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UPDATE OF THE COMPREHENSIVE AQUATIC SYSTEMS MODEL, LAKE TEXOMA (CASM-LT) TO IMPROVE GOLDEN ALGAE (*PRYMNESIUM PARVUM*) AND ZEBRA MUSSEL (*DREISSENA POLYMORPHA*) COMPARTMENTS

Prepared for

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TABLE OF CONTENTS

1. Introduction 1

2. Revisions to Golden Algae in CASM-LT 2

2.1 ENVIRONMENTAL FACTORS 2
2.2 BIOENERGETICS PARAMETERS 2
2.3 TROPHIC INTERACTIONS 2
2.4 TOXIC EFFECTS 3
2.5 CALIBRATION 3

3. Addition of Zebra Mussels to the CASM-LT 5

3.1 HABITAT FACTORS 5
3.2 MODEL FORMULTATION AND PARAMETER ESTIMATION 7
3.3 TROPHIC INTERACTIONS 8
3.4 CALIBRATION 8

4. Results 9

4.1 GOLDEN ALGAE 9
4.2 ZEBRA MUSSELS 10
4.3 CHLORIDE MANAGEMENT ALTERNATIVES 11

5. Discussion 12

6. Summary 14

7. Acknowledgement and Limitations 15

8. References 16

Tables

3-1 Ranges of Mid-Column Depth Measures of Physical-Chemical Parameters from January through September 2010 in Lake Texoma (from Boeckman and Bidwell, 2010)

3-2 Bioenergetics Parameters for Zebra Mussels in the Revised CASM-LT

4-1 Comparison of Original and Revised CASM-LT Baseline Annual Phytoplankton Production

Figures

Figure 1. Revised food web that adds zebra mussels to the CASM-LT and indicates that *P. parvum* is subject to zooplankton grazing.

Figure 2. Relationship between abundance of *P. parvum* and mortality of *Daphnia pulex* derived from data provided in Kohmescher (2007).

Figure 3. Location of pelagic sampling stations (P1-P5) used to compare with simulated results for *P. parvum* production using the revised CASM-LT.

Figure 4. Comparison of model and measured values of *P. parvum* for sampling station P1 and modeled location St 01.

Figure 5. Comparison of model and measured values of *P. parvum* for sampling station P2 and modeled location St 07.

Figure 6. Comparison of model and measured values of *P. parvum* for sampling station P3 and modeled location St 07.

Figure 7. Combined modeled effects of sedimentation, environmental variability, and chloride management on Lake Texoma total phytoplankton.

Figure 8. Combined modeled effects of sedimentation, environmental variability, and chloride management on Lake Texoma total striped bass.

1. Introduction

A version of the comprehensive aquatic systems model (CASM) has been developed to assess the potential effects of managed reductions in total dissolved solids (TDS) on primary production and the flow of energy through key food web components in Lake Texoma (Bartell et al. 2010). The resulting CASM-LT is fundamentally a description of aquatic ecological production dynamics based on population bioenergetics. The CASM-LT calculates daily values of biomass (carbon) for selected populations of aquatic producers and consumers included in the modeled food web structure. The model also simulates the dynamics of various water quality factors (e.g., dissolved oxygen, dissolved inorganic nitrogen, dissolved inorganic phosphorus, silica, DOC, and particulate organic carbon) that influence ecological production of the modeled aquatic producer and consumers. In addition to population biomass and specific water quality factors, the CASM-LT also characterizes spatial-temporal variability total chlorophyll, Secchi depth, and selected ecosystem goods and services in Lake Texoma.

This report describes (1) revisions of the CASM-LT to improve the performance of the model in simulating the production of golden algae (*Prymnesium parvum*) and (2) the modification of the model to include zebra mussels (*Dreissena polymorpha*) as indicated in **Figure 1**. This work has produced an updated operational version of the CASM-LT and further assessment of potential effects of chloride management on the ecological production dynamics in Lake Texoma.

2. Revisions to Golden Algae in CASM-LT

During the original development of the CASM-LT, few data were available that characterized the bioenergetics, ecological requirements, trophic interactions, and production dynamics of golden algae (*P. parvum*) in Lake Texoma (Bartell et al. 2010). The CASM-LT has been revised using additional data and information that have since become available (e.g., Hambright 2008, Hambright et al. in press).

