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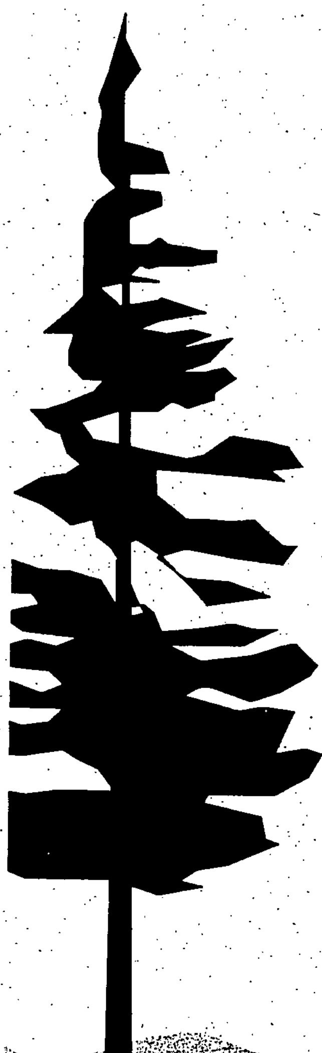
Water Quality in the Greater Vancouver Water Supply Watersheds



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Abstract

This study analyzed data collected from the GVRD (Greater Vancouver Regional District) stations located in the Coquitlam River, Capilano River and Seymour River watersheds from about 1991 to 1993. The main purposes of this study are to determine the processes affecting water quality and to determine an improved sampling program. Hysteresis diagrams were used to determine the processes affecting the water quality. This relationship between runoff and stream chemistry was found to be linear, allowing the use of smoothed lines to assess the existing results. These diagrams reveal that water chemistry is largely controlled by rainfall - runoff, i.e., there is a direct relationship between chemical composition and stream discharge for most variables. Thus, there are only a few cases where storage effects and the effects of other processes were observed. Smoothed hysteresis diagrams were used to determine improvements to the current sampling program. The smoothed hysteresis diagrams of each variable for all stations were plotted to determine the effects of station location on concentration readings within each watershed and ultimately determine where stations are needed and where they are redundant. These plots indicated that the mainstem of the Coquitlam River watershed differs from the rivers and streams to the east and west of the mainstem for both the sediment related variables and ion related variables. Also, these plots suggest that the streams to the east of the mainstem differ from the streams to the west of the mainstem in this watershed for the sediment related variables. For the Capilano River watershed, these plots indicated no

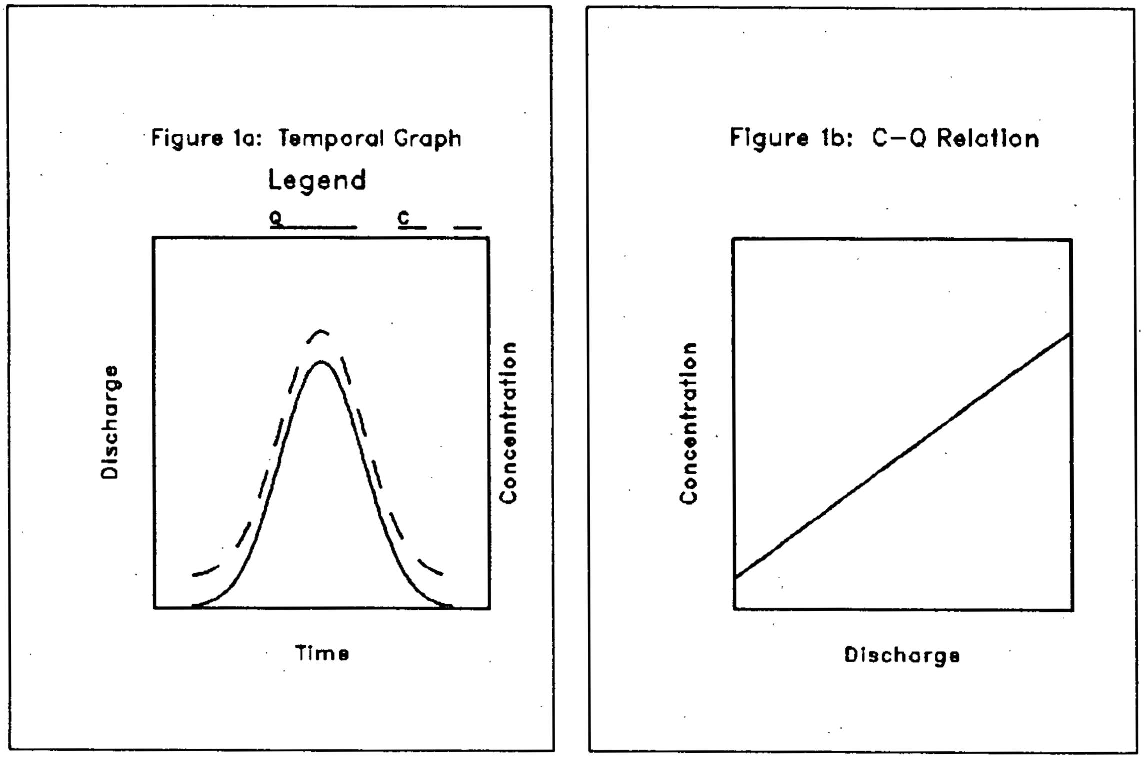
differences between streams to the east and west of the mainstem; however, there was an indication of a difference between the tributaries and the mainstem. No significant difference was found between the stations in the Seymour River watershed.

Introduction

This study examines approximately 2.5 years of water quality data (mid 1991 - 1993) obtained from 55 stations in three watersheds of the Greater Vancouver Regional District (GVRD). The purposes of this study are to determine the processes affecting the water quality in these watersheds, and to assess similarities and differences of the stations within and between the three watersheds so that recommendations on efficient and effective data collection from these watersheds can be provided.

The processes affecting streamflow water quality may be investigated using hysteresis diagrams, that is, plots of water quality observations (C) against water discharge (Q). Williams (1989) studied the relations between sediment concentration (C) and water discharge (Q) for a single hydrological event. He suggested that studying the variations in timing of the concentration cycle in relation to the discharge cycle, as well as skewness and spread, provide a reliable means of classifying C-Q relations. For instance, a straight line occurs when the C-graph and Q-graph have simultaneous peaks and identical spreads and skewnesses, though not necessarily identical relative height of peaks, see Figure 1a and 1b. A loop forms in the C-Q relation when the discharge peak and the concentration peak occur at different times, see Figure 2a and 2b. Whitfield and Clark (1992) also used hysteresis diagrams to determine the processes which affect the water chemistry of eight pristine drainage basins of varying sizes within the province of British Columbia, Canada.

