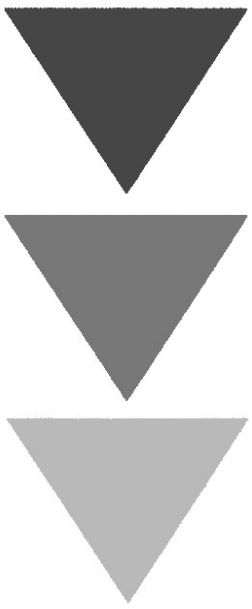
March 2011

File 104J01

Spectacle Lake hydrological assessment

Prepared for
Municipality of the District of Chester



© 2011 earth-water Concepts inc.

earth-water Concepts inc.

groundwater research, surveys, modeling, remediation
water resource development, protection, management

P.O. Box 51015, Halifax, Nova Scotia B3M 4R8
phone 902 457-7010 facsimile 902 457-3934

Executive summary:

The District of the Municipality of Chester, Planning Department, has retained the services of earth-water Concepts inc. to assess the potential for Spectacle Lake to serve as a possible future water supply for the Village of Chester. The general scope of work was to install instruments for lake water level and streamflow measurements; to calibrate the new stream gauging station; collect other data needed including water samples and nearby watershed data to compare to Spectacle Lake data and extend its hydrologic record; and interpret all data utilizing GIS and other software and analytical methods. The work was done in two phases – the intent was for phase 1 to lead to the automatic collection of future data, however, beaver activity caused the destruction of the phase 1 streamflow gauging station, which had to be replaced and the new station calibrated as phase 2. This report covers both, phases 1 and 2 in their entirety.

The Spectacle Lake sub-watershed is a 2,566,640m^2 internal catchment basin located in the east half of coastal watershed 1EG-SD2, in Lunenburg County, less than 2 km northwest of East Chester. Water in the watershed flows north to south. The watershed is 3.38 km long, under 0.5 km wide in the north where Highway 103 crosses it, and 1.46 km wide in the south. Elevations range from 140m in the north, to 32m at Spectacle Lake, which is at the south end of the watershed and has a surface area of roughly 302,069m^2 and total shore length of 4,079m.

Spectacle Lake contains two basins, the deepest of which is roughly 18.2m. The lake is estimated to contain a volume of approximately 2,172,280 m^3 of water. Discharge from the lake is via a man-made channel, or heavily modified stream, which is located at the southwest end of the lake.

The watershed is underlain by glacial till and rocks of the Meguma Group, including granites. A geologic fault appears to transect the watershed from north to south and may be responsible for the shape and depth profile of part of Spectacle Lake. Land use and cover within the Spectacle Lake watershed is 85% forest, wetland and lake. Other land use include minor residential use, the Highway 103 right of way and abandoned construction material borrow pits.

Instruments were installed, and lake level and streamflow data were collected from mid-October 2007 to early January 2009, providing 14 complete months of data during phase 1. Instruments were relocated and recalibrated for phase 2, for which data was collected from mid-September 2009 to early December 2011 to produce an additional 26 complete months of data.

Short-term flows from Spectacle Lake during phases 1 and 2 were found to range from about 1,172 m^3/d during dry periods to 81,429 m^3/d following storm events during wet times of the year. Baseflow, or groundwater contributions to discharge from Spectacle Lake, are estimated to constitute 60.6% of total stream flow (by comparison LaHave River receives about 33.2% baseflow). Total monthly flows from Spectacle Lake during phases 1 and 2 ranged from a low of 63,175 m^3 for the months of September and October 2008, to a high of 651,152 m^3 for Octtober

2011, with a mean annual (12 month) flow for the period of data collection of 2,888,789 m^3. Due to the amount of baseflow present, streamflow was greater than total precipitation some months.

A long-term synthetic flow record was constructed to extend the Spectacle Lake field record based on data from LaHave River (it has 44 years of stream flow data) in an effort to define long-term storage and flow characteristics for Spectacle Lake. However, due to abnormal flows at Spectacle Lake in some months and/or greater amounts of baseflow at Spectacle Lake, the synthetic record was found to overestimate streamflows in the mid-to-high flow ranges and underestimate flows in the lower flow ranges. The level of underestimation cannot be easily quantified and as such, while it does give some insight on order-of-magnitude for some values, it is not prudent to place too much weight on predictions based on the synthetic flow record.

Flow duration curves suggest withdrawal allocations based on 95% exceedance frequency flow values of 2,300 m^3/d based on real data, and 1,200 m^3/d from the synthetic data. An average of the two, or 1,750 m^3/d, may be considered a practical, yet still conservative value. The shape of flow duration curves may be changed with lake storage, such that an average conservative withdrawal allocation value of 2,175 m^3/d may be appropriate with storage at Spectacle Lake. Assuming an average consumption rate of 100 gallons (450 L) per person per day, this represents a capacity from Spectacle Lake to meet the water demand for 2,100 to 2,850 persons using a 1.5x safety factor, or 1,600 to 2,150 people if applying a 2x safety factor.

The water storage requirements for Spectacle Lake to allow proper discharge flow maintenance would require a 61 cm water level change at Spectacle Lake. This may be accomplished by repairing or replacing an existing water control structure at the base of the lake, plus construction of a low berm along parts of the lake's southeast shore. The incremental amount of storage required, and resulting change in lake area, are not enough to trigger an environmental assessment, although a water withdrawal permit would have to be obtained from the Province.

A total of 37 lake waters samples and 14 stream water samples were collected to characterize the lake water quality both spatially and temporally. Water from Spectacle Lake is classed as a very soft, sodium-chloride type water with low Total Dissolved Solids (TDS), low pH, and extremely low alkalinity. The water meets the Guidelines for Canadian Drinking Water Quality for all parameters tested except pH, iron in one sample, and manganese in most water samples. Water color and the Trihalomethane (THM) formation potential are also quite high. The water would require treatment to increase alkalinity and adjust pH, to remove manganese, and to remove the organic compounds that are present to serve as precursors for THM formation. The concentration of aluminum present in the water may need to be addressed also depending upon the methods selected to treat the water from Spectacle Lake.

Table of contents:

page

1. Introduction 1

2. The study plan 1

3. Watershed description 4
Location and watershed boundaries 4
Watershed elevation and drainage 4
Bedrock geology 5
Surficial geology 6
Land use and land cover 7
Spectacle Lake bathymetry 9

4. Hydrologic field-data collection 10
Lake water level measurements 10
Phase 1 lake water level measurements 10
Phase 2 lake water level measurements 11
Local stream flow measurements 11
Phase 1 gauging station 11
Phase 2 gauging station 12
Flow velocity measurements 13
Measuring stream bottom profiles 13
Gauge station calibration 15
Measured data 15
Calculating stream flow volumes 16
Quality of the calibration data 17
Defining stream functions 18
Defining a phase 1 stream function 22
Defining a phase 2 stream function 25

5. Hydrologic assessment 29
Data collection 29
Precipitation data acquisition 29
Precipitation modelling 30
Selecting data to synthesize stream flow records for Spectacle Lake 33
Analysis of total monthly precipitation 33
Precipitation during phase 1 36
Precipitation during phase 2 38
Assessment of long-term precipitation 39
Stream hydrographs 40
Peak flow characteristics 40
Spectacle Lake channel baseflow 43
Flow/precipitation ratios 44
Spectacle Lake outflow versus water levels 46
Watershed water balance 47

Construction of a synthetic flow record for Spectacle Lake 50
A word about modelling uncertainty 50
Method used for Spectacle Lake 51
Results and evaluation 52
Model and data validation 55
Flow duration curves 58
Suggested withdrawal allocation values 59
Drought analysis 61
Assessment of sustainable yield 63
Suggested allocation values versus demand 63
Lake storage requirements 63

6. Lake water quality 65
Lake water sampling program and locations 65
Lake water sampling methodology 65
Stream water sampling methodology 66
THM results 66
Inorganic chemistry 67
Groundwater influences on quality 77
Water treatment requirements 77

7. Conclusions and recommendations 78
Recommendations for follow-up work 79
Data related recommendations 80
Supply/security related recommendations 80

8. References cited 82

Back cover pocket ..... Digital copy of report

List of Tables

page

1. Spectacle Lake watershed land cover 8
2. Flow volume and stream depth values used for phase 1 stream gauge calibration 17
3. Flow volume and lake depth values for phase 2 stream gauge calibration 18
4. Phase 1 results of 1st regression analysis using all 16 points 23
5. Phase 1 results of 2nd regression analysis using 15 points 23
6. Calculated stream flow results 24
7. WMO climate station data used to GIS model monthly total precipitation 30
8. Gauge stations considered for synthesis of flow record for Spectacle Lake 34
9. Total monthly/annual precipitation for Spectacle Lake watershed per GIS modeling 35
10. Total monthly/annual precipitation for LaHave River watershed per GIS modeling 37
11. Monthly total flows vs. precipitation 45
12. Monthly and annual water balances for the Spectacle Lake watertshed 49
13. Coefficients of variability obtained for differences in overlapping daily F/P data 56
14. Measured channel flow versus calculated synthetic flows for Spectacle Lake 57
15. Low 7, 14, 30 and 60 contiguous day flows for 10, 50 and 100 year drought 62
16. Comparison of low flows obtained from synthetic record vs. measured flows 62
17. Mean monthly surplus, deficits and residual stream flows after withdrawing 64
18. THM results 67
19. Lab analysis results for Spectacle Lake water samples collected on 29 November 2007 … 70
20. Lab analysis results for Spectacle Lake water samples collected on 08 February 2008 ….. 71
21. Lab analysis results for Spectacle Lake water samples collected on 22 May 2008 71
22. Lab analysis results for Spectacle Lake water samples collected on 05 September 2008 ... 73
23. Lab analysis results for Spectacle Lake water samples collected on 05 September 2008 ... 74
24. Lab analysis results for Spectacle Lake water samples collected on 05 September 2008 ... 75

List of Photos

page

1. View of the phase 2 streamflow gauging station standing at the dam looking south 12

List of Figures

page

1. Watershed location 3
2. Spectacle Lake watershed elevations 4
3. Bedrock geology 5
4. Surficial geology 6
5. Watershed land cover 7
6. Spectacle Lake bathymetry 8
7. Three-dimensional views of Spectacle Lake 9
8. Stream profile at the phase 1 gauging station 14
9. Stream profile at the phase 2 gauging station 14
10. Elements used to calculate wet areas of the stream 16
11. Distribution of phase 1 stream depth data used for calibration 19
12. Distribution of phase 1 streamflow volumes used for calibration 19
13. Distribution of the 22,170 phase 1 water depths recorded 20
14. Distribution of phase 2 stream depth data used for calibration 20
15. Distribution of phase 2 lake depth data used for calibration 21
16. Distribution of phase 2 streamflow volumes used for calibration 21
17. Distribution of the 39,275 phase 2 stream water depths recorded 22
18. Distribution of the 19,003 phase 2 lake water depths recorded 22
19. X-Y plots for all 16 available stream flow volume versus water depth measurements 24
20. X-Y plots for 15 of the available stream flow volume versus water depth measurements .. 25
21. Spectacle Lake phase 1 lake water levels and streamflows 27
22. Spectacle Lake phase 1 lake water levels vs. streamflows 27
23. Hydrograph of raw stream water depths 28
24. Total annual precipitation January to December 2008 32
25. Mean total annual precipitation, 30 year period 1971 to 2000 32
26. Active hydrometric stations in Nova Scotia 34
27. Five year running mean of total monthly precipitation, Kentville, NS 40
28. Spectacle Lake, LaHave River phase 1 streamflows and precipitation 41
29. Spectacle Lake, LaHave River phase 2 streamflows and precipitation 42
30. Spectacle Lake channel baseflow 44
31. Monthly water balance, Spectacle Lake watershed 50
32. Spectacle Lake vs. LaHave River flow by calendar day 53
33. LaHave River F/P vs. Spectacle Lake watershed F/P 53
34. F/P at Spectacle Lake and LaHave River watersheds by calendar day 54
35. Spectacle Lake F/P vs. LaHave River watershed F/P per calendar day 54
36. Values β_{Rs} used to construct the Spectacle Lake discharge stream long-term flow 55
37. Flow duration curve, synthetic daily streamflow 01 January 1967 to 31 December 2011 .. 59
38. Flow duration curve for measured streamflows for phases 1 and 2 59
39. Piper diagram for lake and stream water samples from Spectacle Lake 68

Report disclaimer

This report was prepared for the sole benefit of the Municipality of the District of Chester for assessing the potential for Spectacle Lake to serve as a possible water supply for part of the municipality. This report cannot be used for any other purpose or by any other person or entity without the express written consent of earth-water Concepts inc., and the Municipality of the District of Chester.

The interpretations in this report are based on site inspections, the field work completed, and data available at the time the work was carried out. The data and interpretations presented in this report are based solely on the conditions present when the work was performed. There are levels of uncertainty adherent to any hydrological assessments which are subject to change as different information becomes available. Data obtained for this assessment represent conditions about a limited time period and area surrounding the subject site and as such, the information obtained can be expected to be variable with respect to location and time. This work is specific to the site, conditions and land use considerations described herein, and cannot be used or applied under any circumstances to a location and situation that has not been specifically outlined.

This report must be read in its entirely to ensure proper context with regard to the data and its limitations, assumptions, and the conclusions and recommendations made herein. Therefore, this document is copyright; no part of it may be reproduced, either electronically, photographically or in other hard copy form, without the written consent of earth-water Concepts inc.

The information presented in this report is based upon work undertaken according to sound hydrological practices by trained professional and technical staff. Should future investigations provide information which supplements or differs from the information presented in this report, we request to be notified and permitted to reassess the results and interpretations provided herein.

1. Introduction:

The Municipality of the District of Chester, Planning Department, has retained the services of earth-water Concepts inc. to help assess the potential for Spectacle Lake to serve as a possible future water supply for the Village of Chester. This report describes the two phases of work completed to this end.

The first phase consisted of installing a data logger stream-gauge a short distance below Spectacle Lake, collecting and assessing streamflow and other data covering the period 09 October 2007 to 13 January 2009, and preparing a report entitled "Spectacle Lake hydrological assessment", dated April 2009. That work was intended to end the station calibration process and provide for the semi-automatic collection of hydrologic data from the Spectacle Lake watershed over the long term. However, near the end of the work, beavers changed the course of the stream above the gauge, making so it could no longer be used for taking streamflow measurements.

The second phase of work entailed placing new gauging stations in the lake and in the stream just below the lake (above where beavers had done their work), collecting new gauge data from 10 September 2009 to 04 December 2011, calibrating these new stations for future use, and using the old and new data to better characterize the hydrology of the Spectacle Lake watershed.

Much of the material covered in the April 2009 report is presented again in this report so readers do not need to go back and forth between reports.

The scope of work and role of earth-water Concepts inc. during both phases of work was to:

- help Planning Department staff collect lake water level and raw lake discharge streamflow data,
- help Planning Department staff collect lake water samples from the lake, the input stream, and outlet stream, for lab analysis,
- obtain and compile the precipitation data needed for watershed characterization,
- use existing information and new data to carry out a preliminary hydrological assessment of the lake and its watershed in order to define:
  a) a possible withdrawal allocation as might be obtained for permitting,
  b) the volumes of water likely to be available month-to-month during an average water year,
  c) the spatial and seasonal lake water quality distribution during one year.
- prepare this report on the Spectacle Lake watershed.

2. The study plan

A study plan was presented for consideration by the Municipality of the District of Chester by email in March 2007. It included the following general activities:

- Define watershed boundaries, catchment area[1] and best locations for lake level and streamflow gauging stations[1, 2]. This included reconnaissance surveys of the area[1, 2].
- Survey lake bathymetry using GPS and an electronic or mechanical sounder[1].
- Install lake level and outflow streamflow gauging stations. Included a manual water level gauge for reading lake levels[1], a pressure transducer with electronic data logger for reading lake levels[2], and pressure transducer with electronic data logger for measuring stream stage[1, 2].
- Measure a stream bottom profile at the streamflow monitoring station, from which to assess flow volumes[1, 2].
- Manually collect streamflow velocity readings from time to time to calibrate the electronic streamflow gauge[1, 2].
- Collect stream stage data for a period of at least one year[1, 2].
- Collect lake water samples quarterly for water quality lab analysis[1].
- Obtain and compile precipitation data for use in hydrological assessments[1, 2].
- Produce a lake outflow hydrograph and calculate a watershed water balance[1, 2].
- Use the above to assess possible monthly surplus/deficits under different water taking scenarios[1, 2]. Do a preliminary assessment of lake storage requirements.
- Estimate a long-term water balance for Spectacle Lake via long-term synthetic data from a nearby gauged watershed; to estimate possible 7-day and 60-day low flow analysis based on 1:50 year drought return calculations[1, 2].
- Estimate current natural (lake) and possible future reservoir capacity, a possible withdrawal allocation, and estimate sustainable yields (near-future, distant-future) based on the above[1, 2].

To reduce the number of trips from Halifax needed to collect stream gauge calibration data (and thus reduce overall study costs), earth-water Concepts inc. trained Planning Department staff so they could collect the data (lake water level measurements, manual streamflow velocity readings, and data logger downloads) according to their own work schedules.

Planning Department staff also carried out a couple of lake bathymetry surveys, assisted with lake water sample collection, and did all of the stream water sample collection. All other study activities (i.e. data management, hydrologic interpretations, reporting) were done by earth-water Concepts inc.

Locations in this report are reported as UTM coordinates with datum Nad 83, Zone 20. While it is normal to report precipitation in millimetres and streamflow in m^3/sec, this report uses m^3/day equivalents to help the reader better relate values to water supply.

1 Activity carried out for Phase 1.
2 Activity carried out for Phase 2.

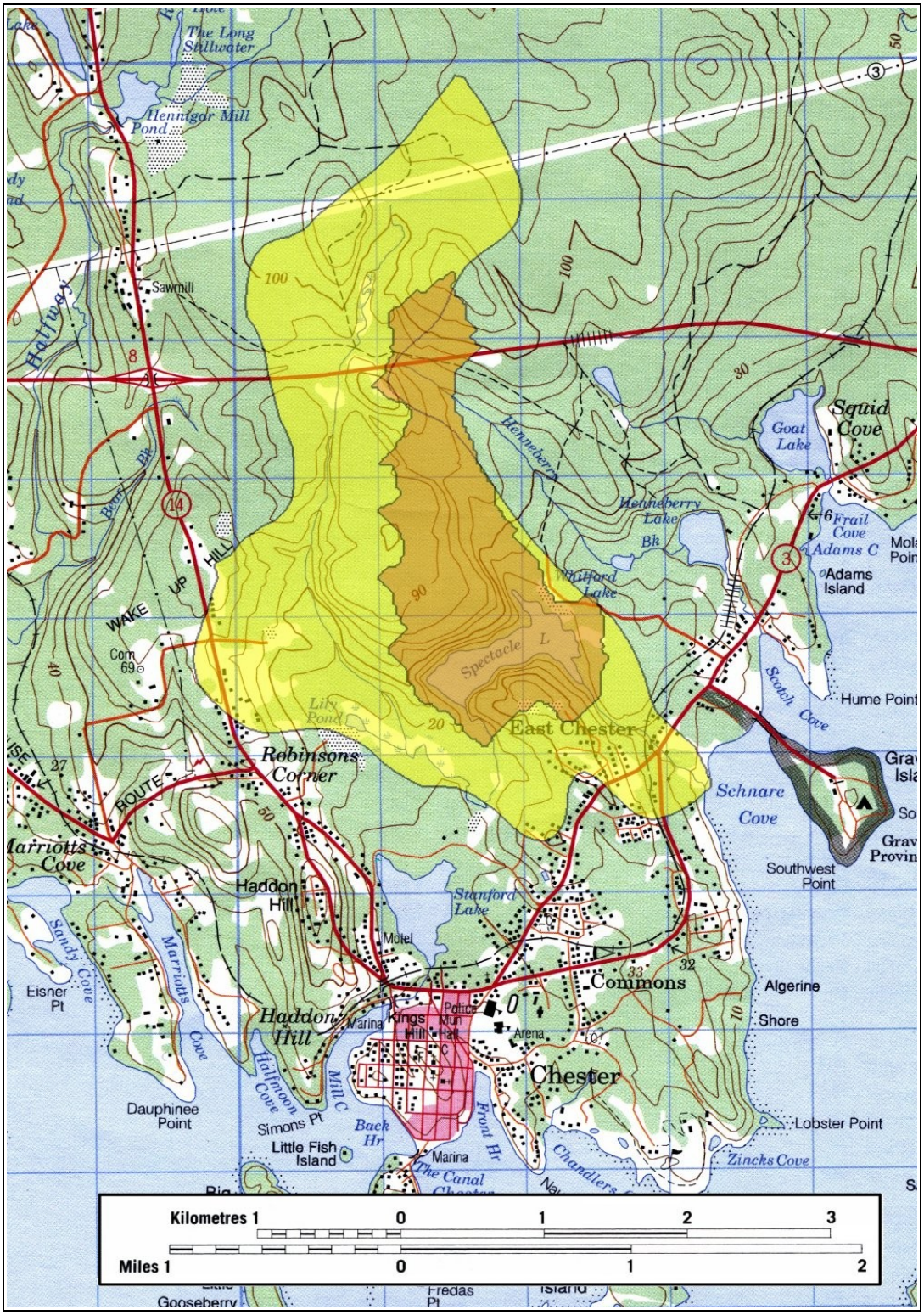


Figure 1. Watershed locations. Watershed 1EG-SD2 is identified by yellow shading. The Spectacle Lake sub-watershed is identified by orange shading. (Base map: CTI, 2000; elevation contour interval: 10 m).

3. Watershed description

The Spectacle Lake watershed is a small (2,566,640 m^2) internal catchment basin located in the east half of coastal watershed 1EG-SD2 (MRMS, 1980) in Lunenburg County, less than 2 km northwest of the hamlet of East Chester (UTM ~4936700N/401500E). Spectacle Lake is situated at the south end of the watershed (UTM 4935750N/401900E) at elevation of 32 m (Geobase, 2004). It has a surface area of approximately 302,069 m^2, and total shore length of about 4,079 m.

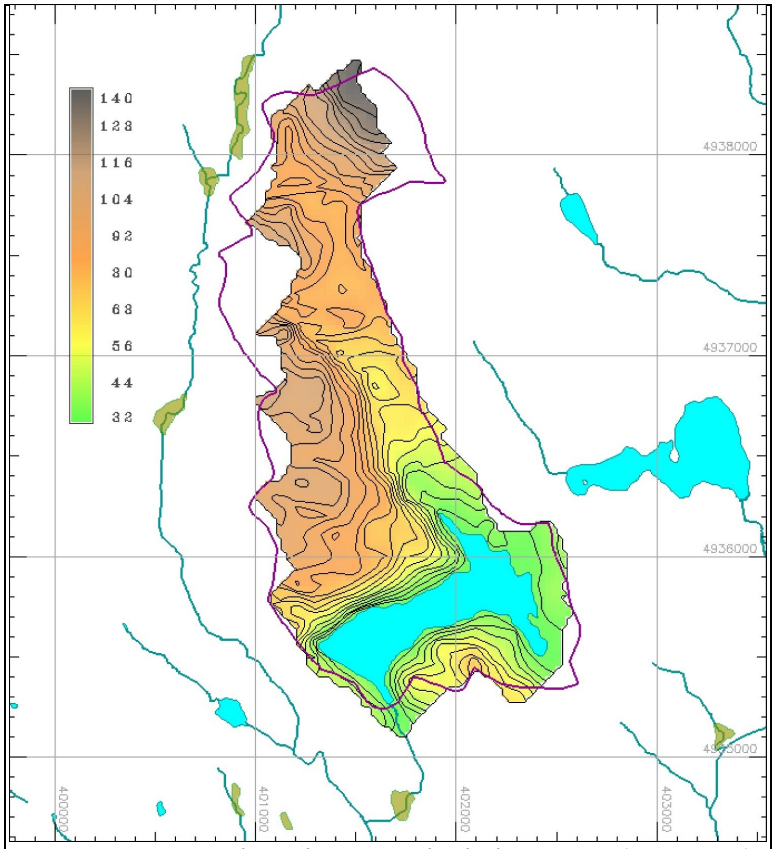


Figure 2. Spectacle Lake watershed elevations (in metres) and local surface water features. The watershed boundary produced by the Municipality of the District of Chester for source protection purposes is shown in purple.

Location and watershed boundaries:

Figure 1 shows the locations of the watersheds described above. For this study, the Spectacle Lake watershed boundaries were defined from digital elevation model (DEM) data (Geobase, 2004) using the watershed analysis and the basin creation modelling methods in GRASS GIS (2011)[3]. The eastern edges of the Spectacle Lake sub-watershed and of watershed 1EG-SD2 do not coincide exactly – this is because of scale and elevation differences for these two separate data sources, and the Spectacle Lake watershed boundary is the more accurate.

Watershed elevation and drainage:

Figure 2 shows the local water features and surface topography of the Spectacle Lake watershed. The watershed is 3.38 km long, less than 0.5 km wide in the north, and 1.46 km wide in the south. Elevations range from 140 m in the north, to 32 m at and around the lake. There is an escarpment at the centre of the watershed with a 25 to 35 m drop to the east. Surface water flow overland is generally from the north and from the east and west flanks of the watershed toward the centre of the basin into a stream that flows below the escarpment and directly into Spectacle Lake.

3 It was necessary to decrease DEM values along the discharge stream from Spectacle Lake by 1 m to properly reflect the modifications made to the stream many years ago. Otherwise, GRASS attempted to create discharge from the southeast corner of Spectacle Lake, where the land to the south of the lake is flat and low lying.

In the south, water flows overland directly into the lake.

Discharge from Spectacle Lake is via an altered channel at the south-west end of the lake. There are remnants of a control structure at the head of this channel, as well as several beaver dams upstream of the gauging station installed during phase 1 of this study. This channel exits the Spectacle Lake sub-watershed and joins up with a another stream (bottom of Figure 2) that drains the west half of watershed 1EG-SD2, then flows south into Stanford Lake.

To avoid confusion, it is important to note that stream locations and flow directions in the current 1:50,000 scale map (CTI, 2000) (base map for Figure 1) are incorrect. Spectacle Lake does not drain into Schnare Cove as is shown on the 1:50,000 scale map. However, should flow along the existing lake outflow channel become blocked causing lake levels to rise, Spectacle Lake would likely flood the low-lying area to the southeast and cause water to flow overland towards Schnare Cove.

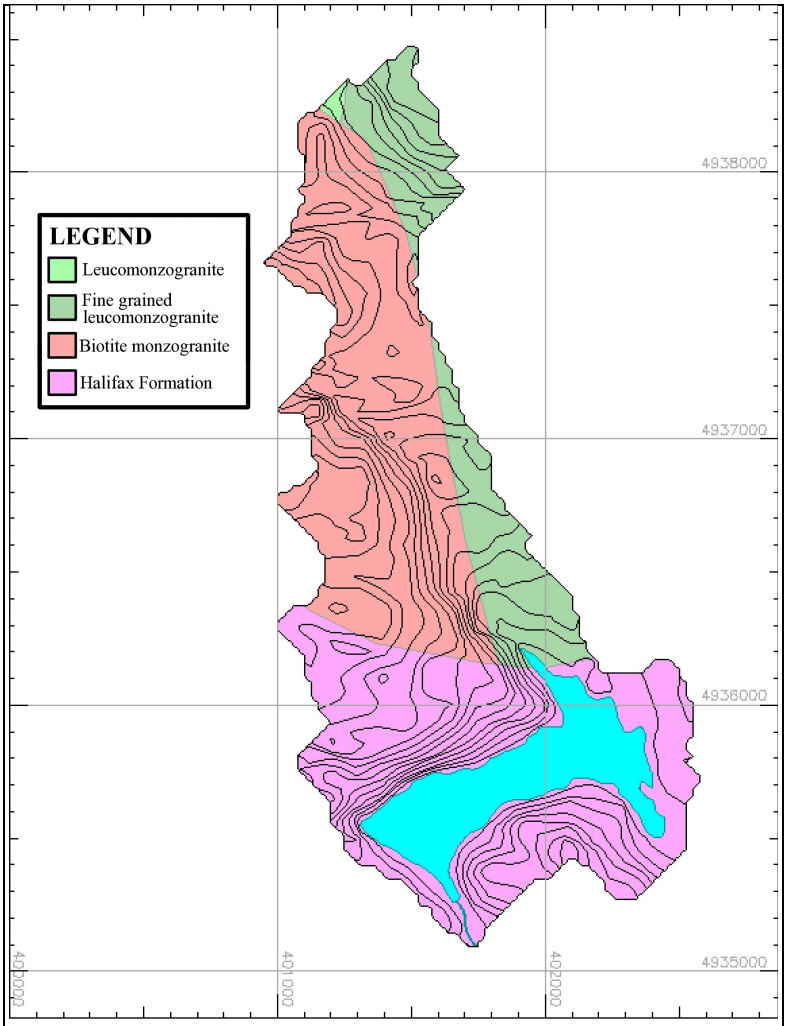


Figure 3. Bedrock geology (after Fisher, 2006a).

Bedrock geology:

Figure 3 shows the bedrock geology at the Spectacle Lake watershed based on Corey (1990), Keppie (2000) and Fisher (2006a). O'Brien et. al., (1985) show the Cunard Member of the Halifax Formation as being present beneath Spectacle Lake and in areas further south. However, they also show the contact between the metasediments and granites to be at the north shore of the lake, as opposed to where it is shown in Figure 3. A recent site visit has confirmed that granitic rocks are present at the north shore of the lake near UTM 4936000N/402000E.

O'Brien et. al. (1985) describe the Cunard Member as containing black slates

interbedded with pyritiferous, cross-stratified, fine-grained grey sandstones. The sandstone beds are 20-50 cm thick and commonly display giant concretions made up of chlorite, carbonate and sulfide. The slate-to-sandstone ratio is variable.

Corey (1990) describes the granitic intrusives as follows:

- New Ross and Panuke Lake (fine grained) Leucomonzo-granites; light buff to pinkish-grey, equi-granular to porphy-ritic; biotite 2-6%, muscovite trace-6%, cordierite trace-4%; alteration effects produce rocks of episyenite (quartz depleted) to syenogranite composition.
- Sandy Lake Monzogranite: whitish-grey, medium to coarse grained, megacrystic (10-20%) to slightly porphyritic; biotite 10-15%, muscovite trace-1%, cordierite trace-3%.

Figure 3 suggests that the escarpment at the centre of the Spectacle Lake watershed may not be entirely related to a change in bedrock lithology. As such, the elevation drop and the linearity of this escarpment relative to the shape Spectacle Lake's eastern shore, may suggest a north-northwesterly fault along part of the axis of the watershed.

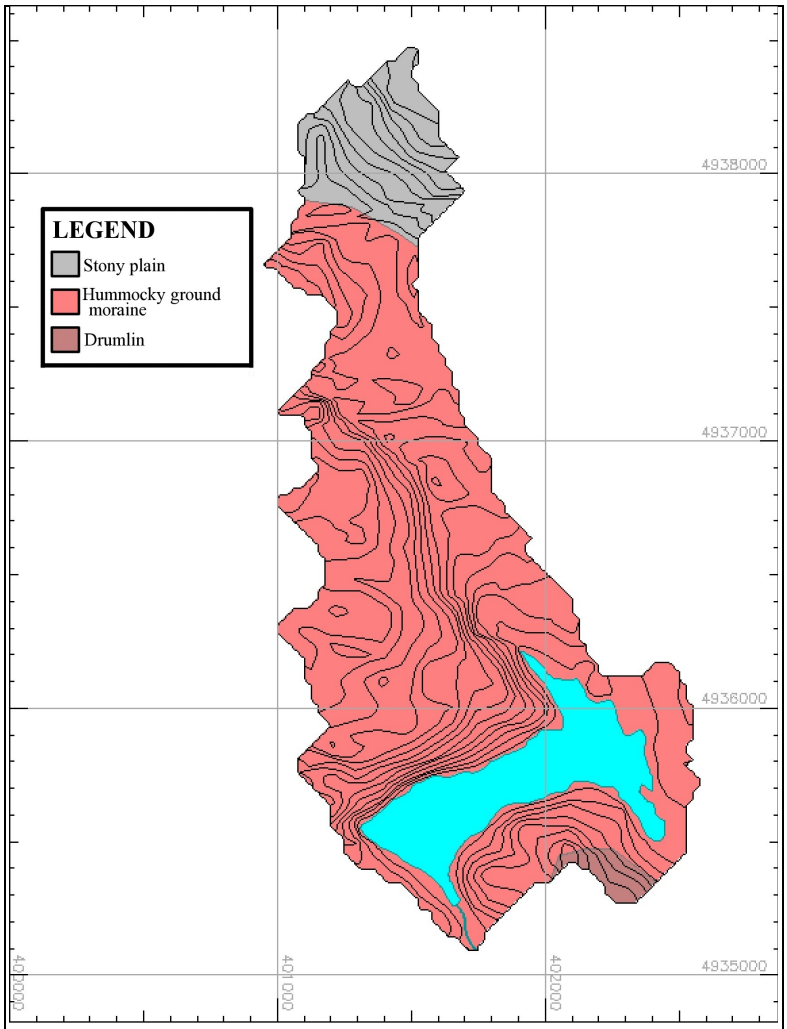


Figure 4. Surficial geology (after Fisher, 2006b).

Surficial geology:

The bedrock within the watershed is overlain by ground moraine (Figure 4). A drumlin is present and forms the hillside along the south shore of Spectacle Lake.

Stea et. al. (1992) have identified the surficial deposits within the watershed generally as a ground moraine and streamlined drift till – basically, a hummocky ground moraine (a mixture of gravel, sand and mud of variable thickness from 2 to 25 m) to the south, and

stony till (stony, sandy matrix, derived from local rocks, ranging from 2 to 20 m thick) north of Hwy. 103. The drumlin materials in the area are described as stony till, but are siltier.

Graves and Finck (1990) further differentiate the surficial deposits as Granite Till B and Granite Till C to the north of Spectacle Lake, and Slate Till C beneath and to the south of Spectacle Lake. They are characterized as follows:

- Granite Till B: loose to moderately compact, moderate yellowish-brown but may vary from greyish-orange to dark yellowish-brown; stony though matrix to clast ratio is variable; matrix 80% to 90% sand, 10% to 20% silt and clay; washed sand zones around boulders.
- Granite Till C: loose, pale brown to yellowish-brown, structured sandy matrix with bedded sand and sand-and-gravel lenses.
- Slate Till C: loose, pale brown to light yellowish-brown, comminuted granite and slate with structured sandy matrix and interbedded sands; gossan stained.

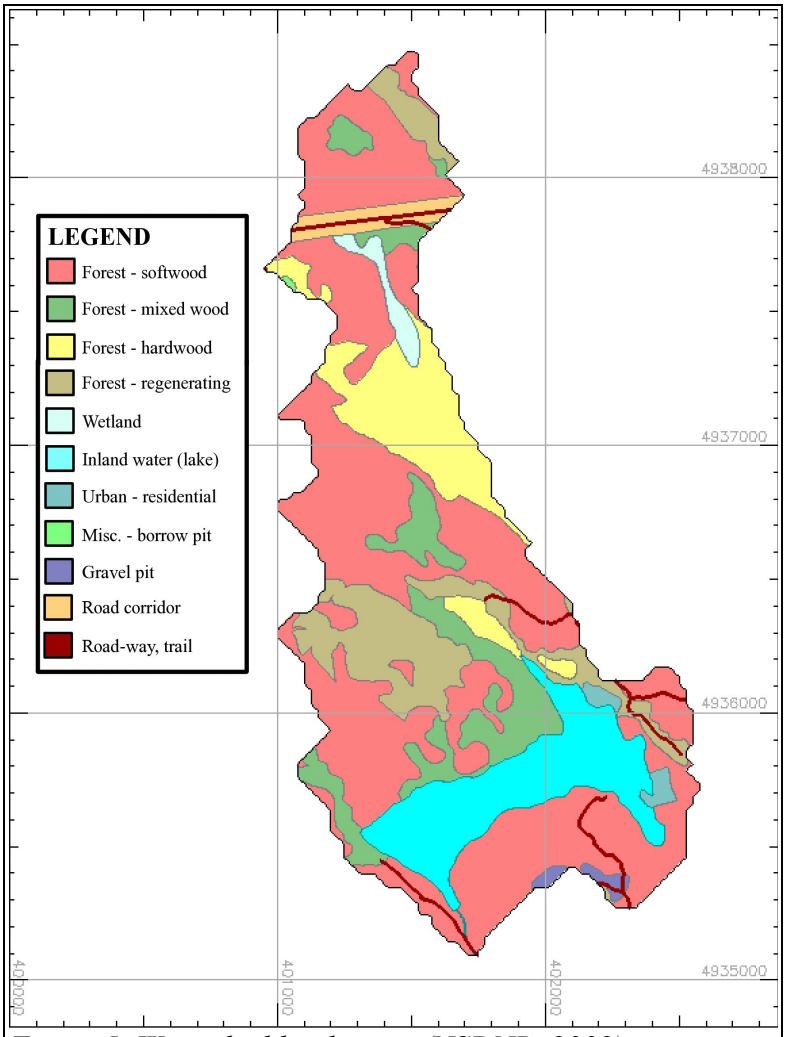


Figure 5. Watershed land cover (NSDNR, 2002).