Revisions to the golden algae components of the original CASM-LT included:

- Review, evaluation, and modification of the environmental factors that influence the growth of golden algae in the model,
- Review, evaluation, and modification of basic bioenergetics parameters used to quantify the growth dynamics of golden algae,
- Revision of the trophic interactions involving grazing of golden algae by modeled zooplankton,
- Incorporation of potential toxic effects of golden algae on herbivorous zooplankton and modeled fish populations, and
- Calibration of model values of golden algae production to available data.

2.1 ENVIRONMENTAL FACTORS

Hambright (2008) described spatial temporal patterns of golden algae biomass based on a comprehensive monitoring of Lake Texoma. Production appeared greatest during periods of lower temperatures, high nutrient availability, and higher salinities in Lake Texoma. These observations were used to review the temperature preferences defined for golden algae in the original derivation of the CASM-LT. Half-saturation constants for dissolved inorganic phosphorus (DIP) and dissolved inorganic nitrogen (DIN) previously derived for golden algae were also examined in relation to the results of the 2006 - 2008 monitoring in Lake Texoma.

Using the results of the monitoring data, the optimal temperature range for golden algae growth was changed from 10 - 14 °C to 10 - 15 °C. The upper temperature limit was increased from 18 to 20 °C (Hambright 2008). The DIN half saturation constant for P. parvum of 0.6 mg/L is higher than values assigned to the other phytoplankton populations (Bartell et al. 2010) and reflects the observations that golden algae is characteristic of high nutrient conditions. The half saturation constant defined for DIP of 0.006 mg/L is lower than for most populations, but is consistent with the observations that golden algae is characteristic of N-limiting conditions in Lake Texoma (i.e., low N:P ratios).

2.2 BIOENERGETICS PARAMETERS

The bioenergetics of golden algae remains poorly described and largely unreported. However, earlier assumptions that golden algae were not grazed may have resulted in underestimates of potential growth rates of this species in the original calibration of the CASM-LT.

2.3 TROPHIC INTERACTIONS

In the original development of the CASM-LT, it was assumed that golden algae was not subject to grazing. More recent studies suggest golden algae is grazed by zooplankton (Hambright et al., in press). The food web interaction data file was correspondingly revised to define grazing of golden algae by herbivorous zooplankton populations included in the CASM-LT.

2.4 TOXIC EFFECTS

The potential toxic effects of golden algae on fish were recognized during the development of the CASM-LT. However, the available data were not sufficient to incorporate toxicity into the model formulation. However, as the result of more recent studies (e.g., Hambright 2007, Hambright et al., in press), preliminary revisions were made to the model to address (1) relationships between golden algae biomass lethal effects on modeled fish populations, and (2) sublethal effects of golden algae biomass on reproduction by herbivorous zooplankton. The formulations for these two categories of toxic effects have been included as revisions to the CASM-LT code.

The results of toxicity tests for fathead minnow fry and the relative sensitivity of other test species compared to fathead minnow fry (Hambright 2007) were used to develop fish mortality rates as a function of golden algae abundance and N:P ratios in the revised CASM-LT. Hambright (2007) observed an apparent relationship between effects of golden algae on fathead minnow fry and N:P ratios under controlled laboratory conditions. Therefore, the incorporation of toxic effects into the revised CASM-LT included a dependence on N:P conditions derived from the Hambright (2007) experimental results. Mortality rates were applied equally to all modeled fish species, except juvenile and adult striped bass. These modeled effects are consistent with the descriptions of fish mortality in relation to golden algae production for various N:P ratios observed in Lake Texoma (Hambright 2007).

Kohmescher (2007) demonstrated the potential effects of golden algae on several cladoceran life-history parameters in laboratory studies with *Daphnia pulicaria*. Because the model does not separately address juvenile life stages of cladocerans (or other modeled zooplankton), the observed effects of golden algae consumption on juvenile daphnia growth rates were simply extrapolated to all modeled zooplankton. The resulting values obtained from Kohmescher (2007) were used to develop exposure-response functions that altered zooplankton growth rates based on the daily modeled concentrations of golden algae. This conservative assumption might result in overestimates of the potential effects of golden algae on zooplankton production in the revised CASM-LT.

