78	-1.281	0.100	0.159	0.136
96	05DA007	-40	-0.536	0.296	-0.080	0.281
97	05DA009	-39	-0.620	0.268	0.016	0.271
98	05DA010	106	1.970	0.024	0.252	0.062
99	05DE007	-65	-1.070	0.142	-0.048	0.131
100	05FB002	-63	-0.774	0.219	-0.052	0.208
101	05LD001	247	2.256	0.012	0.073	0.018
102	05LD003	9	0.264	0.396	0.0041	0.396
103	05LG004	-131	-1.771	0.038	0.181	0.066
104	05LH005	70	0.675	0.250	0.325	0.312
105	05LJ005	306	2.711	0.003	0.493	0.055
106	05PB014	360	1.438	0.075	0.342	0.156

Table A-9 (continued). Estimated statistics for 7-day low-flow.

No. (1)	Station ID (2)	S (3)	Z (4)	P (5)	ACF (6)	P* (7)
107	05SA002	343	3.238	0.001	0.109	0.002
108	05TD001	-101	-1.622	0.052	0.460	0.153
109	05TG002	0	0.000	0.500	0.331	0.495
110	05UH002	53	1.027	0.152	0.194	0.198
111	06AB002	-213	-3.039	0.001	0.539	0.044
112	06BD001	-110	-1.768	0.039	0.2951	0.094
113	06CD002	-263	-3.169	0.001	0.698	0.083
114	06DA004	-199	-3.068	0.001	0.5727	0.050
115	06FB002	-99	-1.748	0.040	0.080	0.049
116	06GD001	4	0.026	0.490	0.132	0.491
117	06JB001	25	0.840	0.201	0.411	0.289
118	06KC003	118	2.439	0.007	0.739	0.157
119	06LA001	152	2.449	0.007	0.536	0.084
120	06LC001	183	3.093	0.001	0.269	0.009
121	07AA001	98	1.916	0.028	0.382	0.096
122	07AA002	74	1.131	0.129	0.132	0.160
123	07AH002	-139	-2.766	0.003	0.252	0.015
124	07CD001	-244	-2.320	0.010	0.239	0.034
125	07DD002	137	2.107	0.018	0.497	0.106
126	07EA002	6	0.162	0.436	-0.2557	0.418
127	07EC002	52	1.008	0.157	-0.4024	0.065
128	07EE009	8	0.138	0.445	0.2059	0.455
129	07FB001	-80	-0.980	0.164	-0.0223	0.158
130	07FC003	-212	-3.454	0.000	0.5714	0.032
131	07GG001	-91	-1.425	0.077	0.434	0.181
132	07JC001	-28	-0.573	0.283	0.230	0.324
133	07KE001	93	1.253	0.105	0.152	0.140
134	07LE002	126	1.804	0.036	0.3306	0.098
135	07OB001	238	2.761	0.003	0.383	0.031
136	07OB003	102	1.895	0.029	0.054	0.036
137	07RD001	46	0.639	0.261	0.416	0.338
138	08CC001	112	1.800	0.036	0.0222	0.039
139	08CD001	46	0.589	0.278	0.2509	0.323
140	08CE001	138	1.657	0.049	-0.1032	0.033
141	08CG001	115	1.379	0.084	0.1278	0.112
142	08DA005	76	1.162	0.123	0.3732	0.212
143	08DC006	176	2.838	0.002	0.4144	0.031
144	08DD001	59	1.088	0.138	0.1952	0.184
145	08ED001	84	1.411	0.079	0.2011	0.123
146	08FA002	63	0.779	0.218	-0.1284	0.188
147	08FB006	-57	-0.986	0.162	-0.0527	0.150
148	08FB007	-4	-0.085	0.466	0.1571	0.471
149	08GA010	-33	-0.125	0.450	0.322	0.464
150	08GA061	-102	-1.838	0.033	0.081	0.045
151	08GD004	42	0.697	0.243	0.1573	0.275
152	08HA001	-94	-1.782	0.037	-0.0495	0.031
153	08HA003	-197	-1.982	0.024	0.0987	0.036
154	08HB002	10	0.223	0.412	0.495	0.447
155	08HB008	-668	-3.956	0.000	0.3192	0.002
156	08HB025	4	0.135	0.446	-0.5967	0.400
157	08HC002	67	2.309	0.221	0.010	0.018
158	08HE006	-146	-1.923	0.027	0.2486	0.010
159	08HF004	-1	-0.042	0.483	0.2099	0.2486

Table A-9 (continued). Estimated statistics for 7-day low-flow.

No. (1)	Station ID (2)	S (3)	Z (4)	P (5)	ACF (6)	P* (7)
160	08JB002	-284	-2.171	0.015	0.1592	0.032
161	08JE001	204	1.557	0.060	-0.0005	0.060
162	08KA009	-34	-0.568	0.285	-0.0772	0.270
163	08KH006	453	3.032	0.001	0.1048	0.003
164	08LA001	238	1.818	0.035	0.0735	0.045
165	08LD001	-50	-0.516	0.303	0.0661	0.314
166	08LG016	25	0.408	0.342	0.2701	0.377
167	08MA002	-53	-0.767	0.222	-0.0443	0.212
168	08MB006	18	0.319	0.375	0.1951	0.396
169	08MG005	315	1.465	0.071	0.2631	0.130
170	08MH006	-189	-1.988	0.023	-0.0658	0.017
171	08MH016	-294	-2.866	0.002	0.1513	0.007
172	08NB005	-331	-2.346	0.009	0.1142	0.018
173	08NC004	-10	-0.187	0.426	0.3839	0.450
174	08ND013	-115	-1.403	0.080	-0.2563	0.035
175	08NE001	-93	-0.951	0.171	-0.0096	0.169
176	08NE006	-151	-2.355	0.009	0.0249	0.011
177	08NE077	-195	-1.488	0.068	0.1319	0.096
178	08NE087	49	0.581	0.281	0.4965	0.366
179	08NF001	93	0.963	0.168	-0.0407	0.158
180	08NH005	130	1.560	0.059	0.352	0.137
181	08NH016	-2	-0.074	0.470	0.1519	0.474
182	08NH084	78	1.193	0.116	0.2055	0.163
183	08NH115	-226	-2.746	0.003	0.5073	0.053
184	08NH130	26	0.446	0.328	0.0761	0.339
185	08NH131	-29	-0.535	0.296	-0.1671	0.266
186	08NJ130	-151	-1.988	0.023	0.4205	0.099
187	08NL007	-348	-2.269	0.012	0.3366	0.054
188	08NL070	-67	-1.276	0.101	0.1258	0.129
189	08NM174	-115	-1.797	0.036	0.1193	0.055
190	08NN015	66	0.817	0.207	0.1009	0.229
191	08OA002	67	1.122	0.131	0.1062	0.156
192	09AA006	365	2.956	0.002	0.3251	0.017
193	09AA015	27	0.464	0.321	0.0185	0.324
194	09AC001	205	1.522	0.064	0.14	0.093
195	09AE003	0	-0.012	0.495	0.1009	0.496
196	09BA001	183	2.202	0.014	0.077	0.021
197	09BC001	36	0.354	0.362	0.236	0.390
198	09FC001	11	0.248	0.402	0.211	0.420
199	10AB001	54	0.641	0.261	0.36	0.329
200	10AC004	110	1.853	0.032	0.1206	0.050
201	10BE004	258	3.361	0.000	0.2882	0.006
202	10BE007	36	0.657	0.256	0.3633	0.324
203	10CB001	182	2.190	0.014	0.3599	0.064
204	10CD001	330	3.980	0.000	0.3932	0.004
205	10EB001	161	2.719	0.003	0.6583	0.100
206	10FA002	195	2.876	0.002	0.5934	0.068
207	10GA001	88	2.627	0.004	0.5376	0.067
208	10GB006	14	0.393	0.347	0.5236	0.410
209	10LA002	13	0.186	0.426	0.5856	0.461
210	10MC002	132	2.887	0.002	0.4127	0.029
211	10NC001	-79	-1.668	0.048	0.4036	0.134
212	10PB001	115	1.938	0.026	0.4544	0.118