Not only is it important to determine the processes which affect water quality it is equally important to determine if there



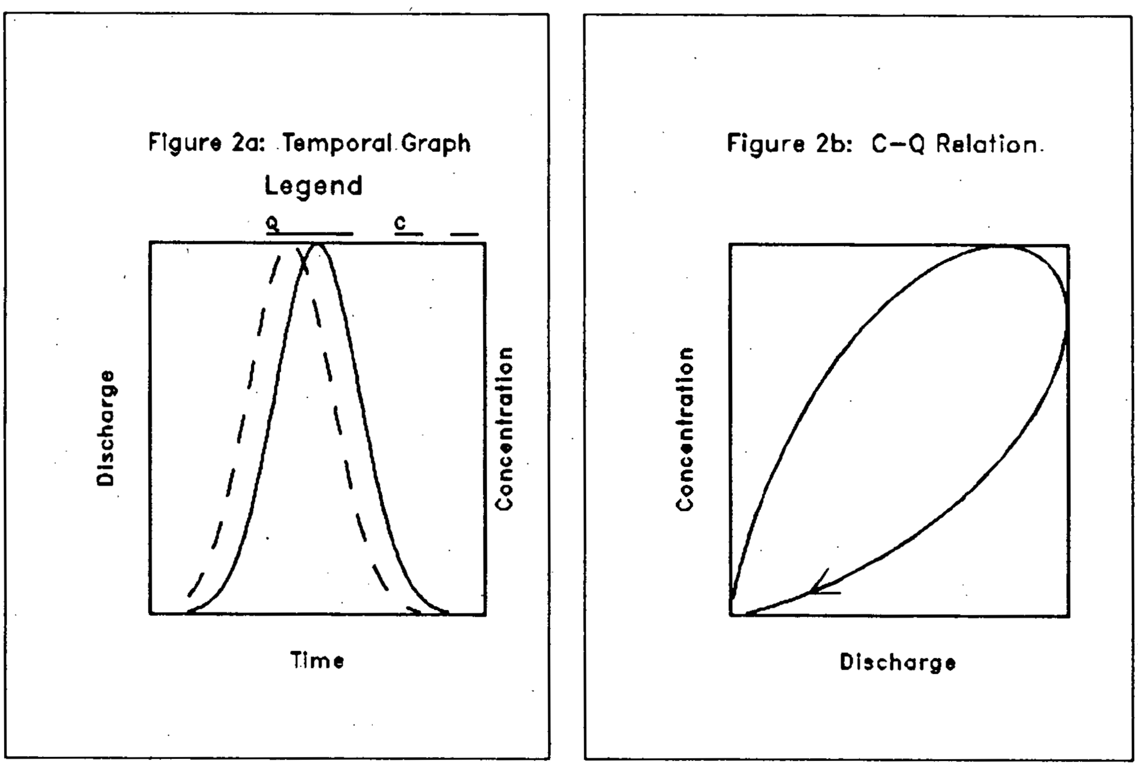


Figure 2a and 2b: A clockwise loop occurs when the concentration peak occurs before the discharge peak.

is overall change in water quality over time. Plotting the water quality variables against time may reveal seasonality, outliers and trends in the data record, and as a result, appropriate corrective action can be taken.

Study Area and Data Sources

There are three GVRD watersheds involved in this study: Coquitlam, Capilano and Seymour. Information concerning these watersheds is provided in Table 1.

Table 1: Information on GVRD Watersheds

	Coquitlam	**Capilano**	**Seymour**
Map Reference	Figure 3	Figure 4	Figure 5
Drainage Area	215 km^2	199 km^2	131 km^2
No. of GVRD WQ Stations	14	25	16
WSOC* Gauge	08MH141	08GA010	08GA030
Gauged Area	54.7 km^2	172 km^2	176 km^2

* Water Survey of Canada (WSOC)

The drainage area for the Coquitlam watershed was taken from a point downstream of Coquitlam Lake as shown in Figure 3. The drainage area for the Capilano watershed was taken above Cleveland Dam and for the Seymour watershed above Seymour Falls Dam.

Coquitlam

The water quality data from the stations in the Coquitlam watershed were collected biweekly in 1991 (Jun 1991 - Dec 1991), 1992 (Feb 1992 - Nov 1992), and 1993 (Apr 1993 - Nov 1993). Turbidity data, however, were gathered more frequently and over a longer period of time - weekly samples in 1990 (Jul 1990 - Nov 1990), 1991 (Mar 1991 - Nov 1991) and 1992 (Feb 1992 - Nov 1992), and biweekly samples in 1993 (Apr 1993 - Dec 1993).

Figure 3

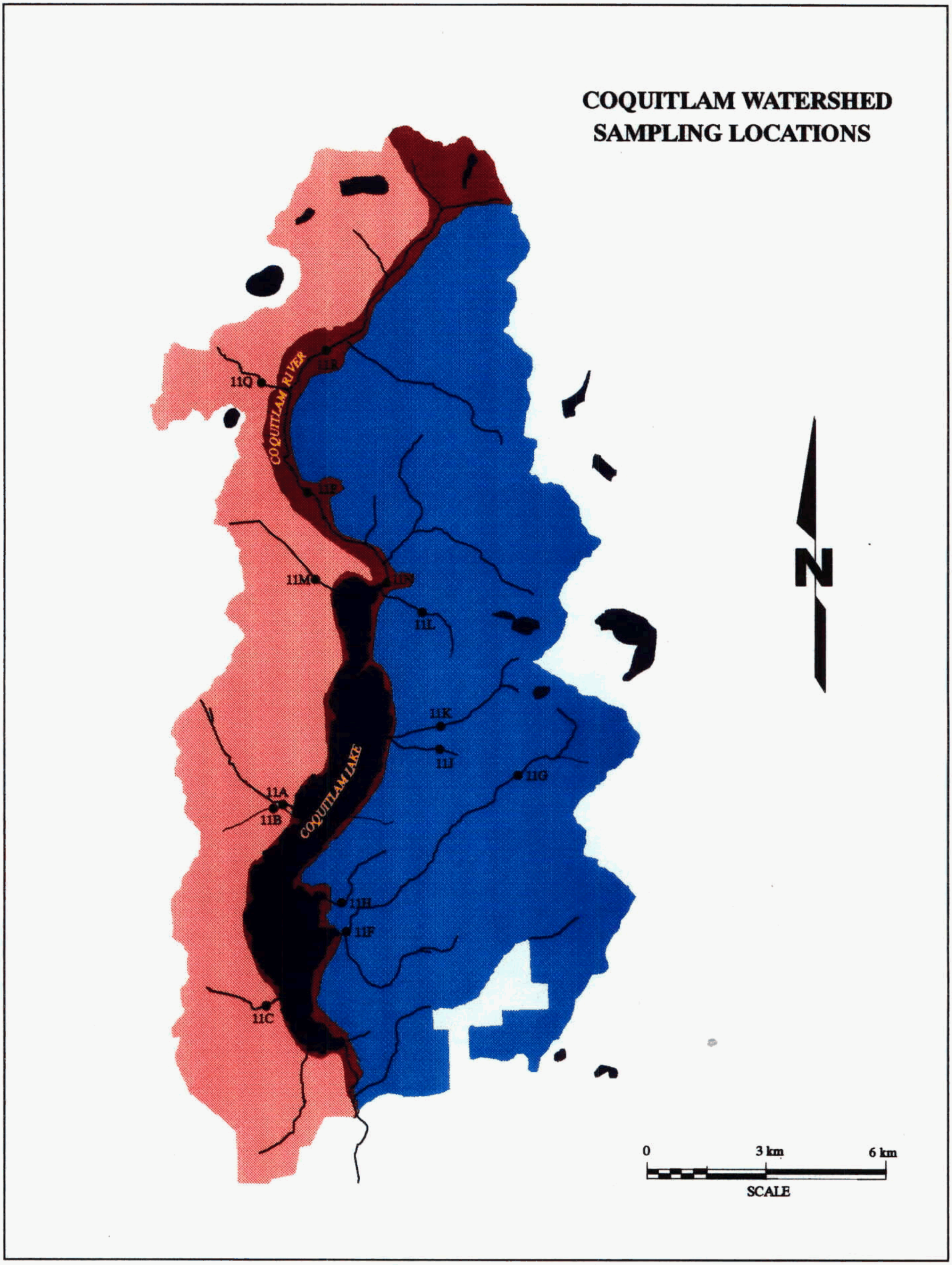

COQUITLAM WATERSHED
SAMPLING LOCATIONS
COQUITLAM RIVER
COQUITLAM LAKE
11Q
11R
11P
11M
11N
11L
11K
11J
11G
11A
11B
11H
11F
11C
N
0
3 km
6 km
SCALE

