LINKED HYDROLOGIC AND CLIMATE VARIATIONS IN BRITISH COLUMBIA AND YUKON

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Abstract. Climatic and hydrologic variations between the decades 1976–1985 and 1986–1995 are examined at 34 climate stations and 275 hydrology stations. The variations in climate are distributed across a broad spatial area. Temperatures were generally warmer in the most recent decade, with many stations showing significant increases during the spring and fall. No significant decreases in temperature were found. Significant increases in temperature were more frequent in the south than in the northern portions of the region. Significant changes in precipitation were also more prevalent in the south. In coastal areas, there were significant decreases in precipitation during the dry season, and significant increases during the wet season. In the BC interior, significant precipitation decreases occurred during the fall, with significant increases during the winter and spring. In the north there were few changes in precipitation. The hydrologic responses to these variations in climate follow six distinctive patterns. The spatial distribution of these patterns suggests that in different ecozones, small variations in climate, particularly temperature, elicit different hydrologic responses.

Keywords: climate variations, ecozones, streamflow response

1. Introduction

There is a great deal of interest in the potential impacts of climate change on the water resources. This is particularly true in the agricultural regions of western Canada. Comparing the periods 1971–1983 and 1984–1995, Leith and Whitfield (1998) found an earlier onset of hydrologic spring and an extended summer resulting in lower stream flows at the end of summer in south-central British Columbia. They also observed higher early winter flows resulting from rainfall rather than snowfall. In a study of watersheds in coastal British Columbia (BC), Whitfield and Taylor (1998) compared the decade 1946–1955 with 1986–1995 and found a common pattern of higher decade-average air temperatures in the recent decade with lower spring and summer river flows, despite the slightly higher annual precipitation. The commonality between Leith and Whitfield (1998) and Whitfield and Taylor (1998) was streamflow changes during the transition between the seasons, and the existence of a common response within localized geographic areas. This leads to the questions 1) 'what is the extent of the changes in climate across British Columbia and the Yukon?', and 2) 'what other hydrologic responses exist?' Based

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upon these two studies, one would expect that if other hydrological responses exist there would be multiple cases, and they would occur in similar ecological areas.

Loaiciga *et al.* (1996) reviewed the issues and state of knowledge of climate change and the hydrological cycle. GCM predictions of global hydrologic impact in mid-latitudes streams (e.g., Columbia and Fraser Rivers) indicate flow volumes within ±20% of present under a $2 \times CO_2$ atmosphere. Nevertheless, changes in temperature are having a pronounced impact on water resources. Westmacott and Burn (1997) showed that temperature changes over the last 100 yr affected both the magnitude and timing of hydrologic events in the Churchill-Nelson River system. They found that the magnitude of hydrologic events decreased over time while snowmelt events occurred earlier. This change in timing was strongly influenced by temperature (Westmacott and Burn, 1997).

Dvorak *et al.* (1997) considered the hydrologic impact of GCM scenarios using three hydrological models. Their results show a shift forward in time of spring runoff coupled with lower late summer runoff. Brubaker and Rango (1996) indicate that in mountainous regions a warmer climate is expected to shift snowmelt earlier into the winter and spring decreasing summer runoff. Changes in precipitation which may accompany temperature changes may modify that signal.

The stability of streamflow regimes in relation to climate fluctuations were studies by Krasovskaia and Gottschalk (1992) in Fenno-Scandia. They found that Dettinger and Cayan (1995) examined a timing shift in snowmelt in mountainous catchments in California in relation to atmospheric circulation patterns. Their results illustrate the sensitivity of the timing of snowmelt to temperature.

2. Methods

The present study examines variations in temperature, precipitation, and streamflow at representative stations across British Columbia and Yukon between the decades 1976–1985 and 1986–1995, and groups stations using a visual classification. Mean daily temperature and total precipitation were examined at 34 climate stations while mean daily discharge was considered at 275 hydrometric stations for the decades 1976–1985 and 1986–1995. The climate stations were chosen on the basis of geographical location and the completeness of record during the two decades being considered. The hydrometric stations were composed of those stations which had complete records during the two decades, and were considered to have natural flows. A small number of representative streams from the Okanagan basin where streams with natural flows are rare were considered. Leith and Whitfield (1998) found that the hydrologic response to climate variations was similar in watersheds which had no land-use alterations and in those where significant land-use had occurred. The data evaluated in this study were collected using standard methods and obtained from Environment Canada.

Leith and Whitfield (1998) found that smoothing hydrometric data from daily to 5 day averages allowed examination of timing shifts in streamflow curves. The same procedure was used in this work. The use of 5 day averages results in the year being divided into 73 periods (i.e., $73 \times 5 = 365$). The climate data was reduced to 10 day averages to achieve approximately the same amount of smoothing. As a result only the odd numbers in the series apply to the temperature and precipitation series. Testing of difference between the two decades was evaluated using the Mann-Whitney test which is a non-parametric test. This test is robust against non-normality.

Hydrographs for each river in this study showing the two decades and showing statistically significant differences ($p < 0.05$) were generated. These patterns were classified by visual examination based upon the hydrograph type (rainfall-runoff, snowmelt etc.) and by the apparent timing shifts in specific time periods. Examples are shown later that are typical of most of the stations. A small number of stations were difficult to classify and were included into the group that was most similar.

3. Results and Discussion

3.1. Temperature and Precipitation

The 10 day average temperature and precipitation records at each of the 34 climate stations from across the region were tested for statistical differences between the two decades. The location of these stations is given in Figure 1.

The climate stations were divided into three groups based upon physiographic regions and similarly of climatic pattern. These groups were (1) coastal BC, (2) southern BC, and (3) northern BC including Yukon. A summary of the temperature and precipitation differences for the three groups is given in Table I. Every significant difference in temperature between the two decades was an increase, and the total absence of significant decreases is unexpected. While there is a general similarity between the three groups, there were a higher frequency of significant increases in temperature on the coast and southern interior than the more northern regions. On the coast, the temperature increases occurred from spring through summer and into the winter (Table I). In the southern interior, the temperature increases occurred in the late winter, spring and fall, with fewer increases in the summer months than on the coast. In the north, there were fewer temperature increases and these were distributed from fall through spring with few temperature increases in the summer periods (Table I).

