Phosphorus Loading Model for the Lake Bellaire, Clam Lake and Torch Lake Watersheds

FINAL REPORT

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Phosphorus Loading Model for the Lake Bellaire, Clam Lake and Torch Lake Watersheds

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EXECUTIVE SUMMARY

Lake Bellaire, Clam Lake and Torch Lake are located primarily in Antrim County, Michigan; an area with a growing population. The purpose of this study was to develop a watershed model to predict current and future watershed phosphorus loads to each of the lakes.

The watershed model was developed for current (2006) conditions and calculates annual phosphorus loads from each lake's watershed, from a variety of sources. These sources include: surface runoff from different land uses, septic systems, point sources and groundwater. Model-predicted phosphorus loads were determined to be consistent with measured tributary loads (calculated from instream measurements). Currently, the majority of phosphorus load to each of the lakes originates from surface runoff.

Watershed*	Modeled loads		Loads based on field measurements	
	Surface runoff	Failing septic	Other sources	Shallow groundwater
Lake Bellaire	1,946	214	86	214
Clam Lake	1,013	79	264	0
Torch Lake	1,994	310	0	1,480

*Phosphorus loads exported from upstream lakes (e.g., lake outflow) are not included in the summary above, as they are the focus of an ongoing lake modeling task.

A map-based user-friendly interface was developed for the model so that stakeholders could use the model to test the impact of various development scenarios on resulting phosphorus loads. Four development scenarios have been run in the model and phosphorus loads to the lakes are forecast to increase under each scenario.

INTRODUCTION

Limno-Tech, Inc. (LTI), in cooperation with Great Lakes Environmental Center (GLEC) and the Three Lakes Association (TLA) has developed a watershed phosphorus model for Lake Bellaire, Clam Lake and Torch Lake. These three lakes and their watersheds are located primarily in Antrim County, Michigan, with a small portion of the watershed extending into Kalkaska County.

Watershed modeling is part of a larger project that is funded by a grant from the Michigan Department of Environmental Quality (MDEQ), which includes water quality monitoring as well as lake water quality model development and application. Under this grant, a watershed model was developed to predict phosphorus loads to the lakes under current and future conditions.

The development and application of the watershed model are described in the following sections of this report:

- Model development: *describes modeling approach and inputs*
- Model application: *describes the user interface and model development for current and future conditions*
- Results: *presents the modeling results for current and future conditions*

MODEL DEVELOPMENT

This section briefly describes the project study area, presents the rationale for the modeling approach selected, and describes model inputs used to apply the model for current conditions.

Study Area

The project study area is shown in color in Figure 1 and is defined as the area downstream of the Intermediate Lake outlet, which drains to Lake Bellaire (drainage shown in green), Clam Lake (drainage shown in yellow) and Torch Lake (drainage shown in pink). Watershed loads upstream of Intermediate Lake are not the focus of this modeling study. The study area is located primarily in Antrim County, Michigan, with smaller portions extending south into Kalkaska County. The total land area of the study area equals 121 square miles; this total excludes the surface area of the three lakes.

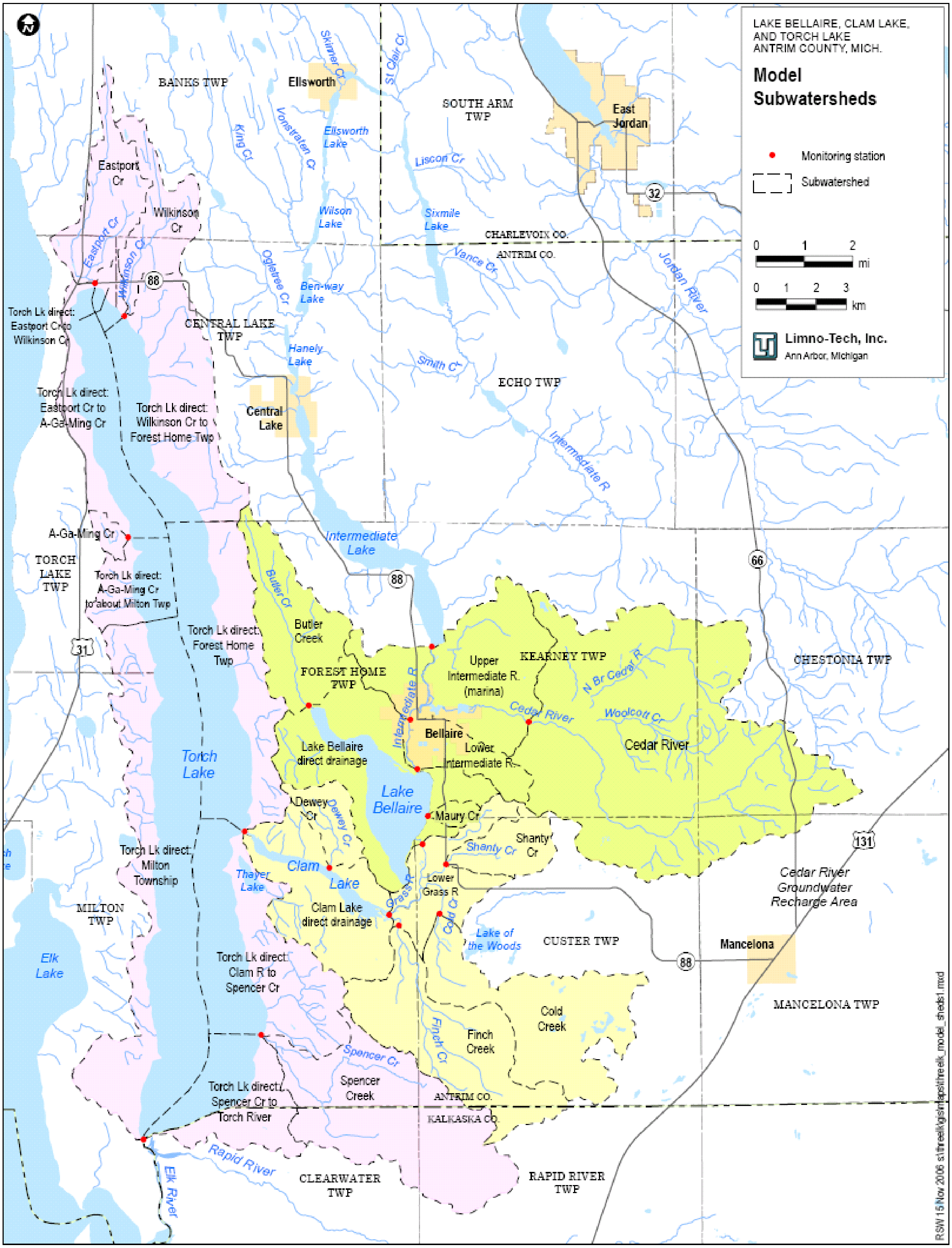


Figure 1. Study area

Modeling Approach

Watershed phosphorus loads originate from a variety of sources. These sources include surface runoff from different land uses, as well as septic systems, point sources and other natural and anthropogenic sources, which can enter surface water from ground water. In addition to watershed phosphorus sources, other sources of phosphorus to the lakes include direct deposition from the atmosphere and, in some lakes, phosphorus release from lake bottom sediments. These latter two sources are not modeled as part of this work, which instead is focused on watershed sources of phosphorus.