Figure 4

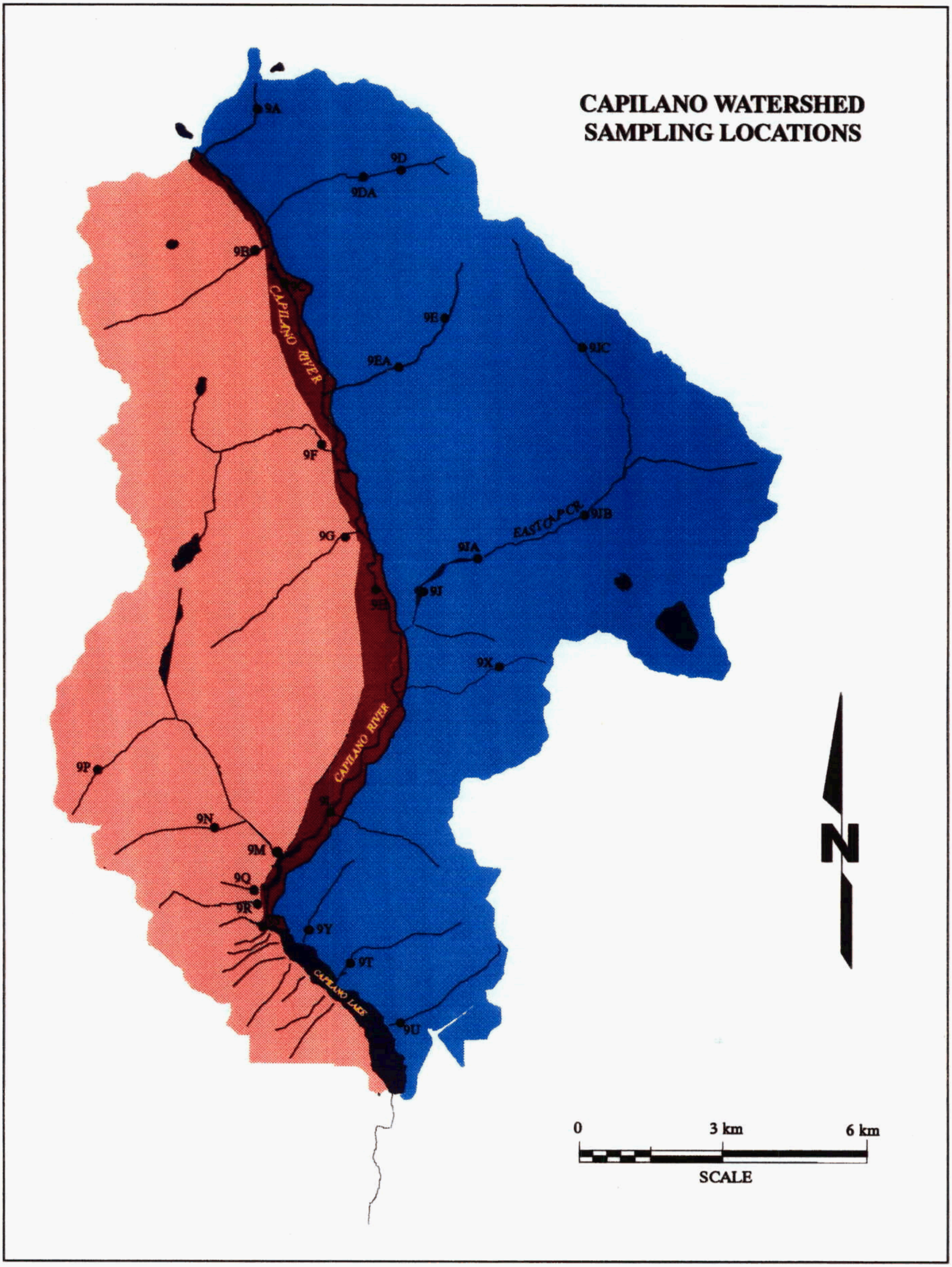
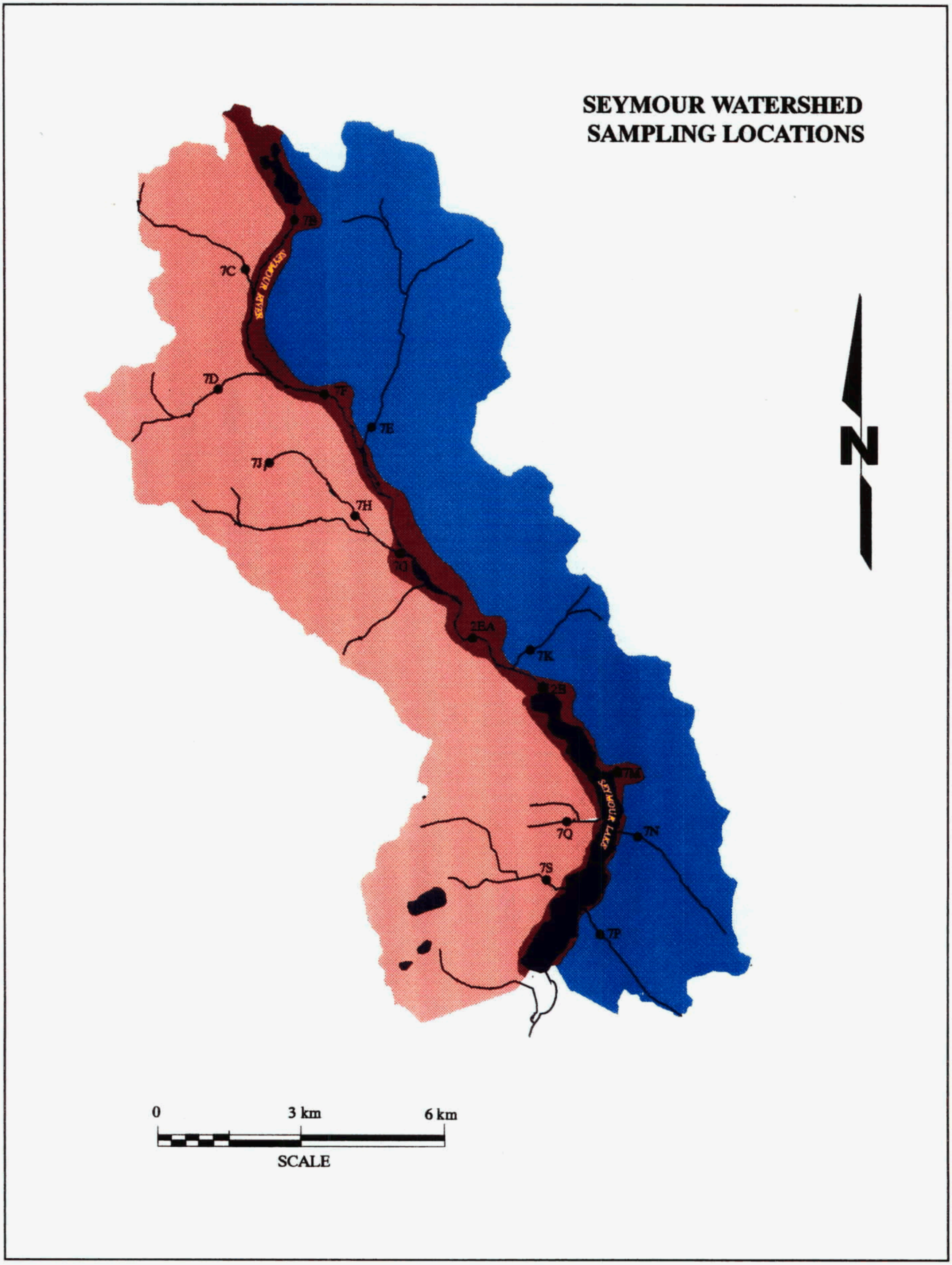