Table A-10. Estimated statistics for 14-day low-flow.

No. (1)	Station ID (2)	S (3)	Z (4)	P (5)	ACF (6)	P* (7)
1	01AD002	-920	-4.04204	0.000	0.0737	0.000
2	01AD003	-271	-2.193	0.014	-0.0521	0.009
3	01AJ004	-93	-1.25312	0.105	-0.2611	0.052
4	01AJ010	-135	-2.3907	0.008	-0.0991	0.005
5	01AK001	-379	-2.41086	0.008	-0.062	0.005
6	01AP002	-108	-1.20182	0.115	-0.1116	0.090
7	01AP004	-188	-2.10037	0.018	0.0759	0.030
8	01AQ001	-34	-0.12748	0.449	0.0753	0.452
9	01BC001	-88	-0.97718	0.164	-0.1748	0.110
10	01BE001	-114	-0.72071	0.236	0.0436	0.236
11	01BH005	-43	-0.71385	0.238	0.0666	0.246
12	01BJ003	-117	-1.40324	0.080	0.0304	0.084
13	01BL002	-121	-1.77893	0.038	0.1721	0.066
14	01BO001	-171	-1.84236	0.033	0.0549	0.040
15	01BP001	-239	-1.87808	0.030	0.0874	0.037
16	01BQ001	-221	-2.38423	0.009	0.0031	0.005
17	01BS001	-38	-0.44758	0.327	-0.0124	0.326
18	01BU002	-130	-1.39802	0.081	0.1143	0.105
19	01BV006	-181	-2.17744	0.015	0.1117	0.024
20	01CA003	-50	-0.55036	0.291	0.0885	0.307
21	01CB004	-43	-0.71385	0.238	0.142	0.267
22	01DG003	-547	-2.22681	0.013	-0.165	0.005
23	01DL001	-107	-1.80162	0.036	0.0432	0.042
24	01DP004	32	0.422248	0.336	-0.2176	0.296
25	01EC001	-359	-1.68003	0.046	-0.2216	0.020
26	01ED005	-158	-2.54598	0.005	-0.1994	0.001
27	01ED007	-201	-2.96489	0.002	-0.0304	0.001
28	01EF001	-317	-1.15848	0.123	-0.1074	0.100
29	01EG002	-37	-0.61187	0.270	-0.3403	0.200
30	01EO001	-43	-0.15397	0.439	-0.1853	0.431
31	01FA001	-12	-0.17003	0.432	-0.1512	0.420
32	01FB001	304	1.235757	0.108	-0.0298	0.107
33	01FB003	447	1.722937	0.042	-0.068	0.034
34	02AA001	218	0.973215	0.165	0.2302	0.225
35	02AB008	96	0.794661	0.213	0.162	0.242
36	02BF002	-138	-1.8933	0.029	0.2325	0.066
37	02CF008	71	1.459284	0.072	-0.1744	0.043
38	02EA005	90	0.320764	0.374	0.1682	0.391
39	02EC002	-480	-1.72636	0.042	0.2323	0.081
40	02FB007	256	2.579137	0.005	0.4159	0.046
41	02FC001	306	1.080872	0.140	-0.0975	0.126
42	02GA010	335	2.130228	0.017	0.3458	0.066
43	02HL004	140	1.235438	0.108	0.1838	0.148
44	02JC008	81	1.239553	0.108	0.0253	0.088
45	02KB001	-712	-2.56251	0.005	0.1964	0.016
46	02LB007	99	0.731119	0.232	-0.0633	0.214
47	02LG005	64	1.471363	0.071	-0.1446	0.046
48	02LH004	-14	-0.30361	0.381	-0.0247	0.374
49	02NE011	-183	-2.58466	0.005	-0.0059	0.001
50	02NF003	-67	-0.44273	0.329	0.082	0.338
51	02OE027	-151	-1.37557	0.084	0.0792	0.102
52	02PB006	43	0.59646	0.275	0.1618	0.310
53	02PJ007	651	2.97329	0.001	0.1876	0.009

Table A-10 (continued). Estimated statistics for 14-day low-flow.