Based on experimental results reported by Kohmescher (2007), zooplankton mortality was simulated in relation to golden algae abundance (cells/mL). The experimental results were used to define a linear exposure-response function for *Daphnia pulex* as shown in **Figure 2**. The function illustrated in **Figure 2** was applied to all modeled zooplankton.

2.5 CALIBRATION

Monthly samples of golden algae were collected from several stations located throughout Lake Texoma during 2006 – 2008, including five pelagic sampling locations (P1-P5) (Hambright 2008) (Figure 3):

P1 – the upper red River main channel south of Lebanon Pool,

P2 – the Red River main channel between the mouths of Buncombe and Big Mineral Creeks,

P3 – the Red River main channel south of Treasure Island, P4 – the main basin adjacent to Dennison Dam, and

P5 – the Washita River main channel just south of the railway Bridge.

Each sample was a grab sample of the top 10 m of the water column. Cell counts for golden algae sampled from the five pelagic locations from this monitoring program within Lake Texoma were converted to units of carbon using relationships between cell volume and cell carbon (Kasim 2011, Eppley 1968, Strathmann 1967, and Mullins et al. 1966). The resulting data were used to evaluate the biomass values (gC/m^2) simulated by the revised CASM-LT.

The monitoring program also included sampling of zooplankton (and several water quality parameters) in addition to golden algae (Hambright 2008). The zooplankton data provided an opportunity to further evaluate the performance of the CASM-LT in simulating food web production dynamics in Lake Texoma. Monthly values of dry weight (µg DW/mL) reported for cladocerans, calanoid copepods, and cyclopoid copepods were converted to carbon using a conversion factor (0.48) reported for freshwater zooplankton by Andersen and Hessen (1991).

The calibration of the revised CASM-LT was performed by adjusting the bioenergetics and food web interaction parameters of golden algae and the modeled zooplankton grazing rates in order to simulate golden algae and zooplankton biomass values consistent with those derived from Hambright (2008) for Lake Texoma. The maximum growth rate for golden algae was increased from 0.60 (day^{-1}) in the original model to 0.83 to achieve the level of agreement in the calibration. The original food web input file for the CASM-LT was revised to define grazing of golden algae by all modeled zooplankton.

3. Addition of Zebra Mussels to the CASM-LT

The potential implications of invasive zebra mussels (*Dreissena polymorpha*) on the outcomes of chloride management actions, as well as on the overall ecological integrity of Lake Texoma have increased since the original development of the CASM-LT. Zebra mussels were not modeled specifically in the original effort, but were aggregated as part of a generalized mollusk population. The purpose of work reported here was to specifically include zebra mussels in the revised CASM-LT.

Incorporation of zebra mussels into the CASM-LT involved the following tasks:

- Review of physical-chemical factors known to influence habitat quality and growth of zebra mussels in relation to values of these factors reported for Lake Texoma,
- Derivation of equations and bioenergetics parameters that determine growth rates of zebra mussels in the modeled Lake Texoma environment,
- Definition of trophic interactions among zebra mussels and other components of the modeled Lake Texoma food web, and
- Calibration of the zebra mussel model components to values of zebra mussel production (biomass) reported for Lake Texoma.

3.1 HABITAT FACTORS

Several physical-chemical factors determine the suitability of aquatic habitat for zebra mussels. These factors include temperature, salinity, dissolved oxygen, pH, conductivity, and total hardness. The initial approach to including zebra mussels in the CASM-LT was to examine the physical-chemical habitat requirements of zebra mussels in relation to values reported for Lake Texoma. Where necessary, additional habitat suitability modifiers could be added to those currently included in the model (Bartell et al. 2010).

Boeckman and Bidwell (2010) report ranges for several of these factors measured in different locations and depths where zebra mussels were sampled throughout Lake Texoma (Table 3-1). Zebra mussels exhibit distinct pH tolerances and are seldom found at pH values <7.3 (Cohen and Weinstein 2001). Development rates are maximum at a pH of ~8.4 (Sprung 1993). The pH values reported for Lake Texoma appear generally compatible with the requirements of zebra mussels.