CAPILANO WATERSHED
SAMPLING LOCATIONS
9A
9D
9DA
9B
CAPILANO RIVER
9E
9EA
9JC
9F
9G
EAST CAP CR.
9JB
9JA
9J
9X
CAPILANO RIVER
9P
9N
9M
9Q
9R
9Y
9T
9U
N
0
3 km
6 km
SCALE

Figure 5


SEYMOUR WATERSHED
SAMPLING LOCATIONS
SEYMOUR RIVER
SEYMOUR LAKE
7B
7C
7D
7F
7E
7J
7H
7G
2BA
7K
2B
7M
7Q
7N
7S
7P
N
0
3 km
6 km
SCALE

Capilano

Data from the stations in the Capilano watershed were collected weekly in 1991 (May 1991 - Dec 1991), and 1992 (Jan 1992-Nov 1992) and biweekly in 1993 (Apr 1993 - Nov 1993). For turbidity, samples were collected weekly in 1990 (Jul 1990 - Dec 1990), 1991 (Mar 1991 - Dec 1991) and 1992 (Jan 1992 - Nov 1992), and biweekly in 1993 (Apr 1993 - Nov 1993).

Seymour

Samples from the Seymour watershed were collected biweekly in 1991 (Jun 1991 - Dec 1991), weekly in 1992 (Jan 1992 - Nov 1992) and biweekly in 1993 (Apr 1993 - Nov 1993). Turbidity data were collected weekly in 1990 (Jul 1990 - Dec 1990), 1991 (Mar 1991 - Dec 1991), and 1992 (Jan 1992 - Nov 1992) and biweekly in 1993 (Apr 1993 - Nov 1993). Appendix I shows the data collection for the three watersheds.

Seven water quality variables were investigated for each station in the three watersheds. These variables were: true colour, total iron, total organic carbon (TOC), turbidity, conductance, alkalinity, and nitrate+nitrite.

Since flow data are not available at any of the GVRD stations, the Water Survey of Canada (WSOC) stations were used to estimate flows. The drainage area for each GVRD station was delineated on 1:50,000 scale map sheets. The ratio of the drainage area above the GVRD station to the drainage area of WSOC station in the watershed was multiplied by the flow at the WSOC station. The assumption of uniform flow in the watershed was made. This assumption was tested using Capilano data from the late 1920's, see Appendix II.

Methods

Process Analysis

At each GVRD sampling station time series plots were prepared for each of the seven water quality variables. A time series plot presents observations in a time ordered sequence. These plots can be used: to reveal outliers, i.e., unusually high or low values which may be errors; to examine for trends, that is changes in level of a variable; and to examine for seasonality (periodicity).

Hysteresis plots of each water quality variable against estimated discharge were prepared at each sampling station. This analysis has been applied to all data sets even though each is an intermittent sampling with significant periods of missing data. This type of assessment is normally applied to complete years of data. These plots provide a means of examining the driving mechanisms of water quality variables. For certain circumstances a water quality variable may have different relations to discharge depending upon level of discharge and whether discharge is increasing or decreasing. An example of a hysteresis loop is provided in Figure 6. If there is only one relationship between a water quality variable and discharge and they are in phase, i.e., peaks of one quantity coincide with peaks of the other, then the hysteresis curve becomes a straight line with positive slope.

Smoothed hysteresis plots were also prepared for each water quality variable. For the smoothed plot, a best fit line was constructed to the data. This is done for several stations so that the responses at a set of stations can be compared.

