EXCELLENCE IN ENVIRONMENTAL CONSULTING SERVICES

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FINAL REPORT
TIER 3 WATER BUDGET
COMMUNITY OF SYDENHAM

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1. INTRODUCTION

The Tier 1 Water Budget and Water Quantity Stress Assessment Report (XCG, 2010a) for the Cataraqui Source Protection Area (CSPA) identified two subwatersheds that were flagged for Tier 2 analysis based on the percent water demand calculation. XCG was contracted by the Cataraqui Region Conservation Authority (CRCA) to conduct the Tier 2 study on the Sydenham Lake subwatershed (see Figure 1). The results of the study documented in “Tier 2 Water Budget for Sydenham Lake Subwatershed” (XCG, 2010b) again hinged on the percent water demand calculation which identified that the subwatershed was under significant stress. Preliminary evaluation of the storage available within Sydenham Lake suggested that ample water was available for supply. Discussions with the Ministry of Natural Resources (MNR) revealed similar findings for other small headwater basins with municipal supplies being drawn from lakes and that, based on the Technical Rules (MOE, 2009), a Tier 3 assessment would be required for the Community of Sydenham Water Supply. Tier 3 is formally defined in Part I.1 of the Technical Rules (2009) as follows.

> *"Tier Three" in respect of water budget means a water budget developed using computer-based three-dimensional groundwater flow models and computer-based continuous surface water flow models to assess groundwater flows and levels, surface water flows and levels and the interactions between them, and that includes the consideration of the following circumstances:*
>
> *current and future land cover within the area;*
>
> *(a) hydraulic flow controls within the area;*
>
> *(b) water taken by the surface water intakes and wells related to the area;*
>
> *(c) other uses of water within and downstream of the area;*
>
> *(d) steady and transient states in groundwater;*
>
> *(e) drought conditions*
>
> *(f) the average daily supply and demand for surface water within the area; and*
>
> *(g) average monthly supply and average monthly demand for groundwater within the area.*

The goal of the Tier 3 assessment is to determine risk by applying a complex model, estimates of water demand and professional judgment.

The Tier 3 process is quite rigorous, involving the application of complex tools, detailed peer review by MNR staff, Conservation Authority staff and outside experts. Of key importance for the completion of this project was the collaboration between municipalities, conservation authorities and MNR.

The following report focuses on the results of the Tier 3 process in support of the Assessment and makes frequent reference to the applicable rules, that is, the Technical Rules (MOE, 2009) and the Technical Bulletin (MOE, 2010).

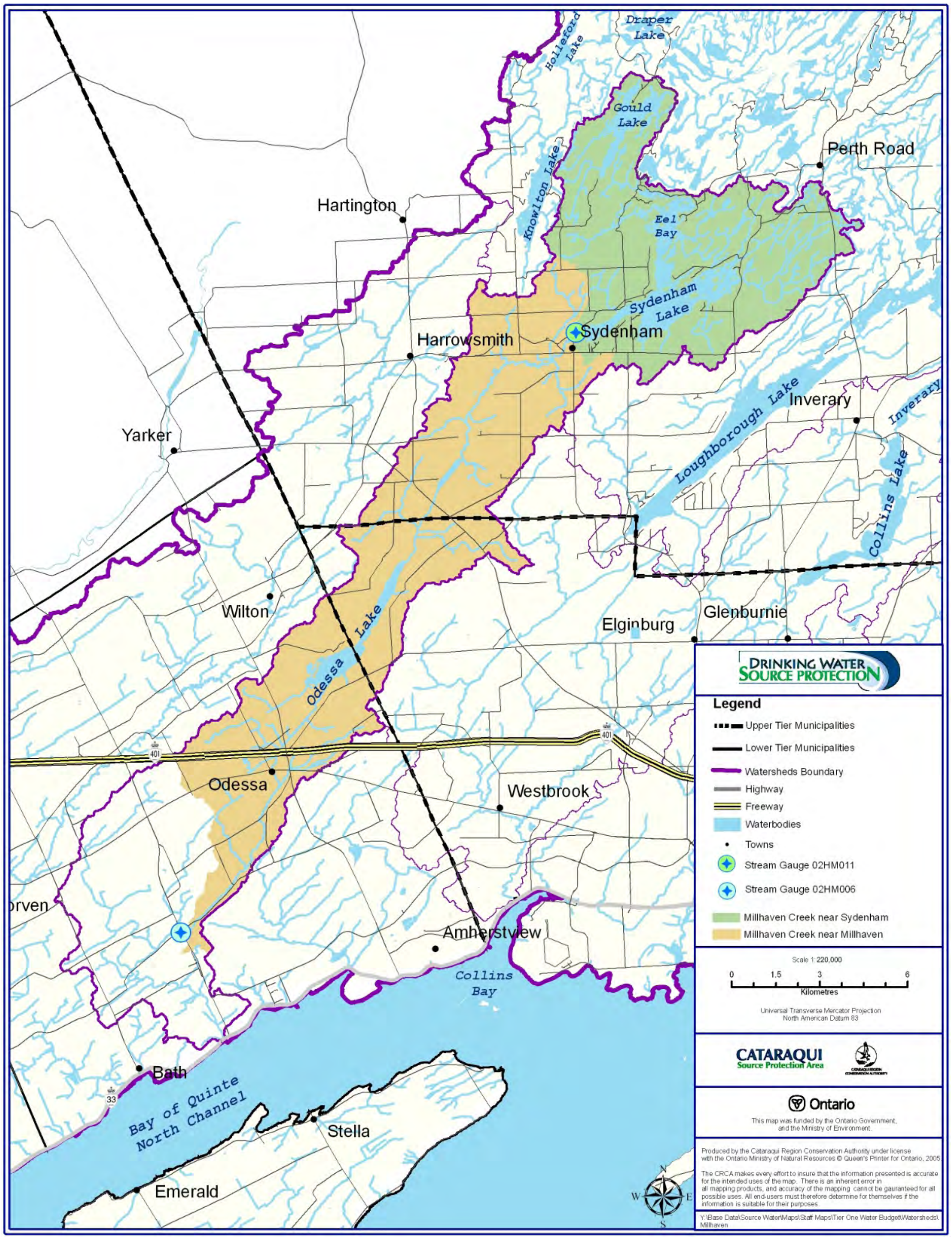


Figure 1 Sydenham Lake Subwatershed

1.1 Background

Of critical importance is to understand why, for the Tier 2 assessment, a stress level of significant was assigned. The stress level was assigned following rule 34(1) shown below.

> *34. For the purposes of rule 23 or 25, a subwatershed shall be assigned a surface water stress level of significant, moderate or low in accordance with the following:*
>
> *(1) Significant, if one or both of the following circumstances exist:*
>
> *(a) Significant scenario A or B in Table 1, the maximum monthly percent water demand for the surface water from the subwatershed would be greater than or equal to 50%.*
>
> *(b) Does not apply.*

The Technical Rules Part I.1 (MOE, 2009) state that "*the following equation shall be used where these rules require the calculation of a percent water demand in relation to surface water*":

$$\%WaterDemand = \frac{QDEMAND}{QSUPPLY - QRESERVE} \times 100$$

QDEMAND - Definition: Surface Water Consumptive Use; Calculation: Surface Water Consumptive Use is calculated as the portions of estimated monthly surface water takings in a subwatershed that is not returned to the surface water body that is the source of water taking.

QSUPPLY - Definition: Surface Water Supply; Calculation: Monthly surface water supply is calculated by determining the monthly median flow of a surface water body. Where median flow conditions cannot be determined, best available monthly baseflow measurements or estimates should be used.

QRESERVE - Definition: Surface Water Reserve; Calculation: Surface water reserve should be estimated using, as a minimum, the 10th percentile monthly median flow.

The monthly flows are estimated at the subwatershed outlet (i.e. directly downstream of the Sydenham Lake dam). Typically during the summer months the outflow is approximately zero; thus QSUPPLY and QRESERVE are zero. This occurs because the water inflow into the lake is less than the amount of water that evaporates from the lake. Over time the water level falls further and further below the top of the highest log in the dam (see Figure 2); for outflow to occur the water level must exceed the elevation of the top of the highest log. A rainfall event may cause the lake level to rise without resulting in any outflow from the dam.

Figure 2 Photos of Sydenham Lake Level in Relation to Highest Level

When QSUPPLY is zero, the percent water demand equation gives a result of infinity (see Table 1). Following Rule 34, a stress level of significant is assigned.

Table 1 Sydenham Lake Subwatershed Percent Water Demand (Tier 2)

Month	QSUPPLY (mm)	QRESERVE (mm)	QSUPPLY – QRESERVE (mm)	QDEMAND (mm)		Percent Water Demand (%)	
				Current	Future	Current	Future
Jan	28.0	10.6	17.4	0.09	0.69	1	4
Feb	24.7	8.1	16.6	0.08	0.65	0	4
Mar	77.0	30.3	46.7	0.08	0.69	0	1
Apr	84.6	52.7	31.9	0.09	0.67	0	2
May	37.0	17.8	19.2	0.1	0.7	1	4
Jun	11.3	4.2	7.1	0.11	0.68	2	10
Jul	2.5	0.0	2.5	0.1	0.71	4	28
Aug	0.0	0.0	0.0	0.11	0.71	∞	∞
Sep	0.0	0.0	0.0	0.12	0.68	∞	∞
Oct	4.1	0.0	4.1	0.12	0.7	3	17
Nov	20.4	3.0	17.4	0.12	0.67	1	4
Dec	39.7	19.8	19.9	0.12	0.69	1	3

2. LOCAL AREA DELINEATION

A Tier 3 analysis differs from Tier 1 and Tier 2 analyses in that the Tier 3 focuses on a local area rather than a subwatershed. In Part I.1 of the Technical Rules (MOE, 2009) a local area is defined as follows:

> *"local area" means,*
>
> *(a) In respect of a surface water intake, the drainage area that contributes surface water to the intake and the area that provides recharge to an aquifer that contributes groundwater discharge to the drainage area; and*
>
> *(b) is in respect of wells and hence is not applicable, in the case of Sydenham.*

In the case of the Community of Sydenham surface water supply, the local area coincides exactly with the Sydenham Lake subwatershed. This occurs as any water draining into the lake would potentially supply the intake. The surface watershed and the groundwater basin are assumed to have the same boundary because there is no evidence to the contrary (i.e., geologic features or hydrologic data). The local area is displayed in Figure 3.

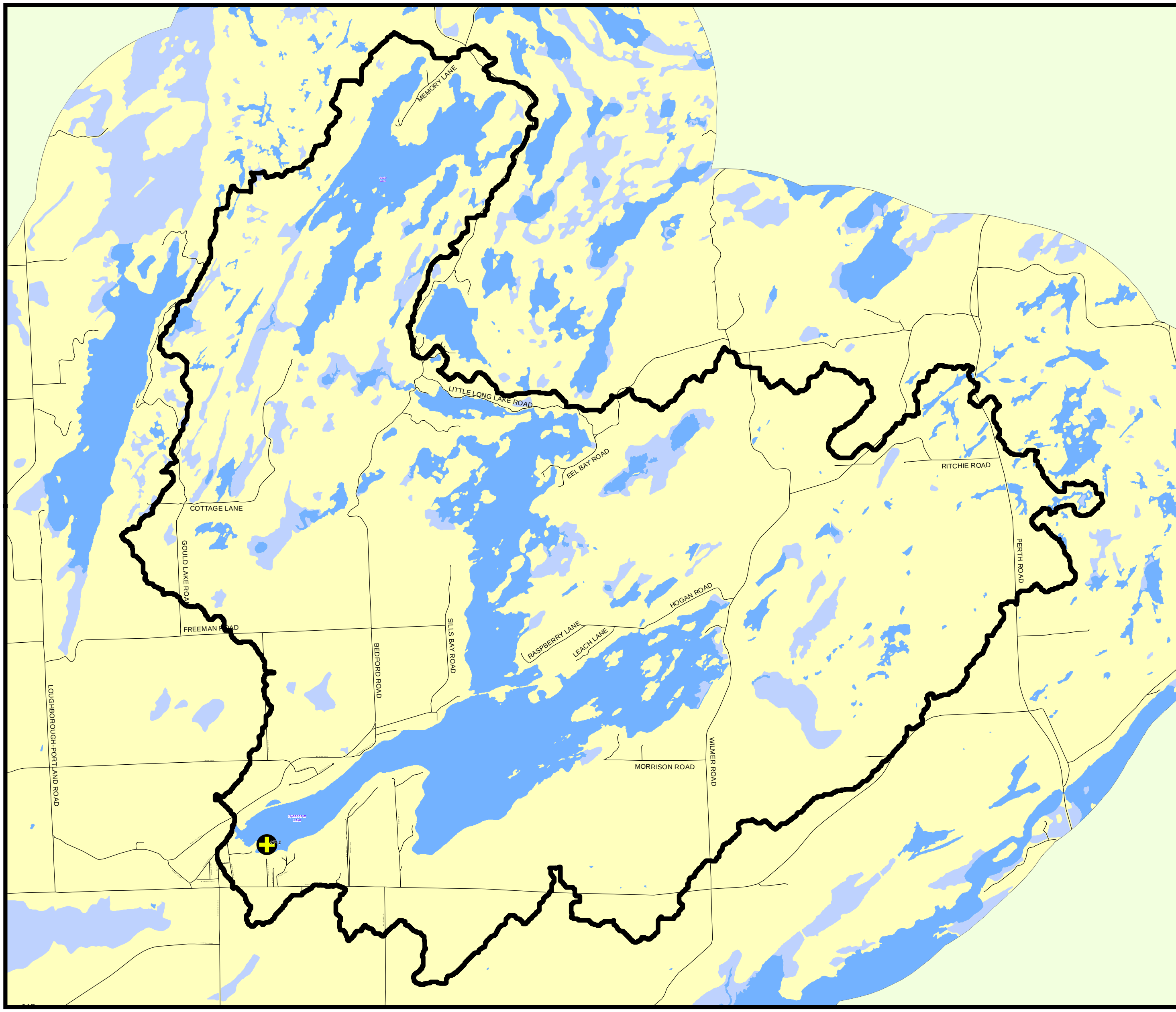
2.1 Details of the Community of Sydenham Water Supply

The Community of Sydenham is located in South Frontenac Township with the bulk of the population being located directly downstream of Sydenham Lake.

The community was historically serviced by private groundwater wells; deteriorating water quality in the groundwater led to the development of a surface water supply that draws from Sydenham Lake. The Community of Sydenham water supply was commissioned in 2006 and to date, of a possible 273 connections, 145 have connected to the water distribution system.

The intake is located in Sydenham Lake at an invert elevation of approximately 122.80 m. The intake conveys water into the wet well (invert 128.00 m). The intake pipe ties into the wet well at a centerline elevation of 128.20 m; the top of the three low lift pumps (2 duty, 1 standby) are approximately at elevation 129.6 m. It is estimated that the pumps could continue to operate with water level elevations as low as 130.00 m. Sydenham Lake water levels are maintained by regulation between 130.45 m to 131.08 m; indicating the wet well levels typically range between 2.5 – 3.0 m. All levels of interest are displayed in Figure 4.

Figure 3:
Community of Sydenham
“Local Area”



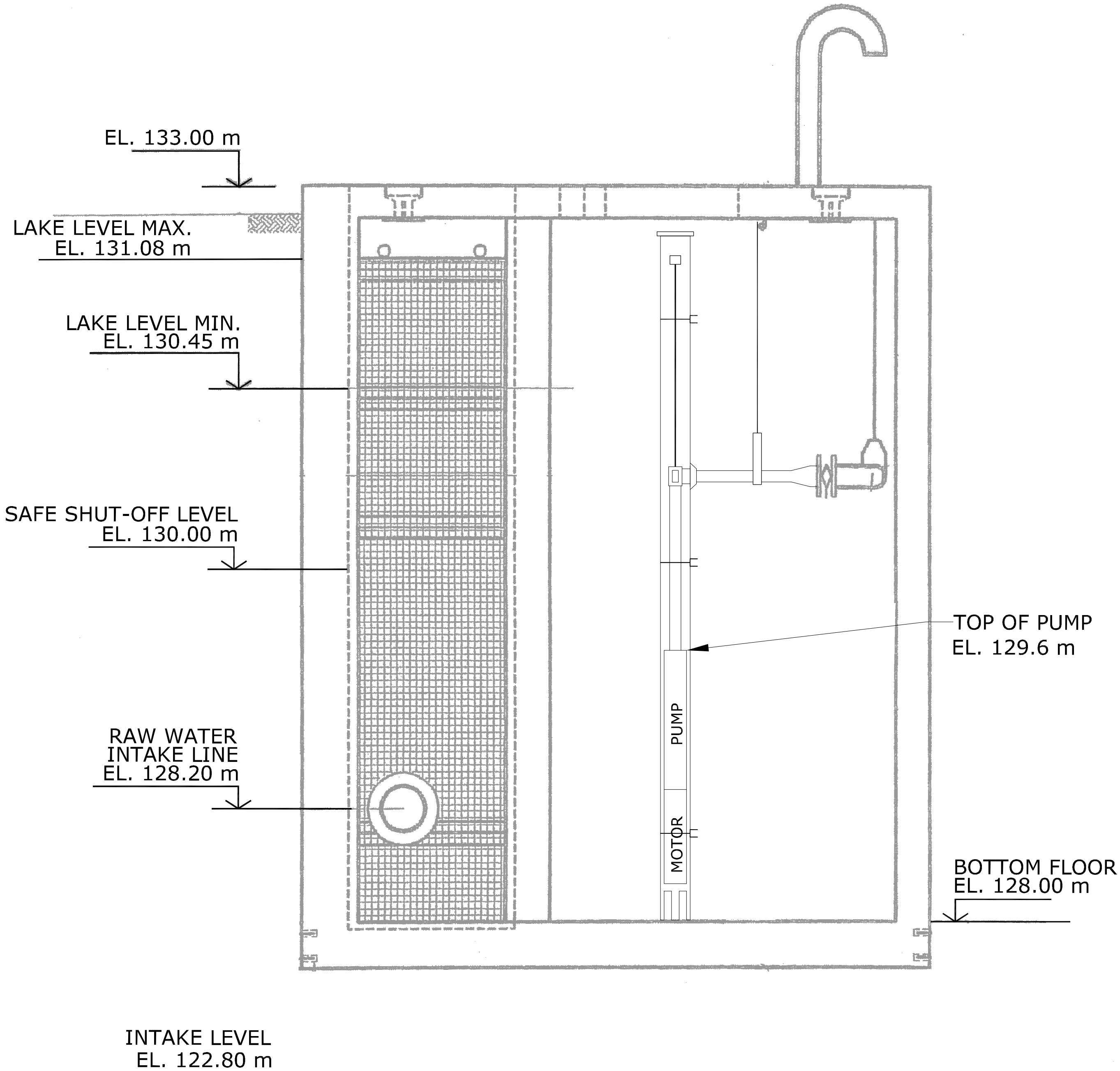
Watershed Boundary
Intake
Major Roads
Waterbodies
Wetland Area

Produced for the Cataraqui Region Conservation Authority, under license with the Ontario Ministry of Natural Resources.

N

0 500 1,000 2,000
Metres

XCG



1. Drawing information based on Sydenham WTP Upgrades 2010, XCG Consultants Ltd. Low Lift Pumping Station, Dwg. P106.

XCG
Environmental Engineers & Scientists

Project: Community of Sydenham Tier 3 Water Budget

Title: **Water Treatment Plant Levels of interest**

Date: Jan 2011	Scale: N.T.S.
Project No: 1-1074-05-02	Drawing No:

\\xcg-king-file\projects\projects\water resources\1074 cataraqui region conservation authority\1-1074-05-02 sydenham lake tier 3\figures\sydenham wtp - low lift pump.dwg

2.2 Alternative Approach for Part IX – Local Area Risk Level

Technical Bulletin: Part IX Local Area Risk Level (MOE, 2010) provides an alternative method for the assessment and assignment of a risk level to a local area. Before this method is applied Technical Rule 15.1 must be satisfied (see below).

> *15.1 Despite any provision of these rules, in preparing an assessment report a source protection committee may use an alternate method or approach for gathering information or for performing a task that departs from the method or approach prescribed in these rules if the following conditions are met:*
>
> *(1) The assessment report includes,*
>
> *(a) a rationale for the departure; and*
>
> *(b) an explanation of how the method or approach used by the source protection committee to gather information or perform the task is equivalent to or better than the approach or method prescribed in these rules.*
>
> *(2) The Director has provided the source protection committee with written confirmation that he or she agrees to the departure and a copy of the confirmation is included in the assessment report.*

The rationale for the use of the method and the explanation of how the method is equivalent or better than that in the Technical Rules (MOE, 2009) is detailed in the Technical Bulletin mentioned above. Director approval has been given for the application of the method outlined in the Technical Bulletin.

3. TASK 1: EVALUATION OF RISK LEVEL

3.1 Overview

The relevant sections of the Technical Bulletin (MOE, 2010) are provided below.

