

Supporting Documents



Hutchinson

Environmental Sciences Ltd.

Shoreline Development Capacity
of Elliot Lake Area Lakes Based
on Phosphorus and Lake Trout
Habitat

Prepared for: City of Elliot Lake
Job #: J100005

October 15, 2012



October 15, 2012

HESL Job #: J100005

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Dear Sir/Madam:

Re: Shoreline Development Capacity of Elliot Lake Area Lakes Based on Phosphorus and Lake Trout Habitat


Hutchinson Environmental Sciences Ltd. (HESL) is pleased to submit this draft report detailing development and use of a phosphorus model and dissolved oxygen data and models to assess shoreline development capacity of Elliot Lake area lakes. These models were originally developed for Lakeshore Properties by HESL staff while employed by AECOM (formerly Gartner Lee Limited) in their report Shoreline Capacity of Recreational Lakes in the City of Elliot Lake (November 17, 2008). In 2010, HESL revised the models with new phosphorus and dissolved oxygen monitoring data collected in 2009 and 2010 and based on comments received from the Ontario Ministry of the Environment (MOE; comments from Mr. Ed Snucins, January 2009). The present report includes updates to the models with the inclusion of additional monitoring data (2011 and 2012), and revisions to address additional comments from the MOE (comments from Mr. Ed Snucins, November 2011, January 2012, August 2012) and updates to the Provincial guidance.

We are delighted to continue our work with the City of Elliot Lake on this most interesting assignment as staff at HESL. Please do not hesitate to contact us if you have any questions or concerns regarding this report.

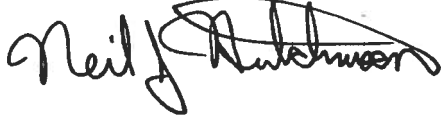
Sincerely,
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Draft



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Shoreline Development Capacity of Elliot Lake Area Lakes

1. Background

The *Elliot Lake Act* received royal assent in June 2001, which allows the disposition of Crown land in the City of Elliot Lake for residential shoreline development on area lakes as a means to increase the City's revenue base. The City of Elliot Lake has since developed 244 shoreline lots on Popeye, Dunlop and Quirke lakes and has little remaining inventory. Given the proven success of this program and continued market interest, the City of Elliot Lake plans to expand the shoreline development program.

To guide an environmentally responsible planning strategy for additional shoreline development, the City retained Gartner Lee Limited (assumed by AECOM in 2009) in 2006 to 1) assess of the potential impact of shoreline development on water quality, specifically phosphorus concentrations and dissolved oxygen concentrations (as they relate to lake trout habitat in MNR-designated lake trout lakes), and 2) use this information to recommend lakes suitable for lot development and the number of lots that could be developed while protecting water quality and coldwater fish habitat in the subject lakes and downstream. The first report (AECOM, 2008) included:

- Development of a watershed-based phosphorus model to determine the amount of shoreline lot development that could occur on area lakes while maintaining phosphorus concentrations within an acceptable limit to protect water quality,
- Assessment of dissolved oxygen concentrations for lake trout lakes using measured data and a modelling approach, and
- Implementation of a monitoring program for a) spring overturn total phosphorus concentrations to validate the phosphorus model, b) monthly total phosphorus concentrations in lakes affected or potentially affected by effluent from the Esten Wastewater Treatment Plant (WWTP), and c) end-of-summer temperature and dissolved oxygen to improve estimates of existing oxygen concentrations for lake trout habitat.
- Identification of suitable lakes and lot numbers to meet the City's development needs and environmental constraints.

In 2010, the City retained Hutchinson Environmental Sciences (HESL) to revise the AECOM (2008) study to address comments from the Ministry of the Environment (MOE) and the Ministry of Natural Resources (MNR) and to update the assessment with newly obtained monitoring data and changes in lakes and lot numbers proposed for development. This final report addresses further comments from MOE and incorporates revised Provincial guidance for the assessment of lakeshore capacity and monitoring data that became available following production of the HESL (2010) report.

2. Proposed Development

The City of Elliot Lake is proposing to request the disposition of Crown land for the development of 668 shoreline lots on 11 lakes in the Municipality that lie within the Serpent River watershed (Figure 1, Table 1). Road access is planned for 355 of the proposed lots and the remaining 313 proposed lots will have water access only. In addition to this proposed development, there are 34



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lots that were previously approved for disposition on Rossmere Lake, which lies outside the Serpent River watershed and are not considered in this report. Seven of the lakes proposed for development are designated lake trout lakes by the Ministry of Natural Resources (MNR)(Table 1).

Table 1. Proposed Shoreline Development of Elliot Lake Area Lakes

Lake Name	Proposed Development		Lake Trout Lakes
	Road Access Lots	Water Access Lots	
Belle Lake (SSM 230)	12		
Esten Lake	75	25	✓
Grandeur Lake	26	30	
Marshland Lake	18	6	
May Lake	64	35	✓
McCarthy Lake	112	58	✓
Pecors Lake		50	✓
Quirke Lake	4	91	✓
Rye Lake	10		
Summers Lake	34		✓
Trout Lake		18	
Total	355	313	



Figure 1. Study Lakes and Watersheds

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3. Impacts of Shoreline Development on Phosphorus Concentrations

Phosphorus limits the growth of aquatic plants and algae in most Canadian Shield lakes and so increased phosphorus loads from shoreline development (i.e., due to septic inputs and shoreline clearance) can impair water quality and habitat for coldwater fish due to the excessive production of nuisance aquatic plants and a decline in oxygen with to decomposition of that plant matter. The Province of Ontario's (2010) *Lakeshore Capacity Assessment Handbook* provides guidance to municipalities and other stakeholders involved in the management of shoreline development of Ontario's inland lakes to protect water quality and coldwater fish habitat as they relate to phosphorus and oxygen concentrations. The handbook recommends a modelling approach, the Lakeshore Capacity Model (LCM), to determine lakeshore capacity, which is defined as the amount of shoreline development that can occur while maintaining acceptable phosphorus and oxygen concentrations.

The LCM is a variant of the original MOE Lakeshore Capacity Study Trophic Status Model (Dillon *et al.* 1986), which has been substantially reworked and updated over the years to reflect improved scientific understanding of phosphorus loads to lakes and lake responses to those loads (Hutchinson 2002; Paterson *et al.* 2006). This steady-state mass balance model estimates hydrologic and phosphorus loading from natural (watershed runoff and atmospheric deposition) and human (septic systems and land disturbance) sources for all lakes within a watershed and links them together considering lake dynamics to predict total phosphorus concentrations in lakes. The model has been used routinely by the MOE and various municipalities to manage shoreline development (e.g., District Municipality of Muskoka, Seguin Township).

The revised Provincial Water Quality Objective (PWQO) allows a 50% increase in phosphorus concentration over a modelled baseline (i.e., the concentration that would occur if all human development was removed from the watershed) to a maximum cap of 20 µg/L to protect water quality and habitat for coldwater fish. In situations where modeling fails to confidently predict phosphorus concentration in a lake, the Province recommends that the former interim PWQO be used to assess shoreline development capacity. The interim PWQO allows an increase in phosphorus concentration to 10 µg/L from development for lakes that have concentrations below 10 µg/L naturally, and 20 µg/L for all other lakes (MOE, 1994).

The Province recognizes that phosphorus concentrations in lakes are variable from year to year and that there are inaccuracies in some of the input parameters and assumptions used by the LCM that contribute to error in predictions. It is recommended that if the predicted total phosphorus concentration of a lake is within 10% of the PWQO, then some flexibility be allowed when making management decisions. Decisions should consider site-specific knowledge of the system such as lake sensitivity to phosphorus loading, history of algal blooms, and other potential threats to water quality.



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3.1 Phosphorus Model Development

The Elliot Lake phosphorus model was developed using this most recent Provincial guidance (Province of Ontario, 2010, 2011), herein called the Handbook, including suggested input parameters and coefficients to provide scientifically-defensible estimates of phosphorus loads and concentrations upon which to determine shoreline development capacities lakes in Elliot Lake.

The watershed-based model recognizes the fact that water and phosphorus move through the watershed such that the phosphorus contained in an upstream lake forms part of the phosphorus load to downstream lakes. The Elliot Lake model includes 177 lakes within 1) the Serpent River watershed upstream of and including McCarthy Lake (168 lakes), and 2) the White River watershed upstream of and including Flack Lake (9 lakes). Together, the 177 lakes and their watersheds encompass an area of 1,037 km² (Figure 1).

All of the lakes that are proposed for development lie within the Serpent River Watershed with the exception of Rossmere Lake, which was approved previously for the creation of 34 lots and not included in the model.

