Chapter 4
Data Analysis and Discussion

4.1 *Simple and Seasonal Averages of THM Data*

THM precursors and their impact on THM formation potential have been discussed in Chapter 3 of this report. As a part of the source water quality monitoring program, raw water quality data is available for 258 of the total 329 surface-based water supplies. This information along with regional data gaps on source water quality is presented in Figure 4.1.

As shown in Figure 4.2, there are a total of 2157 THM samples recorded in the THM database as of Dec. 31st, 1999. **However, it is important to note that the analysis presented in this report is based on the THM data collected during the period of Jan. 1st, 1996 to Dec. 31st, 1999.** This decision was based on the following factors:

- Routine departmental THM monitoring program began in 1996.
- Data discontinuity from 1989 to 1995 as no THM monitoring was carried out during this period.
- Data collected during 1985 to 1989 was on an ad hoc basis without any information on sampling and analytical protocols.

The total number of samples in the database, collected during the time period (1996 to 1999) and selected for data analyses, are 2054. Of the total 2054 records, 124 values are recorded as 0 µg/L, 1084 values fall between > 0 µg/L and 100 µg/L, and 846 values are recorded as > 100 µg/L. It is most likely that samples with zero THM values were collected at a time when chlorination was either non-operational or partially operational. A copy of the processed THM data set is included in Appendix F.

In order to compare THM values to the national guideline, it is necessary to collect THM samples for each of the four seasons. Keeping this in mind, the available data was analyzed for seasonal adequacy, inadequacy, and no data. The analysis results are presented in Figures 4.3 and 4.4. Figure 4.4 shows that of the 207 active water supplies with THM data, 82 have adequate seasonal data while 125 have inadequate seasonal data. There is no THM data for the remaining 106 active public water supplies. In all regions throughout the province, the number of water supplies with adequate seasonal data is slightly lower than the number of supplies with inadequate seasonal data. These gaps in seasonal data can be seen in Tables 1, 2 and 3 of Appendix G.

For the purpose of data analysis, the seasons were defined as follows:

Winter → Dec. 22nd - March 21st
Spring → March 22nd - June 21st

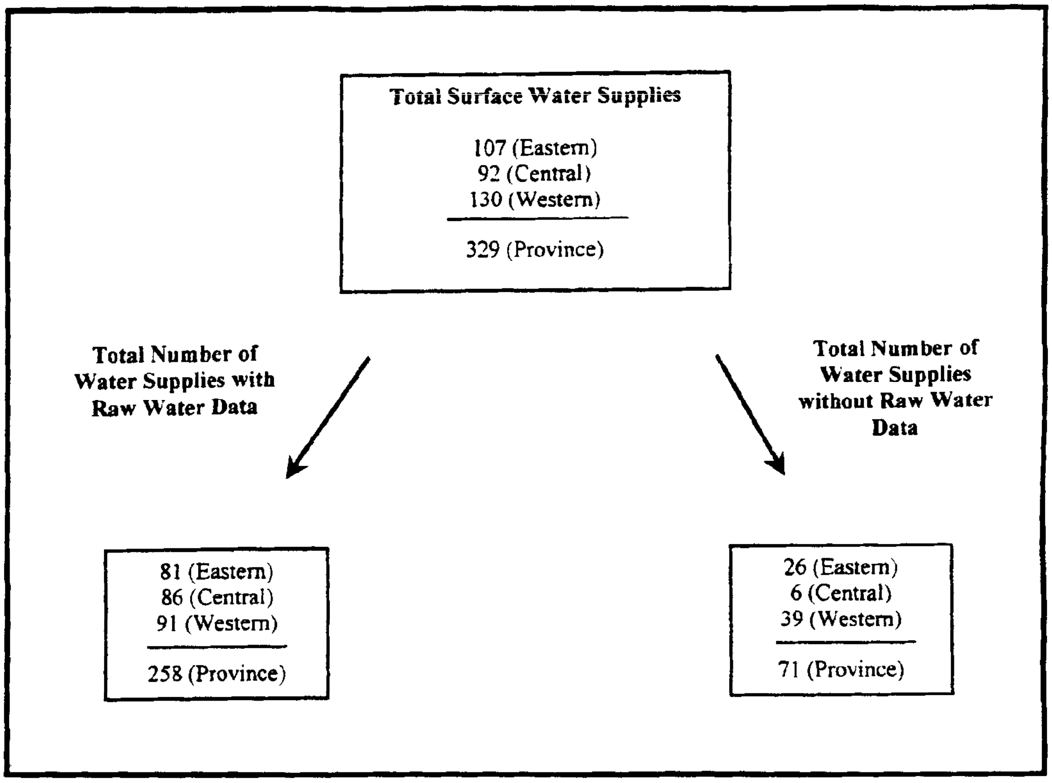


Figure 4.1: Status of Source Water Quality Monitoring in the Province

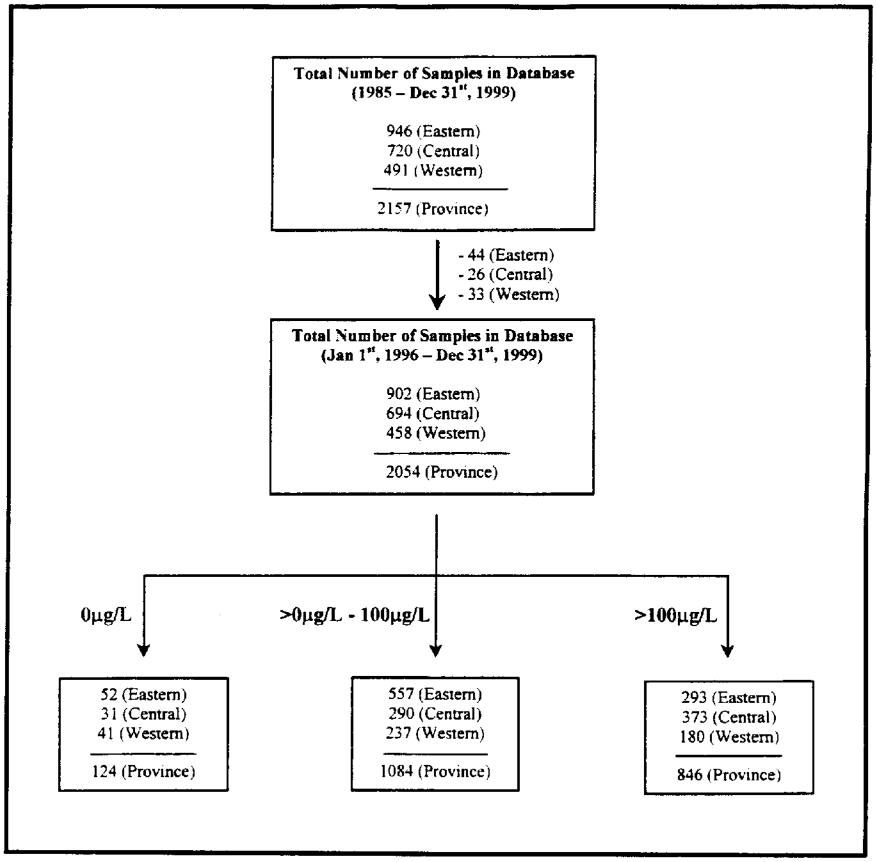


Figure 4.2: Status of THM Samples

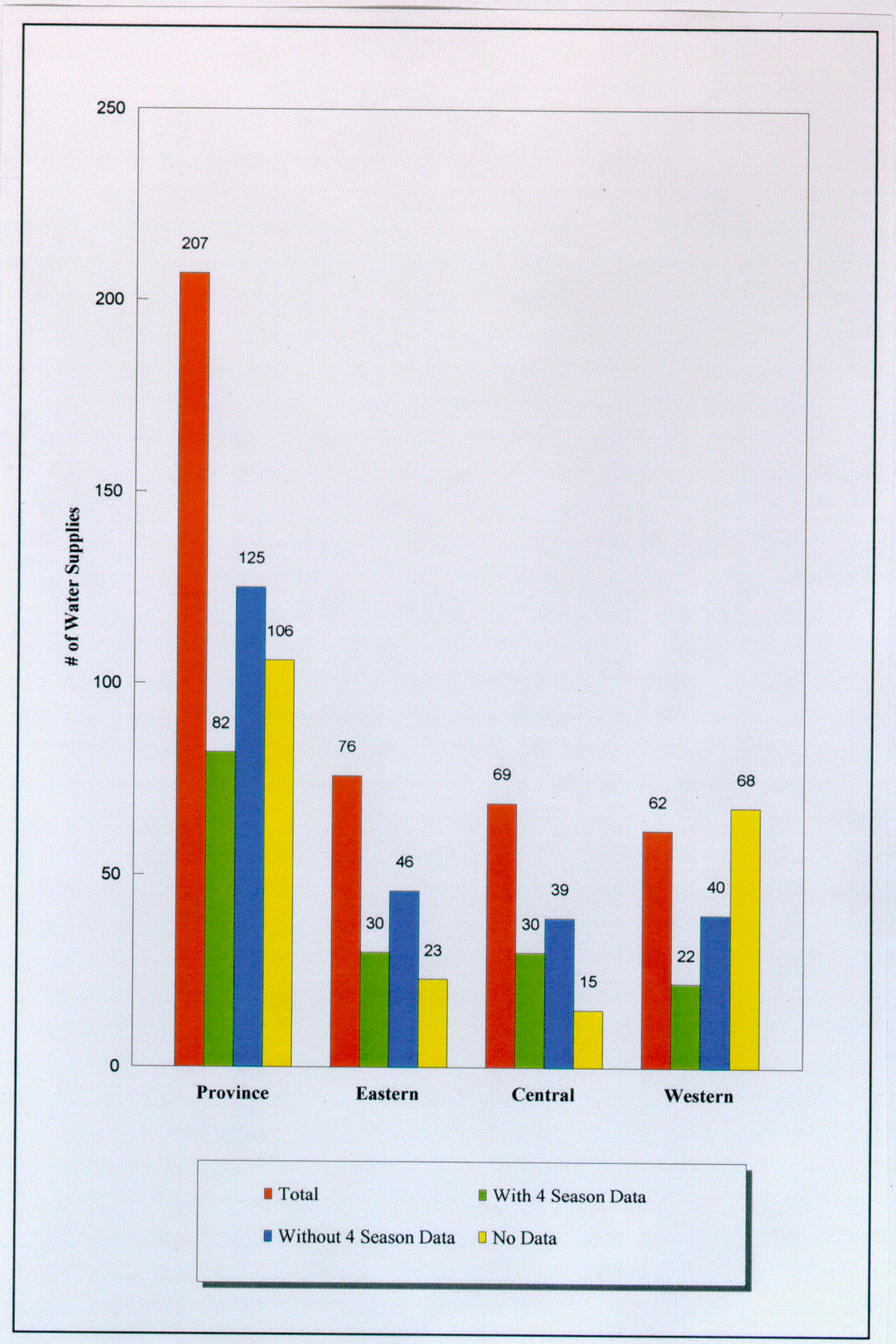


Figure 4.3: Status of THM Data

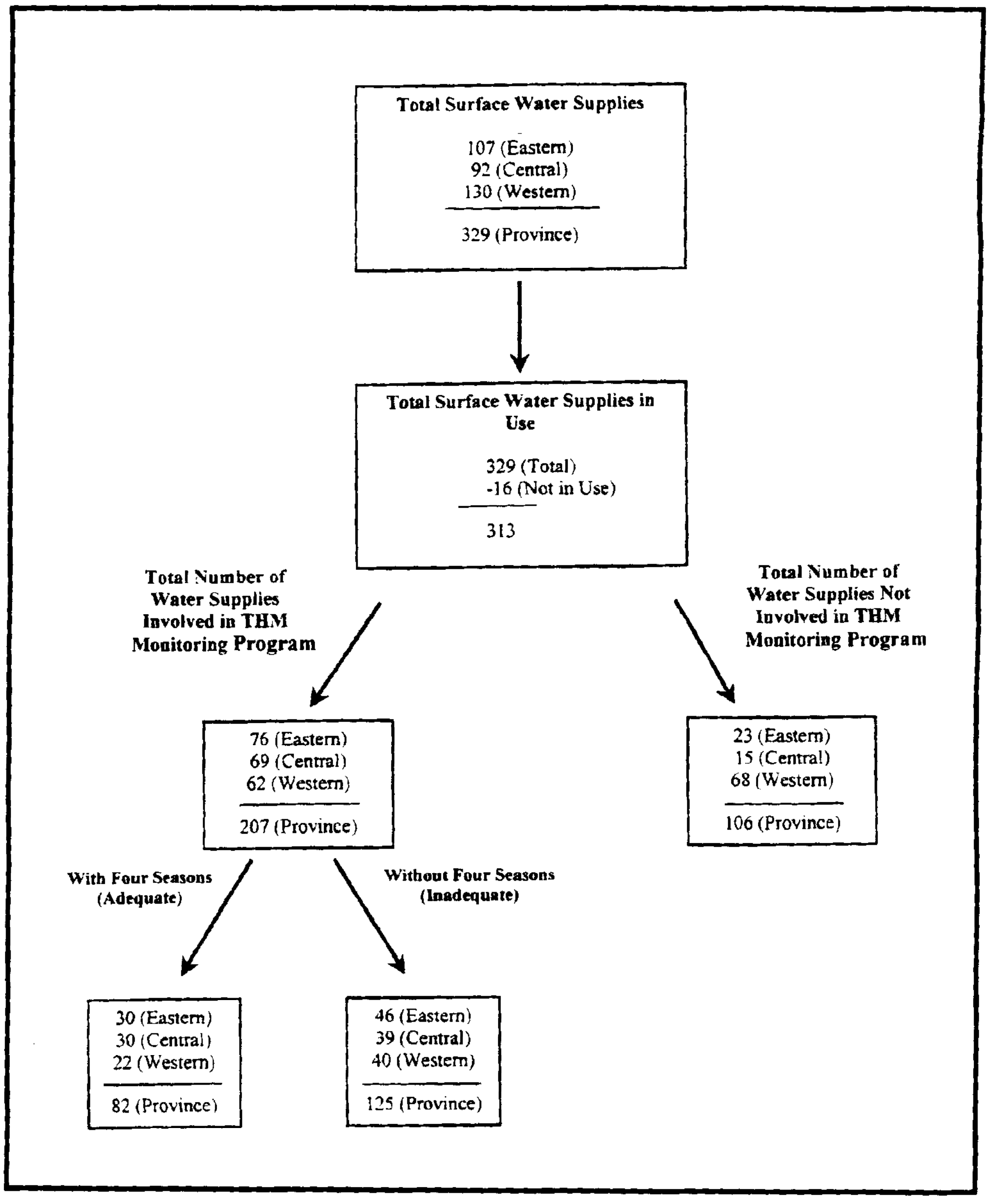


Figure 4.4: Status of THM Data with Seasonal Adequacy

Summer → June 22nd - Sept. 21st
Fall → Sept. 22nd - Dec. 21st

Any water supply with data available for each of the four seasons at least once over the period of Jan. 1st, 1996 to Dec. 31st, 1999, is considered as adequate to calculate the seasonal average or annual running average. On the other hand, any water supply with missing values for any one of the four seasons is considered as inadequate for the calculation of seasonal average. For supplies with inadequate seasonal data, only a simple average of the total samples from 1996 to 1999 was calculated and reported. This simple average cannot be compared with the national guideline for THMs. Tables 1, 2 and 3 of Appendix H list the simple or seasonal average as well as the minimum and maximum THM values for each of the sampled water supplies.

Figure 4.5 presents data on the number of water supplies within the defined THM ranges. This figure is based on data derived using simple and seasonal averages. Approximately 70% of the water supplies recorded seasonal or simple averages below the national guideline of 100 µg/L while approximately 30% are above 100 µg/L. As shown in Figure 4.5, 65 water supplies show THM values ≤ 50 µg/L; 67 water supplies between > 50 µg/L and 100 µg/L; 24 water supplies between > 100 µg/L and 150 µg/L; 21 water supplies between > 150 µg/L and 200 µg/L; 7 water supplies between > 200 µg/L and 250 µg/L; 2 water supplies between > 250 µg/L and 300 µg/L; and 2 water supplies between > 300 µg/L and 350 µg/L.