While the A and B horizon soils in the watershed may vary in composition and drainage capability, they are thin (normally less than 25 cm deep), and since the surficial materials and bedrock are expected to both have low primary permeability, fracture flow in the bedrock hydrostratigraphic unit is expected to serve as the major means for groundwater flow at the watershed and nearby surrounding areas.

Land use and land cover:
Figure 5 shows land use and land cover types and distribution within the Spectacle Lake watershed. Table 1 lists the land cover types by total surface area and percent distribution.

The watershed is 96.4 percent covered by forest, wetland and water. Of the total forest area, 13.5 percent is regenerating forest. The watershed is traversed east-to-west by Hwy. 103 in the north, and in the south contains only a few trails and gravel roads.

Excluding trails and gravel roads, anthropogenic land use (including the Hwy 103 corridor) accounts for 3.7 percent of the total watershed area.

Table 1. Spectacle Lake watershed land cover.

Land cover classification	Area	
	m²	%
Softwood (>75%)	1,324,307	51.6
Mixed wood (74-25% soft)	259,091	10.1
Hardwood (<25% soft)	264,803	10.3
Regenerating forest	289,227	11.3
Wetland - general	33,411	1.3
Lake (open water)	302,077	11.8
Misc. (borrow pit)	1,557	0.1
Gravel pit	16,868	0.7
Urban (residential, cottage)	20,473	0.8
Road corridor (Hwy. 103)	53,584	2.1
total	2,565,398	100.0

Data for this and Figure 5 include air photo interpretation, digital satellite images, silvicultrural field activities, and other field data. Photo source years range from 1988 to 1999 with updates from 1999 and 2000 satellite imagery (NSDNR, 2002).

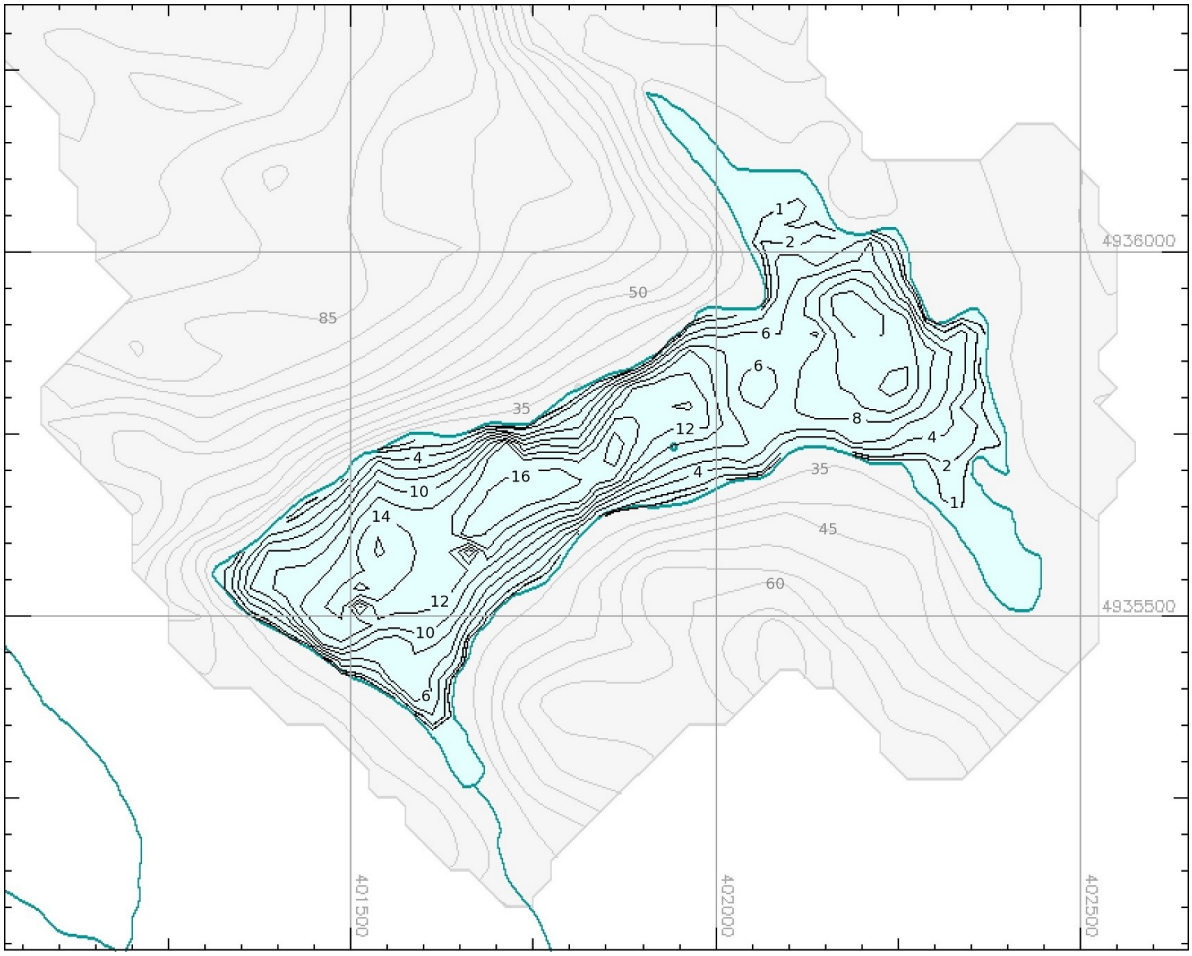
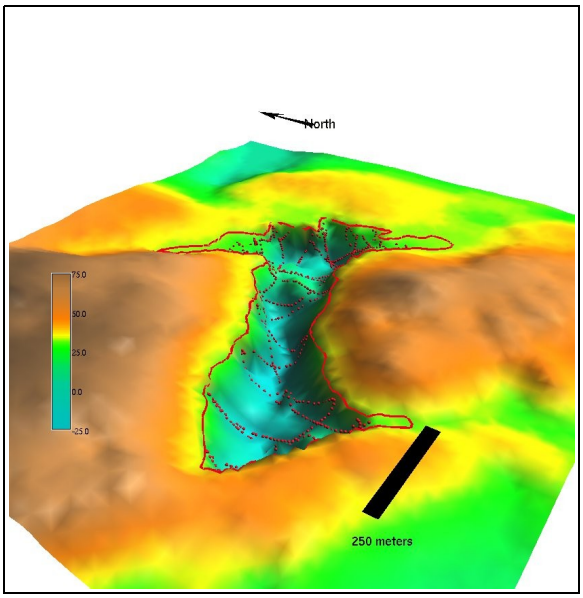
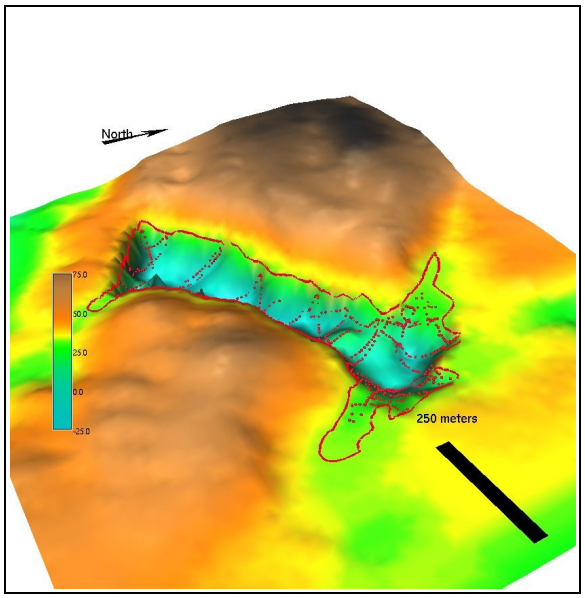


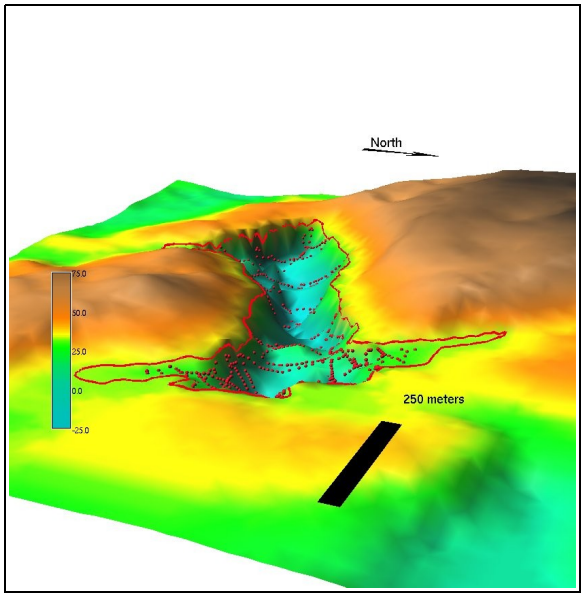
Figure 6. Spectacle Lake depth bathymetry (depth contours 2m, topographic contours 5 m).



a)



b)



c)

Figure 7. Three-dimensional views of Spectacle Lake produced using GRASS-GIS (2011). *All elevations are in metres with 3.28X exaggeration applied to lake (underwater) elevations relative to land surface elevations. The water surface at the lake shore (32 m elevation) is represented by a red line. Raw lake depth data locations (erroneous and questionable data removed) are shown as red dots sitting on the lake bottom. View a) is from a height of 630 m looking northeast. View b) is from a height of 630 m looking northwest. View c) is from a height of 470 m looking west-southwest. The sun is in the southwest (i.e. "shots" for all views were taken in mid-afternoon).*

Spectacle Lake bathymetry:

A small boat was used to traverse the lake in late fall 2007 and a total of 714 lake depth measurements were taken by Municipality of the District of Chester planning staff to map lake bathymetry. Data locations were mapped by GPS and data was made available to earth-water Concepts inc. in ESRI shapefile format.

The lake depth point-data was imported into GRASS GIS (2011), and corrections made as

required, to generate a floating-point raster-format surface of the lake bottom at 25 m by 25 m resolution using regularized spline interpolation with tension. Then contour lines and lake volume calculations were obtained from the lake bottom raster surface. Figure 6 shows the Spectacle Lake bottom contours, and Figures 7a, b and c show the lake in 3-D from different directions and elevations.

Spectacle Lake has a mean depth of 6.17 m, a maximum (smoothed) depth of 18.2 m, and a total volume (assuming a water surface elevation of 32 m) of roughly 2,172,280 m^3. Spectacle Lake contains two underwater sub-basins: a northwest-trending basin located in the far east that has a maximum depth of approximately 13.4 m, and a northeasterly-trending basin the western ¾ of the lake that has a maximum depth of about 18.19 m.

Besides a couple of other elevation highs, there is a ridge between the two sub-basins where water depths range from about 7.5m in the north and south regions of the ridge, to only approximately 4.5 m at the centre of the ridge and lake. These lake bottom elevation features are clearly visible in Figures 6 and 7.

4. Hydrologic field-data collection:

This chapter describes the methods used to construct and calibrate the temporary gauging stations installed in the discharge channel downstream of Spectacle Lake during phase 1, and in the lake and at the discharge channel immediately below the lake during phase 2, in order to obtain the data needed for this study.

The tasks of monitoring lake water levels and collecting stream-flow data were done largely by Municipality of the District of Chester planning department staff with direction and help from earth-water Concepts inc. All other data needed for this study was collected by earth-water Concepts inc.

Lake water level measurements:
Water levels were measured at the lake with the intent to correlate lake water levels with streamflow and as a possible backup mode of taking measurements should something happen to the stream-flow gauges.

Phase 1 lake water level measurements:
During phase 1, lake water levels were measured from a staff gauge attached to a granite boulder situated on the northeast shore of the lake. That location was chosen because of the relative stability of the boulder (permanent reference), distance from roads (less likely to be tampered with), and the ability to view it through binoculars from an easily accessed road.

The staff gauge was originally attached to the boulder with Tapcon® anchor screws, but ice pulled it off the boulder in early spring 2008, so it was reattached using stronger bolts. The second staff gauge location did not precisely match the first; data corrections were done reference to the relative locations of the screw holes for the two installations.

Lake water levels were available for all periods of open water, pending the availability of personnel to take readings.

Phase 2 lake water level measurements:
The manual staff gauge was not used during phase 2. Instead, lake water levels were measured using a pressure transducer and electronic data logger installed at about UTM 4935380N/401565E. That location was chosen because of the slope of the lake bottom at the shore, the relative ease of access to that location, and its proximity to the stream-flow station used for phase 2.

Relative lake water levels were recorded by measuring water depths using a Global Water model WL16 water level logger equipped with a 0-3 foot (0-6.93 psi) range barometric-pressure compensated pressure transducer connected via 25 feet of vented cable to a flash-memory data logger with 81,759 time-date stamped data storage capacity.

The pressure transducer was placed inside a 2” slotted, geotextile-wrapped PVC tube and then a steel pipe to protect it and help secure it to the bottom of the lake. The electronic data logger was placed inside a capped PVC tube strapped onto a nearby tree.

The data logger was programmed to record time, date, water depth, and battery voltage hourly. It was set to continuously wrap data at the end of available memory so there could be data overlap from download to download (as opposed to resetting memory each time, in which case data could be lost).

Batteries were replaced and data retrieved from the data logger at roughly 3 month intervals using a Palm-Pilot to offload data.

Local streamflow measurements:
Streamflow measurements for phases 1 and 2 were obtained from stream gauging stations constructed using the same model of pressure transducer and data logger as at the lake.

Phase 1 gauging station:
The phase 1 gauging station was placed in the discharge channel roughly 130 m downstream of the lake at about UTM 4935140N/401695E. That location was chosen based on:

- relative ease of access (could be reached by road in spring, summer and fall, and over lake ice in winter),
- obscure location (less likely to be found and tampered with by strangers),
- best channel depth and shape with zero flow contributions from the flanks of the stream or from other overland areas, and
- ease of measuring flow velocities for station calibration purposes (narrow enough to allow a log over the stream to be used as a work platform).

In addition, the stream's topographic relief downstream of the chosen location appeared to drop more than at other possible gauging locations, providing for greater opportunities for open water year-round and a greater chance of reducing ice back-water conditions during the winter.

The pressure transducer was placed inside a 2” slotted, geotextile-wrapped PVC tube to protect it from rocks and to more easily

secure it at the channel bottom. The data logger was placed inside a capped PVC tube strapped to a nearby tree.

The data logger was programmed to record time, date, water depth, and battery voltage every 30 minutes It was set to continuously wrap data at the end of available memory to avoid possible data loss. As at the lake, the logger batteries were replaced and data was retrieved from the logger at roughly 3 month intervals using a Palm-Pilot.

Phase 2 gauging station:

Work by beavers had caused the discharge channel from the lake to bifurcate into two or three new channels a short distance above the phase 1 stream gauging station. Therefore, the station could no longer be used to accurately monitor streamflows, and was

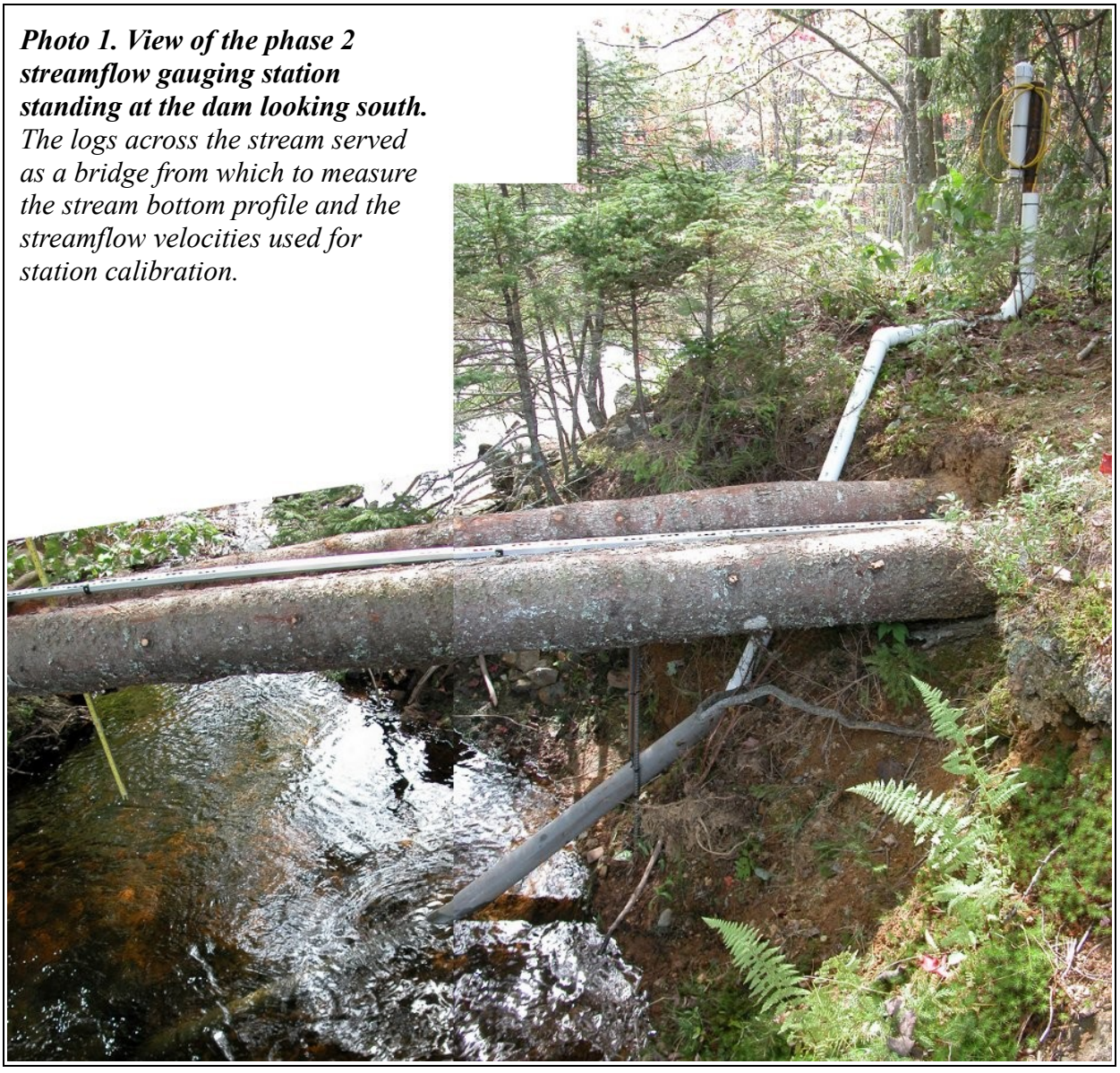


Photo 1. View of the phase 2 streamflow gauging station standing at the dam looking south. *The logs across the stream served as a bridge from which to measure the stream bottom profile and the streamflow velocities used for station calibration.*

moved to the next-best location in the channel; above the beaver work, immediately below the old broken dam at the lake.

The pressure transducer for the phase 2 station was also placed inside a 2" slotted, geotextile-wrapped PVC tube, which was then placed inside a 4" steel tube to further protect it and secure it at the channel bottom. The data logger was placed inside a capped PVC tube strapped to steel pole planted into the ground (see Photo 1). The data logger was programmed the same as for the phase 1 stream gauging station (readings taken every 30 minutes).

Flow velocity measurements:

To determine streamflow rates (i.e. volume of water flowing per unit time), it was necessary to correlate the records of stream water depths taken from the data logger, to a number of known streamflow velocities where the stream cross-section area is known (i.e. at the log bridge shown in Photo 1 in the case of the phase 2 station). To accomplish this, flow velocities were measured at times of peak, normal, and low flow in an attempt to characterize both rising and dropping stream stages.

Due to stream ice conditions and the risk of falling off the log bridge, few streamflow velocity measurements were made in winter.

A Global Water model FP101 Flow Probe was used to measure streamflow velocity. Average streamflow readings were obtained by sweeping the instrument impeller from side to side and top to bottom of the channel several times during a 30 to 60 second period in order to account for stream surging.

To further account for stream surging, two or three separate measurements were made and the average of those was used for station calibration purposes. Maximum flow velocities were also recorded to ensure that the flow meter was functioning correctly and to help assess the reasonableness of the data being collected.

Streamflow at the phase 1 gauging station was relatively laminar and consistent across the entire width of the channel, so velocity measurements there were taken as one reading across the entire width of the stream.

Streamflow velocity at the phase 2 gauging station varied considerably across the channel. To account for this and to improve accuracy, streamflow velocity measurements were taken as three readings within separate cells or vertical panels across the channel; one at the east half of the channel, another at the centre quarter of the channel, and a third at the west quarter of the channel. However, this method of taking measurements could not accommodate the vertical variation (a dead zone at the bottom of the channel) that was later found to exist at the phase 2 stream-flow gauging station.

Measuring stream bottom profiles:

Stream bottom profiles where flow velocity measurements were made to calibrate the gauging stations were obtained by placing a

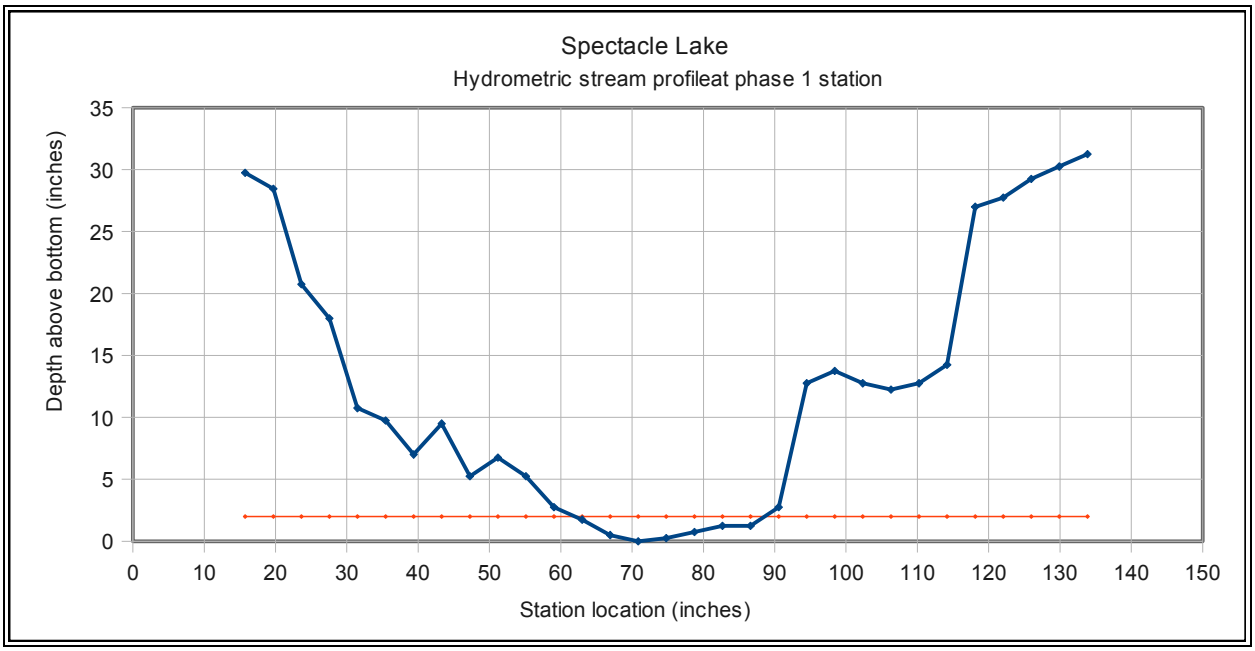


Figure 8. Stream profile at the phase 1 stream-flow gauging station. The blue line represents the stream bottom as measured in the field. The red line represents the depth of the pressure transducer within the stream channel (used for calibration calculation purposes).

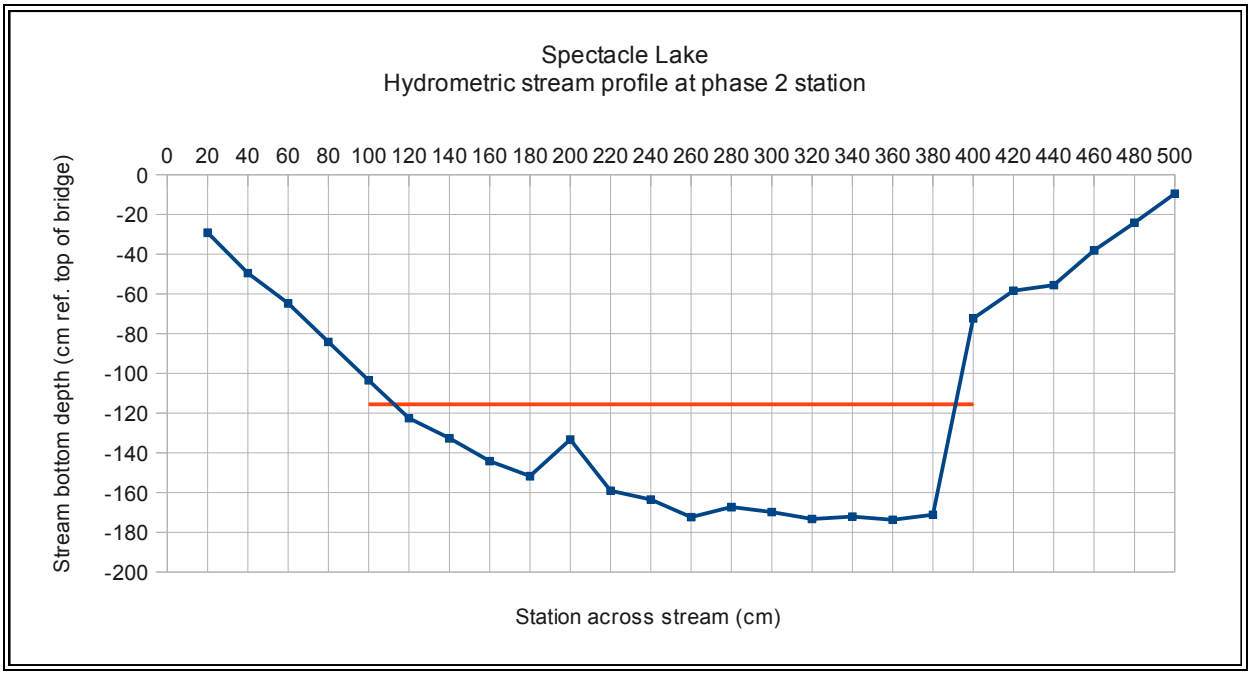


Figure 9. Stream profile at the phase 2 stream-flow gauging station. The blue line represents the stream bottom as measured in the field. The red line represents the depth below which the channel was found (numerically) to have zero flow due to the longitudinal profile (basin-shape) of the channel at the station location (used for calibration calculation purposes).

survey rod horizontally (using a carpenter's level) across the stream and recording the vertical distance from the rod to the bottom of the channel. Measurements were made every 10 cm along the rod at the phase 1 station, and every 20 cm at the phase 2 station. Figures 8 and 9 show the stream cross-section profile at the phase 1 and phase 2 gauging stations, respectively.

Gauge station calibration:
A nearly-continuous streamflow volume (Q) hydrograph can be constructed by relating the stream depths recorded by the data logger at 30 or 60 minute intervals, to known stream-flow velocity and wet channel cross-section area at the times when each flow velocity measurement is made. A hydrograph of this type is needed to define the volume of water that spills out of Spectacle Lake and to define a water balance for the entire watershed.

Measured data:
The logger and streamflow velocity data that became available from the field about every three months was imported into a spreadsheet and to create a stream stage hydrograph to help identify if there were any significant gaps in the data. This was used to determine when best to collect additional streamflow data for stream gauge calibration purposes.

To characterize flow from Spectacle Lake, during phase 1 a total of 16 streamflow velocity measurements and 22,170 water depth readings (30 minute intervals) were obtained during the roughly 15 month period from 09 October 2007 to 13 January 2009.

During phase 2, a total of 19 streamflow velocity measurements, 39,275 stream water depth readings (30 minute intervals), and 19,003 lake depth readings (1 hour intervals) were obtained during the 26.5 and 28 months from 11 September 2009 to 05 December 2011 and 25 January 2012, respectively.

The maximum-minimum water depths (above pressure transducer) recorded during phase 1 were 2.21 and 0.67 feet (674 and 204 mm), respectively, with a overall mean value of 1.27 feet (387 mm). The maximum-minimum average flow velocities measured during phase 1 were 1.09 and 0.16 ft/sec (0.33 and 0.05 m/sec), respectively. The maximum-minimum “maximum” or top flow velocities measured were 2.2 and 0.2 ft/sec (0.67 and 0.06 m/sec), respectively.

The maximum-minimum stream water depths (above pressure transducer) recorded during phase 2 were 3.28 and 1.41 feet (1,000 and 430 mm), respectively, with a overall mean value of 2.30 feet (701 mm). The maximum-minimum average flow velocities measured during phase 2 were 3.44 and 0.04 ft/sec (1.05 and 0.01 m/sec), respectively.

The maximum-minimum “maximum” or top flow velocities measured were 7.5 and -1.25 ft/sec (2.29 and -0.38 m/sec) in the centre and the west quarters of the channel, respectively. Negative values for the west quarter were obtained unfortunately as a result of eddy currents at the gauging station which were not apparent during station installation.

Calculating streamflow volumes:
Obtaining flow volumes requires knowing average flow velocity and wet stream area. This section describes the spreadsheet calculations used to define the wet cross-section area of the stream for each flow velocity measurement (16 events for phase 1, 19 for phase 2). Figure 10 is a piece of the profile from Figure 8 to help explain this.

For each 10 cm vertical slice of water within the stream (pink triangular and rectangular areas in Figure 10), the wet area above the bottom of the channel was defined by a combination of Boolean logic to assess water depth (from pressure transducer readings) relative to the steam bottom geometry at the vertical slice, using the following equation. This equation determines if each or either of the triangle or rectangle within the vertical slice are wet, and if they are, calculates the appropriate sums of each wet sub-area within each vertical slice.

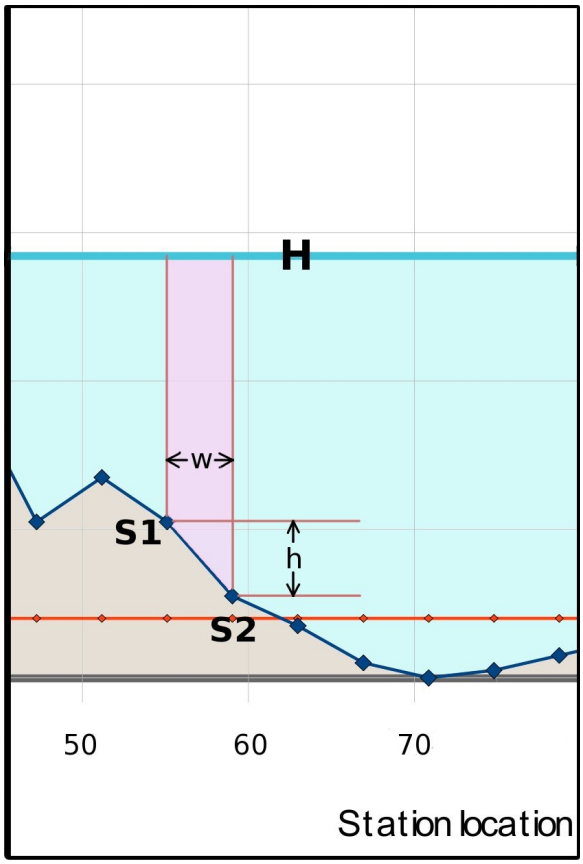


Figure 10. Elements used to calculate wet areas of the stream. Blue represents water, grey represents stream bottom. Red line is the depth of pressure transducer in stream. Other elements are described in the text.

$A = A_T + A_R$

$= IF(H>S1;w•h/2;IF(H<S2;0;(H-S2)•w•((H-S2)/h)/2)) + IF(H>S1;(H-S1)•w;0)$

where:

A = total wet area within the vertical slice

A_T = wet triangular area (part of equation highlighted yellow)

A_R = wet rectangular area (part of equation highlighted orange)

S1 = higher measured stream profile elevation for the vertical slice

S2 = lower measured stream profile elevation for the vertical slice

H = height of water surface above lowest part of stream bottom (adjusted to account for pressure transducer height above stream bottom, in this case, 2")

h = S1-S2 (vertical distance between S1 and S2, varied according to profile)

w = S1-S2 (horizontal distance between S1 and S2, in this case 10 cm)

IF = Spreadsheet Boolean test function.

and where the spreadsheet Boolean test function works as follows:

IF (Test ; then_value ; otherwise_value)

This equation is specific to a vertical strip with stream bottom section with a negative slope, such as would be found on the west side of the stream. A similar approach but a slightly different equation was used where stream bottom sections had a positive slope.

By repeating the calculations above for each 10 cm (for phase 1) and 20 cm (for phase 2) wide vertical slice of the stream, the total wet area of the stream was then defined by adding the areas for all wet vertical slices within the stream. This was done for each of the streamflow velocity measurements – 16 times for the phase 1 data, and 19 times for the phase 2 data.

With the wet stream areas known, flow volumes (Q) were obtained by:

1. for phase 1 data, multiplying each of the 16 total wet channel areas by their respective field-measured flow velocity,
2. for phase 2 data, for each of the 19 sets of data, multiplying the wet channel area for each flow measurement panel by its respective flow velocity.

These flow volumes and their corresponding stream water depths, as recorded by the data logger, were the data used to calibrate the stream gauge.

Quality of the calibration data:

The flow volume and stream and lake depth values used to calibrate the phase 1 and 2 stream gauges are listed in Tables 2 and 3, respectively.

Table 2. Flow volume and stream depth values used for phase 1 stream gauge calibration.

Date stream flow measured	Stream depth (mm)	Q (m^3/day)
09/10/07	331	2309
09/11/07	530	17587
18/12/07	488	13629
08/02/08	485	14627
07/05/08	346	4394
13/06/08	346	5218
27/06/08	279	1983
18/07/08	250	1429
23/07/08	259	2332
14/08/08	274	2996
05/09/08	263	3156
08/09/08	266	2818
22/09/08	252	2340
04/12/08	448	21583
09/12/08	438	14720
09/01/09	395	9872

Figures 11 and 12 show the frequency distributions for stream water depth and flow volume data collected to calibrate the phase 1 stream gauging station. These show that data used to calibrate the gauging station is not normally distributed – it is skewed toward lower flows and low water levels.

However, this is not a grave concern in consideration that the 22,170 water depths recorded by the data logger during phase 1 are also skewed the same way (see Figure 13). As such, the data available for the phase 1 stream gauge calibration appears to be a fair representation of the water depth database for phase 1.

Table 3. Flow volume and lake depth* values used for phase 2 stream gauge calibration.		
Date stream flow measured	**Lake depth* (mm)**	**Q (m^3/day)**
11/09/09	609	1065
07/10/09	705	7677
05/11/09	680	4627
10/12/09	763	13944
21/05/10	601	3153
31/05/10	585	192
08/06/10	699	8674
16/07/10	742	15210
13/08/10	592	332
21/09/10	598	361
08/11/10	959	88095
10/11/10	881	44170
15/11/10	688	10357
15/12/10	776	14382
05/01/11	658	7197
01/05/11	669	6981
12/05/11	775	18677
16/09/11	604	2616
05/12/11	737	12495
* Lake depths (corrected values) were shown instead of stream depths because of the apparent back water errors in the stream data caused by beaver and/or human activity at the stream gauging station.		

Figures 14, 15 and 16 show the frequency distributions for stream water depth, lake water depth, and streamflow volume data, respectively, collected to calibrate the phase 2 stream gauging station.

The lake water depth data is distributed approximately normally, while the stream water depth data is more broadly distributed but is still positioned roughly around the centre. However, the streamflow volume data is skewed significantly toward the higher flows (note the x-axis in Figure 16 is not linear), which suggests a less than optimum fit between the stream/lake water depth data and the streamflow volume data.

Of the 39,275 stream water depth recordings and the 19,003 lake water depths recorded by the data loggers during phase 2, the lake data is more tightly distributed about the mean (see Figures 17 and 18). As with the data distribution shown in Figure 16, the data in Figure 18 is slightly skewed toward higher lake water levels, but only slightly so by comparison to the flow volume data.

Based on the above, the phase 2 stream and lake data available for stream gauge calibration does not appear to represent the water depth database (for stream or lake) as well as the phase 1 data.

Defining stream functions:

The process of calibrating a gauging station usually involves determining what numerical relationship may be used to best represent field-measured values of Q versus their respective measured water depths – H. This is normally done by data regression analysis utilizing x-y data plots.

Once obtained, the proper relationship can then be applied to each water depth reading available (22,170 stream depth readings for phase 1 and 39,275 stream depth or 19,003 lake depth readings for phase 2), plus any future readings collected by the data logger (assuming that the discharge channel or the data loggers are not disturbed) to create a hydrograph of water volumes leaving Spectacle Lake.