The modeling approach selected for this project was based on discussions with the Three Lakes Association, considering available data, resources and the goals of the project. A unit area load approach was selected for modeling current and future annual surface runoff loads of phosphorus. Unit area loads (also called export coefficients) are routinely used to develop estimates of pollutant loads in a watershed. An export coefficient is a value expressing pollutant generation per unit area and unit time for a specific land use (Novotny and Olem, 1994). The use of unit areal loading or export coefficients has been used extensively in estimating loading contributions from different land uses (Beaulac 1980, Reckhow et al. 1980, Reckhow and Simpson 1980, Uttormark et al. 1974). The concept is straightforward; different land use areas contribute different loads to receiving waters. By summing the amount of pollutant exported per unit area of land use in the watershed, the total pollutant load to the receiving system can be calculated.

Background phosphorus loads from shallow groundwater are estimated from monitoring data. Loads from failing septic systems are based on housing density, population density, local failure rates and literature values for phosphorus loads. Three wastewater treatment plants and a fish farm are also included in the model. The treatment plants all discharge to drain fields and so their contribution is included as a component of the groundwater phosphorus load. Model inputs are described in more detail in the subsections below.

Model Inputs

This section describes the model inputs required to calculate phosphorus loads from surface runoff, groundwater, septic systems, and permitted dischargers. A list of data sources supporting development of these inputs is provided in Appendix A.

Watershed boundaries

The watershed boundaries for each of the three lakes were delineated in a Geographic Information System (GIS), based on stream network and topographic information. The watersheds for each of the three lakes were further divided into smaller units called subwatersheds. Subwatershed boundaries were primarily delineated to sampling stations. However, some subwatersheds, such as direct drainage areas to Torch Lake were further subdivided along township boundaries so that smaller areas could be investigated for the future scenario modeling. The map shown in Figure 1 shows both the project watersheds (color coded for each lake) and subwatersheds (labeled and shown with dashed lines).

Current land use

Land use data representing 1998 conditions are available for the portion of the study area within Antrim County. This is the most recent land use information available in electronic format. The land use data was updated as part of this study to include golf courses that do not appear in the 1998 dataset. Golf courses were identified using recent (2006) aerial imagery of Antrim County, which was obtained from the NRCS. 1992 land cover data was used to characterize the small portions of the study area within Kalkaska County (6% of the study area). These two data sets are used to define current land use within the study area.

As shown in Figure 2, the project study area is predominantly undeveloped with the majority of land being forested or used for agricultural uses (cropland and pasture). Approximately 7% of the study area is developed. Within the model, developed lands are classified as either low density development (LDD) with 1 housing unit per acre, or as high density development (HDD) with 5.6 housing units per acre. Current land use is tabulated in Table 1. Figure 2 shows the modeled land use for current conditions, sewer boundaries, wastewater treatment plant drain field locations and the location of a fish farm.

Table 1. Current land use distribution in the study area

Land Use	Lake Bellaire Watershed	Clam Lake Watershed	Torch Lake Watershed
Forest	69%	71%	65%
Pasture	10%	9%	7%
Cropland	8%	11%	16%
Low density development[1]	6%	4%	9%
Golf course	4%	2%	1%
Wetland	2%	2%	2%
High density development[2]	1%	0%	0%

[1]Low density development (LDD) – defined as 1 house/acre
[2]High density development (HDD) – defined as 1 structure/acre, with an average of 5.6 housing units per structure.