No. (1)	Station ID (2)	S (3)	Z (4)	P (5)	ACF (6)	P* (7)
54	02QA002	-288	-3.60814	0.000	0.1669	0.001
55	02RD002	124	1.512109	0.065	0.2308	0.114
56	02RF001	229	2.866394	0.002	0.3457	0.021
57	02RG005	39	1.003597	0.158	-0.215	0.109
58	02UC002	-181	-3.05936	0.001	0.1631	0.004
59	02VC001	-220	-2.21502	0.013	0.2269	0.037
60	02YA001	-85	-1.75114	0.040	0.2	0.075
61	02YC001	-231	-2.40705	0.008	0.2833	0.035
62	02YJ001	-61	-0.88947	0.187	0.1981	0.232
63	02YL001	-249	-2.20423	0.014	0.0522	0.017
64	02YQ001	62	0.481356	0.315	0.0051	0.317
65	02YR001	53	0.544202	0.293	0.1779	0.324
66	02YS003	-109	-1.53375	0.063	0.2825	0.123
67	02ZB001	-102	-1.17675	0.120	0.067	0.136
68	02ZF001	-282	-2.49754	0.006	0.1888	0.017
69	02ZG001	-110	-1.10245	0.135	0.1685	0.179
70	02ZH001	-14	-0.10874	0.457	0.0675	0.457
71	02ZK001	15	0.128386	0.449	0.0498	0.451
72	02ZM006	97	0.827504	0.204	0.0954	0.224
73	03FA003	-18	-0.55155	0.291	0.2849	0.332
74	03KC004	-2	-0.12358	0.451	-0.0059	0.452
75	03MB002	-34	-0.44949	0.327	0.0614	0.333
76	03NF001	8	0.173631	0.431	0.163	0.442
77	03NG001	-61	-2.27266	0.012	0.2306	0.035
78	03QC001	-105	-1.41657	0.078	0.4972	0.196
79	03QC002	0	0.023355	0.491	-0.0582	0.490
80	04AD002	-150	-1.50703	0.066	0.2099	0.113
81	04DA001	-128	-1.68718	0.046	0.2775	0.092
82	04GA002	-7	-0.14273	0.443	0.0992	0.448
83	04GB004	13	0.214092	0.415	0.1084	0.423
84	04JC002	-48	-0.37586	0.354	0.0397	0.360
85	04KA001	77	1.126658	0.130	-0.0816	0.107
86	04LJ001	-234	-0.91632	0.180	-0.0037	0.184
87	04MF001	-40	-0.53623	0.296	0.0983	0.310
88	04NA001	570	3.221328	0.001	0.1194	0.002
89	05AA008	-169	-2.13722	0.016	0.1894	0.038
90	05AA023	-227	-1.70097	0.044	0.2335	0.088
91	05AD003	-326	-1.12104	0.131	0.1655	0.169
92	05AD005	-447	-1.51101	0.065	0.1124	0.088
93	05BA002	-13	-0.4898	0.312	-0.0275	0.308
94	05BB001	649	2.221511	0.013	0.2629	0.044
95	05BL022	-64	-1.05407	0.146	0.2186	0.203
96	05DA007	1	0	0.500	-0.0955	0.500
97	05DA009	-10	-0.17044	0.432	-0.1022	0.425
98	05DA010	96	1.782016	0.037	0.1988	0.071
99	05DE007	-34	-0.56758	0.285	-0.1616	0.253
100	05FB002	-91	-1.11291	0.133	0.0478	0.144
101	05LD001	258	2.356807	0.009	0.1757	0.023
102	05LD003	-6	-0.13205	0.447	-0.0584	0.443
103	05LG004	-91	-1.22588	0.110	0.2308	0.164
104	05LH005	118	1.144531	0.126	0.3398	0.209
105	05LJ005	259	2.293114	0.011	0.4219	0.069
106	05PB014	397	1.615049	0.053	0.3259	0.120

Table A-10 (continued). Estimated statistics for 14-day low-flow.

No. (1)	Station ID (2)	S (3)	Z (4)	P (5)	ACF (6)	P* (7)
107	05SA002	359	3.389598	0.000	0.1689	0.002
108	05TD001	-141	-2.41349	0.008	0.2717	0.032
109	05TG002	45	0.869287	0.192	0.1966	0.237
110	05UH002	-217	-3.09591	0.001	0.54	0.042
111	06AB002	-100	-1.60543	0.054	0.2694	0.100
112	06BD001	-283	-3.41132	0.000	0.7028	0.072
113	06CD002	-188	-2.89746	0.002	0.55	0.055
114	06DA004	-91	-1.60569	0.054	0.0639	0.063
115	06FB002	22	0.181017	0.428	0.1304	0.435
116	06GD001	29	0.979596	0.164	0.3822	0.248
117	06JB001	118	2.439088	0.007	0.7353	0.148
118	06KC003	154	2.481117	0.007	0.5272	0.072
119	06LA001	169	2.855398	0.002	0.2206	0.007
120	06LC001	110	2.153461	0.016	0.351	0.065
121	07AA001	92	1.409992	0.079	0.0835	0.096
122	07AA002	-134	-2.66713	0.004	0.219	0.016
123	07AH002	-225	-2.1398	0.016	0.2673	0.051
124	07CD001	130	1.998779	0.023	0.5108	0.122
125	07DD002	2	0.032444	0.487	-0.2818	0.482
126	07EA002	49	0.948313	0.171	-0.4028	0.077
127	07EC002	14	0.256835	0.399	0.2315	0.420
128	07EE009	-78	-0.95565	0.170	-0.0883	0.151
129	07FB001	-203	-3.30816	0.000	0.4696	0.021
130	07FC003	-110	-1.71988	0.043	0.4155	0.129
131	07GG001	-27	-0.55318	0.290	0.1147	0.309
132	07JC001	92	1.239501	0.108	0.1504	0.142
133	07KE001	129	1.846186	0.032	0.3228	0.086
134	07LE002	232	2.691389	0.004	0.3818	0.033
135	07OB001	102	1.894564	0.029	0.0529	0.036
136	07OB003	45	0.624863	0.266	0.4105	0.342
137	07RD001	110	1.767593	0.039	0.024	0.041
138	08CC001	46	0.58855	0.278	0.2794	0.326
139	08CD001	149	1.790337	0.037	-0.0858	0.026
140	08CE001	121	1.451625	0.073	0.0972	0.093
141	08CG001	85	1.301531	0.097	0.3549	0.178
142	08DA005	176	2.837879	0.002	0.3207	0.020
143	08DC006	58	1.06921	0.142	0.164	0.180
144	08DD001	77	1.291728	0.098	0.1733	0.132
145	08ED001	37	0.452589	0.325	-0.0942	0.317
146	08FA002	-53	-0.91781	0.179	-0.0706	0.154
147	08FB006	3	0.033993	0.486	0.1654	0.489
148	08FB007	71	0.256625	0.399	0.3169	0.423
149	08GA010	-117	-2.10524	0.018	0.1127	0.029
150	08GA061	30	0.492896	0.311	0.09	0.326
151	08GD004	-82	-1.55692	0.060	-0.0585	0.050
152	08HA001	-202	-2.03297	0.021	0.0592	0.028
153	08HA003	14	0.322457	0.374	0.4462	0.418
154	08HB002	-683	-4.045	0.000	0.2806	0.001
155	08HB008	4	0.135068	0.446	-0.6013	0.420
156	08HB025	67	2.309048	0.010	0.1475	0.022
157	08HC002	-115	-1.51715	0.065	0.2555	0.118
158	08HE006	9	0.166775	0.434	0.1945	0.443
159	08HF004	-286	-2.18615	0.014	0.1642	0.031

Table A-10 (continued). Estimated statistics for 14-day low-flow.