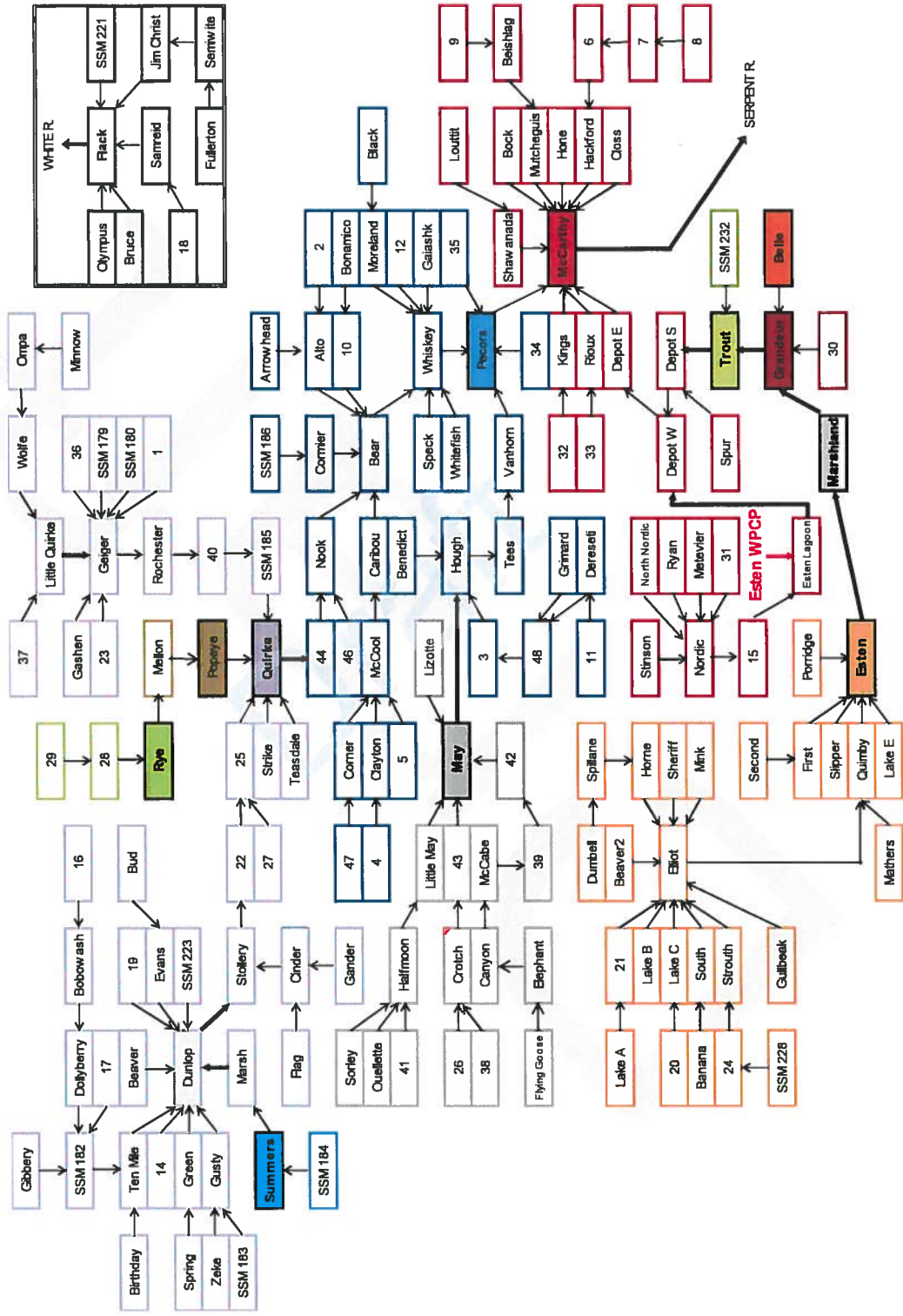
Watershed and lake surface areas were determined using a hydrologic model constructed from the Ministry of Natural Resources' 10-m resolution Digital Elevation Model (DEM) and ArchHYDRO, a GIS-based modelling suite for all lakes with a surface area of 10 ha or greater. The Handbook recommends that only lakes with a surface area of at least 25 ha be included in the LCM because for very small lakes, minor differences in surface area can have a large impact on the model output. The Elliot Lake model was developed prior to this guidance and the decision to include small lakes (between 10 and 25 ha) is consistent with previous practice. Theoretically, if small lakes are excluded from the model, this would result in less accurate predictions because 1) phosphorus retention in these lakes would not be accounted for resulting in over-prediction of phosphorus, and 2) natural phosphorus loads (from runoff and atmospheric deposition) would be underpredicted because phosphorus export from atmospheric deposition to the surface of a lake is higher than the export from runoff. If accurate lake and watershed area data are available, as is the case for the Elliot Lake study area, then inclusion of small lakes would improve model performance. There are 88 small lakes representing 50% of the total number of lakes in the Elliot Lake model, with excellent agreement between measured and modelled total phosphorus concentrations (see Section 3.2). This suggests that the GIS data used to determine lake and watershed areas is accurate and does not contribute to significant error in the model. Revision of the model to exclude the large number of small lakes therefore is not recommended as this would likely result in less accurate predictions.

The natural drainage conditions have been altered for two lakes, North Nordic and Esten lakes. North Nordic Lake originally drained to Spillane Lake, but its outflow was redirected to Nordic Lake via a series of wetlands. The east bay of Esten Lake, called Esten Lagoon, was isolated from the main body of the lake by an earthen berm to isolate effluent discharge from the Esten Lake water pollution control plant (WPCP) from the main basin of Esten Lake. Water flows from the Esten Lagoon to the west basin of Depot Lake via a constructed channel. These hydrological changes were taken into account in the development of the model. A schematic illustrating the hydrological linkage of all the lakes in the model is provided in Figure 2.



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Figure 2. Hydrological linkage of 177 lakes included in the model. Solid cells indicate lakes proposed for shoreline development and stippled cells indicate lakes that were developed under the initial shoreline development program.



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Phosphorus inputs to each of the lakes were determined using input parameters recommended by the Handbook (2010) as summarized in Table 2.

Table 2. Summary of Model Input Parameters

Parameter	Value
Runoff (m/yr)	0.487
Precipitation P Deposition Rate (mg/m²/yr)	16.70
P-Export (mg/m²/yr)	
Wooded area (<15% cleared area):	
Wetland Area <3.5%	5.50
Wetland Area ≥3.5%	0.47 * wetland area + 3.82
Cleared area (≥15% cleared area):	
Wetland Area <3.5%	9.80
Wetland Area ≥3.5%	(0.47 * wetland area + 3.82) * 1.8
Urban area	50.00
Lake shore lot within 200 m of the shoreline	9.80
Golf Course	14.00
Usage Figures (capita years/yr)	
Permanent Occupancy	2.56
Seasonal Occupancy and Elliot Lake Proposed Development Lots with Water Access Only	0.69
Elliot Lake proposed development with road access and exiting vacant lots (19% permanent and 81% extended seasonal) ¹	1.52
Campgrounds/Tent Trailers/RV parks	0.37
Phosphorus Supply from Tile Field (kg/capita/yr)	
Cottage Lots, Trailer and Camp Sites within 300 m of the shoreline	0.66
Average Developed Areas (m²/unit) (may be smaller than actual lot size)	
Shoreline Lot	3,798
Resort/Trailer lot	1,000
Golf Course (per hole)	20,000

Notes: ¹Hybrid usage factor based on existing breakdown of seasonal and permanent dwellings for previously approved Lakeshore Properties development lots (see Table 3), as recommended by the Handbook. The extended seasonal usage figure of 1.27 capita years/yr was applied to the portion of seasonal residences and the permanent usage figure was applied to permanent residences.

Existing cottage and residence numbers were obtained from lake management plans produced in 2001 by the Elliot Lake Research Field Station of Laurentian University Environmental Services for the Elliot Lake Waterfront Development Committee, a survey of topographic maps and through discussions with City of Elliot Lake staff, and local business owners. Lakeshore Properties staff conducted shoreline



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surveys of Dunlop, Quirke, and Popeye lakes in 2008 and 2009 to determine the number of cottages, residences (and stage of construction), and septic/outhouses on lots sold under the Lakeshore Properties Program (Table 3). To model existing phosphorus concentrations, all lots with septic or outhouses were included as phosphorus sources, regardless of the stage of building construction. Modeled phosphorus inputs from these lots may therefore be higher than the actual loads because many of the buildings are not presently built or occupied.

Table 3. Existing Shoreline Residential Development as of 2009

Lake	Total Number of Lots	Number of Seasonal Cottages			Number of Permanent Residences	Vacant Lots
		Septics	Outhouses	Total	Septics	
Previously Approved Lakeshore Properties Development:						
Dunlop	169	47	5	52	8	109
Quirke	57	14	6	20	9	28
Popeye	11					11
Total	237	61	11	72	17	148
<i>% of Total Developed</i>				<i>81</i>	<i>19</i>	
Other Known Existing Development:						
Flack	2			1	1	
Ten Mile	1			1		
Quirke	1			1		
Gullbeak	1			1		
Quimby	2			2		
Marshland	7			7		
McCarthy	2			2		
Total	16			15	1	
<i>% of Total Developed</i>				<i>94</i>	<i>6</i>	

There are two known campgrounds on Dunlop Lake with a total of 146 serviced campsites/tent trailer and a small resort/lodge with 11 seasonal rooms within 300 m of the lake that were included in the model. Also included in the model were 60 campsites at Mississagi Provincial Park Campground located on Semivite Lake.

A key assumption of the model is that all phosphorus supply from the tile field of a septic system within 300 m of the shoreline of a lake or connecting tributary will enter that lake. This conservative assumption is made only to satisfy the requirements of the MOE model and we note the abundance of direct measurements of tile fields published in the scientific literature that challenge it (see Hutchinson 2002 for a review).

The Esten Lake water pollution control plant (WPCP) is the only known point source of phosphorus in the study area. The plant formerly discharged treated sewage to Esten Lake. Since 1981, discharges have been to Esten Lagoon at the far east end of Esten Lake, which is physically separated from the Esten



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Lake by an earthen berm. The Esten Lagoon discharges to the west basin of Depot Lake under normal flow conditions via a constructed diversion channel. Under high water conditions like those that occurred in spring 2008, flow can occur into Esten Lake via overflow drain pipes. Since construction of the berm, overflow to the main basin of Esten Lake has only been observed in spring 2008 and in 2009, and these overflow conditions lasted only a few days. Therefore, the model was not adjusted to account for phosphorus loads to Esten Lake from the lagoon as the load which would occur from 2 to 3 days of overflow would be insignificant given the total phosphorus load to the lake under normal flow conditions.

The phosphorus load from the WPCP to Esten Lagoon is 1,119.8 kg/yr based on a mean daily effluent flow of 6,255 m³ and a mean monthly phosphorus concentration of 0.50 mg/L from 2004-2011 (Table 4). The average operational flow and phosphorus concentrations over this time period were approximately one half of the rated capacity of the plant, which has serviced a population of 11,348 (Statistics Canada, 2011 Census) to 11,549 persons (Statistics Canada, 2006 Census). Over the past several decades, however, the population of Elliot Lake has varied considerably with changes in mining activity in the area, and reached a maximum population of approximately 26,000 people in the 1980s. The present rated flow capacity of the plant was to service a population of over 20,000. It is, however, very unlikely that Elliot Lake would reach this population in the foreseeable future. Population Growth Estimates by the City project a population increase to 13,042 over the next 7 years assuming that the planned shoreline development takes place (Fred Bauthus, former CAO, City of Elliot Lake, pers. comm.).

Table 4. Esten Lake WPCP Effluent Flows and Phosphorus Concentrations (2004-2011)

Year	Average Daily Flow	Average Monthly Phosphorous Concentration	Average Phosphorus Load
	(m ³)	(mg/L)	(kg/yr)
2004	6,210	0.43	974.7
2005	5,884	0.46	987.9
2006	6,406	0.60	1,402.9
2007	5,649	0.53	1,092.8
2008	8,596	0.42	1,317.8
2009	6,718	0.51	1,238.2
2010	4,856	0.60	1,050.1
2011	5,720	0.46	952.9
Average Operational	6,255	0.50	1,119.8
Rated Capacity	13,000	1.00	4,745.0
Potential with Population Increase to 15,000	8,202	0.50	1,497.5

To account for potential growth in the area and increased servicing by the WPCP, future phosphorus concentrations for lakes downstream of the effluent discharge were estimated using phosphorus loads that would occur with estimated plant flows generated for a population of 15,000 and the current average operational phosphorus concentration of 0.50 mg/L. The phosphorus load to Esten Lagoon from the WPCP at these flows and phosphorus concentration would be 1,491 kg/yr. This population increase



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provides a reasonable future scenario given the population growth estimates described above. If another population boom should occur, the City would need to consider phosphorus load impacts downstream of the plant and the need to improve phosphorus removal efficiency at the plant.