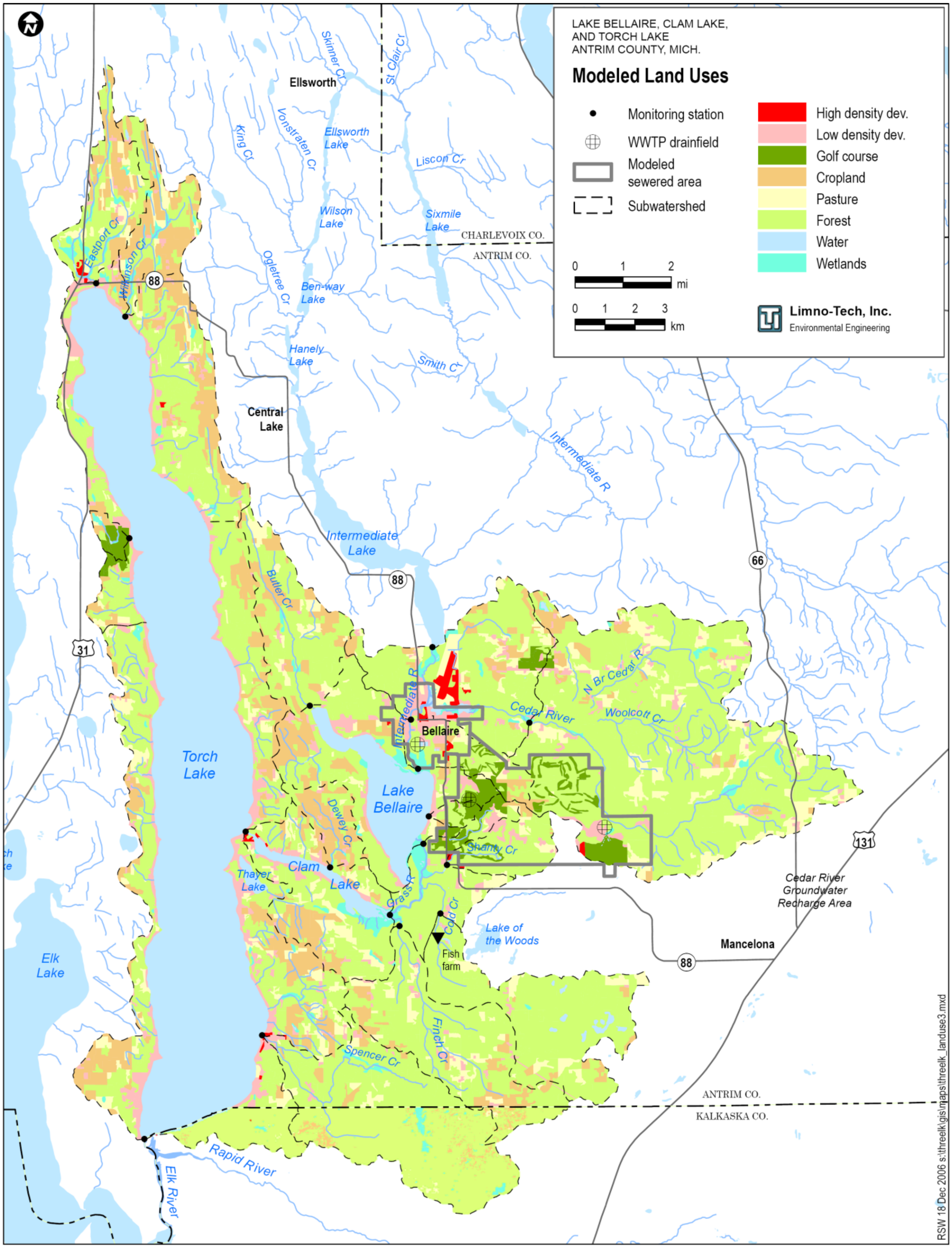


Figure 2. Modeled land use – current conditions

Sewered areas

Information on sewered areas was obtained from the Village of Bellaire and the Shanty Creek/Schuss Mountain resort (Branson, personal communication). This information was digitized in the GIS so that development serviced by sewer could be identified (Figure 2). Developed areas served by sewer were flagged so that they would be treated differently in the model than developed areas served by septic. Within the study area, 15% of the developed land is currently serviced by sewer. The percent of developed land that is serviced varies between watersheds. Thirty-seven percent of developed land in the Lake Bellaire watershed is serviced by sewer and 19% of development is served by sewer in the Clam Lake watershed. Developments in the Torch Lake watershed are all on septic systems. None of the developed land in the Torch Lake watershed is sewered.

Wastewater generated in the sewered areas is routed to a treatment plant, where it is treated to remove phosphorus and other pollutants. The treated effluent is then discharged to a drain field. Wastewater discharged to these drain fields eventually enters groundwater; there is no surface discharge of effluent from any of the three existing wastewater treatment facilities. The phosphorus concentrations in the effluent varies between wastewater treatment facilities, as shown in Table 2.

Septic loads

For the septic load calculation, it is assumed that properly functioning septic systems contribute no phosphorus load. Phosphorus loads from failing septic systems are based on an estimate of the number of people served by failing septic systems and literature estimates of phosphorus load from failing systems. A brief description of the calculation for failing systems is provided below. This approach assumes 1 septic field per housing unit.

> Septic load = Septic load from Low Density Development (LDD) + Septic load from High Density Development (HDD)
>
> Septic load from LDD = acres LDD on septic * 1 housing unit/acre * 1.91 people/ housing unit * 3.33% failing * 1.5 kg P /person-yr
>
> Septic load from HDD = acres HDD on septic * 1 structure/acre * 5.6 housing units/structure * 1.91 people/housing unit * 3.33% failing * 1.5 kg P /person-yr

The inputs used in these calculations are described in additional detail below.

1. **Areas served by septic** were identified by tabulating low and high density development located outside the sewer service area. This information was output by subwatershed, so that septic loads could be calculated in the model at the subwatershed scale.

2. **Housing density** was estimated using aerial photographs in combination with the GIS to investigate characteristics of developed lands. Low density development was calculated to have an average of 1 housing unit/acre. High density development was observed to have approximately 1 structure/acre. Information available for Bellaire (http://www.city-data.com/housing/houses-Bellaire-Michigan.html) was used to estimate the average number of housing units/structure for high density development. This average equals 5.6 housing units/structure.

3. **The average number of people per household unit** for homes occupied year-round was estimated from 2000 Census data. It is assumed that the number of people in homes serviced by septic system and by sewer is the same. An average of 2.38 people/housing unit was used for homes that are occupied year-round. For homes occupied only seasonally (approximately 65% of the homes in the study area), the occupancy rate for a four-month period was set equal to 5 people/home. The weighted occupancy rate per home, considering both seasonal occupancy and year-round occupancy rates equals 1.91 people/home.

4. **The septic failure rate** was obtained from a study by Conkel et al. (2004), which was conducted by the Three Lakes Association. A failure rate of 3.33% was applied in the model.

5. **Information on phosphorus loading from failing systems** was obtained from the USEPA (2002) On-site Wastewater Treatment Systems Manual. An average load of 1.5 g P/capita-day was used. This is the average of the range presented in the manual (range 1 –2 g/capita-day).

Wastewater treatment plants

There are three wastewater treatment plants in the study area (Table 2). All three treat the wastewater to remove phosphorus and then discharge the treated effluent to drain fields. The locations of the drain fields are shown in Figure 2.

Table 2. Summary of point source phosphorus loads

<table>
<tr><th>Facility</th><th>Location (subwatershed)</th><th>Estimated population served</th><th>Average annual flow (MGD)</th><th>Average concentration (mg P/l)</th><th>Annual Load (kg P/yr)</th></tr>
<tr><td>Schuss Mountain Resort</td><td>Cedar River</td><td rowspan="2">933</td><td>0.023</td><td>0.28</td><td>8.9</td></tr>
<tr><td>Summit Village</td><td>Lake Bellaire Direct Drainage</td><td>0.054</td><td>0.65</td><td>48.5</td></tr>
<tr><td>Bellaire WWTP</td><td>Lower Intermediate River</td><td>1,525</td><td>0.218</td><td>0.096</td><td>28.9</td></tr>
</table>

The phosphorus loads for the Schuss Mountain Resort and Summit Village wastewater treatment facilities were estimated from average annual effluent flows and average phosphorus concentrations in effluent prior to its discharge to drain fields (Nelson and Bartech, personal communication). Phosphorus loads for the Bellaire treatment plant were obtained from the US EPA PCS database, which presented monthly monitoring results for the effluent prior to its discharge to drain fields for 2005 and 2006. Additional phosphorus removal that likely occurs in the ground is not considered in these calculations. Therefore the treatment plant phosphorus loads presented in Table 2 likely overestimate the actual contribution from the permitted dischargers.

Fish farm

A fish farm located in the Cold Creek watershed discharges to Cold Creek. An estimate of phosphorus loads from this facility was based on in stream monitoring data collected upstream and downstream of the hatchery. The estimated load from this facility equals 264 kg P/yr.

Export coefficients

Export coefficients describe the amount of a pollutant, in this case, phosphorus, generated annually from surface runoff for a given land use. Phosphorus export coefficients were obtained from literature, and selected based on watershed characteristics such as land use, professional judgment and available monitoring data. When results from the Platte watershed modeling project become available (expected in 2007), the model can be updated with those phosphorus loading rates, which are expected to reflect region-specific conditions. The phosphorus export coefficients applied in the model are summarized in Table 3. Water and wetlands are not expected to generate phosphorus loads and so an export coefficient of zero was used for these two categories.