A summary of the significant differences in precipitation between 10 day periods is also given in Table I. Significant increases and decreases in precipitation were observed in the three groups. These were concentrated into the spring (Periods 9–21), the fall (Periods 49–53) and the winter (Periods 63–73). In the coast group precipitation increased in the winter (Periods 1–7 and 61–73) and generally

TABLE I

Distribution of significant differences in temperature and precipitation amongst 10 day periods. The numbering of the periods is based upon the sequential number of 5 day periods. The numbers in the table indicate the percentage of the total number of stations that showed and increase + (decrease –)

Period	Temperature						Precipitation					
	Coast n = 12		South n = 14		North n = 8		Coast n = 12		South n = 14		North n = 8	
	+	–	+	–	+	–	+	–	+	–	+	–
1												
3			43				8		7			
5							17					
7			14						7			
9								33				
11								8				
13							8		7		25	
15									29			
17	8		7		13			8	7			
19			21						14			
21	50		43		38			8	7		13	
23												
25	67		29									
27	8											
29	8											
31			7									
33							8		7			
35	50		14		13			8	14			
37	17							8				
39	8							8				
41											13	
43	17						8					
45												
47												
49	50		36		13			58				
51								33				
53	8							8			13	
55	33		21		13			8				
57												
59	25		7									
61												
63							25		14			
65	25						25		14		25	
67	33		14		13		25		14		13	
69			7		25							
71							8					
73	8						33		43		13	

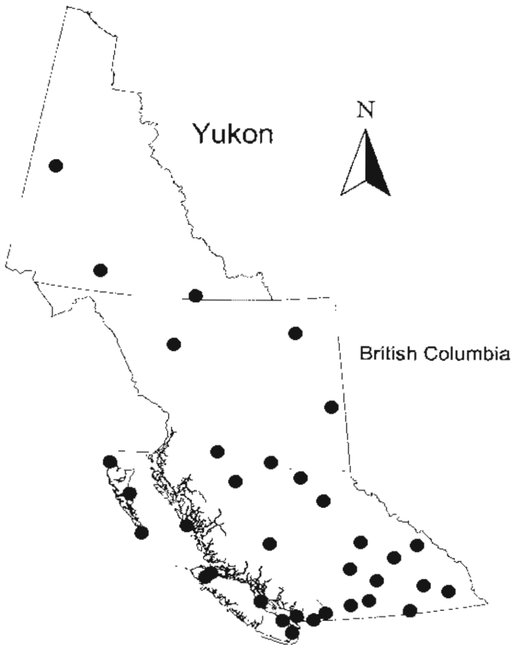
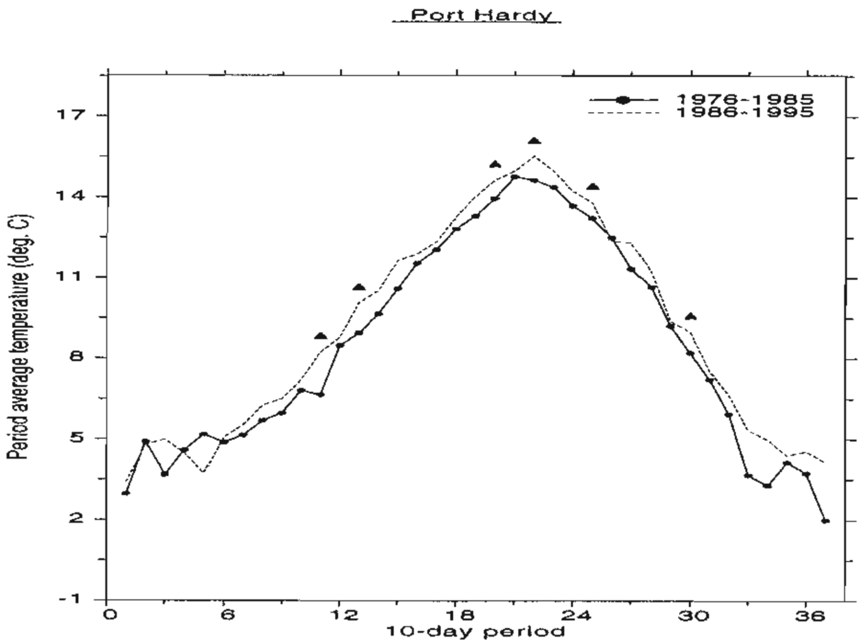


Figure 1. Location of climate stations considered in this study. The lines separate the three zones, Coastal, South, and North.

decreased over the spring and summer. In the south group, increases in precipitation were observed in the period 13–21 and in the period 61–73 (Table I). In the north, increases in precipitation were observed to be less frequent and more distributed throughout the year. There were no significant decreases in precipitation in the south or north groups. During the fall significant decreases in precipitation were observed, while in winter significant differences were increases.

Examples of the differences between the temperature and precipitation between decades are given in Figures 2–4 for each of these groups. These plots show the 10 day average temperature and precipitation for each decade. Those time periods which had significant differences are indicated by an arrowhead. In each of the time series plots, the annual cycle is 73 periods of 5 day intervals; for climate data, which was averaged over 10 day periods, only the odd numbers apply. All three example stations show increased temperature in the spring (period 21, Figures 2, 3, and 4). Port Hardy (Figure 2) and Vernon (Figure 3) both show a significant increase in the fall (Period 51) and Port Hardy also increases in the middle of summer (Figure 2). Each of these results were typical of all stations in the group, and in general the most recent decade was warmer throughout the entire year.

Similarly, example time series plots for precipitation are given in Figures 2–4. For precipitation, both significant increases and decreases were observed. Port Hardy shows periods of significant decrease during the fall, and significant increases in the winter (Figure 2). Significant differences at Vernon are distributed



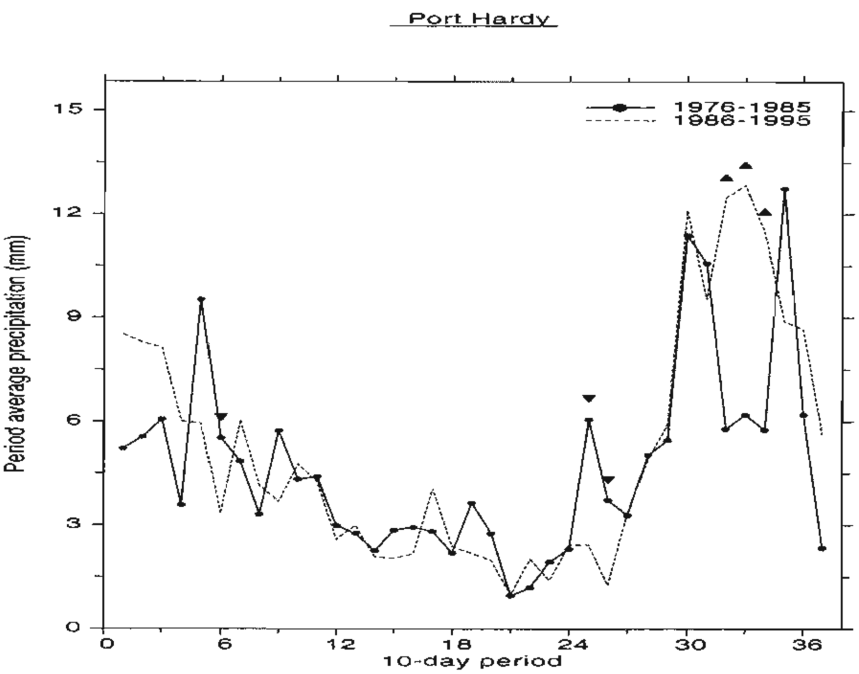


Figure 2. Decadal 10 day temperature and precipitation from Port Hardy (Vancouver Island). Up arrows indicate statistically significant increases, and down arrows significant decreases.