No. (1)	Station ID (2)	S (3)	Z (4)	P (5)	ACF (6)	P* (7)
160	08JB002	182	1.388397	0.083	-0.0248	0.075
161	08JE001	-32	-0.53514	0.296	-0.0467	0.278
162	08KA009	449	3.005178	0.001	0.0893	0.003
163	08KH006	246	1.879322	0.030	0.0795	0.041
164	08LA001	-59	-0.60686	0.272	0.0662	0.287
165	08LD001	37	0.611871	0.270	0.3357	0.335
166	08LG016	-49	-0.71007	0.239	-0.0359	0.232
167	08MA002	12	0.206339	0.418	0.1969	0.438
168	08MB006	329	1.530689	0.063	0.2654	0.119
169	08MG005	-203	-2.13495	0.016	-0.1035	0.010
170	08MH006	-262	-2.55319	0.005	0.134	0.012
171	08MH016	-264	-1.8729	0.031	0.1074	0.045
172	08NB005	4	0.050989	0.480	0.3655	0.483
173	08NC004	-92	-1.12501	0.130	-0.3157	0.054
174	08ND013	-35	-0.37676	0.353	-0.0209	0.352
175	08NE001	-166	-2.58757	0.005	0.0941	0.009
176	08NE006	-167	-1.27334	0.101	0.1081	0.117
177	08NE077	67	0.798394	0.212	0.515	0.322
178	08NE087	51	0.541869	0.294	-0.085	0.279
179	08NF001	121	1.451625	0.073	0.3037	0.141
180	08NH005	-16	-0.42167	0.337	0.2423	0.364
181	08NH016	102	1.564936	0.059	0.2832	0.118
182	08NH084	-210	-2.55244	0.005	0.5222	0.067
183	08NH115	53	0.927734	0.177	0.0928	0.200
184	08NH130	-20	-0.37466	0.354	-0.1899	0.326
185	08NH131	-146	-1.9226	0.027	0.3985	0.094
186	08NJ130	-377	-2.45885	0.007	0.3639	0.045
187	08NL007	-100	-1.89456	0.029	0.1167	0.046
188	08NL070	-77	-1.26488	0.103	0.1916	0.154
189	08NM174	65	0.804602	0.211	0.1151	0.239
190	08NN015	70	1.172753	0.120	0.164	0.158
191	08OA002	369	2.988974	0.001	0.3288	0.018
192	09AA006	35	0.606595	0.272	0.0195	0.276
193	09AA015	200	1.48462	0.069	0.1511	0.100
194	09AC001	22	0.244672	0.403	0.1161	0.414
195	09AE003	175	2.104856	0.018	0.0657	0.024
196	09BA001	49	0.50234	0.308	0.2277	0.346
197	09BC001	-1	-0.04961	0.480	0.1929	0.483
198	09FC001	52	0.61694	0.269	0.3614	0.333
199	10AB001	115	1.937592	0.026	0.1263	0.043
200	10AC004	270	3.518219	0.000	0.2813	0.004
201	10BE004	38	0.694048	0.244	0.3658	0.315
202	10BE007	199	2.395181	0.008	0.3547	0.047
203	10CB001	333	4.016162	0.000	0.3944	0.003
204	10CD001	189	3.195326	0.001	0.6586	0.055
205	10EB001	190	2.928444	0.002	0.5774	0.053
206	10FA002	88	2.627132	0.004	0.5407	0.068
207	10GA001	19	0.543545	0.293	0.5248	0.376
208	10GB006	304	4.694807	0.000	0.5739	0.004
209	10LA002	137	2.997651	0.001	0.4058	0.023
210	10MC002	-83	-1.70945	0.044	0.3897	0.119
211	10NC001	117	1.971584	0.024	0.4733	0.119
212	10PB001	-108	-1.45744	0.072	0.4408	0.178

Table A-11. Estimated statistics for 21-day low-flow.

No. (1)	Station ID (2)	S (3)	Z (4)	P (5)	ACF (6)	P* (7)
1	01AD002	-862	-3.78694	0.000	0.0737	0.000
2	01AD003	-271	-2.193	0.014	-0.0521	0.009
3	01AJ004	-95	-1.28036	0.100	-0.247	0.048
4	01AJ010	-123	-2.17661	0.015	-0.1902	0.005
5	01AK001	-379	-2.41086	0.008	-0.062	0.005
6	01AP002	-132	-1.47138	0.071	-0.0959	0.052
7	01AP004	-186	-2.07791	0.019	0.1027	0.031
8	01AQ001	-6	-0.01932	0.492	0.0753	0.493
9	01BC001	-65	-0.71884	0.236	-0.2087	0.183
10	01BE001	-122	-0.77173	0.220	0.0436	0.221
11	01BH005	-57	-0.9518	0.171	0.04	0.180
12	01BJ003	-105	-1.25807	0.104	0.0225	0.109
13	01BL002	-109	-1.60104	0.055	0.1568	0.083
14	01BO001	-169	-1.82068	0.034	0.0117	0.036
15	01BP001	-239	-1.87808	0.030	0.0874	0.037
16	01BQ001	-163	-1.75566	0.040	-0.0607	0.030
17	01BS001	-31	-0.36291	0.358	-0.0053	0.358
18	01BU002	-125	-1.34384	0.090	0.1538	0.123
19	01BV006	-179	-2.15324	0.016	0.1045	0.025
20	01CA003	-46	-0.50544	0.307	0.0912	0.322
21	01CB004	-63	-1.05378	0.146	0.0604	0.160
22	01DG003	-123	-2.02289	0.022	-0.1937	0.010
23	01DL001	-125	-2.10756	0.018	-0.09	0.011
24	01DP004	0	-0.01362	0.495	-0.2368	0.493
25	01EC001	-366	-1.71269	0.043	-0.2226	0.018
26	01ED005	-156	-2.51355	0.006	-0.227	0.001
27	01ED007	-201	-2.96489	0.002	-0.0288	0.001
28	01EF001	-299	-1.09249	0.137	-0.1277	0.102
29	01EG002	-23	-0.37392	0.354	-0.33	0.303
30	01EO001	-45	-0.16131	0.436	-0.1795	0.427
31	01FA001	-16	-0.22234	0.412	-0.1677	0.395
32	01FB001	300	1.219444	0.111	0.0219	0.110
33	01FB003	387	1.491152	0.068	-0.0615	0.057
34	02AA001	192	0.856608	0.196	0.248	0.253
35	02AB008	83	0.685918	0.246	0.1362	0.273
36	02BF002	-106	-1.45744	0.072	0.2756	0.135
37	02CF008	57	1.167427	0.122	-0.104	0.099
38	02EA005	83	0.295536	0.384	0.1506	0.400
39	02EC002	-467	-1.67951	0.047	0.2069	0.087
40	02FB007	238	2.39708	0.008	0.3807	0.052
41	02FC001	352	1.243889	0.107	-0.0616	0.093
42	02GA010	324	2.060071	0.020	0.3625	0.077
43	02HL004	134	1.182109	0.119	0.1696	0.159
44	02JC008	62	0.945159	0.172	-0.0931	0.151
45	02KB001	-658	-2.36789	0.009	0.1868	0.024
46	02LB007	115	0.850486	0.198	-0.0711	0.179
47	02LG005	74	1.704913	0.044	-0.0653	0.037
48	02LH004	-18	-0.39703	0.346	-0.0609	0.337
49	02NE011	-145	-2.04501	0.020	-0.1203	0.009
50	02NF003	-31	-0.20124	0.420	0.0739	0.425
51	02OE027	-110	-0.99958	0.159	0.0409	0.168
52	02PB006	55	0.766877	0.222	0.1954	0.262
53	02PJ007	544	2.483841	0.006	0.2239	0.023

Table A-11 (continued). Estimated statistics for 21-day low-flow.