Not all phosphorus contained in a lake is passed on to downstream lakes because a portion of the phosphorus is lost from the water column to the sediments. The proportion of phosphorus lost to the sediments (the Retention coefficient, R_p) in a stratified lake is related to the settling velocity (v) of phosphorus and the areal water load (q_s), and is calculated in the model as:

$$R_p = v/(v+q_s)$$

The model assumes a settling velocity of 12.4 m/yr for oligotrophic, stratified Precambrian Shield lakes with oxic hypolimnia, which is the mean observed settling velocity of lakes in central Ontario (Dillon and Kirchner, 1975). Lakes with anoxic hypolimnia are known to retain less phosphorus than lakes with oxic hypolimnia because phosphorus is released from the sediment (called internal loading) or there is less efficient removal of the phosphorus to the sediment. A lower settling velocity of 7.2 m/yr therefore is assumed in the model for lakes with anoxic hypolimnia, which was derived empirically for a single lake (Red Chalk Lake, east basin) that has an anoxic hypolimnion by optimizing the settling velocity such that the predicted and observed total phosphorus concentrations agreed (Dillon et al., 1986). Dillon et al. (1986) suggested that this approach could be used because there was no phosphorus supply to this lake from shoreline development. The settling velocities of 12.4 m/y and 7.2 m/yr were used to calculate phosphorus retention in lakes with oxic and anoxic hypolimnia, respectively.

End-of-summer and/or fall dissolved oxygen monitoring data exist for 34 of the study lakes to assess oxygen status. Dissolved oxygen concentrations in the hypolimnion of lakes can continue to decline until fall turnover and so lakes with a mean hypolimnetic dissolved oxygen concentration of less than 1 mg/L were considered to be potentially anoxic. Potentially anoxic lakes included Belle, Depot (west basin), Gander, Kings, Marsh, Marshland, Quimby, Rye, Slipper, and Trout lakes. The presence of other lakes with anoxic hypolimnia and resulting internal phosphorus loading may contribute to error in the model.

3.2 Model Validation

Confidence in the model's ability to predict phosphorus concentrations requires validation of model results against measured values. The phosphorus model used in this study is a steady-state model and therefore, model results should be validated against long-term mean measured data to account for inter-annual variability in phosphorus measurements. The City of Elliot Lake implemented a monitoring program in 2008 to collect spring overturn total phosphorus concentrations from selected lakes in the watershed. Since 2009, monthly sampling for total phosphorus in the euphotic zone (2x Secchi depth) has also been conducted to: a) monitor the impacts of the Esten Lake WPCP at several locations upstream and downstream of the discharge, and b) to assess recovery of Esten Lake which received WPCP discharge prior to diversion of the discharge to the Esten Lagoon. Results from the sampling surveys are described in the following section and are then compared to modeled phosphorus concentrations to assess the reliability of the model to predict responses of the lakes to phosphorus inputs from shoreline development.

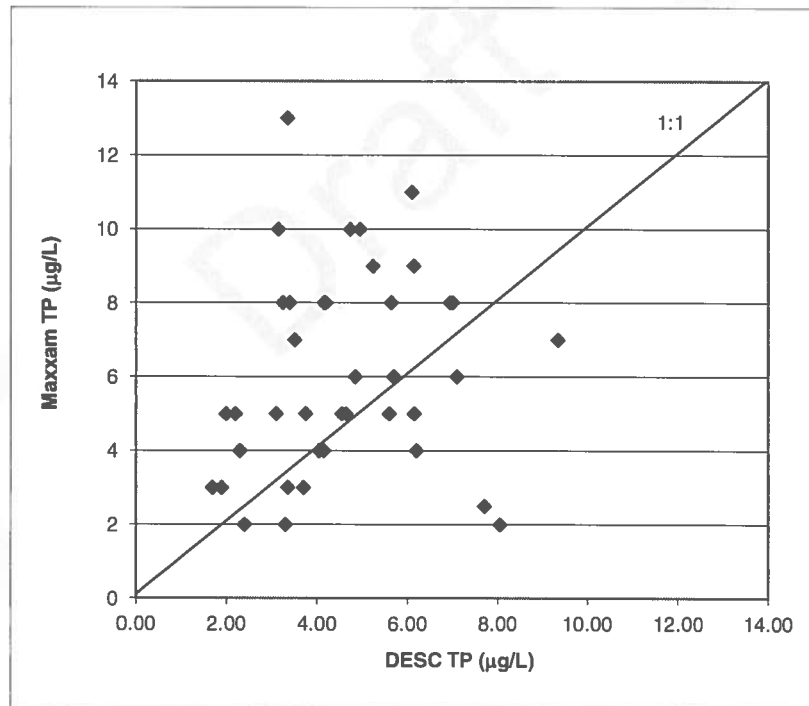


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3.2.1 Measured Total Phosphorus Concentrations

In May 2008, triplicate spring overturn water samples were collected from 43 locations in 25 lakes. One sample from each field triplicate was submitted to Maxxam Analytics, Inc. and the remaining two samples were submitted to the Trent University lab at the Dorset Environmental Science Centre (DESC) for total phosphorus analysis. Reported total phosphorus (TP) concentrations from Maxxam Analytics were higher than those from DESC for 69.8% of the spring 2008 samples (Figure 3). The DESC values are considered to be more reliable due to the better precision and accuracy of measurements from this lab. For this reason, water samples collected in the years following were sent to DESC for analysis and the model was validated using only the DESC concentrations. From 2009 to 2012, 30 lakes have been monitored for spring total phosphorus concentration. Unfortunately, the 2012 data were not able to be used due to an error at the lab. The cause of the lab error is not known, but we suspect that the sampling tubes were mislabelled. Results for the 2012 samples were not received in sufficient time to resample the lakes during spring overturn of that year.

Figure 3. Comparison of 2008 Total Phosphorus (TP) Measurements from Maxxam Analytics, Inc. and Dorset Environmental Science Centre (DESC)



Field duplicates analyzed at the DESC laboratory (2008 to 2011) showed excellent agreement between sample pairs with an absolute mean difference of 1.6 µg/L (20.9%). Variation between field duplicates (split samples) is presumably due to variations in the sample matrix. For data from the MOE's Lake Partner Program analyzed at DESC, a consistent percentage of the samples (5%) showed larger than expected differences between field duplicates (i.e., >4 µg/L). Much investigation has failed to identify the cause for these measured differences. Separate experiments have excluded sample container

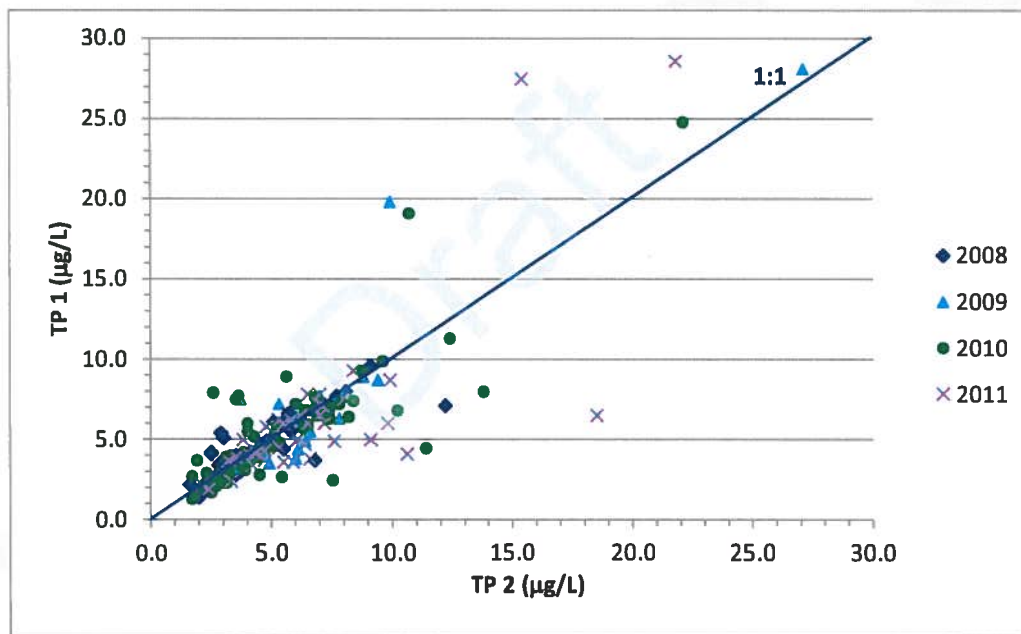


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cleanliness, lab apparatus, variation in the sub 80 μ -sample matrix, and external inputs of phosphorus as sources of contamination. It remains unclear how these samples are contaminated. In almost every case when these samples are reanalyzed, the retested pair of samples agree with the lower of the original two samples in the bad field split. After testing hundreds of such pairs with sample returns from the Lake Partner Program, sufficient confidence was gained to allow the elimination of the higher of the two samples in cases where there are bad splits (Bev Clark, HESL, pers.comm.).

For the Elliot Lake data set, field duplicates that differed by more than 5 $\mu\text{g/L}$ or by more than 30% were considered to be bad splits and the higher value was discarded in each case from the dataset as recommended by the Handbook. The mean difference between field duplicates after removing the bad splits was 10%.

Figure 4. Comparison of Field Duplicate Total Phosphorus (TP) Concentrations from Elliot Lake Area Lakes Analyzed at the Dorset Environmental Science Centre (DESC), 2008-2011 (n=194)



In relatively small datasets like the Elliot Lake data set, the calculation of average total phosphorus concentration is sensitive to outliers, that is, extreme values that are not representative of the site condition. Outliers were assessed statistically using the Grubb's Test (Grubbs, 1969), which is a recommended procedure to screen the DMM's Lake System Health data set for outliers (Gartner Lee Limited, 2008). To perform the Grubb's Test, the ratio 'Z' is calculated as the difference between the suspect sample and the mean divided by the standard deviation (SD) of all values including the outlier. If Z is higher than the critical value of Z for a given sample size (N), the sample is considered to be an outlier at $p < 0.05$. Only two outliers were identified by the Grubb's Test including the 2008 value for Slipper Lake (9.4 $\mu\text{g/L}$) and the 2010 value for Summers Lake (1.9 $\mu\text{g/L}$). These values were removed from the calculation of mean total phosphorus concentration for those lakes.



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The mean spring total phosphorus concentration of the monitoring lakes is provided in Table 5. Three years of data are available for four of the lakes and four years of data are available for the remaining 26 lakes. The Handbook suggests that at least 2 years of spring overturn data are necessary to be 95% confident of being within 20% of the long term mean. The Elliot Lake monitoring data therefore provide mean concentrations within at least 20% of the long term mean ($p < 0.05$) and can be used to validate the model predictions with confidence. There is a large variability in phosphorus concentrations between years in the Esten Lagoon, Depot Lake (west basin) and Depot Lake (east basin), which are influenced by the Esten Lake WPCP discharge.

Mean monthly euphotic zone total phosphorus concentrations are provided in Table 6 for sampling locations in Esten Lake, the Esten Lagoon and Depot Lake.

Annual and ice-free euphotic zone phosphorus concentrations were similar to spring overturn concentrations for Esten Lake and the south basin of Depot Lake as would be expected for deep, oligotrophic lakes (Table 7). By contrast, euphotic zone concentrations were considerably higher in Esten Lagoon and the east and west basins of Depot Lake which receive phosphorus inputs from the Esten Lake WPCP suggesting that these lakes are sensitive to the variable phosphorus loads from the WPCP. Spring overturn concentrations for these basins may not be representative of mean conditions in these lakes, but would reflect recent phosphorus loading from the WPCP.



