LONG-TERM MONITORING PLAN FOR LAKE CHELAN
WRIA 47 PHASE II WATERSHED PLANNING
CHELAN COUNTY, WASHINGTON

Submitted to:

Chelan County Natural Resource Department, Wenatchee, WA

Submitted by:

AMEC Geomatrix, Inc., Lynnwood, WA

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ACRONYMS AND ABBREVIATIONS

BOD	biological oxygen demand
BMP	best management practice
CBOD	carbonaceous biological oxygen demand
DO	dissolved oxygen
DOC	dissolved organic carbon
DOM	dissolved organic matter
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
LTMP	long-term monitoring plan
NTR	National Toxic Rule
PCB	polychlorinated biphenyl
POC	particulate organic carbon
POM	particulate organic matter
RCW	Revised Code of Washington
SPMD	semipermeable membrane device
TOC	total organic carbon
TMDL	total maximum daily load
TSS	total suspended solids
WRIA	Water Resource Inventory Area

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EXECUTIVE SUMMARY

On May 14, 2008, the Water Resource Inventory Area (WRIA) 47 Water Quality Subcommittee met to discuss future objectives for assessing water quality in Lake Chelan. The Subcommittee approved a recommendation to develop and implement a long-term monitoring plan (LTMP) for the lake. This document summaries the recommendations and ideas proposed by Subcommittee members for the development of a LTMP and provides an initial framework for the plan that focuses on the calibration and application of two models (CE-QUAL-W2 and the Lake Chelan food web model). These models will allow the evaluation of water quality dealing with water clarity, eutrophication, and toxics accumulation in fish tissue.

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1.0 INTRODUCTION

The Lake Chelan Watershed Planning Unit was created in 2007 to conduct comprehensive watershed planning under Washington State's Watershed Planning Act (Chapter 90.82 RCW). Phase I of the watershed planning process (organization) was completed in January of 2008 (RH2 and Geomatrix, 2008). Phase II activities to assess water resources and water quality were subsequently initiated.

On May 14, 2008, the Water Resource Inventory Area (WRIA) 47 Water Quality Subcommittee met to discuss future objectives for assessing water quality in Lake Chelan. The Subcommittee approved a recommendation to develop and implement a long-term monitoring plan (LTMP) for the lake. This document summarizes the recommendations and ideas proposed by Subcommittee members for the development of a LTMP and provides an initial framework for the plan.

2.0 MONITORING PLAN GOALS AND OBJECTIVES

There is general agreement that the goals of a LTMP should be to address data gaps, identify water quality trends, and provide a proactive monitoring plan for Lake Chelan. The general objectives identified for the LTMP are:

- Develop a monitoring design supported by water quality models that can be used to evaluate trends in water quality parameters;
- Evaluate concerns about potential future changes in water clarity and lake eutrophication;
- Develop a monitoring approach for constituents that have completed total maximum daily loads (TMDLs) to allow a determination of the effectiveness of post-TMDL remedies (phosphorus, DDT analogs, polychlorinated biphenyls [PCBs]);
- Develop a monitoring design for 303(d)-listed constituents in Lake Chelan that have not yet been addressed by completing a TMDL (chlordane, dieldrin, dioxins/furans);
- Recommend data quality objectives and analytical methods to ensure greater consistency and comparability of data in the future; and
- Develop a monitoring program that can be used to evaluate best management practices (BMPs) that may be implemented to address water quality concerns.

3.0 WATER QUALITY MODELS

Two models are recommended to evaluate water quality issues within Lake Chelan. CE-QUAL-W2 is well suited to evaluate water clarity/eutrophication issues. The Lake Chelan food web model, which is currently under development, models toxics transfer between sediment, water, and the aquatic food chain. These models are described below.