Overall, the THM averages (simple and seasonal) range from a minimum of 1.0 µg/L to a maximum of 348.0 µg/L. These results are consistent with data reported in various other Canadian studies. A study entitled "A National Survey of Chlorinated Disinfection By-Products in Canadian Drinking Water" by Health Canada reported that THM concentrations varied from 0.3 µg/L to 342.4 µg/L. As can be seen in Table 4.1, the mean THM value for treatment plant samples was 16.8 µg/L in the winter and 33.5 µg/L in the summer, while the mean THM value for samples from the distribution system was 33.4 µg/L in the winter and 62.5 µg/L in the summer.

A Nova Scotia study entitled "Characterization and Treatment of Nova Scotia Waters" reported that THM values vary from 0 µg/L to 245 µg/L. The study indicated that 13 of 33 supplies are above the national THM guideline of 100 µg/L.

Figure 4.6 shows the number of water supplies with seasonal averages above and below the national guideline of 100 µg/L for each of the three regions of the province. In total there are 82 water supplies with adequate seasonal data throughout the province. As can be seen in Figure 4.6, of these 82 water supplies, 46 are below 100 µg/L and 36 are above 100 µg/L. In the eastern region, the majority of water supplies (21) are below the national guideline while 9 water supplies are above 100 µg/L. In the western region and Labrador, the number of water supplies (13) below 100 µg/L is slightly higher than the number of water supplies (9) above 100 µg/L. Finally, in the central region, 12 water supplies are below 100 µg/L while 18 water supplies are above 100 µg/L.

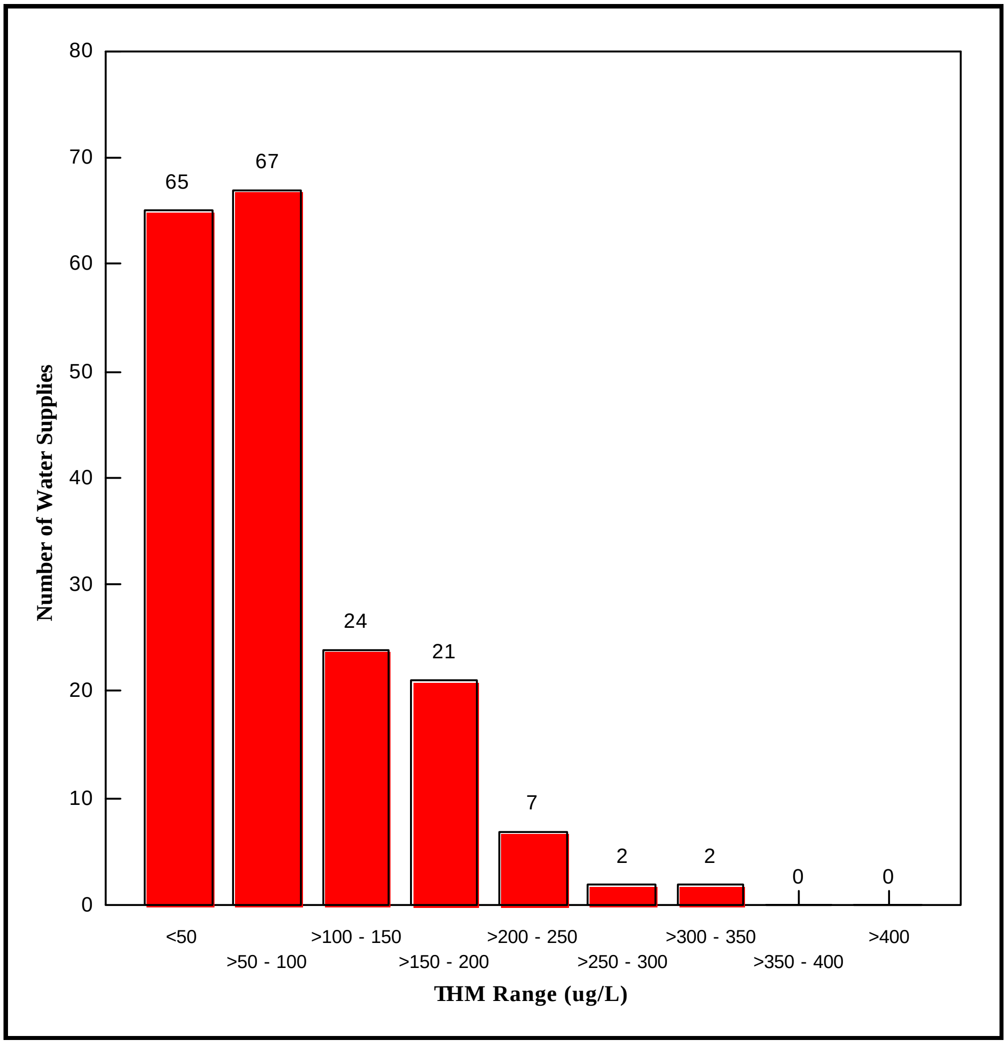


Figure 4.5: Distribution of THM Levels in the Province

Table 4.1: THM Results of Canadian Chlorinated Disinfection By-Products Survey by Health Canada (1995)