No. (1)	Station ID (2)	S (3)	Z (4)	P (5)	ACF (6)	P* (7)
54	02QA002	-263	-3.29384	0.000	0.0781	0.001
55	02RD002	107	1.306462	0.096	0.1163	0.123
56	02RF001	225	2.816107	0.002	0.3424	0.023
57	02RG005	50	1.294112	0.098	-0.1693	0.064
58	02UC002	-166	-2.80441	0.003	0.1452	0.007
59	02VC001	-212	-2.13411	0.016	0.1765	0.037
60	02YA001	-93	-1.75114	0.028	0.1718	0.051
61	02YC001	-218	-2.31286	0.012	0.2483	0.038
62	02YJ001	-47	-0.80052	0.248	0.1653	0.276
63	02YL001	-265	-2.34644	0.009	0.0463	0.012
64	02YQ001	38	0.29197	0.385	0.0143	0.386
65	02YR001	33	0.104654	0.369	0.1583	0.386
66	02YS003	-97	-1.59056	0.086	0.1802	0.127
67	02ZB001	-54	-0.31458	0.268	0.1464	0.295
68	02ZF001	-257	-2.27534	0.011	0.1739	0.027
69	02ZG001	-110	-0.71811	0.135	0.1806	0.179
70	02ZH001	-27	-0.50189	0.414	0.0778	0.415
71	02ZK001	19	0.165068	0.434	0.0544	0.438
72	02ZM006	90	0.224116	0.221	0.1188	0.246
73	03FA003	-16	-0.48666	0.313	0.2676	0.351
74	03KC004	-2	-0.12358	0.451	0.0071	0.452
75	03MB002	-40	-0.53121	0.298	0.0529	0.305
76	03NF001	6	0.074413	0.451	0.1878	0.459
77	03NG001	-61	-2.42417	0.012	0.2333	0.035
78	03QC001	-101	-1.33485	0.087	0.4893	0.206
79	03QC002	4	0.210195	0.454	-0.0482	0.451
80	04AD002	-149	-1.49691	0.067	0.2207	0.114
81	04DA001	-134	-1.76565	0.039	0.2551	0.082
82	04GA002	-11	-0.21409	0.415	0.1009	0.423
83	04GB004	13	0.214092	0.415	0.1097	0.423
84	04JC002	-48	-0.37586	0.354	0.0481	0.360
85	04KA001	91	1.3342	0.091	-0.0967	0.071
86	04LJ001	-235	-0.92025	0.179	0.0197	0.183
87	04MF001	-40	-0.53623	0.296	0.0798	0.310
88	04NA001	554	3.130746	0.001	0.1089	0.002
89	05AA008	-163	-2.06179	0.020	0.1393	0.036
90	05AA023	-240	-1.79796	0.036	0.1858	0.066
91	05AD003	-313	-1.07647	0.141	0.1342	0.172
92	05AD005	-500	-1.68977	0.046	0.1224	0.067
93	05BA002	-15	-0.55977	0.288	-0.068	0.275
94	05BB001	672	2.300361	0.011	0.2476	0.037
95	05BL022	-84	-1.3784	0.084	0.247	0.138
96	05DA007	26	0.326972	0.372	-0.0732	0.362
97	05DA009	20	0.294394	0.384	-0.0416	0.380
98	05DA010	90	1.669468	0.048	0.3554	0.120
99	05DE007	10	0.145948	0.442	-0.1817	0.431
100	05FB002	-151	-1.83872	0.033	0.2585	0.076
101	05LD001	267	2.439341	0.007	0.1676	0.020
102	05LD003	-8	-0.18487	0.427	-0.0891	0.421
103	05LG004	-30	-0.39501	0.346	0.1881	0.370
104	05LH005	106	1.027144	0.152	0.3384	0.234
105	05LJ005	235	2.079801	0.019	0.3987	0.085
106	05PB014	459	1.86791	0.031	0.3186	0.087

Table A-11 (continued). Estimated statistics for 21-day low-flow.

No. (1)	Station ID (2)	S (3)	Z (4)	P (5)	ACF (6)	P* (7)
107	05SA002	356	3.361194	0.000	0.4329	0.016
108	05TD001	51	0.987826	0.162	0.2319	0.231
109	05TG002	-219	-3.12432	0.001	0.5432	0.042
110	05UH002	-113	-1.81624	0.035	0.2683	0.074
111	06AB002	-295	-3.69614	0.000	0.7085	0.057
112	06BD001	-186	-2.86647	0.002	0.5348	0.050
113	06CD002	-96	-1.6949	0.045	0.0532	0.053
114	06DA004	38	0.318934	0.375	0.1241	0.387
115	06FB002	27	0.909625	0.182	0.3662	0.264
116	06GD001	119	2.459935	0.007	0.7287	0.146
117	06JB001	158	2.545983	0.005	0.5162	0.067
118	06KC003	163	2.75342	0.003	0.1663	0.009
119	06LA001	108	2.113948	0.017	0.3684	0.071
120	06LC001	90	1.379003	0.084	0.1517	0.117
121	07AA001	-142	-2.82518	0.002	0.1257	0.006
122	07AA002	-205	-1.95044	0.026	0.2509	0.064
123	07AH002	150	2.308667	0.010	0.5324	0.095
124	07CD001	8	0.22711	0.410	-0.2922	0.378
125	07DD002	55	1.066852	0.143	-0.3868	0.057
126	07EA002	8	0.138296	0.445	0.2201	0.456
127	07EC002	-67	-0.82259	0.205	-0.087	0.187
128	07EE009	-202	-3.29194	0.000	0.4491	0.016
129	07FB001	-112	-1.75087	0.040	0.4006	0.125
130	07FC003	-17	-0.35562	0.361	0.1096	0.375
131	07GG001	90	1.21226	0.113	0.1532	0.148
132	07JC001	128	1.831985	0.033	0.3138	0.087
133	07KE001	234	2.714691	0.003	0.3731	0.031
134	07LE002	234	2.714691	0.003	0.3728	0.031
135	07OB001	100	1.857048	0.032	0.0509	0.038
136	07OB003	49	0.681669	0.248	0.412	0.328
137	07RD001	110	1.73516	0.041	0.008	0.043
138	08CC001	62	0.58855	0.278	0.779	0.413
139	08CD001	165	1.947596	0.026	-0.0846	0.018
140	08CE001	135	1.669368	0.048	0.0753	0.059
141	08CG001	108	1.379003	0.084	0.3491	0.164
142	08DA005	162	2.610849	0.005	0.2416	0.020
143	08DC006	48	0.881629	0.189	0.0718	0.206
144	08DD001	83	1.393706	0.082	0.1572	0.114
145	08ED001	41	0.502876	0.308	-0.0511	0.299
146	08FA002	-56	-0.9688	0.166	-0.0773	0.141
147	08FB006	-11	-0.20396	0.419	0.1795	0.432
148	08FB007	141	0.51325	0.304	0.2804	0.350
149	08GA010	-135	-2.3907	0.008	0.0293	0.019
150	08GA061	46	0.696853	0.243	0.0652	0.262
151	08GD004	-76	-1.48189	0.069	-0.0732	0.057
152	08HA001	-184	-1.85091	0.032	-0.0212	0.030
153	08HA003	10	0.272848	0.392	0.3876	0.427
154	08HB002	-679	-4.02128	0.000	0.2439	0.001
155	08HB008	22	0.315158	0.376	-0.5257	0.318
156	08HB025	45	2.099134	0.018	0.114	0.029
157	08HC002	-114	-1.50407	0.066	0.3308	0.151
158	08HE006	21	0.166775	0.434	0.1689	0.443
159	08HF004	-310	-2.37025	0.009	0.1685	0.022