3.1 CE-QUAL-W2

CE-QUAL-W2 is a two dimensional (longitudinal/vertical) water quality and hydrodynamic model supported by the U.S. Army Corps of Engineers Waterway Experiments Station. The model has been under continuous development and enhancement since 1975. The latest upgrade occurred in January 2008 with the release of Version 3.5 (Cole and Wells, 2008). The model has been widely applied to simulate water quality in lakes and reservoirs. CE-QUAL-W2 allows any combination of constituents to be included or excluded from a simulation. Version 3.5 includes the following water quality state variables in addition to temperature:

- Any number of generic constituents defined along with a decay rate and/or settling velocity and/or Arrhenius temperature rate multiplier to define a conservative tracer, hydraulic residence time, coliform bacteria, or contaminants;
- Any number of phytoplankton, periphyton, macrophyte, and zooplankton groups;
- Nutrients (ammonium, nitrate-nitrite, bioavailable phosphorus);
- Inorganic and organic carbon (labile and refractory and dissolved and particulate species);
- Alkalinity, dissolved oxygen, pH; and
- Organic sediment contributions to nutrients and dissolved oxygen.

CE-QUAL-W2 models basic eutrophication processes such as temperature-nutrient-algae-dissolved oxygen-organic matter and sediment relationships. Application of this model to Lake Chelan would provide a comprehensive framework for understanding relationships among water quality parameters and provide a tool to predict how water quality would be impacted by future changes in nutrient loads or implementation of BMPs.

Application of the model requires that the lake be divided into segments which are arranged in a series along the longitudinal axis of the lake. Three input files (bathymetry file, control file, and meteorological file) must be created for each model application. Data needs for applying the model require information for a water balance (inflows, surface water elevation, and outflows), inflow constituent concentrations, and longitudinal and vertical profiles specifying initial conditions for each cell.

3.2 LAKE CHELAN FOOD WEB MODEL

Lake Chelan has been listed under Section 303(d) of the Clean Water Act for non-attainment of the U.S. Environmental Protection Agency's (EPA's) National Toxic Rule (NTR) criteria for DDE (a degradation product of the insecticide DDT) and PCBs in edible fish tissue. The Washington State Department of Ecology (Ecology) completed a TMDL for DDE and PCBs in 2005. Fish samples collected in the Wapato Basin of Lake Chelan during 2003 showed that fillets from burbot, kokanee, and LAKE trout had total DDT concentrations that exceeded the NTR human health criteria for DDT in fish tissue (32 µg/kg). Fillets for kokanee and lake trout also exceeded the NTR human health criteria for total PCBs in fish tissue (5.3 µg/kg).

Lake Chelan has also been listed for non-attainment of the NTR human health criteria for chlordane, dieldrin, and dioxin/furans in fish tissue based on the analysis of lake trout samples collected near the mouth of Stick Creek during October 2000. TMDLs have not been conducted for these chemicals.

In 2006, the Lake Chelan Water Quality Committee initiated efforts to develop a Lake Chelan food web model (Figure 1). The objective for the initial development of the model was to predict tissue concentrations of DDT and its breakdown products DDE and DDD in the three fish species (burbot, kokanee, and lake trout) that exceed NTR criteria. The modified version of the 1993 Gobas food web bioaccumulation model (Gobas, 1993) was selected to examine the distribution of DDT, DDE, and DDD within Lake Chelan sediments, water, and aquatic biota (Arnot and Gobas, 2004; Gobas and Arnot, 2005). This model has gained general scientific acceptance for predicting chemical residues in aquatic food webs and has been used in a substantial number of scientific and regulatory applications (Burkhard, 1998; Gobas and Arnot, 2005; Gobas et al., 1991; Kelly and Gobas, 2003; Walker and Gobas, 1999). A description of the model theory is provided by Arnot and Gobas (2004). The model can be used to examine the partitioning of sediment DDT to pore water and the overlying water column and to examine the accumulation of DDT in aquatic species from the water and diet. The model simulates two chemical uptake processes: intake via respiratory surfaces and dietary uptake. Four chemical elimination processes are also simulated: elimination via the respiratory surfaces, excretion, chemical metabolism, and growth.

The initial parameterization of the model was completed in March 2006 (Geomatrix, 2006). The final model calibration for DDT analogs will be completed prior to June 30, 2009. It is recommended that the model calibration be expanded to include the other toxics compounds for which TMDLs have not yet been completed (chlordane, dieldrin, and dioxin/furans).