Table 3. Phosphorus export coefficients

Land Use	Phosphorus (kg/ac-yr)	Reference
Forest	0.045	EPA 1999
Pasture	0.053	EPA 1999
Cropland	0.061	Sonzogni et al.
Golf course	0.186	King et al.
Low density development	0.223	EPA 1999
High density development	0.283	EPA 1999

Atmospheric deposition of phosphorus was estimated as part of this study through measurements of rainwater and estimates of dry deposition. The annual deposition rate for the three lakes ranged from to 0.07 kg P/ac-yr (GLEC, undated) to 0.09 kg P/ac-yr (GLEC, 2006). Atmospheric deposition rates are expected to vary both spatially and temporally. These measured rates provide some information on the range expected for the study area.

Measured loads

Estimated phosphorus loads that have been calculated from monitoring data are specified in the model for shallow groundwater. Groundwater loading rates (kg/ac-yr) vary significantly, based on these results, ranging from 0 kg P/ac-yr for Clam Lake to 0.03 kg P/ac for Torch Lake.

Groundwater loads were estimated using data collected by the Three Lakes Association. Groundwater phosphorus loads to each of the three lakes are estimated as:

- 214 kg/yr for Lake Bellaire (GLEC, undated)
- 0 kg/yr for Clam Lake (groundwater flow is negligible; GLEC, undated)
- 1,480 kg/yr for Torch Lake (GLEC, 2006)

The total groundwater loads for each lake watershed was apportioned to each model subwatershed based on subwatershed areas.

MODEL APPLICATION

The model was implemented in Microsoft Excel using the inputs discussed previously. Annual phosphorus loads were estimated for current conditions based on current land use data and representative phosphorus loading rates, point source phosphorus loads, background groundwater phosphorus loads, and estimates of phosphorus from septic systems. The model calculates annual watershed phosphorus loads by subwatershed. The total phosphorus load to each lake is the sum of the subwatershed loads, considering loads from all sources.

To facilitate model application for future conditions, and to enhance the display of data and results, a user interface was developed. This section describes the model interface and application of the model for future conditions.

User Interface

A custom user interface was implemented in parallel with the watershed model. The interface uses spreadsheet features enhanced by macros to support users in the development and evaluation of different growth scenarios. Specifically, the interface:

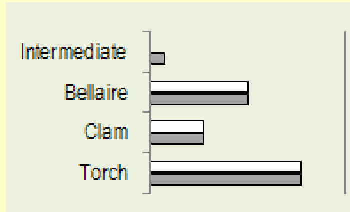
1. Presents summary information by watershed and subwatershed to allow the user to understand changes in loadings.
2. Allows modification on a subwatershed basis of areas in different land uses, and to enter information about point sources and management practices.
3. Supports the storage and retrieval of scenarios.

These capabilities are discussed in more detail below.

Summary information

The use of Excel to implement the model provides several options for display of watershed loads for the scenario being evaluated and for comparison of that scenario to loads under current condition. As currently implemented (Figure 3), the model interface provides a simple bar chart showing total loads to each lake, and a table showing loads by subwatershed. Both bar chart and table compare evaluated loads to current condition "baseline" loads. The chart and table automatically update as changes are made to subwatersheds. Subwatersheds can be selected for review or editing by double-clicking on the subwatershed name in the summary table.

THREE LAKES WATERSHED MODEL - Load Summary



	Scenario (kg P/yr)	Base (kg P/yr)
Intermediate Lake Outlet	**372**	372
01 Maury Creek	32	32
02 Upper Intermediate River (marina)	571	571
03 Butler Creek	186	186
04 Lower Intermediate River	176	176
05 Cedar River	1,118	1,118
06 Lake Bellaire Direct Drainage	426	426
Lake Bellaire Watershed	**2,508**	2,508
01 Finch Creek	267	267
02 Clam Lake Direct Drainage	282	282
03 Cold Creek	497	497
04 Shanty Creek	101	101
05 Lower Grass River	160	160
06 Dewey Creek	67	67
Clam Lake Watershed	**1,374**	1,374
01 Eastport Creek	284	284
02 Eastport Ck. to A-Ga-Ming Ck.	237	237
03 A-Ga-Ming Creek (golf course)	54	54
04 A-Ga-Ming Ck. to Milton Twp	124	124
05 Milton Twp. Direct Drainage	633	633
06 Spencer Ck. to Torch River	212	212
07 Spencer Creek	656	656
08 Clam R. to Spencer Ck.	453	453
09 Forest Home Twp	407	407
10 Wilkinson Ck. to Forest Home Twp	525	525
11 Wilkinson Creek	218	218
12 Eastport Ck. to Wilkinson Ck.	52	52
Torch Lake Watershed	**3,854**	3,854

Figure 3. Summary sheet with table and chart

Modifying land use

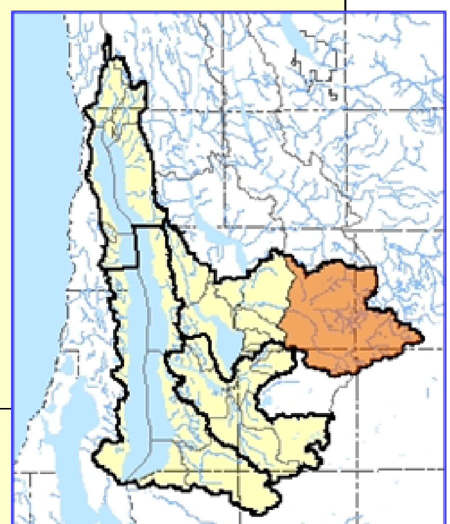
The interface provides the user with the capability to interactively modify the land areas assigned to different land uses by subwatershed (Figure 4). After selecting a subwatershed either through the list box on the subwatershed editing page or by pointing and clicking to the subwatershed using maps (Figure 5), the user is able to enter the change in land area under each land use. The interface tracks changes and makes sure that total subwatershed areas are maintained and that sewered areas are appropriately specified.

THREE LAKES WATERSHED MODEL - Subwatershed Editor

LB05: Cedar River

Update Summary | Reset Windows

		Base	Change	New Area	New Load	BMP Acres	Removal Efficiency	Mass Removed
Total Load	(kg P/yr)	1108.8	373.8		1482.6			0.0
Land Use								
Low-density	(acres)	608.1	*+359.8*	967.9	215.4			0.0
Sewered LDD	(acres)	166.3		166.3				
High-density	(acres)	17.5	*+359.8*	377.3	106.9			0.0
Sewered HDD	(acres)	17.5		17.5				
Golf course	(acres)	543.1		543.1	101.1			0.0
Cropland	(acres)	543.1		543.1	33.0			0.0
Pasture	(acres)	1970.9		1970.9	103.7			0.0
Forest	(acres)	12680.2	*-719.6*	11960.6	532.4			0.0
Water	(acres)	9.6		9.6	0.0			0.0
Wetland	(acres)	156.9		156.9	0.0			0.0
Residual Area	(acres)							
LDD sewer check				OK				
HDD sewer check				OK				
Groundwater	(kg P/yr)	115.7			115.7			
Other sources	(kg P/yr)	8.9			8.9			
Delivery ratio		1.00			1.00			
Population adjustment		0.80			0.80			
Onsite septic	(kg P/yr)	41.6	223.8		265.4			
Nonpoint	(kg P/yr)	942.5	150.0		1092.5			
Sewered		29%		14%				



Scenario 05 Title *Shanty Creek - unsewered development*

Description

Develop 1360 acres in Shanty Creek area with sewer

Load ... | Save ... | Image ...