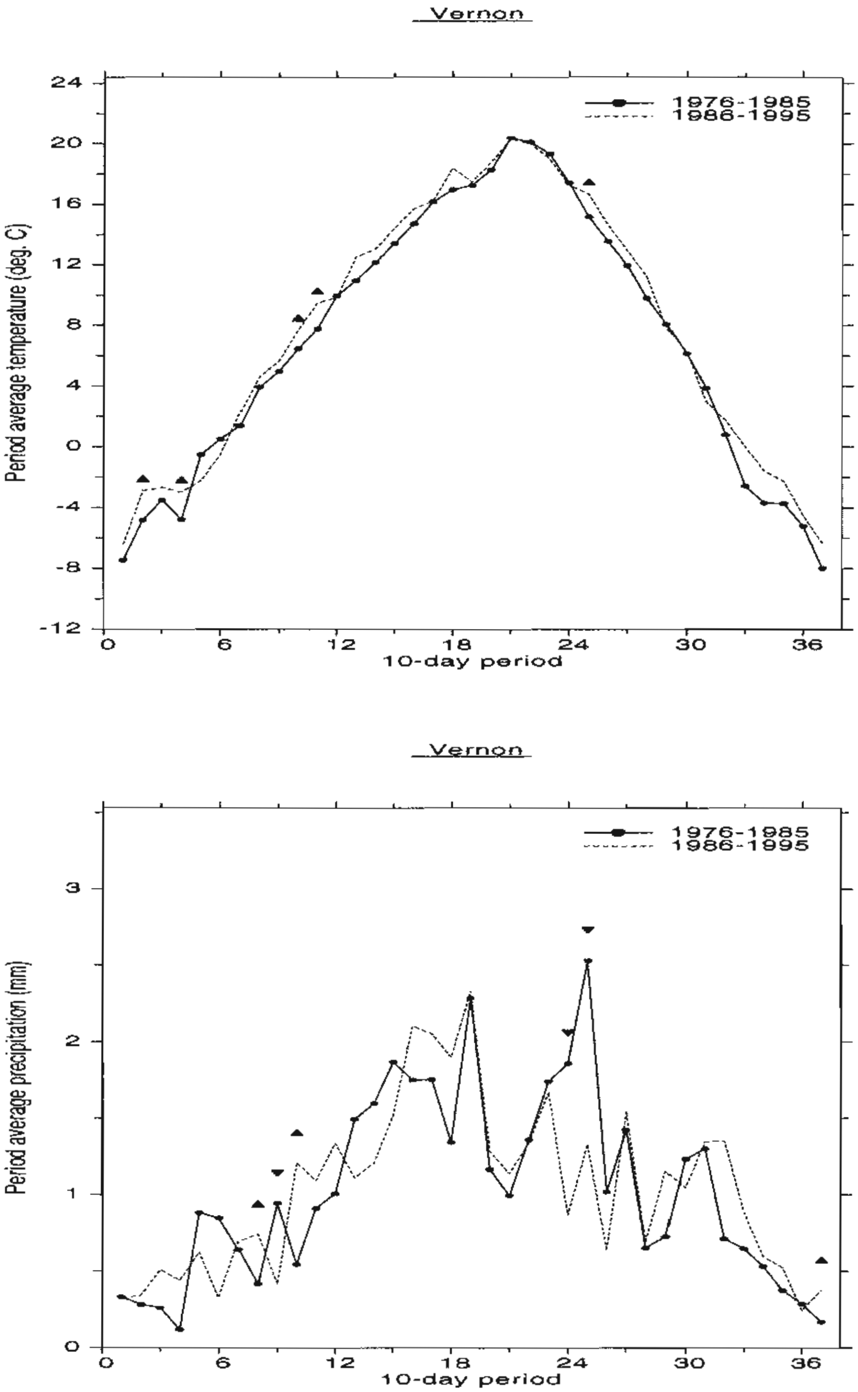


Figure 3. Decadal 10 day temperature and precipitation Vernon (South-central BC). Up arrows indicate statistically significant increases, and down arrows significant decreases.

throughout the year (Figure 3), while there were no significant differences between decades at Whitehorse (Figure 4).

Temperatures were generally warmer during the decade 1986–1995 than in 1976–1985. Climate stations on the coast of British Columbia were found to have significant increases in the spring, in mid summer, in fall, and in the early winter, but no significant changes in the early part of the year. Similar results for temperature were reported for south-central BC (Leith and Whitfield, 1998) and for coastal BC (Whitfield and Taylor, 1998). In the southern interior there were significant increases in temperature in the beginning of the year, during spring at the peak of summer, in the fall and into the winter. In the northern portion of the study area there were relatively few increases, although the records show generally warmer conditions (i.e. Figure 4). Table I indicates the general warming of temperatures between the decades. The number of significant increases in temperatures is greater than expected by chance alone and the total absence of significant decreases was unexpected. Significant differences are most frequent during the transition that takes place during spring and again in fall.

From an ecological perspective, the landscapes of British Columbia and the Yukon had a longer and warmer summer during the period 1986–1995 that in the previous ten years. This results in a longer growing season, and likely increases in total evapotranspiration. The shifts in temperature patterns observed can be expected to affect streamflows as predicted for mountainous areas by Brubaker and Rango (1996) and as noted for the Canadian prairie by Westmacott and Burn (1997).

While there appears to be no significant change in the annual amount of precipitation between the two decades, changes in precipitation patterns were observed. There are a large number of significant increases in precipitation during winter beginning with and the early portion of winter and continuing into the early portion of the year. During spring there is a mixture of both significant increases and decreases in precipitation (Table I), and significant decreases in precipitation during fall. In the coastal areas, significant changes in precipitation occur in the fall and the winter, while the southern interior exhibits most of the significant changes in the spring. Similar to temperature, the northern group shows fewer significant changes in precipitation, but the pattern is generally similar to the southern interior.

It is important to note that the climate observation stations considered here are located in valley bottoms, and may not be representative of the entire elevation range or of the interdecadal variations in precipitation at higher elevations.