Additional monitoring data that are recommended to reduce model uncertainties include:

- Water column concentrations of dissolved organic carbon (DOC) and particulate organic carbon (POC);
- Tissue concentrations of toxics in key prey species (three-spine stickleback, peamouth chub, mysids); and
- Synoptic data set for toxics concentration in sediment, pore water, and benthic biota.

Once the model is calibrated, it can be used to address important management questions. Some examples include:

- Predict the fraction of tissue contaminants that are derived from water, sediment, and diet.
- How will sediment deposition trends affect tissue concentrations? Total DDT concentration in Wapato Basin sediments increase with depth. Over the depth range of 7 to 0 cm, total DDT concentrations decrease approximately 110 μg/kg with each 1 cm of deposition (i.e., more recent sediments have lower DDT concentrations). Using an estimate of the sediment deposition rate, the model can predict how fish tissue concentrations will change based on future changes in sediment concentrations.
- How will changes in contaminant loads from tributaries and irrigation drains affect fish tissue concentrations?
- The model predicts tissue concentrations increase with fish size. What sizes of burbot, kokanee, or lake trout are predicted to have tissue concentrations below the National Toxics Rule?
- Given predicted changes in fish tissue concentration over time, what monitoring interval should occur to be able to detect statistically significant changes?

4.0 MONITORING PARAMETERS AND FREQUENCY OF SAMPLING

Monitoring programs that are designed around the calibration of models typically have an intensive first phase that is designed to collect sufficient data to calibrate the model. This is followed by less frequent sampling as the model allows a greater understanding of the system and better prediction of the sampling intervals that are necessary to capture measurable changes in parameters. A discussion of the parameters and frequency of sampling is provided for each of the models discussed above.

4.1 CE-QUAL-W2

This model categorizes constituents into four levels, depending on whether they affect phytoplankton/nutrient/dissolved oxygen dynamics and whether they are transported longitudinally or vertically within the lake (Table 1). In order to evaluate water clarity/eutrophication issues in Lake Chelan, Level II and Level IV constituents will need to be monitored. Given the low productivity and steep nearshore bathymetry of most of the lake, Level III constituents are likely not necessary for an understanding of lake eutrophication trends.

Calibration of the model requires monitoring data for the boundary conditions. Boundary conditions frame the grid area that is simulated by the model. Surface boundary conditions and hydraulic parameters are required for model application boundary conditions for inflows; outflows are optional.

Surface boundary conditions include the following:

- **Surface heat exchange** – calculated from latitude, longitude, air temperature, dew point temperature, wind speed and direction, and cloud cover;
- **Solar radiation absorption** – solar radiation is determined from latitude, longitude, and date. Distribution of solar radiation in the water column is controlled by the fraction of radiation absorbed in the surface layer (user specified) and the attenuation rate due to water, inorganic, and organic suspended solids (if modeled);
- **Wind stress** – this boundary condition is determined from wind speed and direction; and
- **Gas exchange** – wind speed is also used for computing gas exchange at the water surface if dissolved oxygen and/or total inorganic carbon are simulated.

Hydraulic boundary conditions include the following:

- **Dispersion/diffusion coefficients** – the model allows selection of default values for horizontal dispersion coefficients for momentum and temperature. The model is relatively insensitive to variation in these values. Vertical diffusion coefficients for momentum and temperature vary in time and space and are computed by the model.
- **Bottom friction** – user can enter different values for the Chezy coefficient or Manning’s N for bottom friction for each model cell.

Inflow boundary conditions include the following:

- **Upstream inflows (optional)** – Model provides an option to distribute inflows evenly throughout the inflow segment (farthest up-lake segment – likely would be located in the lower Lucerne Basin) or distribute flows according to density. If this option is used, then a separate file is needed for inflow, temperature, and all constituents that are being modeled (Table 2);

- **Tributary inflows (optional)** – If this option is selected, then the same data requirements as upstream inflow are required for each tributary. If the model was setup to examine the lower Lucerne and Wapato basins, potential tributaries to include would be Twenty-Five Mile Creek, Stink Creek, First Creek, Knapp Coulee Creek, and Purtteman Creek.