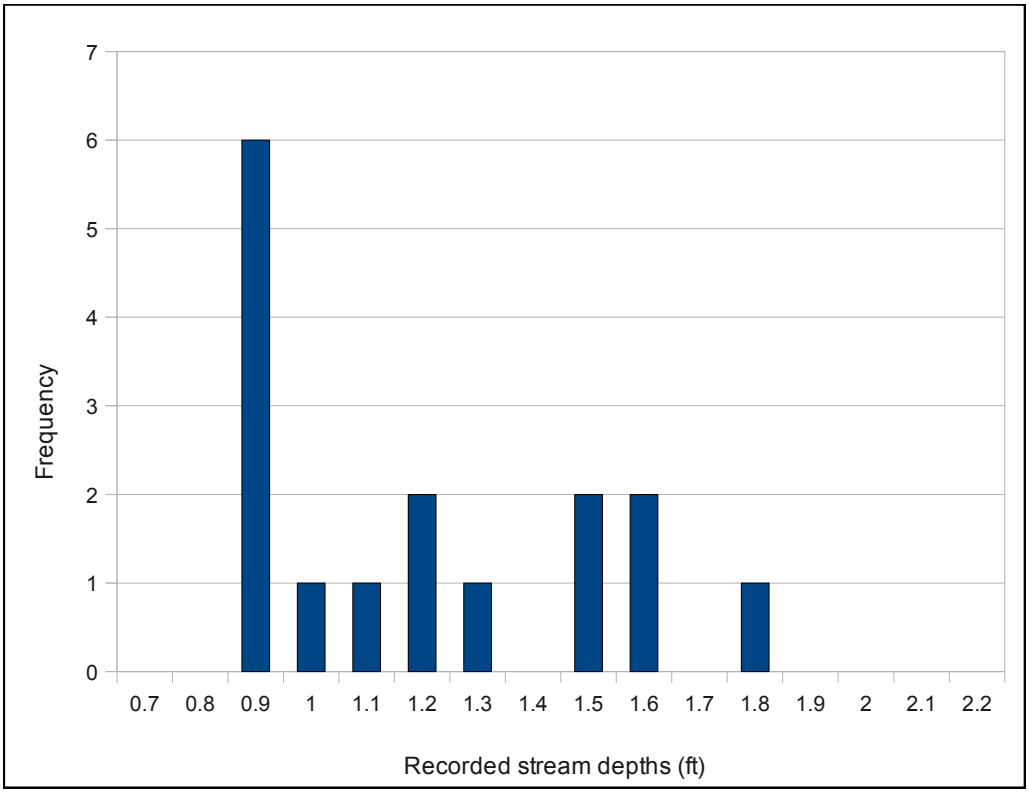


Figure 11. Distribution of phase 1 stream depth data used for calibration.

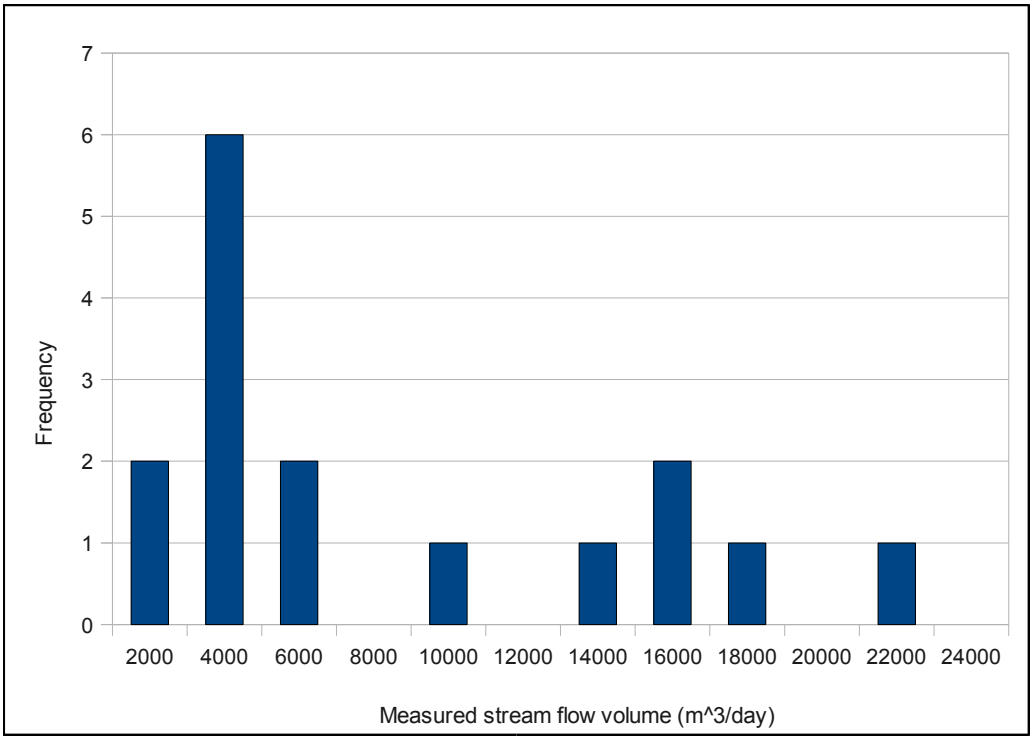


Figure 12. Distribution of phase 1 streamflow volumes used for calibration.

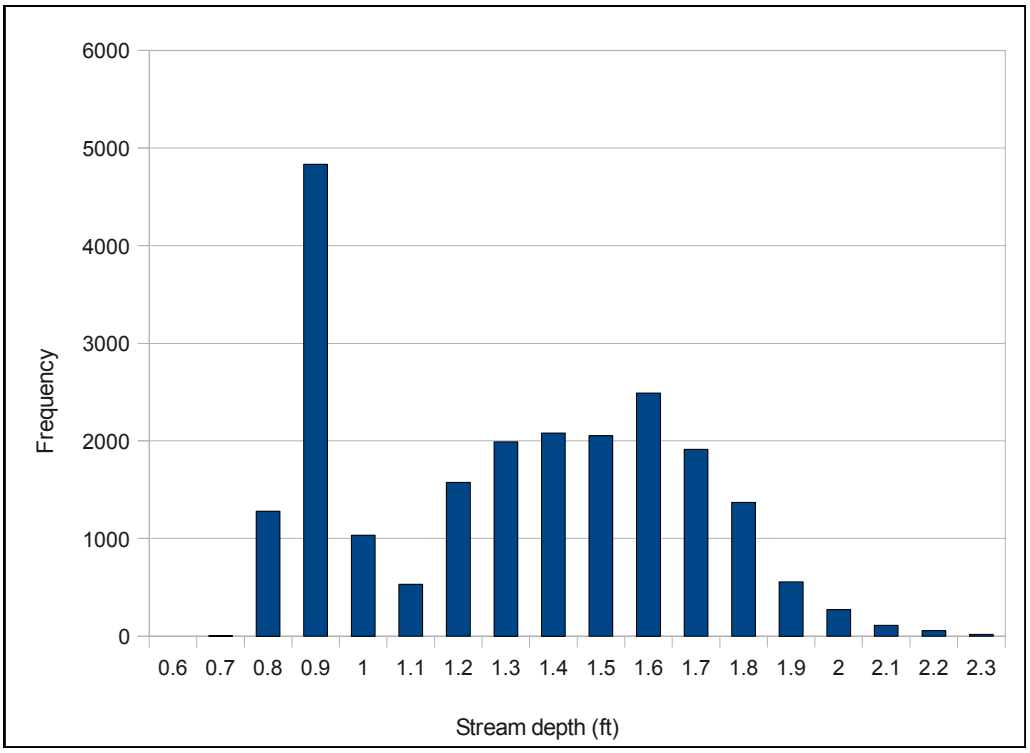


Figure 13. Distribution of the 22,170 phase 1 stream water depths recorded.

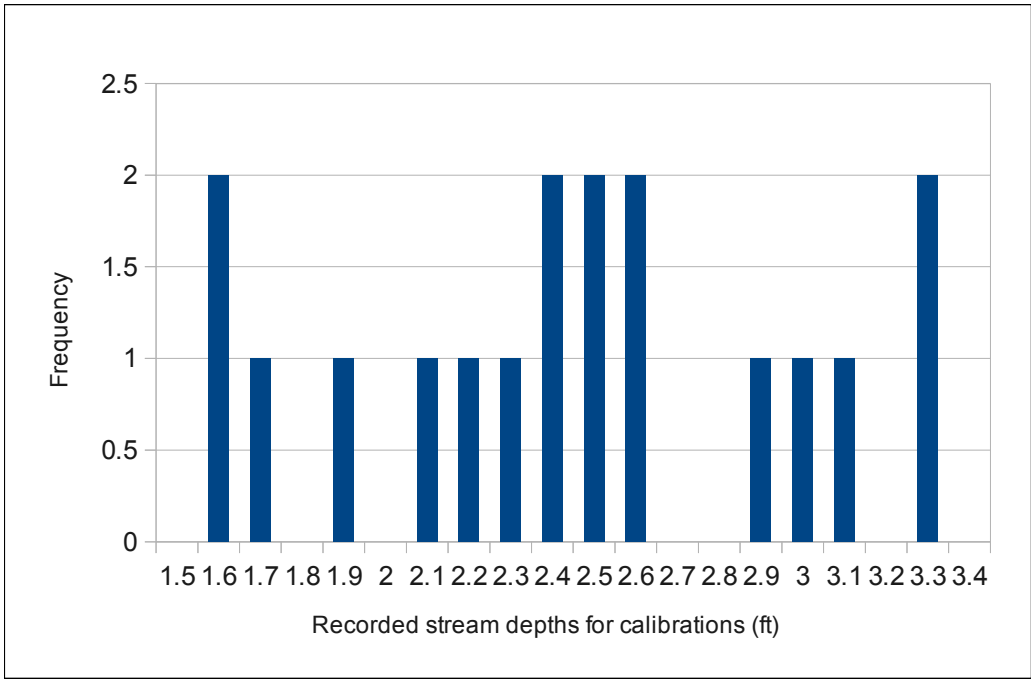


Figure 14. Distribution of phase 2 stream depth data used for calibration.

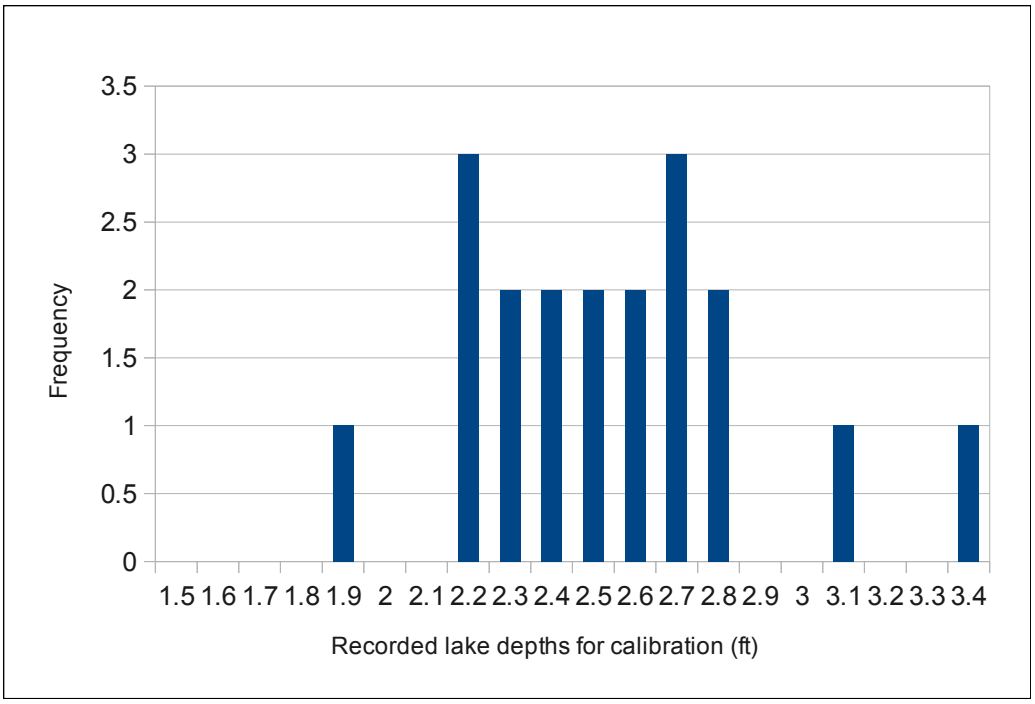


Figure 15. Distribution of phase 2 lake depth data used for calibration.

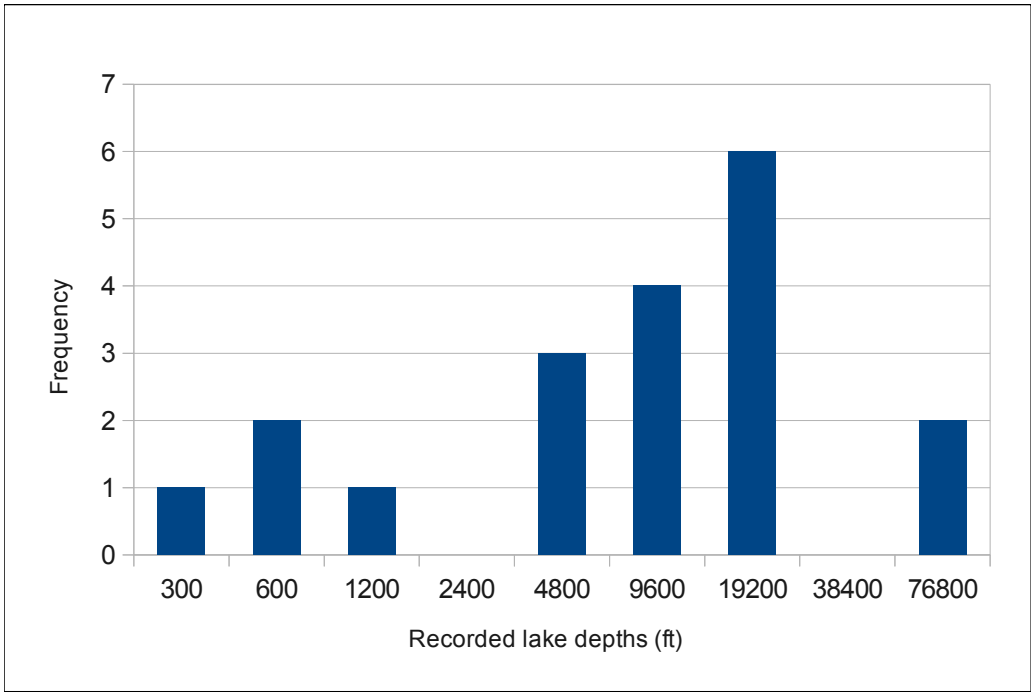


Figure 16. Distribution of phase 2 streamflow volumes used for calibration.

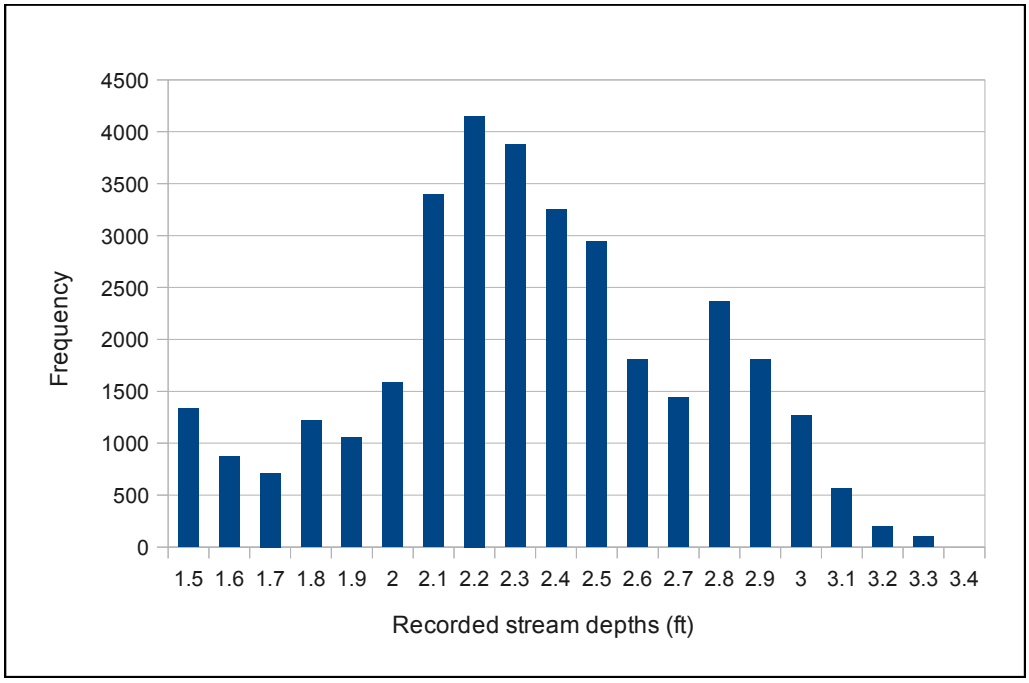


Figure 17. Distribution of the 39,275 phase 2 stream water depths recorded.

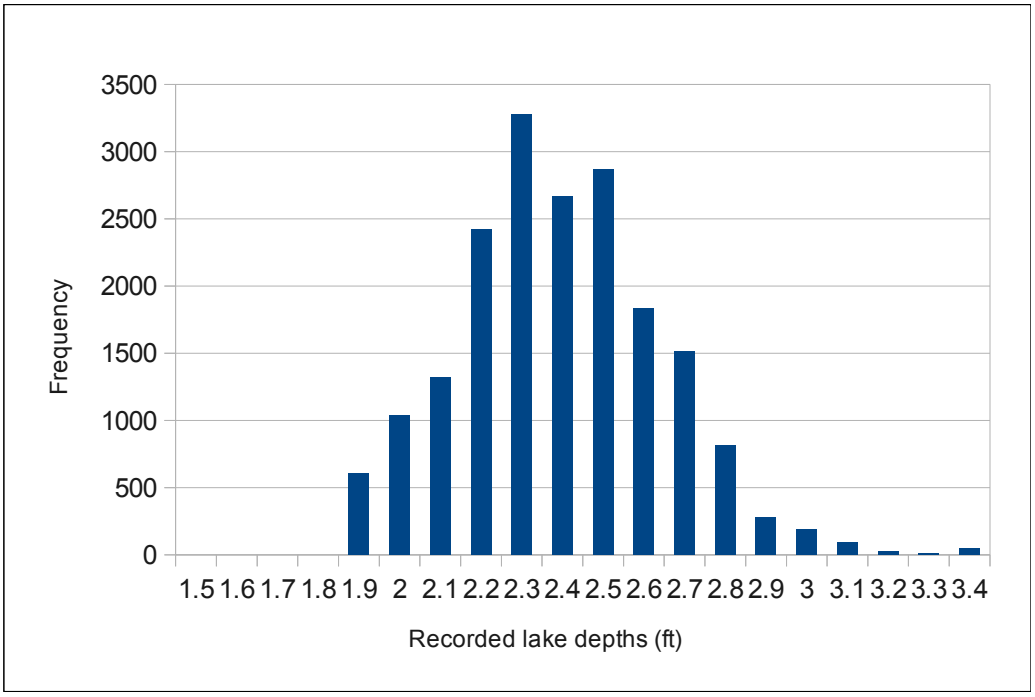


Figure 18. Distribution of the 19,003 phase 2 lake water depths recorded.

Defining a phase 1 stream function:
Two attempts were made to define the best fit for the available data using linear, logarithmic, exponential, and power methods[4]. In the first attempt all 16 of the Q vs H data points available were used. In the second attempt, only 15 data of the available data points were used (the outlying, possibly erroneous value for 04 December 2008 was removed). Figures 19 and 20 show the plots obtained from each attempt. Results of the regression analysis using 16 and 15 points are summarized in Tables 4 and 5, respectively.

Table 4. Phase 1 results, 1st regression analysis using all 16 data points available.

method		relationship	R^2
a	linear	Q=19151.05•H-14618.5	0.84
b	logarithmic	Q=22506.28•ln(H)+5034.86	0.82
c	exponential	$Q=229.93•14.63^{H}$	0.88
d	power	$Q=35943.39•H^{3.19}$	0.89

Table 5. Phase 1 results, 2nd regression analysis with 15 points (04/12/08 data removed).

method		relationship	R^2
a	linear	Q=17275.64H-13020.9	0.93
b	logarithmic	Q=20229.74ln(H)+4724.82	0.90
c	exponential	$Q=258.82•12.73^{H}$	0.90
d	power	$Q=315.76•H^{3.03}$	0.90

A much better data fit is possible when using 15 data points, where R^2 values ranged from 0.90 to 0.93, than when using all 16 flow volume measurements, where R^2 values ranged from 0.82 to 0.89. Therefore, the use of 15 data points was preferred for the phase 1 stream gauge calibration.

The results for 15 data points as shown in Table 4 yielded a higher R^2 value for linear regression than for any of the other three regression methods used. However, the use of a linear regression can result in negative flow volumes during dry times of year when water levels at the phase 1 gauging station location fell below 228 mm. Water levels did fall below this value on several occasions during the phase 1 October 2007 to January 2009 period of data collection.

Therefore, regardless of how good the data fit might be, a linear function could not be used to properly describe flow at the Spectacle Lake outflow channel. Furthermore, due to stream bottom geometry, the flow to water height relationship at most streams typically follow some form of power function[5]. Therefore, based on the current data available, the power function $Q=315.76•H^{3.03}$ was chosen as the one best likely to represent streamflow based on water height from the phase 1 stream gauging station.

4 Best fit analysis were done employing linear (y=m•x+b), logarithmic (y=a•ln(x)+b) , exponential ($y=b•m^{x}$, which was transformed by the spreadsheet function to ln(y)=ln(b)+ln(m)•x), and power regression ($y=b•x^{a}$, which was transformed by the spreadsheet function to ln(y)=ln(b)+a•ln(x)). Correlation coefficient R^2 assessed by RSQ(data-y; data-x).

5 Due to the complexity of stream bed shape, some streams require more than one power function equation, each one applied at specific water level thresholds, to properly describe flow. However, this does not appear to be the case for the outflow channel from Spectacle Lake.

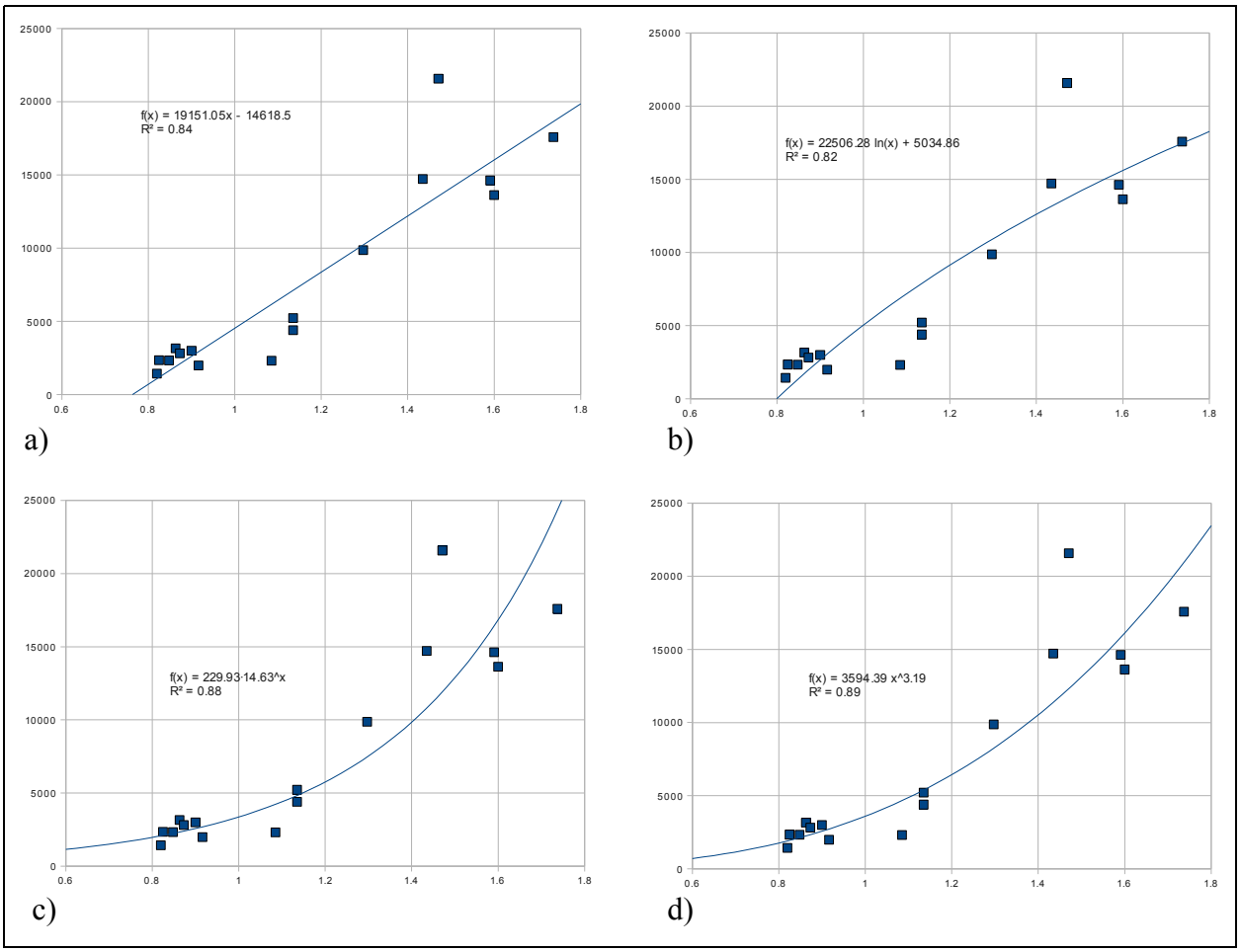


Figure 19. X-Y plots for all 16 available stream-flow volume versus water depth (above pressure transducer) measurements, showing best fit regression trends by: a) linear, b) logarithmic, c) exponential, and d) power methods.

Table 6. Calculated streamflow results obtained utilizing three different numerical relationships under possible consideration. See text for explanation.

		Column 1	Column 2	Column 3
Function used	table	4	5	5
	row	d	a	d
Total for period		4,465,998	4,102,626	4,098,593
Maximum		45,237	25,193	38,969
Minimum		992	-1,481	1,035

To help illustrate the outcome of using this particular function, Table 6 summarizes the total, maximum and minimum flows as determined from data logger readings for the entire phase 1 period of record from 09 October 2007 to 13 January 2009 using three different functions from Tables 4 and 5.

The values in the Column-1 of Table 6 were obtained by utilizing the power function (Table 4, row d) for all 16 data points. The linear function from Table 5, row a was used to calculate the values in Column-2 of Table 6. Finally, Column-3 in Table 6 shows values

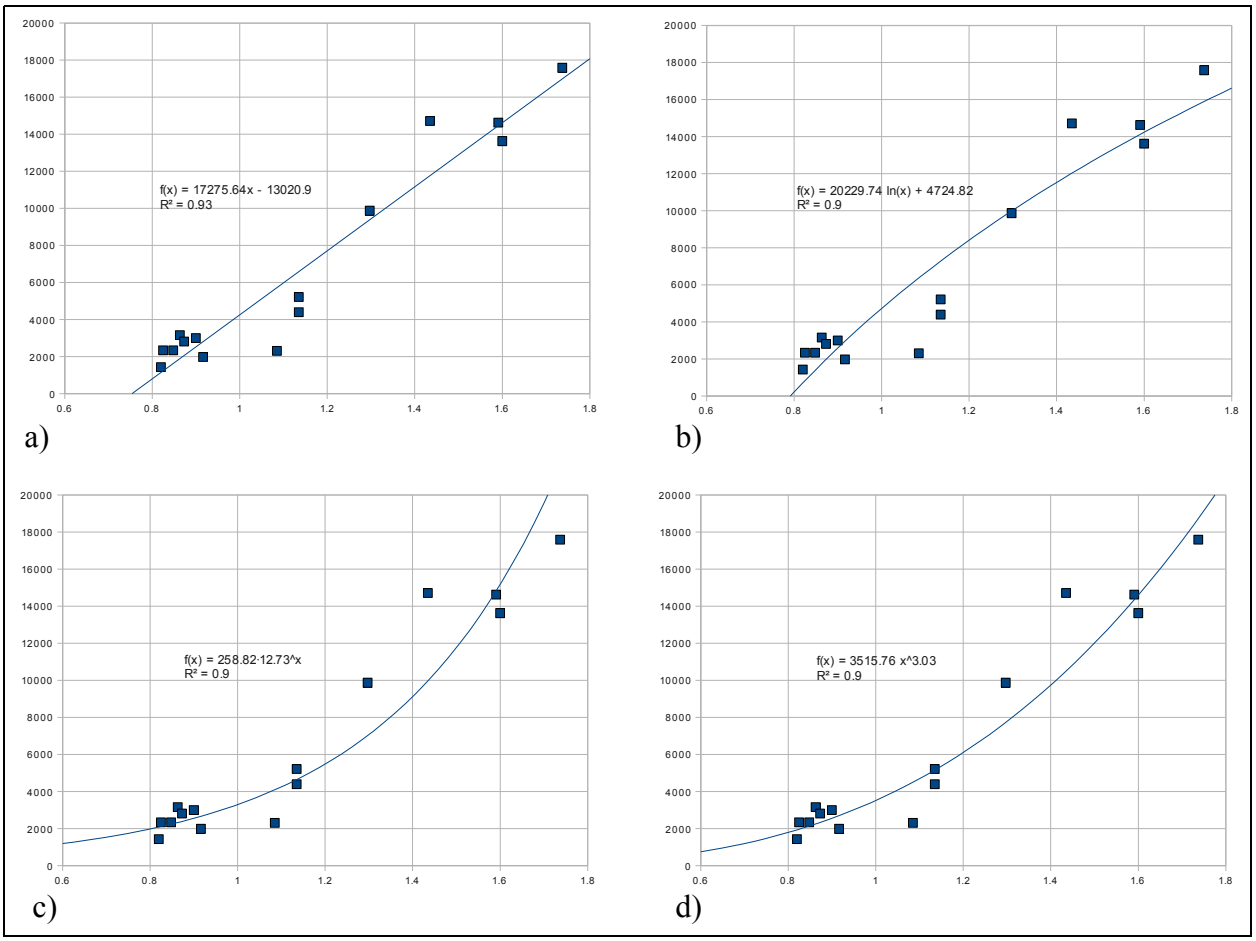


Figure 20. X-Y plots for 15 of the available stream-flow volume versus water depth (above pressure transducer) measurements (data point for 04 December 2008 removed), showing best fit regression trends by: a) linear, b) logarithmic, c) exponential, and d) power method.

obtained when using the preferred function, as noted above – namely, the power function shown in Table 5, row d.

The outcome of removing the 04 December 2008 data point and to carry out a regression analysis based on only 15 data points instead of 16 points, and of using a power function ($Q=315.76 \bullet H^{3.03}$) instead of a linear function to describe streamflow, is to:

1. obtain the most realistic and reliable (R^2 is greater) stream function possible based on available data, and
2. produce a more conservative hydrograph where total calculated streamflow for the period of available record is slightly less and the spread between maximum and minimum flows is also less.

Defining a phase 2 stream function:

Initial efforts to calibrate the phase 2 stream gauge station presented significant difficulty. No matter what stream function was applied or what data was removed to test for best fit, early calibrations simply did not work. All

attempts yielded unreasonably large flows; annual flow to precipitation ratios (F/P, values used later in this report to describe water balance) were around 2.5 and monthly F/P ranged from 5 to 8 for the period January to March 2011 – way more than should ever be expected even when accounting for spring snow melt. And best regression coefficient R^2 values were also very low, ranging from 0.69 to 0.86 for power functions, and 0.66 to 0.83 for logarithmic functions.

Two things were found to be causing the calibration problems:

1. beaver and human activity at the stream gauging station, and
2. a bottom section of the channel at the gauging station with no apparent flow that was giving erroneously high flow volumes when included in calculations.

Regarding the first issue, beaver dams were frequently found upstream of the gauging station and were removed by Municipality staff when they visited the site. Staff also made sure to keep the narrow part of the channel downstream of the pressure transducer clear of debris. However, there is evidence in the data that beaver dams were constructed and destroyed at other times, at which debris collected in the narrow part of the channel downstream.

Municipality Staff noted that lake residents may have been dismantling beaver dams in attempts to keep lake levels stable. However, the resulting debris collecting in the narrow part of the channel would likely not have been cleared by them, as damming there would not have affected lake levels.
The presence of beaver dams upstream would have caused water levels at gauging station to become lowered, giving lower calculated flows. Debris jamming in the narrow part of the channel would have the reverse affect, creating backwater conditions.

Some of the backwater conditions were easy to recognize in the data record and could thus be easily corrected. They were characterized by a sudden drop in water level at the end of the backwater cycle as debris was cleared from the channel, either my Municipality Staff, or naturally.

Other backwater conditions were not so easy to define. From a general comparison of the stream and lake water levels, these less-well understood backwater events appeared to be worse during the period 04 November 2010 to 30 April 2011. However, any attempts to correct these would have been hampered by uncertainty and subjectivity.

Regarding the second issue, the bottom of the channel is reasonably horizontal where the pressure transducer was installed. However, the bottom of the channel drops sharply at the old dam located upstream of the transducer, then rises again further downstream where the channel narrows. This longitudinal stream profile could cause the lower part of the channel to have zero flow, resulting in a much shallower active channel than was measured in the channel cross-section used for earlier calibration attempts.

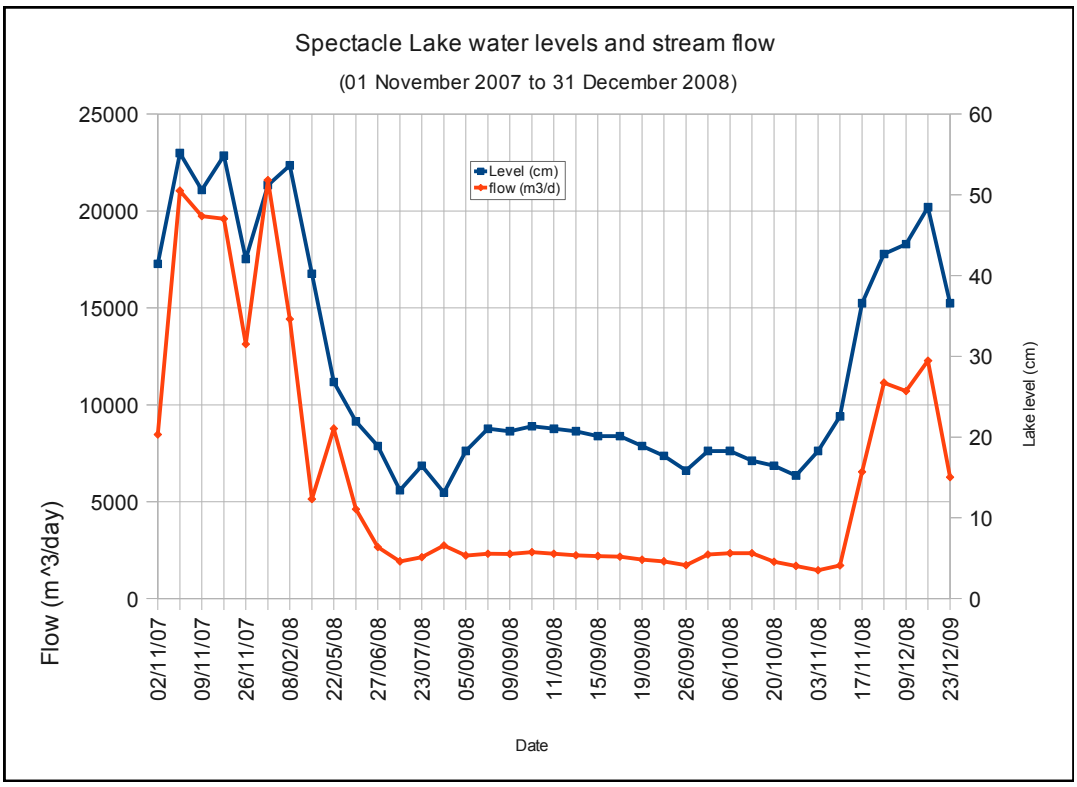


Figure 21. Spectacle Lake phase 1 lake water levels and streamflows.

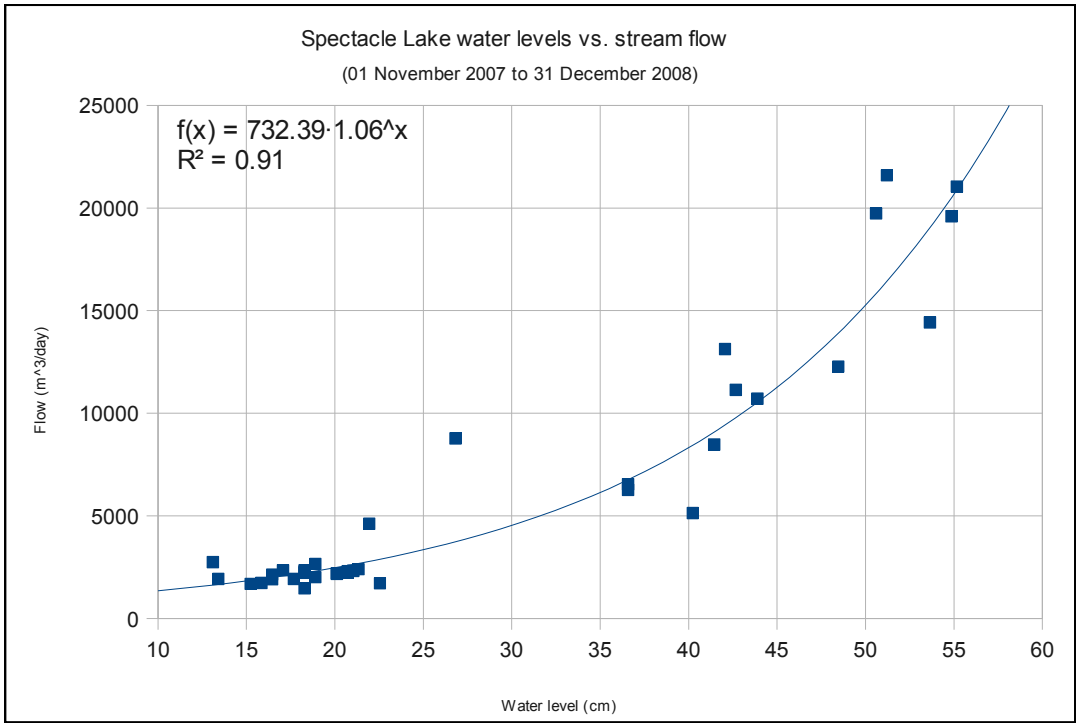


Figure 22. Spectacle Lake phase 1 lake water levels versus streamflows.