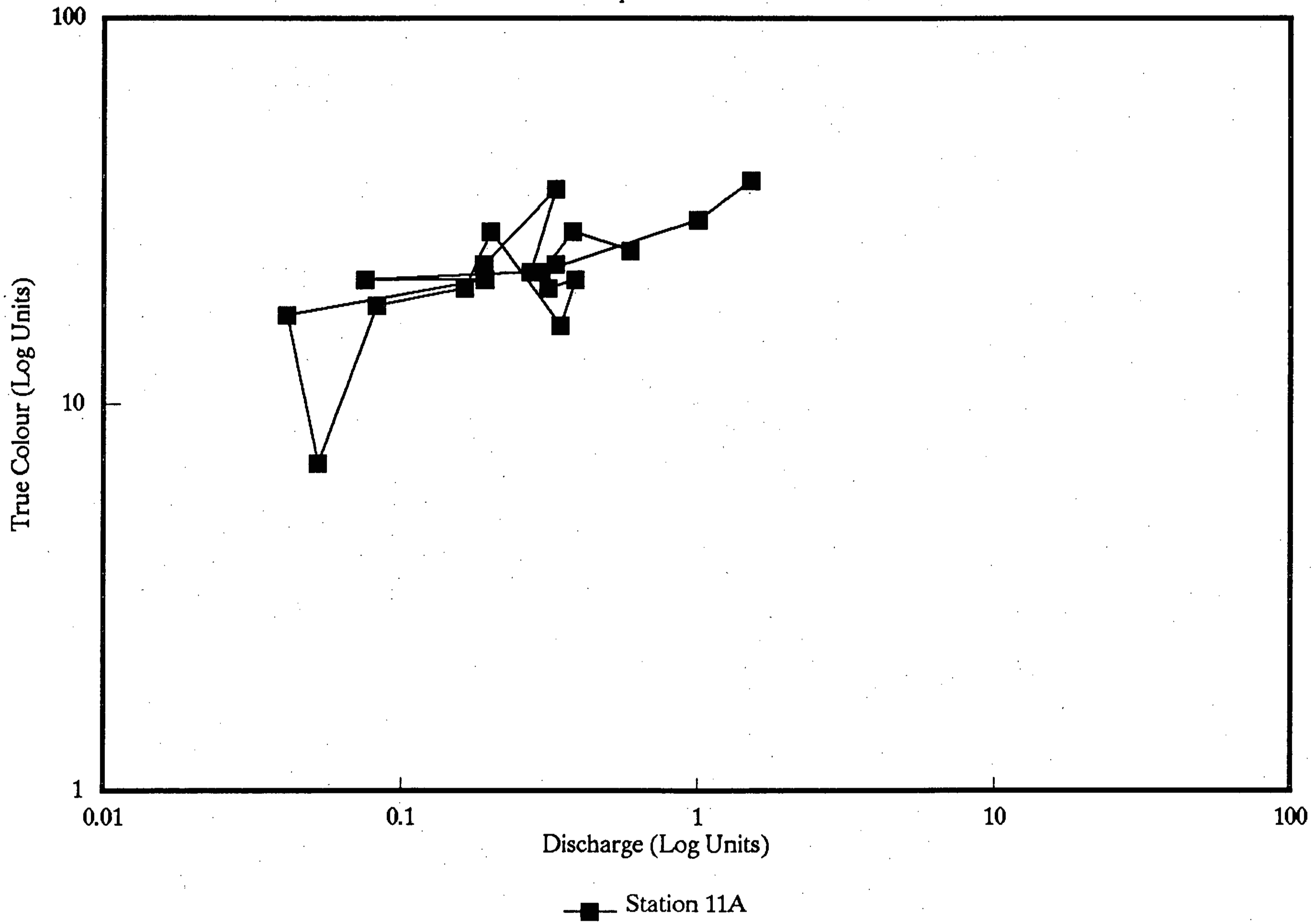
Results

Coquitlam River

Time series plots revealed seasonal variation for several variables. Discharge peaks in May; conductance and alkalinity, groundwater or ion related variables, peak in September; while sediment related variables did not show clear seasonal peaks. Nitrate+nitrite also show peaks in September-October.

Figure 6: Hystersis plot for true colour (1992)

Coquitlam River Watersheds



The results of the hysteresis plots for the Coquitlam River watershed are summarized in Table 2.

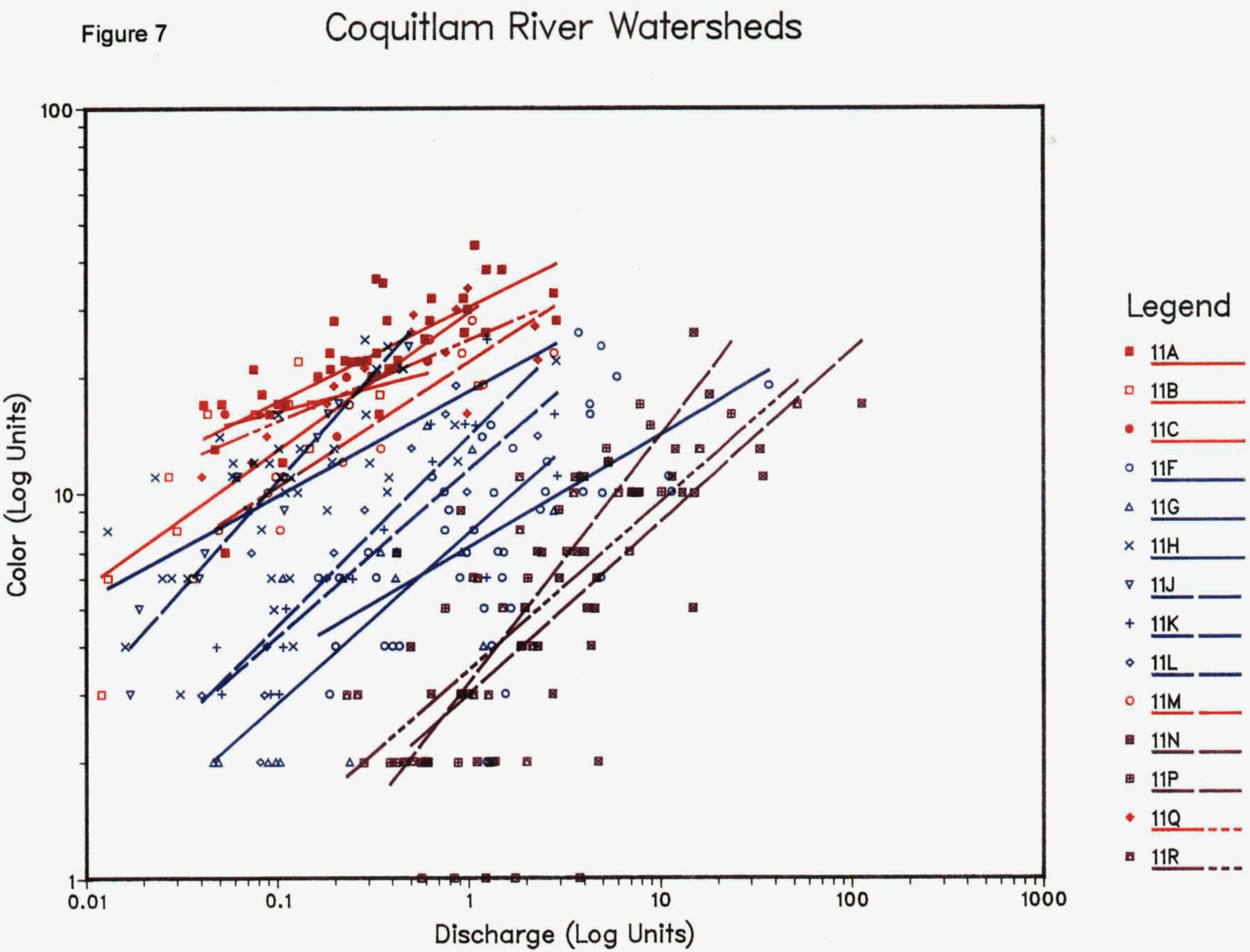
Table 2: Hysteresis patterns - Coquitlam River watershed

	Variable	Hysteresis Pattern	Relationship To Discharge
	Sediment Related Variables		
1.	True Colour	/	Positive
2.	Total Iron	/	Positive
3.	TOC	/	Positive
4.	Turbidity	/	Positive
	Ion Related Variables		
5.	Conductance	\	Negative
6.	Alkalinity	\	Negative
	Nutrients		
7.	Nitrate+Nitrite	\	Negative

The hysteresis patterns for sediment related variables show a positive linear relation with discharge. The ground water or ion related variables show negative linear patterns. The nutrient measured, nitrate + nitrite, shows a negative linear relation. Figure 6 shows the hysteresis plot for true colour at station 11A. There is scatter of the points but the pattern is interpreted as a positive slope with linear relation.

The results of the smoothed hysteresis analysis indicates that for sediment related variables, concentrations were highest for tributaries in the west of the watershed and lowest for the mainstem. For the groundwater variables the highest concentrations occurred in the mainstem with no distinct differences between east and west tributaries. For the nutrient concentrations there were no differences between east tributaries, west tributaries and mainstem. The smoothed hysteresis plot for true colour is provided in Figure 7. The lines are fitted to the data from appropriate

Figure 7



Coquitlam River Watersheds
100
10
1
0.01
0.1
1
10
100
1000
Color (Log Units)
Discharge (Log Units)
Legend
11A
11B
11C
11F
11G
11H
11J
11K
11L
11M
11N
11P
11Q
11R

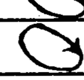
sampling station, see legend for station identification and plotting symbol code. The tributaries to the west of the watershed tend to have higher concentration than those of the east tributaries. The lowest responses are for stations on the mainstem.