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Table 5. Mean Spring Total Phosphorus Concentrations for Elliot Lake Area Lakes (n=30)

Lake	Total Phosphorus ($\mu\text{g/L}$)					
	2008	2009	2010	2011	Mean	Standard Deviation
Belle	nd	7.0	4.9	5.3	5.7	1.1
Depot (east basin)	3.2	9.5	8.5	7.4	7.1	2.8
Depot (south basin)	7.0	6.8	7.4	6.3	6.9	0.5
Depot (west basin)	4.8	8.9	11.9	7.8	8.3	2.9
Dunlop	5.0	4.1	2.6	4.3	4.0	1.0
Elliot	4.3	5.3	3.5	4.2	4.3	0.7
Esten	6.0	7.3	7.1	6.6	6.7	0.6
Esten Lagoon	nd	27.6	46.4	21.8	31.9	12.9
Gander	7.1	5.7	4.7	3.8	5.3	1.4
Grandeur	7.0	7.2	6.7	5.8	6.7	0.6
Gullbeak	4.9	6.7	7.3	6.6	6.4	1.0
Hough	2.9	4.0	2.7	5.0	3.7	1.1
Kings	4.2	6.1	6.2	12.7	7.3	3.7
Little Quirke	3.3	6.0	3.5	5.5	4.6	1.3
Marsh	nd	4.3	3.2	5.5	4.3	1.1
Marshland	5.0	7.3	7.0	6.4	6.4	1.0
Mathers	4.7	5.3	4.5	3.7	4.5	0.7
May	2.2	3.3	3.0	6.1	3.6	1.7
McCarthy	3.6	6.2	5.6	6.3	5.4	1.3
Nordic	5.7	3.9	3.1	6.0	4.7	1.4
Pecors	4.2	4.1	2.3	5.6	4.0	1.3
Popeye	6.1	6.1	3.8	4.5	5.1	1.2
Quimby	6.2	4.0	4.0	4.4	4.6	1.0
Quirke	1.5	3.5	2.1	2.3	2.4	0.9
Rossmere	6.2	nd	6.1	7.2	6.5	0.6
Rye	3.7	6.8	5.6	6.4	5.6	1.4
Slipper	9.4 ¹	5.1	4.5	4.3	4.6	0.4
Summers	3.5	3.7	1.9 ¹	3.7	3.6	0.1
Ten Mile	2.9	2.9	2.3	3.3	2.8	0.4
Trout	5.7	6.9	6.6	6.8	6.5	0.6
<i>Mean</i>	4.6	6.4	6.4	6.2	6.1	1.6
<i>Minimum</i>	1.5	2.9	2.1	2.3	2.4	0.1
<i>Maximum</i>	7.1	27.6	46.4	21.8	31.9	12.9

Notes: nd = no data, ¹statistical outlier based on Grubb's Test ($p > 0.05$) and not included in summary statistics



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Table 6. Mean Monthly Total Phosphorus Concentrations for Monitoring Sites in Esten Lake, the Esten Lagoon, and Depot Lake (2008-2012)

Site	2008		2009		2010		2011		2012		Mean TP ¹ (09-12) (µg/L)
	TP (µg/L)	n	TP (µg/L)	n	TP (µg/L)	n	TP (µg/L)	N	TP (µg/L)	n	
Depot (east basin)	9.3	1	7.8	11	10.6	11	6.9	11	7.7	9	8.2
Depot (south basin)	6.3	3	6.4	9	7.8	10	7.1	10	6.7	8	7.0
Depot (west basin)	8.3	3	9.3	10	10.5	11	8.5	11	10.3	9	9.6
Depot (littoral zone, west basin)	16.3	3	19.4	9	24.3	11	43.6	11	24.5	9	27.9
Esten (east basin)	Nd		7.8	7	7.9	10	7.1	10	6.0	9	7.2
Esten Lagoon	70.5	2	39.5	10	57.6	11	38.9	11	38.7	9	43.7
Esten Lagoon at discharge	64.0	2	33.1	9	39.6	11	31.0	11	34.8	9	34.6
Esten Lagoon in diversion channel	79.6	1	33.5	11	37.8	11	30.3	11	38.8	9	35.1
Esten (west basin)	Nd		6.4	7	6.6	10	5.8	10	5.8	9	6.1
Nordic discharge	Nd		5.5	8	4.6	11	5.1	10	6.1	9	5.3

Notes: ¹2008 was not monitored monthly over the full year and so is not included in the calculation of the mean

Table 7. Comparison of Annual and Ice Free Euphotic Zone and Spring Overturn Total Phosphorus Concentrations in Esten Lake, Esten Lagoon and Depot Lake (2009-2012)

Site	Mean TP Concentration (µg/L)		
	Annual Euphotic Zone	Ice Free (Apr-Nov) Euphotic Zone	Spring Overturn
Depot (east basin)	8.2	8.2	7.1
Depot (south basin)	7.0	6.9	6.9
Depot (west basin)	9.6	9.0	8.3
Depot (littoral zone, west basin)	27.9	16.7	13.4
Esten (east basin)	7.2	6.9	7.1
Esten Lagoon	43.7	42.5	31.9
Esten Lagoon at discharge	34.6	36.3	36.6
Esten Lagoon in diversion channel	35.1	37.2	28.6
Esten (west basin)	6.1	6.1	6.3
Nordic discharge	5.3	5.6	4.8



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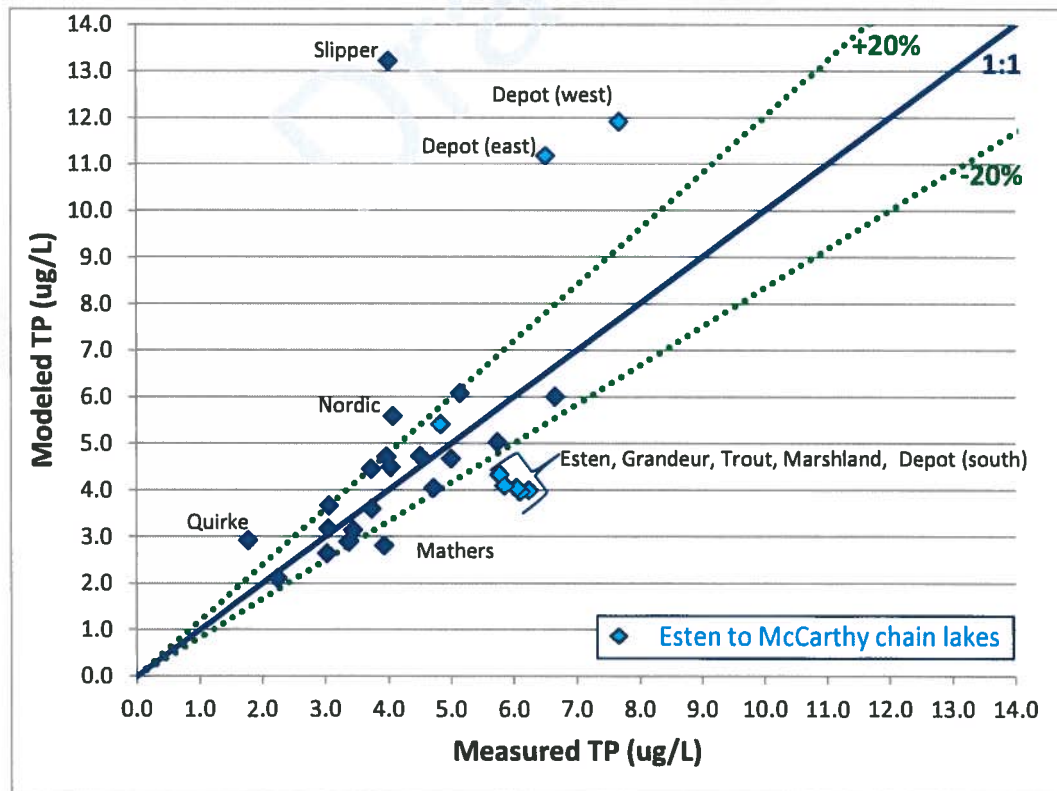
3.2.2 Predicted vs. Measured Total Phosphorus

The LCM model predicts mean volume-weighted ice free total phosphorus concentrations (TP_{if}). Measured mean spring overturn total phosphorus (TP_{so}) concentrations were converted to ice free concentrations for comparison to model results following Clark et al. (2010), where:

$$TP_{if} = TP_{so} * 0.992 - 0.563$$

Modeled total phosphorus concentrations are within 20% of the measured values for 19 of the 30 study lakes, suggesting that the model provides confident predictions for these lakes (Figure 5). For the remaining 10 lakes and the Esten Lagoon, however, modeled and measured concentrations differ by more than 20%. The Handbook recommends that “if the modeled estimates and measured values differ by more than 20%, then lake managers should inspect the measured record for quality and the data used in the model for accuracy, consider alternative coefficients that may be more accurate, and consult other water quality measurements (i.e., Secchi depth and oxygen-temperature records).” Causes for differences between measured and modeled values and suggested refinements to the model to improve predictions are provided in the following section (Section 3.3).

Figure 5. Comparison of modeled and measured total phosphorus concentrations in Elliot Lake area lakes (n=29). Measured and modeled concentrations are 31.1 µg/L and 63.1 µg/L, respectively for Esten Lagoon (not shown).



3.3 Model Refinements

Initial modeling results identified poor phosphorus predictions for several lakes with >20% difference between measured and modeled values. All assumptions and input parameters of the model and quality of the measured total phosphorus were reviewed for those lakes that modeled poorly and refinements to the LCM model are recommended to improve predictions. The suggested refinements consider that the LCM was developed and calibrated based on a few study lakes in central Ontario and several assumptions and input parameters may not be appropriate for all Precambrian Shield lakes.

The LCM tends to underestimate the phosphorus concentration in shallow lakes because it was developed for deeper stratified lakes where wind mixing has less influence on the settling of phosphorus. In shallow lakes, wind mixing can cause resuspension of phosphorus into the water column and result in higher phosphorus concentrations. To account for this, the settling velocity for three known shallow lakes was set to 7.2 m/yr, including unnamed lake 30, Lake E, Belle Lake and Lake SSM 232. This settling velocity is the value used by MOE for anoxic stratified lakes that produce an internal load of phosphorus and recognizes the fact that shallow lakes also generate an internal load or remove phosphorus to the sediments less effectively than stratified lakes and is now recommended by the Lakeshore Capacity Users' Manual (Province of Ontario, 2011). Use of the lower settling velocity for the shallow lakes resulted in a closer relationship between measured and modeled total phosphorus concentrations in downstream lakes including Esten, Grandeur and Trout lakes for which the model underestimated total phosphorus concentration. We note that lake depth information was limited to only the lakes that were considered for shoreline development and a few small nearby lakes. The presence of other shallow lakes may contribute to underestimation by the model.