3.2. Discharge

The decadal 5 day average discharges were tested for significant differences for 275 hydrometric stations using the method developed by Leith and Whitfield (1988). In south central British Columbia, Leith and Whitfield found a hydrologic response pattern to the warmer climate to be an earlier hydrologic spring (snowmelt),

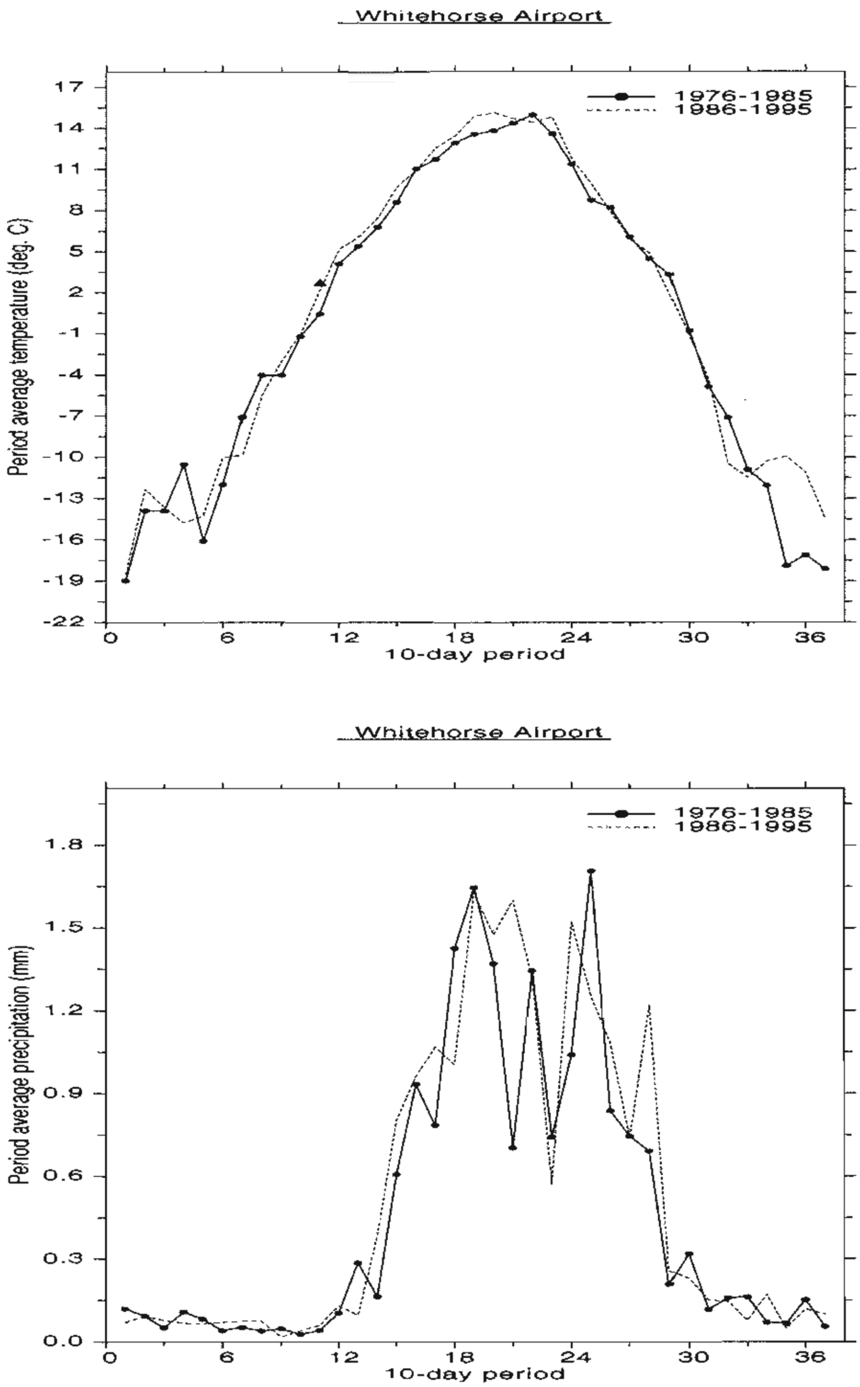


Figure 4. Decadal 10 day temperature and precipitation from Whitehorse (Yukon). Up arrows indicate statistically significant increases, and down arrows significant decreases.

with a longer summer recession with lower fall flows, followed by higher early winter flows. Whitfield and Taylor (1998) examined coastal streams using this same method and found decreases in stream discharge during the coastal 'dry' season, an increased duration to the dry period, and increases in discharge during winter periods. The 275 stations could be grouped into six different hydrologic response types. This visual classification was performed by comparing pairs of hydrographs for similarity of hydrologic pattern and hydrologic shift between the two decades. For most of the 275 station this was quite simple; stations from coastal BC all exhibited the same winter rainfall hydrology with similar inter-decadal shift to drier summers and wetter winters. Similarly for the pattern reported by Leith and Whitfield (1998). There were some cases which were close in some respects, i.e. similar hydrologic pattern but slightly different shift patterns. When several of these existed in the same region it seems practical to separate these stations into another group. Future work should evaluate a statistical clustering of these stations to replace the semi-arbitrary visual system.

Example hydrographs from these groupings are given in Figures 5–10. Response Class 1 is the type described by Whitfield and Taylor (1998). In these streams, streamflow decreases occur from the onset of spring [end of the wet season] into fall, with the fall low flow period being extended by several 5 day periods. An example of this pattern is given for the Capilano River in Figure 5. Response Class 2 exhibits an earlier onset to spring (the beginning of the rise in stream level) and lower mid-summer flows. Figure 6 illustrates this class for the Lillooet River. Response Class 3 is the type previously described by Leith and Whitfield (1998) with earlier spring runoff, extended summer and lower flows at the end of the summer recession. The Similkameen River is a typical example of this class (Figure 7). Response Class 4 exists where the onset of spring appears earlier but the change is not significant. These stations do exhibit the lower flows at the end of the extended summer recession. One example of this class is Van Tine Creek (Figure 8). Response Class 5 shows increased discharges during the entire year, particularly in the spring and fall. Figure 9 presents one example of this class, the Chilco River. Finally, Response Class 6 exhibits lower flows through most of the year. This class was only observed in streams in the Okanagan Valley which had multiple water uses. An example which demonstrates the decreased flows during the last decade is given for Kelowna Creek (Figure 10). Each station was then classified into one of these response classes.

3.2.1. *Response Class 1*

Watershed in class 1 are coastal watersheds, where the hydrology is dominated by rainfall, particularly winter rainfall. In all these streams the onset of the 'dry' season (an example is give in Figure 5) results in lower streamflows throughout the dry season. The increases in temperature result in the dry season beginning earlier and lasting longer into the fall (Whitfield and Taylor, 1998). This shift in hydrologic pattern is exacerbated by the reduction in precipitation during the fall

TABLE II

Distribution of significant differences in streamflow for Response Classes 1–6 between two decades for 5 day periods. The numbering of the periods is based upon the sequential number of 5 day periods. The number in the table are the percentage of stations classified into that group that show an increase '+' or decrease '–', only non-zero values are show

Period	Class 1 n = 37		Class 2 n = 21		Class 3 n = 172		Class 4 n = 6		Class 5 n = 31		Class 6 n = 8	
	+	–	+	–	+	–	+	–	+	–	+	–
1			5		1	8			29			63
2			5		1	9			32			63
3	32		5		1	7			35			50
4					1	5			35			63
5					1	8			32			63
6	14		14		1	3			42			50
7	57		19		1	2			39			38
8	14	3	5		1	2			32			38
9	3	14			1	6			39			25
10		8				8			39			25
11		8				6			39			25
12		5				5			32			38
13	3		33		3	1			35			13
14			10		5	1			29			13
15			10		5	1			29			
16			19		8				26			13
17			19		5	1			23			13
18			29		9				39			13
19			52		45		17		45			
20	3	5	10		53				45			
21		16	19		41				55			
22	5		76		57		17		71		13	
23		5	62		49		17		71			
24			14		11		17		68			
25			19		5	2			42			
26		3	24		16		17		32			
27			48		31				45			
28		3	24		5	3		17	13			13
29		11	19		1	9		17	26			25
30		5	29		4	6		33	39			
31			24		1	6		17	13			13
32		22	19		6	6		17	16			25
33			24		3	8		17	10			13
34			10		1	8		17	10			25
35		3	10		0	6			10	6		13