Conductivity values <22 µS/cm can limit the distribution of zebra mussels, while values >83 µS/cm greatly favor zebra mussel colonization and establishment (Cohen and Weinstein 2001). The conductivities reported for Lake Texoma, as shown in **Table 3-1**, indicate that this factor should not constrain zebra mussel growth in this reservoir.

Similarly, Cohen and Weinstein (2001) report that zebra mussels grow poorly at total hardness values <25 mg/L and grow well where total hardness exceeds 90 mg/L. Total hardness values measured for Lake Texoma are all well above 90 mg/L as indicated in **Table 3-1**.

Calcium concentrations of 35 mg/L provide conditions that are favorable for the growth of zebra mussels (EPRI 1992), while values of ~15 mg/L appear as lower thresholds for growth and reproduction (Cohen and Weinstein 1998). Clyde (2004) reports calcium concentrations that range from 69 – 236 mg/L for Lake Texoma.

Concentrations of potassium >100 mg/L are lethal for adult zebra mussels (Wildridge et al. 1998). However, potassium concentrations reported for Lake Texoma ranged between 2.3 and 10.8 mg/L, with a median value of 6.3 (Clyde 2004). Potassium will not likely constrain zebra mussel growth in Lake Texoma.

Dreissenids, including *D. polymorpha,* are sensitive to salinity, and salinity values >6 ppt are generally lethal. Reproduction has been documented as occurring at salinity values as high as 2-3 ppt (Setzler-Hamilton et al. 1997). Salinity values for Lake Texoma in 2005 were ~0.53 ppt in the Washita River portion of the reservoir; values associated with the Red River arm of the reservoir were ~2 ppt. Salinity is not likely to be a limiting factor in zebra mussel growth and reproduction.

The effects of water temperature on consumption and respiration rates of consumer populations were included in the original development of the CASM-LT (Bartell et al. 2010). The parameter values for these relationships applicable to zebra mussels were derived from previous zebra mussel models (e.g., Schneider 1992, Madenjian 1995, Griebeler and Seitz 2007). As part of the revised model formulation for the consumer populations, a functional relationship between dissolved oxygen and zebra mussel growth based on reported DO tolerances for this species was specified in the revised CASM-LT.

Based on comparison of zebra mussel requirements and data reported for Lake Texoma, the physical-chemical environment of this reservoir appears favorable for the growth and establishment of zebra mussels.

Table 3-1

Ranges of mid-column depth measures of physical-chemical parameters from January through September 2010 in Lake Texoma (from Boeckman and Bidwell, 2010).

Location	**Temperature(°C)**	**Dissolved oxygen (mg/L)**	**pH (standard units)**	**Conductivity (mS/cm)**	**Hardness (mg/L as $CaCO_3$)**
Caney Creek	6.1 – 30.7	4.8 – 13.2	6.9 – 8.3	1.4 – 2.2	286 – 390
Catfish Bay	5.9 – 30.4	3.5 – 12.1	7.4 – 8.2	0.9 – 1.7	286 – 340
Eisenhower Park	6.1 – 29.6	4.0 – 12.7	7.1 – 8.3	1.3 – 2.1	302 – 344
Highpoint Marina	5.4 – 29.9	6.4 – 12.3	7.5 – 8.5	1.5 – 2.4	310 – 402
Sheppard Annex	6.2 – 30.2	4.4 – 11.2	7.6 – 8.2	1.3 – 3.1	256 – 526
OU Biological Station	5.6 – 31.4	4.4 – 12.0	7.9 – 8.6	1.6 – 2.6	280 – 420

3.2 MODEL FORMULATION AND PARAMETER ESTIMATION

The bioenergetics equations of the CASM-LT are presented in detail in Bartell et al. (2010) and are not reproduced in this report. Incorporation of zebra mussels into the revised CASM-LT was based on bioenergetic models developed previously for this species (Schneider 1992, Schneider et al. 1998, Madenjian 1995, Griebeler and Seitz 2007). Three age-classes were specified for zebra mussels in the revised CASM-LT food web in accordance with the existing models for *D. polymorpha*: (1) age young-of-year YOY, which includes reproductive outputs in the form of planktonic and attached veligers; (2) attached mussels of age 1-2 years; and (3) mussels 2 or more years of age as shown in **Figure 1**.