<u>Capilano</u>

Time series plots of discharge showed peaks in May and November. True colour and organic carbon also showed peaks in May and November. Total iron was missing a large number of data. The major peak for turbidity occurred in October with secondary peaks occurring at various times during the year. Conductance and alkalinity both showed peaks in September with secondary peaks in November. Nitrate-Nitrite concentrations were highest in October and November.

The hysteresis plots for the water quality variables are summarized in Table 3.

Table 3: Hysteresis patterns - Capilano River watershed

	Variable	Hysteresis Pattern	Relationship To Discharge
	Sediment Related Variables		
1.	True Colour	/	Positive
2.	Total Iron		Undetermined
3.	TOC	/	Positive
4.	Turbidity	/	Positive
	Ion Related Variables		
5.	Conductance	C.W.* 	Negative
6.	Alkalinity	C.W. 	Negative
	Nutrients		
7.	Nitrate+Nitrite	C.W. 	No Relationship

* C.W. abbreviation for clockwise

True colour, total organic carbon and turbidity revealed positive linear relationships. Conductance and alkalinity exhibited open clockwise loops with a negative relation to discharge, Figure 8. The negative relation refers to the slope of the major axis of the loop. Nitrate+nitrite revealed an open clockwise hysteresis loop with no apparent slope of the major axis.

Smoothed hysteresis plots indicated no differences in concentration for the stations in the east and west tributaries for the sediment, ground water or nutrient variables. However, stations on the mainstem did display distinctively higher conductance readings than tributary stations, Figure 9. Readings for true colour are lower from the mainstem than from the tributary stations.

<u>Seymour</u>

The time series plot of discharge indicated major peaks in February, May, September, and November. The sediment related variables peaked between November and December. True colour and total organic carbon also peaked in May. However, these variables exhibited large variability making determination of secondary peaks difficult. The groundwater variables peaked in September. Nitrate+Nitrite peaked in October-November.

Figure 8: Hysteresis plot for conductance (1993)

Capilano River watersheds

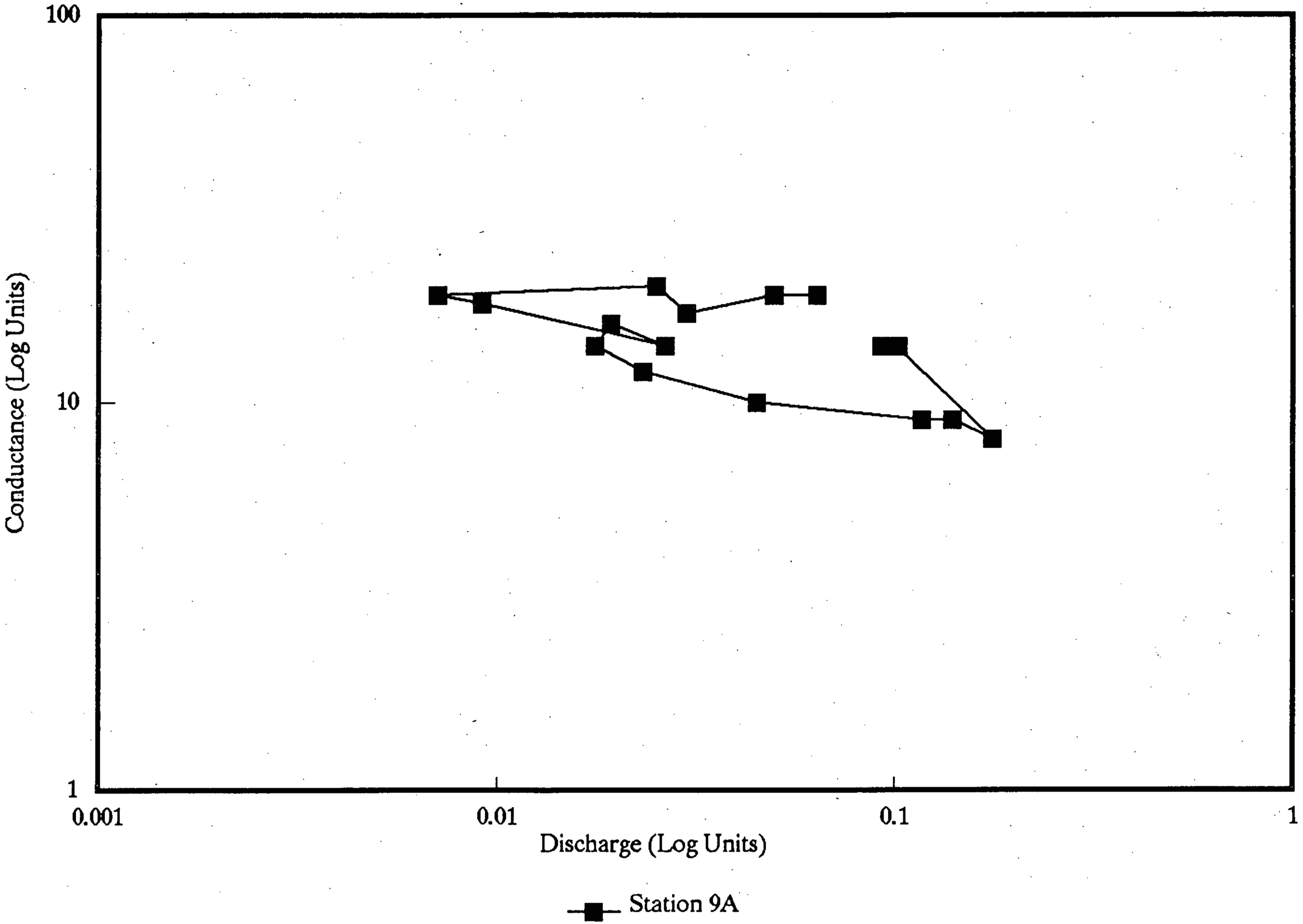
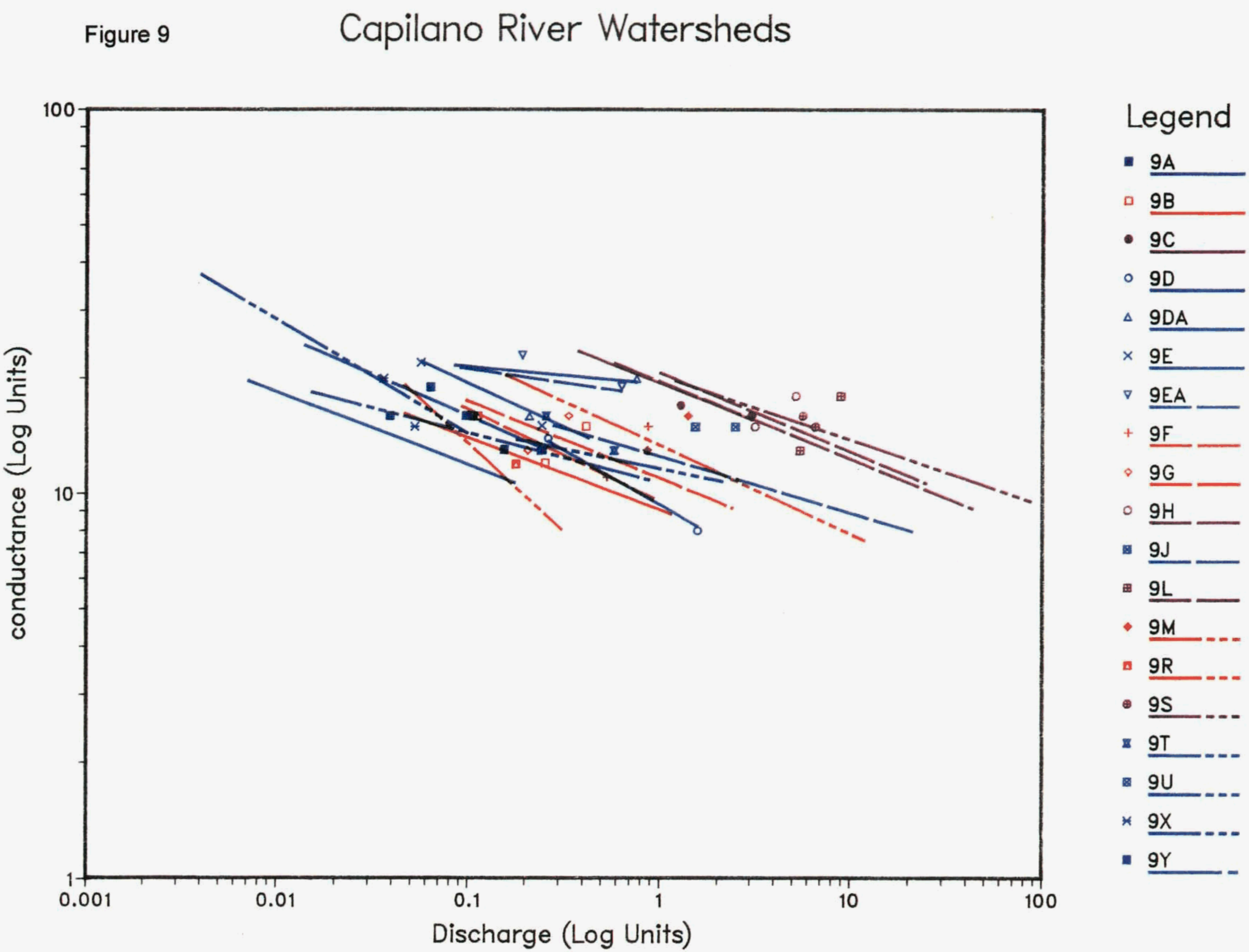
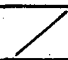
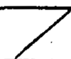
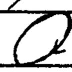
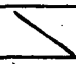