> *(1) A risk level must be assigned to every local area required to be delineated in accordance with Part III of the Technical Rules. The risk level must be assigned by:*
>
> - *evaluating the scenarios developed in the water budget models for the Tier 3 of the WQnRA, and described in Tables 4A and 4B which are provided below in this Technical Bulletin*
> - *for each scenario, evaluating the circumstances in Tables 4C and 4D which are provided below in this Technical Bulletin.*
>
> *Tables 4A and 4B describe respectively the Surface Water and the Groundwater Risk Scenarios. For each assessment Scenario, the Tables provide the time period for the assessment, as well as requirements for land cover, municipal allocated pumping rate, non-municipal pumping rates and model simulation approach.*
>
> *Tables 4C and 4D provide the Circumstances to be taken into account for each Scenario to assign significant or moderate Risk, for each type of drinking water system.*

> *The models used in Part III of the Technical Rules to prepare the water budget for the local area shall be used to assess the scenarios described in Task 3.*

The Community of Sydenham Intake local area is fully encompassed in the Sydenham Lake Subwatershed Tier 2 HSPF model. Details of model selection and calibration can be found in Appendix A.

Technical Bulletin Tables 4A and 4C, which apply to the surface water assessment are reproduced below as Table 2 and Table 3.

Table 2 Surface Water Risk Scenarios (Table 4A)

Scenario	Time Period	Surface Water Model Scenarios				
		Land Cover	**Allocated Pumping Rate (municipal)**	**Pumping Rate (non-municipal)**	**Model Simulation**	
A	The period for which climate and stream flow data are available for the local area	Existing	Existing	Existing	Continuous (Daily); Monthly pumping	
B	2/10 year drought period	Existing	Existing	Existing	Continuous (Daily); Monthly pumping	
E(1)	The period for which climate and stream flow data are available for the local area	Land cover reflective of the planned or existing plus committed (Official Plan)	Existing plus committed plus planned	Future	New impervious areas and Increase in Total Demand	Continuous (Daily); Monthly Pumping
E(2)		Existing	Existing plus committed plus planned	Existing	Increase in Municipal Demand	
E(3)		Land cover reflective of the planned or existing plus committed (Official Plan)	Existing	Future	New Impervious Areas and Increase in Non-Municipal Demand	
F(1)	2/10 year drought period	Land cover reflective of the planned or existing plus committed (Official Plan)	Existing plus committed plus planned	Future	New impervious areas and Increase in Total Demand	Continuous (Daily); Monthly pumping
F(2)	2/10 year drought period	Existing	Existing plus committed plus planned	Existing	Increase in Municipal Demand	
F(3)	2/10 year drought period	Land cover reflective of the planned or existing plus committed (Official Plan)	Existing	Future	New Impervious Areas and Increase in Non-Municipal Demand	

Table 3 Risk Scenarios and Circumstances – Surface Water (Table 4C)

Local Area – Significant Risk		
Type of System	**Scenarios**	**Circumstances**
Surface Water One or More	A- Existing – average annual B- Existing – 2/10 year drought	a) the quantity of water that could have been taken from surface water bodies in the local area would not have been sufficient to meet the allocated quantity of water taken by those municipal surface water intakes. b) the quantity of water that could have been taken from surface water bodies in the local area would have been sufficient to meet the allocated quantity of water taken by those municipal surface water intakes and the tolerance is Low.
Surface Water One or More	E- Planned system or existing system with committed demand – average annual	a) the quantity of water that can be taken from surface water bodies in the local area would not be sufficient to meet the allocated quantity of water for those municipal surface water intakes. b) the quantity of water that can be taken from surface water bodies in the local area would be sufficient to meet the allocated quantity of water for those municipal surface water intakes and one or more of the following circumstance exists: (i) the reduction in existing surface water levels and/or flows results, in response to the allocated pumping rates, in unacceptable impacts to existing regulated water levels and/or flows or permits. (ii) the reduction in existing surface water levels and/or flows results, in response to the allocated pumping rates, in unacceptable impacts to aquatic habitat and provincially significant wetlands. (iii) the reduction in existing groundwater levels and/or flows results, in response to the allocated pumping rates, in unacceptable impacts to provincially significant wetlands.
Surface Water One or More	F- Planned system or existing system with committed demand – 2/10 year drought	a) the quantity of water that can be taken from surface water bodies in the local area would not be sufficient to meet the allocated quantity of water for those municipal surface water intakes.
Local Area – Moderate Risk		
Surface Water One or More	E - Planned system or existing system with committed demand – average annual	a) the quantity of water that can be taken from surface water bodies in the local area would be sufficient to meet the allocated quantity of water for those municipal surface water intakes and one or more of the following circumstance exists: (i) the reduction in existing surface water flows and/or levels results, in response to the allocated pumping rates, in measurable and potentially unacceptable impacts to existing regulated water levels and/or flows or permits. (ii) the reduction in existing surface water levels and/or flows results, in response to the allocated pumping rates, in measurable and potentially unacceptable impacts to aquatic habitat and provincially significant wetlands. (iii) the reduction in existing groundwater levels and/or flows results, in response to the allocated pumping rates, in unacceptable impacts to provincially significant wetlands.

Part I.1 of the Technical Rules (MOE, 2009) sets out some definitions to assist in the interpretation of the scenario requirements shown in Table 2 and Table 3.

> *"ten year drought period" means the continuous ten year period for which precipitation records exist with the lowest mean annual precipitation;*
>
> *"two year drought period" means,*
>
> *(a) In relation to an assessment of surface water quantity, the continuous two year period for which precipitation records exist with the lowest mean annual precipitation; and*
>
> *(b) Not applicable.*
>
> *"study year" means the calendar year immediately before the year in which the most recent terms of reference related to the source protection area was required to be submitted to the Minister in accordance with section 10 of the Act.*

With regard to the Technical Rules, the water demands in general can be split into two distinct categories 1) "water users" and 2) "water uses". "Water users" include all anthropogenic takings that are consumptive in nature and typically include permitted, domestic and agricultural takings. Demand from all "water users" must be representative of the "study year" (defined above); ideally these values are based on physical measurements or reasonable estimates. "Water uses" typically require minimum water level or in-stream flow requirements (i.e., navigation and wastewater assimilation; in the case of controlled systems these "water uses" are typically incorporated into the operational rule curve of the structure).

3.2 Assessment of Circumstances

> *(2) For the purposes of assessing the circumstances described in Tasks 2 and 3 below:*
>
> *(A) the time period to be assessed is the time period described in Column 2 of Tables 4A and 4B; and*
>
> *(B) the data used shall meet the requirements listed in Columns 3 and 4 of Tables 4A and 4B where one or more parameters in respect of the data are listed, and in all other cases the data shall be reflective of conditions that existed during the time period.*

The climate data used for the simulations was from the in-filled Hartington climate station provided by MNR. The available period of record for this in-filled climate station was from 1950 – 2005. For scenarios A and E (1 – 3) the entire period of record was applied; for scenarios B and F (1 – 3) the two year drought period was from 1963 – 1964 and the ten year drought period was from 1958 – 1967.

The Technical Bulletin requires that change in land cover be considered in the simulations. For the Community of Sydenham Local Area, the bulk of existing development is located downstream of Sydenham Lake. New developments are expected to occur in and around the existing community. As such, it is not anticipated that there will be a significant increase in impervious area or a significant conversion of existing land cover upstream of Sydenham Lake. Therefore, the land cover was modelled as existing conditions for all scenarios (A – F).

As described in Section 3.1, "water users" include permitted, domestic and agricultural demands. In the local area of the Community of Sydenham, the only consumptive permitted demand is the Sydenham WTP. Discussions with Source Protection Committee members throughout the water budgeting process have revealed that the bulk of the domestic and agricultural water users obtain water from groundwater resources. While there are certainly some shore wells located along the shorelines of the lakes (Sydenham Lake, Gould Lake, Long Lake, etc.) the associated takings have been assumed to be negligible in comparison to the municipal demand. This assumption is justified in that the Community of Sydenham is the most densely populated section of the local area and that the use at Community of Sydenham is 100% consumptive (i.e., no water is returned to Sydenham Lake).

Based on the above discussion, the only substantial demand in the local area is the existing municipal water treatment plant. Representative use for the "study year" was estimated as the actual pumping values recorded for 2008 at the Community of Sydenham WTP. The monthly average pumping rates are summarized in Table 4.

Table 4 2008 Municipal Demand

Month	2008 Average Day Flow (m^3/day)	2008 Max Daily Flow (m^3/day)	2008 Peak Daily Flow (L/min)
January	174	444	1031
February	152	420	1052
March	151	474	948
April	171	547	1199
May	172	484	1139
June	192	649	1263
July	169	465	1197
August	182	515	1193
September	205	577	1145
October	210	465	1130
November	221	484	1217
December	215	463	1086

Scenarios E (1 – 3) & F (1 – 3) require that risk scenario be evaluated using "existing plus committed demand". The "existing plus committed demand" can be defined as the amount of water that has been officially approved by the municipality and will be built out in the near term. The "existing plus committed demand" does not include long-term projections but rather on the books demand.

Estimating the "existing plus committed demand" for the Sydenham WTP poses some difficulty as the plant is relatively new (brought online in 2006) and the timeline to get residents hooked up to the system is unknown (currently, there is no existing by-law that forces residents to hook up to the municipal water system). In total there are 273 possible connections of which only 145 are currently in use. The low number of connections results in a water demand from the system that is small relative to the available capacity. Low use requires that significant amounts of water be bled from the system in order to maintain residual chlorine levels. This results in artificially inflated demand when evaluating the existing connections and makes the existing use values unreliable for estimating "existing plus committed demand".

Based on the above, the "existing plus committed demand" was based on the flow estimates used for the design of the WTP. The WTP system was designed to service an existing population of 940 and to ultimately service 1,147 over a 20-year time frame. Since the inception of the plant the population of the community of Sydenham remains relatively unchanged (i.e., population = 940). Following this, the municipality has committed to service an existing population of 940; the time frame in which these 940 will receive service is unknown (see above). A review of on the books development revealed that there are no proposed developments that would fall within the existing service area. The "Community of Sydenham Water Treatment System Pre-design Report" by TSH (April, 2003) tabulated the design flows for a population of 940 (replicated below, see Table 5). The "existing plus committed demand" for the 940 people is 423 m^3/day.

Table 5 Community Water Demand

Design Period	Equivalent Population (Capita)	Average Day (m^3/day)	Maximum Day (m^3/day)	Maximum Hour (m^3/hour)
Existing	940	423	1,058	66
2010	1,039	468	1,169	73
2020	1,147	516	1,290	81
* Population estimates are based on a 1 %/year growth rate				
Source: Community of Sydenham Water Treatment System Pre-design report by TSH (April, 2003)				

It should be noted that there are no other planned municipal systems in the Community of Sydenham local area.

3.3 *Other Uses of Water*

In common with the Tier 1 and Tier 2 water budgets there is a need to estimate the water demand in the local area. The Technical Bulletin provides further clarification for other uses of water in the local area.

(A)	*with respect to surface water,*
	(a) wastewater assimilation,
	(b) surface water takings downstream of the intake or intakes,
	(c) electric power generation,
	(d) navigation,
	(e) recreation,
	(f) aquatic habitat, and
	(g) provincially significant wetlands; and
(B)	*refers to groundwater and hence is not applicable for Sydenham.*

With regard to (A), the Community of Sydenham Intake local area is not subject to (a), (b) or (c).

Existing requirements for "water uses" are currently incorporated in the operational rule curve (see Section 3.3.1). It should be noted that the "water users" (i.e., the Sydenham WTP) are not incorporated into the operational rule curve; however, the water levels maintained by the operational rule curve exceed the minimum level required for the WTP.

3.3.1 Operational Rule Curve

The CRCA took possession of the Sydenham Lake Dam in 1976 and completed reconstruction to its current form in 1979. When the dam was turned over to the CRCA, it was agreed that the lake elevations would be adjusted from a minimum level of 130.45 m to a maximum level of 131.08 m. A concession was also made that under times of flood or severe drought that the levels could fall outside the minimum and maximum ranges.

As time progressed, the CRCA worked with local interest groups to refine the operating curve objectives. These objectives included flood control, habitat protection, navigation and recreation. The minimum, maximum and 'objective' levels over the year are shown in Figure 5.

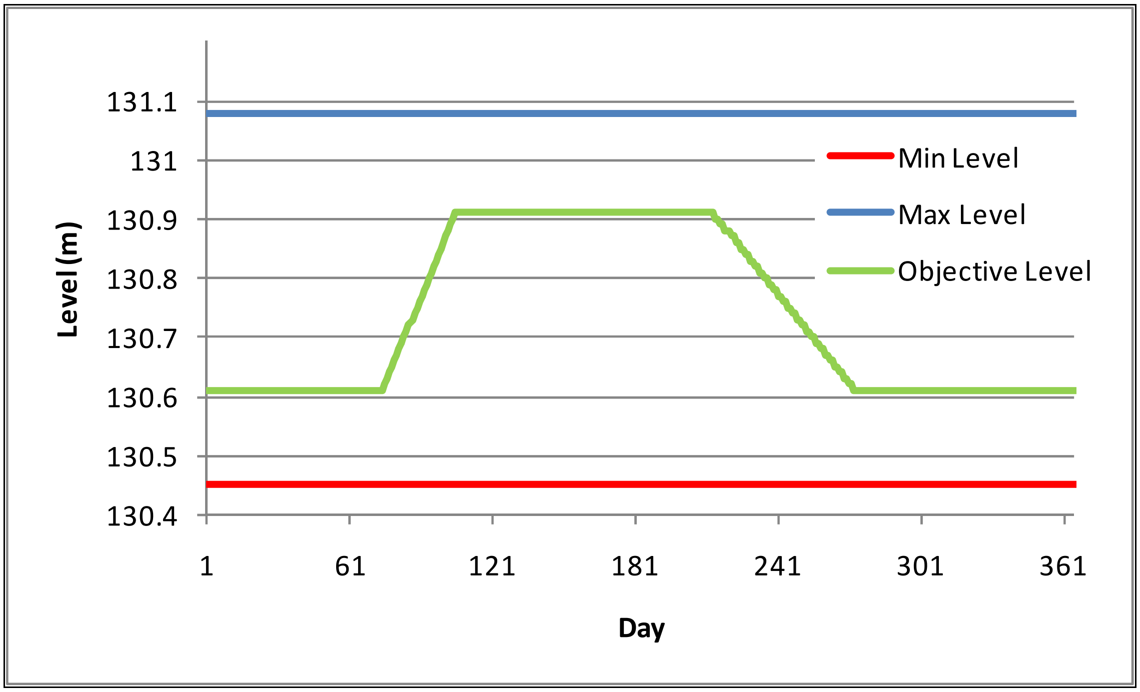


Figure 5 Sydenham Lake Dam Operating Levels

From the end of September to mid March, the water level in Sydenham Lake is kept at a low level to assist with the spring freshet flood control. As shown in Figure 6, the level is kept approximately 150 mm above the minimum level; this higher level was set to aid in the wintering of muskrat and beaver in the northern reaches of the lake. CRCA attempts to maintain a relatively stable level throughout the winter for recreational purposes (i.e., ice fishing and snowmobiling); CRCA routinely reports ice safety conditions on Sydenham Lake. From mid March to mid April, the reservoir is filled and this level is held constant until the beginning of August for recreation and navigation. Problems with small craft navigation begin to occur when the lake level falls below 130.7 m (safe navigation can generally be expected from April to September). Levels are gradually reduced from August to the beginning of October back to the flood control level.

The objective level shown in Figure 5 is a statement of intent and significant alterations on an annual basis may be required due to hydrologic conditions. Figure 6 shows the observed water levels from 1992 – midway thru 2009 in relation to the min, max and objective levels (i.e., target levels). A review of the figure generally indicates that the Sydenham Lake level is kept higher than the objective. The maximum level is exceeded at times during the spring freshet; this occurs as there is a downstream constraint on peak flow. Levels vary significantly above the objective level from November thru January. Change in early November can likely be attributed to late season tropical storms; in some cases it is not possible to draw the lake level down before ice cover forms. When sufficient (subject to operator decision) ice formation occurs the winter setting of three logs in each bay is adopted. As long as water levels do not exceed 130.8 m, this log setting is not changed. This mode of operation is applied to maximize ice safety for recreational purposes. Other causes for higher levels for the remainder of November and December thru February can likely be attributed to rain on snow or snowmelt events that do not coincide with a typical year scenario. Of particular note is that the level has not fallen below the minimum level of 130.45 m.

Further details regarding the dam operations can be found in the "Dam Operation Manual – Sydenham Lake Dam" (CRCA, 1987).

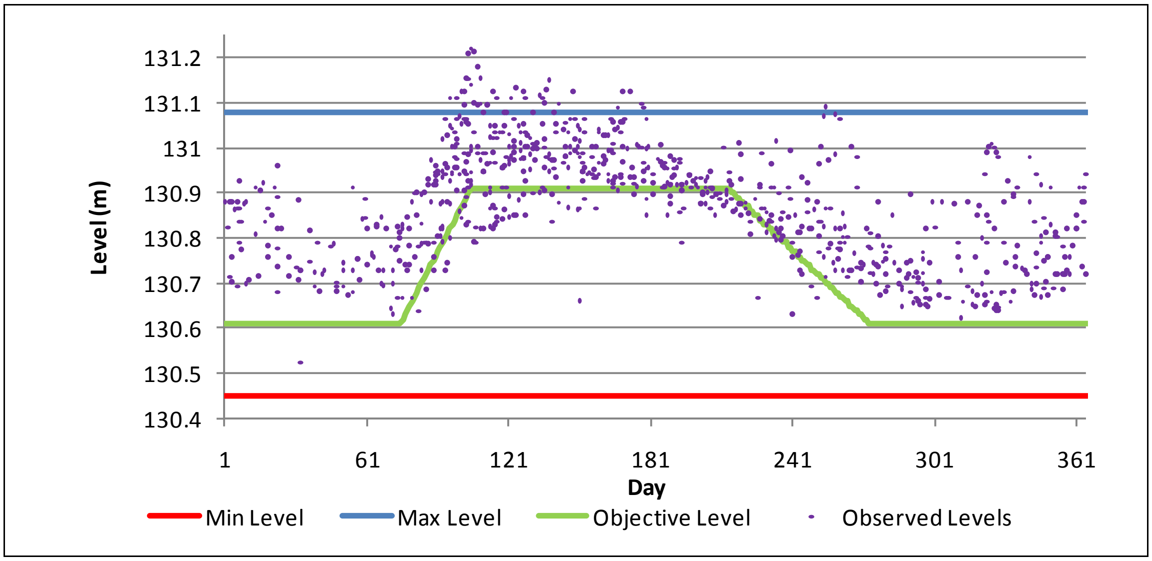


Figure 6 Comparison of Sydenham Lake Observed Levels to Target Levels

3.3.2 Application of RESCOM

RESCOM is a custom reservoir routing model developed by XCG that was applied in the Tier 2 study. The model takes inputs from HSPF and then routes them thru a reservoir depending on the log setting. RESCOM can be run in two modes 1) input time series of log setting or 2) smart setting (RESCOM chooses the log setting based on an operational curve).

Calibration of the Tier 2 HSPF and RESCOM models applied mode 1 (See Appendix A). To assess the drought scenarios for Tier 2, mode 2 was applied using an objective curve that was identical in shape to the objective level but 150 mm higher.

For application in Tier 3, an objective curve was developed to more closely represent the observed levels (see Figure 7).

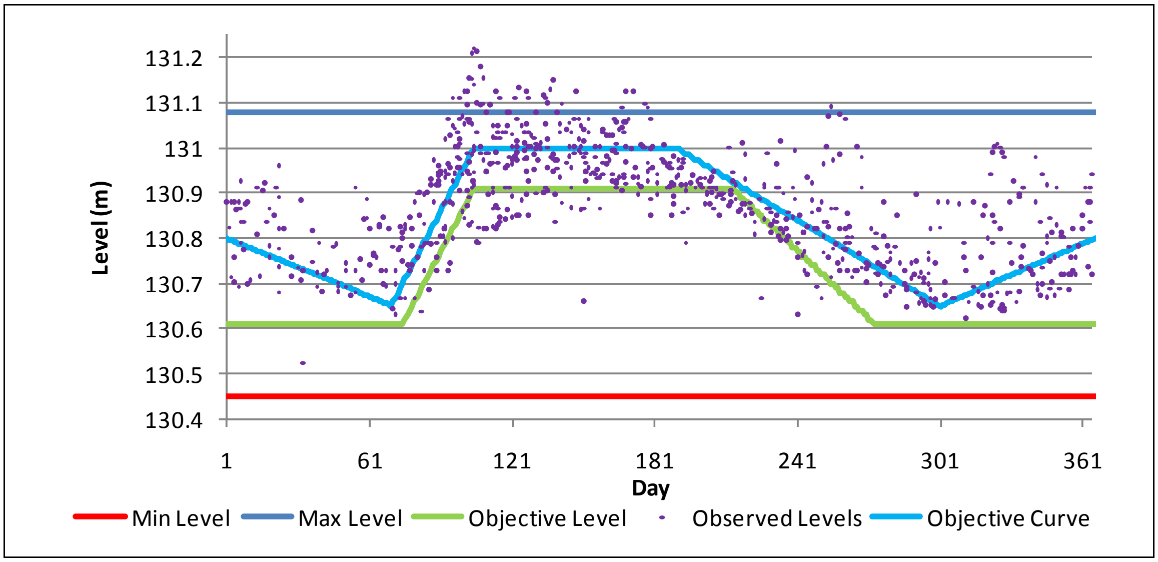


Figure 7 Objective Curve for Sydenham Lake

The HSPF simulated flows (period 1950 – 2005) were routed thru RESCOM using mode 2 and the newly developed objective curve. RESCOM makes log setting decisions once every five days with a goal of matching the objective curve independent of hydrologic conditions. In some cases, following the objective curve may not be appropriate. Two examples have been provided to demonstrate the necessity of varying from the objective curve under certain conditions.