Bioenergetics parameters were estimated for each of the three modeled age-classes and added to the corresponding bioenergetics data input file used by the CASM-LT. The parameter estimates were based largely on the previous modeling studies of zebra mussels (e.g., Schneider 1992, Madenjian 1995, Griebeler and Seitz 2007). **Table 3-2** lists the resulting parameter values for zebra mussels in the revised CASM-LT.

TABLE 3-2

Bioenergetics Parameters for Zebra Mussels in the Revised CASM-LT

CASM Populations	Max Consumption (1/d)	Te_1 (ºC)	Te_2 (ºC)	Te_3 (ºC)	Te_4 (ºC)	Rsda (unit less)
Age YOY	0.066	2	12	21	32	0.172
Age 1-2	0.043	2	12	21	32	0.172
Age 2+	0.035	2	12	21	32	0.172

TABLE 3-2, Continued

Bioenergetics Parameters for Zebra Mussels in the Revised CASM-LT

CASM Populations	Rmax (1/d)	Tr_o (C)	Tr_m (C)	F (unit less)	U (unit less)	Mortality (1/d)
Age YOY	0.0040	28	31	0.18	0.064	0.10
Age 1-2	0.0030	28	31	0.18	0.064	0.001
Age 2+	0.0027	28	31	0.18	0.064	0.001

Reproduction by mature zebra mussels is mainly determined by temperature with a lower threshold of 12 °C. Maximum reproduction occurs at ~17 °C O'Neill (1999). Madenjian (1995) reported that mature mussels lost ~33 percent of their body weight to reproduction, which contrasts with the 5 percent value used by Schneider (1992). These values were used to regulate zebra mussel reproduction in the revised CASM-LT.

Rates of development across the three modeled life stages were based on estimates reported by Griebeler and Seitz (2007). For example, development from eggs through the planktotrophic stage to settled individuals takes approximately 21 days (0.047 d^{-1}). The formulations for transition among the age-classes of zebra mussels were added directly to the CASM-LT code. These equations parallel those specified for development of striped bass reported by Bartell et al. (2010) and are not reproduced in this report. Mortality rates during this stage of development are ~0.99 (Griebeler and Seitz 2007). Mortality rates are included in the bioenergetics parameter input file used by the CASM-LT.

Lake Texoma biomass values for zebra mussels were developed from mussel densities (ind/m^2) reported for several locations throughout the reservoir (Boeckman and Bidwell 2010). Individuals were transformed to units of carbon based on wet weights defined for each age class and reported conversion factors to dry weight and carbon (Schneider 1992).

3.3 TROPHIC INTERACTIONS

Based on the existing models, zebra mussels in the revised CASM-LT consume phytoplankton, particulate organic matter, and herbivorous zooplankton (Garton et al. 2005, Schneider 1992, Schneider et al. 1998, Madenjian 1995). Baines et al. (2005) demonstrated the ability of zebra mussels to assimilate dissolved organic matter. This observation might bear directly on the results of alternative chloride management scenarios. Therefore, zebra mussels “consume” DOC in the revised model for Lake Texoma. The food web interaction input file for the CASM-LT was revised to include these trophic interactions for zebra mussels.

3.4 CALIBRATION

Initial zebra mussel biomass values were arbitrarily assigned 10% of the June values reported by Boeckman and Bidwell (2010). The previously described values of bioenergetics parameters and environmental tolerances of zebra mussels were used in relation to the environmental inputs and trophic dynamics of the revised CASM-LT to simulate daily values of zebra mussel biomass for each of the modeled locations.

4. Results

4.1 GOLDEN ALGAE

The simulated daily biomass values of golden algae were calibrated to values reported for pelagic locations (P1-P5) sampled in Lake Texoma by Hambright (2008) as shown in **Figure 3**. Measured 2006-2008 values were compared to simulated values for spatially similar locations addressed by the CASM-LT. The golden algae values simulated for the Red River station (St 01) in the CASM-LT were compared with the values reported for P1 as illustrated in **Figure 4**. The modeled biomass values were well within the same order of magnitude and in general compared reasonably with the measured values.