Figure 9


Capilano River Watersheds
100
10
1
conductance (Log Units)
0.001
0.01
0.1
1
10
100
Discharge (Log Units)
Legend
9A
9B
9C
9D
9DA
9E
9EA
9F
9G
9H
9J
9L
9M
9R
9S
9T
9U
9X
9Y

The hysteresis plots for the water quality data from Seymour watershed are summarized in Table 4.

Table 4: Hysteresis patterns - Seymour River watershed

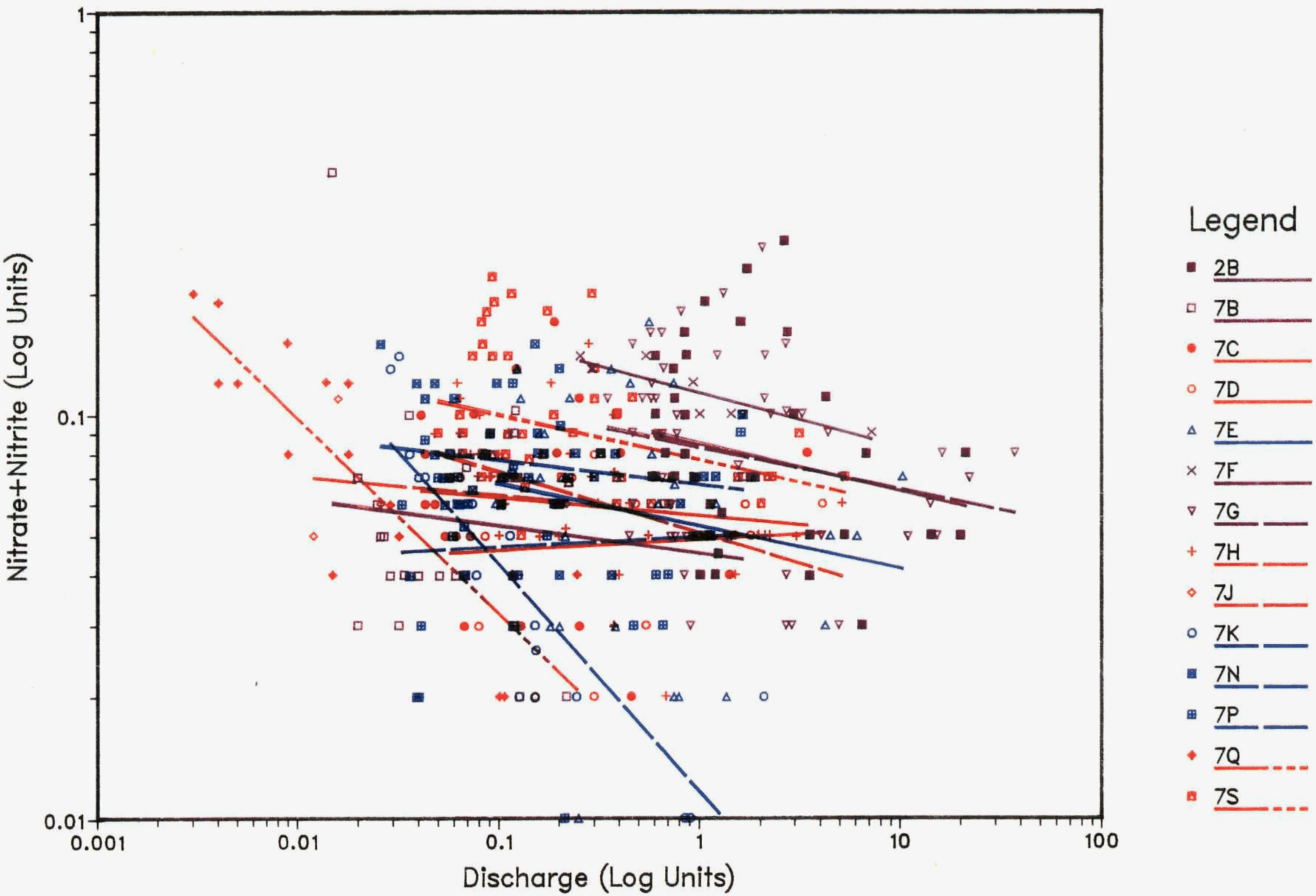
	Variable	Hysteresis Pattern	Relationship To Discharge
	Sediment Related Variables		
1.	True Colour		Positive
2.	Total Iron		No Relationship
3.	TOC		Positive
4.	Turbidity	C.W. 	Positive
	Ion Related Variables		
5.	Conductance		Negative
6.	Alkalinity		Negative
	Nutrients		
7.	Nitrate+Nitrite		Negative

The sediment related variables showed a range of behaviour. True colour and total organic carbon showed positive linear patterns for all stations in the watershed. For total iron, stations 2B, 7D, 7H, 7Q, and 7S exhibited linear hysteresis patterns with zero slope, in other words, no relationship to discharge. The remaining stations in the watershed had varying values of positive slope. Turbidity showed a positive clockwise hysteresis loop. The ground water variables and nutrients exhibited negative linear hysteresis patterns.