Example 1 - Early spring freshet or little snow on the ground

Either case could result in lower water levels throughout the summer if Sydenham Lake were operated using the objective curve. In the case of an early spring freshet (i.e., before day 60), the objective curve would want the level of Sydenham Lake to decrease; there is potential that bypassing too much flow could result in the Lake not reaching summer targets (based on insufficient water to fill the storage). The corrective action in this case is to adjust the timing of the reservoir filling. Little snow on the ground would make it easy to satisfy the objective curve in the late winter but difficulty could arise in filling the reservoir for summer use. The corrective action in this case is to not decrease the water level as severely before the spring freshet.

Example 2 - Significant snow on the ground with rapid melt

This case could result in peak water levels that would significantly exceed the maximum level. Operating according to the objective curve may not draw enough water out of the reservoir in order to cope with the large volumes of spring runoff. The corrective action in this case would be to draw the water level down below the objective curve prior to the spring freshet based on a reliable weather forecast.

The initial simulated average, minimum and maximum water levels from 1950 – 2005 were calculated and are shown in Figure 8. These results were reviewed to identify any atypically high or low water levels (see the circles on Figure 8 for two examples). Atypical highs and lows were reviewed to examine the preceding hydrologic condition and the log setting chosen by RESCOM. If warranted, the log setting was modified to reflect reasonable operation that varied from the objective curve; this new log setting time series was then re-run using mode 1 of RESCOM (the final minimum, maximum and average are plotted in Figure 9).

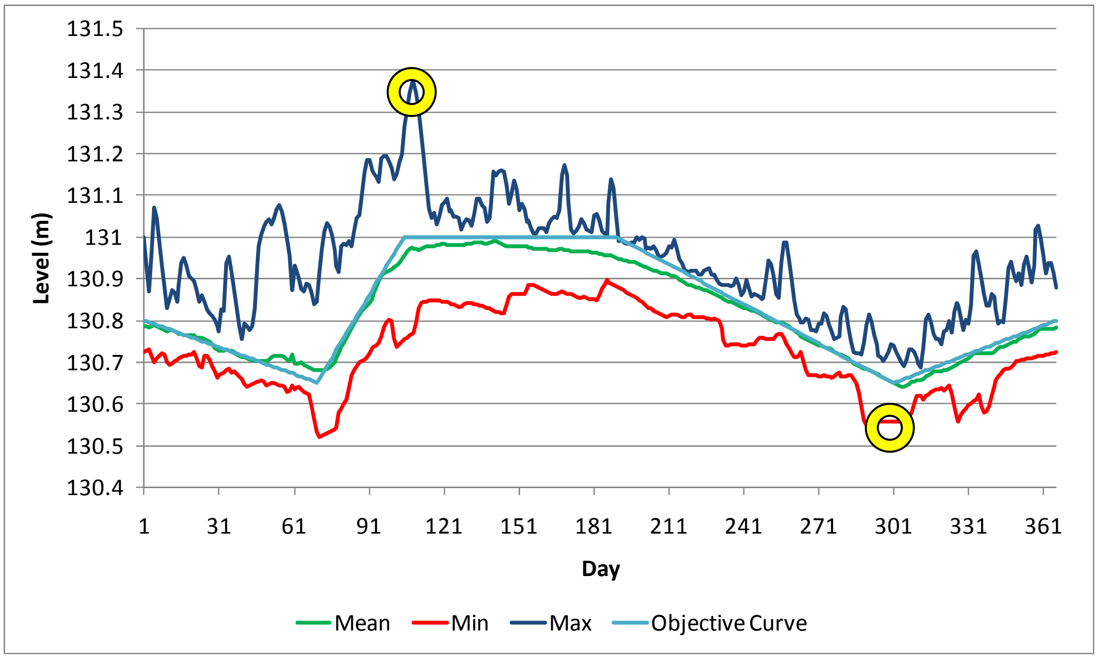


Figure 8 Long-term Simulated Water Levels – RESCOM Mode 2

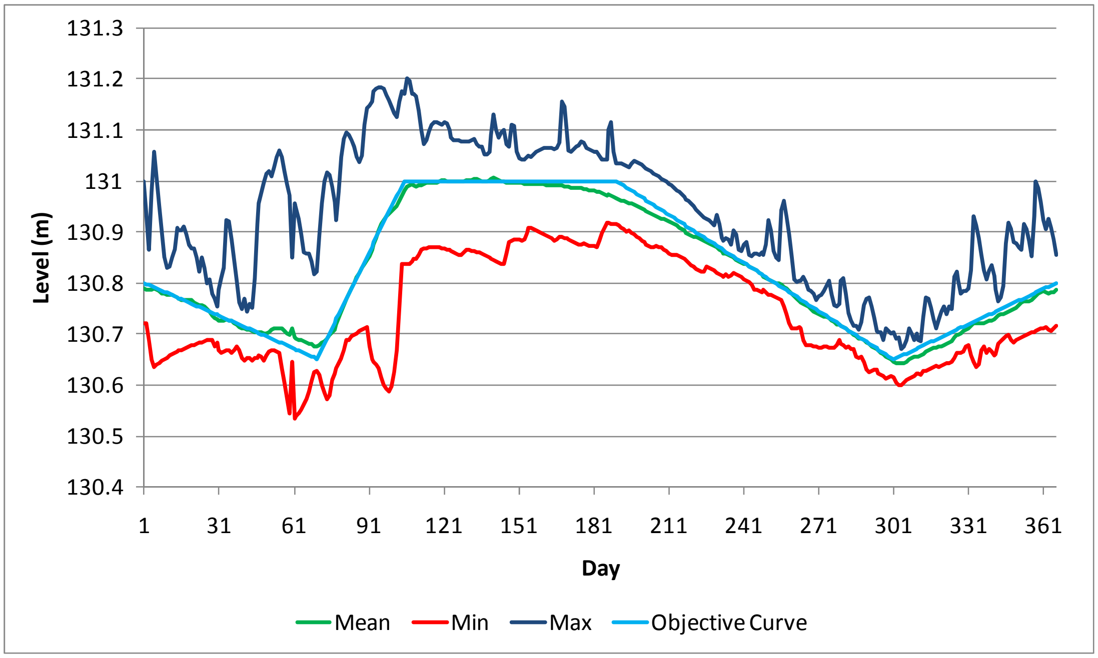


Figure 9 Long-term Simulated Water Levels – Updated RESCOM Mode 1

To further ensure that the RESCOM output generated was reasonable, the minimum, maximum and long-term average water levels were compared with observed water levels (see Figure 10). The figure supports that the log setting decisions and resultant water levels are consistent with the available water level records.

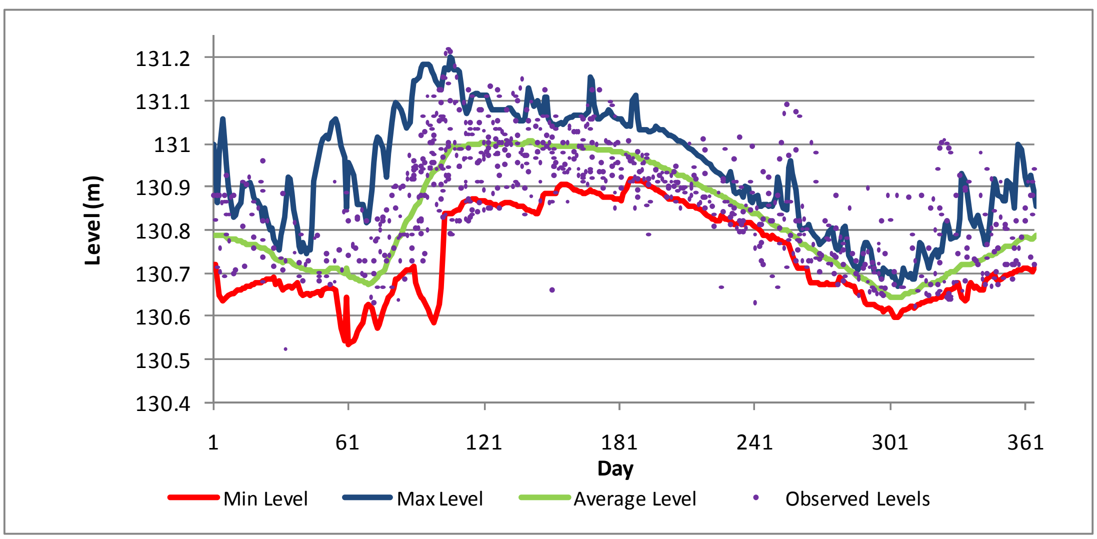


Figure 10 Comparison of Long-term Simulated to Observed Water Levels

3.4 Modelled Scenarios

The scenarios that are required to be run are outlined below in bullet form and summarized in Table 6.

Scenarios A & E3 (these two scenarios are identical for Sydenham)

The simulated streamflow and reservoir levels were based on:

- 1950 – 2005 climate inputs;
- 2008 land cover (uniformity of land cover discussed in Section 3.2); and
- continuous daily monthly pumping for existing (actual 2008) municipal water use; non-municipal takings are assumed to be zero (see Section 3.2).

Sydenham Lake water levels are compared to minimum water level (130.45 m).

Scenarios B & F3 (these two scenarios are identical for Sydenham)

The simulated stream flow and reservoir levels were based on:

- 1963 – 1964 climate inputs for two year drought and 1958 – 1967 climate inputs for ten year drought;
- 2008 land cover (uniformity of land cover discussed in Section 3.2); and
- continuous daily monthly pumping for actual 2008 municipal water use non-municipal takings are assumed to be zero (see Section 3.2).

Sydenham Lake water levels are compared to safe shut-off water level (130.00 m).

Scenarios E1 & E2 (these two scenarios are identical for Sydenham)

The simulated stream flow and reservoir levels were based on:

- 1950 – 2005 climate inputs;
- existing land cover (uniformity of land cover discussed in Section 3.2); and
- continuous daily monthly pumping for committed water demand non-municipal takings are assumed to be zero (see Section 3.2).

Sydenham Lake water levels are compared to minimum water level (130.45 m).

Scenarios F1 & F2 (these two scenarios are identical for Sydenham)

The simulated stream flow and reservoir levels were based on:

- 1963 – 1964 climate inputs for two year drought and 1958 – 1967 climate inputs for ten year drought;
- 2008 land cover (uniformity of land cover discussed in Section 3.2); and
- continuous daily monthly pumping for committed water demand non-municipal takings are assumed to be zero (see Section 3.2).

Sydenham Lake water levels are compared to safe shut-off water level (130.00 m).

Table 6 Summary of Input Data for Required Risk Scenarios

Scenario	Time Period	Land cover	Allocated Pumping Rate Municipal (m^3/day)	Allocated Pumping Rate Non-Municipal (m^3/day)	Comparison Level (m)
A	1950 - 2005	Existing[1] (2008)	Actual[2]	0[4]	130.45[5]
B	2 yr (1963-1964) 10 yr (1958-1967)				130.00[6]
E1	1950 - 2005		423[3]		130.45[5]
E2					
E3			Actual[2]		
F1	2 yr (1963-1964) 10 yr (1958-1967)		423[3]		130.00[6]
F2					
F3			Actual[2]		

Notes:
1. Land cover remains the same for all scenarios see Section 3.2
2. Actual takings from Utilities Kingston for 2008 calendar year
3. See committed demand; Section 3.2
4. See unpermitted demand; Section 3.2
5. Minimum level as defined by CRCA
6. Safe shut-off water level

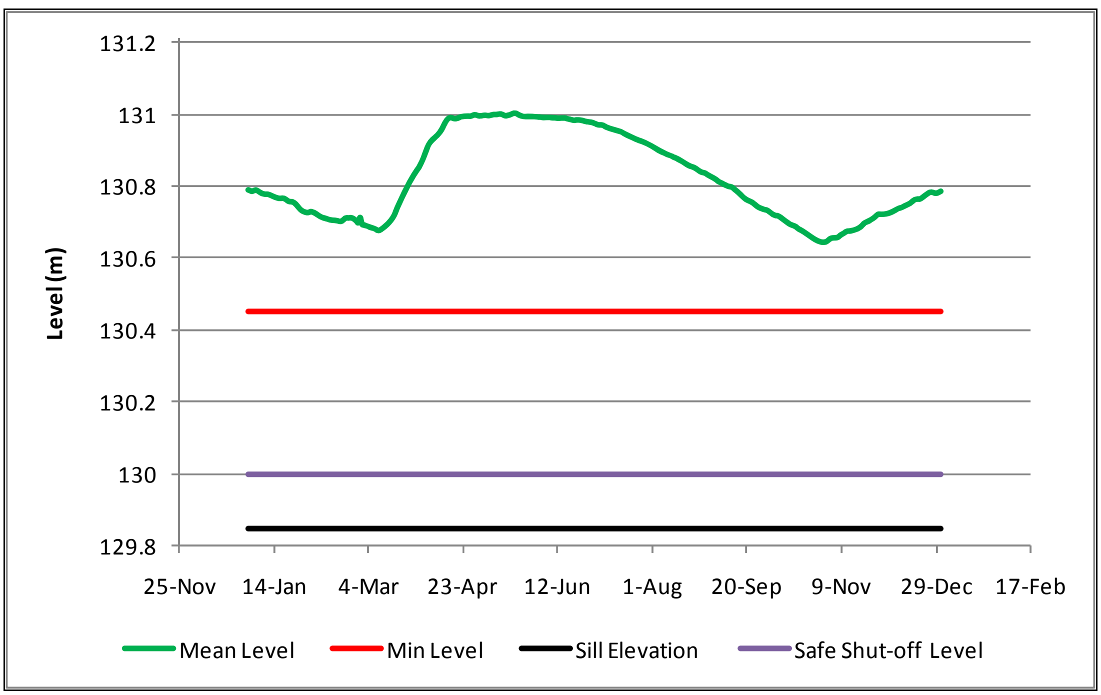


Figure 11 Water Risk Scenario A & E3 (1950 - 2005)

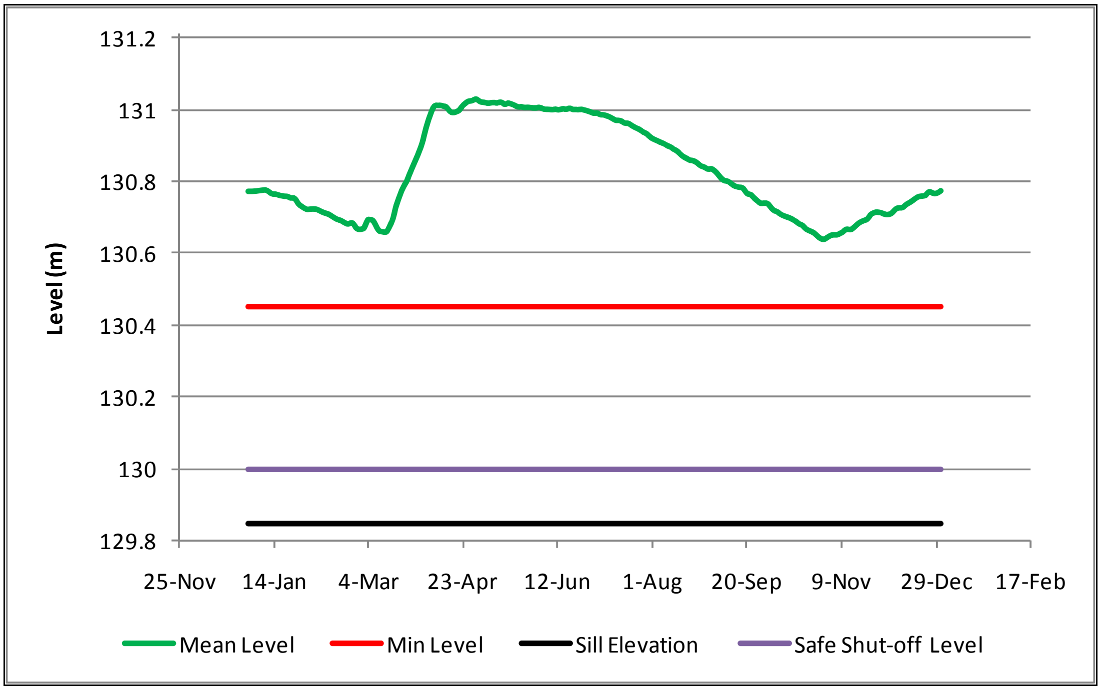


Figure 12 Water Risk Scenario B & F3 10 Yr Drought (1958 - 1967)

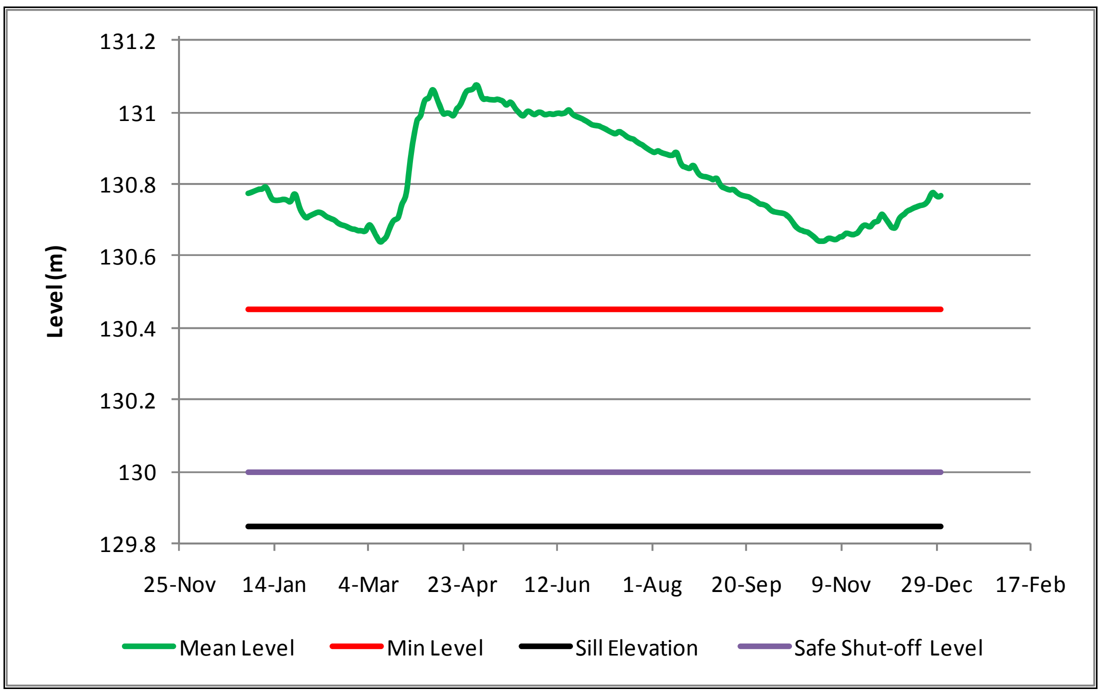


Figure 13 Water Risk Scenario B & F3 2 Yr Drought (1963 – 1964)