Table A-11 (continued). Estimated statistics for 21-day low-flow.

No. (1)	Station ID (2)	S (3)	Z (4)	P (5)	ACF (6)	P* (7)
160	08JB002	170	1.296349	0.097	-0.0353	0.089
161	08JE001	-27	-0.47028	0.319	-0.07	0.302
162	08KA009	445	2.978346	0.001	0.0705	0.002
163	08KH006	220	1.679884	0.046	0.0815	0.060
164	08LA001	-68	-0.4248	0.335	0.0741	0.347
165	08LD001	33	0.509893	0.305	0.3301	0.361
166	08LG016	-35	-0.65327	0.257	-0.01	0.255
167	08MA002	8	0.206339	0.418	0.235	0.438
168	08MB006	335	1.55869	0.060	0.258	0.115
169	08MG005	-261	-2.59542	0.005	-0.0842	0.003
170	08MH006	-236	-2.29885	0.011	0.091	0.018
171	08MH016	-209	-1.48418	0.069	0.0851	0.085
172	08NB005	14	0.220953	0.413	0.3438	0.426
173	08NC004	-55	-0.67742	0.249	-0.3441	0.167
174	08ND013	-35	-0.37676	0.353	-0.0032	0.352
175	08NE001	-196	-3.0524	0.001	0.0604	0.002
176	08NE006	-26	-0.20711	0.418	-0.1236	0.408
177	08NE077	53	0.629037	0.265	0.5214	0.358
178	08NE087	47	0.49852	0.309	-0.0808	0.295
179	08NF001	81	0.96775	0.167	0.2331	0.216
180	08NH005	-6	-0.17363	0.431	0.2342	0.443
181	08NH016	94	1.44098	0.075	0.3243	0.148
182	08NH084	-210	-2.55244	0.005	0.5191	0.067
183	08NH115	63	1.106144	0.134	0.0947	0.158
184	08NH130	-15	-0.28546	0.388	-0.1896	0.366
185	08NH131	-149	-1.96183	0.025	0.383	0.089
186	08NJ130	-401	-2.61579	0.004	0.3958	0.040
187	08NL007	-130	-2.45731	0.007	0.1688	0.019
188	08NL070	-96	-1.573	0.058	0.2229	0.103
189	08NM174	63	0.779458	0.218	0.1233	0.246
190	08NN015	67	1.121764	0.131	0.203	0.178
191	08OA002	361	2.923996	0.002	0.3325	0.020
192	09AA006	33	0.570913	0.284	0.0185	0.287
193	09AA015	184	1.365254	0.086	0.1487	0.120
194	09AC001	16	0.174766	0.431	0.1175	0.438
195	09AE003	179	2.153243	0.016	0.0575	0.021
196	09BA001	50	0.512806	0.304	0.2311	0.343
197	09BC001	1	0	0.500	0.1824	0.500
198	09FC001	58	0.689522	0.245	0.3552	0.314
199	10AB001	113	1.903599	0.028	0.1174	0.045
200	10AC004	249	3.243563	0.001	0.2694	0.007
201	10BE004	42	0.769081	0.221	0.3672	0.297
202	10BE007	191	2.298406	0.011	0.3384	0.050
203	10CB001	328	3.955677	0.000	0.3879	0.004
204	10CD001	203	3.433276	0.000	0.625	0.043
205	10EB001	205	3.024186	0.001	0.56	0.050
206	10FA002	88	2.627132	0.004	0.5391	0.068
207	10GA001	24	0.694529	0.244	0.5242	0.343
208	10GB006	302	4.663818	0.000	0.5593	0.005
209	10LA002	137	2.997651	0.001	0.3963	0.023
210	10MC002	-87	-1.79283	0.036	0.3747	0.108
211	10NC001	115	1.937592	0.026	0.4838	0.123
212	10PB001	-110	-1.48468	0.069	0.4405	0.174

Table A-12. Estimated statistics for 30-day low-flow.