Site	Winter		Summer	
	Mean (µg/L)	Range (µg/L)	Mean (µg/L)	Range (µg/L)
Treatment Plant	16.8	2.0 - 67.9	33.5	1.6 - 120.8
Distribution System	33.4	2.8 - 221.1	62.5	0.3 - 342.4

Table 4.2: Seasonal Dependence of THM Concentrations

Survey	Median THM Concentration (µg/L)			
	Spring	*Summer*	*Fall*	*Winter*
AWWARF	40	44	36	30
EPA	34	44	40	30
AWS	-	90	46	25

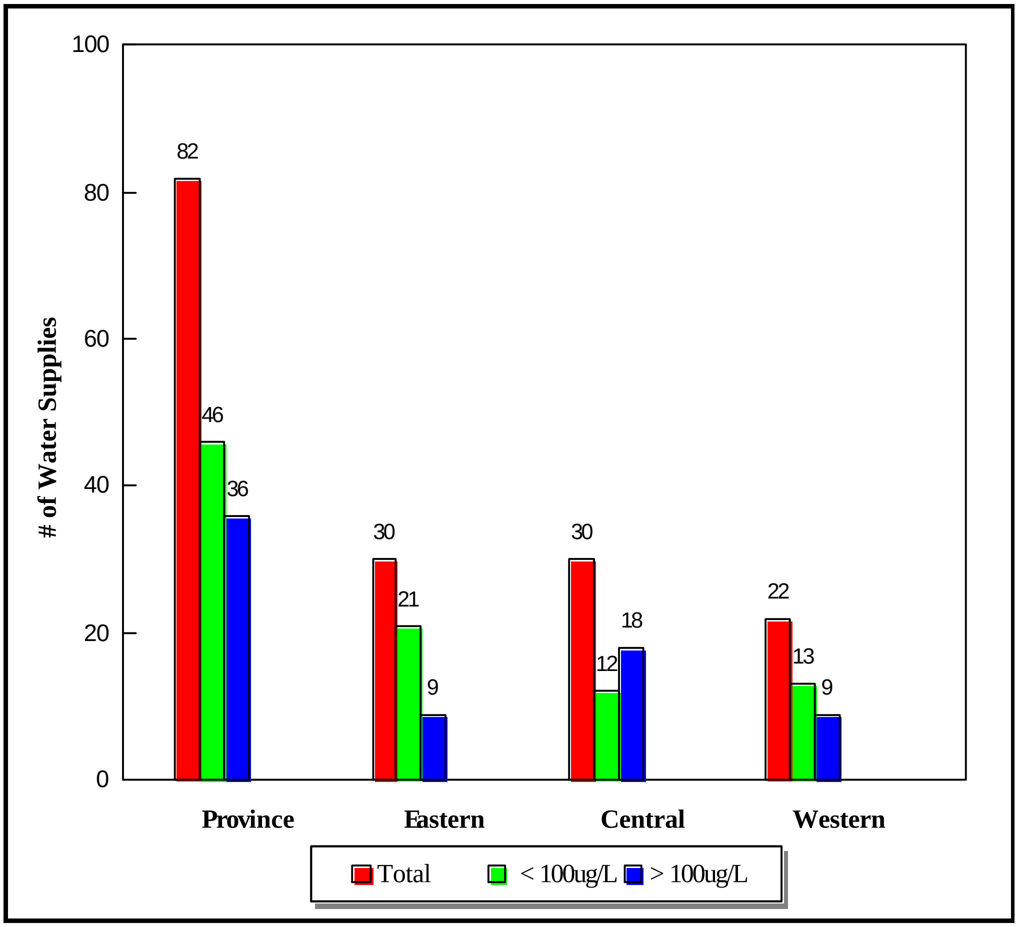


Figure 4.6: Ranking of Water Supplies with Seasonal Averages Above and Below 100 µg/L

All of the previously reported data refers to *total* trihalomethanes which is the sum of concentrations of the four forms of trihalomethanes (chloroform, bromodichloromethane, dibromochloromethane and bromoform). The review of the available data indicates that with the exception of one community (Ramea), in the majority of cases, 99% of THMs are reported as chloroform (85 to 90%) and bromodichloromethane (9 to 14%) and the remaining 1% as bromoform and dibromochloromethane. As shown in Tables 1, 2 and 3 of Appendix I approximately 42 of the 207 active surface water supplies report average dibromochloromethane levels ranging from 0.06 µg/L to 72.73 µg/L. It is important to note that the extreme value of 72.73 µg/L applies to only one water supply (Ramea). This is the only supply which has also reported an average bromoform concentration of 16.27 µg/L. The most likely explanation of high levels of bromoform and dibromochloromethane in the Ramea water supply is the influence of sea water, i.e. high levels of chloride and bromide in source water.

4.2 *Seasonal Variation*

It has been reported in a number of CDBP surveys that THM concentrations vary from season to season due to variation in water temperature, natural organic matter loading, and chlorine demand. In most cases, the overall trend has been that THM values are generally higher during the summer months and lower during the winter months. The most likely reasons for these variations are as follows:

- During the winter months, the catchment of a water supply source is covered with snow and there are very little or no land-based activities. This reduces the contributing organic matter loading to the water supply source. As a result of this, background levels of DOC and colour do not increase during the winter months. On the other hand, during the summer months, organic matter is constantly being added from both natural and anthropogenic sources to the water supply source, leading to an increase in the DOC and colour levels, common precursors for THM formation.

- During the summer months, with increased water temperatures and high levels of precursors, the reaction of chlorine and organic matter is occurring at a fast rate which result in high levels of THMs. On the other hand, during the winter months both precursor levels and water temperature are significantly lower, which slow down the reaction process between chlorine and organic matter. It has been reported (Elshorbagy, 2000) that under given conditions (precursor levels, flow and chlorine dose) the time lag factor for peak chlorine demand during the summer is twice than the winter season, i.e. for example, if peak chlorine demand during the summer months occurs at 10 to 12th hour from the time/point of chlorination, then in the winter months it occurs at 20 to 22nd hour, for the same set of conditions. This time lag in peak chlorine demand is one of the factors for high levels of THMs in the summer months as compared to the winter months, due to the fact that water residence time in an average distribution system would be generally lower than 20 hours.

It should be kept in mind that these reported numbers (10 and 20 hours) are theoretical numbers and may not be applicable to many systems depending on the nature and configuration of water storage and distribution.

The seasonal impact on THM levels has also been reported in a study conducted by Health Canada (1995). According to the results of this study, presented in Table 4.1, the mean THM value for treatment plant samples was 16.8 µg/L in the winter as compared to 33.5 µg/L in the summer. For similar samples collected from the distribution system, the mean THM values varied from 33.4 µg/L in the winter to 62.5 µg/L in the summer. In addition to this Canadian study, three other American studies reported a similar type of variation between summer and winter data. The results of the American studies are summarized in Table 4.2. Based on the results of these studies, it can be stated that summer THM levels are likely to be 50 to 100% higher than winter THM levels.