TABLE II
(continued)

Period	Class 1 n = 37		Class 2 n = 21		Class 3 n = 172		Class 4 n = 6		Class 5 n = 31		Class 6 n = 8	
	+	–	+	–	+	–	+	–	+	–	+	–
36		14	14		0	5		17	6			13
37		11	10		0	5			10			13
38		14	5		0	5		17	10			38
39		35	10	10	1	10		17				38
40		35		5		16		17	3			25
41		24		5		15			3			13
42		16		5		11			3			38
43		22		14		5			3			50
44		11		5	1	5		17				50
45		11		10		8		17				50
46		16		5		6		33	3			38
47		22				7		17				38
48		22		10		12		17	3	3		38
49	11	24		5	1	9		17	10	3		38
50		81	5	14	1	35		50	16	3		38
51		78	10	10		51		67	10	3		25
52		73	10	5		60		83	10	3		50
53		84				58		83	13	3		75
54		46	5			48		50	10			75
55		51				36		67	10			50
56		62		5	1	29		50	26			63
57		70	5			31		50	42			50
58		30			1	23		67	16			50
59		16	5			14		50	6			63
60		5				12		33	10	3		50
61		32			1	19		33	13			63
62		30				19		17	6			50
63		5				6		17	3			50
64			5		1	2		17	6			38
65	8		10		4	2		17	3			50
66	16		10		2	1		17	3			38
67	16		19		2	1		17	13			38
68	19		24		6			17	23			38
69	3		19		6	1			39			38
70		3	19		3	1			32			38
71		3	19		1	3			42			25
72			24		2	2			55			25
73	3		19		3	1			58			13

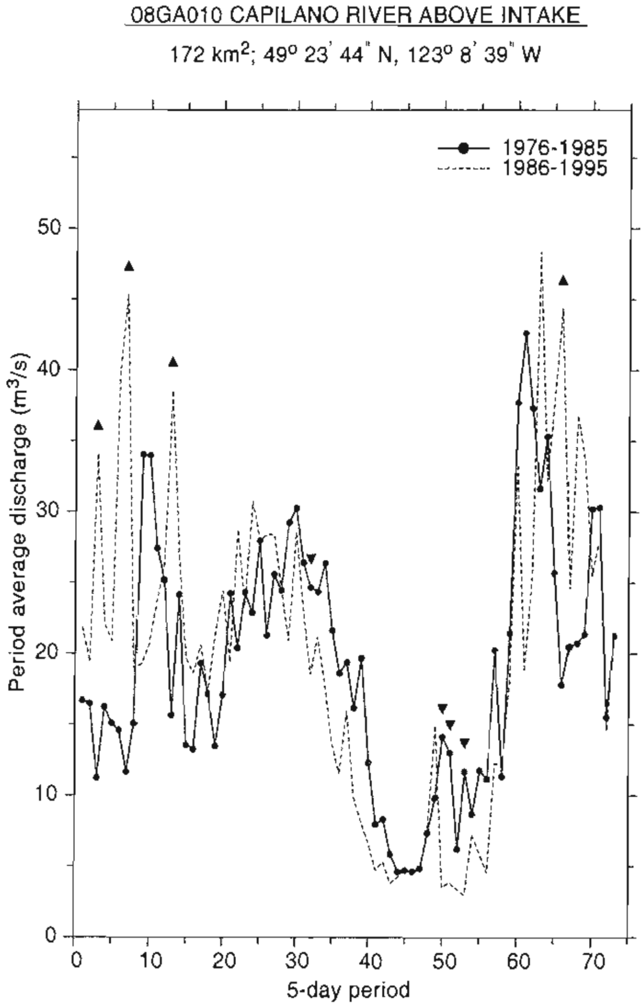


Figure 5. Selected representative example river from Response Class 1. Up arrows indicate statistically significant increases, and down arrows significant decreases.

period. In all the watersheds in this region, reduced amounts of water are being observed, especially during the fall where the recession of streams throughout the dry season are extended further into the fall. Thirty seven streams exhibited this pattern. Watersheds along the coastal areas of British Columbia are rainfall driven. The hydrology of these 37 watersheds can be considered to have two seasons, a winter wet season coinciding with winter rains, and a summer dry season where amounts of rainfall are substantially less, as demonstrated for Port Hardy (Figure 2). Whitfield and Taylor (1998) demonstrated that climate shifts within this coastal zone were coincident with observed changes in streamflow, particularly in the summer regime of coastal rivers. The period of hydrologic summer in these

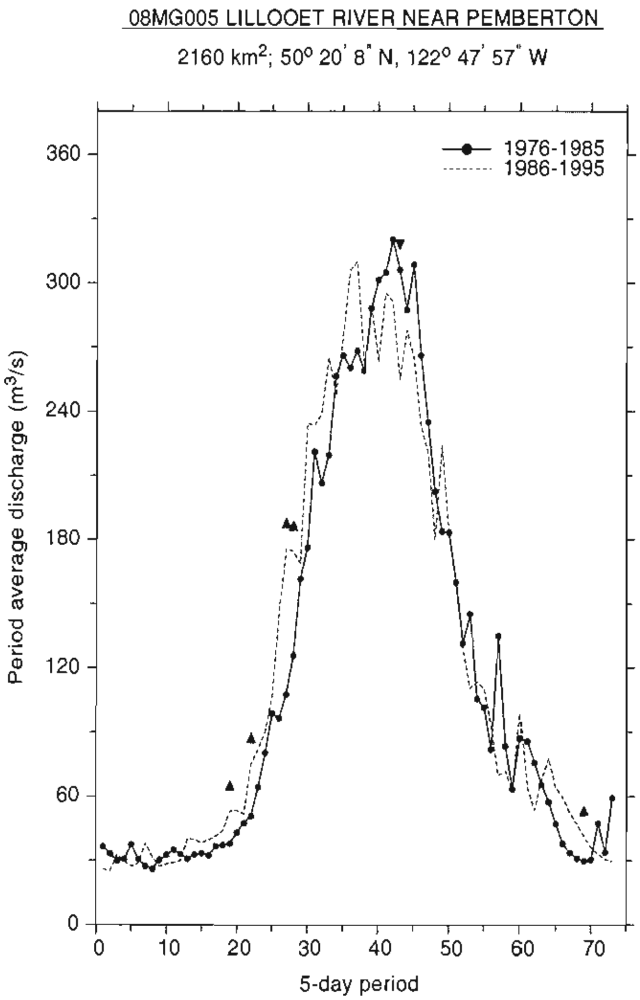


Figure 6. Selected representative example river from Response Class 2. Up arrows indicate statistically significant increases, and down arrows significant decreases.

coastal rivers is noticeably longer in the more recent decade than in the previous decade. These changes are characterized by the summer low flow period beginning earlier in April and May.