- **Distributed tributary inflows (optional)** – these flows represent non-point source inflows that are distributed throughout a segment weighted by the segment surface area. It is unlikely that initial inflows would be specified. However, through the calibration process inflows could be specified to obtain a better fit to collected data. Nutrient input via septic systems or groundwater influx of contaminants could be modeled using this boundary parameter.

Outflow boundary conditions include the following:

- **Downstream outflows (optional)** – for Lake Chelan this would be the water leaving the lake at Chelan Dam. The model allows specification of the depth interval over which water outflow occurs.

- **Lateral withdrawals (optional)** – this option could be used if water loss for human consumption and/or irrigation has a significant impact on the water balance (unlikely).

- **Evaporation (optional)** – this is calculated from air and dew point temperature and wind speed.

As noted above, several of the boundary condition parameters are provided by the model as default values, or are calculated from meteorological data that can be obtained from local or regional reporting stations. The minimum requirement for each boundary cell (upstream inflow or tributary) would be to monitor temperature, total organic carbon, soluble reactive and total phosphorus, nitrate+nitrite, and ammonium (Table 2). Table 2 also shows additional parameters that would substantially improve the predictive capability of the model. Cole and Wells (2008) recommend a weekly sampling frequency that includes capturing storm events. This frequency, while desirable, would not be necessary for an initial calibration of the model. Monthly sampling is recommended for collecting data to calibrate the portion of the lake being modeled (Table 3).

Monitoring data is also needed for each model segment established to simulate water quality conditions in the lake. Each segment would span the width of the lake and a specified longitudinal distance upstream. Typically these segments are setup to capture only one tributary inflow, if that option is being simulated. The minimum amount of monitoring data would collect data from several depths at one location in the middle of the cell. Multiple sites could be sampled if lateral variability is suspected (if this is determined, the model can be setup to evaluate branch segments). Table 3 shows the minimum number of parameters required to simulate the eutrophication features of the model. Additional parameters that would substantially enhance the predictive capability of the model are also shown in Table 3. All of the parameters shown except phytoplankton biomass and type and biological oxygen demand are recommended for initial model calibration.

4.2 LAKE CHELAN FOOD WEB MODEL

Section 3.2 identified additional data that would assist in the initial calibration of the food web model. Once the model is calibrated, it is recommended that the parameters shown in Table 4 be monitored at a frequency of once every 3 to 5 years. Fish tissue and mid-lake sediment samples were last collected in Lake Chelan in 2003. The collection and evaluation of data with the Lake Chelan food web model would provide the effectiveness monitoring required for the DDT and PCB TMDL and perhaps meet the requirements for completing a TMDL for chlordane, dieldrin, and dioxins/furans.

5.0 NEXT STEPS

The next steps in completing a long-term monitoring plan for Lake Chelan will include the following:

- Watershed Planning Committee approval of the application of the models recommended in this report (or alternative models);
- Watershed Planning Committee approval of the constituents to be monitored and the sampling frequency and design;
- Completion of a Quality Assurance Plan for the monitoring program; and
- Implementation of the plan once funding is secured.

6.0 REFERENCES

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TABLES

TABLE 1

CONSTITUENT LEVEL CATEGORIES IN CE-QUAL-W2

WRIA 47 Phase II Watershed Planning
Chelan County, Washington

Level	Group Characterization	Constituent
I	No interaction with phytoplankton/nutrient/DO dynamics	Total dissolved solids
		General constituents
		Inorganic suspended solids
II	Affect phytoplankton/nutrient/DO dynamics	Dissolved inorganic Phosphorus
		Ammonium
		Nitrate-Nitrite
		Dissolved silica
		Particulate biogenic silica
		Total iron
		Labile and refractory DOM
		Labile and refractory POM
		CBOD
		DO
		zooplankton
		phytoplankton
III	Constituents that interact with Level II constituents but are not transported	Periphyton
		Organic sediments
		Macrophytes
IV	Necessary for computing pH and carbonate species; Model state variables	Total inorganic carbon
		Alkalinity