The second issue was identified numerically; by experimenting with various "new bottom" threshold (th-Z) values on calibration data, then applying those resulting new stream functions to recorded stream data to verify whether the new flows actually made sense.

A value for th-Z of 45 cm (i.e. numerically raising the channel bottom by 45 cm) was found to give the best correlation coefficient values R^2 for regression analysis by all four methods. Applying these stream functions to available stream data readings gave annual F/P values of 1.4 year over year, and monthly F/P values from 1.2 to 4.5 during the period December 2010 to May 2011. This was much better than calibrating the station without a th-Z value, but it did not allow for correcting for the unknown backwater effects.

Experiments were then done to substitute lake water depth data for stream data to calibrate the stream gauge station. This is a reasonable approach in that lake levels are less subject to affects from beaver activities. But of greater importance, lake data is not influenced by the backwater conditions that were experienced at the channel. Moreover, during phase 1, good direct and exponential correlations were found to exist between lake levels and streamflows (see Figures 21 and 22, explained later in this report).

Another advantage of using lake data instead of stream data is there is no gap in the lake data, but there is a two month gap in the stream data (see Figure 23) due to a battery failure in the stream data logger.

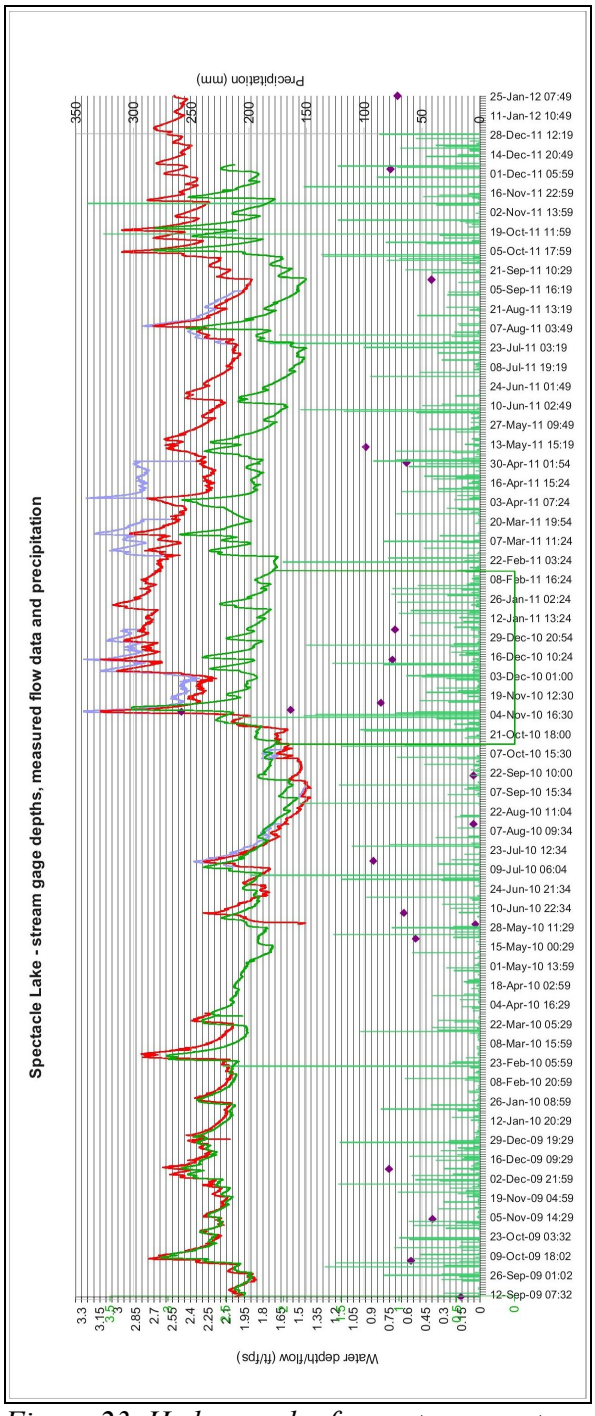


Figure 23. Hydrograph of raw stream water depths (light blue), stream water depths with backwater effects removed (red), and lake water depths (green) corrected for drift and water column differences. Water levels used for calibrations are shown as purple dots, and precipitation as green bars.

Before substituting the stream water depth data with lake data, it was necessary to adjust the lake data for an apparent temporal drift of lake vs stream data. The hydrograph in Figure 23 shows plots of the raw stream water depth data, of stream water depth data with known backwater effects removed, and lake water depths corrected for apparent drift, as well as precipitation during phase 2.

Corrected lake data (as shown in Figure 23) and streamflow velocity measurements were used to calibrate the lake station to define flows volumes in the Spectacle Lake outflow channel. Best fits were obtained from the power function $Q=32.53H^{6.83}$ and from the logarithmic function $Q=16.79 \bullet 15.54^{H}$ (both giving correlation coefficients $R^2=0.95$) using a value for th-Z of 55.5 cm and with the lowest flows from 21 May 2010, 13 August 2010, and 21 September 2010 removed from calibration calculations.

While both functions yielded conservative (slightly underestimated) streamflow values, the power function was more conservative still for both maximum and minimum flows and as such, it is the one suggested be used as the phase 2 lake/stream function for the Spectacle Lake outfall channel. It gives minimum, maximum and mean daily flows of 1,172 m^3/d, 81,429 m^3/d and 8,152 m^3/d, respectively, and annual F/P values in the range of 0.67 to 0.78 and maximum monthly F/P values of 1.20, 1.95 and 2.41 for March 2010, April 2010, and March 2011 (values that appear to properly account for lower than normal precipitation along with snow melt).

5. Hydrologic assessment:

This assessment is based on streamflow data collected at Spectacle Lake during the phase 1 period from 09 October 2007 to 13 January 2009, the phase 2 period from 11 September 2009 to 05 December 2011, and long-term flow values for the Spectacle Lake watershed as synthesized from historic precipitation data and streamflow data from the nearby LaHave River watershed.

Data collection:

The methods used to collect streamflow data and to calibrate the stream gauges installed below Spectacle Lake and in the lake were described in the previous section. Figures 28 and 29 show the stream-flow hydrographs generated for phases 1 and 2 from that data. Discussion on these hydrographs is provided later in this report.

Precipitation data acquisition:

Two separate sets of precipitation data were used for this assessment. They included:

Data Set 1 - daily total precipitation, used for hydrographic analysis and to synthesize long-term flows for the Spectacle Lake watershed, and

Data Set 2 - monthly mean precipitation, for a general view of mean precipitation-flow relationships and water balances.

The criteria used for selecting Environment Canada climate stations for Data Set 1 were to have:

- as complete a daily precipitation record as possible that also matched the entire

period of streamflow data for phases 1 and 2, plus

- a historical daily precipitation record as complete and as long as possible to use to synthesize a long-term flow record for Spectacle Lake.

The closest climate stations that met these criteria and that had long-term (44 years) of continuous daily precipitation data were: the Greenwood, Halifax Airport, Kejimkujik, Kentville, Yarmouth Airport, and Shearwater Airport/Auto stations.

The Kentville station was missing data for the periods 04 to 10 August 2007, 15 to 26 August 2007, and 11 September 2007. These gaps were filled by using readings from the nearby Greenwood station as approximations for GIS modelling purposes.

The Shearwater Airport station had data from mid-1944 to only 20 March 2007. Data from the nearby Shearwater Auto station (values averaged where there was overlap) was used to complete the data to the end of 2008, and data from Shearwater RCS was used through to the end of 2011.

The criteria for selecting climate stations for Data Set 2 was to have as complete and as geographically broad a database as possible to model monthly total precipitation. All of the Environment Canada stations in eastern Atlantic Canada (mapping domain for our GIS) that meet WMO (World Meteorological Organization) standards for precipitation for 1971 to 2000 (see Table 7) were used.

Table 7. WMO climate station data used to GIS model monthly total precipitation.

Inside Nova Scotia	Outside Nova Scotia
Baddeck	Alberton
Bridgewater	Charlottetown A
Cheticamp	East Baltic
Ccollegeville	Long River
Deming	Monticello
Greenwood A	New Glasgow
Halifax Citadel	O'Leary
Halifax Stanfield Int'l A	Summerside A
Ingonish Beach	Acadia Forest Exp St
Liverpool Big Falls	Aroostook
Louisbourg	Bon Accord
Middle Musquodoboit	Buctouche
Mount Uniacke	Doaktown
Nappan Cda	Fredericton A
Parrsboro	Fredericton Cda
Salmon Hole	Gagetown 2
Shearwater A	Miramichi A
Springfield	Moncton
St Margaret's Bay	Moncton A
Summerville	Rexton
Sydney a	Saint John A
Truro	Sussex
Upper Stewiacke	
Westphal	
Yarmouth A	

Precipitation modelling:

A common practice used to define how much precipitation may fall over an area of interest is to calculate an average from a number of blindly selected nearby climate stations. However, precipitation distribution and intensity may vary significantly both spatially and temporally, so this approach may not always correctly represent precipitation amounts over the area of interest, particularly if that area is large. Therefore, other tools must be used to help determine what groups of climate stations are best suited to provide data for analysis.

To determine what groups of climate stations might best represent daily precipitation falling over the Spectacle Lake and LaHave River watersheds, GIS modelling was done to define total monthly precipitation distribution for November 2007 to December 2008, September 2009 to December 2011, and the 30 year mean monthly precipitation for the period 1971 to 2000. The GIS modelling was done by spatial approximation analysis using climate station point data to floating-point raster format (25m by 25m resolution) by regularized spline interpolation with tension in GRASS GIS (2011).

Measures were not needed to incorporate elevation-dependence in the models, as it was assumed that local orographic effects would be inherent to the climate station locations. However, anisotropy (ratio 2 to 1, azimuth 70 degrees) was applied to represent prevailing storm advance directions across Nova Scotia. A tension factor of 30 and zero smoothing were used for interpolation.

Figures 24 and 25 are examples of modelling output. In all, 64 such maps were generated to represent the magnitude and distribution of total monthly precipitation, as follows:

- one for each of the 14 complete months of phase 1 field streamflow data (November 2007 to December 2008),
- one for each complete year of data during the phase 1 field period of record (i.e. November 2007 to October 2008, December 2007 to November 2007, and January 2008 to December 2008),
- one for each of the 28 months of phase 2 field streamflow data (September 2009 to December 2011),
- one for each complete year of data during the phase 2 field period of record (i.e. 2010, 2011, October 2009 to September 2010, November 2009 to October 2010, December 2009 to November 2010, and December 2010 to November 2011),
- one for each 30-year mean monthly precipitation for the period 1971 to 2000,
- one for 30-year mean total annual precipitation for the period 1971 to 2000.

Following the 64 interpolations noted above, total monthly precipitation falling within the boundaries of each, the Spectacle Lake and LaHave River watersheds, was calculated.

While it is not practical to apply the method above to get the daily precipitation data needed to synthesize long-term flow records (doing so would require months), the models do provide insight as to what climate stations to use to calculate daily precipitation means.

A review of the raw and modelled data suggests that means calculated from the Halifax Airport, Shearwater, Greenwood and Kejimkujik climate stations may best represent daily precipitation falling over the Spectacle Lake watershed. Likewise, means from Halifax Airport, Shearwater, Kentville, Kejimkujik and Yarmouth may best represent daily precipitation falling over the LaHave River watershed.

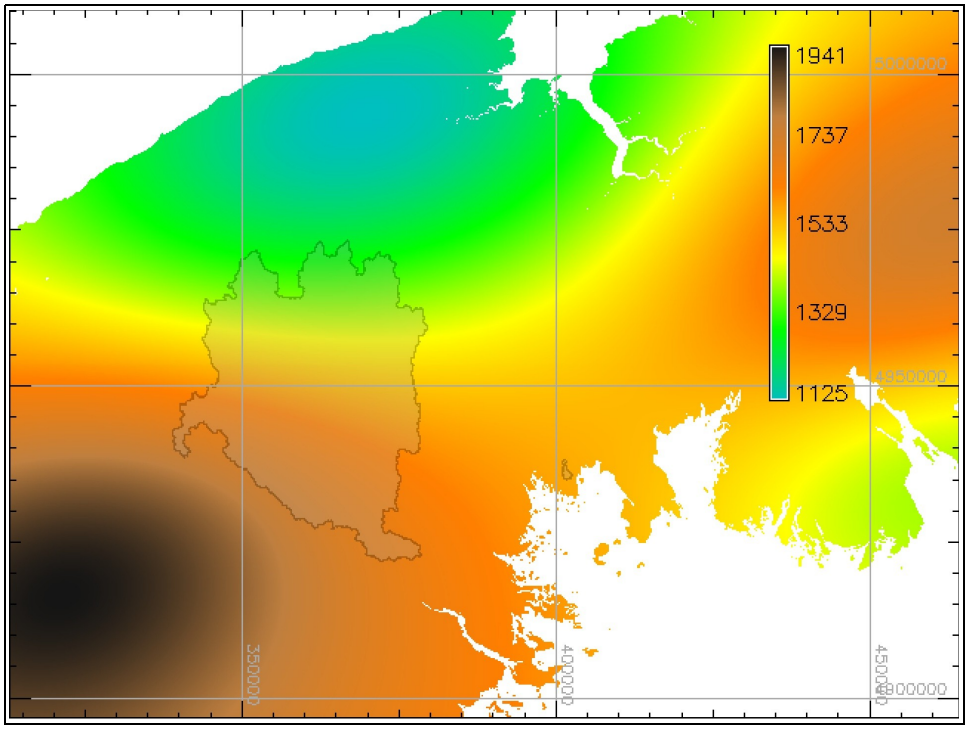


Figure 24. Total annual precipitation, January to December 2008. The Spectacle Lake and LaHave River watersheds are shaded grey.

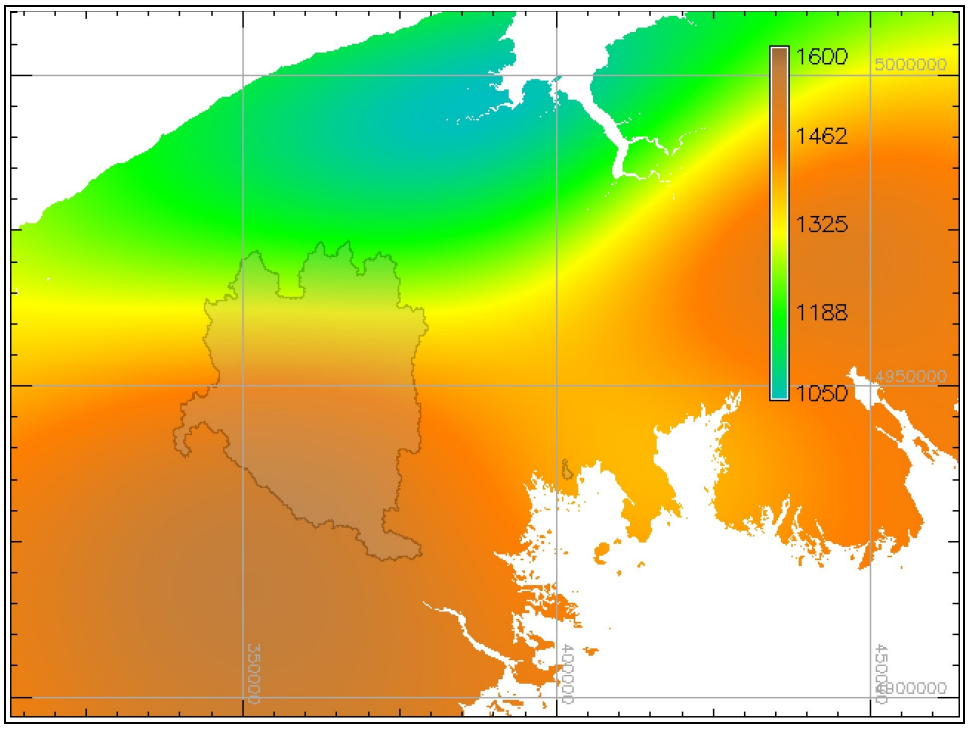


Figure 25. Mean total annual precipitation, 30 year period 1971 to 2000. The Spectacle Lake and LaHave River watersheds are shaded grey.

Errors in the means obtained for the LaHave River watershed are expected to be much greater than for the Spectacle Lake watershed due to the larger size of the LaHave River watershed and the greater precipitation variability over it. Besides the univariate statistics obtained from GIS modelling, it is not possible within the scope of this project to quantify in greater detail what those errors might be.

Selecting data to synthesize streamflow records for Spectacle Lake:

It is often necessary to construct a synthetic long-term flow record for basins that are not gauged. A common approach is to install a temporary discharge monitoring station at the site of interest and to correlate those short-term flow data to discharge records from a nearby watershed that has been gauged for a while. This technique works best when both sites drain similar geologic/geomorphic terrain and have similar climate and land use, although this is not always necessary.

Only those Environment Canada stream gauging stations with a long, nearly complete record that also overlaps the 2007 to 2011 period of on-site field data were considered as possible candidates for data synthesis. This meant using stream data from currently active (automated) stations only.

Figure 26 shows where the automated stream gauge stations are located in Nova Scotia (published data are available only to the end of 2010), and Table 8 lists the stations that were considered for this study.

There were two gauging stations in the final running: at the LaHave River and the Little Sackville River watersheds. Environment Canada were able to provide a complete data record up to the end of 2011 for the LaHave River (preliminary corrections only for ice back-water conditions), but not for the Little Sackville River. Therefore, data from the LaHave River station was used.

The LaHave River gauge (station 01EF001) is located at West Northfield (44.26'48" lat., 64.35'30" lon.). The basin (upper reaches of watershed "1EF" – MRMS, 1980) is reported to have an area of 1,250 km^2. However, a value of 1,254,485,625m^2 was obtained for the watershed boundaries created by GRASS GIS (2011) for this study.

The LaHave River watershed is naturally regulated, and has a complete, verified daily streamflow record from mid-1915 to the end of 2010, and preliminary data from 01 January to 31 December 2011.

Analysis of total monthly precipitation:

Tables 9 and 10 show the values for total monthly precipitation as obtained from GIS modelling for the Spectacle Lake and the LaHave River watersheds. The tables include matching (whole month only) monthly and annual data for the phase 1 period from November 2007 through to the end of December 2008, for the phase 2 period from September 2009 through to the end of December 2011, and for the 30 year (1971 to 2000) annual and January through December monthly means.

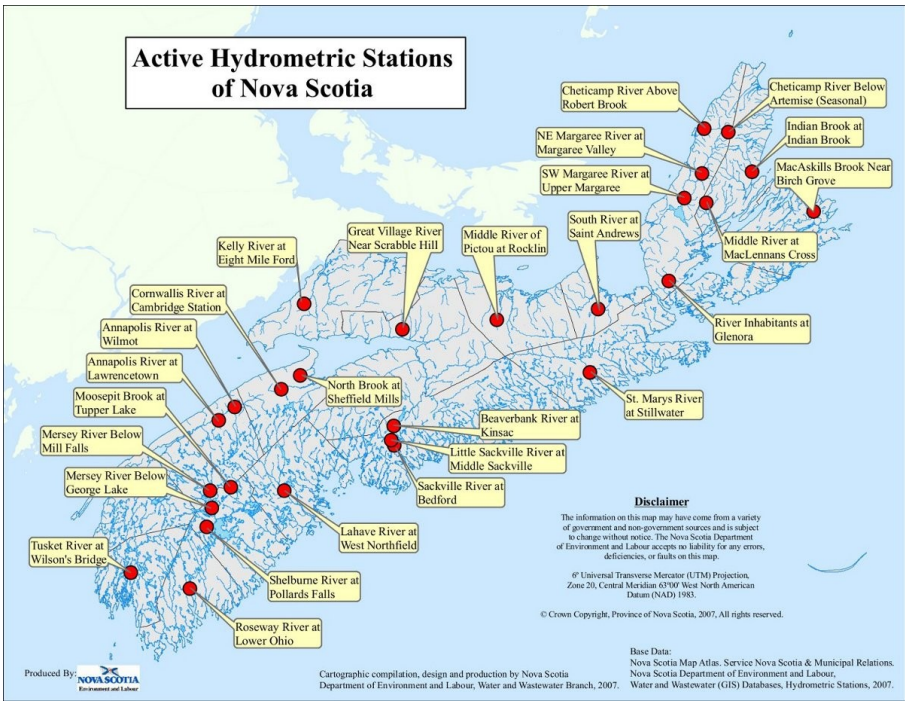


Figure 26. Active hydrometric stations in Nova Scotia (NSE, 2007).

Table 8. Gage stations considered for synthesis of flow record at Spectacle Lake.

Gage station location	Basin size (km^2)	Data record available	Comments
Roseway River at Lower Ohio	495	back to 1915, but some missing data in March 2007	far away, precipitation model cannot provide proper coverage.
Shelburne River at Pollards's Falls	268	only back to 1999, missing data in July, November and December 2006	data record not long or complete enough
Mersey River below George Lake	723	data complete from 1968 to present	geology, topography and land use are too different
Moose Pit Brook at Tupper Lake	17.7	data back to 1881, but missing Sept. 2006 through to mid-Nov 2006 and parts of 2007	closest in size, similar geology, but different topography and recent data not complete enough
LaHave River at West Northfield	1250	data complete from about mid-1915 to the end of 2006	nearest gaged watershed, watershed large with varying geology/climate
Sackville River at Bedford	146	data to 1970, but no recent data to match Spectacle Lake data	data not complete enough
Little Sackville River at Middle Sackville	13.1	data to 1980, missing one week of data in Nov-Dec 2006	distant, but similar geology, basin size and topography
Beaverbank River at Kinsak	96.9	data to 1921, near-complete data for 2006 to 2007	distant, possible second choice candidate to Little Sackville River

Table 9. Total monthly/annual precipitation for Spectacle Lake watershed per GIS precipitation modelling.

	Spectacle Lake	Precipiation (mm)							Precipitation Volume (m^3)	Percent of 30 yr. mean
		Min	Max	Range	Mean	St. Dev.	Variance	var coef %		
Phase 1 data	Nov. 2007	168.95	170.04	1.08	169.48	0.27	0.07	0.16	435,041	121.19
	Dec. 2007	137.93	140.22	2.29	139.30	0.56	0.31	0.40	357,571	98.77
	Jan. 2008	200.20	203.40	3.20	201.82	0.69	0.48	0.34	518,054	145.05
	Feb. 2008	190.64	191.45	0.82	191.03	0.18	0.03	0.09	490,336	176.4
	Mar. 2008	132.30	133.42	1.12	132.80	0.29	0.09	0.22	340,892	96.74
	Apr. 2008	64.81	65.12	0.31	64.98	0.07	0.00	0.10	166,791	58.79
	May 2008	127.43	128.69	1.26	128.13	0.33	0.11	0.26	328,897	115.55
	June 2008	45.08	45.62	0.54	45.29	0.13	0.02	0.28	116,264	44.01
	July 2008	93.29	96.20	2.91	94.88	0.76	0.58	0.80	243,552	99
	Aug. 2008	157.83	160.62	2.79	158.96	0.66	0.43	0.41	408,027	182.24
	Sept. 2008	101.21	103.05	1.84	102.06	0.48	0.23	0.47	261,984	102.31
	Oct. 2008	79.13	79.46	0.33	79.33	0.08	0.01	0.10	203,622	65.37
	Nov. 2008	145.90	147.92	2.02	147.12	0.50	0.25	0.34	377,633	105.2
	Dec. 2008	212.93	214.50	1.57	213.87	0.41	0.17	0.19	548,988	151.65
	12 months Nov. 2007-Oct. 2008	1,506.31	1,510.04	3.73	1,508.07	0.82	0.67	0.05	3,871,030	108.16
	12 months Dec. 2007-Nov. 2008	1,482.45	1,488.22	5.77	1,485.71	1.24	1.55	0.08	3,813,622	106.56
	12 months Jan. 2008-Dec. 2008	1,557.46	1,562.48	5.02	1,560.28	1.08	1.17	0.07	4,005,039	111.9
Phase 2 data	Sept. 2009	69.99	70.24	0.25	70.12	0.05	0	0.08	174,853	68.28
	Oct. 2009	167.62	168.08	0.45	167.9	0.11	0.01	0.06	418,696	134.42
	Nov. 2009	105.32	107.12	1.8	106.44	0.45	0.2	0.42	265,425	73.94
	Dec. 2009	161.61	162.71	1.1	162.28	0.29	0.08	0.18	404,682	111.79
	Jan. 2010	115.79	117.5	1.72	116.85	0.43	0.18	0.37	291,389	81.59
	Feb. 2010	107.32	108.04	0.72	107.68	0.16	0.02	0.14	268,514	96.6
	Mar. 2010	96.24	96.93	0.69	96.61	0.18	0.03	0.19	240,928	68.37
	Apr. 2010	39.53	39.67	0.13	39.62	0.04	0	0.09	98,794	34.82
	May 2010	42.36	43.05	0.7	42.73	0.18	0.03	0.42	106,549	37.43
	June 2010	98.69	101.96	3.27	100.11	0.86	0.74	0.86	249,646	94.49
	July 2010	120.46	121.84	1.38	121.28	0.36	0.13	0.3	302,448	122.94
	Aug. 2010	82.31	83.38	1.07	82.86	0.27	0.07	0.32	206,622	92.29
	Sept. 2010	109.48	109.7	0.21	109.58	0.04	0	0.04	273,264	106.71
	Oct. 2010	151.15	151.57	0.41	151.41	0.11	0.01	0.07	377,577	121.22
	Nov. 2010	263.87	264.75	0.88	264.32	0.19	0.03	0.07	659,140	183.62
	Dec. 2010	189.09	190.45	1.36	189.91	0.36	0.13	0.19	473,577	130.82
	Jan. 2011	128.1	129.74	1.64	129.12	0.42	0.18	0.33	321,999	90.16
	Feb. 2011	165.85	167.23	1.38	166.63	0.36	0.13	0.22	415,542	149.49
	Mar. 2011	62.02	62.59	0.57	62.3	0.14	0.02	0.22	155,370	44.09
	Apr. 2011	118.42	122.56	4.15	120.88	1.08	1.18	0.9	301,439	106.25
	May 2011	121.14	122.54	1.4	121.69	0.33	0.11	0.28	303,470	106.62
	June 2011	140.55	141.15	0.6	140.81	0.14	0.02	0.1	351,144	132.91
	July 2011	92	92.68	0.68	92.34	0.17	0.03	0.19	230,268	93.6
	Aug. 2011	111.34	112.47	1.12	111.95	0.29	0.08	0.26	279,184	124.69

Table 9. total monthly/annual precipitation for Spectacle Lake watershed per GIS precipitation modelling.										
	Spectacle Lake	Precipiation (mm)							Precipitation Volume (m^3)	Percent of 30 yr. mean
		Min	Max	Range	Mean	St. Dev.	Variance	var coef %		
Phase 2 data	Sept. 2011	42.84	43.04	0.19	42.94	0.04	0	0.1	107,084	41.82
	Oct. 2011	293.29	297.43	4.15	295.61	1.09	1.18	0.37	737,164	236.66
	Nov. 2011	214.62	216.13	1.51	215.56	0.37	0.14	0.17	537,551	149.75
	Dec. 2011	175.36	177.78	2.42	176.72	0.64	0.4	0.36	440,682	121.73
	Year 2010	1420.68	1424.6	3.92	1422.94	0.84	0.71	0.06	3,548,448	99.15
	Year 2011	1667.7	1683.31	15.62	1676.55	4.1	16.83	0.24	4,180,897	116.82
	12 months Oct. 2009-Sept. 2010	1251.12	1255.79	4.67	1253.92	1.06	1.12	0.08	3,126,957	87.37
	12 months Nov. 2009-Oct. 2010	1234.65	1239.26	4.61	1237.43	1.06	1.12	0.09	3,085,838	86.22
	12 months Dec. 2009-Nov. 2010	1393.2	1396.9	3.7	1395.31	0.79	0.62	0.06	3,479,552	97.22
	12 months Dec. 2010-Nov. 2011	1681.44	1695.98	14.54	1689.74	3.82	14.6	0.23	4,213,792	117.74
30 year mean values for period 1971 to 2000	January	138.83	139.36	0.53	139.14	0.12	0.02	0.09	357,147	
	February	107.98	108.55	0.57	108.29	0.13	0.02	0.12	277,970	
	March	136.93	137.68	0.75	137.27	0.17	0.03	0.12	352,366	
	April	109.97	110.93	0.96	110.53	0.22	0.05	0.20	283,718	
	May	110.76	110.99	0.23	110.89	0.06	0.00	0.05	284,633	
	June	102.49	103.21	0.72	102.93	0.18	0.03	0.18	264,202	
	July	95.72	95.96	0.24	95.84	0.06	0.00	0.06	246,015	
	August	87.09	87.32	0.23	87.22	0.05	0.00	0.06	223,895	
	September	99.48	100.10	0.62	99.76	0.16	0.02	0.16	256,081	
	October	120.75	121.78	1.02	121.35	0.24	0.06	0.20	311,489	
	November	139.43	140.24	0.81	139.85	0.18	0.03	0.13	358,966	
	December	140.54	141.49	0.95	141.03	0.23	0.05	0.16	362,011	
	Year	1,392.14	1,396.56	4.43	1,394.31	0.98	0.95	0.07	3,579,013	

Precipitation during phase 1:

Tables 9 and 10 show that the total monthly precipitation falling over the Spectacle Lake and LaHave River watersheds during the months of November 2007 and in January, February, May, September, October and December 2008, was greater than the 30 year mean for similar months.

Total monthly precipitation was nearly twice that of the 30 year norm in February 2008 for both watersheds and in August 2008 for the Spectacle Lake watershed.

The wetter-than-normal 2007-08 winter months and fall months of 2008 were offset by much drier than normal April and June 2008 rainfalls. The months of April and June 2008 received approximately half the 30 year normal April and June amounts.

The total 12-month precipitation amounts received at both watersheds were slightly more in 2007-08 than for the 30 year (1971 to 2000 period) annual norm. Also, on an annual basis the Spectacle Lake watershed was slightly wetter than the LaHave River watershed. For example, the mean annual

Table 10. Total monthly/annual precipitation for LaHave River watershed per GIS precipitation modelling.

	Lahave River	Precipitation (mm)							Precipitation Volume (m^3)	Percent of 30 yr. mean
		Min	Max	Range	Mean	stand dev	Variance	var coef %		
Phase 1 data	Nov. 2007	163.50	184.73	21.23	176.03	4.15	17.26	2.36	220,829,622	123.25
	Dec. 2007	90.19	163.89	73.69	132.28	18.64	347.36	14.09	165,942,184	87.21
	Jan. 2008	132.18	325.83	193.65	232.57	45.52	2,072.37	19.57	291,756,550	157.42
	Feb. 2008	165.07	232.37	67.30	201.08	15.07	227.01	7.49	252,249,217	184.51
	Mar. 2008	119.94	144.28	24.34	134.14	5.44	29.62	4.06	168,270,707	96.78
	Apr. 2008	63.48	78.94	15.45	70.89	3.28	10.76	4.63	88,928,340	66.26
	May 2008	97.19	127.58	30.38	113.81	7.41	54.86	6.51	142,770,854	110.95
	June 2008	27.28	42.39	15.11	37.48	3.47	12.04	9.26	47,013,217	38.06
	July 2008	57.30	89.17	31.88	70.50	6.55	42.88	9.29	88,446,242	73
	Aug. 2008	102.15	147.24	45.09	130.66	10.64	113.11	8.14	163,916,838	145.14
	Sept. 2008	107.41	121.51	14.10	117.44	2.74	7.53	2.34	147,328,300	109.13
	Oct. 2008	68.82	91.87	23.05	81.59	5.42	29.37	6.64	102,348,355	68.34
	Nov. 2008	93.98	169.00	75.01	138.17	18.70	349.59	13.53	173,325,826	96.74
	Dec. 2008	184.40	224.65	40.26	209.29	9.20	84.66	4.4	262,553,169	137.99
	12 months Nov. 2007-Oct. 2008	1,224.80	1,701.15	476.35	1,498.46	117.82	13,882.20	7.86	1,879,800,425	106.17
	12 months Dec. 2007-Nov. 2008	1,152.70	1,684.79	532.09	1,460.59	132.53	17,563.50	9.07	1,832,296,628	103.48
	12 months Jan. 2008-Dec. 2008	1,249.56	1,747.40	497.84	1,537.61	122.76	15,069.00	7.98	1,928,907,614	108.94
Phase 2 data	Sept. 2009	62.36	67.6	5.24	65.34	1.27	1.61	1.94	81,971,321	60.72
	Oct. 2009	149.3	172.87	23.57	163.43	5.65	31.89	3.46	205,023,253	136.89
	Nov. 2009	76.9	119.94	43.04	100.6	10.91	119.09	10.85	126,198,277	70.44
	Dec. 2009	136.34	165.85	29.51	153.11	7.17	51.38	4.68	192,068,178	100.94
	Jan. 2010	93.81	128.59	34.79	112.22	8.66	74.94	7.71	140,774,325	75.96
	Feb. 2010	106.39	129.03	22.64	119.26	4.71	22.17	3.95	149,615,047	109.44
	Mar. 2010	74.26	94.88	20.61	84.29	4.7	22.12	5.58	105,735,847	60.81
	Apr. 2010	36.07	40.27	4.2	38.43	1.15	1.32	2.99	48,208,247	35.92
	May 2010	27.86	41.28	13.42	33.49	2.91	8.45	8.68	42,018,473	32.65
	June 2010	97.31	159.14	61.83	127.81	14.4	207.48	11.27	160,339,128	129.79
	July 2010	101.08	127.19	26.11	115.59	6.74	45.43	5.83	145,004,681	119.68
	Aug. 2010	87.77	96.38	8.6	94.84	1.42	2.02	1.5	118,976,552	105.34
	Sept. 2010	93.05	106.12	13.07	100.93	3.1	9.64	3.08	126,615,475	93.79
	Oct. 2010	135.46	153.92	18.47	145.79	4.55	20.68	3.12	182,895,420	122.12
	Nov. 2010	249.13	282.57	33.44	267.82	8.5	72.25	3.17	335,981,276	187.52
	Dec. 2010	249.13	282.57	33.44	267.82	8.5	72.25	3.17	335,981,276	176.58
	Jan. 2011	101.16	138.58	37.42	121.35	9.3	86.4	7.66	152,234,807	82.14
	Feb. 2011	131.65	167.63	35.99	151.18	8.76	76.8	5.8	189,648,624	138.72
	Mar. 2011	45.78	58.83	13.05	52.12	2.99	8.92	5.73	65,377,717	37.6
	Apr. 2011	45.05	135.44	90.39	92.94	22.33	498.42	24.02	116,593,840	86.88
	May 2011	106.82	139.55	32.73	121.85	8.35	69.69	6.85	152,855,964	118.79
	June 2011	125.09	137.84	12.75	133.24	2.54	6.44	1.9	167,151,727	135.31
	July 2011	72.64	89.49	16.85	82.26	3.46	11.94	4.2	103,191,935	85.17
	Aug. 2011	89.81	126.69	36.88	107.38	7.12	50.69	6.63	134,710,912	119.28

Table 10. Total monthly/annual precipitation for LaHave River watershed per GIS precipitation modelling.

	Lahave River	Precipitation (mm)							Precipitation Volume (m^3)	Percent of 30 yr. mean
		Min	Max	Range	Mean	stand dev	Variance	var coef %		
Phase 2 data	Sept. 2011	43.97	47.13	3.16	45.32	0.75	0.57	1.66	56,859,447	42.12
	Oct. 2011	175.85	297.82	121.97	238.07	29.2	852.57	12.26	298,657,618	199.41
	Nov. 2011	167.38	225.98	58.6	200.13	14.38	206.8	7.19	251,060,711	140.13
	Dec. 2011	116.78	177.29	60.51	147.33	14.62	213.85	9.93	184,820,465	97.13
	Year 2010	1342.44	1480.32	137.88	1422.52	35.18	1237.87	2.47	1,784,538,192	100.79
	Year 2011	1285.16	1688.72	403.56	1493.17	98.94	9789.05	6.63	1,873,163,767	105.79
	12 months Oct. 2009-Sept. 2010	1157.44	1305.95	148.51	1244	37.78	1427.07	3.04	1,560,577,482	88.14
	12 months Nov. 2009-Oct. 2010	1143.06	1286.7	143.64	1226.36	36.68	1345.07	2.99	1,538,449,650	86.89
	12 months Dec. 2009-Nov. 2010	1315.32	1449.65	134.33	1393.58	34.31	1177.08	2.46	1,748,232,648	98.74
	12 months Dec. 2010-Nov. 2011	1332.51	1706.48	373.96	1527.89	92.15	8491.69	6.03	1,916,717,024	108.25
30 year mean values for period 1971 to 2000	January	118.56	164.03	45.47	147.74	10.90	118.88	7.38	185,331,288	
	February	89.06	123.05	33.99	108.98	8.49	72.12	7.79	136,710,225	
	March	108.64	157.31	48.67	138.60	12.44	154.85	8.98	173,875,219	
	April	84.35	124.01	39.67	106.98	10.07	101.43	9.41	134,206,000	
	May	88.79	111.06	22.28	102.58	5.74	32.92	5.59	128,678,946	
	June	80.01	107.57	27.56	98.48	7.13	50.82	7.24	123,536,291	
	July	86.99	101.65	14.66	96.58	3.03	9.18	3.14	121,161,993	
	August	80.78	93.63	12.85	90.03	3.14	9.88	3.49	112,939,929	
	September	99.24	112.61	13.37	107.62	2.82	7.94	2.62	135,003,661	
	October	101.25	132.50	31.25	119.39	7.80	60.79	6.53	149,773,064	
	November	116.24	160.25	44.01	142.82	10.88	118.34	7.62	179,168,420	
	December	122.87	165.88	43.02	151.68	10.19	103.82	6.72	190,275,491	
	Year	1,178.54	1,544.68	366.14	1,411.43	90.91	8,264.95	6.44	1,770,614,978	

precipitation for January to December 2008 over the Spectacle Lake watershed was 1,560 mm, versus 1,538 mm for the LaHave River watershed during the same period.