Watersheds along the coastal areas of British Columbia are rainfall driven. The hydrology of these 37 watersheds can be considered to have two seasons, a winter wet season coinciding with winter rains, and a summer dry season where amounts of rainfall are substantially less, as demonstrated for Port Hardy (Figure 2). Whitfield and Taylor (1998) demonstrated that climate shifts within this coastal zone were coincident with observed changes in streamflow, particularly in the summer regime of coastal rivers. The period of hydrologic summer in these coastal rivers is

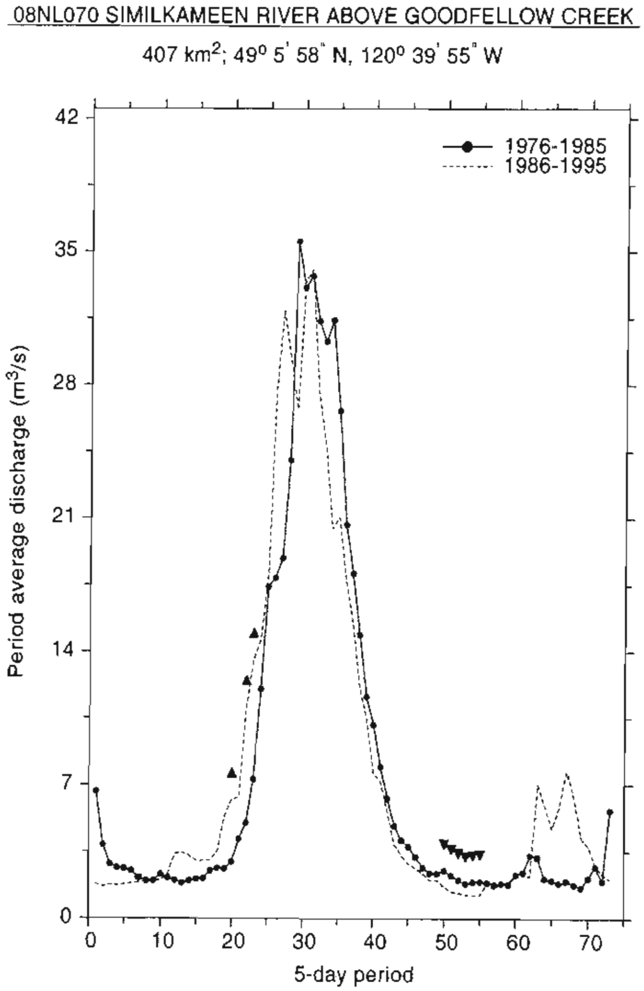


Figure 7. Selected representative example river from Response Class 3. Up arrows indicate statistically significant increases, and down arrows significant decreases.

noticeably longer in the more recent decade than in the previous decade. These changes are characterized by the summer low flow period beginning earlier in April and May. Coastal hydrologic summer also ends later, becoming extended into late September and early October. These results also suggest that coastal, rainfall-driven watersheds are sensitive to changes in temperature and precipitation inputs (Whitfield and Taylor, 1998).

3.2.2. *Response Class 2*

Watersheds in class 2 are located within the coast mountains where the hydrology is dominated by snowfall and glaciers are present. The observed changes in streamflow are an earlier spring runoff and higher streamflows during the early summer,

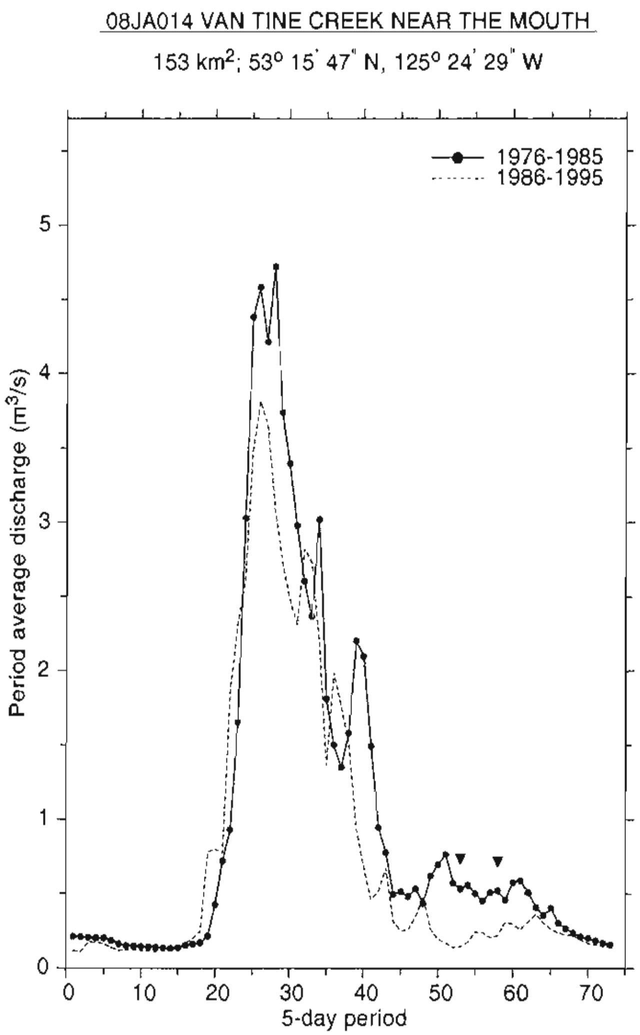


Figure 8. Selected representative example river from Response Class 4. Up arrows indicate statistically significant increases, and down arrows significant decreases.

followed by low flows during late summer and fall. Many of these watersheds also have increased flows during the winter. Twenty-one streams exhibited this pattern.

Watersheds located in the Coast Ranges of British Columbia respond differently than other areas. While the onset of spring snowmelt is advanced in time, summer streamflows are greater in the more recent decade than earlier. This augmentation of streamflow may be due to removal of water from storage in snowfields and glaciers. Only two climate stations were located in this area (Smithers and Tatlayoko Lake). These stations are located in valley bottoms and will likely not be representative of the climatic variations which take place at high elevations in this