The modeled golden algae biomass values for the Red River main lake station (St 07) were compared with the observed values for sampling stations P2 and P3 as indicated in **Figures 5 and 6**. The CASM-LT substantially overestimates golden algae production for month 3 and somewhat underestimates production for months 2 and 5 at station P2.

Similarly, the CASM-LT overestimates golden algae production for month 3 at monitored station compared to modeled location St 07 as shown in **Figure 6**. Modeled values for the other months are quite similar to the measured values.

Modification of parameters for golden algae had some impacts on the baseline modeled results in comparison to the original CASM-LT (Table 4.1). For some taxa and modeled locations, the changes to golden algae improved the modeled values in comparison to measured values (e.g., cyanophytes for Stations 1 and 17; chlorophytes for Station 24, and microflagellates at Stations 9 and 24. Revisions to Golden algae worsened the comparisons for diatoms at Stations 17 and 24. Additional simulations could be performed to further improve the overall comparisons between modeled and observed baseline phytoplankton production. However, in using the model to evaluate chloride management alternatives, any bias in baseline results will similarly affect both simulations of without- and with-project future conditions. The incremental differences between the with- and without-project simulations can still be used to evaluate planning alternatives.

TABLE 4-1

Comparison of Original and Revised CASM-LT Baseline Annual Phytoplankton Production

		Percent of total annual productivity			
		82.9	6.7	2.6	4.4
Lake Texoma Station	**Measured net annual productivity**				
		cyanophytes	**chlorophytes**	**Diatoms**	**microflagellates**
	g-C/m^2/y	g-C/m^2/y	g-C/m^2/y	g-C/m^2/y	g-C/m^2/y
3	326	270 estimated	22	8	14
1		296 original CASM-LT	21	6	9
		284 revised CASM-LT	11	5	5
9	285	236	19	7	13
9		1,125	11	4	30
		1,109	9	3	11
17	267	221	18	7	12
17		424	35	5	21
		382	10	0.1	12
22	308	255	21	8	14
24		317	6	4	8
		321	20	0.3	6

4.2 ZEBRA MUSSELS

Boeckman and Bidwell (2010) reported densities of zebra mussels sampled at several locations throughout Lake Texoma. Based on proximity to locations modeled by the CASM-LT, densities measured at Sheppard Annex were compared with modeled values for St 01 (Red River). Densities measured at the Oklahoma University (OU) Biological Station were compared with modeled locations at St 07 (Red River main lake). Modeled values for the Dennison Dam location were compared with measured mussel densities at Eisenhower Park. The measured values at Catfish Bay were compared to modeled values for St 20 and St 24 (Washita River).

Mussel densities were converted to carbon based on conversions from individual mussel age and wet weight (Schneider 1992). Dry weight was assumed to be 15% of wet weight and carbon was 45% of dry weight (Schneider 1992).

The bioenergetics parameters listed in **Table 3-2, Continued** and the simulated baseline environmental conditions produced modeled maximum values of 45 and 42 gC/m^2 for age 1-2 mussels and 5 and 6 gC/m^2 for age 2+ mussels for Stations 01 and 07. These values are underestimates compared to the maximum observed values of ~100 gC/m^2 measured at Sheppard Annex and the OU Biological Station. The revised CASM-LT simulated maximum mussel biomass values of age 1-2 mussels as 94 gC/m^2 and age 2+ mussels as 24 gC/m^2 for the Dennison Dam location. These values are also underestimates compared to the corresponding values of ~365 and 608 gC/m^2 measured at Eisenhower Park. The model produced maximum biomass estimates of age YOY at Dennison Dam of 175 gC/m^2 compared to the measured maximum value of 743 gC/m^2 at Eisenhower Park. The modeled values similarly underestimated the measured values for the comparisons between the Catfish Bay data and the simulated values for CASM-LT Stations 20 and 24 (Washita River areas).