Figure 4. Subwatershed editing sheet

Management practices

The interface also allows the user to enter information to define simple representations of best management practices (BMPs) that might be installed in the subwatershed. For each land use category, the user can enter the number of acres where BMPs are installed, along with the removal efficiency of that BMP. These data are used to calculate the mass of phosphorus removed.

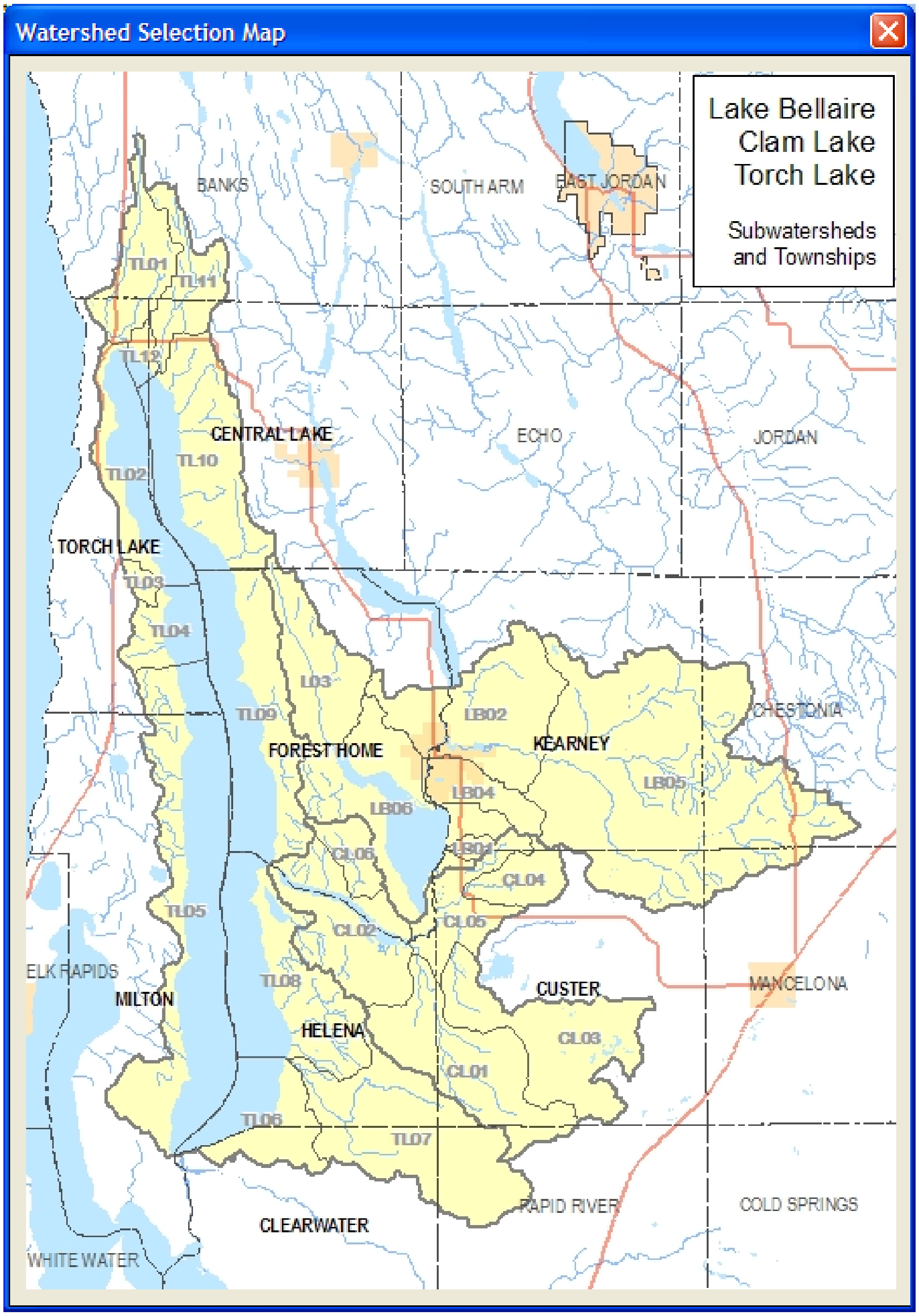


Figure 5. Subwatershed selection map

Point sources

Changes in point source loads can also be entered in the interface. The most likely situation for a change in point source loads is the construction or expansion of a wastewater treatment plant in conjunction with sewered development. The placement of sewered areas within a subwatershed results in the elimination of loads from septic systems within the sewered areas. However, these loads are assumed to be routed to a centralized location for treatment, which will in turn contribute a reduced phosphorus load to the environment. If the treatment location lies within a modeled subwatershed (not necessarily the same subwatershed in areas were sewered), the reduced load should be added to the “other source” total for that subwatershed. The following calculation may be used to estimate added from a treatment plant with subsurface discharge:

Load to Lake = (LDD load+HDD load) * (1-treatment eff) * (1-transmission loss)

LDD Load = sewered acres LDD * 1 dwelling/acre * 1 septic field/dwelling * 1.91 people/septic field * 1.5 kg P /person-yr

HDD Load = sewered acres HDD * 5.6 dwelling/acre * 1 septic field/dwelling * 1.91 people/septic field * 1.5 kg P /person-yr

Treatment efficiency = Fraction of phosphorus removed in WWTP (80%). This is an estimated typical value based on literature review and examination of available discharge monitoring data.

Transmission loss = Fraction of phosphorus discharged not reaching lake (95%). This is an estimated coefficient to characterize the sequestration and removal of phosphorus in groundwater. This coefficient should be estimated based on the site-specific soil and hydrogeological characteristics of the discharge location.

For example, if 100 sewered acres of HDD are added to a subwatershed, the estimated additional point source load would be:

= 100 acres * 5.6 dwellings/acre * 1 field/dwelling * 1.91 people/field *
1.5 kg P/person-yr * (1 – 0.8) * (1 – 0.95)
= 20 kg P/yr

This added point source load should be put into the subwatershed receiving the discharge. If the additional load from sewered areas is removed from the study area (for example, by pumping through force mains), it would be appropriate to include no additional point source load in any subwatershed for the scenario.