No. (1)	Station ID (2)	S (3)	Z (4)	P (5)	ACF (6)	P* (7)
1	01AD002	-862	-3.787	0.000	0.067	0.000
2	01AD003	-271	-2.193	0.014	-0.085	0.009
3	01AJ004	-89	-1.199	0.115	-0.270	0.060
4	01AJ010	-93	-1.641	0.050	-0.182	0.025
5	01AK001	-379	-2.411	0.008	-0.065	0.005
6	01AP002	-148	-1.651	0.049	-0.050	0.041
7	01AP004	-180	-2.011	0.022	0.114	0.036
8	01AQ001	-6	-0.019	0.492	0.063	0.493
9	01BC001	-50	-0.550	0.291	-0.234	0.245
10	01BE001	-122	-0.772	0.220	0.004	0.221
11	01BH005	-39	-0.646	0.259	0.019	0.263
12	01BJ003	-111	-1.331	0.092	-0.015	0.088
13	01BL002	-103	-1.512	0.065	0.093	0.083
14	01BO001	-133	-1.431	0.076	-0.002	0.076
15	01BP001	-239	-1.878	0.030	0.051	0.037
16	01BQ001	-115	-1.235	0.108	-0.078	0.093
17	01BS001	-29	-0.339	0.367	0.024	0.370
18	01BU002	-149	-1.604	0.054	0.117	0.077
19	01BV006	-177	-2.129	0.017	0.071	0.023
20	01CA003	-56	-0.618	0.268	0.069	0.282
21	01CB004	-73	-1.224	0.111	0.004	0.111
22	01DG003	-414	-1.684	0.046	-0.145	0.026
23	01DL001	-149	-2.515	0.006	-0.123	0.002
24	01DP004	-16	-0.232	0.408	-0.186	0.390
25	01EC001	-410	-1.918	0.028	-0.236	0.010
26	01ED005	-146	-2.351	0.009	-0.267	0.001
27	01ED007	-215	-3.172	0.001	-0.073	0.000
28	01EF001	-241	-0.880	0.189	-0.154	0.153
29	01EG002	-11	-0.170	0.433	-0.319	0.407
30	01EO001	-22	-0.077	0.469	-0.129	0.465
31	01FA001	-28	-0.379	0.352	-0.176	0.325
32	01FB001	300	1.219	0.111	0.022	0.116
33	01FB003	358	1.379	0.084	-0.054	0.074
34	02AA001	242	1.081	0.140	0.252	0.200
35	02AB008	46	0.376	0.353	0.194	0.378
36	02BF002	-92	-1.267	0.103	0.284	0.169
37	02CF008	53	1.084	0.139	-0.043	0.129
38	02EA005	126	0.451	0.326	0.153	0.349
39	02EC002	-447	-1.607	0.054	0.154	0.083
40	02FB007	246	2.478	0.007	0.350	0.041
41	02FC001	422	1.492	0.068	-0.033	0.062
42	02GA010	299	1.901	0.029	0.324	0.085
43	02HL004	122	1.075	0.141	0.149	0.177
44	02JC008	28	0.418	0.338	-0.125	0.318
45	02KB001	-551	-1.982	0.024	0.183	0.049
46	02LB007	104	0.768	0.221	-0.083	0.203
47	02LG005	80	1.845	0.033	-0.047	0.027
48	02LH004	-24	-0.537	0.296	-0.037	0.289
49	02NE011	-111	-1.562	0.059	-0.149	0.035
50	02NF003	9	0.067	0.473	0.058	0.475
51	02OE027	-125	-1.137	0.128	-0.125	0.099
52	02PB006	49	0.682	0.248	0.149	0.278
53	02PJ007	502	2.292	0.011	0.150	0.024

Table A-12 (continued). Estimated statistics for 30-day low-flow.

No. (8)	Station ID (9)	S (10)	Z (11)	P (12)	ACF (13)	P* (14)
54	02QA002	-227	-2.841	0.002	-0.052	0.001
55	02RD002	109	1.331	0.092	0.048	0.102
56	02RF001	223	2.791	0.003	0.336	0.024
57	02RG005	47	1.215	0.112	-0.158	0.079
58	02UC002	-163	-2.753	0.003	0.126	0.007
59	02VC001	-216	-2.175	0.015	0.183	0.034
60	02YC001	-222	-2.313	0.010	0.166	0.025
61	02YJ001	-55	-0.801	0.212	0.140	0.243
62	02YL001	-239	-2.115	0.017	0.014	0.018
63	02YQ001	50	0.387	0.350	0.039	0.355
64	02YR001	11	0.105	0.458	0.155	0.464
65	02YS003	-113	-1.591	0.056	0.004	0.057
66	02ZB001	-28	-0.315	0.377	0.084	0.386
67	02ZF001	-253	-2.240	0.013	0.135	0.025
68	02ZG001	-72	-0.718	0.236	0.180	0.274
69	02ZH001	-61	-0.502	0.308	0.019	0.311
70	02ZK001	-1	-0.018	0.493	0.103	0.493
71	02ZM006	27	0.224	0.411	0.026	0.414
72	03FA003	-14	-0.422	0.337	0.246	0.370
73	03KC004	-4	-0.206	0.418	0.027	0.420
74	03MB002	-40	-0.531	0.298	0.041	0.305
75	03NF001	4	0.074	0.470	0.219	0.476
76	03QC001	-99	-1.335	0.091	0.481	0.210
77	03QC002	8	0.210	0.417	-0.055	0.412
78	04AD002	-118	-1.183	0.118	0.206	0.166
79	04DA001	-138	-1.818	0.035	0.243	0.076
80	04GA002	-13	-0.250	0.401	0.102	0.410
81	04GB004	15	0.250	0.401	0.105	0.411
82	04JC002	-146	-1.128	0.130	0.046	0.141
83	04KA001	103	1.512	0.065	-0.108	0.048
84	04LJ001	-187	-0.731	0.232	0.046	0.242
85	04MF001	-54	-0.719	0.236	0.053	0.247
86	04NA001	532	3.006	0.001	0.108	0.003
87	05AA008	-167	-2.112	0.017	0.127	0.031
88	05AA023	-233	-1.746	0.040	0.112	0.059
89	05AD003	-327	-1.124	0.130	0.014	0.134
90	05AD005	-463	-1.565	0.059	0.084	0.074
91	05BA002	-17	-0.630	0.264	-0.048	0.255
92	05BB001	694	2.376	0.009	0.264	0.034
93	05BL022	-84	-1.378	0.084	0.214	0.131
94	05DA007	32	0.405	0.343	-0.081	0.331
95	05DA009	36	0.542	0.294	-0.046	0.285
96	05DA010	83	1.538	0.062	0.426	0.158
97	05DE007	62	0.989	0.161	0.192	0.206
98	05FB002	-118	-1.440	0.075	0.362	0.159
99	05LD001	237	2.164	0.015	0.119	0.027
100	05LD003	6	0.185	0.427	-0.084	0.421
101	05LG004	27	0.381	0.351	0.281	0.386
102	05LH005	93	0.900	0.184	0.338	0.262
103	05LJ005	202	1.786	0.037	0.274	0.086
104	05PB014	583	2.331	0.010	0.313	0.045
105	05SA002	369	3.484	0.000	0.577	0.033
106	05TD001	-91	-1.564	0.059	0.201	0.099

Table A-12 (continued). Estimated statistics for 30-day low-flow.