Smoothed hysteresis plots indicated no apparent differences in sediment, ground water or nutrient variables, in other words the basin appears homogeneous. The smoothed hysteresis plots are shown in Figure 10.

Figure 10

Seymour River Watersheds



Discussion

Coquitlam

In the Coquitlam watershed the linear positive slope of the hysteresis plots of the sediment related water quality variables indicates that as flow increases the amount of sediment increases. The negative linear relation for the groundwater (ion) related variables and the nutrients, nitrate+nitrite indicates that as flow increases the ion concentration is diluted. As Williams (1989) has discussed, this negative linear hysteresis pattern occurs when the water quality variable has minimums in concentration coincident with peaks in discharge. These linear responses are usually an indication that rainfall is the dominant runoff generating factor. The linear relation is also indicative of steep basins with shallow soils.

The smoothed hysteresis plots showed that stations on tributaries to the west of the Coquitlam mainstem had the highest concentrations of sediment related variables while stations on the mainstem had the lowest. These results indicated that tributaries to the west of the mainstem had higher sediment concentrations that the mainstem or tributaries to the east of the mainstem. The plots of ion or groundwater related variables showed that stations on the mainstem had highest levels indicating that the mainstem has a greater proportion of groundwater supplied to streamflow than is the case for the tributaries, which is consistent with the shallow soil observation.

Capilano

In the Capilano watershed the hysteresis relationships for the sediment related variables were positive linear, similar to the Coquitlam watershed. The relationship for total iron was not determined as a great number of data were missing. The groundwater (ion) related variables had a negative relationship to discharge however, the response curves were open clockwise loops. Williams (1989) stated that such loops occur when the peaks in ion concentrations occur before discharge peaks. The clockwise hysteresis diagram indicates that ion concentration is higher in the pre-freshet period than in the post-freshet period. One explanation for this is that groundwater forms a smaller proportion of runoff in the post-freshet than in the pre-freshet. For the nutrients no relationship to discharge was observed, presumably because biological processes have more impact on these variables (Whitfield and Clark, 1992). As was the case for the Coquitlam, the hysteresis plots indicate that the main mechanism affecting water quality in the Capilano River watershed is rainfall driven runoff.

The smoothed hysteresis patterns indicated no apparent difference between tributary stations but there is a difference between mainstem and tributary stations. In particular readings for true colour are lower on the mainstem while readings for conductance are higher on the mainstem. These observations suggest that the mainstem has lower sediment concentration and higher ion concentration than its tributaries.

Seymour

In the Seymour watershed, all sediment variables, except total iron had a positive relationship with discharge. The majority of stations in the watershed had no relationship between iron and discharge, an unusual result. This may have been caused by the use of estimated discharge rather than measured flow data in the preparation of hysteresis diagrams. The only variable to have an open loop was turbidity. The results of the groundwater related variables were negative linear relationships, similar to the results from the Capilano watershed. The nutrients, nitrate+nitrite, had a negative relationship to discharge - similar to the Coquitlam River watershed. The slopes of the hysteresis plots for most of the stations were quite consistent with each other. Stations 7K and 7Q, however, had noticeably greater negative slopes than the other stations. This may have been the result of one or two anomalous/extreme values. The interpretation is the same as for the Coquitlam River watershed, rainfall is the dominant runoff generating factor, and the watershed is characterized by shallow soils and steep slopes.

The smoothed hysteresis patterns indicated no difference in water quality between the various rivers in the Seymour River watershed.

For the three watersheds, there are no indication of trends, in terms of increasing or decreasing levels, however, there is variability in the sampling intervals (from a few days to a few weeks) and the data records are not continuous i.e., data is not collected during the winter, so no trend analysis could be done on the data.

Conclusions And Recommendations

Water chemistry in streams is the result of hydrologic watershed processes. These seasonal and event processes cause temporal variation in water quality. In the Coquitlam, Capilano and Seymour watersheds there is large seasonal variation in water quality. This observation is in agreement with the inference drawn from the hysteresis plots suggesting that the main hydrological process affecting water quality is rainfall.

In the three watersheds the sediment related variables exhibit a positive relationship to discharge and the hysteresis pattern suggests erosional effects. Major ions (groundwater) hysteresis patterns show a fall (heavy rain season) dilution. The nutrients, nitrate+nitrite exhibit a negative relationship to discharge in all the watersheds except for the Capilano, where no relationship to discharge is seen. The linear patterns indicate runoff generation from shallow soils with little storage either in soil or in snow packs. The lack of storage suggests "flashy" streamflow responses with transient events.

For the Coquitlam watershed, the results of this study show areal variability in streamflow water quality. There are differences in concentrations depending upon whether a station samples water from an east tributary, a west tributary or the mainstem. Pending further data analysis all stations should continue operation. In the Capilano watershed there is no apparent east tributary west tributary variation. But there are differences in response from the tributaries to the mainstem. There may be opportunity for reduction in the number of stations in the Capilano watershed. Streamflow water quality appears homogeneous in the Seymour watershed as water quality does not appear to change with station location. The number of stations may be reduced.

In order for more extensive analysis of the data to be conducted equal interval continuous sampling is required. This is true for time series analysis. To develop a better understanding of water quality relations with discharge, increased streamflow data gathering should be coupled with water quality sampling.

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Appendix I: GVRD Water Quality Data Sampling - Duration and Frequency.

	Coquitlam		Capilano		Seymour	
	14 Stations	Turb	25 Stations	Turb	16 Stations	Turb
1990 Jan						
Feb						
Mar						
Apr						
May						
Jun						
Jul		weekly		weekly		weekly
Aug						
Sep						
Oct						
Nov		↓				
Dec				↓		↓
1991 Jan						
Feb						
Mar		weekly		weekly		weekly
Apr						
May			weekly			
Jun	bi-weekly				bi-weekly	
Jul						
Aug						
Sep						
Oct						
Nov		↓				
Dec	↓				↓	
1992 Jan					weekly	
Feb	bi-weekly	weekly				
Mar						
Apr						
May						
Jun						
Jul						
Aug						
Sep						
Oct						
Nov	↓	↓	↓	↓	↓	↓
Dec						
1993 Jan						
Feb						
Mar						
Apr	bi-weekly	bi-weekly	bi-weekly	bi-weekly	bi-weekly	bi-weekly
May						
Jun						
Jul						
Aug						
Sep						
Oct						
Nov	↓		↓	↓	↓	↓
Dec		↓				

Appendix II: Comparison of Daily Flows in the Capilano Basin

08GA026 Capilano River (West Fork) near North Vancouver [69.9 km^2]			08GA027 Capilano River (East Fork) near North Vancouver [41.4 km^2]	
1927: Aug 24	1.13 cms	0.016 cms/km^2	0.906 cms	0.022 cms/km^2
Sept 5	36.8 cms	0.526 cms/km^2	39.9 cms	0.964 cms/km^2
Oct 18	68.2 cms	0.976 cms/km^2	34.5 cms	0.833 cms/km^2

cms cubic meters per second
km^2 square kilometres

Obviously the unit responses for high flow days such as September 5, 1927 can be different, on this day, the unit responses differ by a factor of 0.964/0.526 = 1.8, which could have an impact on the analysis.