Storage and retrieval

Currently, scenarios are stored and retrieved using the Excel File|Save and File|Open commands.

Future Conditions

Two development scenarios were provided by the Three Lakes Association as seeds for discussion. For both scenarios, development was assumed to be evenly distributed across forested land in the portions of subwatersheds within specified development areas (Figure

6). These scenarios included changes in land use. The effect of having this development serviced by septic and by sewer was investigated in the model.

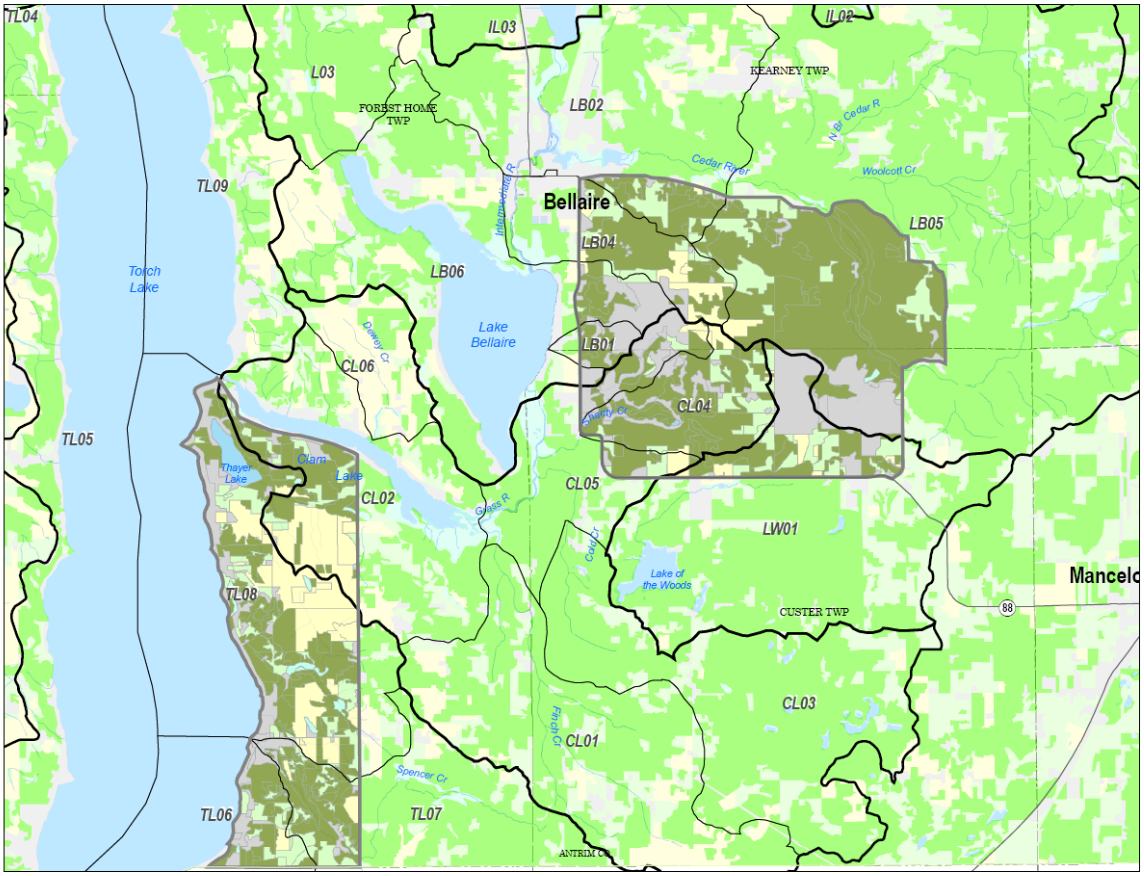


Figure 6. Development areas

For the Alden scenario, 652 acres in four subwatersheds would be developed, while 1362 acres in seven subwatersheds would be developed in the Shanty Creek scenario (plus an additional 110 acres that drain to Lake of the Woods).

RESULTS

The model was applied to predict phosphorus loads under current conditions and for several future scenarios. Model results are discussed in this section by source for each of the lake watersheds. The total measured loads for monitored tributaries are also compared to the modeled loads in this section. Furthermore, surface runoff loads are examined by land use. Finally, phosphorus loads from future scenario model runs are presented and discussed.

Results by Source

Annual phosphorus loads were calculated in the model for current conditions. These loads are presented by watershed in Table 4 and are broken down by general source category. As shown in this table, loads from surface runoff comprise the majority of the phosphorus load to each of the lakes. The groundwater contribution is most significant in the Torch Lake watershed. Contributions from failing septic systems and other sources (the treatment plants and the fish farm) are much less than that from surface runoff.

Table 4. Modeled and measured watershed phosphorus loads (kg/yr) by source for 2006 conditions

Watershed	Modeled		Measured	
	Surface runoff	Failing septic	Other sources	Shallow groundwater
Lake Bellaire	1,946	214	86	214
Clam Lake	1,013	79	264	0
Torch Lake	1,994	310	0	1,480

Direct atmospheric deposition of phosphorus to the lakes contributes another 135 kg/yr to Lake Bellaire, 26 kg/yr to Clam Lake (GLEC, undated) and 1,770 kg/yr to Torch Lake (GLEC, 2006).

Comparison to Measured Loads

Measured loads were calculated from flow and concentration data collected by the Three Lakes Association during 2006. Flows and phosphorus concentrations were measured at discrete times and this information was used to calculate tributary loads, by applying the Beale's Stratified Ratio Estimator (GLEC, undated). Because runoff concentrations and flows vary throughout the year, there is some uncertainty associated with loads based on discrete measurements. The measured/data-based loads are presented in Table 5, by tributary subwatershed.

In general, the model predictions are consistent with the measured loads, considering uncertainty in the measured loads and in the groundwater contribution. Of note, the model predicts lower phosphorus loads in the Cold Creek watershed, than those that were measured, and predicts higher loads in the Finch Creek watershed than those that were measured. The Cold Creek watershed and the Finch Creek watershed are similar in size and have similar land use distributions, so the reason for the difference in the data-based loads is not obvious. Based on a conversation with the local Conservation District, there do not appear to be any phosphorus-generating activities in the Cold Creek subwatershed that are not already included in the model. Additional work to investigate whether significant soil-disturbing activities were occurring during the time of sampling, or whether creek bottom sediments are perhaps contributing phosphorus may improve understanding of the measured load.