No. (1)	Station ID (2)	S (3)	Z (4)	P (5)	ACF (6)	P* (7)
107	05TG002	69	1.343	0.090	0.297	0.159
108	05UH002	69	1.343	0.090	0.297	0.159
109	06AB002	-218	-3.110	0.001	0.551	0.043
110	06BD001	-126	-2.027	0.021	0.233	0.053
111	06CD002	-279	-3.363	0.000	0.707	0.075
112	06DA004	-194	-2.990	0.001	0.525	0.043
113	06FB002	-98	-1.731	0.042	0.024	0.045
114	06GD001	48	0.405	0.343	0.115	0.358
115	06JB001	21	0.700	0.242	0.330	0.306
116	06KC003	125	2.585	0.005	0.719	0.134
117	06LA001	154	2.481	0.007	0.507	0.072
118	06LC001	155	2.617	0.004	0.107	0.009
119	07AA001	102	1.995	0.023	0.380	0.087
120	07AA002	80	1.224	0.110	0.108	0.136
121	07AH002	-131	-2.608	0.005	0.117	0.010
122	07CD001	-211	-2.007	0.022	0.193	0.048
123	07DD002	150	2.309	0.010	0.564	0.104
124	07EA002	4	0.097	0.461	-0.320	0.447
125	07EC002	66	1.284	0.100	-0.388	0.028
126	07EE009	16	0.296	0.383	0.242	0.407
127	07FB001	-55	-0.677	0.249	-0.148	0.216
128	07FC003	-176	-2.870	0.002	0.423	0.031
129	07GG001	-118	-1.844	0.033	0.407	0.113
130	07JC001	-14	-0.296	0.383	0.268	0.410
131	07KE001	100	1.348	0.089	0.295	0.156
132	07LE002	129	1.846	0.032	0.302	0.086
133	07OB001	236	2.738	0.003	0.367	0.030
134	07OB003	100	1.857	0.032	0.051	0.038
135	07RD001	53	0.738	0.230	0.412	0.315
136	08CC001	110	1.768	0.039	-0.016	1.793
137	08CD001	62	0.798	0.212	0.279	0.603
138	08CE001	165	1.984	0.024	-0.056	2.103
139	08CG001	135	1.621	0.053	0.114	1.456
140	08DA005	108	1.658	0.049	0.317	1.203
141	08DC006	170	2.741	0.003	0.203	0.012
142	08DD001	64	1.182	0.119	-0.076	0.102
143	08ED001	83	1.394	0.082	0.151	0.114
144	08FA002	65	0.805	0.211	0.041	0.220
145	08FB006	-53	-0.918	0.179	-0.107	0.154
146	08FB007	-3	-0.068	0.473	0.184	0.477
147	08GA010	363	1.327	0.092	0.286	0.159
148	08GA061	-135	-2.426	0.008	0.154	-2.097
149	08GD004	46	0.765	0.222	0.094	0.701
150	08HA001	-76	-1.444	0.074	-0.068	-1.543
151	08HA003	-162	-1.628	0.052	-0.066	0.042
152	08HB002	10	0.223	0.412	0.391	0.151
153	08HB008	-639	-3.784	0.000	0.220	0.001
154	08HB025	22	0.945	0.172	-0.413	1.419
155	08HC002	45	1.539	0.062	0.039	1.484
156	08HE006	-118	-1.556	0.060	0.369	0.143
157	08HF004	21	0.417	0.338	0.158	0.357
158	08JB002	-308	-2.355	0.009	0.164	0.022
159	08JE001	162	1.235	0.108	-0.038	0.100

Table A-12 (continued). Estimated statistics for 30-day low-flow.

No. (8)	Station ID (9)	S (10)	Z (11)	P (12)	ACF (13)	P* (14)
160	08KA009	-27	-0.454	0.325	-0.102	0.308
161	08KH006	415	2.777	0.003	0.034	0.004
162	08LA001	184	1.404	0.080	0.058	0.092
163	08LD001	-68	-0.698	0.243	0.078	0.259
164	08LG016	33	0.544	0.293	0.356	0.353
165	08MA002	-35	-0.511	0.305	-0.010	0.303
166	08MB006	8	0.131	0.448	0.277	0.460
167	08MG005	308	1.433	0.076	0.208	0.123
168	08MH006	-261	-2.742	0.003	-0.119	0.001
169	08MH016	-214	-2.084	0.019	0.061	0.025
170	08NB005	-178	-1.265	0.103	0.056	0.116
171	08NC004	38	0.629	0.265	0.180	0.299
172	08ND013	-43	-0.532	0.297	-0.349	0.224
173	08NE001	-37	-0.398	0.345	-0.009	0.344
174	08NE006	-196	-3.052	0.001	0.011	0.001
175	08NE077	-40	-0.314	0.377	-0.123	0.362
176	08NE087	21	0.242	0.404	0.513	0.444
177	08NF001	101	1.047	0.148	-0.045	0.138
178	08NH005	71	0.847	0.199	0.214	0.246
179	08NH016	-8	-0.223	0.412	0.203	0.427
180	08NH084	92	1.410	0.079	0.291	0.145
181	08NH115	-207	-2.516	0.006	0.510	0.070
182	08NH130	67	1.178	0.119	0.099	0.143
183	08NH131	-11	-0.214	0.415	-0.190	0.398
184	08NJ130	-142	-1.870	0.031	0.372	0.100
185	08NL007	-415	-2.707	0.003	0.423	0.040
186	08NL070	-94	-1.782	0.037	-0.071	0.028
187	08NM174	-122	-1.906	0.028	0.156	0.052
188	08NN015	73	0.905	0.183	0.136	0.213
189	08OA002	63	1.054	0.146	0.236	0.200
190	09AA006	367	2.973	0.001	0.349	0.019
191	09AA015	33	0.571	0.284	0.024	0.288
192	09AC001	181	1.343	0.090	0.154	0.123
193	09AE003	8	0.082	0.467	0.116	0.471
194	09BA001	175	2.105	0.018	0.059	0.024
195	09BC001	47	0.481	0.315	0.240	0.352
196	09FC001	-5	-0.149	0.441	0.175	0.450
197	10AB001	60	0.714	0.238	0.354	0.308
198	10AC004	125	2.108	0.018	0.098	0.028
199	10BE004	258	3.361	0.000	0.299	0.006
200	10BE007	52	0.957	0.169	0.363	0.253
201	10CB001	205	2.468	0.007	0.327	0.038
202	10CD001	340	4.101	0.000	0.384	0.003
203	10EB001	203	3.433	0.000	0.571	0.032
204	10FA002	190	2.928	0.002	0.487	0.040
205	10GA001	82	2.446	0.007	0.524	0.077
206	10GB006	28	0.815	0.207	0.520	0.318
207	10LA002	308	4.757	0.000	0.541	0.004
208	10MC002	139	3.042	0.001	0.377	0.019
209	10NC001	-81	-1.668	0.048	0.355	0.120
210	10PB001	115	1.938	0.026	0.486	0.123
211	10RC001	-104	-1.403	0.080	0.441	0.187
212	11AB117	8	0.169	0.433	0.318	0.451