As would be expected due to the different watershed sizes, spatial variability in rainfall for the Spectacle Lake watershed is much less than it is for the LaHave River watershed. Notwithstanding the differences in total amounts received at both watersheds during phase 1 versus the 30 year norm, and despite greater individual monthly variances, spatial variability in total annual precipitation at the Spectacle Lake watershed was roughly the same as for 30 year annual mean, but significantly more at the LaHave River watershed for 2007 to 2008 than for the 30 year annual mean.

Precipitation during phase 2:

Following the same kind of analysis as above, the total monthly precipitation falling onto the Spectacle Lake and LaHave River watersheds during the months of October 2009, July 2010, October to December 2010, and February, June, August and October to November 2011, was greater than the 30 year means for similar months.

The total amount of precipitation falling over the Spectacle Lake and the LaHave River watersheds in November 2010, and over the LaHave River watershed in December 2010, was nearly twice the 30 year norm for those months. The total amount of precipitation falling over the LaHave River watershed in October 2011 was fully twice the 30 year norm for October, and nearly 2.5 times the 30 year norm at the Spectacle Lake watershed.

The wetter-than-normal 2010 and 2011 falls and winters were offset by much drier than normal April 2010, May 2010, March 2011 and September 2011 rainfalls, which were slightly less than half of the 30 year normal rainfalls for those months.

Notwithstanding the extremes noted above, the total 12-month precipitation amounts received at both watersheds was normal for the year 2010, and only slightly above (~10%) the 30 year annual norm for January to December 2011, as was the total amount of precipitation received during the twelve months from December 2010 to November 2011. The precipitation received during the twelve month period from December 2009 to November 2010 was at the 30 year norm for the same 12 mouths, whereas the amounts of precipitation received for the twelve month periods of October 2009 to September 2010, and November 2009 to October 2010, were slightly less (~10%) than the 12 month 30 year norms for those same periods.

On an annual basis, the Spectacle Lake watershed was slightly wetter than the LaHave River watershed 12 month periods from January to December 2011 and from December 2010 to November 2011. for example, the mean total annual precipitation for these 2011 periods over the Spectacle Lake watershed was 1,680 mm, versus 1,510 mm for the LaHave River watershed for the same periods. Both watersheds each received roughly the same annual total amount of precipitation for the other 12 month periods discussed earlier.

As with the phase 1 data, due to the different watershed sizes, spatial variability in rainfall for the Spectacle Lake watershed was much less in phase 2 than it was for the LaHave River watershed.

Notwithstanding the differences in total amounts received at both watersheds during phase 2 versus the 30 year norm, and despite greater individual monthly variances, except for the year 2011, spatial variability in total annual precipitation at the Spectacle Lake watershed during phase 2 was roughly the same as for 30 year annual mean. For 2011, the spatial variability in precipitation data was about the same as for the 30 year annual mean, and during phase 2 was much lower for all other 12 month periods.

Assessment of long-term precipitation:
Figure 27 is a plot of the 60 month (5 year) running mean of total monthly precipitation at Kentville from April 1913 to December 2011. It shows that the 30 year 1971-2000 period used for comparisons above was much wetter than the previous two 30 year periods.

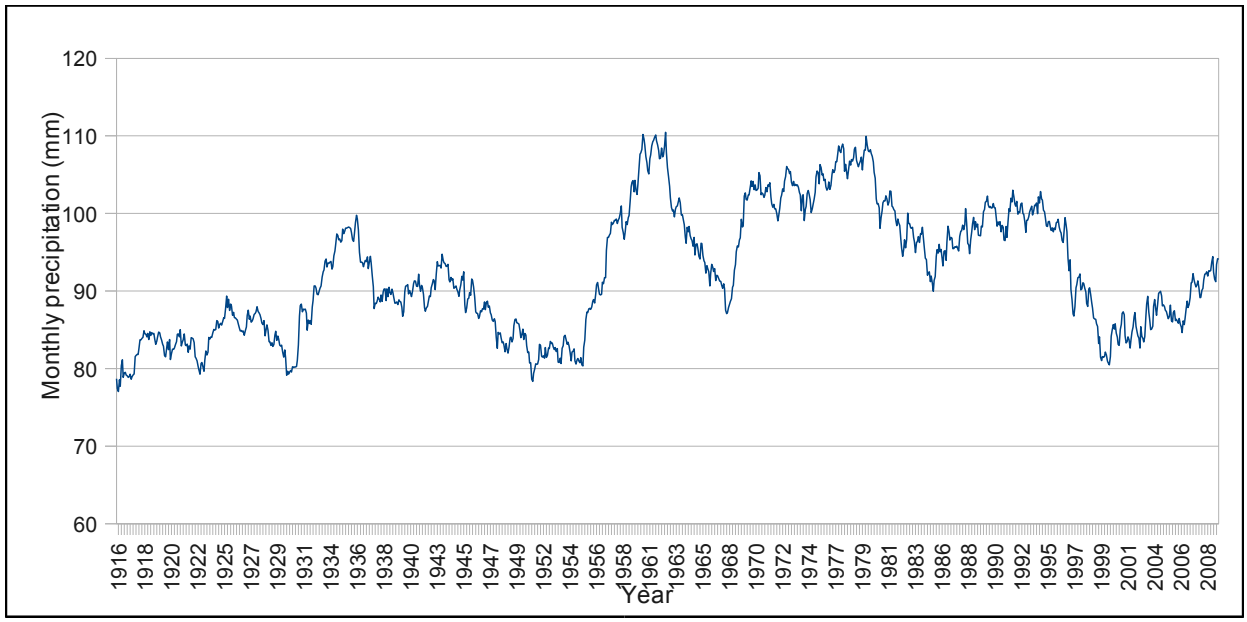


Figure 27. Five year running mean of total monthly precipitation, Kentville, NS.

It also shows that although monthly precipitation amounts have been increasing over the past ten years, the last decade was much drier than the previous decade and the 30 year period from 1971 to 2000.

Stream hydrographs:

Figures 28 and 29 show total daily stream-flow hydrographs and total daily precipitation volumes falling over the watersheds for the Spectacle Lake and LaHave River watersheds for the 448 days with full-day records during the phase 1 period from 11 October 2007 to 31 December 2008, and for the 815 days with full-day records during the phase 2 period from 11 September 2009 to 05 December 2011, respectively.

Peak flow characteristics:

Unit hydrographs were not constructed for either of the watersheds for either phase of work. However, from a close examination of Figures 28 and 29, periods of rainfall excess (time from start of large precipitation events to peak streamflow) for the Spectacle Lake watershed appears to be 1.5 to 2 days. Quickflow[6] duration (time from start of individual precipitation events to a return to baseflow condition) for the Spectacle Lake watershed is 7 to 8 days.

6 Quickflow or direct runoff is the sum of channel precipitation, surface runoff and rapid interflow. It represents the major runoff contribution during storm periods and is also the major contributor to most floods. The terms quickflow and surface runoff can not be used synonymously. Surface runoff is that part of runoff that reaches the basin outlet via overland flow and stream channels, although it may in some circumstances also include interflow that has discharged at the ground surface at some distance from the stream channel. Subsurface runoff, on the other hand, is the sum of interflow and groundwater flow and is normally equal to the total flow of water arriving at the stream as saturated flow into the stream bed itself, and as percolation from the seepage faces of the stream bank (Ward, 1975).

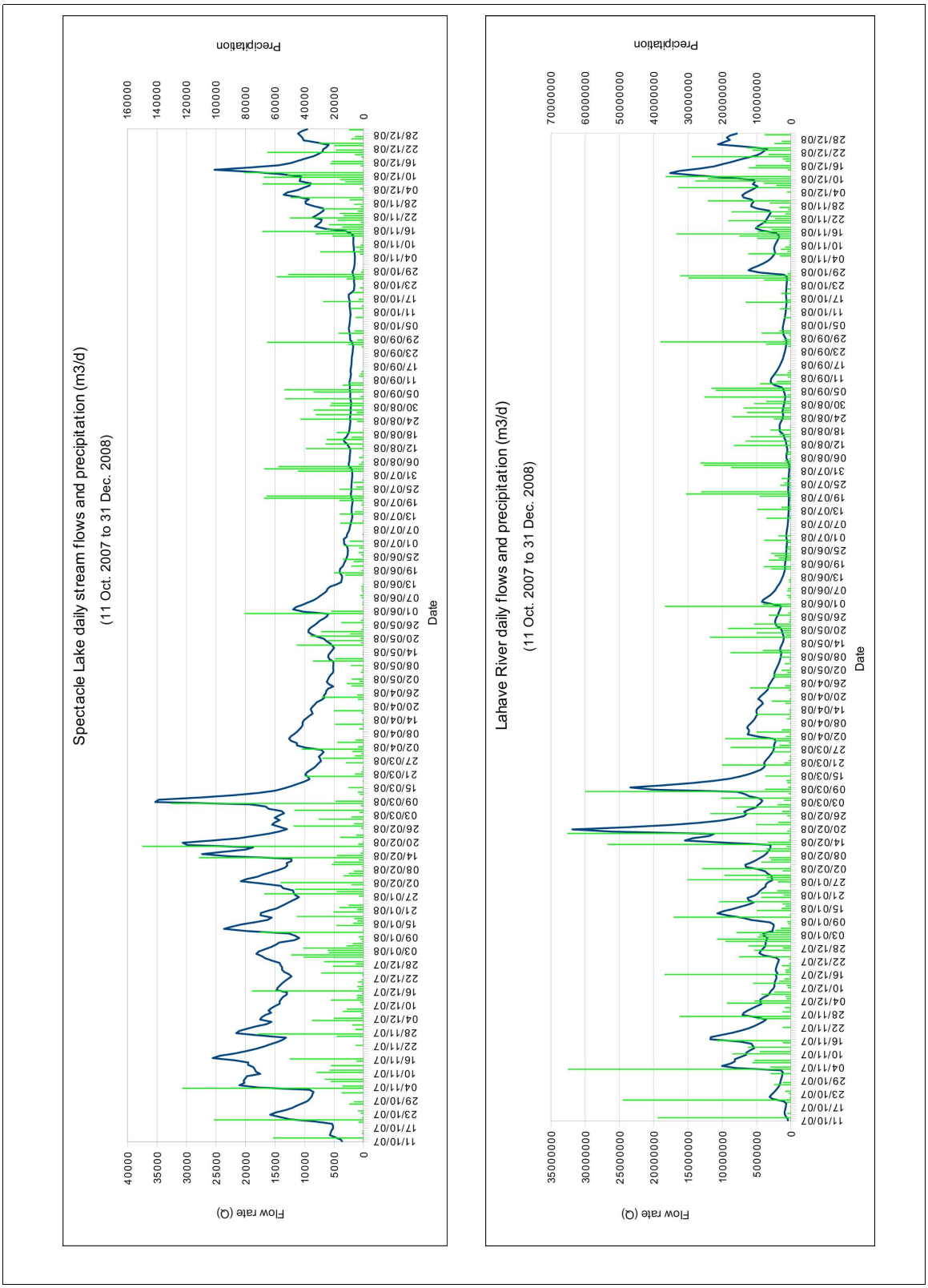


Figure 28. Spectacle Lake, LaHave River phase 1 streamflows and precipitation.

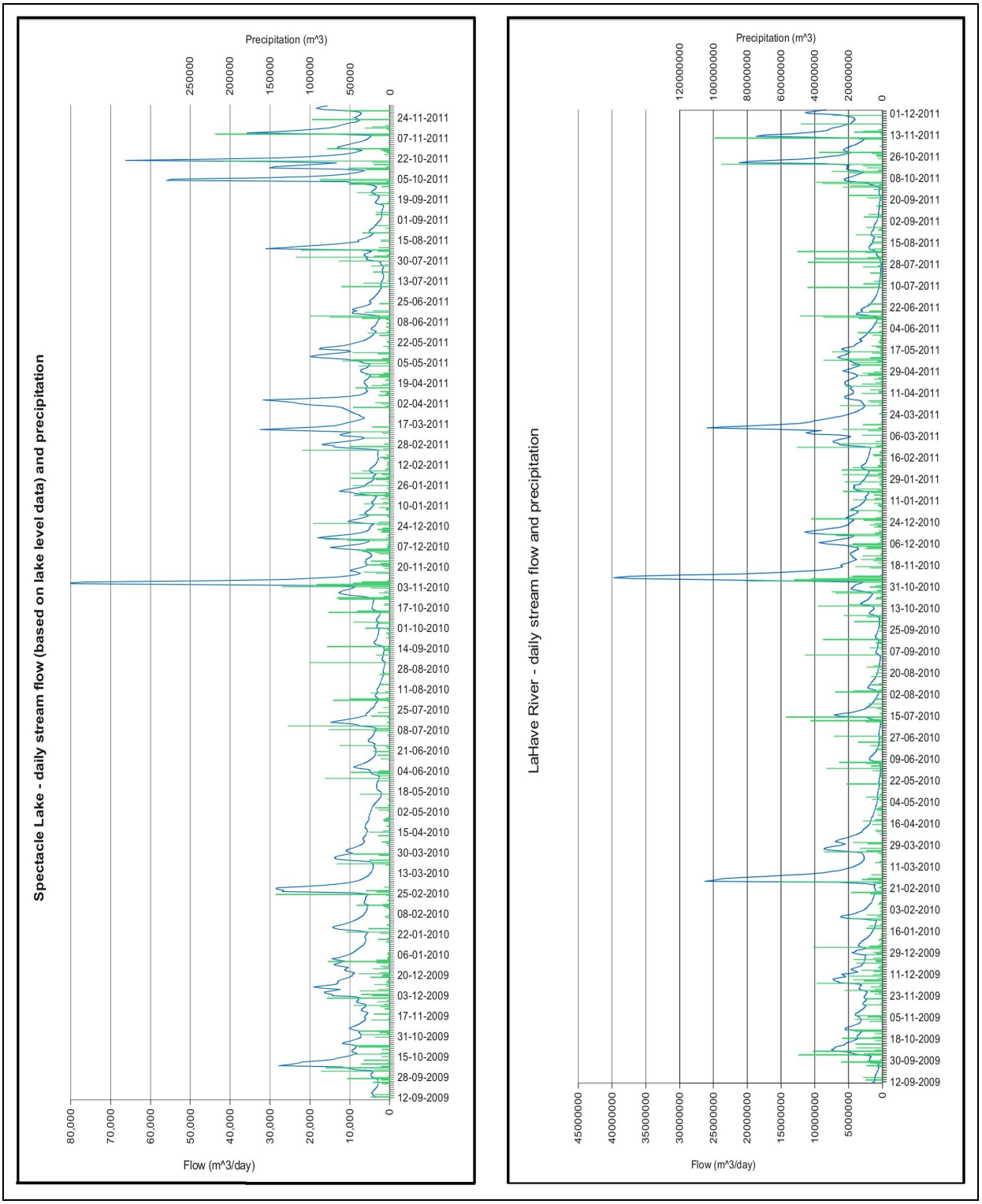


Figure 29. Spectacle Lake, LaHave River phase 2 streamflows and precipitation.

The period-of-rainfall-excess and quickflow characteristics for the Spectacle Lake watershed are amazingly similar to those of the LaHave River watershed, which is nearly 500 times its size and received approximately 483 (phase 1) and 448 (phase 2) times more precipitation and discharged roughly 424 (phase 1) and 446 (phase 2) times more water than the Spectacle Lake watershed.

In the case of large basins, the total outflow hydrograph is determined by summing the runoff contribution from each of many sub-catchments. Where it may take longer for individual flows to reach a given point (i.e when distances are large or where pond action may slow flows), the result is a broader unit hydrograph (greater quickflow duration). The relatively long quickflow durations noted in Figures 28 and 29 for the Spectacle Lake watershed are likely due to a favourable combination of forest ground cover, wetland, open water, and topography.

Notwithstanding the vast differences in size, topography and geology (particularly in the upper reaches) between the two watersheds, as well as other factors such as the greater amount of time expected for changes in soil water storage to occur in the larger watershed, the hydrographs for the LaHave River and Spectacle Lake watersheds appear to correlate very well.

It is interesting to note that while the period of excess rainfall was generally the same as for this study, quickflow duration for the LaHave River watershed was generally about 14 days for the June 2006 to September 2007 period when that watershed was evaluated as part of another study. This suggests either a seasonal change or perhaps even a longer-term climatic influence on water discharges from the LaHave River watershed.

Spectacle Lake channel baseflow:

Baseflow, or base runoff, is defined as the sustained or fair-weather runoff, and is the sum of all groundwater runoff and delayed interflow contributing to a stream channel. One way to estimate baseflow from a stream hydrograph is to separate quickflow peaks from the flow baseline (applicable mostly to periods with receding water levels). Then the total volume of water represented by the area below the baseline can be calculated to obtain an estimate for baseflow.

Assessment of baseflow was done only for phase 1 data. The software package Fityk (Wojdyr, 2007) was used to define total flow values above a baseline that was manually fitted to the data (spline interpolation) on-screen by computer mouse. Figure 30 shows the raw total daily flows in green, and the baseline in red. Except for perhaps after mid-November 2008, this baseline is considered conservative (underestimates baseflow), in that it is clearly below the low flows recorded during the period from July to mid-November 2008.

For the 448 days of record shown in Figure 30, the sum of the daily flows (area below the green curve) was approximately 4,002,650 m^3. The flow amounts calculated by Fityk

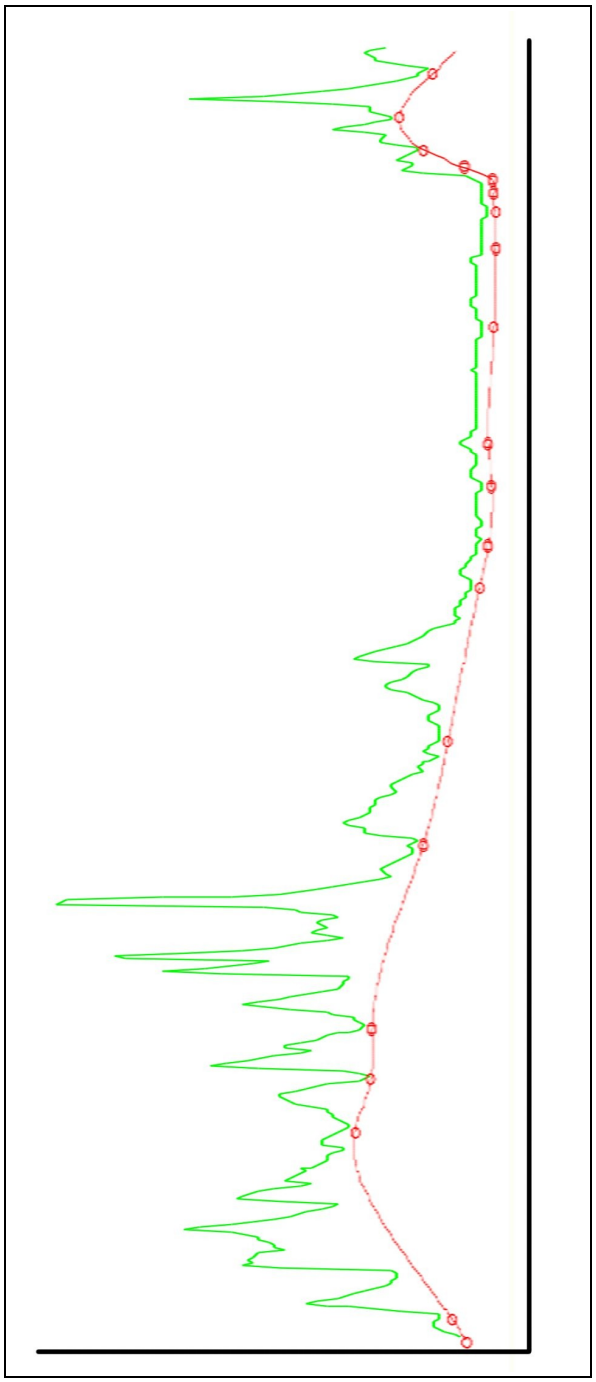


Figure 30. Spectacle Lake channel baseflow.

between the green and red curves is 1,576,173 m^3. Therefore, the value representing baseflow (area below the red curve) is 2,426,477 m^3.

As such, baseflow at the discharge channel below Spectacle Lake during the 448 day period from 11 October 2007 to 31 December 2008 is estimated to have been approximately 60.6 percent of total flow. By comparison, baseflow for the same period at the LaHave River watershed is estimated to have been around 33.2 percent of total flow, or nearly half that of the Spectacle Lake watershed.

Flow/precipitation ratios:

Table 11 shows flow/precipitation (F/P) ratios based on total monthly discharge from, and precipitation (defined by GIS modelling) onto, the Spectacle Lake and LaHave River watersheds, respectively, for phase 1 and 2 for months with complete data. Table 11 also gives summary data and possible long-term flow projections based on 30 year mean monthly and annual precipitation.

Each month of summary data presented at the bottom of Table 11 is an average for three actual months of data from the upper sections of the table (i.e. the "January" data is an average for January 2008, January 2010 and January 2011), except for November, which is an average of four months (there are 4 Novembers with complete data within the total span of field data available). The annual totals given in the very last row of Table 11 are for these averaged values.

The monthly F/P ratio variations in Table 11 are seasonal, in that F/P ratios above 1 are expected for spring months (February to April, generally) as more water is expected to be released during those months due to

Table 11. Monthly total flows vs. precipitation (short-term) and application of F/P to project possible 30-year mean natural discharge from Spectacle Lake.

Period of data represented		Short-term (phase 1 and 2) data						30 year mean	
		Spectacle Lake watershed			LaHave River watershed			Precipitation over Spectacle Lake watershed (m3)	30 year mean flows (m^3) as estimated from F/P
		Streamflow (m^3)	Precipitation (m^3)	F/P	Streamflow (m^3)	Precipitation (m^3)	F/P		
Phase 1 data	Nov. 2007	543,787	435,041	1.25	195,497,280	220,829,622	0.89	--	--
	Dec. 2007	455,443	357,571	1.27	97,243,200	165,942,184	0.59	--	--
	Jan. 2008	474,939	518,054	0.92	151,943,040	291,756,550	0.52	--	--
	Feb. 2008	527,272	490,336	1.08	277,050,240	252,249,217	1.1	--	--
	Mar. 2008	429,299	340,892	1.26	202,452,480	168,270,707	1.2	--	--
	Apr. 2008	272,265	166,791	1.63	132,822,720	88,928,340	1.49	--	--
	May 2008	198,418	328,897	0.6	50,863,680	142,770,854	0.36	--	--
	June 2008	162,434	116,264	1.4	44,873,568	47,013,217	0.95	--	--
	July 2008	68,901	243,552	0.28	11,778,048	88,446,242	0.13	--	--
	Aug. 2008	73,708	408,027	0.18	28,242,432	163,916,838	0.17	--	--
	Sept. 2008	63,175	261,984	0.24	41,984,352	147,328,300	0.28	--	--
	Oct. 2008	64,307	203,622	0.32	38,462,688	102,348,355	0.38	--	--
	Nov. 2008	139,056	377,633	0.37	102,029,760	173,325,826	0.59	--	--
	Dec. 2008	345,185	548,988	0.63	251,959,680	262,553,169	0.96	--	--
Phase 2 data	Oct. 2009	360,492	418,696	0.86	136,632,960	205,023,253	0.67	--	--
	Nov. 2009	220,248	265,425	0.83	89,622,720	126,198,277	0.71	--	--
	Dec. 2009	388,911	404,682	0.96	129,306,240	192,068,178	0.67	--	--
	Jan. 2010	281,986	291,389	0.97	98,496,000	140,774,325	0.7	--	--
	Feb. 2010	250,095	268,514	0.93	100,448,640	149,615,047	0.67	--	--
	Mar. 2010	290,053	240,928	1.2	217,175,040	105,735,847	2.05	--	--
	Apr. 2010	192,637	98,794	1.95	81,501,120	48,208,247	1.69	--	--
	May 2010	102,004	106,549	0.96	18,248,544	42,018,473	0.43	--	--
	June 2010	147,498	249,646	0.59	24,454,656	160,339,128	0.15	--	--
	July 2010	71,775	302,448	0.24	58,420,224	145,004,681	0.4	--	--
	Aug. 2010	72,936	206,622	0.35	30,246,912	118,976,552	0.25	--	--
	Sept. 2010	70,581	273,264	0.26	20,431,008	126,615,475	0.16	--	--
	Oct. 2010	152,834	377,577	0.4	60,173,280	182,895,420	0.33	--	--
	Nov. 2010	480,947	659,140	0.73	333,391,680	335,981,276	0.99	--	--
	Dec. 2010	261,381	473,577	0.55	189,311,040	335,981,276	0.56	--	--
	Jan. 2011	180,784	321,999	0.56	98,496,000	152,234,807	0.65	--	--
	Feb. 2011	145,101	415,542	0.35	73,578,240	189,648,624	0.39	--	--
	Mar. 2011	374,410	155,370	2.41	275,382,720	65,377,717	4.21	--	--
	Apr. 2011	309,295	301,439	1.03	134,524,800	116,593,840	1.15	--	--
	May 2011	291,853	303,470	0.96	134,723,520	152,855,964	0.88	--	--
	June 2011	148,187	351,144	0.42	54,477,792	167,151,727	0.33	--	--
	July 2011	71,775	230,268	0.31	13,839,552	103,191,935	0.13	--	--
	Aug. 2011	245,202	279,184	0.88	39,752,640	134,710,912	0.3	--	--
	Sept. 2011	83,551	107,084	0.78	15,749,856	56,859,447	0.28	--	--
	Oct. 2011	651,152	737,164	0.88	196,408,800	298,657,618	0.66	--	--
	Nov. 2011	350,784	537,551	0.65	195,626,880	251,060,711	0.78	--	--
Summary data	January	312,570	377,147	0.83	116,311,680	194,921,894	0.6	357,147	295,994
	February	307,490	391,464	0.79	150,359,040	197,170,963	0.76	277,970	218,341
	March	364,587	245,730	1.48	231,670,080	113,128,090	2.05	352,366	522,802
	April	258,065	189,008	1.37	116,282,880	84,576,809	1.37	283,718	387,379
	May	197,425	246,305	0.8	67,945,248	112,548,430	0.6	284,633	228,147
	June	152,706	239,018	0.64	41,268,672	124,834,691	0.33	264,202	168,796
	July	70,817	258,756	0.27	28,012,608	112,214,286	0.25	246,015	67,330
	August	130,615	297,944	0.44	32,747,328	139,201,434	0.24	223,895	98,153
	September	72,435	214,111	0.34	26,055,072	110,267,741	0.24	256,081	86,634
	October	289,431	439,454	0.66	98,348,256	194,633,798	0.51	311,489	205,151
	November	378,643	502,341	0.75	206,636,400	245,299,359	0.84	358,966	270,573
	December	362,730	460,045	0.79	179,504,640	254,825,543	0.7	362,011	278,566
	Annual	2,897,516	3,861,324	0.75	1,295,141,904	1,883,623,036	0.69	3,579,013	2,677,582

increased spring precipitation and melting snow-packs. On the other hand, lower F/P ratios should be expected in general for fall periods (August to October) as a reflection of rain being "used up" to infiltrate soils and to recharge groundwater storage following drier summer periods.

It is interesting to note that the F/P ratios for November 2007 and December 2007 at the Spectacle Lake watershed were above 1 and were also greater than the F/P ratios for the same months at the LaHave River watershed. This may be a reflection of a combined increased autumn 2007 rain intensity along with a baseflow surge caused by a wetter than normal June to August 2007 (Gagne, 2008), alongside a greater proportion of baseflow at the Spectacle Lake watershed than at the LaHave River watershed.

The annual F/P ratios of 0.75 and 0.69 are considered fair values for use as runoff coefficients for the Spectacle Lake and LaHave River watersheds – the difference between the two is likely a result of the greater proportion of baseflow available at the Spectacle Lake discharge channel.

Finally, values in the last two columns at the bottom of Table 11 show what stream outflow from Spectacle Lake might look like under a "normal precipitation situations" (eg. assuming precipitation that matches 30 year means from 1971 to 2000), assuming that the F/P ratios obtained from the phase 1 and 2 data are appropriate for use on the long-term conditions (they may not be).

Spectacle Lake outflow versus water levels: During the 01 November 2007 to 31 December 2008 phase 1 period, lake water levels (values corrected to account for relocating the level gauge on 22 May 2008) were found to vary by 42.1 cm; from a high of 55.17 cm, to a low of 13.11 cm, with a mean water level of 28.4 cm during the period of record. These heights are relative to the lake bottom at the shore at the boulder to which the gauge was attached.

The 42.1 cm water level change at Spectacle Lake represents a total annual change in water storage of roughly 127,170 m^3 for the 2007-2008 phase 1 period of record.

During the 11 September 2009 to 05 December 2011 phase 2 period, lake water levels varied by 46.1 cm; from a high of 101.0 cm, to a low of 46.1 cm, with a mean water level of 71.4 cm and a modal level of 67.7 cm during the period of record. These heights are relative to the pressure transducer installed at the south shore of the lake near the lake discharge channel.

The 46.1 cm water level change at Spectacle Lake represents a total annual change in water storage of roughly 139,254 m^3 for the 2009-2011 phase 2 period of record.

Figure 21 tracks changes in lake water levels with discharge during phase 1. It shows a generally good correlation between the two. The plot of water levels versus discharge flows in Figure 22 was done to define the relationship between these two characteristics

for phase 1 data. The best fit results in the following exponential function, which yielded a correlation coefficient (R^2) of 0.91:

$$Q = 732.39 \bullet 1.06^{H}$$

where:

Q = discharge channel flow in m^3/day, and

H = lake water level in cm

By comparison, attempts to fit the data using linear, logarithmic, or power functions gave R^2 values of 0.86, 0.79 and 0.88, respectively.

Watershed water balance:

When stated as an equation including all of the items that may be involved, a general hydrologic budget can be explained as:

$$P_r + SurI + SubI + Imp = R + Exp + ET + U \pm \Delta Soil \pm \Delta Ss \pm \Delta Sg$$

where:

- P_r = precipitation
- SurI = surface inflow
- SubI = subsurface inflow
- Imp = imported water
- R = streamflow
- ET = evapotranspiration
- U = subsurface flow
- Exp = exported water
- ΔSoil = change in soil moisture storage
- ΔSs = changed in surface water storage
- ΔSg = change in groundwater storage

Besides precipitation, there are no known water imports into the Spectacle Lake sub-watershed, so the terms *SurI* and *Imp* may be removed from the water balance equation. There are no known water withdrawals, so the term *Exp* may also be removed.

Due to the relatively high baseflow observed at the discharge channel during the phase 1 period of record, geology (the possibility of a fault along the watershed axis), general shape of the sub-watershed (narrow upper reaches, wide lower section) and its location within watershed 1EG-SD2, plus the position of the sub-watershed relative to others further inland, subsurface flow may be an important factor for the Spectacle Lake watershed.

While in the long-run subsurface inflow may be expected to equal outflow, this may not be the case in the shorter-term, so the variables *SubI* and *U* may be taken out when assessing water balances over long periods of time, but they should remain in the equation when evaluating short-term water balances.

The water storage effect of winter snow pack can have a significant influence on short-term water balances. However, spring flows and flows following winter rain events will account for this storage in the longer term.

Finally, for short-term assessments (i.e. for one or two water years), the water balance equation for the Spectacle Lake watershed may be reduced to the simpler form:

$$P_r + SubI = R + ET + U \pm \Delta Soil \pm \Delta Ss \pm \Delta Sg$$

For longer-term assessments, the water balance equation may be yet further reduced to the form:

$$P_r = R + ET \pm \Delta Soil \pm \Delta Ss \pm \Delta Sg$$

There is no pan evaporation information for the south shore, and evapotranspiration can range between 25% and 45% of total precipitation depending on the watershed. Since Spectacle Lake and wetlands cover only about 13 percent of the sub-watershed, lake water level changes can not be used to adequately represent the evaporative losses from the watershed.

There is empirical data for the water balance equation terms P_r and R, so in the end, the terms $SubI$, ET, U, $\Delta Soil$ and ΔSg remain as relative unknown values that must either be determined by further analysis, by estimating from other circumstantial data, or by judgement (best guess).

The last three terms of the water balance equation, when combined, may be related to lake water levels measured in the field and may, therefore, be at least partly accounted for in the available data.

Table 12 and Figure 31 show monthly (whole month only) and 12 month water balances for the Spectacle Lake watershed for the phase 1 and 2 periods from 01 November 2007 to 31 December 2008 and 01 October 2009 to 30 November 2011, with values for precipitation obtained from GIS modelling.

The water "balance 1" plot in Figure 31 does not include the effects of changes in lake storage (lake water level changes), whereas for comparison purposes, the water "balance 2" plot does include changes in lake storage. A water year in Nova Scotia is generally considered to start in November when autumn rains start, groundwater levels begin to rise, and streamflows increase. The data for Spectacle Lake appears to have followed this general November to October pattern throughout phases 1 and 2, although for 2011 that cycle appears to be one month later.

Outflow exceeded precipitation amounts from November 2007 to April 2008, from March to May 2010, and March to April 2011, all at a slight cost to lake storage, although lake storage did not change all that much during the entire period of record.

There were net water deficits in November and December 2007, February to April 2008, June 2008, March to May 2010, and March 2011; and net surpluses in January (although slight), May, July to December 2008, June 2010 to February 2011, June to August 2011, and October to November 2011.

Evapotranspiration, which is not included as a separate item in the water balances in Table 12 and Figure 31, would serve to reduce the surpluses and lake storage, and increase the deficits. Groundwater inflows into the watershed would have the opposite effect, although the two unfortunately cannot be separated (quantified) from available data.