In order to assess the seasonal trend in Newfoundland data, THM data of 1999 for three water supply systems was analyzed. The seasonal THM variation for each of the three systems is discussed in the following paragraphs. These three water supply systems are considered for illustrative purposes only, assuming that the characteristics of these systems will represent the majority of systems in the province

In the community of Heart's Delight, the average winter and summer THM values for 1999 are very close (112 µg/L - winter; 110 µg/L - summer) possibly due to the mild winter over the past year which might have contributed organic matter to the water supplies and therefore, might have also affected the chlorine decay reaction. However, there is a large discrepancy between the spring and fall THM values (129 µg/L - spring; 291 µg/L - fall) as shown in Figure 4.7a. This 126% increase from the spring to the fall can be attributed to the raw water quality of the water supply in Heart's Delight. The average DOC of the raw water tends to be higher in the fall relative to the spring because of higher organic inputs from falling leaves and decaying shoreline vegetation. This explains the higher formation of THMs observed during the fall relative to those measured in the spring. Also, spring waters tend to be slightly more acidic than fall waters. Since acidic conditions are generally conducive to lower THM formation, this factor may accentuate the difference between fall and spring values.

As shown in Figure 4.7b (Town of Bonavista), the average THM value of 83 µg/L for the winter of 1999 decreases to 54 µg/L in the summer. This finding is opposite of that previously stated in the literature, again possibly due to the mild winter which might have affected organic matter contribution to the water supply and the chlorine decay reaction. However, as was the case with Heart's Delight, there is a 107% increase between the spring and fall THM values (60 µg/L - spring; 124 µg/L - fall). Again, the significant increase in THM levels during the fall may be due in large part to the significant amount of falling leaves and organic matter entering the water system. The generally lower THMs for Bonavista relative to Heart's Delight can be explained as follows. DOC values for Heart's Delight are higher than those for Bonavista, even though the Bonavista watershed tends to have the larger bog areas. The higher DOC for Heart's Delight water supply may be due to (1) the muddy bottom which could consist of organics, in combination with (2) the relatively shallower depth of the water supply.

As shown in Figure 4.7c (Town of Gander), the average winter THM value for 1999 is 208 µg/L which increases to 235 µg/L during the summer months. This increase of approximately 13% is much lower than the seasonal percentage increase of 50 to 100% reported in the literature. Also, the THM values of the fall are relatively lower than that of the spring (227 µg/L - spring; 198 µg/L - fall) which is the reverse of the observed trends for Heart’s Delight and Bonavista. This is mainly due to the fact that the water supply system for Gander is a large lake that receives inputs from both Northwest Gander and Southwest Gander Rivers and is also a hydrological system in itself. Gander Lake tends to stratify in the summer and circulation of the water body, and hence circulation of the water quality constituents, is as yet not fully understood. Based on Gander’s raw water data, there seems to be only 1 to 2 degrees difference in the water temperature of Gander Lake between the fall and spring. The summer and winter temperatures seem to be about 6 degrees higher and lower respectively than the spring/fall water temperatures. The literature suggests that higher water temperatures generally lead to higher THM formation, however, this relationship was not clearly demonstrated.

Based on the analysis of available adequate seasonal data for the province, it was noted that THM values for the winter season are generally lower than other seasons of the year. Summer and fall THM values generally tend to be higher than values for other seasons of the year. This observation is in line with the findings of other studies relating to seasonal variation in THMs.

Overall, it is important to note that seasonal variations were evident at several sites as has been reported in the literature, however, the level of variation differed from site to site. The most significant increases in THM levels were seen between spring and fall, however, this relationship was not fully evident from the data available for the three communities.

It is recommended that a full analysis of seasonal variation of THMs be undertaken in order to devise and implement appropriate THM reduction strategies.

(a)
(b)
(c)

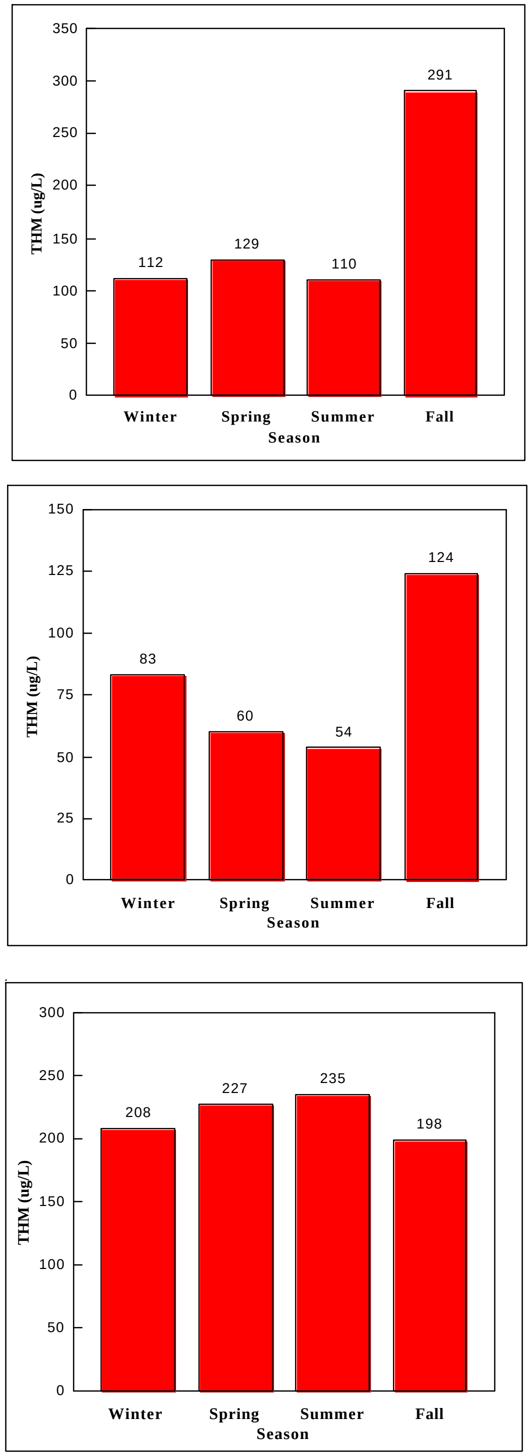


Figure 4.7: Seasonal Variation of THM Values in (a) Heart's Delight (b) Bonavista (c) Gander