Table 5. Annual measured vs. modeled phosphorus by source (kg P/yr)

Tributary	Measured loads (estimated from field data)	Loads by Source			
		Surface runoff	Failing septic	Other sources	Shallow groundwater*
Cedar River	1,350	943	42	9	0 – 490
Cold Creek	729	227	5	264	0 – 144
Finch Creek	137	252	13		0 - 143
Spencer Creek	310	317	10		0 - 328

*Range of loads from shallow groundwater is based on the range of groundwater loading rates calculated from data collected for each lake. The loading rate for Clam Lake is the lowest (0 kg/ac-yr) and the loading rate for Torch Lake is the highest (0.03 kg/ac-yr).

A direct comparison between measured loads (calculated from measured tributary flow and concentration data) and modeled loads is difficult because the load contribution from groundwater at the tributary monitoring stations is not known and instead was estimated from the only available data – the overall groundwater loads to the lakes. An estimated 0.0067 kg/ac-yr of phosphorus enters Lake Bellaire, while the loading rate for Torch Lake is four and a half times higher at 0.03 kg/ac-yr. The groundwater loading rate for Clam Lake is estimated as 0 kg/ac-yr. In Table 5, a range of groundwater loads is presented by subwatershed based on this range of groundwater loading rates (0 – 0.03 kg/ac-yr). This difference is highlighted in the Cedar Creek subwatershed, where monitoring of a TCE plume originating in Mancelona shows that groundwater from outside the study area flows towards the Cedar River (see http://bizhost-a3.mactec.biz/wickes/viewer.htm). The groundwater component of the Cedar Creek load may therefore be higher than that of other subwatersheds.

Surface Runoff Loads by Land Use

Figure 7 presents the percent of the surface runoff load that is generated by different land use categories and Figure 8 presents the land use distribution by lake watershed. In each watershed, forested lands generate the highest phosphorus load. This result is expected because forest is the most common land use (Figure 8), comprising 68% of the study area watershed. Runoff from low density development (LDD) is the second largest source of phosphorus from surface runoff in each watershed. LDD comprises less than 10% of the study area, but generates a larger proportion of the total load due to the higher phosphorus loads generated from this land use.

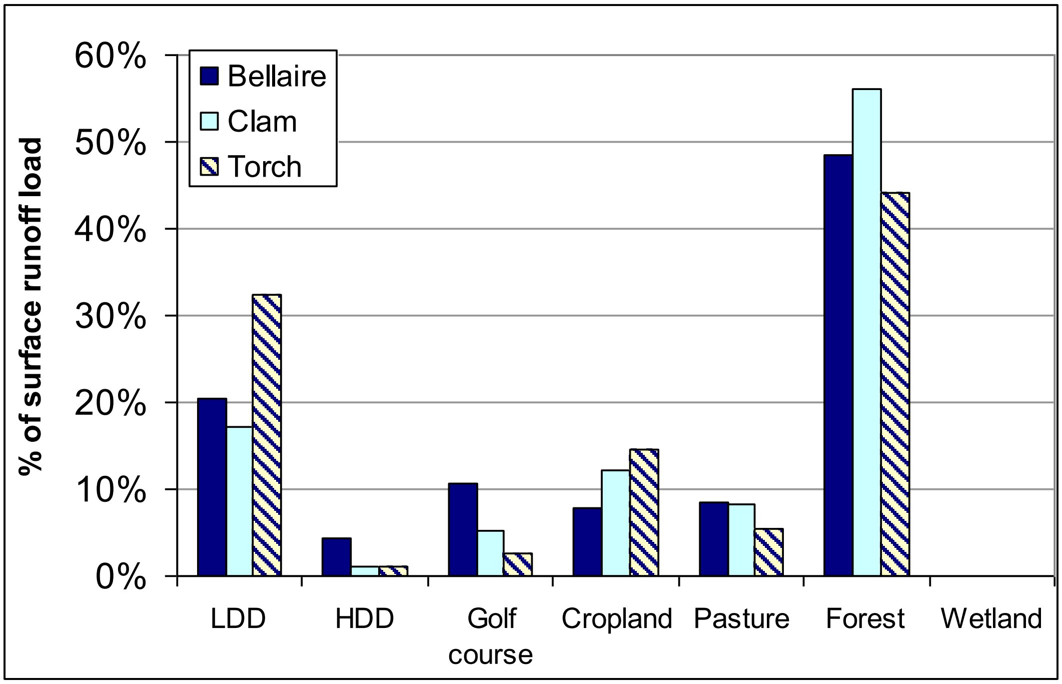


Figure 7. Contribution of surface phosphorus loads by land use and watershed

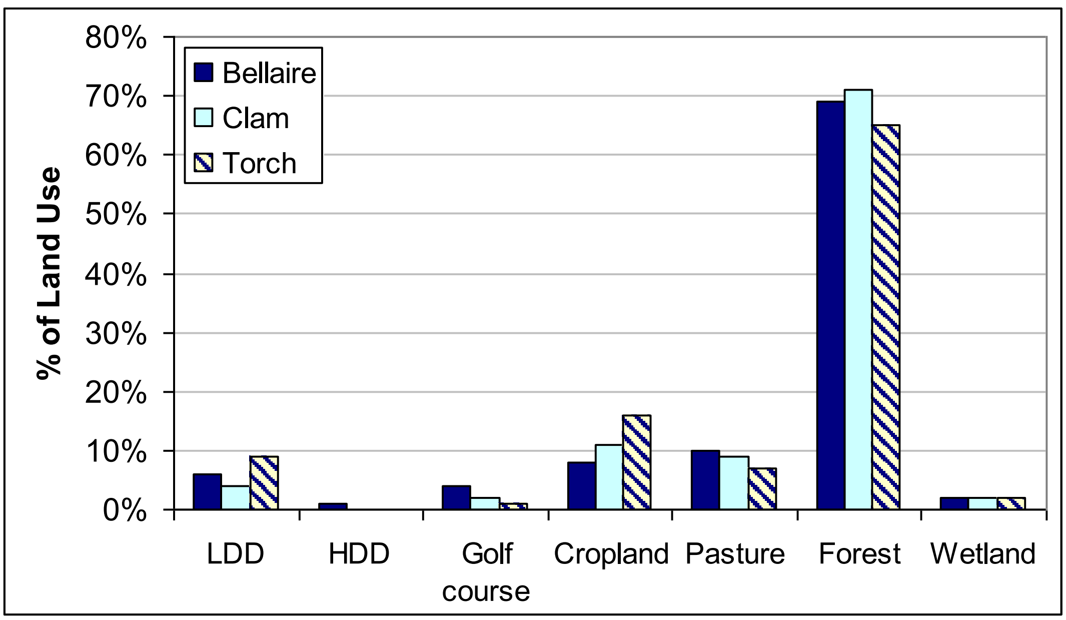


Figure 8. Land use distribution by watershed

Future scenario results

The watershed model was applied for two development scenarios assembled by the Three Lakes Association. The scenarios were each evaluated with and without installation of sewers; for the results with sewers, no additional point source load was included to account for the fraction of additional WWTP discharge that reaches the lakes. The estimated WWTP load from sewered development of 642.5 acres near Alden is 75 kg/year, and from 1,359 acres of sewered development near Shanty Creek is 150 kg/yr. If these WWTPs were located in the study area, then the loads would need to be entered by the user into the model.