On an annual basis, including the effects of changes in lake water levels, there were net surpluses of 15.7, 23.9, 30.8, 26.6, 28.2, 33.4 and 25.5 percent (average 24.1%) of the total precipitation, respectively, for the seven 12-month periods shown in the bottom section of

Table 12. Monthly and annual water balances for the Spectacle Lake watershed (all values in m^3)						
Month		Column 1	Column 2	Column 3	Precipitation surplus	
		Precipitation (from GIS)	Total discharge channel flow	Change in lake storage	Excl. lake storage effect (Col. 1 - 2)	Incl. lake storage effect (Col. 1 - 2 - 3)
Phase 1 monthly	Nov. 2007	435,041	543,787	31,717	-108,747	-140,464
	Dec. 2007	357,571	455,443	3,021	-97,873	-100,893
	Jan. 2008	518,054	474,939	4,531	43,115	38,584
	Feb. 2008	490,336	527,272	-12,083	-36,936	-24,854
	Mar. 2008	340,892	429,299	-15,103	-88,407	-73,304
	Apr. 2008	166,791	272,265	-12,083	-105,474	-93,391
	May 2008	328,897	198,418	9,062	130,479	121,417
	June 2008	116,264	162,434	-80,048	-46,170	33,878
	July 2008	243,552	68,901	-7,552	174,651	182,203
	Aug. 2008	408,027	73,708	7,552	334,319	326,767
	Sept. 2008	261,984	63,175	3,021	198,810	195,789
	Oct. 2008	203,622	64,307	-3,021	139,315	142,336
	Nov. 2008	377,633	139,056	76,031	238,577	162,547
	Dec. 2008	548,988	345,185	-18,638	203,803	222,441
Phase 2 monthly	Oct. 2009	418,696	360,492	12,433	58,204	45,771
	Nov. 2009	265,425	220,248	0	45,177	45,177
	Dec. 2009	404,682	388,911	11,328	15,770	4,443
	Jan. 2010	291,389	281,986	-5,618	9,404	15,022
	Feb. 2010	268,514	250,095	36,101	18,419	-17,682
	Mar. 2010	240,928	290,053	-36,285	-49,125	-12,840
	Apr. 2010	98,794	192,637	-24,681	-93,843	-69,161
	May 2010	106,549	102,004	-6,907	4,544	11,451
	June 2010	249,646	147,498	4,513	102,147	97,635
	July 2010	302,448	71,775	13,446	230,673	217,227
	Aug. 2010	206,622	72,936	-23,944	133,686	157,631
	Sept. 2010	273,264	70,581	17,130	202,684	185,554
	Oct. 2010	377,577	152,834	39,693	224,742	185,050
	Nov. 2010	659,140	480,947	-26,984	178,193	205,177
	Dec. 2010	473,577	261,381	3,684	212,196	208,512
	Jan. 2011	321,999	180,784	-10,591	141,215	151,806
	Feb. 2011	415,542	145,101	43,192	270,441	227,248
	Mar. 2011	155,370	374,410	-737	-219,039	-218,303
	Apr. 2011	301,439	309,295	-32,049	-7,856	24,193
	May 2011	303,470	291,853	-14,735	11,616	26,352
	June 2011	351,144	148,187	-5,894	202,957	208,851
	July 2011	230,268	71,775	13,446	158,493	145,047
	Aug. 2011	279,184	245,202	-23,024	33,982	57,005
	Sept. 2011	107,084	83,551	16,669	23,533	6,864
	Oct. 2011	737,164	651,152	26,155	86,012	59,857
	Nov. 2011	537,551	350,784	11,328	186,767	175,440
12 month periods	Nov. 2007-Oct. 2008	3,871,030	3333947.99	-70986.22	537,082	608,068
	Dec. 2007-Nov. 2008	3,813,622	2929216.46	-26672.69	884,406	911,079
	Jan. 2008-Dec. 2008	4,005,039	2818957.64	-48331.04	1,186,082	1,234,413
	Nov. 2009-Oct. 2010	3,085,838	2241558.19	24773.34	844,279	819,506
	Dec. 2009-Nov. 2010	3,479,552	2502257.04	-2210.26	977,295	979,506
	Jan. 2010-Dec. 2010	3,548,448	2374726.98	-9854.08	1,173,721	1,183,575
	Dec. 2010-Nov. 2011	4,213,792	3113475.28	27444.07	1,100,317	1,072,873

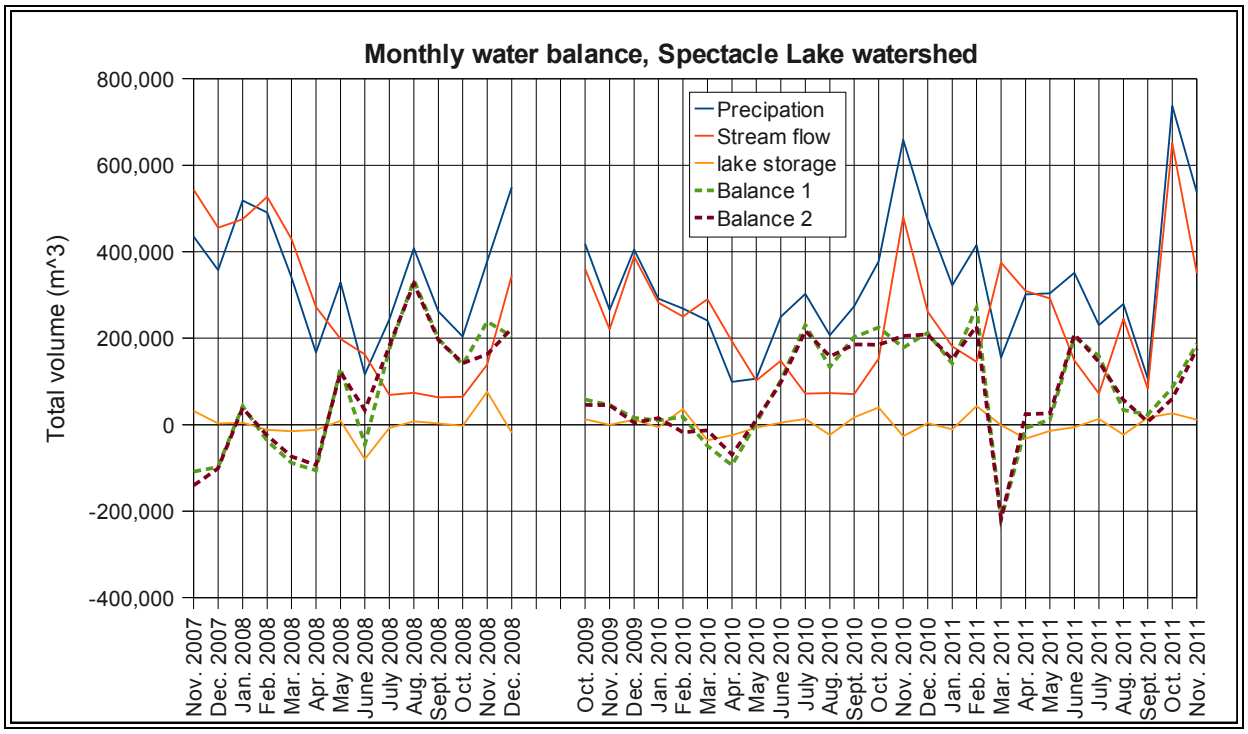


Figure 31. Monthly water balance, Spectacle Lake watershed.

Table 12. These net surpluses would account for such water losses as evapotranspiration, changes in subsurface (groundwater) storage, and/or subsurface outflows.

Construction of a synthetic flow record for the Spectacle Lake outflow channel:
The goal in defining water supply withdrawal allocations is to remove only so much water as to preserve the nature of original stream flows and integrity of ecosystems below water taking locations. This is usually done by statistical evaluation of streamflows and can require 30 to 40 or more years of data.

The outflow channel from Spectacle Lake has been gauged for only a short time. Therefore, its streamflow record must be extended for proper statistical evaluation.

An extended, synthetic streamflow record can be constructed by an interpolation/multi-variate analysis model where the short-term data available for the watershed of interest is assessed against another with a longer record of streamflow data. Since most published methods produce numbers for monthly flows only, a modified version of the multilag model proposed by Beard (1967) and Myron and Jackson (1977) was used to extend the phase 1 streamflow record from Spectacle Lake. This method will be used again on phase 1 and 2 data.

A word about modelling uncertainty:
It is usual practice in designing water resource projects for water supply to base the design on assumed repetition of recorded historical precipitation and streamflows.

Inasmuch as historical precipitation and/or streamflows will not be repeated exactly in the future, and since they are not exactly representative of future expectation, it is important to note that this practice may lead to considerable uncertainty in design.

Method used for Spectacle Lake:
A synthetic long-term streamflow record was constructed for the outflow channel from Spectacle Lake, utilizing phase 1 and 2 data, following these basic steps:

Step 1 – Daily precipitation values for the Spectacle Lake watershed (daily means from Halifax Airport, Shearwater, Kejimkujik and Greenwood) and for the LaHave River watershed (daily means from Halifax Airport, Shearwater, Kejimkujik and Kentville and Yarmouth) were tabulated for the period 01 January 1967 to 31 December 2011.

Step 2 – Daily streamflow from the LaHave River watershed gauge station 01EF001 for the period 01 January 1967 to 31 December 2011 was tabulated alongside the calculated daily mean precipitation values above.

Step 3 – Leap years were reduced to 365 days for ease of calculations.

Step 4 – Total streamflow from Spectacle Lake was tabulated alongside the data above.

Step 5 – 11 October 2007 to 31 December 2008 and 11 September 2009 to 05 December 2011 daily streamflows for Spectacle Lake and LaHave River were matched to their respective sets of calculated precipitation values, which were made to simulate individual "unit hydrograph" peak flow and curve decay. To impose the typical hydrograph shape onto the interpolations, the precipitation values used were the weighted sums of the previous 14 days precipitation, in which the first day's precipitation was made to contribute 100% to flow with contributions decreasing to zero by the 14th day.

Step 6 – Values for flow versus precipitation (F/P) were calculated for Spectacle Lake and LaHave River for each 14-day calculated flow-precipitation data set noted above. Then the ratios of these F/P values were calculated to define the daily relationship (assumed to be linear) between precipitation and flow for the two watersheds. As such, for each day within the 11 October 2007 to 31 December 2008 and the 11 September 2009 to 05 December 2011 periods, an individual coefficient "β_R" was obtained by:

$$\beta_R = \frac{(F_{Lh} \div P_{Lh})}{(F_{Spec} \div P_{Spec})}$$

where β_R represents the correlation found between the two watersheds; F_{Lh} is flow at the LaHave River; P_{Lh} is precipitation at the LaHave River watershed; F_{Spec} is flow from Spectacle Lake; and P_{Spec} is precipitation at the Spectacle Lake watershed.

Step 7 – Individual values for β_R were calculated for each day of record at Spectacle Lake. Where there were three or four values for β_R (i.e. a value for each day of January in 2008, in 2010 and in 2011, etc.) throughout

phases 1 and 2, those values were averaged to obtain a "mean" daily value for β_R for each of the 365 days in a year. Then a 40 day running mean of the averaged β_R dataset was calculated to smooth the data, thus producing 365 new coefficient values β_{Rs} for each day of the year.

Step 8 – The 365 β_{Rs} values obtained above were applied to each set of daily LaHave River watershed flow, precipitation data and Spectacle Lake rainfall data for each year from 01 January 1967 to 31 December 2011, in order to obtain a synthetic record of daily flows for Spectacle lake, using the equation:

$$F_{Spec} = \frac{(P_{Spec} \cdot F_{Lh})}{(\beta_{Rs} \cdot P_{Lh})}$$

The 16,060 individual values obtained for F_{Spec} were then used to produce long-term flow duration curves (presented in the next section of this report) from which to define withdrawal allocation volumes.

Results and evaluation:

A number of data plots were generated to study the relationships of daily precipitation and streamflow at the Spectacle Lake and LaHave River watersheds. What follows is the same evaluation that was done for the phase 1 report, but this time the evaluation is based on 1,259 matched daily streamflow data point sets as opposed to the 446 only available from phase 1.

Not shown here, but plots of 14 day weighted precipitation versus flow for Spectacle Lake and for the LaHave River revealed no clear relation (best fit values R^2 of 0.35 and 0.25, respectively, on attempts to fit the data with linear function). However, a plot of daily flows for one watershed versus the other did show a (albeit complex) slightly better relationship (value R^2 of 0.50 on a linear function) between the two watersheds.

Further comparing daily flows per calendar day, Figure 32 shows a clear cyclical and perhaps also seasonal pattern between the Spectacle Lake and LaHave River watersheds. With the greater amount of data now available including both phase 1 and phase 2 data, it is clear also that the cycles are "out of phase" by approximately 25 days from one year to the next.

Figure 33 shows the relationship, although a complex one with scatter, between the F/P values obtained from the two watersheds. Notwithstanding any apparent complexity, a linear equation appears to best fit this data, where values for R^2 of 0.71, 0.42, 0.50 and 0.64 were obtained from testing for linear, logarithmic, exponential and power relationships, respectively, using phase 1 data alone. Linear regression on phase 1 and 2 data combined yields a R^2 value of 0.65.

Figure 34 better illustrates the nature of the F/P relationship between two watersheds, the cyclicity of the data, the seasonal variability present in the time-series data, along with a "built-in" hydrographic overprint that shows the effects of earlier seasonal climatic influences on each of the individual streamflows. Notwithstanding the greater

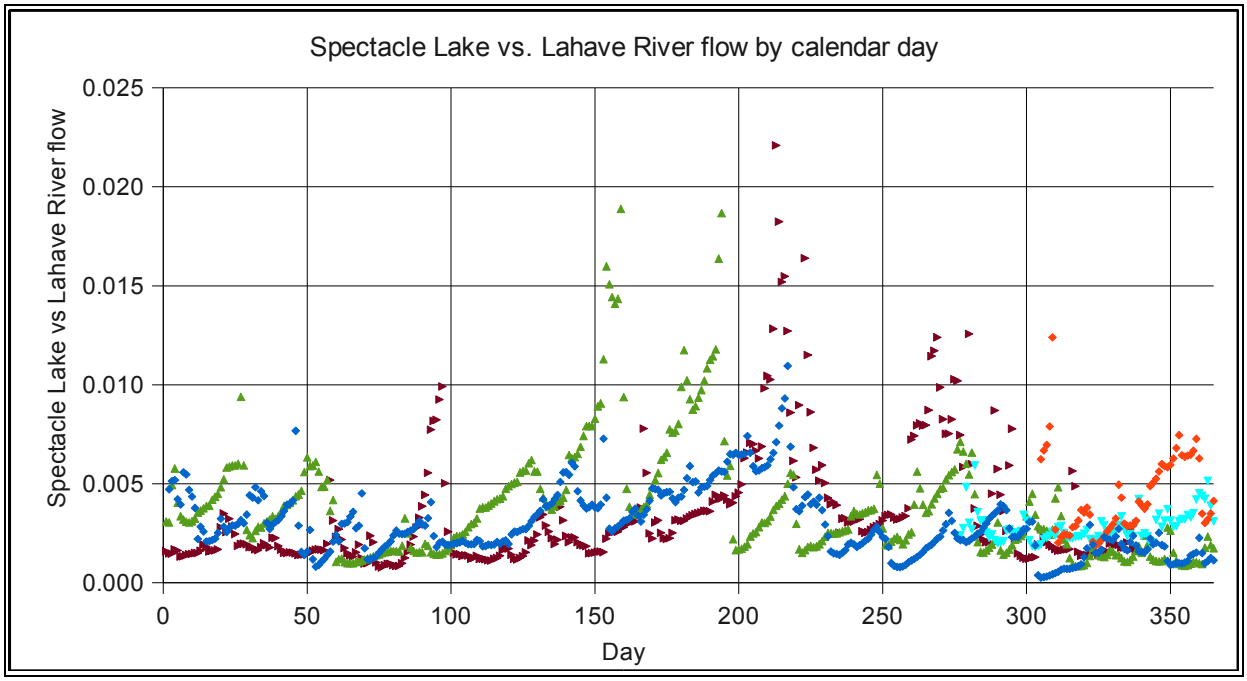


Figure 32. Spectacle Lake vs. LaHave River flow by calendar day. Values for the months of 2007 are shown in red, 2008 in blue, 2009 in cyan, 2010 in green, and 2011 in brown.

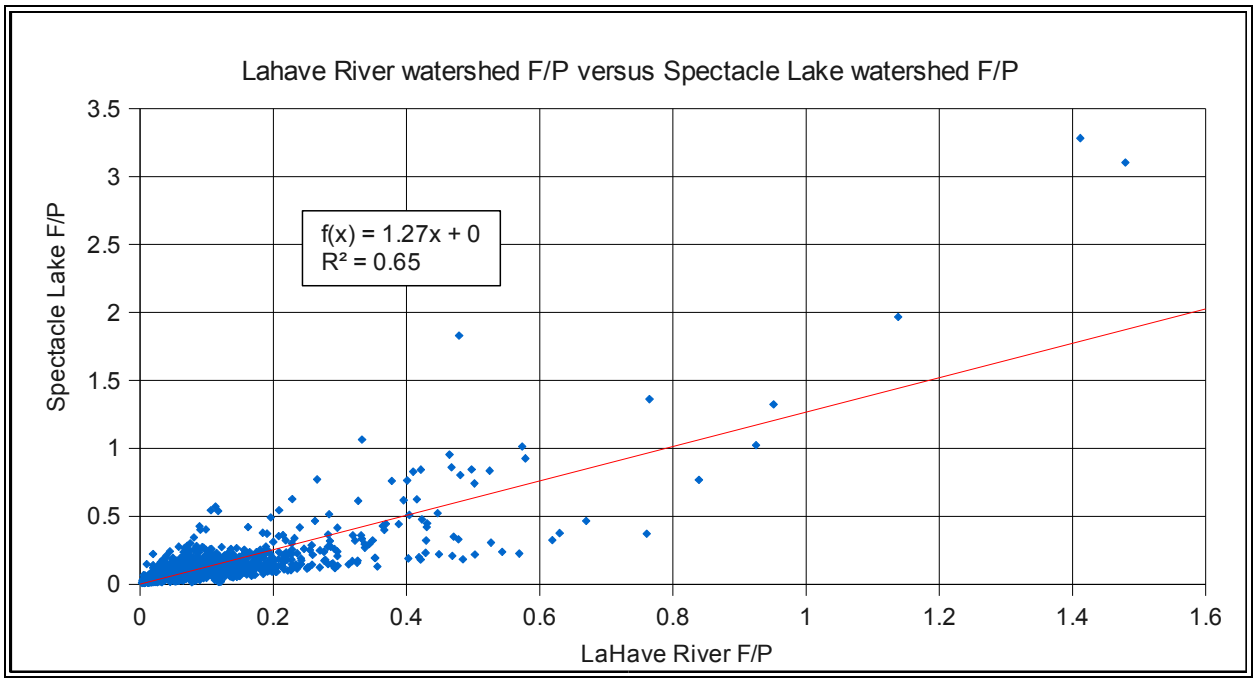


Figure 33. LaHave River watershed F/P vs. Spectacle Lake watershed F/P (for all data from phases 1 and 2).

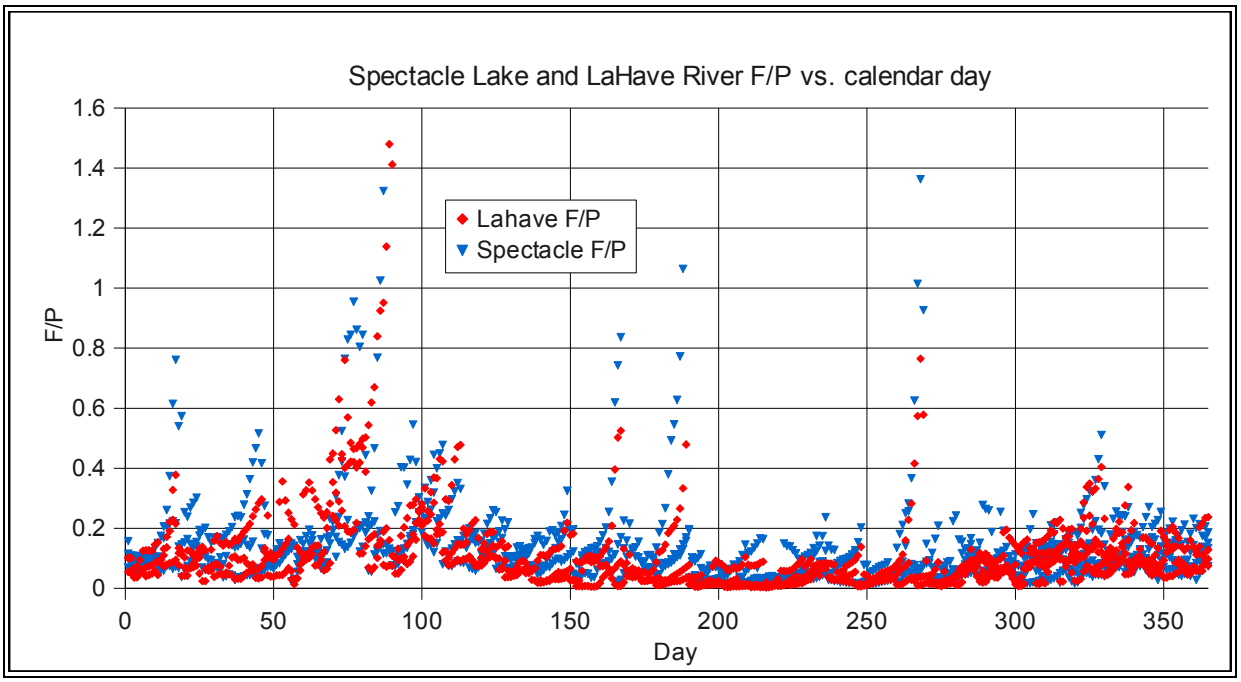


Figure 34. F/P at the Spectacle Lake and LaHave River watersheds by calendar day (for all data from phases 1 and 2).

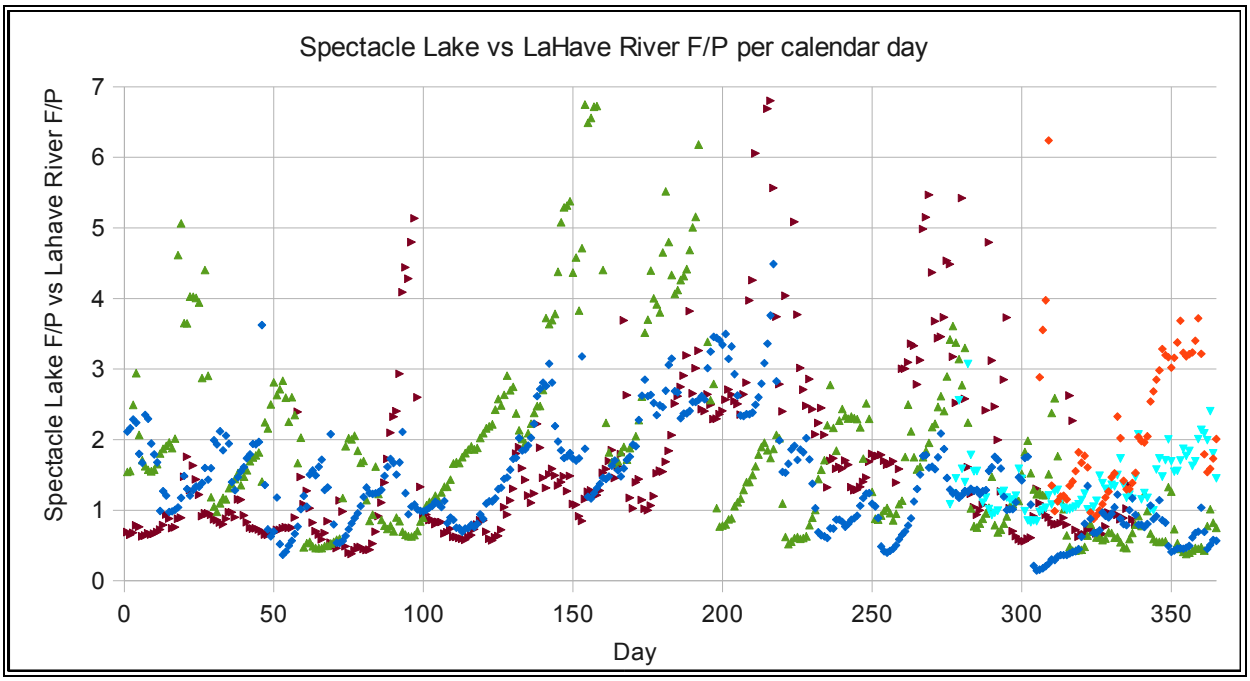


Figure 35. Spectacle Lake F/P vs. LaHave River watershed F/P per calendar day. Values for the months of 2007 are shown in red, 2008 in blue, 2009 in cyan, 2010 in green, and 2011 in brown.

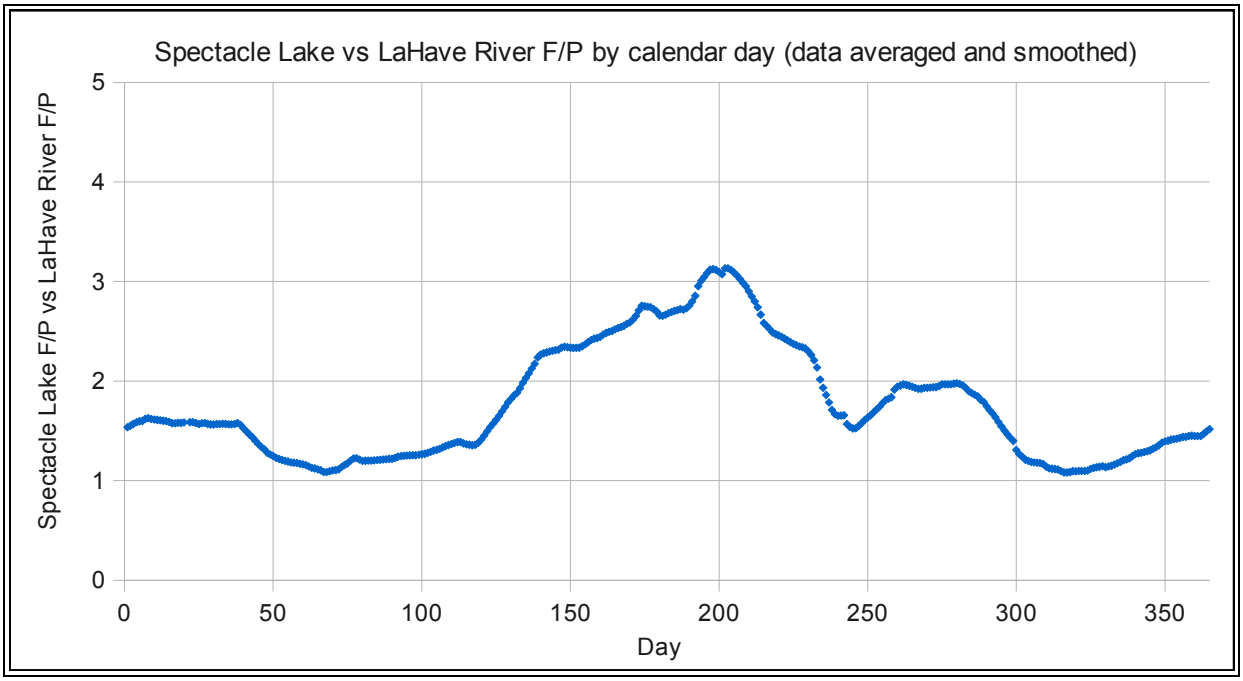


Figure 36. Values of β_{Rs} used to construct the Spectacle Lake discharge long-term streamflow.

amount of data shown in Figure 34 relative to that from the last report that included phase 1 data only, the F/P relationship between the two watersheds appears to remain close.

Figure 35 shows F/P values plotted for one watershed versus the other for each day of available data from the start to end of phases 1 and 2 combined. Figure 36 shows the same data with same months (i.e. March 2007, March 2010 and March 2011, etc.) averaged and with the data smoothed (40 day running mean) to filter out cyclicity in the data.

Figure 36, which incorporates all data from phases 1 and 2, is strikingly similar to Figure 28 in the phase 1 report that included much less data. Figure 36 represents the actual β_{Rs} values used to construct the long-term synthetic flow record and flow frequency curves for the Spectacle Lake watershed.

Model and data validation:

The vertical and horizontal "cycle phase differences" in the β_R values shown in Figure 35 from one year to the next illustrate the degree of variability and error that is inherent to doing this type of analysis (this is why most published models produce only monthly data). The differences are most likely due to:

- differences in temporal and spatial distribution of the precipitation falling over the larger watershed from one year to the next,
- differences in temporal and spatial distribution of precipitation falling over one watershed versus the other,
- the effect on changing F/P relationships due to anomalous and/or extreme precipitation events,
- variability of channel streamflow due to

different spring snow melt regimes,

- differences between the two watersheds relative to the hydrologic cycle, affecting such things as stream bank storage from one season to the other and from year to year, soil/groundwater storage from one season to the next, and the time lag for these to affect streamflow at each respective watershed.

Table 13 summarizes the statistical analysis done of the different daily β_R values obtained for same-months in phase 1, and for the five years (November 2007 to November 2011) of data covered in phases 1 and 2 combined.

Table 13. Coefficients of variability (percent) obtained for differences in overlapping daily F/P "same month" data for the period November 2007 to November 2011.

Description	Value	
	Phase 1 data only	Phase 1 and 2 data
Average % range	69.30%	58.92%
Min % range	6.93%	11.51%
Max % range	130.89%	119.13%
Median % range	72.88%	59.08%
1st quartile % range	44.07%	38.48%
3rd quartile % range	94.51%	76.04%

Table 13 suggests that the reliability/accuracy of the model used to generate the synthetic streamflow record for the Spectacle Lake watershed may have benefited, to a small degree at least, from the greater amount of data available from phases 1 and 2 combined as opposed having phase 1 data only as in the past. However, while the range in β_R values remains large even with greater amounts of data, data smoothing to obtain the β_{Rs} values used to construct the synthetic flow record for Spectacle Lake served to reduce this variability and error slightly.

To further test the model and synthetic flow record for the Spectacle Lake discharge channel, total monthly constructed flows were compared to measured monthly flows and summarized in Table 14 (right half) for phase 1 data for the months of November 2007 to December 2008, and in Table 14 (left half) for phase 1 and 2 data combined for the months of November 2007 to December 2008 plus October 2009 to November 2011.

The right half of Table 14 shows relatively large differences between calculated and measured flows for some months using phase 1 data alone, particularly for the months of November and December 2008. This is likely due to the anomalously high F/P ratios experienced for those same months in 2007.

The overall difference for the 14 months of phase 1 record is roughly 24.7%, although due to the November-December effect, differences for the three available 12 month periods during phase 1 do range from 8.8% to 40.2%. By contrast, excluding data for the months of November and December (looking at January to October 2008 data only), the difference is 20.7 percent.

Comparing the differences for the 14 months of phase 1 utilizing only phase 1 data only (right half of Table 14) versus utilizing phase

Table 14. Measured channel flows vs. calculated synthetic streamflows for the Spectacle Lake watershed.								
Period	Using data from phases 1 and 2				From phase 1 report (phase 1 data alone)			
	Channel flow (m^3)		Difference		Channel flow (m^3)		Difference	
	Measured	Calculated	Flow	%	Measured	Calculated	Flow	%
Nov 07	543,787	444,762	-99,025	-18.21	543,787	489,666	-54,121	-9.95
Dec 07	455,443	268,357	-187,086	-41.08	455,443	317,999	-137,444	-30.18
Jan 08	474,939	530,574	55,635	11.71	474,939	530,461	55,522	11.69
Feb 08	527,272	751,451	224,179	42.52	527,272	773,728	246,456	46.74
Mar 08	429,299	493,940	64,641	15.06	429,299	487,922	58,623	13.66
Apr 08	272,265	360,369	88,104	32.36	272,265	310,993	38,728	14.22
May 08	198,418	217,579	19,161	9.66	198,418	185,054	-13,364	-6.74
Jun 08	162,434	245,926	83,492	51.40	162,434	201,405	38,971	23.99
Jul 08	68,901	70,842	1,941	2.82	68,901	65,312	-3,589	-5.21
Aug 08	73,708	131,180	57,472	77.97	73,708	95,393	21,685	29.42
Sep 08	63,175	142,149	78,974	125.01	63,175	82,853	19,678	31.15
Oct 08	64,307	102,428	38,121	59.28	64,307	84,982	20,675	32.15
Nov 08	139,056	236,739	97,683	70.25	139,056	260,978	121,922	87.68
Dec 08	345,185	735,514	390,329	113.08	345,185	873,619	528,434	153.09
Oct 09	360,492	469,216	108,724	30.16	--	--	--	--
Nov 09	220,248	561,516	341,268	154.95	--	--	--	--
Dec 09	388,911	343,099	-45,812	-11.78	--	--	--	--
Jan 10	281,986	242,307	-39,679	-14.07	--	--	--	--
Feb 10	250,095	234,049	-16,046	-6.42	--	--	--	--
Mar 10	290,053	539,314	249,261	85.94	--	--	--	--
Apr 10	192,637	242,510	49,873	25.89	--	--	--	--
May 10	102,004	71,847	-30,157	-29.56	--	--	--	--
Jun 10	147,498	130,839	-16,659	-11.29	--	--	--	--
Jul 10	71,775	375,515	303,740	423.18	--	--	--	--
Aug 10	72,936	178,737	105,801	145.06	--	--	--	--
Sep 10	70,581	80,697	10,116	14.33	--	--	--	--
Oct 10	152,834	171,517	18,683	12.22	--	--	--	--
Nov 10	480,947	731,274	250,327	52.05	--	--	--	--
Dec 10	261,381	537,988	276,607	105.83	--	--	--	--
Jan 11	180,784	331,145	150,361	83.17	--	--	--	--
Feb 11	145,101	197,375	52,274	36.03	--	--	--	--
Mar 11	374,410	666,367	291,957	77.98	--	--	--	--
Apr 11	309,295	319,669	10,374	3.35	--	--	--	--
May 11	291,853	480,186	188,333	64.53	--	--	--	--
Jun 11	148,187	283,471	135,284	91.29	--	--	--	--
Jul 11	71,775	72,453	678	0.95	--	--	--	--
Aug 11	245,202	174,919	-70,283	-28.66	--	--	--	--
Sep 11	83,551	61,256	-22,295	-26.68	--	--	--	--
Oct 11	651,152	642,583	-8,569	-1.32	--	--	--	--
Nov 11	350,784	457,150	106,366	30.32	--	--	--	--
Total for phase 1 only	3,818,189	4,731,810	913,621	23.93	3,818,189	4,760,365	942,176	24.68
Total for phases 1 and 2	10,014,661	13,328,811	3,314,150	33.09	--	--	--	--
Total for phase 2 only	6,196,472	8,597,001	4,326,796	69.83	--	--	--	--
Year-Nov07-Oct08	3,333,948	3,759,557	425,609	12.77	3,333,948	3,625,768	291,820	8.75
Year-Dec07-Nov08	2,929,217	3,551,534	622,317	21.25	2,929,217	3,397,079	467,862	15.97
Year-Jan08-Dec08	2,818,959	4,018,691	1,199,732	42.56	2,818,959	3,952,700	1,133,741	40.22
Nov. 2009-Oct. 2010	2,241,558	3,171,947	930,389	41.51	--	--	--	--
Dec. 2009-Nov. 2010	2,502,257	3,341,705	839,448	33.55	--	--	--	--
Jan. 2010-Dec. 2010	2,374,727	3,536,594	1,161,867	48.93	--	--	--	--
Dec. 2010-Nov. 2011	3,113,475	4,224,563	1,111,088	35.69	--	--	--	--

1 and 2 data combined (left half of Table 14), the overall difference for the 14 months of phase 1 record is 23.9% – which is slightly better than the 24.7 obtained when using phase 1 data alone. This further suggests that the model has benefited from the use of a larger data base form incorporating phase 1 data with phase 2 data.

This having been said, using phase 1 and 2 data combined for the model produces differences that are slightly larger for the 12-month phase 1 periods of November 2007 to October 2008, December 2007 to November 2008, and January 2008 to December 2008. This may be due to the larger monthly differences obtained for August 2008 and September 2008 (see left side of Table 14). However, the calculated value for December 2008 appears to have improved (see left half vs. right half of Table 14).

The difference in measured versus calculated total streamflow for phases 1 and 2 combined is 33.1%. This higher value (as compared to phase 1 data only) is driven by the phase 2 data, and in particular, the extreme difference obtained for July 2010. The elevated values for July 2010, August 2010, and June 2011, are likely due to these months all having low F/P ratios combined with a high precipitation surplus. The 12-month differences for the 26 months of phase 2 range from 33.6% to 48.9%, which is more than the 8.8% to 40.2% experienced from phase 1 data alone.

Based on the above, the synthetic flow record constructed for the Spectacle Lake watershed using available measured streamflow data from both phases 1 and 2 for the model is likely to overestimate total annual flows by 13 to 48 percent annually, with larger errors possible for some months. A middle of the road correction factor of perhaps 33 percent should be applied to any analysis based on data from this synthetic record.

Flow duration curves:

As noted earlier, statistical methods are used to describe streamflows based on the assumption that conditions recorded in the past may represent conditions in the future. An elementary but useful method is to plot a runoff, or streamflow duration curves. These curves show the percentage of time that any given discharge is exceeded, and can normally be fairly confidently extrapolated at their lower ends.

Flow duration curves are of use not only in studying the frequency of low flows, but also in reflecting the variability of the regime of a river. Thus, flat curves with high minimum values tend to be derived from rivers with a large baseflow component, which will probably show a slow but gradual decline to minimum flows, while a steep curve with low minimum values often represents a large quickflow component, in which the decline to minimum flows is likely to be more rapid.

Figures 37 and 38 show the flow duration curves for the Spectacle Lake watershed for the 44 year long period from 01 January 1967 to 31 December 2011 synthetic flow record, and for the much shorter phase 1 and 2 period

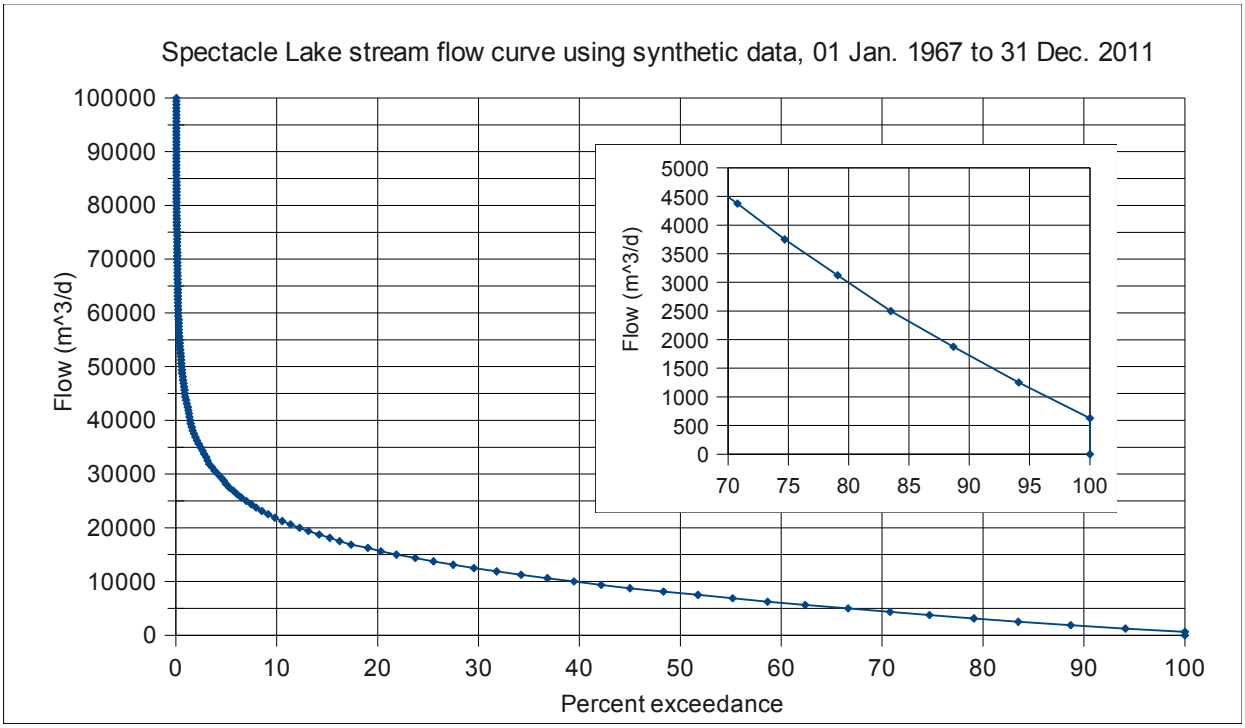


Figure 37. Flow duration curve for synthetic daily streamflow record for Spectacle Lake for the period 01 January 1967 to 31 December 2011.