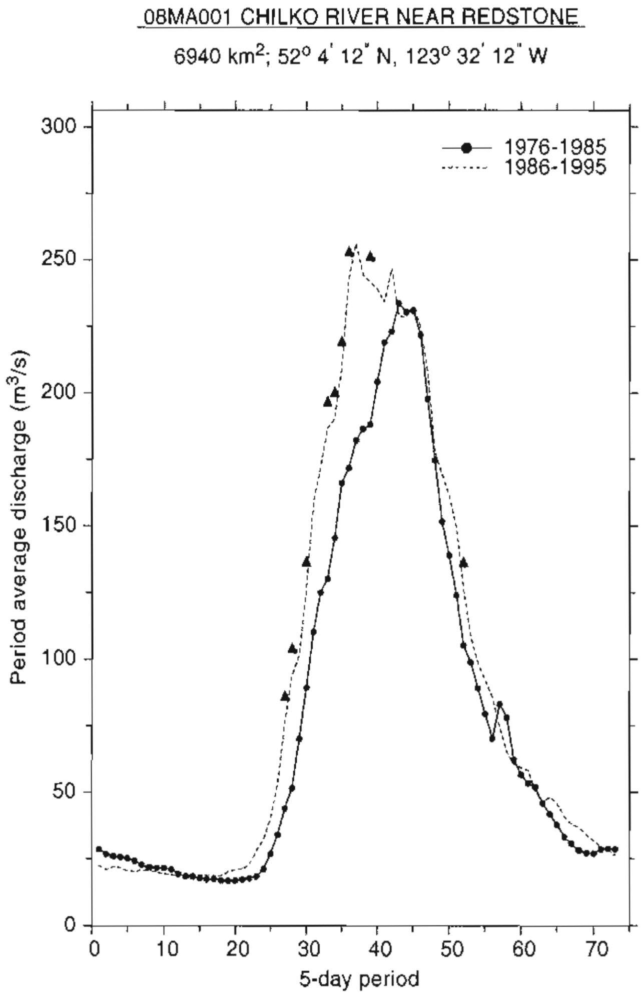


Figure 9. Selected representative example river from Response Class 5. Up arrows indicate statistically significant increases, and down arrows significant decreases.

mountainous area. Many of the 24 watersheds in this class produced significantly lower streamflows during August and September (i.e. periods 40–51 in Table II).

3.2.3. *Response Class 3*

Watersheds in this class occur across the interior of British Columbia. These stream all show the hydrologic pattern shift to an earlier spring freshet, characterized by the increases in the periods 18–22 in Table II. These streams also show the reduction in streamflow that occurs from the extended summer and the reduction in fall precipitation. Some streams in this class show an increase in early winter streamflow, reflecting the warmer and wetter conditions in these areas. One hun-

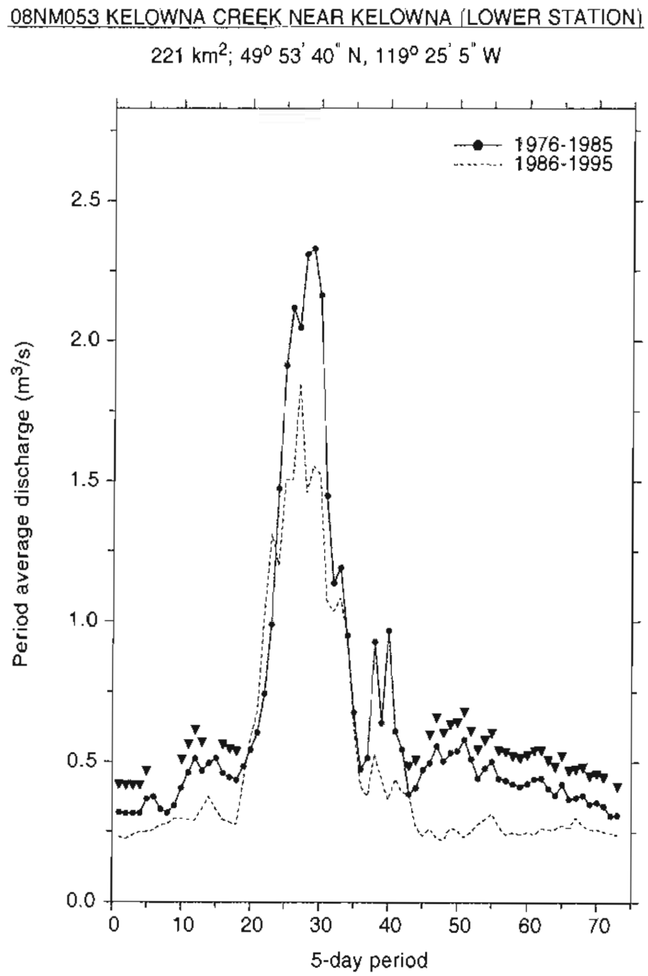


Figure 10. Selected representative example river from Response Class 6. Up arrows indicate statistically significant increases, and down arrows significant decreases.

dred and seventy two streams exhibited this pattern, and Figure 7 shows the pattern for the Similkameen River.

This response class dominates streams in southern BC. Leith and Whitfield (1998) described the hydrologic mechanism in south-central BC and that mechanism applies to all the watersheds in Class 3. The warming in spring advances the onset of the spring snowmelt (i.e. periods 18–25, Table II). The earlier melting of the snow pack lengthens the summer recession. Coupled with lower fall precipitation, results in lower streamflows in September and October, (i.e. periods 48–60, Table II). For some watersheds, increases in temperature changes the form of early winter precipitation from snow to rain, thereby increasing streamflows.