4.3 *Spatial Variation*

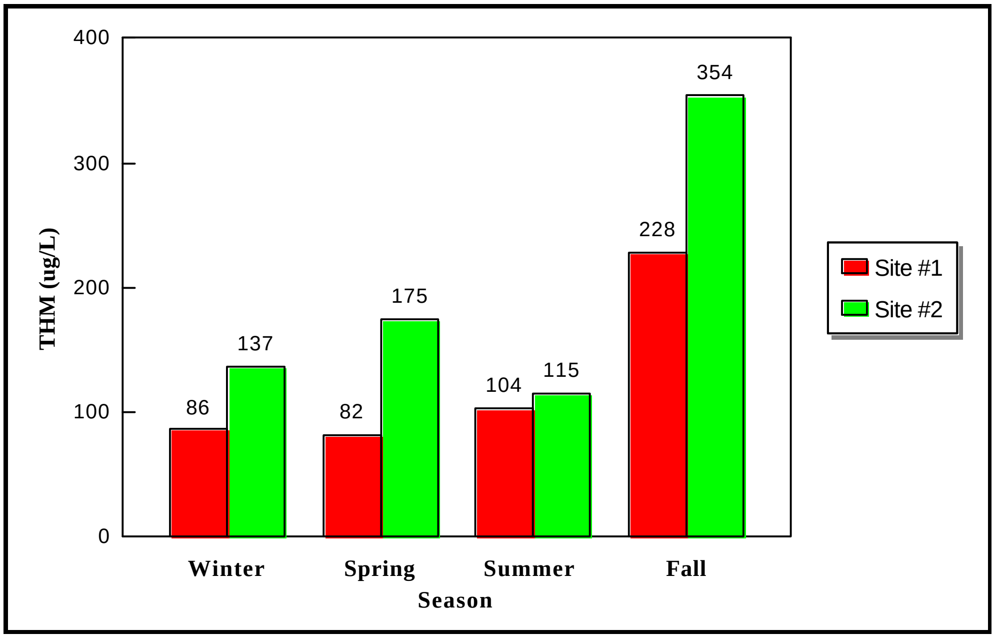
Spatial variation in THM levels is another important aspect that must be taken into consideration, as it relates to actual THM exposure along the distribution system. It has been reported that THM values increase with increased distance from the point of chlorination. This trend occurs due to the overall rate of reaction between the chlorine and organic matter. As was stated in the previous section, the rate of reaction is dependent on the season; the reaction will be faster in the summer as compared to the winter. Therefore, as reported in the literature, during the summer for the first few hours between the time of chlorination and the time of peak chlorine demand, the formation of THMs is steadily increasing. As the water moves along the distribution system, consumers towards the end of the distribution system are likely to receive water with higher THM levels than consumers at the beginning of the distribution system.

A Health Canada (1995) study has reported substantially higher levels of THMs in samples collected from the distribution system as compared to samples collected at the treatment plant. As shown in Table 4.1, during winter, THM values increased from 16.8 µg/L at the treatment plant to 33.4 µg/L in the distribution system. Similarly, during summer, the THM values increased from 33.5 µg/L at the treatment plant to 62.5 µg/L in the distribution system.

In the case of the Newfoundland data, this trend was also observed, however, not consistently. The trend of increasing THM values with increasing distance along the distribution system is evident in the case of Heart's Delight. As can be seen in Figure 4.8, sampling site 1 is located in the middle of the distribution system while sampling site 2 is located toward the end. In all seasons of 1999, there is an increase in the THM values as the water moves through the distribution system. The largest increase in THM values between site 1 and 2 is seen in the fall sampling.

In the case of Bonavista, as shown in Figure 4.9, the THM values for 1999 increased along the distribution system during both the spring and fall sampling. During the winter sampling, the THM values for site 1 and 2 remained very close while the value for site 3 increased as expected. The results of the summer sampling did not follow the expected trend because the THM values increased from site 1 to 2, however, the value decreased at site 3. Ideally, sites 1, 2 and 3 should be situated at the beginning, middle and end of the system. In the case of Bonavista, the distribution system includes two reservoirs where the water may remain for extended periods of time, and would play an important role in the formation of THMs. It is difficult to estimate the exact route the water takes as it moves through the distribution system as well as the amount of time it has been in the distribution system. In reality, some water may bypass the reservoirs and some may pass through the reservoirs.

As shown in Figure 4.10 for the Town of Gander, THM values during the winter, spring and fall seasons of 1999 increased steadily as the water moved through sampling sites 1, 2 and 3 in the distribution system. As shown in Figure 4.10 in the schematic of the distribution system and



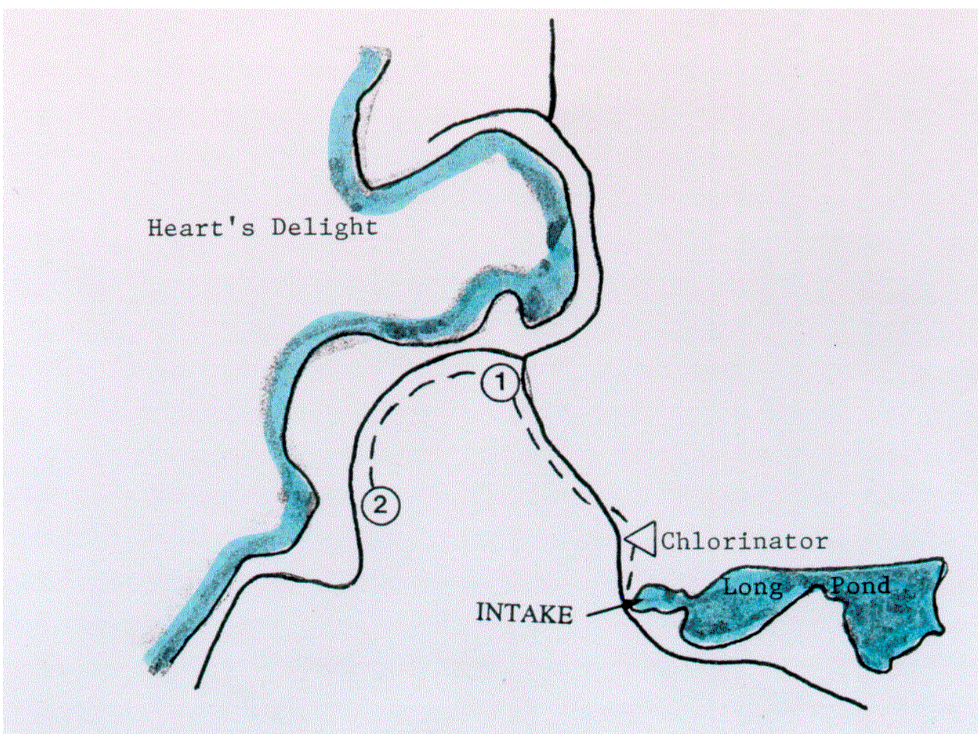
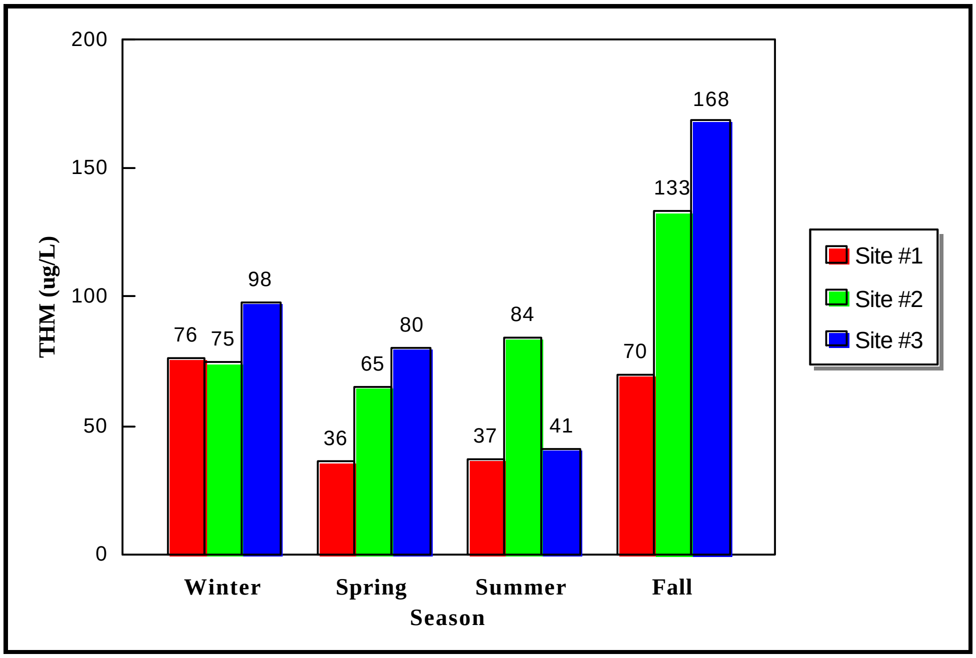