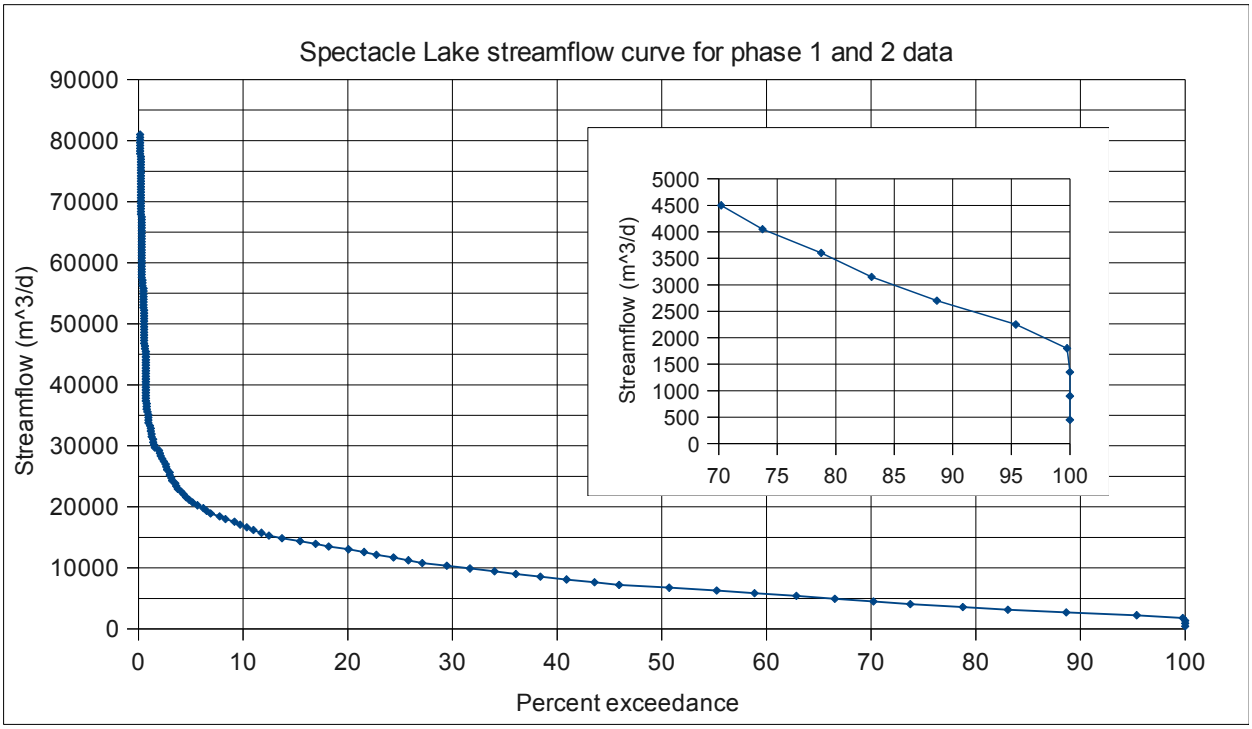


Figure 38. Flow duration curve for measured streamflows from Spectacle Lake for phases 1 and 2 (10 October 2007 to 31 December 2008 plus 11 September 2009 to 05 December 2011).

from 10 October 2007 to 31 December 2008 plus 11 September 2009 to 05 December 2011, respectively.

Figure 37 shows slightly higher streamflows than Figure 38. However, from about the 70 percent exceedance mark-on, flows in Figure 38 are slightly higher than in Figure 37.

The greater range of high flows in Figure 37 may be due to the longer period of synthetic data available, whereby the flows shown likely reflect larger precipitation events than were experienced during the five year period for phases 1 and 2. However, overestimation of the synthetic flow record may in part also account for the greater range of higher flows in Figure 37.

A review of synthetic record values reveals many days with flows from Spectacle Lake as low as 70 m^3/day (too low, too infrequent to be shown in Figure 37). However, such low flows appear unlikely based on field observations.

The field observations, data analysis, and Figures 37 and 38 suggest that synthetic record overestimation may be occurring for middle-to larger-size flows, whereas the synthetic record appears to be underestimating flows slightly in the lower ranges. This may help explain the larger apparent baseflow (flows in the 70 to 100 percent exceedance range) in Figure 38, as compared to those in Figure 37. However, it is not possible to effectively quantify the level of underestimation.

Suggested withdrawal allocation values:
The 95% exceedance frequency value for natural flow is a guideline value used by many jurisdictions, including the province of Nova Scotia, for allocating withdrawals from rivers or lakes.

Figure 37 (see inset figure for greater detail) shows a 95% exceedance flow value of approximately 1,200 m^3/d based on the synthetic flow record of 16,060 days (44 years) for Spectacle Lake. However, since the synthetic record may underestimate flows in the lower ranges, the 1,200 m^3/d may be viewed as being a bit conservative.

The previous report that covered phase 1 only identified a 95% exceedance flow value of about 900 m^3/d based on the synthetic flow record of 15,329 days (42 years).

Figure 38 (see inset figure for greater detail) 29 suggests a much greater 95% exceedance flow value of approximately 2,300 m^3/d as a possible withdrawal allocation from the Spectacle Lake watershed system based on the shorter, roughly 40 month phase 1 and 2 record of real data.

The phase 1 report, which included a real data record of only 14 months, indicated a 95% exceedance flow value of 1,950 to 1,955 m^3/d as possible withdrawal allocation from the Spectacle Lake watershed system.

A more practical and conservative approach to assess a potential withdrawal allocation value for the Spectacle Lake watershed may

be to select a value somewhere between 1,200 m^3/d (the low value obtained from Figure 37) and 1,750 m^3/d (the average of the numbers suggested by Figures 37 and 38). By comparison, an average value of 1,375 m^3/d was suggested from the two flow duration curves produced for the phase 1 report.

The shape of a flow duration curve and, thus, the 95% exceedance frequency value for natural flow, may be increased if storage is provided to extend those natural flows. So in addition to providing water to accommodate periods when there may be water deficits, a dam may be constructed and if controlled properly, used to change the shape of a flow duration curve and increase the 95% exceedance value, or withdrawal allocation, of the system.

Analysis carried out for other projects has suggested that the 90% exceedance frequency value for natural flows may at times be used to approximate the new 95% exceedance value that could result from constructing a dam[7] – one that is small enough as to not cause significant impact to natural flows downstream of the dam.

A 90% exceedance frequency flow value of approximately 1,750 m^3/d is suggested from from Figure 37 utilizing the synthetic record, and value of roughly 2,600 m^3/d is suggested from Figure 38 for the phase 1 and 2 period of field data. Again, a value somewhere between 1,750 m^3/d (the low value obtained from Figure 37) and 2,175 m^3/d (the average of the values obtained from Figures 37 and 38) may serve as an appropriate withdrawal allocation for a flow system that is modified using a properly constructed dam. By comparison, an average value of 1,715 m^3/d was suggested from the two flow duration curves produced for the phase 1 report.

Drought analysis:
Drought (low flow) frequency analysis was performed on 7, 14, 30 and 60 contiguous daily total flows based on data (uncorrected) from the synthetic flow record. For each of the four total-flow data sets calculated, data was ranked in ascending order and the non-exceedance probability was calculated by:

$$P_{ne} = \frac{m}{(n+1)}$$

where: P_{ne} is probability of non-exceedance; m is rank; and n is the number of years of record.

The recurrence interval (return period) was calculated using:

$$T = \frac{1}{P_{ne}}$$

where: T = return period in years.

7 Proper reservoir characterization, assessing affects on discharge below, and flood forecasting to assess water supply structure requirements and related safe operating criteria, should be done using appropriate watershed, stream routing, and reservoir modelling software, such as the US Corps of Engineers HEC-HMS and HEC-ResSim packages. Such modelling work should be done as the next phase of work, and must be done before undertaking any significant engineering design of water supply structures.

A semi-log graph of the recurrence interval (in years) and uncorrected flow (in m^3/d) was plotted for each data set of 7, 14, 30 and 60-day totals. Trend lines were conservatively drawn to estimate values for the 10-year, 20-year, 50-year and 100-year summer droughts for each data set. The results are summarized in Table 15.

Table 15. Low 7, 14, 30 and 60 contiguous day flows (m^3) for 10, 20, 50 and 100 year drought return periods based on the synthetic record.

Return period (years)	Total flow-days			
	7	14	30	60
10	700	1,580	4,125	11,300
20	675	1,550	4,100	11,050
50	645	1,520	4,075	11,000
100	610	1,490	4,050	10,950

The values in Table 15 are nearly double the values that were obtained doing the same analysis for the phase 1 report. Nevertheless, it is important to note that the values in Table 15 may still represent lower-than-expected estimates, as they were obtained from the synthetic record, which it is understood may underestimate the lower range flows from Spectacle Lake.

As an example of the possible level of underestimation, Table 16 compares the lowest daily and 7, 14, 30 and 60 contiguous-daily flows from the synthetic record, to the daily, 7, 14, 30 and 60 contiguous-flows actually measured from 2007 to 2011 during phases 1 and 2. The numbers obtained from both sources are really quite different.

Comparing the values in Table 16 to those from the phase 1 report, the field data values obtained from phases 1 and 2 combined are slightly lower than those from the phase 1 report, while the values obtained from the synthetic record are nearly twice the values obtained for the phase 1 report.

Table 16. Comparison of low flows obtained from the 44 year synthetic record versus 2007-2011 field-measured flows.

Number of contiguous days	Flows (m^3/day) obtained from	
	Synthetic (42 years)	Field data (40 months)
1	71	1,172
7	640	9,799
14	1,506	21,503
30	4,081	50,278
60	11,010	116,301

The synthetic record does represent 44 years of daily streamflows and as such, it would be expected to include a greater number of more significant dry periods than would have been experienced during the much shorter 2007-2011 phase 1 and 2 data collection period.

The annual amounts of precipitation received during the 2007 to 2011 phase 1 and 2 field data collection period were greater than for the 30 year, 1970-2000 norm. These “greater than normal” recent precipitation amounts may explain, to some degree, the differences noted above. However, this relative increase in precipitation is not large enough to fully explain the extreme differences that exist in the drought flow data shown in Table 16.

Assessment of sustainable yield:
To be sustainable, a surface water supply must come from excess precipitation (either as direct runoff or as baseflow), and is the amount of water that can be extracted without reducing the basic amount of flow needed to sustain the lake from which water is being taken, while also allowing sufficient flow to maintain downstream ecosystems at close-to-natural levels. Doing this well would require some form of control structure at the lake.

The ecosystem components of concern at Spectacle Lake would include the lake itself and the outflow channel that was either dug or modified many years ago. Although the channel may be artificial to a certain degree, any "enhancements" that were made to it were done a long time ago, and any related ecosystems will have evolved as a function of the channel morphology and flow regimes since that time.

Water taking may be done in an ecologically sustainable manner by strictly adhering to withdrawal allocations, working within the available average yearly water balance, and carefully managing water level and flow control structures in such a way as to mimic existing streamflows as best as possible.

Suggested allocation values versus demand:
Based on the 44 year synthetic streamflow model developed from the 40 months of phase 1 and 2 field data, a withdrawal allocation value between 1,200 m^3/d and 1,750 m^3/d (median value 1,475 m^3/d) is suggested (revised from 1,375 m^3/d using phase 1 data alone) using a 95% exceedance frequency flow. A withdrawal allocation value between 1,750 m^3/d and 2,175 m^3/d (median value 1,960 m^3/d) is suggested (revised from 1,715 m^3/d using phase 1 data alone) using a 90% exceedance frequency flow to approximate the possible affects of constructing and proper managing a flow control dam at Spectacle lake.

If water taking volumes are to equal the allocation values, assuming a mean rate of consumption of 100 gallons (450 litres) per person per day, then notwithstanding any system design safety factors, a water supply at Spectacle Lake may be able to service a maximum of 2,600 to 3,800 (median value 3,200) people, or 3,800 to 4800 (median value 4,300) people, depending upon the streamflow control scenarios noted above.

Allowing a 1.5x safety factor to account for interpretive errors, changes in climate, water distribution, and other losses, then Spectacle Lake may be able to service 1,700 to 2,500 (median value 2,100) people or 2,500 to 3,200 (median value 2,850) people. Using a safety factor of 2, those numbers drop to 1,300 to 1,900 (median value 1,600) people, or 1,900 to 2,400 (median value 2,150) people. More may be serviced if water conservation measures are enforced.

Lake storage requirements:
The median withdrawal allocation values noted above will be used here solely to facilitate the discussion that follows.

Table 17. Mean monthly surplus, deficits and residual streamflows after withdrawing either 1,475 m3/d or 1,960 m3/d from Spectacle Lake, based on mean flows for the phase 1 and 2 period of 2007 to 2011.

Measured data		Proposed permissible flow reduction (m^3)		Possible demand (m^3)		Net surplus or deficit (m^3)		Residual streamflow (m^3)	
Period	Column 1	Column 2	Column 3	Column 4	Column 5				
	Mean flow (m^3)	at 18.6% of flow	at 24.8% of flow	1,475 m^3/d	1,960 m^3/d	Col 2-4	Col 3-5	Col 1-2	Col 1-3
January	312,570	58,236	77,385	44,988	59,780	13,249	17,605	254,333	235,184
February	307,490	57,290	76,128	44,988	59,780	12,302	16,348	250,200	231,362
March	364,587	67,928	90,264	44,988	59,780	22,940	30,484	296,659	274,324
April	258,065	48,081	63,891	44,988	59,780	3,094	4,111	209,984	194,174
May	197,425	36,783	48,878	44,988	59,780	-8,204	-10,902	160,642	148,547
June	152,706	28,451	37,807	44,988	59,780	-16,536	-21,973	124,255	114,900
July	70,817	13,194	17,533	44,988	59,780	-31,793	-42,247	57,623	53,284
August	130,615	24,336	32,337	44,988	59,780	-20,652	-27,443	106,280	98,278
September	72,435	13,496	17,933	44,988	59,780	-31,492	-41,847	58,940	54,502
October	289,431	53,925	71,657	44,988	59,780	8,938	11,877	235,506	217,774
November	378,643	70,547	93,744	44,988	59,780	25,559	33,964	308,097	284,900
December	362,730	67,582	89,804	44,988	59,780	22,594	30,024	295,148	272,926
Year	2,897,516	539,850	717,360	539,850	717,360	0	0	2,357,666	2,180,156

A certain amount of water storage will be needed at Spectacle Lake, as net monthly withdrawals of 44,250 m^3 (1,475 m^3/d) or 58,800 m^3 (1,960 m^3/d) could cause flows at the discharge channel below Spectacle Lake to become reduced, or to possibly stop altogether during the drier months.

Table 17 was developed from measured flows[8] as a means to allow a preliminary assessment of how much storage might be needed to help maintain acceptable stream flows below Spectacle Lake.

The median withdrawal allocation values of 1,475 m^3/d and 1,715 m^3/d discussed above are equal to 18.6% and 24.8% of total measured mean annual flow, respectively. On the assumption that these percentages ought to represent the maximum effects of any withdrawal on any monthly flow, they were applied to the measured monthly flows in Column 1 of Table 17 to obtain the values shown in Columns 2 and 3.

Columns 2 and 3 represent what may be considered to be total flow contributions to withdrawals, and it is from this that flow surpluses and deficits and thus, lake storage requirements, can be calculated.

From Table 17, the total net annual deficit (sum of negative amounts May to September) for water taking at rates of 1,475 m^3/d and 1,960 m^3/d were found to be 108,667 m^3 and 144,412 m^3, respectively. These would be the volumes of water needing to be stored annually during the periods of high flow, in order to maintain adequate flows below Spectacle Lake during periods of low flow.

8 In light of the uncertainty in the synthetic flow record, it is perhaps more prudent to evaluate demand capability and lake storage requirements from the real data collected for phases 1 and 2 of this study.

These volumes would represent water level changes at Spectacle Lake of 36 cm and 48 cm, respectively.

These changes in lake water storage may be obtained by allowing the lake level to drop, or by repairing (replacing) the existing water control structure to cause water levels to rise, or a combination of both.

Allowing water levels to drop or to rise by large amounts may cause environmental concerns, and in light that raising the lake water level by a great amount would also require a berm along parts of the southeast shore (other parts of the lake shore appear high and steep enough to accommodate the necessary water level changes), it may be best to plan to have water levels at Spectacle Lake fluctuate by approximately 0.5 m above and below existing mean high-low levels.

Spectacle Lake has a surface area of about 30.2 hectares, and flooding by adding to lake storage (assuming a 1 m water level rise – worse case) could create a new water surface area of about 37.9 hectares. The new area and amount of storage required are both less than the 100 hectare surface area and 10,000,000 m^3 incremental storage needed to trigger an environmental assessment under the current Provincial Environment regulations.

6. Lake water quality:

The lake's water chemistry was characterized both spatially and seasonally through the collection and evaluation of 37 lake water samples during phase 1, and 14 stream water samples during phase 2, of which 7 samples were collect from the stream feeding into Spectacle Lake, and 7 were collected from the discharge channel below the lake.

Lake water sampling program:
There were four separate lake water sampling events, one to represent each of the seasons: on 29 November 2007 (fall), on 08 February 2008 (winter), on 22 May 2008 (spring) and on 05 September 2008 (late summer).

For each event, sample suites were collected from three locations on the lake: one at roughly the centre (deepest part) of the eastern basin, another at about the overall centre of the lake, and a third at roughly the deepest part of the western basin. At each location, water samples were collected from three separate depths: one at 40 feet (12.2m), on at 20 feet (3.6m), and one at surface.

One sample (collected in November 2007) was analyzed for total trihalomethane (THM) formation potential. All of the other water samples were analyzed for general chemistry and metals. The February 2008 water samples were also analyzed for fluoride.

Lake water sampling methodology:
A canoe was used to access the sampling locations during periods of open water. The February 2008 water samples were taken by auguring through the ice.

The 40 and 20 foot lake water samples were collected using a WaterMark® vertical point sampler – an open tube with messenger-

activated release mechanism to close both ends of the tube with rubber plugs – thus allowing discrete water samples to be taken at any desired depth. The samples were then transferred either to appropriate lab-supplied sampling bottles, or to a syringe for filtration.

The surface water samples were taken by immersing the lab-supplied water bottles or a syringe directly into the lake.

The water samples for general chemistry were placed into sterile, lab-supplied 200 ml polyethylene bottles.

The water samples for metals analysis were placed into 60 ml luer-lok syringes, to which disposable Millipore® 0.45µ filters were attached to filter the samples. Filtration was done immediately either in the canoe or on the ice upon collecting each sample. Sample filtrate was placed into sterile, lab-supplied 50 ml polyethylene vials.

The 50 ml sample vials for metals analysis were not field preserved (addition of nitric acid) in fear of contaminating them due to the uncontrolled field environment. The lab was instructed to do the preservation and to allow sufficient time for metals to become dissorbed from the sample bottles before further processing them.

All water samples were placed on ice in a cooler immediately after collection and during transport to the lab on the same day. The samples were analyzed at Maxxam Analytics Inc. in Bedford, NS.

Stream water sampling methodology:
The stream water samples were collected by immersing the lab-supplied water bottles or a syringe directly into the running stream water.

The stream water samples collected for metal analysis were collected and filtered the same way as the lake water samples, with sample preservation done by the lab.

As with the lake water samples, all stream water samples were placed on ice in a cooler immediately after collection and during transport to the lab on the same day. The samples were analyzed at Maxxam Analytics Inc. in Bedford, NS.

THM results:
THMs, or trihalomethanes, are among one of a suite of chemical compounds that can be formed as a byproduct of disinfecting drinking water with chlorine. THMs occur when chlorine reacts with organic matter in water, and for this reason are more common in surface water supplies. The concerns with THMs include the possibility of certain cancers, changes to the nervous system, and potential growth problems following very long periods (many years) of exposure.

The THMs most frequently found in chlorine treated drinking water are chloroform, bromodichloromethane, bromoform and dibromochloromethane. The factors that control the formation of THMs are complex, but THMs increase as the values for chlorine, humic acid, temperature, contact time, pH

and Bromide ion increase. In the presence of bromide, brominated THMs are formed preferentially and chloroform concentration decreases proportionally.

A THM formation potential analysis involves subjecting a water sample to ideal conditions for THMs to form in the lab. The result generally represents what may be worse-case concentrations.

The THM formation potential analysis results for the sample collected in November 2007 are summarized in Table 18.

Table 18. THM analysis results.

Parameter	units	value
Bromodichloromethane	µg/L	20
Bromoform	µg/L	< 1
Chlorodibromomethane	µg/L	< 1
Chloroform	µg/L	500
THM Formation Potential	µg/L	530

Health Canada recommends that the average value for four water samples collected quarterly be less than 100 µg/L.

In light of the numbers presented in Table 18, there is no need to collect additional samples for THM evaluation – the results clearly show that THM formation is likely to occur with chlorination should Spectacle Lake be developed as a water supply. Therefore, proper water filtration will be required before any other water treatment and/or distribution can take place from Spectacle Lake

Inorganic chemistry:

The lake water sample results for inorganic parameters are summarized in Tables 19 to 22. The stream water sample results are summarized in Tables 23 and 24. The data from Tables 19 to 24 is also summarized in the Piper diagram[9] in Figure 39.

The water from Spectacle Lake is classed as a very soft, sodium-chloride type water with low Total Dissolved Solids (TDS) (~30 mg/L), low pH (5.17 to 6), and extremely low alkalinity (non detect).

The water samples all meet all of the GCDWQ (2010) recommended guideline values for all parameters tested except a few. In general, the values for pH (recommended range is 6.5 to 8.5) are all low, iron is above the recommended guideline in one lake water sample (less than 0.3 mg/L is recommended), and manganese is above the 0.05 mg/L recommended level in most lake and stream water samples. The guidelines values for these parameters are for aesthetic purposes.

The values for aluminum in lake and stream water samples were found to range from about 30 mg/L to 180 mg/L (modal values

9 Piper diagrams are used to characterize waters by assessing the relative distribution of major ions in the water. Variations in water composition and/or water mixing can become very apparent in Piper diagrams. They are produced by calculating the percent distribution of the major cations and major anions (expressed in meq/L or mili-equivalents per litre, thus normalizing the values to account for the different atomic weights of the various elements), which are each plotted onto their own tertiary diagram. These are then projected onto a third diagram above the two tertiary plots.

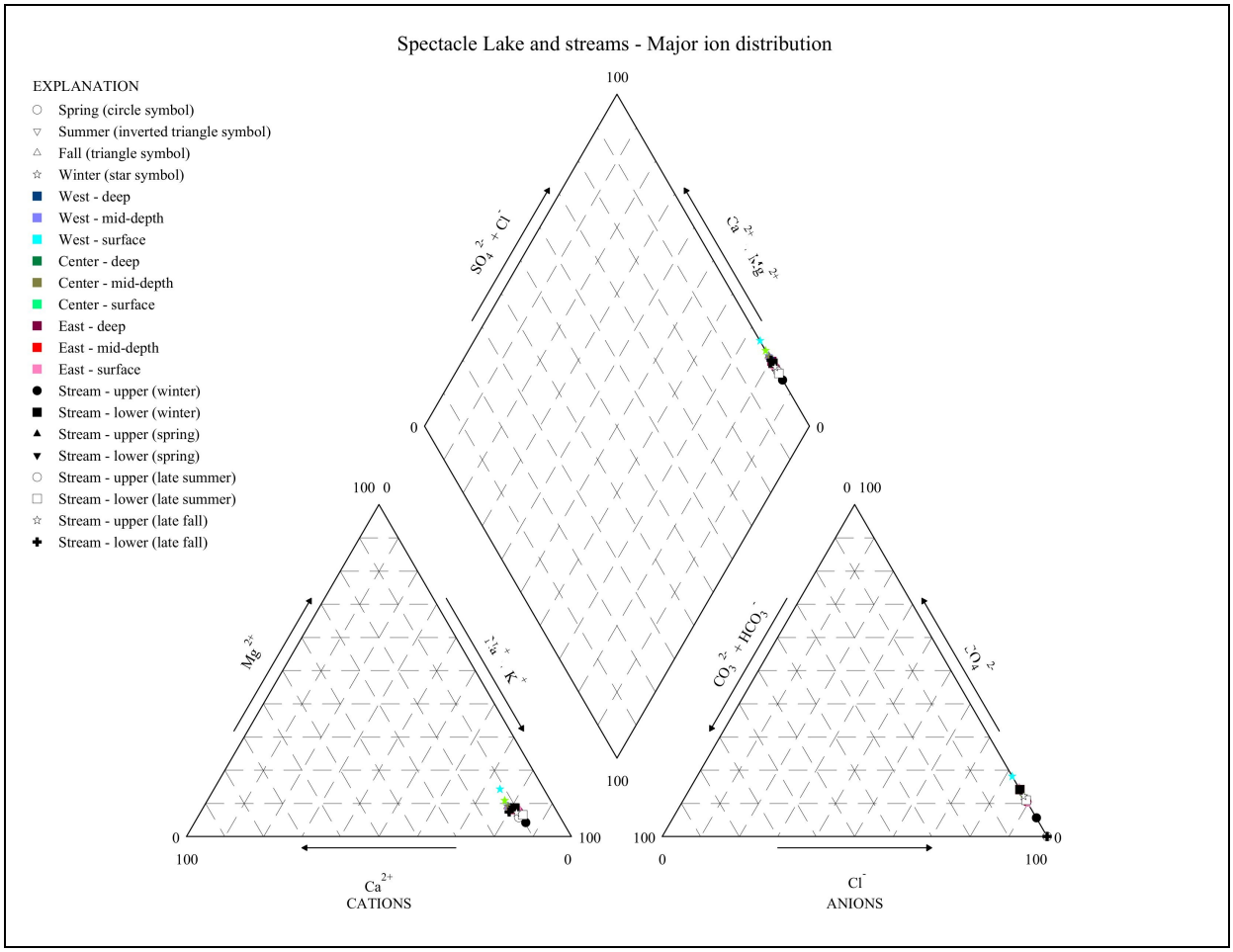


Figure 39. Piper diagram for lake and stream water samples from Spectacle Lake.

were around 100 mg/L). The values for aluminum in water samples from the stream above Spectacle Lake were generally higher than those from the stream below the lake. Aluminum is a concern as relates to certain types of treatment[10] applied to water supplies.

What follows is a general discussion of the lake and stream water hydrochemical spatial and temporal trends as noted from Tables 19 to 24 and Figure 39:

- TDS values appear to increase generally over time in all lake and stream water samples from winter, to spring, through summer, and then drop back down again in the fall. Values for TDS are usually greater in the upper stream samples than in the lower stream samples.
- TDS concentrations were found to decrease generally from depth to surface in both the winter and summer lake water samples, which suggests possible

10 This is an operational guidance value, designed to apply only to drinking water treatment plants using aluminum-based coagulants. The operational guidance values of 0.1 mg/L applies to conventional treatment plants, and 0.2 m g/L applies to other types of treatment systems.

lake water stratification.

- The concentrations for silica, chloride, sulfate, sodium, calcium, magnesium, nitrate, hardness, and total dissolved solids are all lower in the discharge stream water samples relative to the feeder stream water samples. The drops in concentration for chloride, sodium and TDS are somewhat significant from a general water composition point of view.
- While the values for sodium, calcium, magnesium, hardness and total dissolved solids have varied over time in water samples from the feeder stream, they have remained relatively steady within the lake and at the discharge stream.
- The winter lake water samples appear in general to be more magnesium-sulfate rich than samples from other times of the year. In addition, the shallow summer lake water samples become slightly more magnesium-sulfate rich from east to west across the lake.
- Chloride concentrations in lake and stream water samples increase from fall through winter, spring and summer (concentrations are generally lowest in the fall). Based on the data available, this cycle appears to repeat annually.
- Color in the lake and stream water samples in general increases from fall through winter and into spring.
- Iron concentrations in general decrease from depth to surface for the winter and spring lake water samples. Iron is present only in the deepest lake water samples collected in summer.
- In general, manganese concentrations decrease from depth to surface in lake water samples from the west end of the lake. Manganese is present mostly at depth in east, and was found at very high concentrations in the summer.
- While the values for aluminum are generally lower in the discharge stream water samples than in the feeder stream samples, no clear seasonal trends in aluminum concentration are apparent from the available data.
- Zinc concentrations in the lake water samples generally decrease from depth to surface and from west to east in all seasons. Zinc concentrations in the lake water samples are lowest overall in the summer, whereas they do not appear to change significantly in water samples from the feeder stream.
- Zinc concentrations are generally lower for all seasons in the discharge stream water samples than in the feeder stream.
- Values for pH were up in both spring-time stream water samples compared to the winter-time samples. This may be a function of the source waters (i.e. rainfall), or some other unidentified phenomena, as there are no significant apparent changes based on lab results in waters from either samples which could explain an increase in buffering capacity from winter time to the spring.

Table 19. Lab analysis results for Spectacle Lake water samples collected on 29 November 2007.											
Location		West			Centre			East			RDL
		deep	mid	surface	deep	mid	surface	deep	mid	surface	
Parameter	Units	1a	1b	1c	2a	2b	2c	3a	3b	3c	
Anion Sum	me/L	0.42	0.42	0.42	0.42	0.42	0.42	0.41	0.42	0.42	N/A
Bicarb. Alkalinity (calc. as CaCO3)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	1
Calculated TDS	mg/L	29	29	29	29	29	29	29	29	29	1
Carb. Alkalinity (calc. as CaCO3)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	1
Cation Sum	me/L	0.48	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	N/A
Hardness (CaCO3)	mg/L	5	5	5	5	5	5	5	5	5	1
Ion Balance (% Difference)	%	6.67	5.62	5.62	5.62	5.62	5.62	6.82	5.62	5.62	N/A
Langelier Index (@ 20C)	N/A	NC	NC	NC	NC	NC	NC	NC	NC	NC	N/A
Langelier Index (@ 4C)	N/A	NC	NC	NC	NC	NC	NC	NC	NC	NC	N/A
Nitrate (N)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.05
Saturation pH (@ 20C)	N/A	NC	NC	NC	NC	NC	NC	NC	NC	NC	N/A
Saturation pH (@ 4C)	N/A	NC	NC	NC	NC	NC	NC	NC	NC	NC	N/A
Total Alkalinity (Total as CaCO3)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	5
Dissolved Chloride (Cl)	mg/L	13	13	13	13	13	13	13	13	13	1
Colour	TCU	17	17	17	17	17	17	17	17	17	5
Nitrate + Nitrite	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.05
Nitrite (N)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.01
Nitrogen (Ammonia Nitrogen)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.05
Total Organic Carbon (C)	mg/L	3	3.5	3.7	3.6	3.1	3.7	3.2	3.3	3.5	0.5
Orthophosphate (P)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.01
pH	pH	6.02	5.89	5.87	5.87	5.85	5.88	5.87	5.88	5.87	N/A
Reactive Silica (SiO2)	mg/L	2.9	2.9	2.9	2.9	2.9	2.9	3	3	3	0.5
Dissolved Sulphate (SO4)	mg/L	3	3	3	3	3	3	3	3	3	2
Turbidity	NTU	0.8	1	1.2	1	0.9	0.9	1.3	0.9	1	0.1
Conductivity	uS/cm	57	57	57	57	57	57	57	57	57	1
Dissolved Aluminum (Al)	ug/L	110	110	110	110	110	100	100	110	110	10
Dissolved Antimony (Sb)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Arsenic (As)	ug/L	ND	ND	ND	2	2	ND	ND	ND	ND	2
Dissolved Barium (Ba)	ug/L	7	7	7	7	7	7	7	7	7	5
Dissolved Beryllium (Be)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Bismuth (Bi)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Boron (B)	ug/L	6	6	ND	5	ND	ND	ND	ND	ND	5
Dissolved Cadmium (Cd)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.3
Dissolved Chromium (Cr)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Cobalt (Co)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	1
Dissolved Copper (Cu)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Iron (Fe)	ug/L	210	200	200	200	200	200	200	200	200	50
Dissolved Lead (Pb)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.5
Dissolved Manganese (Mn)	ug/L	86	87	85	86	86	84	82	84	83	2
Dissolved Molybdenum (Mo)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Nickel (Ni)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Selenium (Se)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Silver (Ag)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.5
Dissolved Strontium (Sr)	ug/L	7	7	7	7	7	7	7	7	7	5
Dissolved Thallium (Tl)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.1
Dissolved Tin (Sn)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Titanium (Ti)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Uranium (U)	ug/L	0.1	ND	ND	ND	ND	0.1	ND	ND	ND	0.1
Dissolved Vanadium (V)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Zinc (Zn)	ug/L	40	36	5	17	9	5	12	14	5	5
Dissolved Calcium (Ca)	mg/L	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	0.1
Dissolved Magnesium (Mg)	mg/L	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.1
Dissolved Phosphorus (P)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.1
Dissolved Potassium (K)	mg/L	0.6	0.4	0.4	0.4	0.5	0.5	0.4	0.4	0.4	0.1
Dissolved Sodium (Na)	mg/L	8.1	8.1	8.1	8	8.1	8.1	8.1	8.1	8.1	0.1
RDL=reportable detection limit, ND=non-detected, NC=non-calculable.											

Table 20. Lab analysis results for Spectacle Lake water samples collected on 08 February 2008.											
Location		West			Centre			East			RDL
		deep	mid	surface	deep	mid	surface	deep	mid	surface	
Parameter	Units	3a	3b	3c	2a	2b	2c	1a	1b	1c	
Anion Sum	me/L	0.54	0.51	0.35	0.58	0.53	0.36	0.61	0.61	0.63	N/A
Bicarb. Alkalinity (calc. as CaCO3)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	1
Calculated TDS	mg/L	37	34	24	38	35	26	40	40	41	1
Carb. Alkalinity (calc. as CaCO3)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	1
Cation Sum	me/L	0.58	0.55	0.35	0.6	0.56	0.4	0.64	0.62	0.66	N/A
Hardness (CaCO3)	mg/L	6	6	4	6	6	5	6	6	6	1
Ion Balance (% Difference)	%	3.57	3.77	0	1.69	2.75	5.26	2.4	0.81	2.33	N/A
Langelier Index (@ 20C)	N/A	NC	NC	NC	NC	NC	NC	NC	NC	NC	N/A
Langelier Index (@ 4C)	N/A	NC	NC	NC	NC	NC	NC	NC	NC	NC	N/A
Nitrate (N)	mg/L	0.06	ND	0.05	ND	ND	0.06	ND	ND	0.07	0.05
Saturation pH (@ 20C)	N/A	NC	NC	NC	NC	NC	NC	NC	NC	NC	N/A
Saturation pH (@ 4C)	N/A	NC	NC	NC	NC	NC	NC	NC	NC	NC	N/A
Total Alkalinity (Total as CaCO3)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	5
Dissolved Chloride (Cl)	mg/L	17	16	10	18	17	11	19	19	20	1
Colour	TCU	19	17	ND	17	17	15	17	17	15	5
Dissolved Fluoride (F-)	mg/L		ND		ND	ND	ND		ND		0.1
Nitrate + Nitrite	mg/L	0.06	ND	0.05	ND	ND	0.06	ND	ND	0.07	0.05
Nitrite (N)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.01
Nitrogen (Ammonia Nitrogen)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.05
Total Organic Carbon (C)	mg/L	3.3	3.4	1.4	3.1	2.9	3	3.1	3.2	2.8	0.5
Orthophosphate (P)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.01
pH	pH	5.67	5.59	5.18	5.55	5.62	5.17	5.38	5.47	5.17	N/A
Reactive Silica (SiO2)	mg/L	3.7	3.3	3.5	3.5	3.3	3.5	3.2	3.3	3.1	0.5
Dissolved Sulphate (SO4)	mg/L	3	3	3	3	3	2	3	3	3	2
Turbidity	NTU	0.6	0.4	0.2	0.5	0.5	0.4	0.6	0.5	0.5	0.1
Conductivity	uS/cm	67	63	44	71	65	48	75	74	76	1
Dissolved Aluminum (Al)	ug/L	120	120	180	120	120	130	130	120	120	10
Dissolved Antimony (Sb)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Arsenic (As)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Barium (Ba)	ug/L	8	8	7	8	8	8	8	8	8	5
Dissolved Beryllium (Be)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Bismuth (Bi)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Boron (B)	ug/L	ND	ND	ND	5	ND	ND	ND	ND	ND	5
Dissolved Cadmium (Cd)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.3
Dissolved Chromium (Cr)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Cobalt (Co)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	1
Dissolved Copper (Cu)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Iron (Fe)	ug/L	220	190	ND	200	200	130	180	190	150	50
Dissolved Lead (Pb)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	0.6	0.5
Dissolved Manganese (Mn)	ug/L	96	79	43	86	81	120	88	85	82	2
Dissolved Molybdenum (Mo)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Nickel (Ni)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Selenium (Se)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Silver (Ag)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.5
Dissolved Strontium (Sr)	ug/L	8	7	5	8	8	6	8	8	8	5
Dissolved Thallium (Tl)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.1
Dissolved Tin (Sn)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Titanium (Ti)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Uranium (U)	ug/L	ND	ND	ND	ND	ND	ND	0.1	ND	0.1	0.1
Dissolved Vanadium (V)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Zinc (Zn)	ug/L	6	7	7	8	6	6	30	8	9	5
Dissolved Calcium (Ca)	mg/L	1.3	1.3	0.8	1.3	1.3	0.9	1.4	1.4	1.3	0.1
Dissolved Magnesium (Mg)	mg/L	0.6	0.6	0.6	0.6	0.6	0.5	0.6	0.6	0.6	0.1
Dissolved Phosphorus (P)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.1
Dissolved Potassium (K)	mg/L	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.1
Dissolved Sodium (Na)	mg/L	10	9.5	5.7	11	9.7	6.5	11	11	12	0.1
RDL=reportable detection limit, ND=non-detected, NC=non-calculable.											