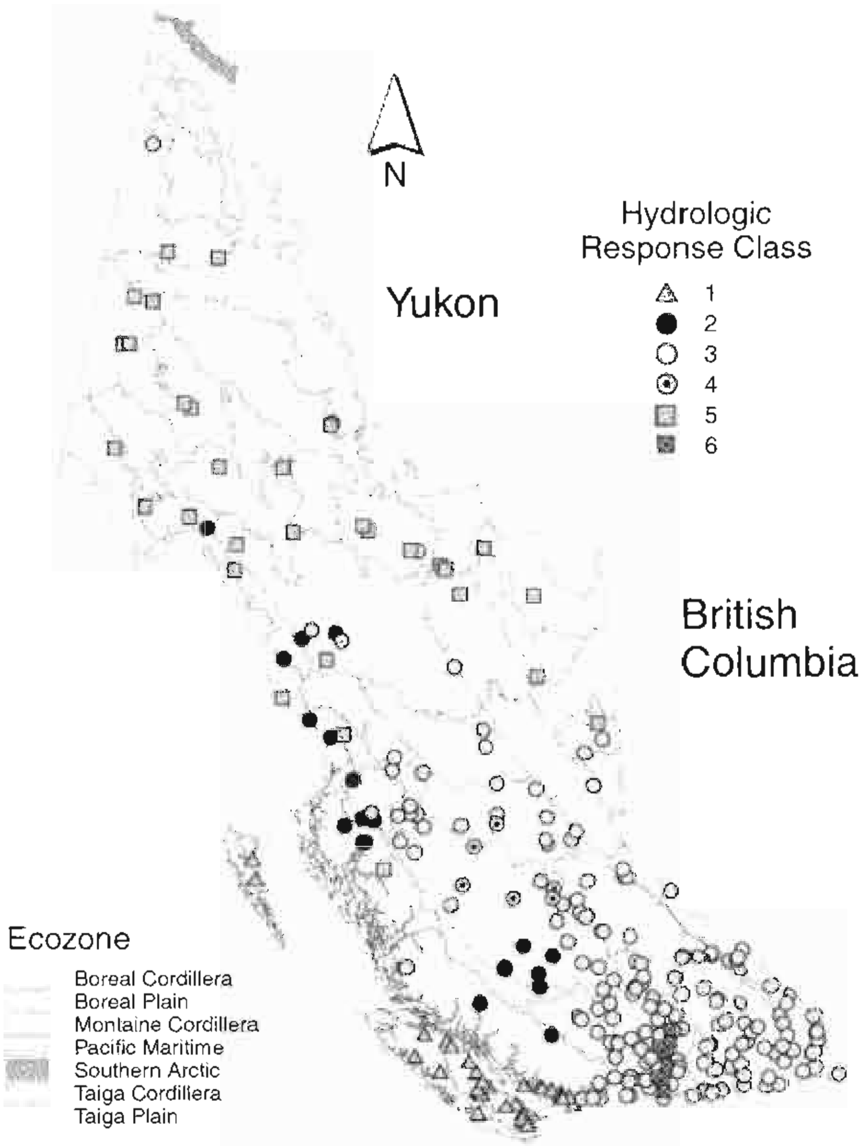


Figure 11. Spatial distribution of the six hydrologic response classes for 275 streams amongst the ecoregions of British Columbia and Yukon.

3.2.4. *Response Class 4*

Class 4 watersheds occur in a specific area northwest of Prince George, BC. These watersheds do not exhibit the earlier onset to spring but do show the reduced flows during the end of the summer recessions (Table II).

Six watersheds were grouped into this class. These watersheds are generally similar to the members in class 3 in that they exhibit significant decreases in streamflow in periods 48–60 (Table II). However, this class does not show the earlier onset of spring snowmelt. The onset of freshet has not changed in time as evident from periods 18–20 in Table II. The area where these stations are located is an interior plateau, and the climate stations in this area (Fort St. James and Wistaria) show few significant increases in temperature, only one of which is during the spring. An example member of this group is shown in Figure 8. The lack of advance in spring freshet is thought to be related to the lack of vertical extent in these watersheds, (the stations in class 3 are more mountainous terrain).

3.2.5. *Response Class 5*

The watersheds in this class are distributed across the northern portion of the region from the northern Prairie and through most of the Yukon. In these watersheds streamflow has increased between the two decades throughout most of the year (Table II). Only a few increases were observed in mid-summer in these thirty-one streams. The Chilko River is one example of this group (Figure 9).

In northern BC and the Yukon increased streamflows were observed throughout most of the year, particularly in the winter months. This landscape is typified as having long cold winters and stores of water in glaciers, aufeis, permafrost and snow deposits. Warming of the climate would release water from each of these stores. Michel and van Everdingen (1994) suggest that the degradation of the permafrost would increase the hydraulic conductivity of warmed areas, further increasing the movement of water off the landscape. The results presented here are consistent with those of Xu and Halldin (1997). Their model of impacts of climate change at high latitudes shows a shift in the peak flow and higher runoff.

3.2.6. *Response Class 6*

Class 6 watersheds occur only in the Okanagan Valley. The streams in this group are no longer pristine, but have shown extensive changes in land use including water withdrawals. In these streams, discharges are lower particularly during winter (Table II). Eight streams exhibited this pattern.

Watersheds in this class are to a degree special cases. All of these streams are located within the Okanagan drainage, and do not represent pristine watershed conditions. Leith and Whitfield (1998) found that the hydrologic response to variations in climate was strong, land use alterations did not alter the response in the Similkameen drainage. Amongst these stations the expected natural response would correspond to Response Class 3. The eight streams in this group show consistent decreases in streamflow throughout the entire year (Table II). These decreases occurred during the non-freshet period of the year – the late summer, fall and winter. The one significant increase that was found was during spring freshet. The example presented for Kelowna Creek (Figure 10) is typical of the streams in this class. While there is a similar amount of water present during the snow melt period, during the remainder of the year there is much less water present in these streams that in the earlier decade. The major common characteristic of these streams is that they are in a valley with large demands on available supplies of water for agriculture and for human consumption.

The distribution of the hydrologic types and the responses classes of the 275 rivers in this study is not random. The distribution of the response classes are plotted on the ecozones of British Columbia and Yukon in Figure 4. Stations in Response Class 1 occur only in the Pacific Maritime ecozone. Stations from Response Class 2 are found along the interior margin of the Pacific Maritime and into the western portion of the Montaine Cordillera. Response Class 3 dominates rivers and streams across the Montaine Cordillera, and Response Class 4 rivers all occur in a single discrete area within that zone. Response Class 5 dominate the rivers that are observed in the Boreal and Taiga ecozones (Boreal Cordillera and Boreal Plain; Taiga Cordillera and Taiga Plain).

While the climate variation observed was rather small, the hydrologic response to these changes is impressive. The hydrological changes that were observed indicate a response to these variations in climate. Two things stand out in these responses. First, different hydrologic types respond to the climate variations in different manners. Second, there is a clear linkage between the type of hydrology, the response to climate variation, and the ecology of the study area. The response characteristics vary across the region, but fall into 6 distinctive groups. These groups reflect the basic nature of the hydrological system in these areas and how the water on the landscape responds to the shifts in temperature and precipitation between the two decades examined. The spatial mapping of these response classes (Figure 10) indicates that the distribution of responses is not random. Each response class occurs in a specific geographic area. Each class that was identified indicates a different response of the hydrologic system to the variations in climate in that region. Class 1 occurs in every watershed in coastal BC from the Queen Charlotte Islands through Vancouver Island and throughout the lower Fraser Valley. Class 2 occurs only within the region of the Coast Mountains. Class 3, to which most watersheds belong, occurs in the southern portion of BC with a few cases in the north. Class 4 only occurs northwest of Prince George while Class 5 occurs across the Yukon and northern BC. Finally, Class 6 occurs in specific watersheds in the Okanagan Valley. These response classes reflect the changes in the hydrology which have occurred as a result of the variations in climate.

4. Conclusions

The landscapes of British Columbia and the Yukon had longer and warmer summer during the period 1986–1995 that in the previous ten years. In coastal BC the shifts in precipitation patterns indicate increases in winter precipitation, and decreases in precipitation during the dry season. In the BC interior, and extending into the north, winter precipitation increased, spring showed a shift in patterns between periods, and precipitation decreased during fall.

The hydrologic response to these changes varied among ecoregions, but was consistent within these regions. In coastal watersheds the wet season is shorter and wetter and the dry season is drier and longer. In the coast mountains, spring is earlier, and early summer flows and winter flows are higher. In the southern interior hydrologic spring is earlier, and summer was extended resulting in lower flows in the late summer and early fall. In the Nechako Plateau several watersheds showed lower flows in the late summer and early fall due to extended summers, but not the shift in hydrologic spring. Throughout the northern regions, the dominant pattern is a streamflow increase throughout the year believed to be due to increased hydraulic conductivity and the de-watering of permanent stores of water. Finally, in selected watersheds in the Okanagan Valley, freshets were similar between decades, but persistent significant decreases in streamflow in fall and winter were observed in the most recent decade.

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