Modeled phosphorus concentration is overestimated by 48% in the Esten Lagoon which receives point source discharge from the Esten Lake WPCP, and by 55% and 72% in the downstream west and east basins of Depot Lake. Phosphorus loads to the lagoon were calculated from long-term measured data providing confidence in average annual loads used in the model. There is likely some overestimation in phosphorus load to the lagoon from upstream Nordic Lake (total phosphorus is overestimated by the model in Nordic Lake), however, this load represents less than 1% of the total phosphorus load to the lagoon and is insufficient to account for the model error. The overestimation of phosphorus export from the lagoon is most likely due to the fact that the STP uses alum in its treatment process, which binds phosphorus and reduces its potential for release from the sediments. Moreover, the settling velocities developed for use in the LCM are meant to reflect conditions in deep, stratifying, oligotrophic lakes, and are not appropriate for this eutrophic lagoon setting. Phosphorus retention (R_p) in the lagoon was therefore calculated explicitly as:

$$R_p = 1 - (TP_{if} * 0.956 * qs / (L / A_o)),$$

Where TP_{if} is the mean measured ice free total phosphorus concentration, qs is the areal water load, L is the phosphorus load and A_o is the lake surface area, which is the same approach that was used to develop the settling velocity (used to calculate R_p) for anoxic lakes (Dillon et al., 1986). This calculation results in a phosphorus retention (R_p) of 59% for Esten Lagoon and improves predictions of phosphorus concentration in the east and west basins of Depot Lake to within 20% of the measured values. Predictions were also improved for McCarthy Lake.



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The model largely underestimates phosphorus concentrations in the Esten to Depot (south basin) chain of lakes by an average of 32% (Table 5) suggesting that either the phosphorus loads to these lakes are underestimated, or that there is less phosphorus retention in these lakes than predicted by the model. After evaluation of all input data and coefficients used in the model, we suggest that the most likely reason for the poor model performance for these lakes is related to hydraulics of the system, specifically the large aerial water load to these lakes and rapid flushing rates that affect inflake phosphorus retention. Hydrological characteristics of the lakes fall outside the range for the lakes that were used to develop and calibrate the LCM (Table 8) and so it is reasonable to expect that the LCM may not be suitable to predict phosphorus concentrations in these lakes due to .

Table 8. Comparison of Hydrological Characteristics of the Esten to McCarthy Chain of Lakes and the LCM Calibration Lakes in Dorset Ontario

Lake	Lake Surface Area (A _o)	Volume	Discharge (Q)	Areal Water Load (qs)	Flushing Rate	Water Residence Time	LCM Retention (R _p)	Difference Between Modeled and Measured TP ¹
	(km ²)	(10 ⁶ m ³)	(10 ⁶ m ³ /yr)	(m/yr)	(times/yr)	(yrs)	(prop.)	%
Esten	4.60	64.88	80.94	17.59	1.25	0.80	0.41	35
Marshland	1.68	9.24	88.24	52.55	9.55	0.10	0.19	25
Grandeur	1.21	9.68	93.36	77.29	9.65	0.10	0.14	33
Trout	0.47	2.62	95.67	204.55	36.53	0.03	0.03	30
Depot (south)	0.61	4.77	98.43	161.02	20.64	0.05	0.07	36
Depot (west)	0.88	6.84	117.25	133.75	17.15	0.06	0.05	-55
Depot (east)	0.69	5.39	119.69	173.24	22.21	0.05	0.04	-72
McCarthy	6.57	58.11	474.69	72.28	8.17	0.12	0.15	-12
Dorset Calibration Lakes:								
<i>Minimum</i>	<i>0.11</i>	<i>0.89</i>	<i>0.18</i>	<i>1.69</i>	<i>0.21</i>	<i>1.46</i>		
<i>Maximum</i>	<i>1.24</i>	<i>16.40</i>	<i>10.78</i>	<i>8.69</i>	<i>0.66</i>	<i>5.23</i>		
<i>Mean</i>				<i>4.58</i>		<i>2.75</i>		

Notes: ¹ difference between measured and modeled values following refinements to the model for shallow lakes and retention in the Esten Lagoon and using the LCM calculated retention (R_p); negative values represent over-prediction by the model and positive values represent under-prediction by the model.

Phosphorus in lakes with rapid flushing rates like those of the Esten to McCarthy chain of lakes is not lost as efficiently to sediments as lakes with longer water residence times, but rather the phosphorus would remain in the water column and pass readily to downstream lakes. This is consistent with the findings of Brett and Benjamin (2008) who determined that rate loss of phosphorus (equivalent to the settling velocity) is an inverse function of a lake's hydraulic retention time, explaining 84% of the variation in phosphorus retention in 305 lakes. The similar phosphorus concentrations in the Esten to Depot south chain of lakes, upstream of the influence of WPCP inputs supports the lack of significant phosphorus retention in these lakes (i.e., the phosphorus concentration is conserved as water moves downstream).



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The LCM does predict relatively low phosphorus retention (R_p) for Esten Lake and all downstream lakes to McCarthy Lake, however, the R_p is likely still too high for the study lakes, particularly Esten Lake and Grandeur Lake due to morphological characteristics of these lakes. Esten and Grandeur lakes differ from the other lakes along the chain in that they have large inlets that contribute a significant portion of their total phosphorus and water loads, but inputs from these inlets are 'shunted' toward the outlet. In these cases, water (and phosphorus) is not likely to mix with the main basin of the lake, with little opportunity for phosphorus from the inlets to settle out. The main inlet to Esten Lake drains Quimby Lake and input from this inlet contributes 79% of the total aerial water load and 59% of the total phosphorus load to Esten Lake. The Quimby Lake inlet is located at the south west end of the lake and water flow is strongly directed eastward toward the outlet of Esten Lake at the south east to Marshland River, bypassing the main basin of the lake (Figure 6). Similarly for Grandeur Lake, the Marshland River inlet contributes 95% of the water flow to the lake, but this flow is shunted to the outlet of the lake, bypassing the main basin (Figure 6). It is therefore unlikely that the phosphorus and water loads from the Quimby Lake inlet to Esten Lake and from the Marshland River inlet to Grandeur Lake get fully mixed with the main basin of these lakes and that phosphorus from these sources has opportunity to settle out.

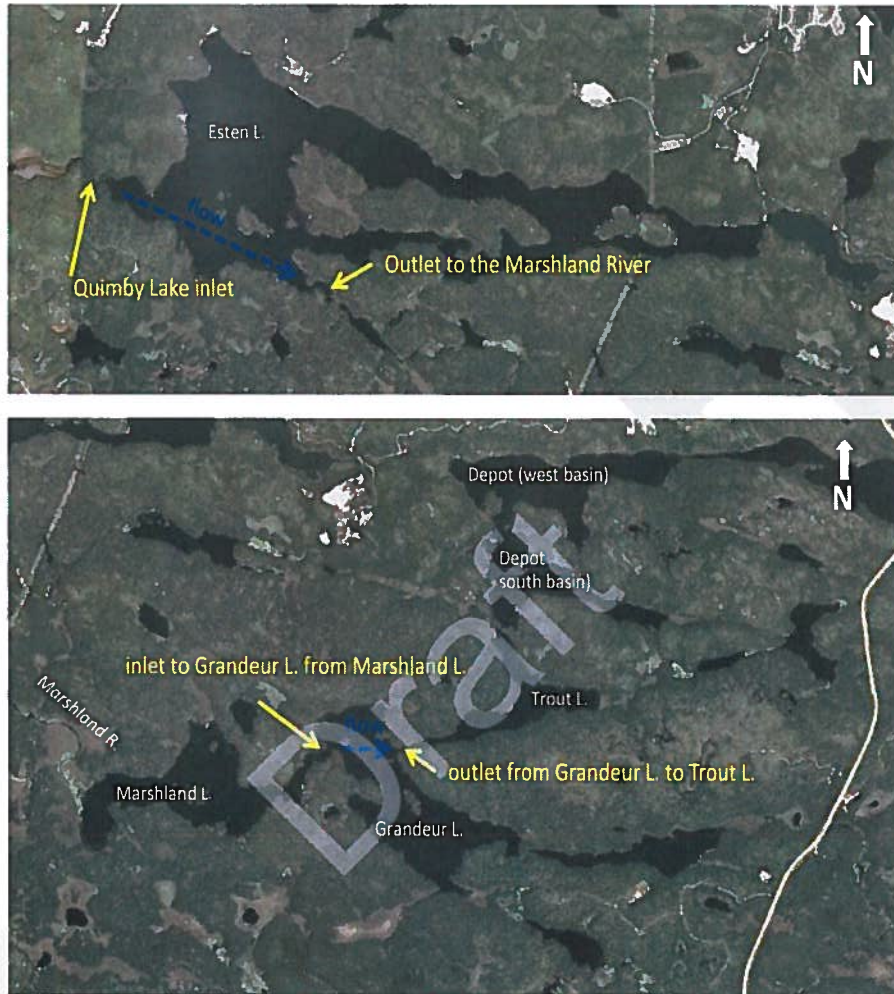
We recommend that phosphorus retention (R_p) in the model be calculated for Esten and Grandeur lakes based on observed measured mean total phosphorus concentration (TP_{it}) as was done for the Esten Lagoon, which gives a phosphorus retention of 0.09 for Esten Lake and 0.04 for Grandeur Lake. Use of these calculated phosphorus retention coefficients results in predicted total phosphorus concentrations that are within 20% of the measured values for Esten Lake and all lakes downstream along the Esten to McCarthy chain with the exception of the east basin of Depot Lake. The model overestimates total phosphorus concentration by 31% in the east basin of Depot Lake with all suggested refinements to the model (adjusted retention for shallow lakes, Esten and Grandeur lakes and for the Esten Lagoon).

The suggested refinements noted above greatly improve the predictive capability of the Elliot Lake model with only 5 lakes that model poorly, including Quirke Lake, Mathers Lake, Slipper Lake and the east basin of Depot Lake (Figure 7).



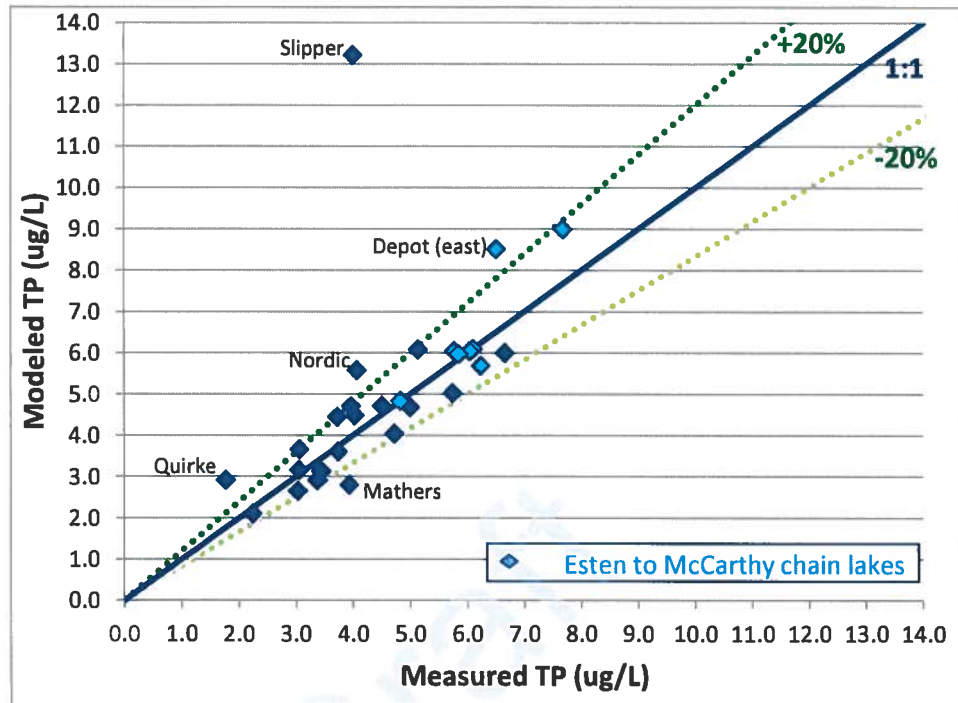
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Figure 6. Position of the major inlet relative to the outlet for Esten Lake (top panel) and Grandeur Lake (bottom panel).