Figure 4.8: Spatial Variation of THM Values in Heart's Delight



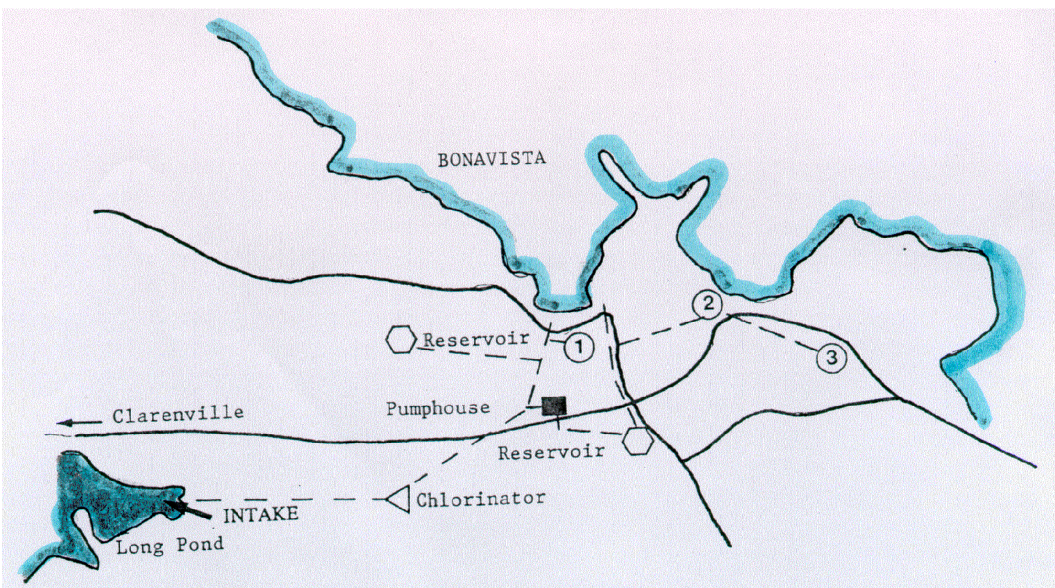
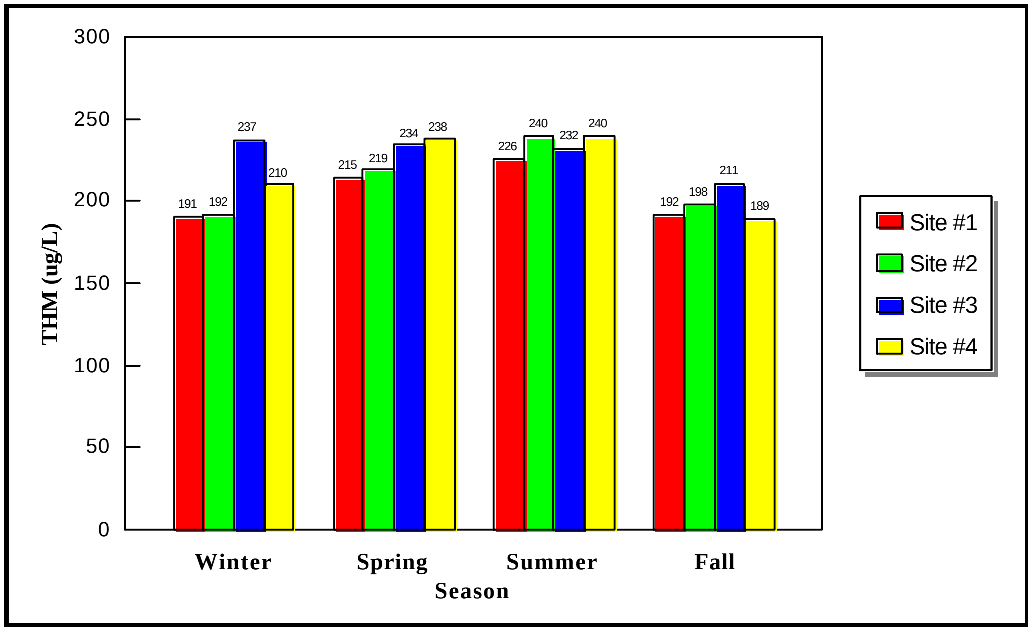