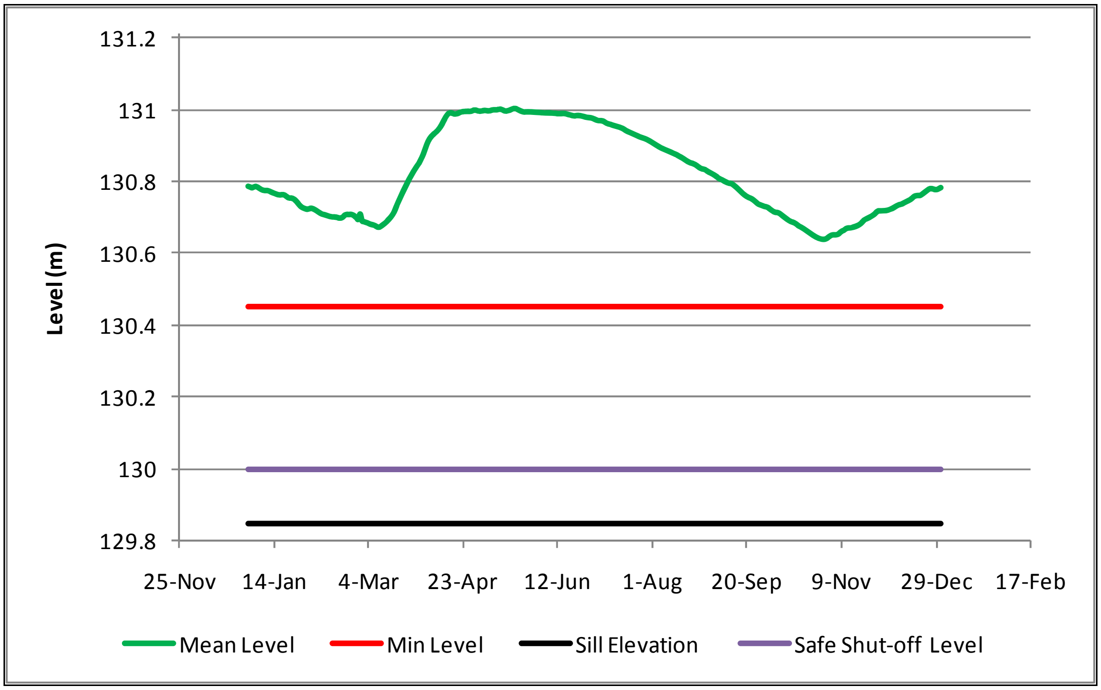


Figure 14 Water Risk Scenario E1 & E2 (1950 – 2005)

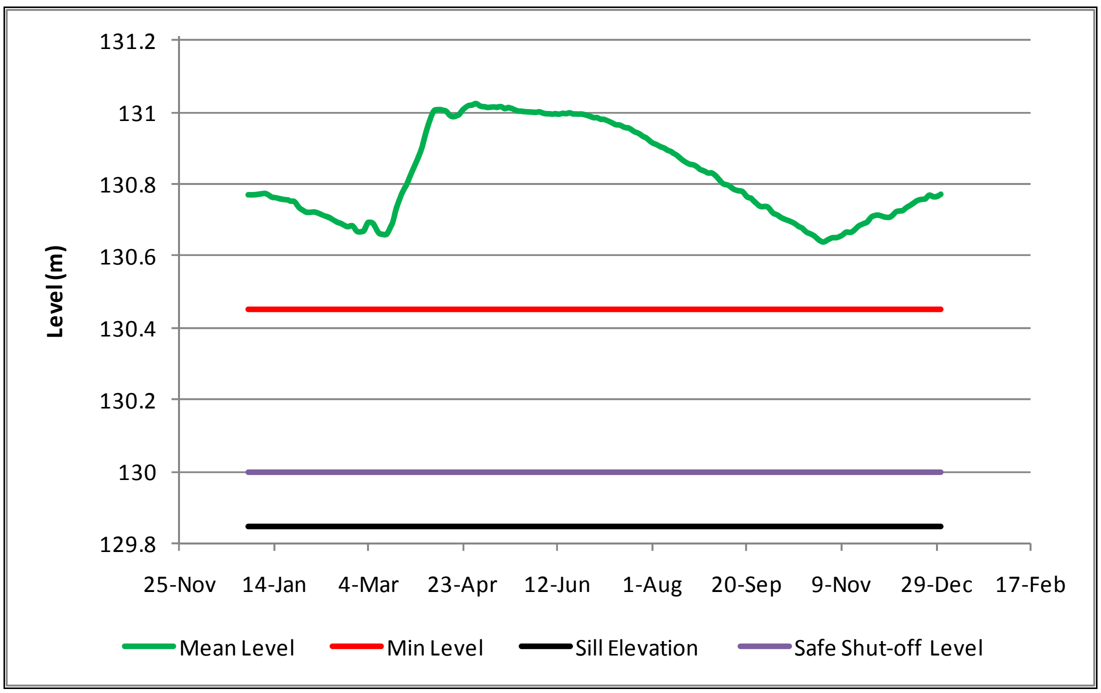


Figure 15 Water Risk Scenario F1 & F2 10 Yr Drought (1958 -1967)

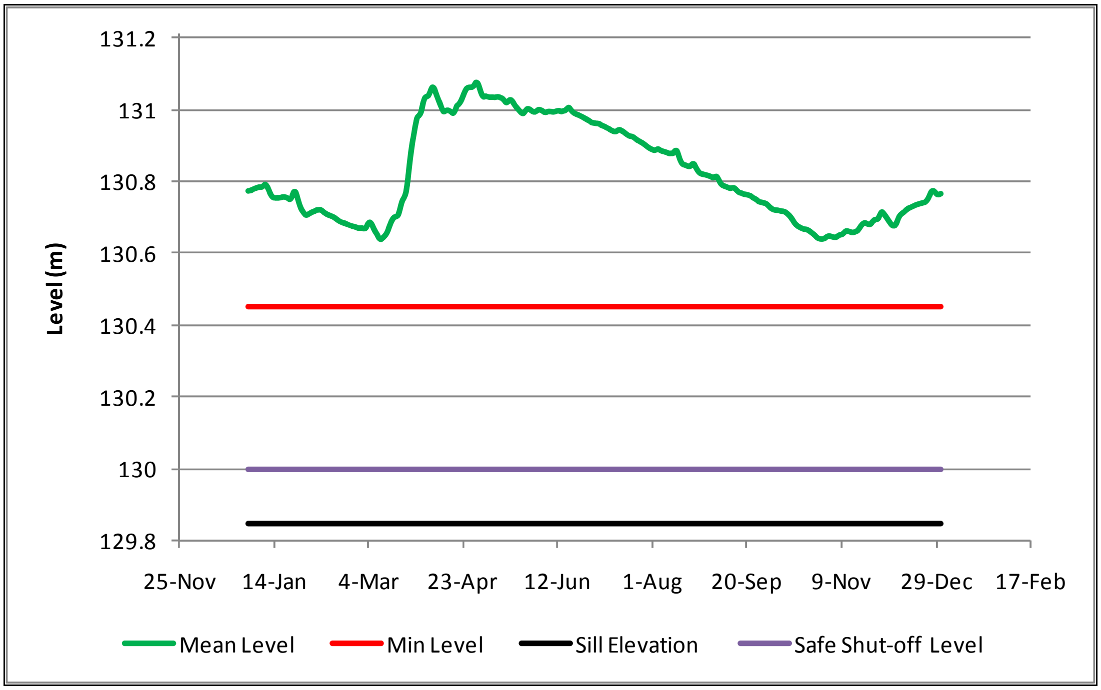


Figure 16 Water Risk Scenario F1 & F2 2 Yr Drought (1963 - 1964)

The graphical results of each scenario are shown in Figures 11 – 16. Each figure shows that despite the taking at the Sydenham WTP the lake level always remains above the sill, safe shut-off and minimum levels. Table 7 summarizes the critical level for each scenario as well as the minimum simulated level and the depth above the critical level. The minimum average level of 130.64 m (note: to the nearest 0.01 m) was simulated for all scenarios; this level corresponds with the rule curve target for the beginning of October. The lack of difference at the nearest 0.01 m level is due to the small taking and the amount of storage available.

Table 7 Water Risk Scenario Result Summary

Scenario	Critical Level (m)	Minimum Simulated Level (m)	Depth Above Critical Level (m)	Result
A & E3	130.45[1]	130.64	0.19	Sufficient water
B & F3 (10 YR)	130.00[2]	130.64	0.64	Sufficient water
B & F3 (2 YR)		130.64	0.64	Sufficient water
E1 & E2	130.45[1]	130.64	0.19	Sufficient water
F1 & F2 (10 YR)	130.00[2]	130.64	0.64	Sufficient water
F1 & F2 (2 YR)		130.64	0.64	Sufficient water
Notes: 1. Minimum level as defined by CRCA 2. Safe shut-off water level				

4. TASK 2: TOLERANCE LEVEL, EXISTING DRINKING WATER SYSTEMS

The Technical Bulletin sets out the conditions under which a system is deemed to have a tolerance level of "High" or "Low."

> *An existing type I, II or III system shall be assigned one of the following tolerance levels:*
>
> *(1) High, if the system obtains water from a surface water intake relating to a local area assessed in accordance with the circumstances described in Task 3.1(1)(b) of this Technical Bulletin and at all times during that assessment, the system would have been capable of meeting the peak demands of users of the system.*
>
> *(2) Refers to wells and does not apply to this study.*
>
> *(3) Low, if a tolerance level is not assigned in accordance with either of (1) or (2) above.*

For the Community of Sydenham, the tolerance was evaluated by applying the RESCOM model with municipal demand set to the actual peak demand (see Table 8) as monitored by Utilities Kingston.

Table 8 2008 Municipal Demand

Month	2008 Average Day Flow (m^3/day)	2008 Peak Daily Flow (L/min)	2008 Peak Daily Flow (m^3/day)
January	174	1031	1485
February	152	1052	1515
March	151	948	1365
April	171	1199	1727
May	172	1139	1640
June	192	1263	1819
July	169	1197	1724
August	182	1193	1718
September	205	1145	1649
October	210	1130	1627
November	221	1217	1752
December	215	1086	1564

Figures 17, 18 and 19 show the graphical results for Scenarios A & B as set out in the Technical Bulletin (MOE, 2010). Each figure shows the average simulated water level for the time period, the minimum water control level, the safe shut-off level and the sill level.

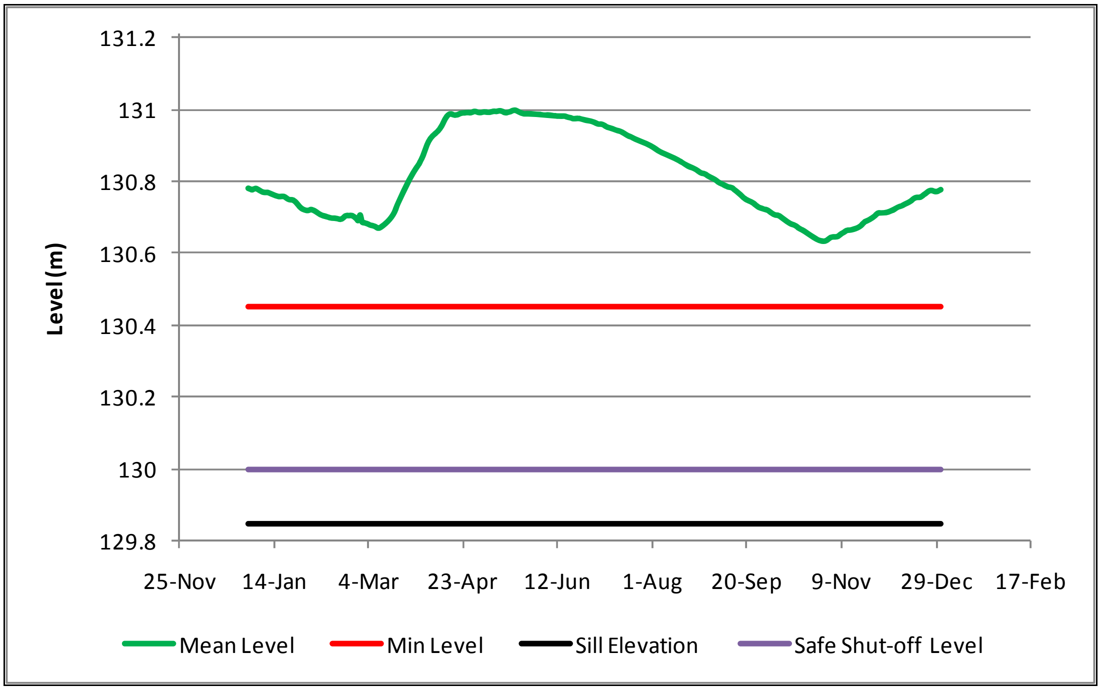


Figure 17 Tolerance - Scenario A (1950 - 2005)

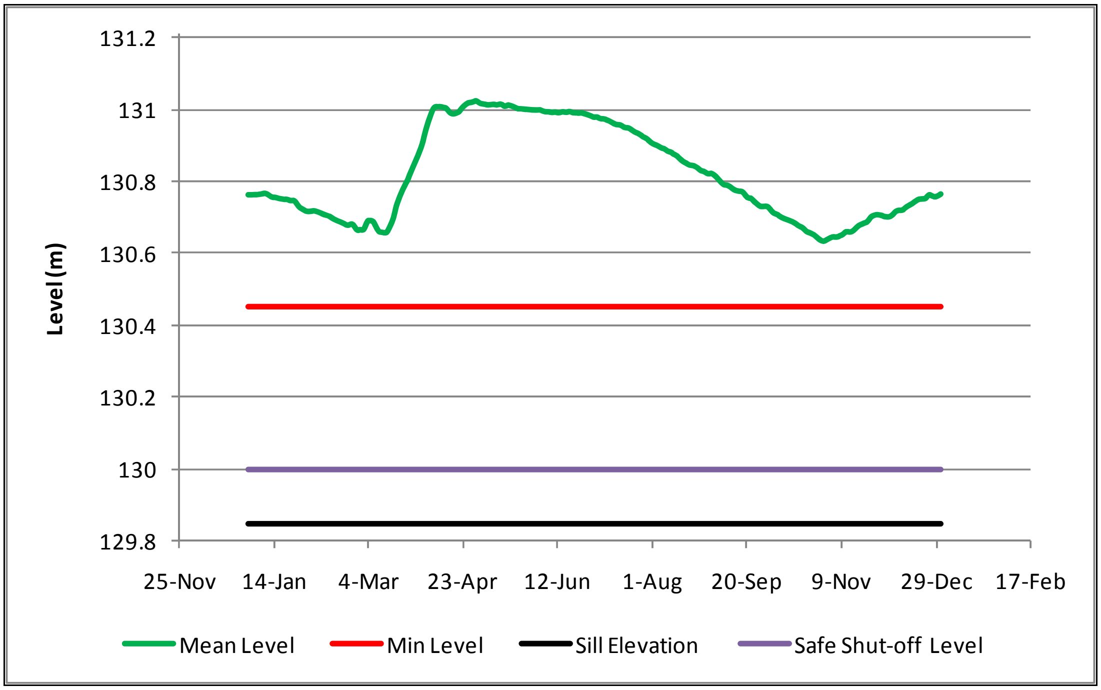


Figure 18 Tolerance - Scenario B 10 Yr Drought (1958 - 1967)

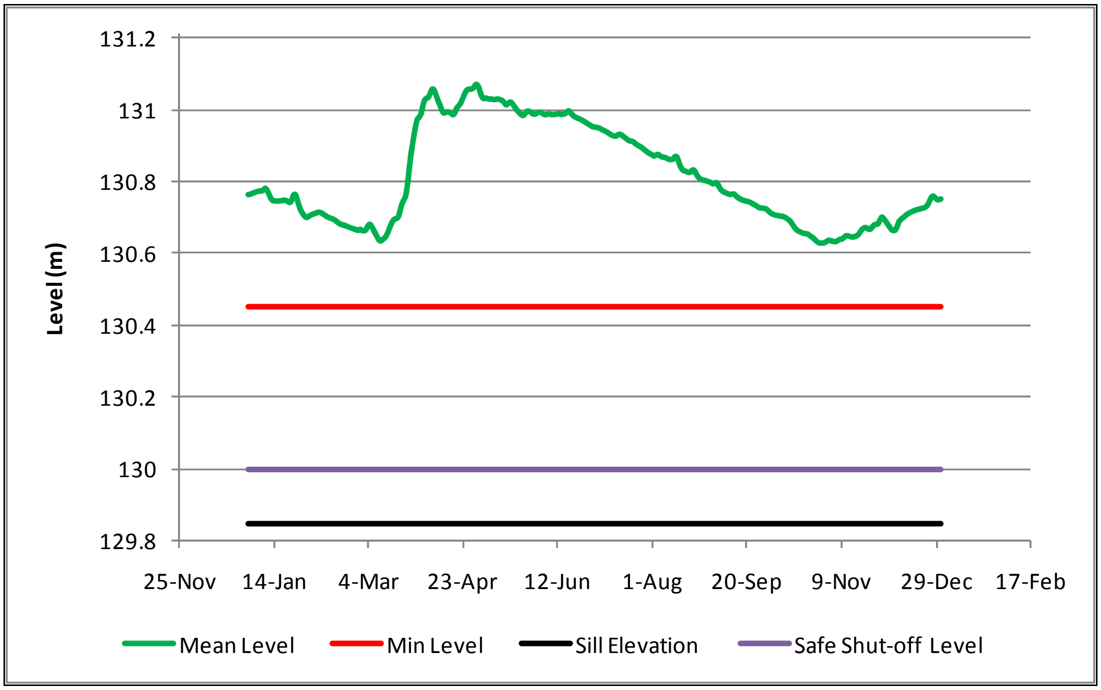


Figure 19 Tolerance - Scenario B 2 Yr Drought (1963 - 1964)

A review of the figures shows that in all cases the water levels remain above the safe shut-off level which indicates that ample water is available to meet the existing peak demand. Table 9 shows that, for both scenarios A & B under peak pumping conditions, that the system has a high tolerance level.

Table 9 Evaluation of Tolerance Level

Scenario	Time Period	Minimum Simulated Water Level (m)	Safe Shut-off Level (m)	Tolerance (High/Low)
A	1950 – 2005	130.63	130.00	High
B (10 year drought)	1958 – 1967	130.63		High
B (2 year drought)	1963 – 1964	130.63		High

Figure 20 shows the modelled mean level for the scenario A tolerance and water risk simulations. The figure illustrates that the modelled level for the tolerance simulation is marginally lower than that generated for the water risk scenario. This small difference in water level can be attributed to the large volume of storage available in Sydenham Lake. The volume of water above the safe shut-off provides a large buffer to small takings (such as the Sydenham WTP). Further, the control on Sydenham

Lake allows for a high degree of water level control; simply adjusting log settings can substantially increase or decrease water levels in a short period of time.

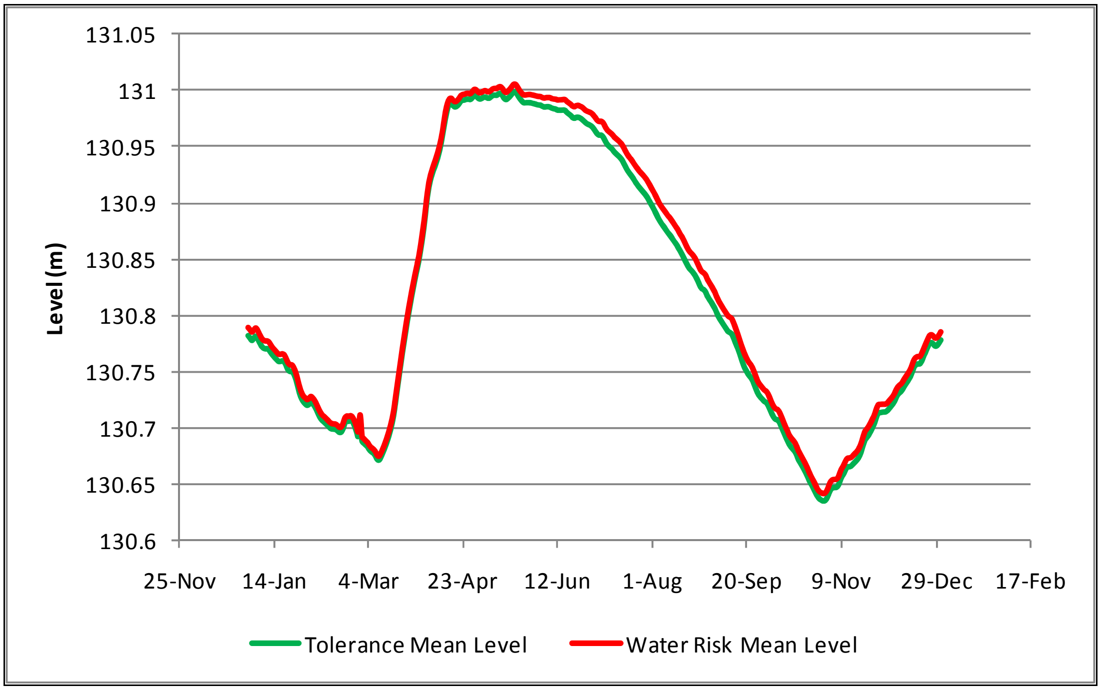


Figure 20 Mean Water Levels for Scenario A Tolerance and Water Risk

5. TASK 3: ASSIGNMENT OF RISK LEVEL

The final risk assignment is based on the results of the water risk scenarios, the tolerance and the model uncertainty.

5.1 Task 3.1: Assignment of Significant Risk Level

The Technical Bulletin (MOE, 2010) identifies a significant risk level as follows.

A local area has a risk level of significant if one or more of the following circumstances exist:

(1) Scenarios A and B in Tables 4A and 4C - One or More Surface Water Intakes.

(a) If at any time during scenario A or B the quantity of water that could have been taken from surface water bodies in the local area would not have been sufficient to meet the allocated quantity of water taken by those municipal surface water intakes.

(b) If at any time during scenario A or B the quantity of water that could have been taken from surface water bodies in the local area would have been sufficient to meet the allocated quantity of water taken by those municipal surface water intakes and the tolerance is Low.