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Figure 7. Comparison of modeled and measured total phosphorus concentrations in Elliot Lake area lakes (n=29) using the refined model. The measured and modeled total phosphorus concentration for the Esten Lagoon is 31.1 mg/L and 33 mg/L



The refined model overpredicts total phosphorus concentration by 65% in Quirke Lake and underpredicts in Mathers Lake by 29%. The low total phosphorus concentration in these lakes (measured TP = 1.8 ± 1.2 $\mu\text{g/L}$ and 4.8 ± 1.1 $\mu\text{g/L}$), however, makes the % difference between measured and modeled values sensitive to variability in measured data and model error. The difference between measured and modeled concentration is 1.2 $\mu\text{g/L}$ and 1.1 mg/L for Quirke and Mathers lakes, respectively which is equal to the standard deviation of measured values for these lakes. The difference between measured and modeled values therefore is most likely due to interannual variation in total phosphorus measurements and not model error. The model therefore likely provides accurate estimates of phosphorus concentrations for these lakes.

The refined model overpredicts phosphorus concentrations in Nordic and Slipper lakes by 37% and 231%, respectively. Both of these lakes have urban lands in their catchments and high phosphorus export assumed for urban lands (50 mg/m²/yr) likely results in overestimation by the model. The phosphorus export coefficient used for urban lands in the LCM was derived for southern Ontario lakes draining low- to mid-density residential development and may not be appropriate for this northern Ontario setting. There are no known export coefficients derived for urban lands near Elliot Lake and so the export coefficient was not adjusted in the model. Overestimation of phosphorus loads from urban lands, however, will not significantly influence predictions for lakes that are proposed for development because these loads represent a very small fraction of their total phosphorus load. Moreover, maintaining higher phosphorus export from urban lands is a conservative approach that increases existing anthropogenic



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inputs and thereby reduces the capacity for shoreline development (i.e., reduces the allowable increase in phosphorus loading from future shoreline development).

Measured and modeled phosphorus concentrations differ by 31% for the east basin of Depot Lake, even with refinements to the model. Measured total phosphorus concentrations in the east and west basins of Depot Lake are highly variable over the course of the year and are most likely dependent upon variable phosphorus loads from the Esten Lagoon. For these two lakes, the mean spring total phosphorus concentration may not be strongly related to ice-free total phosphorus concentration, which is predicted by the model. The equation to convert spring overturn to ice-free total phosphorus concentrations was developed for oligotrophic lakes, and may not be suitable for lakes that receive significant and variable phosphorus loads from point sources. The surface water total phosphorus concentration (euphotic zone composites) in the east and west basins of Depot Lake over the ice-free period from April to November (2009-2012) is 8.2 and 9.0 µg/L, respectively. These values appear better suited for comparison with the model output as they better describe higher phosphorus concentrations that occur over the ice free period than do the spring overturn data, and result in a difference between measured and modeled total phosphorus concentration of 0% and 4% for the west and east basins, respectively.

The above refinements to the model are based on site-specific knowledge of the lakes, long-term monitoring data and in-depth knowledge of assumptions used in the LCM model. Without the suggested refinements, the model fails to confidently predict impacts of proposed development for seven lakes. In cases where the model fails, the Province recommends using the interim PWQO to assess capacity. All lakes proposed for development and downstream lakes that will be influenced by the proposed development have measured total phosphorus concentrations below 10 µg/L, and so the interim PWQO would allow phosphorus to be increased to 10 µg/L in these lakes. Based on the interim PWQO, all of the proposed development lakes are therefore considered to have capacity for shoreline development. There is presently no guidance from the Province to determine the number of lots that could be developed on lakes to meet the interim PWQO (i.e., without the use of the model). The refined model, therefore, is the best available, scientifically-defensible method to assess impacts of shoreline development on these lakes.

3.4 Impact of Proposed Shoreline Development

The phosphorus model with the refinements described in Section 3.3 was used to determine the impact of increased phosphorus inputs to the lakes from the proposed shoreline lot development.

The model assumed:

1. 100% movement of the septic phosphorus to the lake,
2. a conservative estimate of usage (1.52 capita years/year, see Table 2) for lots with planned road access and for existing lots of record (vacant lots),
3. seasonal usage (0.69 capita years/year) for lots with planned water access only,
4. that all lots are shoreline lots within 100 m of the shoreline, and
5. that the Esten Lake WPCP is operating at rated capacity flows and existing mean effluent total phosphorus concentration of 0.50 mg/L.



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The Elliot Lake model predicts that development of the proposed shoreline lots, existing vacant lots and increased WPCP flows would increase total phosphorus concentrations of the development lakes by 8% to 49% over background concentration (Table 9). This increase is below the Ministry of the Environment's PWQO that would limit phosphorus increases from development to background concentrations plus 50% in Canadian Shield lakes. **The development of the proposed shoreline lots would therefore not impair water quality in any of the proposed development lakes with respect to total phosphorus concentration.**

Three lakes that would receive phosphorus loads from the proposed development upstream, however, presently exceed background plus 50% in the absence of the proposed lot development including Dunlop Lake and Depot Lake (east and west basins).

Table 9. Predicted Total Phosphorus Concentrations for Proposed Development Lakes

Lake Name	# of Proposed Lots			Total Phosphorus Concentration ($\mu\text{g/L}$)				
				Background	Modeled Existing	Measured Existing	Modeled Future	% Increase Over Background
	Road Access	Water Access	Total					
Belle	12	0	12	6.1	6.1	5.1	9.0	49
Esten	75	25	100	5.4	6.1	6.1	7.1	31
Grandeur	26	30	56	5.5	6.0	6.0	7.5	36
Marshland	18	6	24	5.5	6.0	5.8	7.1	31
May	64	35	99	3.2	3.2	3.0	4.3	37
McCarthy	112	58	170	4.0	4.8	4.8	5.7	43
Pecors	0	50	50	3.1	3.1	3.4	3.4	8
Quirke	4	91	95	2.8	2.9	1.8	3.2	16
Rye	10	0	10	4.7	4.7	5.0	7.3	57
Summers	34	0	34	2.7	2.7	3.0	3.7	39
Trout	0	18	18	5.5	6.0	5.8	7.5	36

In 2001, 169 shoreline lots were approved for development on Dunlop Lake. The lake is not presently over threshold for phosphorus, but full build-out of 2001-approved lots and approved development on upstream Ten Mile Lake are predicted to increase total phosphorus concentration in Dunlop Lake to 5.7 $\mu\text{g/L}$, which exceeds background by 51%. The 2001 approval was based on assessments completed in the late 1990s using the interim PWQO of 10 $\mu\text{g/L}$ and an older version of the Lakeshore Capacity Model. Development of 34 lots on upstream Summers Lake is predicted to increase phosphorus concentrations in Dunlop Lake an additional 0.02 $\mu\text{g/L}$ to 52% over background. The Handbook states that:

"Because of natural variability in phosphorus concentrations over time, and inaccuracies in some model coefficients when applied to lakes across the Precambrian Shield, there is some error associated with the model predictions. Thus, we recommend that in cases where the predicted



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value is within 10% of the revised PWQO for phosphorus, that some flexibility be allowed when making management decisions."

The small increase from development on Summers Lake would maintain phosphorus concentration in Dunlop Lake to well within 10% of the PWQO and meets the Provincial requirements for allowable development capacity.

The west and east basins of Depot Lake have existing modeled phosphorus concentrations that are 89% and 84% over background for the west and east basins, respectively, which greatly exceed the revised PWQO of background plus 50%. The elevated phosphorus concentrations in this lake are due to inputs from the Esten Lake WPCP as there is presently little other human sources of phosphorus to these lakes. In the absence of WPCP inputs, other existing human sources of phosphorus (shoreline development and urban runoff) increase phosphorus concentration by 0.4 µg/L and 0.3 µg/L in the west and east basins, respectively.

The proposed development on lakes upstream of the west basin of Depot Lake (Esten, Marshland, Grandeur, Trout, and Belle) would increase total phosphorus concentrations by 1.5 µg/L in the west basin and 1.0 µg/L in the east basin of Depot Lake, respectively. With all proposed development and predicted increased flows from the WPCP, phosphorus concentrations will increase to 9.0 µg/L (138% over background in the west basin) and to 8.2 µg/L (130% over background) in the east basin. In the absence of STP loads, this increase in phosphorus concentration represents less than a 50% increase over background for both of the basins.

The upstream development proposed on Esten, Marshland, Grandeur, Trout and Belle lakes constitutes a significant portion of the proposed development (210 lots) and is critical to the success of the project. Without this lot allocation, there would be insufficient lots to make the project viable. In recognition of the Province's policies and guidelines to maintain water quality, the City has committed to undertake measures to reduce phosphorus loading from the WPCP by at least 123 kg/yr, which is equivalent to the predicted increase in phosphorus load from the proposed development on upstream lakes. **The proposed development would not further impair water quality in the east and west basins of Depot Lake with improved operations of the Esten Lake WPCP to reduce phosphorus loads by at least 123 kg/yr.**

The above predictions are based on a conservative approach that assumes that 100% of the phosphorus from septic systems moves to the lake; an assumption that is not supported fully supported by the scientific literature (see Hutchinson, 2002). Recent studies have shown that much of the septic phosphorus load to a lake is attenuated by acidic and mineral-rich soils found in the Precambrian Shield, such that over 90% of septic phosphorus may be immobilized and stable within 0.5 m of the tile drains in a septic field (Robertson *et al.*, 1998, Robertson, 2003). Dillon *et al.* (1994) reported that only 26% of the potential loading of phosphorus from septic systems around Harp Lake, Muskoka, could be accounted for in the measured phosphorus budget of the lake likely due to attenuation of septic phosphorus in thick tills in the catchment. For Dunlop and Summers lakes, for example, the dominant terrain is that of bedrock with ground moraines composed of till. It is therefore reasonable to assume that pockets of till present around Dunlop and Summers lakes would attenuate a portion of the septic phosphorus.