Figure 4.9: Spatial Variation of THM Values in Bonavista



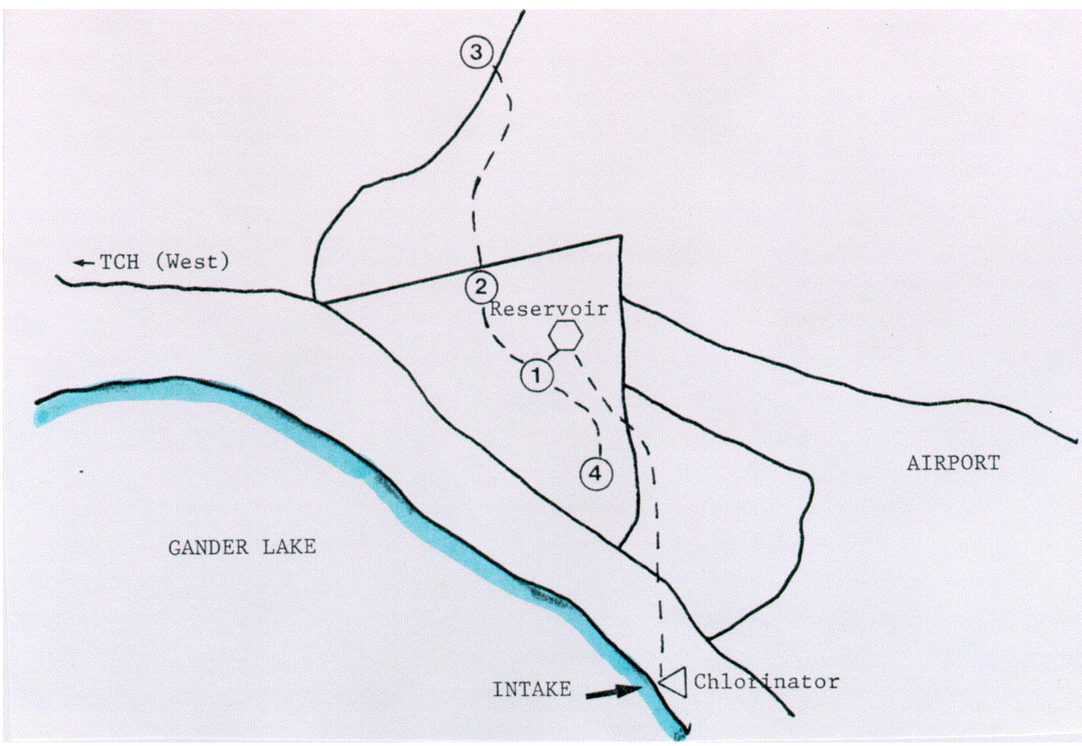


Figure 4.10: Spatial Variation of THM Values in Gander

associated sampling sites, site 4 is not located in sequence after site 3, rather, it is subjected to a relatively shorter residence time. The location of sampling site 4 explains the decrease in THM levels during the winter and fall. The spring and summer THM values for site 4 remain close to that of the other sampling sites.

Overall, it is essential to note that spatial variations were evident at several sites, however, the spatial variation was not consistent and predictable in all cases mainly due to the complex layout of distribution systems. In general, spatial THM levels are mostly affected by the residence time of the water in the distribution system. The residence time depends on a number of factors such as water reservoirs, length of distribution system, water demand, etc.

Design of THM reduction strategies will have to take into consideration the spatial layout of the water distribution system as well as infrastructure such as storage tanks within the system.

4.4 *Identification of Water Supplies for THM Control*

As shown in Figure 4.6, there are 36 water supplies in the province with THM seasonal averages above 100 µg/L, the limit under the Guidelines for Canadian Drinking Water Quality. It is reiterated that only seasonal averages can be accurately compared to the guideline. Communities with public water supplies that exceed the national THM guideline of 100 µg/L need to be identified in order to determine the best techniques that can be implemented to reduce THM levels in these water supplies. Numerous techniques for THM reduction will be discussed in Chapter 5.

In addition to the 36 water supplies with average seasonal THM levels over 100 µg/L, there are 20 other water supplies with simple averages over 100 µg/L. In total, these 56 water supplies service 57 communities. All communities and associated water supplies with THM levels (simple and seasonal averages) over 100 µg/L are listed in Table 4.3.

4.5 *THM Control Strategies*

The following factors will be considered in the development of THM control strategies:

- Land-use management
- Raw water quality
- Seasonal factors
- Spatial layout and system characteristics

Table 4.3: Communities and Associated Water Supplies with THM Concentrations Above 100 µg/L

Community	*Region*	*Water Supply*	*Simple Average*	*Seasonal Average*
BIRCHY BAY	C	JUMPER'S POND		179.5
BOTWOOD / PETERVIEW	C	PETER'S RIVER		185.8
BRIGHTON	C	HYNES COVE POND	348.0	
CENTREVILLE-WAREHAM-TRINITY	C	SOUTHWEST FEEDER POND	103.1	
COMFORT COVE-NEWSTEAD	C	STEADY COVE POND	271.3	
CONNE RIVER	C	SOUTHWEST BROOK		138.7
EMBREE	C	TROKE'S COVE POND	233.3	
FOGO	C	FREEMAN'S POND		164.5
GANDER	C	GANDER LAKE		209.1
GAULTOIS	C	PICCAIRE POND		134.7
HAPPY ADVENTURE	C	GOOSE NECK POND	132.3	
HARBOUR BRETON	C	CONNAIGRA POND/HUTCHINGS POND		156.1
HERMITAGE-SANDYVILLE	C	GRANFER'S POND	106.7	
LEADING TICKLES	C	COOK'S POND	173.1	
LEWISPORTE	C	STANHOPE POND		140.9
LUSHES BIGHT-BEAUMONT-BEAUMONT NORTH	C	MILKBOY'S POND	151.0	
MILES COVE	C	PADDOCK'S POND	165.8	
MILLTOWN-HEAD OF BAY D'ESPOIR	C	JERSEY POND		106.4
NORRIS ARM	C	MILL LAKE		114.5
PLEASANTVIEW	C	LITTLE ARM POND		185.4
POINT LEMINGTON	C	LITTLE POND	155.5	
PORT ANSON	C	ANCHOR POND	230.4	
PURCELL'S HARBOUR	C	PURCELL'S HARBOUR POND		171.8
ROBERT'S ARM	C	YOUNG'S POND		135.0
SEAL COVE, FORTUNE BAY	C	BIG BLACK DUCK POND		155.8
SEDDOM-LITTLE SELDOM	C	BULLOCK COVE POND		127.4
SPRINGDALE	C	SULLIVAN'S POND/HUXTER'S POND		102.4
SUMMERFORD / COTTLESVILLE	C	RUSTY COVE POND		198.0
TILTING	C	SANDY COVE POND		186.9
TWILLINGATE	C	WILD COVE POND	187.3	
CLARENVILLE	E	SHOAL HARBOUR RIVER (to Shoal Harbour)		153.4
HEART'S DELIGHT-ISLINGTON	E	LONG POND		157.6
KEELS	E	BOLAND'S POND	244.4	
LONG HARBOUR- MOUNT ARLINGTON HEIGHTS	E	TROUT POND		103.2
MARYSTOWN	E	LINTON LAKE		144.3
PETTY HARBOUR-MADDOX COVE	E	BEER POND	131.0	
PLACENTIA (including Dunville)	E	WYSE'S POND (to Dunville)		158.7
PORTUGAL COVE-ST. PHILLIPS	E	BLAST HOLE PONDS		214.3
QUEENS COVE	E	RESERVOIR		123.8
TERRENCEVILLE	E	BIG BROOK		123.4
THORNLEA	E	BIG BAKEAPPLE POND	101.6	
TREPASSEY	E	MILLER'S POND		131.5
WHITBOURNE	E	HODGE RIVER	102.3	
BAIE VERTE	W	BAIE VERTE RIVER		105.6
BURGEO	W	LONG POND		177.3
CONCHE	W	MARTIN'S BROOK		138.0
ENGLEE	W	ISLAND COVE POND	111.1	
HAWKES BAY	W	TORRENT RIVER	118.9	
IRISHTOWN-SUMMERSIDE	W	IRISHTOWN BROOK		147.6
LOURDES	W	VICTOR'S BROOK		169.5
RAMEA	W	NORTHWEST POND		299.3
RODDICKTON	W	EAST BROOK POND	175.4	
ST. GEORGE'S	W	DRIBBLE BROOK		328.5
ST. PAUL'S	W	TWO MILE POND	240.7	
STEPHENVILLE	W	NED'S POND (Area 13)		145.5
		NED'S POND (Townsite)		207.6
		NOEL'S POND		232.5