<u>Abbreviations</u>

BOD:	biological oxygen demand
CBOD:	carbonaceous biological oxygen demand
DO:	dissolved oxygen
DOM:	dissolved organic matter
POM:	particulate organic matter

TABLE 2

GENERAL GUIDELINES FOR SAMPLING BOUNDARY CONDITIONS

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Minimum Parameters	Additional Parameters	Sampling Frequency
Inflow and Outflow Temperature	Conductivity, DO, pH Total Dissolved Solids[1]	Daily or continuous
TOC	DOC, POC, BOD[2]	Weekly, with storm sampling
Soluble Reactive Phosphorus Total Phosphorus	Total Dissolved Phosphorus Total Inorganic Phosphorus Dissolved Inorganic Phosphorus	Weekly, with storm sampling
Nitrate + Nitrite Ammonium	Total Kjeldahl Nitrogen Dissolved Kjeldahl Nitrogen	Weekly, with storm sampling
	TSS[3]	Weekly, with storm sampling
	Chlorophyll a Dissolved silica[4] Alkalinity	Weekly, with storm sampling

Notes

1 Enough samples to correlate to conductivity (important for density effects)
2 Used to characterize decay rates of organic matter
3 Suspended solids affect phosphorus partitioning, light penetration, and density
4 May be limiting for diatom growth

Abbreviations

BOD: biological oxygen demand
DO: dissolved oxygen
DOC: dissolved organic carbon
POC: particulate organic carbon
TOC: total organic carbon
TSS: total suspended solids

TABLE 3

GENERAL GUIDELINES FOR IN-POOL WATER QUALITY SAMPLING

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Minimum Parameters	Additional Parameters	Sampling Frequency
Temperature[1], DO[1], pH[1] Conductivitry[1]	Total Dissolved Solids[2]	Monthly
Chlorophyll *a*[3]	Phytoplankton biomass and type (e.g., diatoms, green, blue-green)	Monthly
TOC[3]	DOC, POC, BOD	Monthly
Soluble Reactive Phosphorus[3] Total Phosphorus[3]	Total Dissolved Phosphorus Total Inorganic Phosphorus Dissolved Inorganic Phosphorus	Monthly
Nitrate + Nitrite[3] Ammonium[3]	Total Kjeldahl Nitrogen Dissolved Kjeldahl Nitrogen	Monthly
	Secchi depth/light transmission	Monthly
	Total inorganic carbon Alkalinity TSS	Monthly

Notes

1 Preferably biweekly; samples should be taken at 1-m intervals
2 Enough samples to correlate with conductivity
3 Minimum number of samples includes one each in epilimnion, metalimnion, and hypolimnion; preferred sampling would be at 3-m intervals

Abbreviations

BOD:	biological oxygen demand
DO:	dissolved oxygen
DOC:	dissolved organic carbon
POC:	particulate organic carbon
TOC:	total organic carbon
TSS:	total suspended solids

TABLE 4

MONITORING RECOMMENDATIONS FOR THE LAKE CHELAN FOOD WEB MODEL

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Parameter	Sample Description	Sampling Frequency
TMDL fish species[1]	Composite fillets without skin	3 to 5 years
Key prey species[2]	Composite whole-body	3 to 5 years
TMDL constituents in sediment[3]	Several samples along mid-lake transect	3 to 5 years
Freely dissolved TMDL constituents[3]	SPMD deployments for approximately 30 days	3 to 5 years