4. Impacts of Shoreline Development on Lake Trout Habitat

Human activities that increase phosphorus loads to lakes can impair habitat for coldwater fish by reducing oxygen in deep, cool hypolimnetic waters. Phosphorus promotes the growth of aquatic plants and algae and decomposition of this plant matter consumes oxygen. Coldwater fish, particularly lake trout, are highly sensitive to dissolved oxygen concentrations. For lakes designated as "lake trout lakes" by the Ontario Ministry of Natural Resources (MNR), the criterion for dissolved oxygen is 7 mg/L, measured as mean volume-weighted hypolimnetic dissolved oxygen (MVWHDO) (EBR Registry Number: PB06E6807). This requires that MVWHDO be maintained at or above 7 mg/L. The capacity of designated lake trout lakes affected by the proposed shoreline development is assessed against the MNR criterion using a combination of measured and modeled MVWHDO.

4.1 Measured MVWHDO

Measured oxygen concentrations are the most accurate means to determine MVWHDO. The MNRs' criterion standardizes MVWHDO to the first day in September and recommends using oxygen profiles that are collected between two weeks before and two weeks following September 01. This date is fixed because a) oxygen habitat continues to degrade in most lakes until destratification, which does not occur on the same date between years, and b) lakes typically cool after September 1, such that losses in oxygenated habitat in the hypolimnion are offset by gains in thermal habitat in near surface, well-oxygenated waters. MNR recommends that three to five years of data are required to derive a mean value that will account for between-year variation. This is important because opposite extremes in a lake's oxygen habitat can occur in adjacent years.

Measured dissolved oxygen and temperature profiles have been collected since 2008 by contractors hired by the City lake trout lakes that will receive phosphorus loads from the proposed development. Measured data were also available for several lakes from the late 1990s that were collected by the Elliot Lake Research Field Station (Laurentian University). All measured data were evaluated for quality (e.g., date, length, and shape of the profile) and suspect profiles or profiles that were >5 m too short were excluded from the calculations. Suspect profiles included:

- Profiles collected in 2009 for all lakes, with the exception of Hough Lake. The 2009 dissolved oxygen profiles were considered anomalous because they did not follow expected patterns of declining oxygen concentration with depth in the hypolimnion, they displayed undersaturated conditions in the epilimnion and the MVWHDO calculated from these profiles was on average 1.3 mg/L lower than the mean for all other years, except for Hough Lake. The reason for the anomalous data in 2009 is not known, but may be due to equipment malfunction (calibration of the oxygen meter) and/or weather patterns that produced extreme oxygen conditions that are not representative of the average oxygen status of the lakes. The 2009 data were therefore excluded from calculation of MVWHDO in all lakes except for Hough Lake.
- 1999 profiles for McCarthy Lake. The 1999 profiles displayed supersaturation in the epilimnion of the north basin and very large metalimnetic oxygen peaks that extended into the hypolimnion of the north and south basin. This resulted in MVWHDO that is considerably higher than that observed for all other years and is not likely representative of oxygen status in this lake. The



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oxygen profiles from 1999 were therefore excluded from calculation of MVWHDO for McCarthy Lake.

- 2008 profiles for May Lake and Pecors Lake. Oxygen concentrations were greatly undersaturated in the epilimnion of both lakes in 2008 and displayed large metalimnetic peaks that extended into the hypolimnion of Pecors Lake. This resulted in MVWHDO that is considerably higher than that observed for all other years in Pecors Lake and is not likely representative of oxygen status in this lake. MVWHDO in 2008 was similar to other years for May Lake, but given the anomalous shape of the oxygen profile and undersaturated conditions in the surface waters, the resulting MVWHDO The oxygen profiles from 1999 were therefore excluded from calculation of MVWHDO for May and Pecors lakes.

All designated lake trout lakes that will be influence by the proposed development have at least three years of quality measured dissolved oxygen and temperature profiles, which allow confident calculation of MVWHDO according to MNR protocols (MNR, 2009).

MVWHDO was calculated following Evans et al. (1996). The MNR (2009) has developed draft internal guidelines for the application, data collection protocols and interpretation of the dissolved oxygen criterion. In previous reviews of this report, the MOE noted that our method to calculate MVWHDO differed from the MNR (2009) draft guidelines with respect to delineation of the top of the hypolimnion. Our calculation identifies the top of the hypolimnion as the "top of the first 1-m interval where the change in temperature is $\leq 1^{\circ}\text{C}$ " (herein called the 'top method') whereas the MNR (2009) guidelines define the top of the hypolimnion as the "bottom of the first 1-m interval where the change in temperature is $< 1^{\circ}\text{C}$ " (herein called the 'bottom method'). The 'bottom method' excludes a large portion of well-oxygenated cool hypolimnetic waters suitable for lake trout habitat and in some cases, may underestimate the availability of suitable lake trout habitat. We have therefore provided MVWHDO results for both methods. Our final capacity assessment, however, is based on the more conservative 'bottom method'.

4.2 Modeled MVWHDO

Molot *et al.* (1992) developed a model (the 'Molot model') that can accurately predict oxygen profiles in Ontario lakes using elements of lake morphometry and total phosphorus concentrations as input. In cases where measured profiles do not exist, the model can be used to estimate MVWHDO. Estimating MVWHDOs using modeled profiles has some advantages over using measured data because a) the modeled profiles describe steady state conditions that are not influenced by between-year differences in the annual MVWHDO values, and b) the model can predict how the MVWHDO will respond to changes in phosphorus predicted by the phosphorus model.

The Molot model relies on accurate spring overturn total phosphorus concentrations to predict mean (steady state) hypolimnetic oxygen profiles. Modeled MVWHDOs were derived using modeled phosphorus as input. As a conservative approach, predicted MVWHDO following the development of the proposed lots was estimated by subtracting the modeled loss in MVWHDO from the measured MVWHDO (following protocol of Clark 2002). Lakes were considered to be over capacity for shoreline development if the MVWHDO was reduced to below 7 mg/L from increased phosphorus loads.



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4.3 Impacts of Proposed Development

Results of the measured and modeled MVWHDO concentration for each designated lake trout lake that will be affected by the proposed shoreline development are summarized in Table 11, with two exceptions. MVWHDO was not assessed for Marsh Lake and Dunlop Lake, both of which will receive phosphorus loads from upstream development on Summers Lake. Impacts of development on these lakes area considered below. For lakes with distinct basins (i.e., basins separated by submerged sills higher than the top of the hypolimnion and with maximum depth >13 m following MNR (2009)), MVWHDO for the entire lake is calculated as the volume weighted average of all basins. Calculations of measured and modeled MVWHDO are provided in Appendix B.

All of the proposed development lakes except Esten Lake have existing MVWHDO greater than 7 mg/L, and predicted increased phosphorus inputs from lot development would not reduce MVWHDO below 7.0 mg/L. Based on these results, development of the proposed shoreline lots would not impair lake trout habitat with respect to oxygen concentrations in any designated lake trout lake proposed for development, with the exception of Esten Lake.

There are three designated lake trout lakes will receive phosphorus loads from proposed development on upstream lakes:

1. Hough Lake will receive phosphorus loads from development on May Lake, but MVWHDO for this lake is predicted to remain above the MNR criterion of 7 mg/L (Table 11). Upstream development will therefore not impair lake trout habitat in this lake.
2. Dunlop Lake will receive phosphorus loads from development on Summers Lake. Measured and modeled MVWHDO were not calculated for this lake in the present study. Dissolved oxygen profiles however, do exist for Dunlop Lake. Mean hypolimnetic dissolved oxygen in this lake was 7.9, 8.5 and 8.8 mg/L in 2010, 2011 and 2012, respectively. While these values are not volume-weighted, they suggest that Dunlop Lake has ample dissolved oxygen to meet the MNR criteria. In addition, phosphorus loads are predicted to increase the phosphorus concentration in Dunlop Lake by only 0.02 µg/L. This increase in phosphorus concentration is small and it is unlikely to affect the dissolved oxygen status of Dunlop Lake (Mr. Ed Snucins, MOE, Memorandum to Marty Blake, MNR dated August 15, 2012). Calculation of MVWHDO can be completed for Dunlop Lake if required to support the development application.
3. Marsh Lake lies upstream of Dunlop Lake will also receive phosphorus loads from proposed development on Summers Lake. Phosphorus concentrations are predicted to increase by 0.6 µg/L from this upstream development. Measured and modeled MVWHDO was not assessed for this lake in this report, however end-of-summer temperature and dissolved oxygen profiles are available for Marsh Lake for 2008-2012 to assess oxygen status. The maximum depth of Marsh Lake is 12 m and the top of the hypolimnion was between 9 and 10 m over that time period, providing a shallow hypolimnion of only two to three meters. The hypolimnion was hypoxic (DO<0.1 mg/L) in all years with dissolved oxygen concentrations ranging from 0.06 to 0.28 mg/L. Hypoxia also extended up into the thermocline by as much as three meters. Based on this information, Marsh Lake would be considered to have no capacity for development because the MVWHDO for this lake would be <0.28 mg/L. The hypoxic condition of the hypolimnion and thermocline would be lethal for lake trout (Evans, 2007). There is presently no development on Marsh Lake or in the upstream catchment that would contribute human phosphorus loads to the



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lake and so the observed oxygen concentrations are natural and likely a result of basin morphometry. Given the naturally hypoxic and lethal conditions of the hypolimnion and thermocline, it is highly unlikely that the hypolimnion or thermocline of this lake is usable habitat for lake trout, that is, there is naturally no hypolimnetic habitat for lake trout in this lake. The decline in dissolved oxygen in the hypolimnion of this lake due to the small predicted increase in phosphorus concentration ($<1 \mu\text{g/L}$) would therefore not impair hypolimnetic habitat for lake trout.

Based on the above, we conclude that impacts of the proposed development will not impair lake trout habitat with respect to dissolved oxygen status in downstream lake trout lakes (Hough, Dunlop and Marsh lakes).



Table 10. Mean Volume-Weighted Hypolimnetic Dissolved Oxygen Concentrations (MVVHDO) in Lake Trout Lakes Affected by Shoreline Development.

Lake	Basin	Method ¹	Modeled MVVHDO (mg/L)		Measured VVHDO (mg/L)										Whole Lake Volume-Weighted MVVHDO ² (mg/L)				
			Existing	With Lots	1998	1999	2006	2008	2009	2010	2011	2012	Mean	Existing	O2 Loss	With Lots			
Esten	West	Top	8.8	8.4	7.3	7.5	4.9	6.4	6.9	7.4	7.1								
		Bottom	8.7	8.3	7.0	7.2	4.8	6.2	6.9	7.3	6.9							6.6 (6.5)	
	East	Top	6.9	6.6		7.8	5.0	6.3	6.9	7.3	7.0								
		Bottom	9.1	8.8		7.4	4.9	6.1	6.8	7.1	6.9								
Hough	Top	7.1	7.0		7.2	7.7	7.9	no data	7.6									7.5 (7.3)	
	Bottom	6.9	6.8		7.0	7.5	7.7	no data	7.4										
May	South	Top	9.1	8.9		8.8	7.0	7.8	8.6	9.0	8.5								
		Bottom	9.0	8.8		8.5	6.8	7.5	8.4	8.8	8.2								8.8 (8.3)
	Central	Top	9.1	8.8			7.9	8.9	9.9	10.3	9.7								
		Bottom	9.0	8.7			7.7	8.7	9.8	8.1	8.9								
McCarthy	South	Top	7.4	7.2		7.3	6.1	7.1	7.6	8.1	7.5								
		Bottom	7.1	6.9		7.2	6.0	6.8	7.4	7.7	7.3								
	North	Top	7.8	7.6		7.8	5.9	7.1	6.6	7.1	7.3								
		Bottom	7.6	7.3		7.5	5.9	6.8	6.6	6.9	7.1								
Pecors	Top	7.4	7.4		9.9	6.8	7.6	7.9	8.8	7.8									
	Bottom	7.4	7.3		9.4	6.6	7.2	7.7	8.4	7.5									
Quirke	Top	11.6	11.5		short profiles		10.8	10.7	10.7	10.8									
	Bottom	11.5	11.4		short profiles		10.7	10.6	10.6	10.6									

Notes: Shaded cells represent suspect values and are not included in the calculation of Mean VVHDO. ¹The top of the hypolimnion is defined as the top (Top Method) or bottom (Bottom Method) of the first one-meter interval where the temperature change is <1°C. ²The value is given for the Top Method (Bottom Method result is in parentheses); values in red represent MVVHDO below the MNR criteria for Lake Trout.