The scenario results are tabulated by subwatershed in Table 6. These same results are also shown graphically in Figure 9. Spatial differences can be see by looking at the scenario results. For example, the Alden development does not affect phosphorus loads to Lake Bellaire because this development is not located in this lake's watershed. Instead, this development affects loads to Clam and Torch Lakes.

Table 6. Watershed Phosphorus Loads in kg/yr (and changes from Baseline) Under Baseline Conditions and Development Scenarios

	Bellaire (kg/yr)		Clam (kg/yr)		Torch Kg(yr)	
Baseline	2,508		1,374		3,854	
Alden – 642.5 ac development, ~5,000 added residents						
Unsewered	2,508		1,453	(+79)	4,346	(+492)
Sewered	2,508		1,402	(+28)	4,028	(+174)
Shanty Creek – 1,359 ac development, ~10,000 added residents						
Unsewered	3,114	(+606)	1,610	(+236)	3,854	
Sewered	2,723	(+215)	1,512	(+59)	3,854	

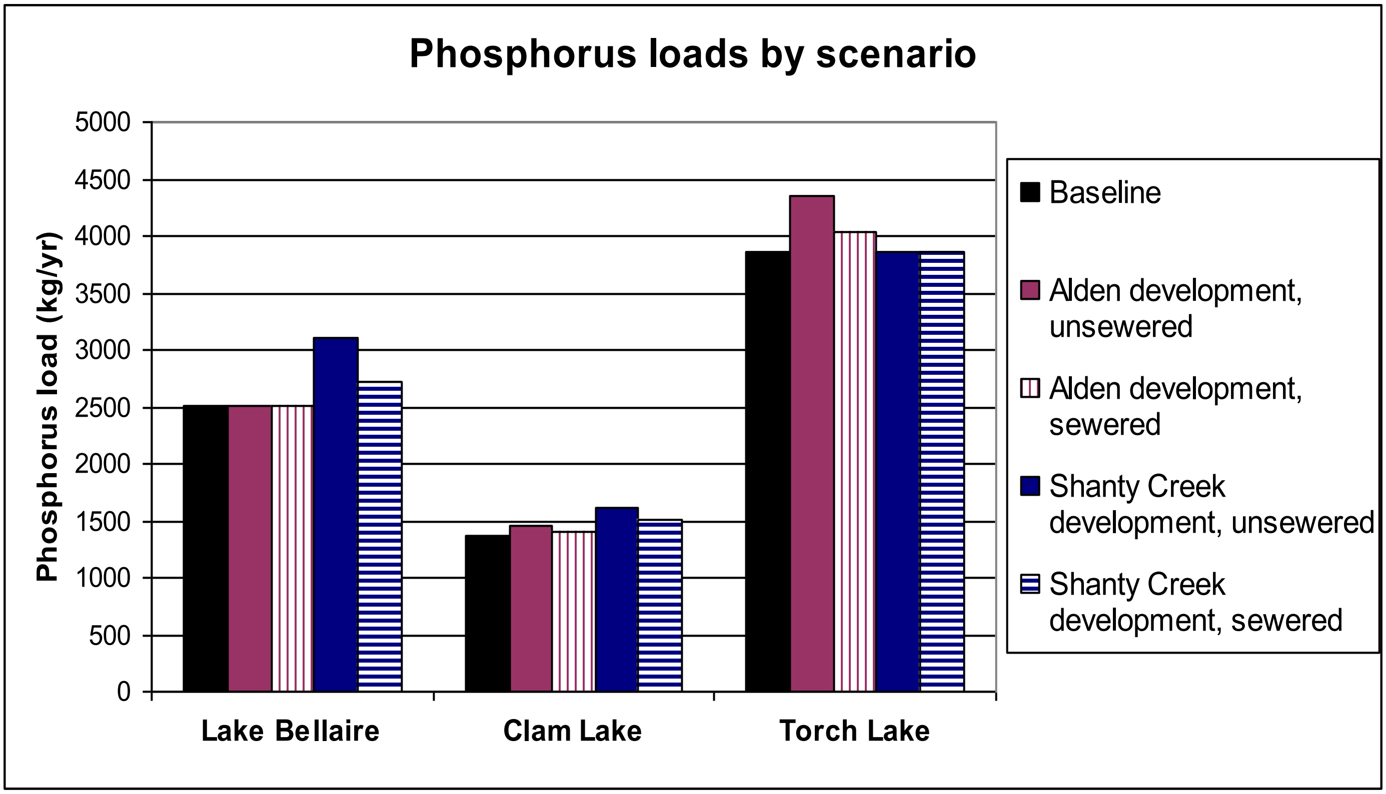


Figure 9. Watershed Phosphorus Loads Under Baseline Conditions and Development Scenarios

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APPENDIX A. DATA SOURCES

The table below presents sources for the various model inputs used in the watershed model.

Description	**Source**
GIS Information	
Current (1998) land use	Antrim County, Land Use Atlas
Land cover (1992)	National Land Cover Dataset, 1992, from the Multi-Resolution Land Characteristics Consortium http://gisdata.usgs.net/website/MRLC/viewer.php
Recent (2006) aerial image of Antrim County	Natural Resources Conservation Service (NRCS), under the USDA National Agriculture Imagery Program (NAIP)
Future land use	Digitized in the GIS based on input from Dean Branson
Watershed and subwatershed boundaries	Based on data from the Michigan Geographic Data Library http://www.mcgi.state.mi.us/mgdl/ Additional linework digitized in GIS based on stream network and topographic information.
Stream network Cities, villages, townships, counties, roads, railroads	Michigan Geographic Data Library http://www.mcgi.state.mi.us/mgdl/
Soils	SSURGO (county-level) and STATSGO (state-level) obtained from the NRCS http://www.mi.nrcs.usda.gov/soils.html http://soildatamart.nrcs.usda.gov/
Mid-point of drain field locations	Dean Branson, Three Lakes Association
Sewered areas	Digitized based on maps and photos provided by Dean Branson
Data	
Groundwater phosphorus loads	Calculated from data by GLEC
Phosphorus loading rates	Literature
Average # people/house	U.S. Census Bureau website. Averaged information for Census Tracts 9603, 9604, 9605
Septic failure rate	Conkle et al., 2004
Phosphorus load from failing septic systems	US EPA, 2002. Onsite Wastewater Treatment Systems Manual. EPA/625/R-00/008. Office of Water, Office of Research and Development