(2) Refers to groundwater and does not apply to this study.

(3) Scenarios E1, E2, E3 and F1, F2, F3 in Tables 4A and 4C - One or More Surface Water Intakes.

(a) If a planned system or an existing system with a committed demand greater than 0 L/s, at any time during scenarios E1,2,3 or F1,2,3 the quantity of water that can be taken from surface water bodies in the local area would not be sufficient to meet the allocated quantity of water for those municipal surface water intakes.

(b) If a planned system or an existing system with a committed demand greater than 0 L/s, at any time during scenario E1,2,3 the quantity of water that can be taken from surface water bodies in the local area would be sufficient to meet the allocated quantity of water for those municipal surface water intakes and one or more of the following circumstance exists:

(i) the reduction in existing surface water levels and/or flows results, in response to the allocated pumping rates, in unacceptable impacts to existing regulated water levels and/or flows or permits.

(ii) the reduction in existing surface water levels and/or flows results, in response to the allocated pumping rates, in unacceptable impacts to aquatic habitat and provincially significant wetlands.

(4) Refers to wells and does not apply to this study.

Table 7 shows that the conditions specified in *(1)(a)*, *3(a)* and *3(b)* do not exist; Table 9 shows that the conditions specified in *(1)(b)* do not exist. Therefore, the local area does not have a risk level of significant.

5.2 Task 3.2: Assignment of Moderate Risk Level

The Technical Bulletin (MOE, 2010) identifies a moderate risk level as follows.

> *A local area has a risk level of moderate if one or more of the following circumstances exist:*
>
> *(1) Scenarios E1, E2, E3 in Tables 4A and 4C - One or More Surface Water Intakes.*
>
> *(a) If a planned system or an existing system with a committed demand greater than 0 L/s, at any time during scenarios E1,2,3 the quantity of water that can be taken from surface water bodies in the local area would be sufficient to meet the allocated quantity of water for those municipal surface water intakes and one or more of the following circumstance exists:*
>
> *(i) the reduction in existing surface water levels and/or flows results, in response to the allocated pumping rates, in measurable and potentially unacceptable impacts to existing regulated water levels and/or flows or permits.*
>
> *(ii) the reduction in existing surface water levels and/or flows results, in response to the allocated pumping rates, in a measurable and potentially unacceptable impact to aquatic habitat and provincially significant wetlands.*
>
> *(2) Refers to wells and does not apply to this study.*

Table 7 shows that the conditions specified in *(1)(a)* in the box above do not exist. Therefore, the local area does not have a risk level of moderate.

5.3 Task 3.3: Uncertainty and Sensitivity Analysis

The Technical Bulletin (MOE, 2010) sets out the conditions governing the analysis of uncertainty and the factors to be considered (below).

An analysis of the uncertainty, characterized as high or low, must be made in respect of the risk level for the local area.

(1) The following factors shall be considered in an analysis of uncertainty for Task 3.2:
  - *(a) The distribution, variability, quality and relevance of the available input data;*
  - *(b) The ability of the methods and models used to accurately reflect the hydrologic system;*
  - *(c) The quality assurance and quality control procedures applied; and*
  - *(d) The extent and level of calibration and validation achieved for any groundwater and surface models used or calculations and general assessments completed.*

(2) Despite Task 3.2, a local area has a risk level of significant if,
  - *(a) uncertainty determined in accordance with (1) is high; and*
  - *(b) a sensitivity analysis of the data used to prepare the water budget for the local area suggests that the risk level for the local area could be significant.*

Input Data

Data inputs for the HSPF/RESCOM include meteorological data (precipitation and temperature) and log settings.

The meteorological data employed was based on an infilled dataset for the Environment Canada Hartington meteorological station (#6103367). More than 25 percent of the dataset consisted of infilled data and if biased could lead to problems in long term simulated results (note that the drought scenarios inputs are based exclusively on infilled data). The infilling process was completed province wide and was independently peer reviewed.

The log setting dataset is directly applicable for calculation of Sydenham Lake levels. Problems arise with this data if a log setting change was not recorded; this can lead to significant error depending on the duration of the log setting applied.

Other data input include estimates of demand. The estimates of demand are based on actual takings when available and estimate techniques consistent with MOE guidance.

In the opinion of the modellers, the input data ranges from satisfactory to good.

Representation of Hydrologic System

Model selection was geared to representation of the hydrologic system. On the basis of professional judgement, the modellers feel that the hydrologic system is represented satisfactorily. This opinion is supported by the statistics for the Model Calibration (see Appendix A).

QA/QC Procedures Applied

The quality assurance and quality control procedures were those typically applied in hydrological modelling studies. These included evaluation of the appropriateness of the model applied, detailed review of input data and quantitative and qualitative analysis of modelled results.

Level of Calibration

The level of calibration achieved for Wilton Creek (see Appendix A) was deemed acceptable. That being said, there is room for improvement should better input data become available.

The overall model was loosely calibrated to Sydenham Lake levels measured at the dam. The word loosely is used as a detailed statistical evaluation was not completed as a continuous water level record was not available.

Details of the model calibrations can be found in Appendix A.

Based on the above, the modellers feel that the level of calibration attained was satisfactory.

Uncertainty Assignment

Based on the above discussion the uncertainty for the local area has been assessed as low. Since the uncertainty is low the conditions specified in *(2)* do not exist, the local area does not have a risk level of significant.

5.4 Task 3.4: Assignment of Low Risk Level

The Technical Bulletin (MOE, 2010), identifies a low risk level as follows.

Where a local area was not assigned a risk level of significant or moderate in accordance with Tasks 3.1, 3.2 and 3.3, the local area has a risk level of low.

Following the Technical Bulletin the local area does not have a risk level of significant of moderate; therefore, the risk level is low.

6. SUMMARY AND CONCLUSIONS

Following the Technical Rules (MOE, 2009) and the Technical Bulletin (MOE, 2010), tolerance, uncertainty and risk have been assigned for the Community of Sydenham Local Area. The study incorporated hydrologic inputs, water takings and detailed Sydenham Lake operation. Required scenarios were run via simulation using HSPF combined with RESCOM.

In conclusion, the risk level assigned to the Community of Sydenham Local Area is low.

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APPENDIX A
TECH MEMO 2: TIER 2 WATER BUDGET – MODEL DEVELOPMENT, SYDENHAM SUBWATERSHED

XCG File #1-1074-05-01

August 17, 2009

EXCELLENCE IN ENVIRONMENTAL CONSULTING SERVICES

TECH MEMORANDUM 2
TIER 2 WATER BUDGET – MODEL DEVELOPMENT
SYDENHAM SUBWATERSHED

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1. INTRODUCTION

1.1 Overview

The Peer Review Committee approved the XCG recommendation that

1. HSPF be adopted as the continuous hydrologic simulation model for the Sydenham Lake study, and
2. a custom reservoir routing and assessment model be developed to
    - simulate reservoir outflows:
        i. over the stop log controlled spillway structure for any number of log settings,
        ii. via leakage between the stop logs and
    - calculate corresponding water levels,
    - compare calculated and observed water levels, and
    - calculate performance statistics to assess the accuracy of the simulation.

The focus of this report is the development and calibration of the HSPF model for the Wilton Creek Subwatershed (WSC gauge 02 HM 005). While this creek is not contained within the Sydenham Lake subwatershed, it has been used in the past to represent inflows into Sydenham Lake. In addition, the development of the custom routing and assessment model (see 2 above) is presented along with some preliminary results.

1.2 XCG Model Configuration

For modelling purposes, the Sydenham subwatershed was configured as a series of linked watershed, channel and reservoir model elements following the guidelines set out in The Hydrology of Floods in Canada (Watt et al. 1989). Model nodes were placed at the downstream end of each element and at junctions. After consultation with Cataraqui Region Conservation Authority (CRCA) staff, seven watershed elements and two reservoir elements were selected. The areas modelled by these elements are shown on Figure 1-1; they include

- Gould Lake Outlet (GLO),
- Gould Lake (GL)
- Sydenham Lake North (SLN),
- Sydenham Lake East (SLE),
- Sydenham Lake West (SLW),
- Sydenham Lake South (SLS), and
- Sydenham Lake Dam (SLD).

There is a Water Survey of Canada hydrometric station located directly downstream of the Sydenham Lake Dam (station 02 HM 011, Millhaven Creek at Sydenham).

This station has a very short period of record (2005 – 2008) and for the current Tier 2 water budget activities the data quality may still be suspect.

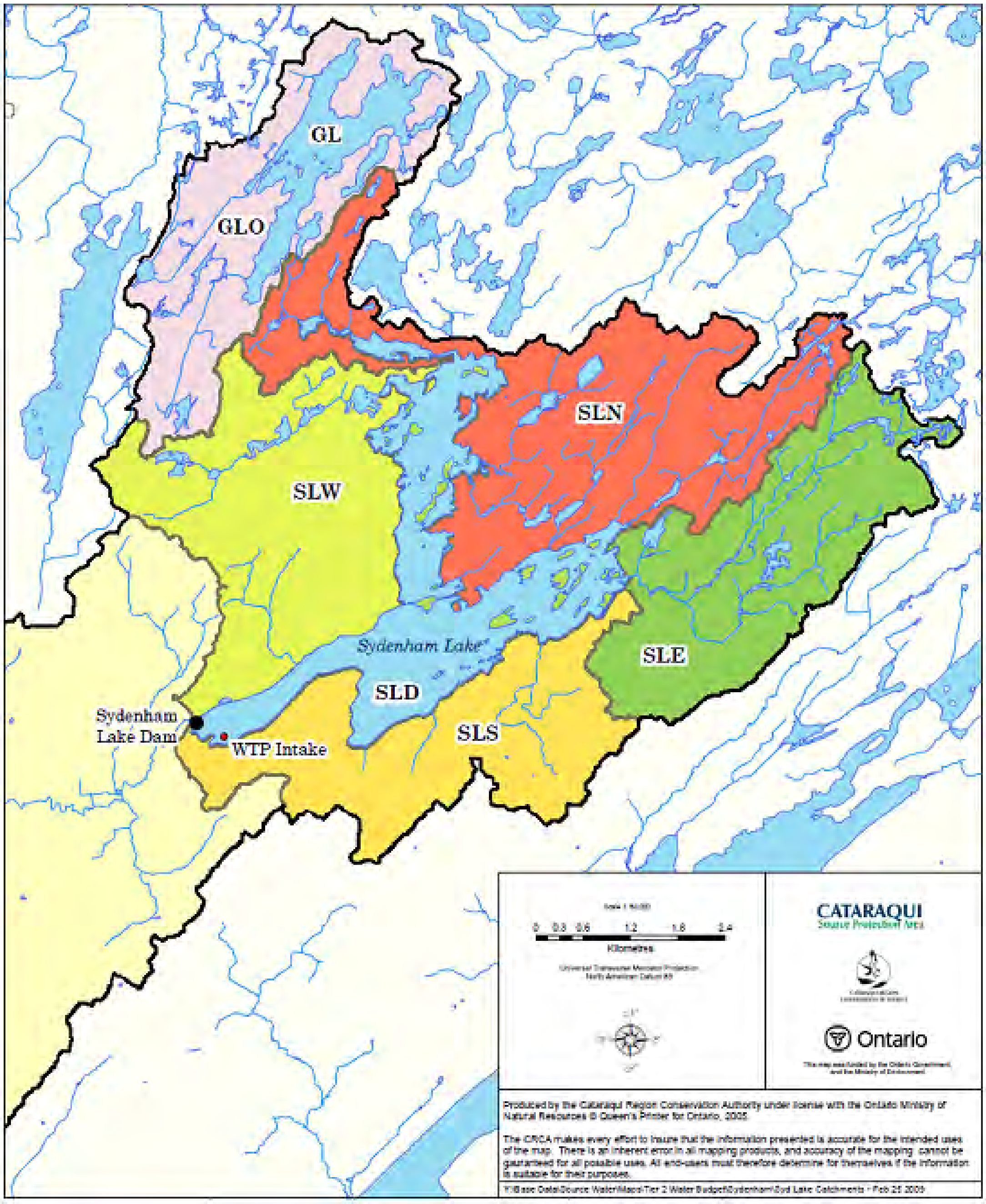

Figure 1-1 Sydenham Lake Watershed Discretization

The element network input to the model is shown in Figure 1-2. The SD and GD elements below identify the outflow from Sydenham Lake and Gould Lake respectively.

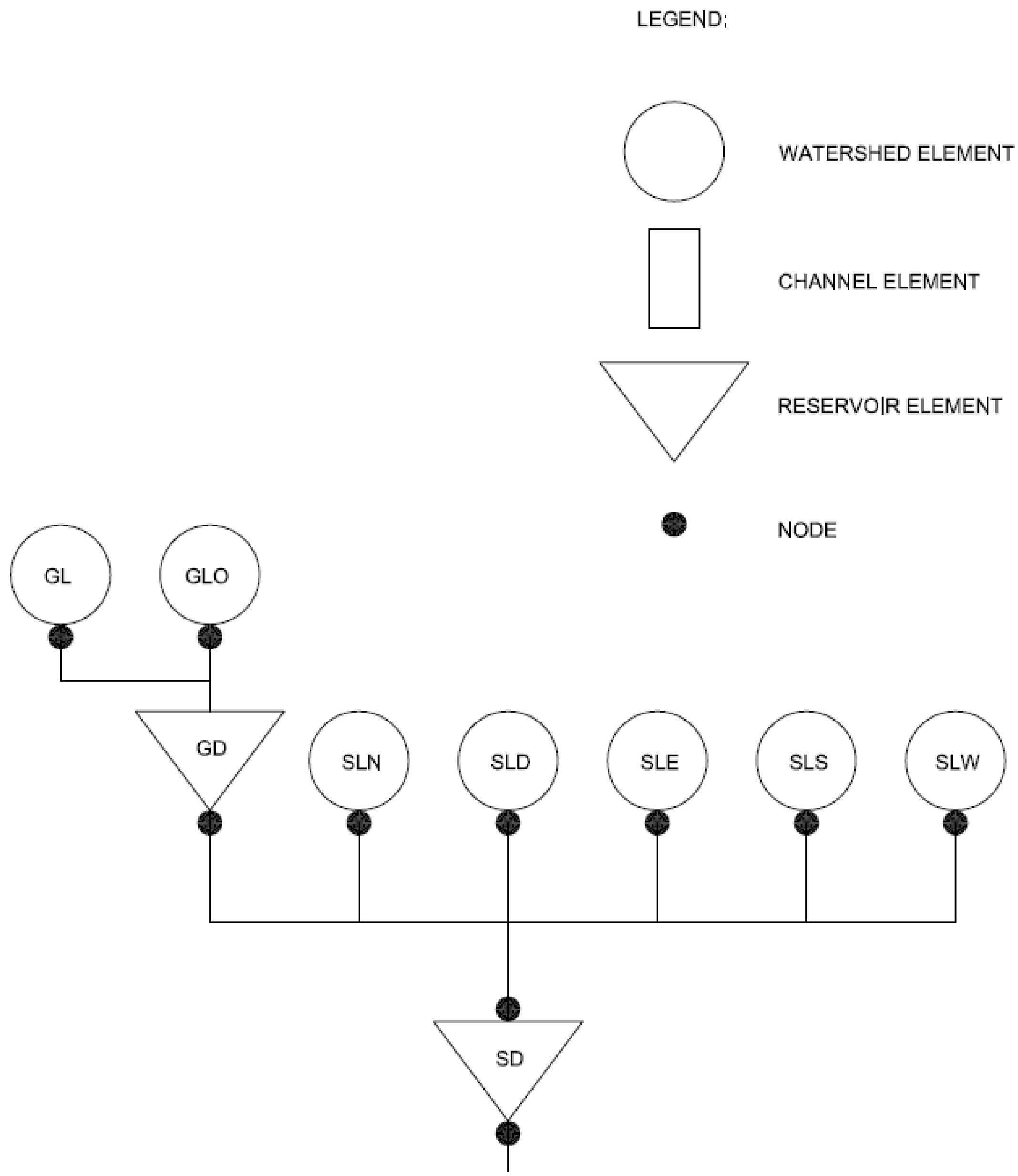

Figure 1-2 Schematic - Hydrologic Element Network

2. CALIBRATION OF HSPF MODEL FOR WATERSHED ELEMENTS

2.1 Calibration for Wilton Creek Watershed

As mentioned earlier the most representative basin available for calibration is the Wilton Creek watershed.

2.1.1 Streamflow and Climate Data

Input data: In order to simulate streamflow, the model requires the following meteorological inputs, all averaged over the watershed: potential evapotranspiration (PET), temperature, rainfall and snowfall. PET was simulated using Hargreaves (for more details on the equation please see the Handbook of Hydrology Maidment, 1993) equation based on temperature at the Hartington climate station (# 6103367). Temperature and snowfall at Hartington were taken as representative of the watershed; Hartington station is the closest long-term station to the study area. Hourly in-filled rainfall data for Hartington were obtained from MNR through CRCA staff.

Model output: The primary model output in this case is streamflow at the outlet of the watershed. To calibrate the model, simulated streamflow is compared to recorded streamflow, in this case, at station 02 HM 005. A secondary model output is snowpack water equivalent, which can be compared to observed water equivalent to assess parameters of the snowmelt model. Observed values of snowpack water equivalent for the Gould Lake snow course were obtained from CRCA staff.

Model time step: The model was run on an hourly time step; hence, hourly input and output data were required.

Period of simulation: Selection of the period of simulation was governed by two considerations. First, the period must be long enough to produce a satisfactory calibration and validation of the simulation model, generally at least ten years. The calibration for Wilton was completed from 1966 – 1995. Second, the calibration of the overall model at Sydenham Lake is dependent on reliable data on reservoir level and log settings. Based on these two considerations, the period of simulation was selected as 1992-2004.

Assessment of data quality/importance: Data quality is assessed herein in terms of two parameters: accuracy and reliability of the measurements, and representativeness of the point data to the average for the overall watershed. Data importance is assessed in terms of one parameter, how much influence an error in the data has on the assessment of the model output when compared to the observed streamflow. In Table 2-1, each type of data is assigned a score for each parameter, the score ranging from one to ten.

Table 2-1 Data Accuracy/Importance Matrix

Type of Data	Accuracy of Point Value	Representativeness of Point Value	Importance
PET	N/A	8	8
Temperature	10	8	9
Rainfall	7	6	8
Snowfall	6	7	8
Snowpack	8	6	5
Streamflow	9	10	10

The reasons for the values given in Table 2-1 are discussed below.

PET is not a measured parameter and therefore its accuracy cannot be assessed. The methods for estimating PET have substantial variation and have a high uncertainty attached. From the modelling perspective, a method yielding a lower PET leads to issues in estimating the actual evapotranspiration (AET) as insufficient water is available to satisfy the ET component. In terms of representativeness, it is not expected that PET would vary greatly across the region and, from work in the Tier 1 water budget, would not vary highly across the entire Cataraqui Source Protection Area.

Temperature at a point can be measured accurately and, when evaluated on an average daily basis, can be quite representative over a large area. The advantage of looking at average daily data is that it eliminates some of the noise inherent in the hourly dataset. Hourly temperature data is more critical when event matching is being completed during the snowmelt season. The model uses temperature to switch precipitation from rain to snow and temperature drives the snowmelt component of the model. Errors or inconsistencies in this dataset can have large impacts during the snowmelt season.

Rainfall, measured as a point value at the meteorological station, is known have a negative bias due to under catch; hence, its accuracy at times can be questionable especially for small rainfall depths. Coincidentally, these small rainfall events generally do not result in substantial runoff and are taken up by ET or changes in soil water storage. Assuming measured point values of rainfall (MNR infilled Hartington data) applies over the subwatershed can lead to substantial error in occurrence, total depth and timing, particularly for convective type rainfall events. An additional source of potential error is the distribution of daily data to an hourly time step. This hourly distribution was completed outside of the current study. As such some events may have significantly larger or smaller hourly intensities associated with them. If the amount synthesized in a particular hour exceeds the actual rainfall the simulated streamflow will be significantly larger. As can be expected, the water input to the system has a large impact on streamflow.

Snowfall is not a direct input to the model, rather it is generated internally by taking total precipitation and converting it to snow, based on temperature; hence, the accuracy of the data is questionable. Based on the relatively poor accuracy of the snowfall estimates, the representativeness of a given snow course in the vicinity is a good representation of actual, as weighted station analysis and highly intensive evaluation of other snow course data would not improve the overall quality of data in any location. Snowfall is a key parameter for the streamflow because it increases the snowpack which, when it melts in the spring, is the dominant component of water input to the model. Snowmelt also recharges the aquifers in the area and yields summer flows.

Snowpack water equivalent, as measured at the Gould Lake snow course, is quite accurate. However, the time of measurement is known only within a seven-day interval. This can result in uncertainties when comparing simulated and observed snowpack water equivalents over time intervals less than seven days. Limited information exists as to the representativeness of this data.