Table 11. (continued)

Lake	Basin	Method	Modeled MVWHDO (mg/L)		Measured MVWHDO (mg/L)										Whole Lake Volume-Weighted MVWHDO (mg/L)		
			Existing	With Lots	1998	1999	2006	2008	2009	2010	2011	2012	Mean	Existing	O2 Loss	With Lots	
Summers	Central	Top	7.7	7.5				11.1	7.9	7.5	9.9	10.6	10.3	10.1 (9.8)	0.1	10.0 (9.7)	
		Bottom	7.0	6.8			10.9	6.8	7.3	9.1	9.1	9.1					
	East	Top	4.5	4.4				11.5	4.8	4.5	7.2	8.8	8.6				
		Bottom	4.2	4.1				11.1	4.5	5.2	6.7	6.8	7.9				
	West	Top	4.6	4.5				10.4	7.0	7.4	7.8	8.9	8.6				
		Bottom	4.4	4.3				9.9	6.7	6.8	7.3	8.4	8.1				

Notes: Shaded cells represent suspect values and are not included in the calculation of Mean VWHDO. ¹The top of the hypolimnion is defined as the top (Top Method) or bottom (Bottom Method) of the first one-meter interval where the temperature change is <1°C. ²The value is given for the Top Method (Bottom Method result is in parentheses); values in red represent MVWHDO below the MNR criteria for Lake Trout.



5. Conclusions

The City of Elliot Lake plans to request the disposition of Crown Land under the Elliot Lake Act (2001) for 688 shoreline development lots on 11 area lakes. Assessment of impacts from this proposed development on water quality and lake trout habitat are as follows:

Development Impacts on Phosphorus

1. Overall, the 177-lake watershed-based phosphorus model performs well and predicts total phosphorus concentrations to within 20% of measured values for 19 of 30 lakes with measured data.
2. Seven lakes that will be influenced by the proposed development model poorly with greater than 20% difference between measured and modeled values. Model refinements that adjust inlake phosphorus retention for shallow lakes, the Esten Lagoon which receives point-source discharge from the Esten Lake WPCP and two flow-through lakes (Esten Lake and Grandeur Lake) improves model performance and allows accurate predictions of phosphorus concentrations for all of these lakes except Quirke Lake. Due to the low phosphorus concentration in Quirke Lake (measured TP = $1.8 \pm 1.2 \mu\text{g/L}$), the % difference between measured and modeled values are highly sensitive to variability in measured data and model error. The model is considered to provide accurate estimates of phosphorus concentrations for Quirke Lake considering interannual variability in phosphorus concentrations.
3. All of the lakes proposed for development have existing total phosphorus concentrations that are within the PWQO of background plus 50% and therefore have capacity for development with respect to phosphorus.
4. All lakes downstream of the proposed development have existing total phosphorus concentrations that are within 10% of the PWQO of background plus 50% and therefore have capacity for phosphorus loads from upstream development with the exception of the east and west basins of Depot Lake.
5. The east and west basins of Depot Lake are presently over capacity for development due to high phosphorus loads from the Esten Lake WPCP. Impacts to these basins can be mitigated by reducing phosphorus loads from the Esten Lake WPCP by at least 123 kg/yr to offset the predicted phosphorus loads from upstream development on Esten, Marshland, Grandeur, Trout and Belle lakes.
6. Total phosphorus concentrations in the lakes proposed for development are predicted to increase by 8% to 49% over background concentration, and therefore meet the PWQO of background plus 50%. All lakes downstream of the proposed development are predicted to maintain total phosphorus concentrations to within 10% of the PWQO.

Development Impacts on Lake Trout Habitat

1. Seven of the proposed development lakes and three downstream lakes that will receive phosphorus loads from upstream development are MNR-designated lake trout lakes.
2. All of the lake trout lakes that will receive phosphorus loads from development have MVWHDO greater than the MNR criterion of 7 mg/L for the protection of lake trout habitat and therefore have capacity for shoreline development. One exception is Esten Lake.



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3. All of the lake trout lakes (excluding Esten Lake) are predicted to maintain MVWHDO at or above the MNR criterion of 7 mg/L with phosphorus loads from the proposed development.

In conclusion, proposed shoreline development of 588 lots (280 lots with road access and 288 lots with water access only) on 10 lakes will not impair water quality in the development lakes or lakes downstream of the development with respect to:

1. phosphorus concentrations, which will be maintained to within 10% of the PWQO of background plus 50%, and
2. MVWHDO concentrations, which will be maintained at or above the MNR criterion of 7 mg/L in MNR-designated lake trout lakes for the protection of lake trout habitat.

This conclusion is based on three key assumptions:

1. That the phosphorus model used to predict total phosphorus concentrations in the study lakes is refined to improve estimates of phosphorus retention,
2. That Marsh Lake has no hypolimnetic lake trout habitat such that oxygen loss from increased phosphorus loads to this lake trout lake will not impair oxygenated lake trout habitat, and
3. That phosphorus loads from the Esten Lake WPCP can be reduced to offset development loads upstream of Depot Lake.

Esten Lake has capacity for the proposed 75 road access lots and 25 water access lots with respect to phosphorus concentrations, but capacity is limited in this MNR-designated lake trout lake due to existing MVWHDO (6.9 mg/L) that is below the criterion of 7 mg/L. Some consideration for lot development on this lake may be warranted because a) there is a high degree of between year variability in measured WWHDO (range of 6.2 mg/L to 7.5 mg/L) which compromises the ability to assess the long-term MVWHDO with certainty, and b) Esten Lake is a prime candidate lake for the cottage lot program and loss of the proposed 100 lots would jeopardize the economic feasibility of the program. If development were to proceed, strict septic system design and site plan rules should be implemented to mitigate phosphorus loads. Phosphorus and oxygen concentrations should continue to be monitored closely with a plan to respond if there is evidence of impacts from cottage lot development that jeopardize lake trout habitat.



6. References

- Brett, M.T. and M.M. Benjamin, 2008:
A review and reassessment of lake phosphorus retention and the nutrient loading concept.
Freshwater Biology 53:194-211.
- Clark, B., P.J. Dillon, L.A. Molot and H.E. Evans. 2002:
Application of a Hypolimnetic Oxygen Profile Model to Lakes in Ontario, *Lake Reserv. Manage.*
18(1):32-43.
- Clark, B.J., A.M. Paterson, A. Jeziorski, and S. Kelsey, 2010:
Assessing variability in total phosphorus measurements in Ontario lakes. *Lake and Reservoir
Management*, 26:63-72.
- Dillon, P.J., K.H. Nicholls, W.A. Scheider, N.D. Yan and D.S. Jeffries. 1986:
Lakeshore Capacity Study, Trophic Status. Research and Special Projects Branch, Ontario
Ministry of Municipal Affairs and Housing. Queens Printer for Ontario. 89p.
- Dillon, P.J., W.A. Scheider, R.A. Reid and D.S. Jeffries, 1994:
Lakeshore Capacity Study: Part 1 – Test of effects of shoreline development on the trophic status
of lakes. *Lake Reserv. Manage.* 8:121-129.
- Evans, D.O., K.H. Nicholls, Y.C. Allen and M.J. McMurty, 1996:
Historical land use, phosphorus loading and loss of fish habitat in Lake Simcoe, Canada. *Can. J.
Fish aquat. Sci.* 53 (Suppl. 1):194-218.
- Evans, D.O., 2007:
Effects of hypoxia on scope-for-activity and power capacity of lake trout (*Salvelynus namaycush*),
Can. J. Fish. Aquat. Sci. 64:345-361.
- Grubbs, F.E., 1969:
Procedures for detecting outlying observations. *Technometrics* 11:1-21.
- Hutchinson, N.J., B.P. Neary and P.J. Dillon, 1991:
Validation and use of Ontario's trophic Status Model for establishing lake development guidelines.
Lake Reserv. Manage. 7:13-23.
- Hutchinson, N.J., 2002:
Limnology, plumbing and planning: Evaluation of nutrient-based limits to shoreline development
in Precambrian Shield watersheds. In: R.L. France (ed). *Handbook of Water Sensitive Planning
and Design*, CRC Press, London. Pp. 647-680.
- Molot, L.A., P.J. Dillon, B. Clark and B.P. Neary. 1992:
Predicting end-of-summer oxygen profiles in stratified lakes. *Can. J. Fish. Aquat. Sci.* 49:2363-
2372.
- Ontario Ministry of the Environment, Lake Partner Program,
http://www.ene.gov.on.ca/envision/water/lake_partner/index.htm
- Province of Ontario. 2010:
Lakeshore Capacity Handbook - Protecting Water Quality in Inland Lakes on Ontario's
Precambrian Shield, EBR registry number 010-0690,
http://www.ene.gov.on.ca/envision/env_reg/er/documents/2008/Lakeshore%20Handbook.pdf
- Province of Ontario, 2011:
Lakeshore Capacity Model Users Manual, Version 4. November 2011. Prepared by Crystal V.
Hyatt, Federation of Ontario Cottagers' Associations, Andrew M. Paterson, Ontario Ministry of the
Environment, and Eleanor Stainsby, Ontario Ministry of the Environment.



- Ontario Ministry of Environment and Energy. 1996:
1995 Performance Report: Water Quality Analyses Section (ISSN 1198-3043).
- Ontario Ministry of Natural Resources (MNR), 2009:
Guidelines for the Application of a Dissolved Oxygen Criterion for the Protection of Lake Trout Habitat. 2009 WORKING DRAFT version 2009.10. Fish and Wildlife Branch. Ontario Ministry of Natural Resources. Peterborough, Ontario
- Paterson, A. M., P. J. Dillon, N. J. Hutchinson, M. N. Futter, B.J. Clark, R. B. Mills R. A. Reid and W. A. Scheider 2006:
A review of the components, coefficients, and technical assumptions of Ontario's Lakeshore Capacity Model. Lake Reserv. Manage. 22: 7-18.

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