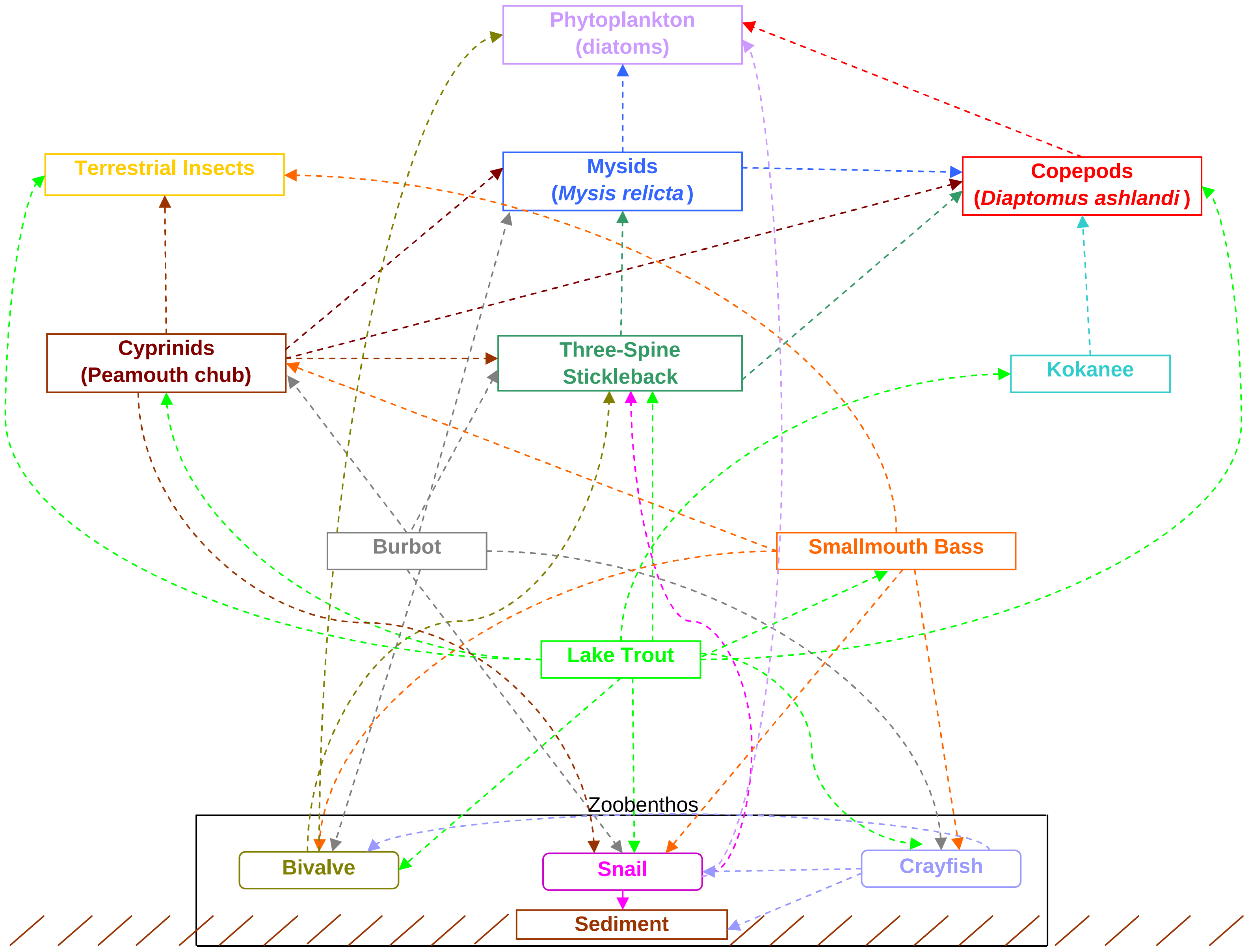
Notes

1 Burbot, kokanee, lake trout
2 Mysids, three-spine stickleback
3 Chlordane, dieldrin, dioxins/furans, DDT analogs, polychlorinated biphenyls (PCBs)

Abbreviations

SPMD: semipermeable membrane device
TMDL: total maximum daily load

FIGURE



CONCEPTUAL DIAGRAM SHOWING ORGANISMS INCLUDED IN THE LAKE CHELAN CONTAMINANT FOOD WEB MODEL

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By: sge	Date: 07/23/08	Project No. 13462.002

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Figure 1