Table 21. Lab analysis results for Spectacle Lake water samples collected on 22 May 2008.											
Location		West			Centre			East			RDL
		deep	mid	surface	deep	mid	surface	deep	mid	surface	
Parameter	Units	1A	1B	1C	2A	2B	2C	3A	3B	3C	
Anion Sum	me/L	0.59	0.58	0.58	0.6	0.58	0.57	0.59	0.58	0.58	N/A
Bicarb. Alkalinity (calc. as CaCO3)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	1
Calculated TDS	mg/L	39	38	38	40	38	38	40	38	38	1
Carb. Alkalinity (calc. as CaCO3)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	1
Cation Sum	me/L	0.64	0.62	0.62	0.64	0.62	0.62	0.64	0.62	0.61	N/A
Hardness (CaCO3)	mg/L	6	6	6	6	5	5	6	6	6	1
Ion Balance (% Difference)	%	4.07	3.33	3.33	3.23	3.33	4.2	4.07	3.33	2.52	N/A
Langelier Index (@ 20C)	N/A	NC	NC	NC	NC	NC	NC	NC	NC	NC	
Langelier Index (@ 4C)	N/A	NC	NC	NC	NC	NC	NC	NC	NC	NC	
Nitrate (N)	mg/L	ND	ND	ND	0.05	ND	ND	ND	ND	ND	0.05
Saturation pH (@ 20C)	N/A	NC	NC	NC	NC	NC	NC	NC	NC	NC	
Saturation pH (@ 4C)	N/A	NC	NC	NC	NC	NC	NC	NC	NC	NC	
Total Alkalinity (Total as CaCO3)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	5
Dissolved Chloride (Cl)	mg/L	18	18	18	19	18	18	19	18	18	1
Colour	TCU	24	18	18	25	19	17	25	20	19	5
Nitrate + Nitrite	mg/L	ND	ND	ND	0.05	ND	ND	ND	ND	ND	0.05
Nitrite (N)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.01
Nitrogen (Ammonia Nitrogen)	mg/L	0.05	ND	ND	ND	ND	0.11	ND	ND	ND	0.05
Total Organic Carbon (C)	mg/L	2.9	2.6	2.8	3.1	3.1	2.8	3	2.8	2.9	0.5
Orthophosphate (P)	mg/L	ND	ND	ND	0.03	ND	ND	ND	ND	ND	0.01
pH	pH	5.5	5.63	5.67	5.47	5.64	5.73	5.45	5.75	5.69	N/A
Reactive Silica (SiO2)	mg/L	3.1	2.9	2.9	3.4	2.9	3.2	3.4	2.9	2.9	0.5
Dissolved Sulphate (SO4)	mg/L	3	3	3	3	3	3	3	3	3	2
Turbidity	NTU	0.5	0.4	0.5	0.4	0.5	0.5	0.6	0.6	0.5	0.1
Conductivity	uS/cm	75	74	74	77	74	74	77	74	74	1
Dissolved Aluminum (Al)	ug/L	110	100	100	120	110	97	120	100	97	10
Dissolved Antimony (Sb)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Arsenic (As)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Barium (Ba)	ug/L	8	8	8	8	8	7	8	8	8	5
Dissolved Beryllium (Be)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Bismuth (Bi)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Boron (B)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	5
Dissolved Cadmium (Cd)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.3
Dissolved Chromium (Cr)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Cobalt (Co)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	1
Dissolved Copper (Cu)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Iron (Fe)	ug/L	180	200	91	150	120	110	190	120	110	50
Dissolved Lead (Pb)	ug/L	ND	ND	ND	0.6	ND	ND	120	ND	ND	0.5
Dissolved Manganese (Mn)	ug/L	83	69	67	89	67	64	95	63	64	2
Dissolved Molybdenum (Mo)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Nickel (Ni)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Selenium (Se)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Silver (Ag)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.5
Dissolved Strontium (Sr)	ug/L	8	8	8	7	8	7	8	8	7	5
Dissolved Thallium (Tl)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.1
Dissolved Tin (Sn)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Titanium (Ti)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Uranium (U)	ug/L	0.1	ND	ND	ND	ND	ND	ND	ND	ND	0.1
Dissolved Vanadium (V)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Zinc (Zn)	ug/L	16	22	6	9	10	5	9	9	5	5
Dissolved Calcium (Ca)	mg/L	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.2	0.1
Dissolved Magnesium (Mg)	mg/L	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.1
Dissolved Phosphorus (P)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.1
Dissolved Potassium (K)	mg/L	0.4	0.4	0.4	0.5	0.4	0.4	0.4	0.4	0.4	0.1
Dissolved Sodium (Na)	mg/L	11	11	11	12	11	11	12	11	11	0.1
Dissolved Sulphur (S)	mg/L	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	0.5
RDL=reportable detection limit, ND=non-detected, NC=non-calculable.											

Table 22. Lab analysis results for Spectacle Lake water samples collected on 05 September 2008.

Location		West			Centre			East			RDL
		deep	mid	surface	deep	mid	surface	deep	mid	surface	
Parameter	**Units**	**3a**	**3b**	**3c**	**2a**	**2b**	**2c**	**1a**	**1b**	**1c**	
Anion Sum	me/L	0.580	0.590	0.590	0.590	0.590	0.580	0.600	0.590	0.590	N/A
Bicarb. Alkalinity (calc. as CaCO3)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	1
Calculated TDS	mg/L	39	37	37	40	37	37	42	37	37	1
Carb. Alkalinity (calc. as CaCO3)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	1
Cation Sum	me/L	0.630	0.620	0.620	0.630	0.620	0.620	0.650	0.620	0.610	N/A
Hardness (CaCO3)	mg/L	6	6	6	6	6	6	6	6	6	1
Ion Balance (% Difference)	%	4.13	2.48	2.48	3.28	2.48	3.33	4.00	2.48	1.67	N/A
Langelier Index (@ 20C)	N/A	NC	NC	NC	NC	NC	NC	NC	NC	NC	
Langelier Index (@ 4C)	N/A	NC	NC	NC	NC	NC	NC	NC	NC	NC	
Nitrate (N)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.05
Saturation pH (@ 20C)	N/A	NC	NC	NC	NC	NC	NC	NC	NC	NC	
Saturation pH (@ 4C)	N/A	NC	NC	NC	NC	NC	NC	NC	NC	NC	
Total Alkalinity (Total as CaCO3)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	5
Dissolved Chloride (Cl)	mg/L	18	18	18	18	18	18	18	18	18	1
Colour	TCU	19	13	10	22	9	8	30	11	9	5
Nitrate + Nitrite	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.05
Nitrite (N)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.01
Nitrogen (Ammonia Nitrogen)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.05
Total Organic Carbon (C)	mg/L	1.9	2.0	2.3	2.1	1.7	1.8	2.8	2.0	2.6	0.5
Orthophosphate (P)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.01
pH	pH	5.48	5.71	5.81	5.33	5.70	5.74	5.87	5.90	5.80	N/A
Reactive Silica (SiO2)	mg/L	3.3	1.7	1.7	3.8	1.7	1.6	4.6	1.8	1.6	0.5
Dissolved Sulphate (SO4)	mg/L	4	4	4	4	4	4	4	4	4	2
Turbidity	NTU	0.3	0.3	0.2	0.3	0.3	0.3	0.9	0.3	0.3	0.1
Conductivity	uS/cm	75	73	74	76	74	74	83	76	76	1
Dissolved Aluminum (Al)	ug/L	120	36	30	120	38	28	120	48	30	10
Dissolved Antimony (Sb)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Arsenic (As)	ug/L	ND	ND	ND	ND	ND	ND	3	ND	ND	2
Dissolved Barium (Ba)	ug/L	9	7	7	9	8	7	9	8	7	5
Dissolved Beryllium (Be)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Bismuth (Bi)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Boron (B)	ug/L	ND	ND	ND	ND	ND	ND	6	ND	ND	5
Dissolved Cadmium (Cd)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.3
Dissolved Chromium (Cr)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Cobalt (Co)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	1
Dissolved Copper (Cu)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Iron (Fe)	ug/L	120	ND	ND	150	ND	ND	580	ND	ND	50
Dissolved Lead (Pb)	ug/L	1.2	ND	ND	ND	ND	ND	1.2	ND	ND	0.5
Dissolved Manganese (Mn)	ug/L	87	34	25	130	39	24	360	54	25	2
Dissolved Molybdenum (Mo)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Nickel (Ni)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Selenium (Se)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Silver (Ag)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.5
Dissolved Strontium (Sr)	ug/L	8	8	8	8	8	8	9	8	8	5
Dissolved Thallium (Tl)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.1
Dissolved Tin (Sn)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Titanium (Ti)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Uranium (U)	ug/L	0.1	ND	ND	ND	ND	ND	ND	0.1	ND	0.1
Dissolved Vanadium (V)	ug/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Dissolved Zinc (Zn)	ug/L	9	6	ND	12	7	ND	19	9	ND	5
Dissolved Calcium (Ca)	mg/L	1.3	1.3	1.3	1.3	1.3	1.3	1.4	1.3	1.3	0.1
Dissolved Magnesium (Mg)	mg/L	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.1
Dissolved Phosphorus (P)	mg/L	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.1
Dissolved Potassium (K)	mg/L	0.4	0.4	0.5	0.5	0.4	0.4	0.5	0.5	0.5	0.1
Dissolved Sodium (Na)	mg/L	11	11	11	11	11	11	11	11	11	0.1
Dissolved Sulphur (S)	mg/L	1.4	1.3	1.3	1.5	1.4	1.2	1.3	1.4	1.3	0.5

RDL=reportable detection limit, ND=non-detected, NC=non-calculable.

Table 23. Lab analysis results for feeder (upper) and discharge (lower) stream water samples.

Parameter	Unit	Sampling date and stream location								RDL
		2010-02-22		2010-05-31		2010-09-03		2010-12-20		
		upper	lower	upper	lower	upper	lower	upper	lower	
pH		5.3	5.6	5.89	5.68	5.99	6.4	5.69	4.66	N/A
Reactive Silica as SiO2	mg/L	6.4	3.7	5.6	2.9	8.4	2.2	3.3	5.3	0.5
Chloride	mg/L	87	18	48	18	27	18	16	17	1
Fluoride	mg/L	<0.1	<0.1							
Sulphate	mg/L	7	4	ND	3	ND	3	3	ND	2
Alkalinity	mg/L	<5	<5	ND	ND	ND	ND	ND	ND	5
True Color	TCU	20	20	63	17	81	8	36	63	30
Turbidity	NTU	0.4	0.7	0.4	0.9	0.5	0.5	0.8	0.4	0.1
Electrical Conductivity	umho/cm	310	72	160	70	110	71	66	73	1
Nitrate + Nitrite as N	mg/L	0.28	0.11	0.11	ND	0.09	ND	ND	ND	0.05
Nitrate as N	mg/L	0.28	0.11	0.11	ND	0.09	ND	ND	ND	0.05
Nitrite as N	mg/L	<0.05	<0.05	ND	ND	ND	ND	ND	ND	0.01
Ammonia as N	mg/L	<0.05	<0.05	ND	ND	ND	ND	ND	ND	0.05
Total Organic Carbon	mg/L	4.1	5	4.0	2.3	7.3	2.4	3.9	6.3	0.5
Ortho-Phosphate as P	mg/L	<0.01	<0.01	ND	ND	0.01	ND	ND	ND	0.01
Dissolved Sodium	mg/L	49.7	10.5	25	9.8	19	12	11	10	0.1
Dissolved Potassium	mg/L	0.6	0.4	0.51	0.36	0.73	0.51	0.91	0.49	0.1
Dissolved Calcium	mg/L	4.9	1.2	2.8	1.2	2.2	1.2	1.3	1.4	0.1
Dissolved Magnesium	mg/L	1.3	0.6	0.92	0.57	0.7	0.52	0.53	0.5	0.1
Dissolved Phosphorous	mg/L	<0.1	<0.1	ND	ND	ND	ND	ND	ND	0.1
Bicarb. Alkalinity (as CaCO3)	mg/L	<5	<5	ND	ND	ND	ND	ND	ND	5
Carb. Alkalinity (as CaCO3)	mg/L	<10	<10	ND	ND	ND	ND	ND	ND	1
Hydroxide	mg/L	<5	<5			ND	ND			1
Calculated TDS	mg/L	152	35	83	36	59	38	37	35	1
Hardness	mg/L	17.6	5.5	11	5	9	5	5	5	1
Langelier Index (@20C)	NA	-4.92	-5.17	NC	NC	NC	NC	NC	NC	
Langelier Index (@ 4C)	NA	-5.24	-5.49	NC	NC	NC	NC	NC	NC	
Saturation pH (@ 20C)	NA	10.2	10.8	NC	NC	NC	NC	NC	NC	
Saturation pH (@ 4C)	NA	10.5	11.1	NC	NC	NC	NC	NC	NC	
Anion Sum	me/L	2.62	0.6	1.35	0.580	0.770	0.570	0.510	0.480	N/A
Cation sum	me/L	2.55	0.6	1.31	0.550	1.04	0.650	0.630	0.610	N/A
% Difference/ Ion Balance (NS)	%	1.3	0.3	1.50	2.65	14.9	6.56	10.5	11.9	N/A
Dissolved Aluminum	ug/L	115	106	120	71	160	27	110	200	5
Dissolved Antimony	ug/L	<2	<2	ND	ND	ND	ND	ND	ND	1
Dissolved Arsenic	ug/L	<2	<2	ND	1	2	3	2	ND	1
Dissolved Barium	ug/L	22	8	7	8	4	5	8	7	1
Dissolved Beryllium	ug/L	<2	<2	ND	ND	ND	ND	ND	ND	1
Dissolved Bismuth	ug/L	<2	<2	ND	ND	ND	ND	ND	ND	2
Dissolved Boron	ug/L	<5	<5	7	5	6	5	6	5	5
Dissolved Cadmium	ug/L	<0.3	<0.3	ND	ND	0.05	0.02	0.09	0.03	0.02
Dissolved Chromium	ug/L	<2	<2	ND	ND	ND	ND	ND	ND	1
Dissolved Cobalt	ug/L	<1	<1	ND	ND	ND	ND	ND	ND	0.4
Dissolved Copper	ug/L	<2	<2	ND	ND	4	ND	ND	ND	2
Dissolved Iron	ug/L	53	76	350	71	370	55	240	270	50
Dissolved Lead	ug/L	<0.5	<0.5	ND	ND	1.1	ND	0.6	ND	0.5
Dissolved Manganese	ug/L	126	64	28	22	43	85	91	87	2
Dissolved Molybdenum	ug/L	<2	<2	ND	ND	ND	ND	ND	ND	2
Dissolved Nickel	ug/L	<2	<2	ND	ND	ND	ND	ND	ND	2
Dissolved Selenium	ug/L	<2	<2	ND	ND	1	ND	ND	ND	1
Dissolved Silver	ug/L	<0.5	<0.5	ND	ND	ND	ND	ND	ND	0.1
Dissolved Strontium	ug/L	26	7	13	7	10	7	7	7	2
Dissolved Thallium	ug/L	<0.1	<0.1	ND	ND	ND	ND	ND	ND	0.1
Dissolved Tin	ug/L	<2	<2	ND	ND	ND	ND	ND	ND	2
Dissolved Titanium	ug/L	<2	<2	ND	ND	2	ND	ND	ND	2
Dissolved Uranium	ug/L	<0.1	<0.1	0.2	ND	0.3	ND	0.1	0.2	0.1
Dissolved Vanadium	ug/L	<2	<2	ND	ND	ND	ND	ND	ND	2
Dissolved Zinc	ug/L	10	5	6	6	11	7	11	9	5

RDL=reportable detection limit, ND=non-detected, NC=non-calculable.

Table 24. Lab analysis results for feeder (upper) and discharge (lower) stream water samples.

Parameter	Unit	Sampling date and stream location						RDL
		2011-02-23		2011-04-15		19-09-2011 8:30		
		upper	lower	upper	lower	upper	lower	
pH		5.31	5.46	5.40	5.58	5.67	5.78	N/A
Reactive Silica as SiO2	mg/L	6.3	3.9	4.2	3.2	7.6	2.0	0.5
Chloride	mg/L	50	16	27	17	19	14	1
Fluoride	mg/L							
Sulphate	mg/L	4	3	ND	5	ND	3	2
Alkalinity	mg/L	ND	ND	ND	ND	7	ND	5
True Color	TCU	25	25	74	24	160	30	30
Turbidity	NTU	0.1	0.4	0.8	0.7	2.6	0.3	0.1
Electrical Conductivity	umho/cm	190	66	100	64	71	54	1
Nitrate + Nitrite as N	mg/L	0.08	0.05	ND	ND	0.08	ND	0.05
Nitrate as N	mg/L	0.08	0.05	ND	ND	0.08	ND	0.05
Nitrite as N	mg/L	ND	ND	ND	ND	ND	ND	0.01
Ammonia as N	mg/L	ND	ND	ND	ND	ND	ND	0.05
Total Organic Carbon	mg/L	2.7	3.3	6.8	3.5	12	5.0	0.5
Ortho-Phosphate as P	mg/L	ND	ND	ND	ND	ND	ND	0.01
Dissolved Sodium	mg/L	27	8.76	16	9.63	11000	100	0.1
Dissolved Potassium	mg/L	0.52	0.42	0.52	0.43	944	100	0.1
Dissolved Calcium	mg/L	3.04	1.12	1.62	1.22	1800	100	0.1
Dissolved Magnesium	mg/L	0.98	0.64	0.51	0.57	614	100	0.1
Dissolved Phosphorous	mg/L	ND	ND	ND	ND	ND	100	0.1
Bicarb. Alkalinity (as CaCO3)	mg/L	ND	ND	ND	ND	7	ND	5
Carb. Alkalinity (as CaCO3)	mg/L	ND	ND	ND	ND	ND	ND	1
Hydroxide	mg/L							1
Calculated TDS	mg/L	92	34	50	37	47	29	1
Hardness	mg/L	12	5	6	5	7	5	1
Langelier Index (@20C)	NA	NC	NC	NC	NC	-4.53	NC	
Langelier Index (@ 4C)	NA	NC	NC	NC	NC	-4.78	NC	
Saturation pH (@ 20C)	NA	NC	NC	NC	NC	10.2	NC	
Saturation pH (@ 4C)	NA	NC	NC	NC	NC	10.5	NC	
Anion Sum	me/L	1.49	0.500	0.760	0.570	0.680	0.450	N/A
Cation sum	me/L	1.43	0.510	0.850	0.550	0.690	0.450	N/A
% Difference/ Ion Balance (NS)	%	2.05	0.990	5.59	1.79	0.730	0	N/A
Dissolved Aluminum	ug/L	151	155	254	129	322	5.0	5
Dissolved Antimony	ug/L	ND	ND	ND	ND	ND	1.0	1
Dissolved Arsenic	ug/L	ND	1.9	ND	1.4	1.7	1.0	1
Dissolved Barium	ug/L	11.7	8.0	7.4	8.1	5.4	1.0	1
Dissolved Beryllium	ug/L	ND	ND	ND	ND	ND	1.0	1
Dissolved Bismuth	ug/L	ND	ND	ND	ND	ND	2.0	2
Dissolved Boron	ug/L	ND	ND	ND	ND	ND	50	5
Dissolved Cadmium	ug/L	0.03	0.03	0.02	0.03	0.1	0.02	0.02
Dissolved Chromium	ug/L	ND	ND	ND	ND	ND	1.0	1
Dissolved Cobalt	ug/L	ND	ND	ND	ND	ND	0.40	0.4
Dissolved Copper	ug/L	ND	ND	ND	ND	3.8	2.0	2
Dissolved Iron	ug/L	134	217	304	182	1170	50	50
Dissolved Lead	ug/L	ND	ND	ND	ND	0.62	0.50	0.5
Dissolved Manganese	ug/L	56.5	82.0	45.7	74.9	62.0	2.0	2
Dissolved Molybdenum	ug/L	ND	ND	ND	ND	ND	2.0	2
Dissolved Nickel	ug/L	ND	ND	ND	ND	ND	2.0	2
Dissolved Selenium	ug/L	ND	ND	ND	ND	ND	1.0	1
Dissolved Silver	ug/L	ND	ND	ND	ND	ND	0.10	0.1
Dissolved Strontium	ug/L	14.8	7.5	7.4	7.2	8.4	2.0	2
Dissolved Thallium	ug/L	ND	ND	ND	ND	ND	0.10	0.1
Dissolved Tin	ug/L	ND	ND	ND	ND	ND	2.0	2
Dissolved Titanium	ug/L	ND	ND	ND	ND	2.5	2.0	2
Dissolved Uranium	ug/L	ND	ND	0.21	ND	0.40	0.10	0.1
Dissolved Vanadium	ug/L	ND	ND	ND	ND	ND	2.0	2
Dissolved Zinc	ug/L	9.5	5.8	ND	5.7	8.6	5.0	5

RDL=reportable detection limit, ND=non-detected, NC=non-calculable.

One must bear in mind that the spatial and temporal variations noted above are very subtle in most cases, and may reflect minor changes in water source and/or temperature variations. For example, the presence of iron and manganese at greater concentrations at depth with the lake during the summer are most certainly due to lower oxygen levels, and thus lower redox conditions present – warm water will dissolve less oxygen than colder water.

The current stream samples help to shed some light on the subtle variations in major ion composition noted in the lake for winter samples. This subtle change was due to a relative decrease in sodium and chloride (salt). As such, the data suggests that Hwy 103 may be having a slight influence on the water quality at Spectacle Lake.

To help better define the severity of possible affect of Hwy 103 on the Spectacle Lake water resource, one may wish to profile chloride concentrations along the feeder stream, particularly near the end of winter, to define where the boundaries of influence, if any, exist. This may help to better define land use planning needs and best forestry practices within the upper reaches of the watershed.

The piper diagram shows no significant change in major ion composition or distribution for spring, summer or fall samples as relates to either location or depth for earlier samples collected from the lake. However, the piper diagram does show a subtle change in major ion distribution in the lake for winter surface water samples, whereby the relative proportions of chloride and sodium ions decreased from east to west, and conversely, sulfate and magnesium ions increase from east to west.

The stream water samples appear to follow this same trend, where relative proportions of chloride and sodium ions are in general greater at the feeder stream than at the lake discharge stream water samples, and the relative proportion of sulfate and magnesium ions is greater at the lake discharge stream than in the feeder stream water samples.

Manganese may be binding with organics in the lake and precipitating out of solution, thus causing the concentration to decrease across the lake and in the discharge stream sample versus the feeder stream water samples. This may be partly explained by the relative concentrations for total organic carbon, which were conversely higher in the stream water samples (and also higher than in the lake water samples collected earlier – nearly double, from a range of ~2 to 3.5 mg/L for lake water samples, to 4 and 5 mg/L for stream water samples).

The differences in iron concentrations may be within the range of sample variability for the watershed system, so no clear suggestions for the slight changes in iron conclusions can be drawn from the available data.

Except for iron and manganese, the variations noted above are really not significant and may be more of academic interest than a

concern about overall water quality and/or treatment requirements.

Groundwater influences on quality:
While the discharge hydrograph suggests a large component of baseflow in the discharge from Spectacle Lake, this is not clearly apparent from the lake water chemistry. That said, the nature of the bedrock that is present within the majority of the Spectacle Lake watershed and immediately upstream of the lake is not conducive to causing significant changes to the chemical composition of rain or snow melt infiltrating through it.

A general overview of the major ion distribution over time and space suggests that the feeder stream water samples may be more representative of groundwater than the discharge stream samples. The relative drops in concentration for nearly all water quality parameters tested in the lake and the stream water samples suggests that there is dilution happening within the system from the feeder stream sampling location to the lake discharge stream sampling location.

This suggests that the feeder stream water samples may have been collected somewhere near or below a groundwater discharge point (a spring?), and that overland flow into the lower parts of the upper stream, or into the lake itself, are causing dilution of any groundwater that may be entering the lake .

Any groundwater that may be moving through and/or beneath the watershed would be doing so within one or more of three general flow regimes – within the soil and bedrock at very shallow depths (local flow regime), at slightly greater depths and primarily within bedrock (the intermediate flow regime, which may transcend surface watershed boundaries), or at much greater depths and over very long distances entirely within bedrock (regional flow regime, which can include groundwater flowing from the centre of the Province to the ocean). The residence time for each of these flow regimes becomes greater, with more time for the water to dissolve minerals along the way.

The lab results for water samples collected for this project and the flow/precipitation ratios observed from this study suggest that groundwater influence on lake water quality, if any, is likely to be from a local flow regime and perhaps marginally from the intermediate groundwater flow regime.

Water treatment requirements:
Based on the langelier index values available for three of the stream water samples, and due to the very low values obtained for alkalinity throughout the sample suite, water from Spectacle Lake is expected to be extremely corrosive. Therefore, in addition to filtration to reduce the potential for THM formation, in order to ensure the integrity of the water supply's distribution system, of customer plumbing systems, and to improve the aesthetic quality of the water, treatment should include increasing the alkalinity and pH of the source water, and decreasing the concentrations of manganese.

7. Conclusions, recommendations:

The Spectacle Lake sub-watershed has a surface area of 2,566,640m^2 and is underlain by tills and rocks of the Meguma Group (Halifax Formation, granitic rocks). A fault may be present along the length of the watershed. The watershed is 3.38 km long, less than 0.5 km wide in the north, and 1.46 km wide in the south. It ranges in elevation from 140m in the north to 32m at Spectacle Lake. Spectacle Lake has a surface area of roughly 302,069 m^2, a total shore length of 4,079 m, it is up to 18.2 m deep, and estimated to contain about 2,172,280 m^3 of water.

Field work to collect streamflow data from Spectacle Lake was done in two phases. The phase 1 field work was carried out from 09 October 2007 to 13 January 2009 and yielded 14 complete months of data. The phase 2 field work was done from 11 September 2009 to 05 December 2011 (data collection is on-going) and produced 26 complete months of streamflow data.

Based on the 40 complete months of data from phases 1 and 2, measured streamflows from Spectacle Lake were found to range from 1,172 m^3/d to 81,429 m^3/d, with baseflow contributing to an estimated 60.6% of total streamflow. Total monthly flows from Spectacle Lake ranged from about 63,175 m^3 in September 2008, to 651,152 m^3 in October 2011. Because of the baseflow, streamflow amounts exceeded precipitation amounts for some months. The mean annual (12 month) flow for the 2007-2011 period of phase 1 and 2 data collection was 2,888,789 m^3.

The long-term synthetic flow constructed for Spectacle Lake from the LaHave River has benefited slightly from the 40 month period of record obtained after phase 2, as opposed to the shorter record available from phase 1 alone. However, the it does not quite model Spectacle Lake watershed precisely, in that it appears to overestimate streamflows in the mid-to-high ranges, and underestimate streamflows in the lower ranges. The level of over or under-estimation cannot be easily quantified, so caution must be used when applying the synthetic flow model for predictions at Spectacle Lake.

Short-term (from measured field data) and long-term (from the synthetic streamflow record) duration curves suggest median withdrawal allocations based on 95% exceedance frequency flow values of 1,475 m^3/d, which may be increased to 1,960 m^3/d with water storage and controlled discharge from the lake.

Assuming an average consumption rate of 450 L per person per day, this represents capacity for Spectacle Lake to meet water demand for 2,100 to 2,850 persons using a 1.5x safety factor, or for 1,600 to 2,150 people when applying a 2x safety factor (all median values assuming 95% and 90% flow exceedances).

Depending upon the water taking regime, the water storage needed at Spectacle Lake to allow proper discharge flow maintenance would require about 36 to 48 cm of water level change at the lake. This may be

accomplished by repair or replacement of the existing water control structure at the base of the lake, plus construction of a low berm along parts of the lake's southeast shore.

The relatively small incremental amount of storage needed and resulting change in lake area are not expected to trigger an environmental assessment, although a water withdrawal permit would be required.

Water from Spectacle Lake is classed as a very soft, sodium-chloride type water with low TDS, low pH, and extremely low alkalinity. The water meets the GCDWQ (2007) for all parameters tested except pH, iron in one sample, and manganese in most water samples. Water color and the THM formation potential are also quite high and would also require treatment. Aluminum may become a concern depending upon the method of water treatment used.

Recommendations for follow-up work

The phase 1 report provided a number of recommendations, some of which have already been carried out. However, some may not have been fully completed, so to avoid the reader having to refer to two reports, many of the phase 1 recommendations are again provided here along with ones that stem from the more recent phase 2 work.

Phase 2 of this study further establishes and supports the capacity for Spectacle Lake to serve as possible water supply for the Village of Chester. However, baseflow appears to be a large component of total streamflow at the lake discharge channel. Related, perhaps, is the synthetic streamflow model developed for this project does not appear to represent the Spectacle Lake watershed as precisely as it perhaps should. Therefore, we recommend that monitoring of channel streamflows and lake water levels be continued so as to build a proper, true, longer-term hydrologic record for the Spectacle Lake watershed.

Because of the interference by beaver and human activities at the outfall channel, the lake gauging station should now be viewed as the primary gauging station. Streamflow readings from the channel should be used to help verify and augment this data, and serve as source for data correction should there be any data drift over time.

Further to the above, the lake gauging station should be made more permanent – perhaps by way of a wet well at the lake shore. Such a wet well could be built using concrete crocks placed near the current stream gauge station for better ease of access for both construction equipment and possible year-round access.

In addition to improving the quality of data, efforts should undertaken towards ensuring the security of water supply with regard to:

1) defining possible land purchases and/or policy development options to control land use within the watershed, and
2) identifying the possible issues related to increasing lake levels to ensure that there can be adequate and safe lake storage for a proper water supply.

In this regard, we make the following two sets of recommendations.

Data-related recommendations:

- Before proceeding with any significant amount of engineering design, carry out watershed, streamflow routing and reservoir modelling using proven software programming (such as the US Corps of Engineers HEC-HMS and HEC-ResSim packages) to better:
  - characterize Spectacle Lake generally as a water supply and reservoir as regards meeting supply demand,
  - review reservoir control options and do flood forecasting to assess safe and sound reservoir structure operating options and conditions,
  - evaluate the effects of reservoir storage on existing discharge below the lake,
  - review and assess options for possible emergency drainage should reservoir overtopping be viewed and accepted as a severe flood control measure,
  - characterize such possible emergency flood drainage in terms of streamflow severity, duration, flood risks, and downstream protective infrastructure needs to mitigate possible risks.
- Continue to collect water samples for laboratory analysis (general chemistry, metals), perhaps twice yearly, from the feeder and discharge streams above and below the lake, in a continued effort to define long-term and seasonal water characteristics with regards to future treatment needs.
- Do a couple of water quality sampling suites up the lake feeder channel to better define the water quality profile as may relate to either groundwater influences and/or Hwy 103 affects.
- In an attempt to isolate surface waters from groundwater (baseflow), check levels and flow rates at the stream above Spectacle lake to assess overall flows (does the stream go dry during summer, does it flow perpetually?) and to target possible times to collect water samples to help better define groundwater influence (as noted above), if any, on water quality.
- Give consideration to installing and monitoring over the short-term, a temporary evaporation pan at or near the lake. This would help to better understand the overall watershed water balance and (indirectly) give more insight on the actual amounts of baseflow in Spectacle Lake discharge.
- Compile, interpret and summarize the above-noted information annually to confirm and/or correct the current understanding of the Spectacle Lake watershed hydrology.

Supply/security related recommendations:

- Conduct elevation surveys, by GPS initially, then proper surveys, of the lake shore and adjacent lands to determine what areas may become flooded as a result of raising lake water levels.

- Based on the above, determine which parcels of land along the lake shoreline to consider purchasing and/or define alternative options.
- In parallel with the above, develop a lake shoreline land purchase plan/program to protect the quality of the lake if it is to become a water supply.
- Conduct reconnaissance, and then more detailed surveys in the Highway 103 area to assess possible routes (most likely locations for vehicular accidents) for contamination into the watershed.
- Carry out general ground confirmation of the watershed boundaries and map out land ownership within the watershed, to help assess possible best options (purchase, land use polity, etc.) for protecting the watershed.
- Start to identify/define possible major, specific watershed management and protection requirements for future planning and budgeting purposes. This may include initiating contacts with the NS Department of Transport with regard to possible placement of water source protection along sections of Hwy103.
- Wherever possible, involve key landowners in mapping and/or policy development processes, with the premise that keeping them involved may enhance future levels or participation.

8. References cited:

Beard, L.R., 1967: Streamflow Synthesis for Ungaged Rivers; US Army Corps of Engineers, Hydrologic Engineering Center, publication TP-5, 30 p.

Corey, M.C., 1990: Geological Map of Chester; Nova Scotia Department of Mines and Energy Map 90-9, scale 1:50,000.

CTI, 2000: Topographic map sheet 21 A/9, Centre for Topographic Information, Natural Resources Canada, scale 1:50,000.

Gagne, R.P., 2008: Hydrological assessment report: Oakland Lake water supply withdrawal application; unpublished report prepared for the Town of Mahone Bay, 55p.

Geobase, 2004: Canadian Digital Elevation Data, 0.75 to 3 arc second resolution, Natural Resources Canada, Earth Sciences Sector, Geomatics Canada, Centre for Topographic Information, http://www.geobase.ca (resampled to 25m by 25m raster using GRASS (2011) and nearest neighbour method).

Fisher, B.E., 2006a: Version 2, 2006, Digital Version 2 (DP-ME-43) of Nova Scotia Department of Natural Resources Map-ME-2000-1, Geological Map of the Province of Nova Scotia, scale 1:500,000, compiled by J. D. Keppie, 2000.

Fisher, B.E., 2006b: Digital Version 2 (DP-ME-36) of Nova Scotia Department of Natural Resources Map ME 1992-3, Surficial Geology Map of the Province of Nova Scotia, 1:500 000, by R. R. Stea, H. Conley and Y. Brown, 1992.

GCDWQ, 2007: Guidelines for Canadian Drinking Water Quality, summary table, prepared by the Federal-Provincial-Territorial Committee on Drinking Water of the Federal-Provincial-Territorial Committee on Health and the Environment, March 2007.

GRASS, 2011: GRASS Development Team, 2011. Geographic Resources Analysis Support System (GRASS) Software. Open Source Geospatial Foundation Project. http://grass.osgeo.org.

Graves, R.M. and Finck, P.W., 1990: Till Clast and Glacial Geology of Chester, N.T.S. Sheet 21 A/09, Nova Scotia Department of Mines and Energy Map 90-4, scale 1:50,000

Keppie, J.D., 2000: Geological Map of the Province of Nova Scotia; Nova Scotia Department of Natural Resources Map-ME-2000-1, scale 1:500,000.

MRMS, 1980: Nova Scotia Watershed Areas; Maritime Resource Management Service, Amherst, Nova Scotia, digital database, scale 1:50,000.

Myron, B.F. and Jackson, B.B., 1977: Synthetic Streamflows; Water Resources Monograph Series, American Geophysical Union, second printing by McGregor & Werner Inc., Washington, D.C., 98 p.

NSDNR, 2002: Forest Landcover; digital data, Nova Scotia Department of Natural Resources, scale 1:50,000.

NSE, 2007: Active Hydrometric Stations of Nova Scotia; Nova Scotia Department of Environment and Labour, Water and Wastewater Branch, scale unknown.

O'Brien, B.H., Barrette, P.D., Kenney, D.A., Gouthro, G.F. and Palmer, S.E., 1985: Geological Map of the Mahone Bay Area, Nova Scotia; GSC Open File 1373, 1986; map sheets A and C, scale 1:25,000.

Stea, R.R., Conley, H. and Brown, Y.: Surficial Geology Map of the Province of Nova Scotia; Nova Scotia Department of Natural Resources Map ME 1992-3, scale 1:500,000

Ward, R.C., 1975: Principles of Hydrology, Second Edition; McGraw-Hill Book Co. (UK) Ltd., 367p.

Wojdyr, M., 2007: Fityk, a curve fitting and data analysis program, version 0.8.1, http://www.unipress.waw.pl/fityk/.