Streamflow, as measured at the Water Survey of Canada hydrometric station (Wilton Creek near Napanee, 02 HM 004), is quite accurate and represents the integrated runoff generated over the entire watershed. Because measured streamflow is the target for the simulated streamflow, it carries the highest importance of any data.

2.1.2 Objective of Calibration

The overall objective of the calibration exercise was to find the set of parameter values that provided the best overall fit of simulated to observed flows over the period of record, while recognizing that the simulation for the first two or three years may not be as good as the remainder of the simulation period because of the assumptions made for initial conditions.

Notwithstanding the overall objective set out above, the ultimate use of the calibrated/validated model must be kept in mind: it is to provide, in companion with the calibrated custom reservoir model, the monthly supply and reserve terms in the stress or percent water demand relation for the month in which the stress is a maximum. Because demand has a small monthly variation, the month of maximum stress will be the month of minimum (supply – reserve), which is likely to be July, August or September. Accordingly, in the calibration process, attention was directed more to accurate simulation for these months rather than say January.

2.1.3 Calibration Methodology

The calibration was conducted on the first portion of the period of simulation: 1966-1995. Model parameters were adjusted on the basis of comparison of simulated to observed monthly averages for that period. It should be noted that the HSPF model has a large number of parameters (11 in the degree-day snowmelt model alone and 22 in the modules representing the soil moisture balance and routing of outflows to the stream). Accordingly, adjustment of this large number of parameters, most of which can vary over a large range, is not a trivial task.

It must also be recognized that even with such a large number of parameters, simulated flows will not always closely approximate observed flows, even when the comparison is done on a monthly basis. The principal reasons for this lack of agreement are summarized below.

1. The model is not a perfect representation of nature and cannot accurately simulate extreme events (e.g. a two-day rainfall in January during a cold January with the same parameter set used to model typical events).
2. A sustained difference of one or two degrees between point temperature used in the model and average temperature experienced by the watershed, when the temperature is close to the melting point, can result in significant differences between simulated and observed flows.
3. A rainfall that occurs at the meteorological station, but not over the watershed, or vice-versa, can result in significant differences between simulated and observed flows. This effect is more pronounced for convective rainfall events.
4. The effect of any of the above may carry further forward than the month in which it occurred.

Once the parameter set had been finalized, the calibrated model was tested on the remainder of the period of simulation, 1996 - 2004.

2.1.4 Calibration Results

At an early stage in the calibration process, the snowmelt parameters were adjusted to generate acceptable agreement between simulated and observed snowpack water equivalent. Figure 2-1 provides an example of the level of agreement obtained for one winter in the calibration period.

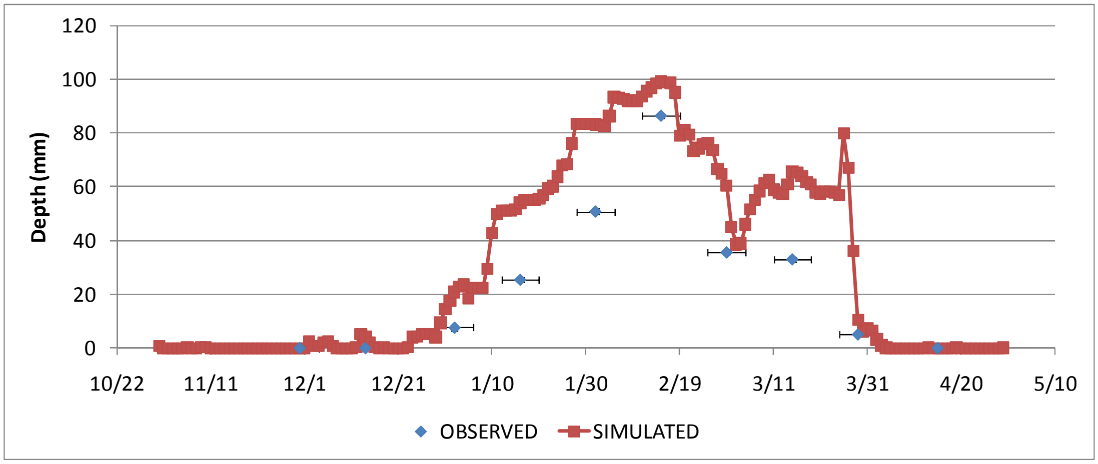

Figure 2-1 Comparison of Observed Gould Lake to Simulated Snow Water Equivalent for 1996 – 1997 Winter

Then, the remaining parameters were adjusted to generate acceptable agreement between simulated and observed values of streamflow, first on an annual basis and then on a monthly basis, with particular attention paid to the months of July, August and September. Simulated and observed values of streamflow on an annual basis are compared in Figure 2-2.

> [*Note that the output of the HSPF model is streamflow expressed as an average depth of water over the drainage basin, in mm.]*

The mean annual runoff from the model output is 405 mm, whereas that the observed value is 413 mm, indicating that on a long-term annual average basis, the simulation is very good.

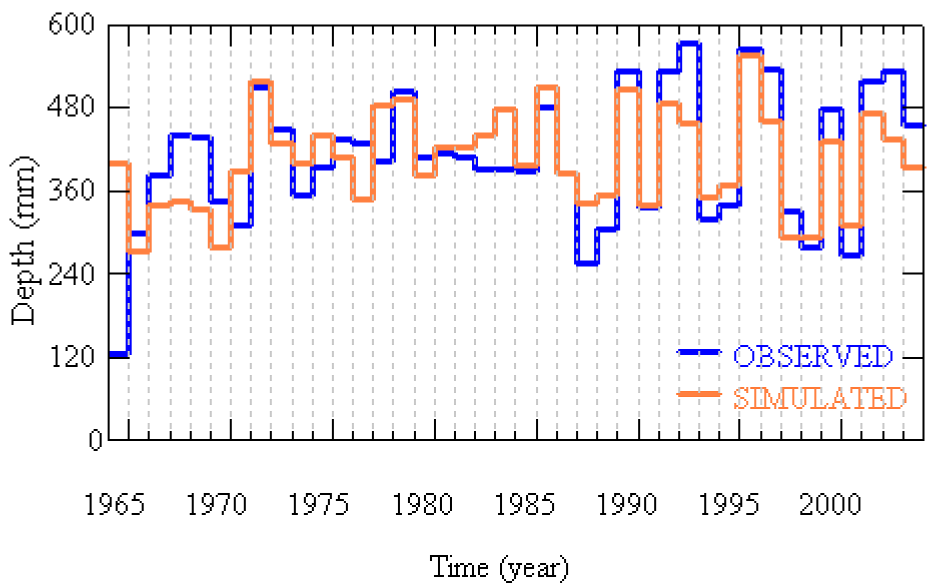

Figure 2-2 Comparison of Observed and Simulated Annual Streamflow

Figure 2-2 shows that the model, on an annual basis, represents observed streamflow quite well except 1965, which did not have a complete record of flow for that year.

Simulated and observed flows, on a long-term mean monthly basis, are compared in Figure 2-3. It can be seen that the means are well represented. There are some discrepancies for April and June. More focus was placed on the low flow months as they are the most sensitive for %water demand calculations. The Nash-Sutcliffe statistic was also calculated on a monthly basis to evaluate the performance of the model (see Table 2-2). Values greater than zero indicate that the model produces a better estimate than the mean. The higher the positive value indicates better model performance.

Table 2-2 Monthly Nash-Sutcliffe Statistic for Wilton Creek

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.53	0.77	0.67	0.50	0.59	0.45	0.20	0.39	0.72	0.67	0.69	0.73

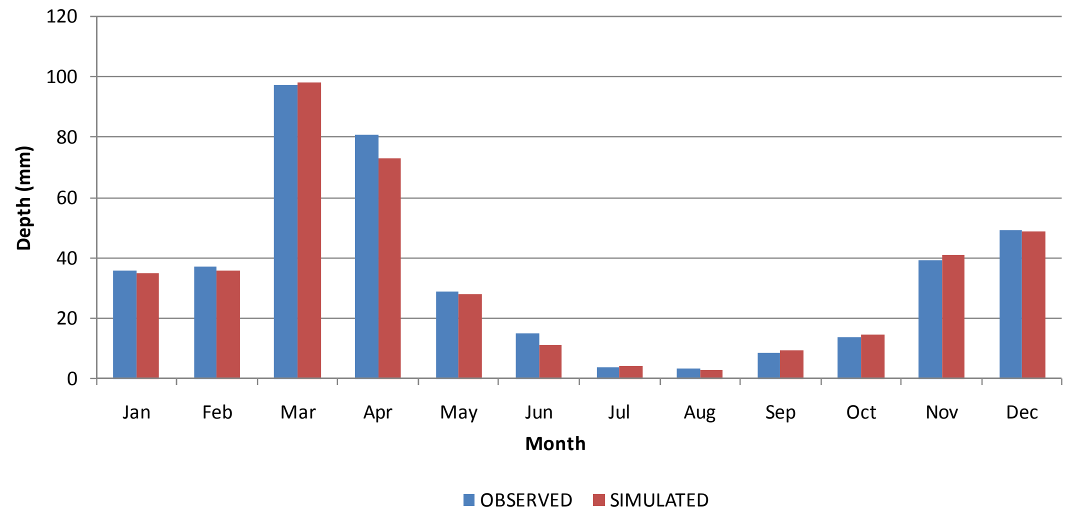

Figure 2-3 Comparison of Long-Term Observed and Simulated Monthly Streamflow

As indicated above, the ultimate use of the calibrated model is to provide, in companion with the calibrated custom reservoir model, the monthly supply and reserve terms in the stress or percent water demand relation for the month in which the stress is a maximum (i.e. July, August or September). Accordingly, the simulated and observed monthly values of (Supply-Reserve), as represented by the median minus the 10th percentile, are compared in Table 2-2.

Table 2-3 Comparison of Observed and Simulated Wilton Streamflow Statistics 1966-2004

Month	Simulated Percentiles (mm)			Observed (mm)		
	50th	10th	50th - 10th	50th	10th	50th - 10th
January	31.5	6.8	24.7	28.0	8.1	19.9
February	27.8	7.0	20.8	30.2	6.7	23.5
March	99.9	54.2	45.7	104.0	41.6	62.4
April	63.9	32.6	31.3	79.8	31.1	48.7
May	23.7	12.1	11.6	29.2	6.7	22.5
June	9.0	6.4	2.6	7.4	2.8	4.6
July	4.3	2.8	1.5	2.3	0.6	1.7
August	2.0	1.2	0.8	1.1	0.3	0.8
September	2.7	0.9	1.8	1.8	0.4	1.4
October	9.3	2.4	6.9	6.7	2.0	4.7
November	37.3	19.5	17.8	34.0	10.7	23.3
December	43.4	17.4	26.0	43.0	15.2	27.8

As expected, there are differences between observed and simulated percentiles. In truth there is no substitute for observations; however, there is an acceptable agreement between observed and simulated values.

2.2 Extension of HSPF Model to Other Watershed Elements

2.2.1 Land-dominated areas

The HSPF model was extended to the other watershed elements using the same PET, temperature, snowfall and rainfall data used for Wilton Creek. While there were some differences certainly in topography, soil type, area of lakes and swamps on average the differences were not substantial enough to require parameter adjustment for the subwatersheds (a parameter summary is shown in Appendix A).

2.2.2 Water-dominated areas

The HSPF model was extended to the two lake elements (Gould Lake and Sydenham Lake). Initial values for the parameters were taken as the Wilton parameters, adjusted to reflect the fact that the surface of this element is 100 % water (surface was modelled as if it was an impervious area).

3. CALIBRATION OF CUSTOM MODEL FOR RESERVOIR ROUTING

3.1 Overview

The structure of the overall Sydenham Lake model is shown in Figure 2-4. The model is a linked network of five land-dominated watershed elements and two water dominated watershed elements, all modelled using HSPF, and one complex reservoir element, modelled using RESCOM, a custom reservoir routing model developed by XCG.

This model receives inputs generated by HSPF from a number of watershed elements, routes these inputs through channel storage and then through reservoir storage defined by a stage-storage relation and a rating curve defined by a time - dependent relation (to simulate variable stop log settings) representing the controlled stop log spillway.

The routing is accomplished using the modified Puls method. A summary of the model outputs, reservoir discharge and reservoir level, is provided in both tabular and graphical formats.

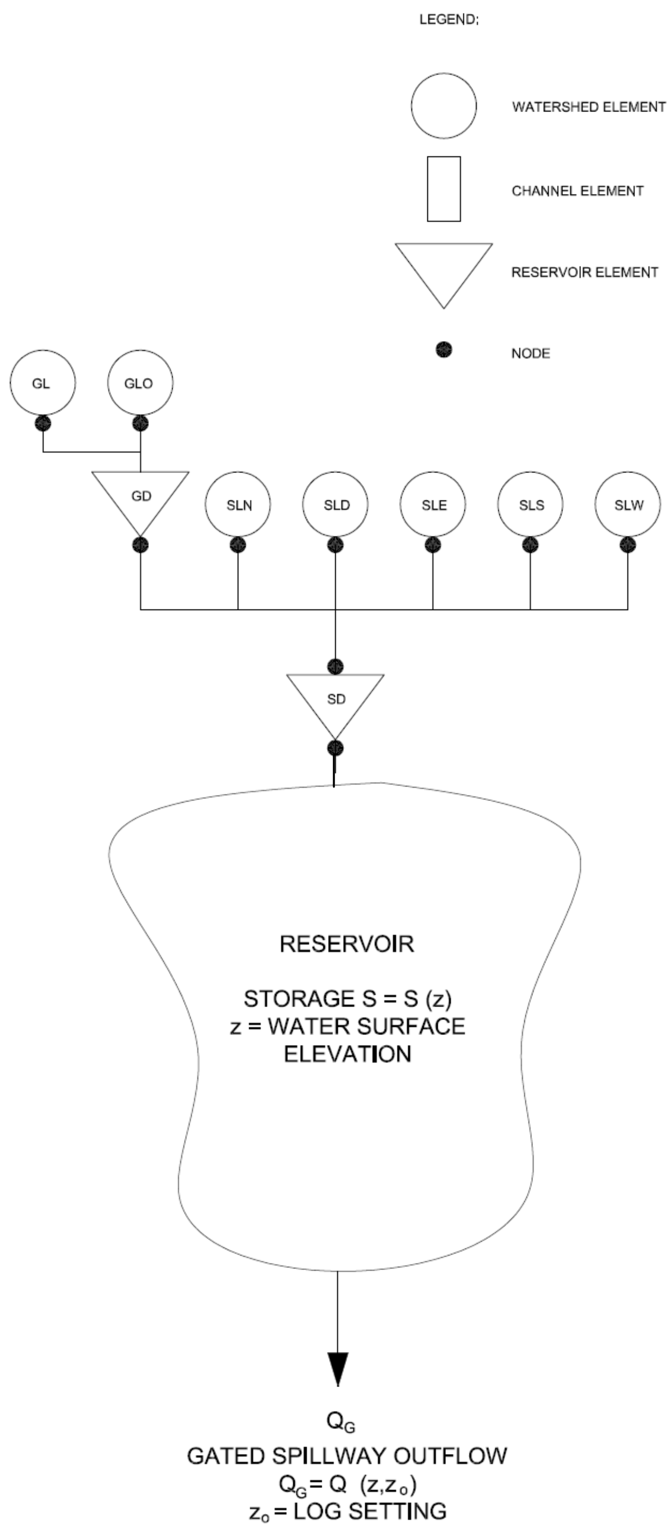

Figure 3-1 Schematic - Custom Reservoir Model – Sydenham Lake

3.2 Calibration of Overall Model

3.2.1 Rating Curve for Sydenham Lake Dam Structure

The rating curve used for the Sydenham Lake Dam for the Tier 1 analysis was generated in house by staff of the CRCA. This rating curve provided good insight for the Tier 1 application but had some limitations. XCG has since developed rating curves to represent the flow over the log dams. Flow over the log dams is modelled by the broad and sharp-crested weir equations depending on head over the logs. Leakage between the logs was not modelled as no data was available to assess the leakage term.

3.2.2 Target for Calibration

The ultimate target for calibration of the overall model is inflow into the reservoir element shown in Figure 1-2. However, since there are no flow measurements at this location, the observed water level in the reservoir (for which measurements are available) is taken as the target. It should be noted that there is not a complete record of water level data available at the structure (generally readings are taking on a bi-weekly basis or when a log change is completed).

The net water inputs to the reservoir are the HSPF simulated flows for the watershed and lake elements shown in Figure 1-1 and Figure 3-1. The output is water released through the outlet structures. Additional input data include the historic time series of log settings for the simulation period. The custom reservoir model discussed above was used to route the inputs through the reservoir, given the historical log settings. It should be clearly noted that discussions with CRCA revealed that it was highly likely that not all log changes were recorded. The log setting is the most critical component for determining stage in the reservoir; inconsistencies in log settings result in significant differences in the water level calculated. Accordingly, a simple graphical comparison of time series was deemed to be appropriate in this case. Plots were evaluated on a goodness of fit that examined not only simulated level but also comparison of the time series shapes.

3.2.3 Calibration Results

As mentioned earlier, it was not uncommon for log changes to not be documented; this problem was more severe prior to 1996. To compensate for this deficiency in input data, ‘estimated’ log changes were added to the time input time series. The result was obviously a much better fit to the observed water levels. Estimated log changes were made only on days when a water level observation was collected; the rationale being that a level measurement would likely be coincident with a log setting change. Modifications were made for the years 1991 – 1996 (see Figure 3-2); modifications were not made after 1996 (see Figure 3-3). All time series plots are located in Appendix B.

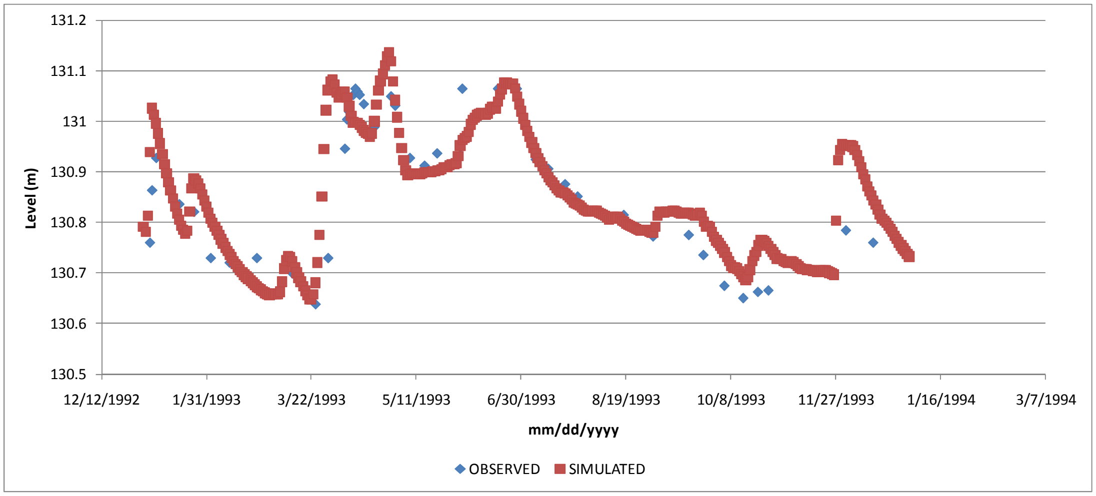

Figure 3-2 Time Series Plot for Sydenham Lake 1993 – Modified Log Settings

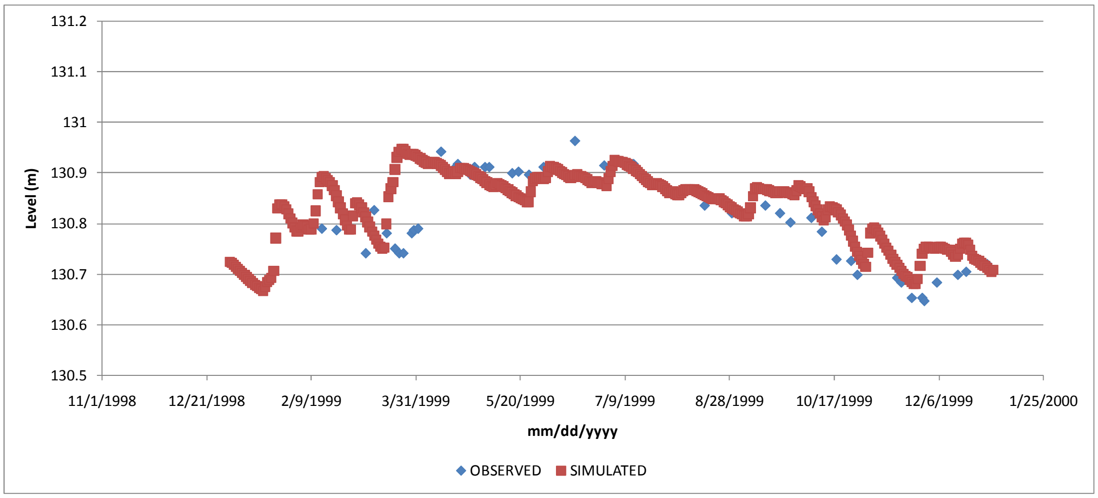

Figure 3-3 Time Series Plot for Sydenham Lake 1999

In general the results from the combined HSPF and RESCOM models are satisfactory and can be used to run the other required scenarios.

4. APPLICATION OF COMBINED MODELS TO SCENARIOS

4.1.1 Required Scenarios

With the model in place the Technical Rules require that several stress scenarios be evaluated (summarized below).

Scenario A (Existing System - Average): The historical climate dataset (1950 – 2005) will be used to determine streamflow (supply). Demand will be estimated as the existing average monthly demand.

Scenario B (Existing System – Future Demand): The historical climate dataset (1950 – 2005) will be used to determine streamflow (supply). Modifications to land cover shall be incorporated. Demand will be estimated as the future average monthly demand.

Scenario D (Existing System – Two Year Drought): The continuous two year period with the lowest mean annual precipitation from the 1950 – 2005 dataset will be used to determine streamflow (supply). Demand will be estimated as the existing average monthly demand.

Scenario E (Existing System – Future Two Year Drought): The continuous two year period with the lowest mean annual precipitation from the 1950 – 2005 dataset will be used to determine streamflow (supply). Modifications to land cover shall be incorporated. Demand will be estimated as the future average monthly demand.

Scenario G (Existing System – Ten Year Drought): The continuous ten year period with the lowest mean annual precipitation from the 1950 – 2005 dataset will be used to determine streamflow (supply). Demand will be estimated as the existing average monthly demand.

Scenario H (Existing System – Future Ten Year Drought): The continuous ten year period with the lowest mean annual precipitation from the 1950 – 2005 dataset will be used to determine streamflow (supply). Modifications to land cover shall be incorporated. Demand will be estimated as the future average monthly demand.

4.1.2 Evaluation of Storage

The advantage of the Tier 2 analysis is that it allows for the inclusion of storage in the modelling and specifically in this case for determining the lake level. In the case of the Sydenham Lake subwatershed the storage term (i.e. lake storage) is significant. Over the years there have been large changes at the Sydenham Lake control structure including a rebuild and modifications in the operational curve. To standardize the record based on how the system would be operated now, it was necessary to add a routine to the routing model that selects log settings based on the hydrologic and hydraulic responses of the subwatershed.

To complete the analysis it was necessary to input a rule curve into the model. The applied rule curve is a modified version of the one that is currently in place (see Figure 4-1). The modification was necessary as the rule curve currently in use is generally applied as a lower boundary. The curve shown below is identical except that all elevations were increased by six inches (note the dam is currently operated in feet).

The analysis was completed for the entire simulation period. The long-term minimum, maximum and average daily stages are shown below in Figure 4-2. The mean closely approximates the rule curve and the minimum value generally does not fall below the lower bound rule curve. It should be noted that the minimums in the simulation can be affected by early season melts (i.e. a large melt in January or February with little snow afterwards can lead to lower reservoir levels; this is because the decision matrix does not account for the amount of snow in the system). Levels for the two-year (1962-1963) and ten-year drought (1958-1967) scenarios are shown below in Figure 4-3 and Figure 4-4. These figures show even during extended drought periods that target water levels can be maintained based on the current operation considerations.

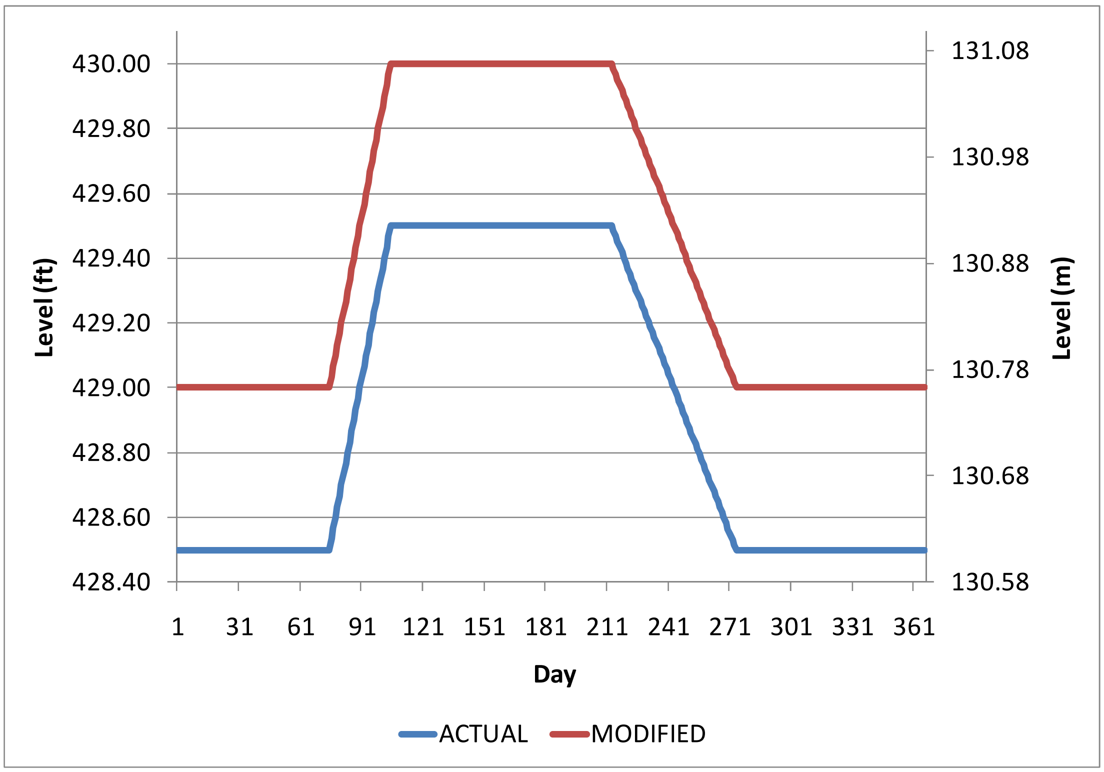

Figure 4-1 Comparison of Actual and Modified Rule Curves

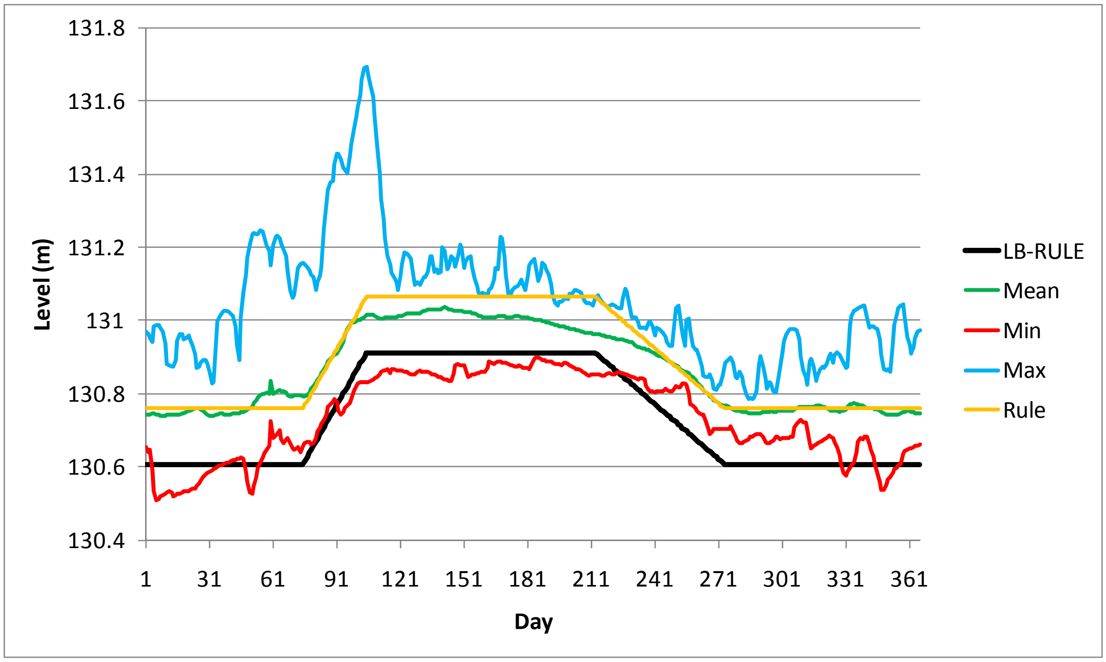

Figure 4-2 Model Simulation Results (1950 – 2005)

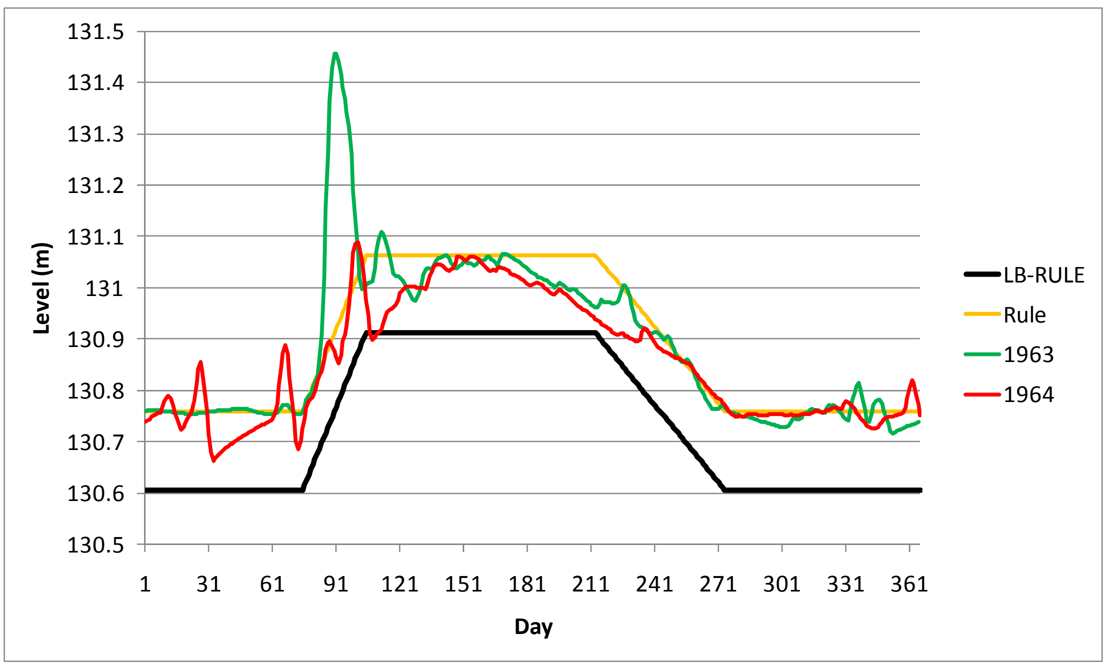

Figure 4-3 Model Simulation Results – 2 Year Drought (1962-1963)

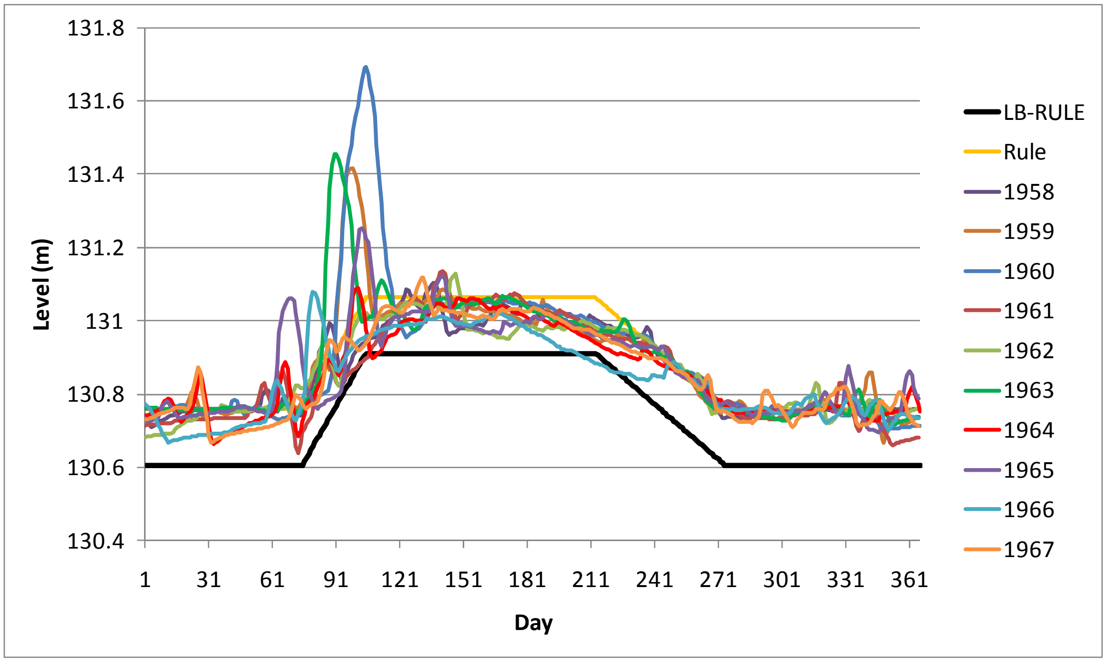

Figure 4-4 Model Simulation Results – 10 Year Drought (1958-1967)

It should also be noted that the Certificate of Approval describes the intake being in approximately six metres of water. The variation of the water level based on the current operation of the dam shows that during the two drought scenarios that the intake is far below this level.

5. NEXT STEPS

- Calculation of supply and reserve terms.
- Quantification of consumptive demand.
- Calculate percent water demand for all scenarios.
- Updating of SGRAs.
- Reporting.
- Training.

6. REFERENCES

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APPENDIX A

HSPF PARAMETERS AND VALUE RANGES

HSPF PARAMETERS AND VALUE RANGES

NAME	DEFINITION	UNITS	RANGE OF VALUES POSSIBLE		CALIBRATED VALUES By Subwatershed				
			MIN	MAX	GLO	SLN	SLE	SLW	SLS
SNOW - PARM1									
SHADE	Fraction shaded from solar radiation	none	0	0.8	0.15	0.15	0.15	0.15	0.15
SNOWOF	Snow gage catch connection factor	none	1	2	1.1	1.1	1.1	1.1	1.1
COVIND	Snowfall required to fully cover surface	inches	0.1	10	25 mm	25 mm	25 mm	25 mm	25 mm
KMELT	Degree-day null factor	mm/°C	-	-	3 - 6	3 - 6	3 - 6	3 - 6	3 - 6
TBASE	Base temperature for degree-day snowfall	°C	-7	7	0	0	0	0	0
SNOW - PARM2									
RDCSN	Density of new snow	none	0.05	0.3	0.09	0.09	0.09	0.09	0.09
TSNOW	Temperature at which precip becomes snow	°F	30	40	1 °C	1 °C	1 °C	1 °C	1 °C
SNOEVP	Snow evaporation factor	none	0	0.5	0.1	0.1	0.1	0.1	0.1
CCFACT	Condensation/convection melt factor	none	0.5	8	1	1	1	1	1
MWATER	Liquid water storage capacity in snowpack	in/in	0.005	0.2	0.05	0.05	0.05	0.05	0.05
MGMELT	Ground heat daily melt rate	in/day	0	0.1	0.3 mm/d	0.3 mm/d	0.3 mm/d	0.3 mm/d	0.3 mm/d
PWAT - PARM2									
LZSN	Lower zone nominal soil moisture storage	inches	2	15	150 mm	150 mm	150 mm	150 mm	150 mm
INFILT	Index to Infiltration Capacity	in/hr	0.001	0.5	0.43 mm/h	0.43 mm/h	0.43 mm/h	0.43 mm/h	0.43 mm/h
LSUR	Length of overland flow	feet	100	700	120 m	120 m	120 m	120 m	120 m
SLSUR	Slope of overland flow plane	ft./ft.	0.001	0.3	0.003	0.003	0.003	0.003	0.003
KVARY	Variable groundwater recession	1/inches	0	5	0.03 1/mm	0.03 1/mm	0.03 1/mm	0.03 1/mm	0.03 1/mm
AGWRC	Base groundwater recession	none	0.85	0.999	0.972	0.972	0.972	0.972	0.972
PWAT - PARM3									
PETMAX	Temp below which ET is reduced	°F	32	48	4 °C	4 °C	4 °C	4 °C	4 °C
PETMIN	Temp below which ET is set to zero	°F	30	40	1.7 °C	1.7 °C	1.7 °C	1.7 °C	1.7 °C
INFEXP	Exponent in infiltration equation	none	1	3	2	2	2	2	2
INFILD	Ratio of max/mean infiltration capacities	none	1	3	2	2	2	2	2
DEEPFR	Fraction of GW inflow to deep recharge	none	0	0.5	0	0	0	0	0
BASETP	Fraction of remaining ET from baseflow	none	0	0.2	0	0	0	0	0
AGWETP	Fraction of remaining ET from active GW	none	0	0.2	0	0	0	0	0
PWAT - PARM4									
CEPSC	Interception storage capacity	inches	0.01	0.4	1 - 12 mm	1 - 12 mm	1 - 12 mm	1 - 12 mm	1 - 12 mm
UZSN	Upper zone nominal soil moisutre storage	inches	0.05	2	2 - 25.4 mm	2 - 25.4 mm	2 - 25.4 mm	2 - 25.4 mm	2 - 25.4 mm
NSUR	Manning's n (roughness) for overland flow	none	0.05	0.5	0.2	0.2	0.2	0.2	0.2
INTFW	Interflow inflow parameter	none	1	10	5	5	5	5	5
IRC	Interflow recession parameter	none	0.3	0.85	0.67	0.67	0.67	0.67	0.67
LZETP	Lower zone ET parameter	none	0.1	0.9	0.25 - 0.6	0.25 - 0.6	0.25 - 0.6	0.25 - 0.6	0.25 - 0.6

* Min and Max values from United States Environmental Protection Agency BASINS Technical Note 6

APPENDIX B

SYDENHAM LAKE TIME SERIES PLOTS

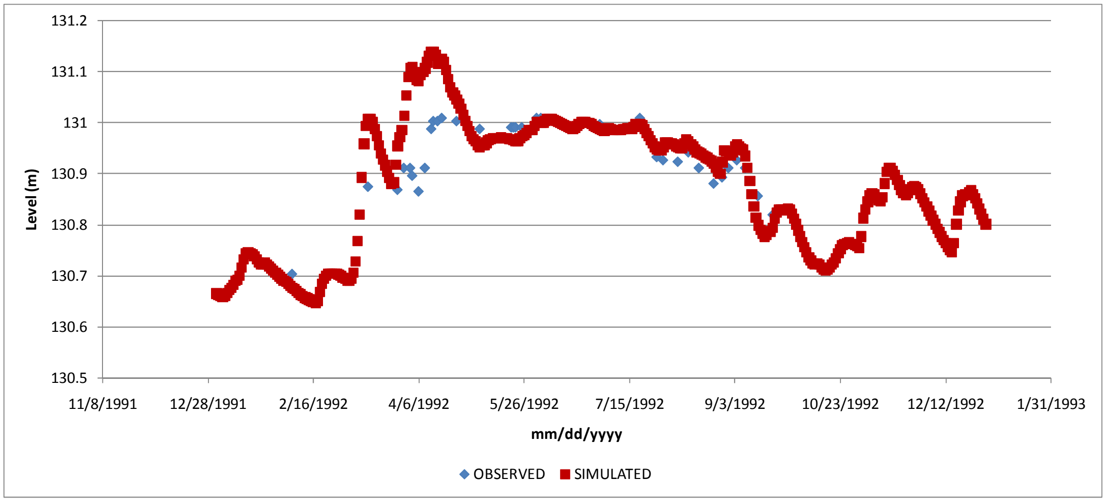

Figure B-1 Time Series Plot for Sydenham Lake 1992

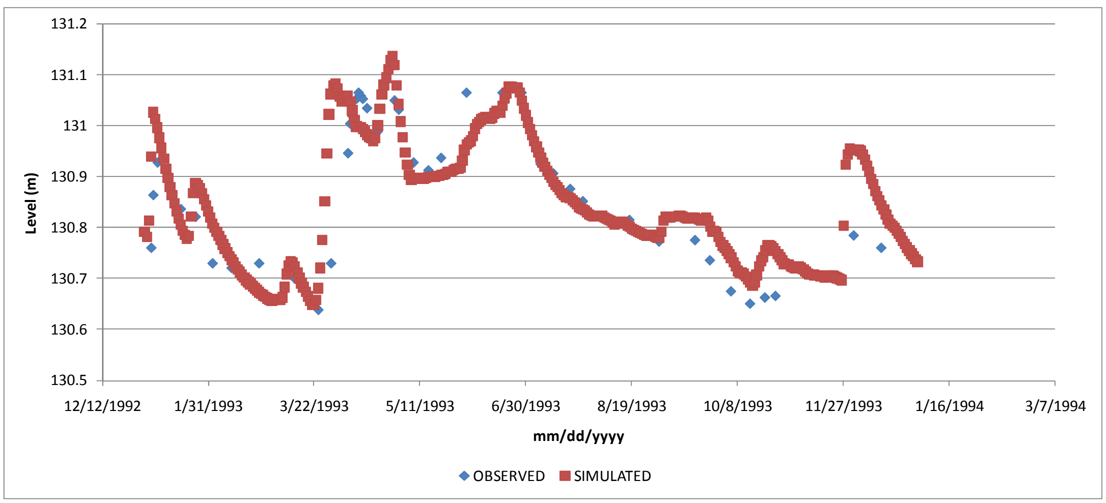

Figure B-2 Time Series Plot for Sydenham Lake 1993

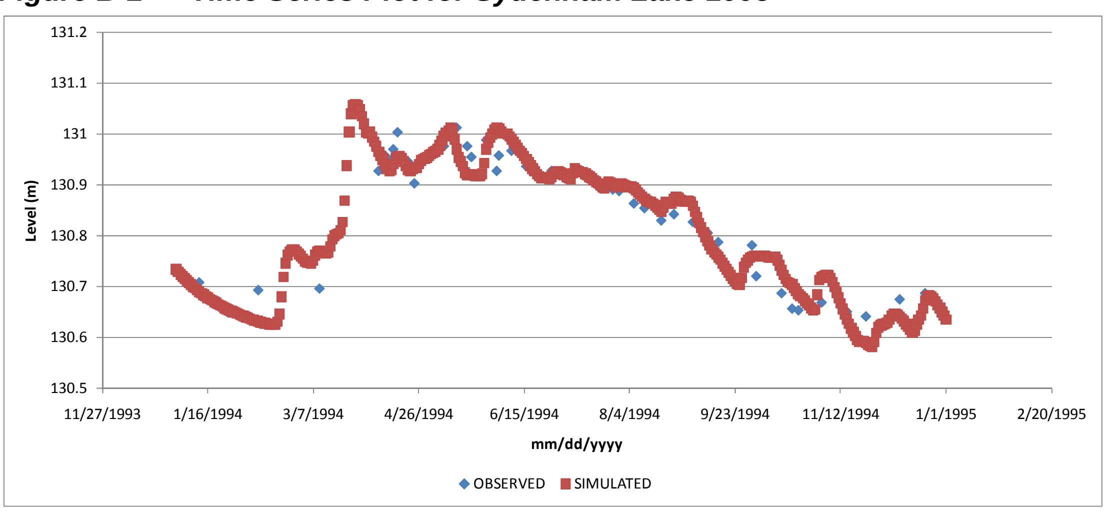

Figure B-3 Time Series Plot for Sydenham Lake 1994

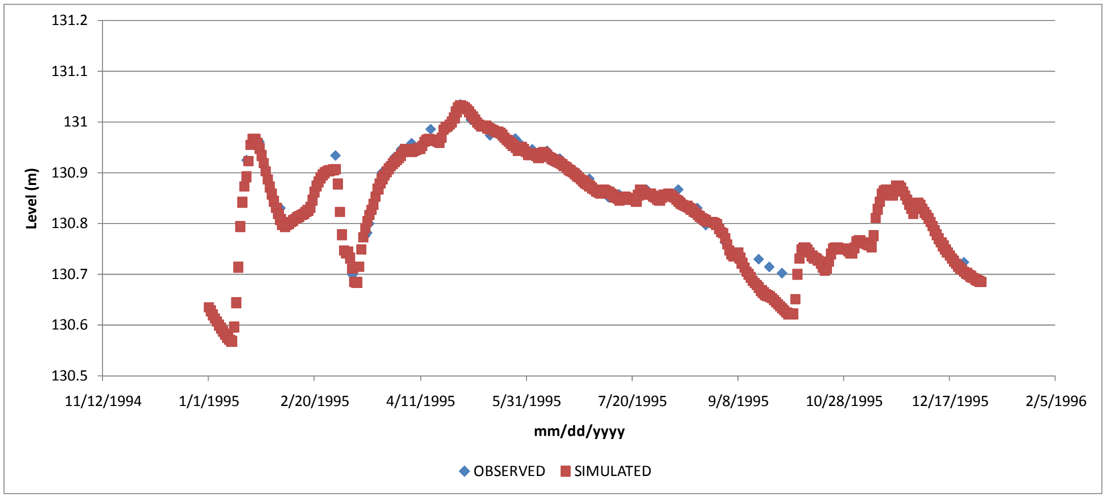

Figure B-4 Time Series Plot for Sydenham Lake 1995

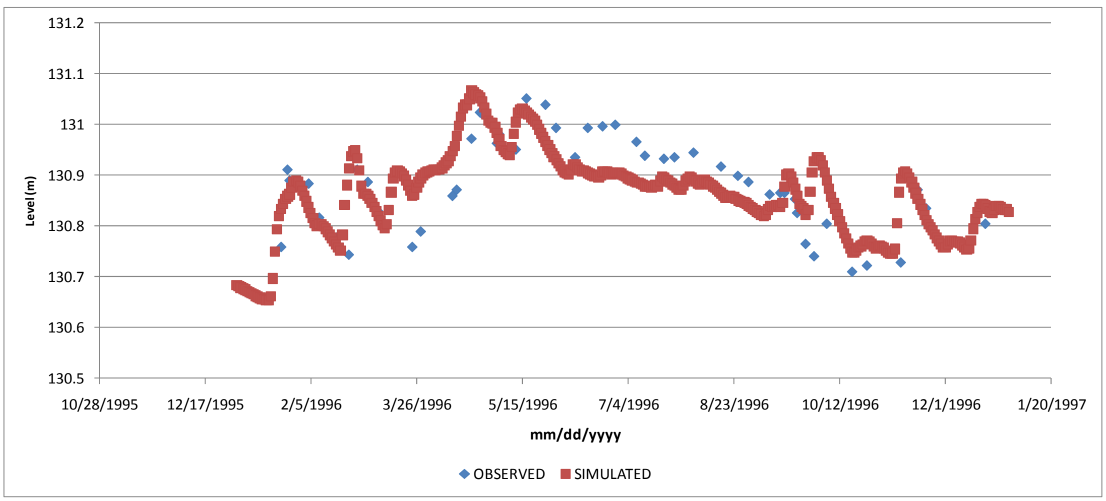

Figure B-5 Time Series Plot for Sydenham Lake 1996

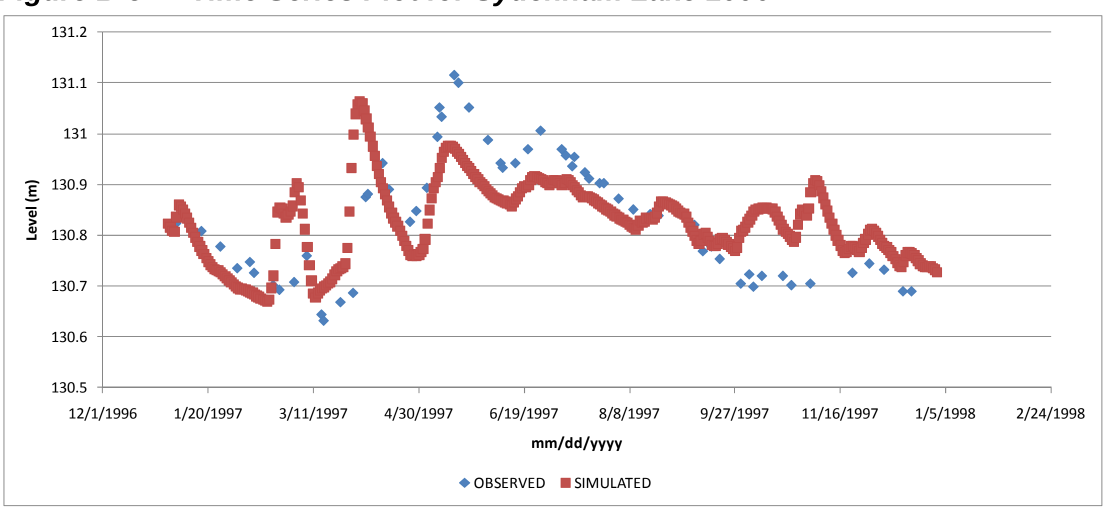

Figure B-6 Time Series Plot for Sydenham Lake 1997

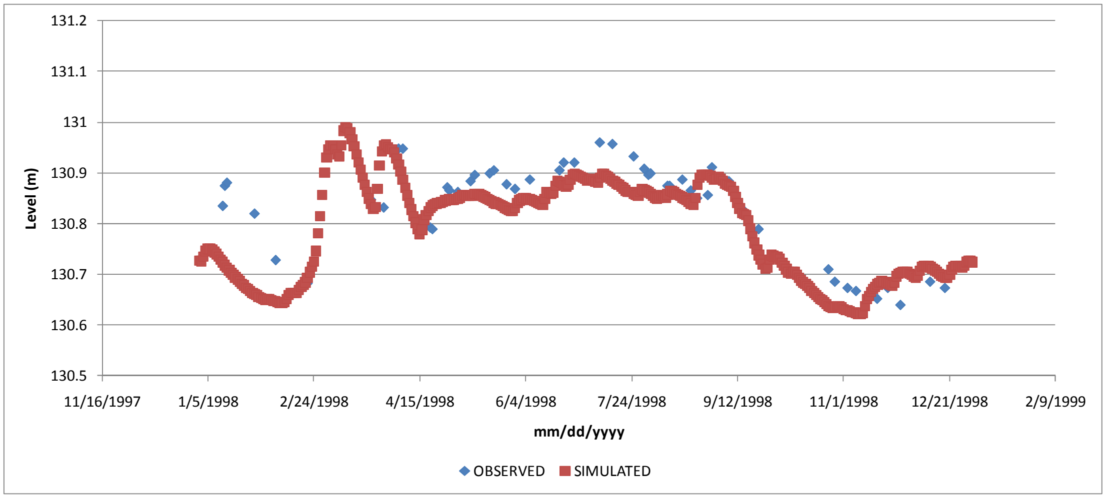

Figure B-7 Time Series Plot for Sydenham Lake 1998

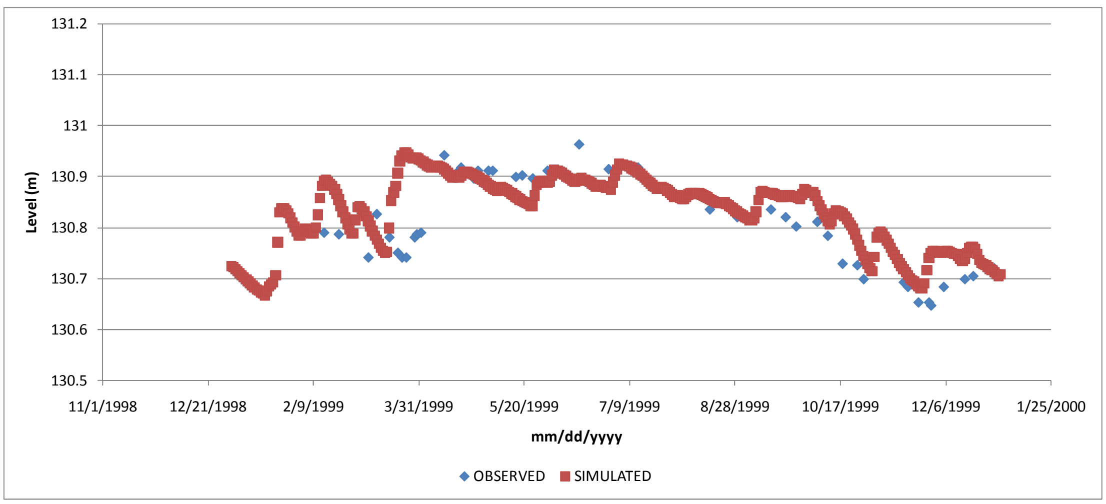

Figure B-8 Time Series Plot for Sydenham Lake 1999

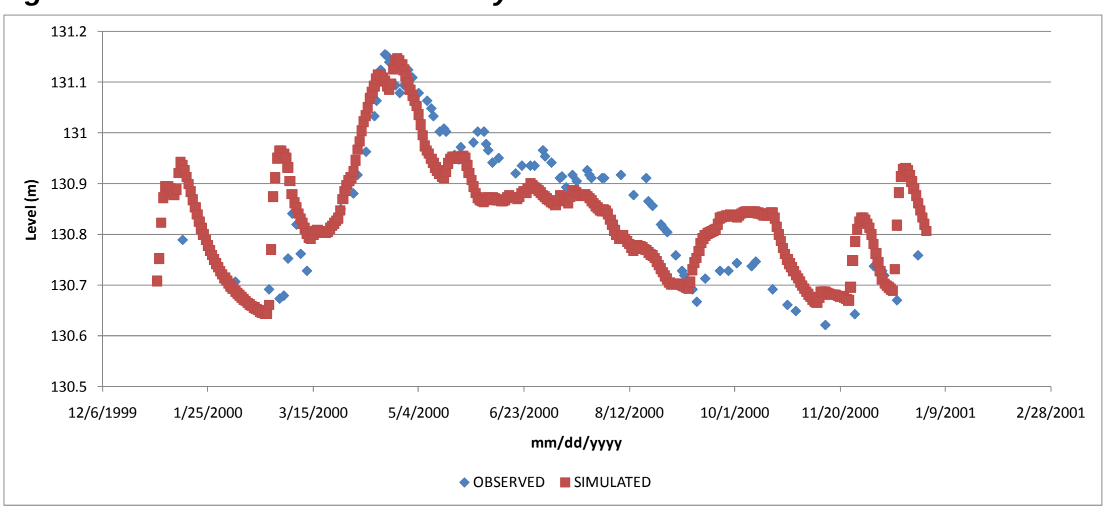

Figure B-9 Time Series Plot for Sydenham Lake 2000

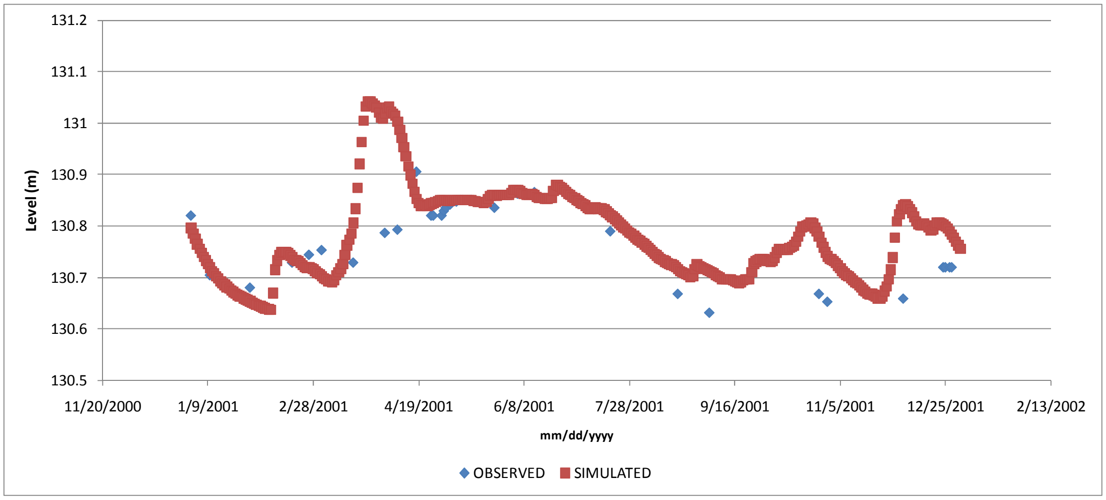

Figure B-10 Time Series Plot for Sydenham Lake 2001

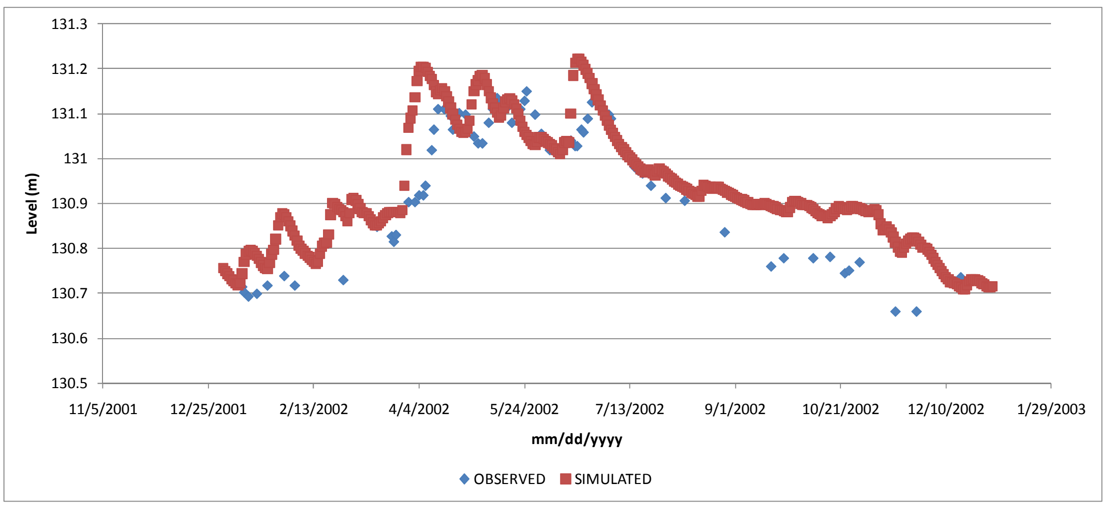

Figure B-11 Time Series Plot for Sydenham Lake 2002

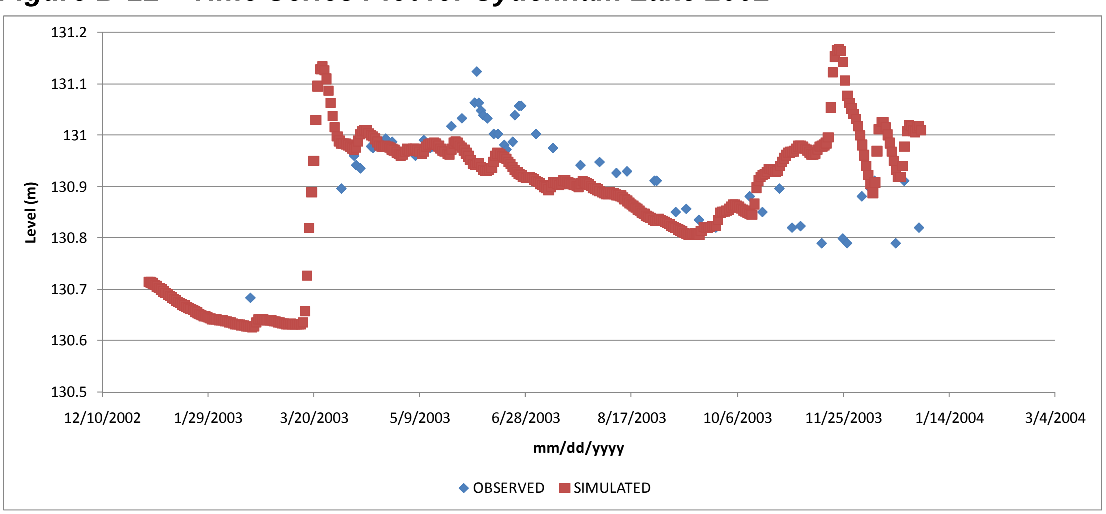

Figure B-12 Time Series Plot for Sydenham Lake 2003

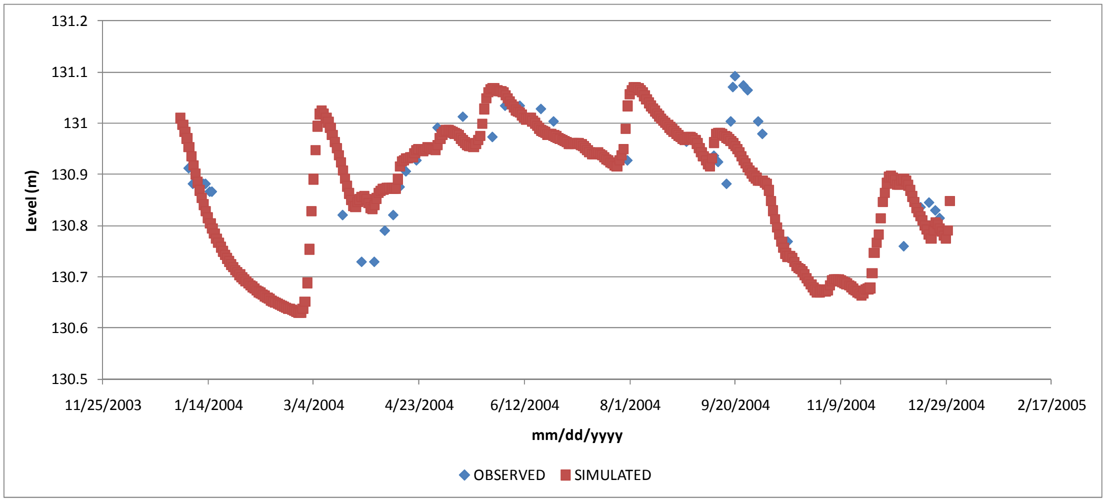

Figure B-13   Time Series Plot for Sydenham Lake 2004