4.3 CHLORIDE MANAGEMENT ALTERNATIVES

The revised CASM-LT was used to examine the implications of the same chloride management alternatives addressed previously with the original model (Bartell et al. 2010). Simulations were performed using inter-annual variations in environmental input parameters, with and without sedimentation. Only the results that include sedimentation are reported here. **Figure 7** illustrates the 50-y simulation of the various percentage reductions in total dissolved solids and total annual phytoplankton biomass for Lake Texoma using the revised CASM-LT. The results are very similar to those obtained with the original model (Bartell et al. 2010). Depending on differing environmental scenarios, reducing TDS can result in slight increases or decreases in total annual phytoplankton biomass. However, the variations in phytoplankton production are influenced more by year-to-year variations in environmental inputs than by reductions in TDS. In the longer term (50-y), sedimentation reduces total phytoplankton biomass more than environmental variations or reductions in TDS.

The results using the revised CASM-LT demonstrate that for some environmental conditions, reductions in TDS are associated with reductions in total annual biomass of striped bass as indicated in **Figure 8**. For other environmental conditions, reductions in TDS appear to have no impact on striped bass production. Similar to the results for phytoplankton, **Figure 8** also suggests that year-to-year variations in environmental conditions more strongly influence striped bass production than do reductions in TDS. Also, longer-term sedimentation (50-y) has a greater overall impact on modeled striped bass production using the revised CASM-LT.

5. Discussion

Slight revisions to the modeled temperature preferences of golden algae in addition to redefined trophic interactions produced CASM-LT values of golden algae that compared favorably with the values reported for 2006-2008 by Hambright (2008). Calibration of the revised CASM-LT required increasing the maximum growth rate from 0.50 to 0.83 day^{-1}. In the absence of detailed studies of the bioenergetics of golden algae, the maximum growth rate that produced the results described in this study remains as a hypothesis concerning potential growth of this harmful algal species in Lake Texoma.

Except for two simulated concentrations of golden algae corresponding to March for modeled stations St 01 and St 07, the modeled results would suggest minimal toxic effects on zooplankton growth, zooplankton mortality, and fish mortality. The results of the simulations of the revised CASM-LT should be examined in greater detail to determine the values of the toxic effects modifiers produced in relation to simulated values of golden algae biomass. The results of the monthly monitoring suggest potential toxic effects on zooplankton (Hambright 2008, Kohmescher 2007). The revised CASM-LT might underestimate these effects and additional analysis and calibration may be required to more accurately assess such effects.

The revisions made to the CASM-LT to more realistically simulate the growth of golden algae did not alter the original model conclusions concerning the relative importance of chloride management, environmental variability, and longer-term sedimentation on overall phytoplankton production in Lake Texoma. Environmental conditions for some of the 50 modeled years did suggest that reductions in chloride (TDS) could reduce phytoplankton biomass. However, the year-to-year environmental variability in the near-term and the longer-term sedimentation of Lake Texoma appear to have greater impacts on phytoplankton production according to the revised CASM-LT.

The revised CASM-LT consistently underestimated the production dynamics of zebra mussels compared to the few available measurements from Lake Texoma (i.e., Boeckman and Bidwell 2010). The bioenergetics and temperature tolerance values used in adding zebra mussels to the CASM-LT were taken from previous zebra mussel modeling studies for the Great Lakes and Rhine River, which are much cooler environments. It is possible that the zebra mussels invading Lake Texoma have adapted to the comparatively warmer waters and the parameter values used in the CASM-LT require corresponding revision. For example, increasing the range of temperature values that are conducive to zebra mussel growth might simply account for the model's current underestimation of zebra mussel growth in Lake Texoma. This could be examined by re-defining the temperature tolerance values used in the CASM-LT and repeating simulations in further sensitivity analysis of the revised model. In addition, the CASM-LT feeding rates specified for zebra mussels in Lake Texoma might underestimate actual values. This would require laboratory experimental evaluation of feeding rates for mussels obtained from Lake Texoma.

Using the revised CASM-LT to repeat the 50-y simulations for the same chloride management scenarios examined in Bartell et al. (2010) produced slightly different values for total annual biomass of phytoplankton and striped bass as shown in **Figures 7 and 8**. Consistent with the results of the original CASM-LT (Bartell et al. 2010), reductions of TDS in combination with changes in other environmental inputs factors (e.g., DIN, DIP, temperature, etc.) could either increase or decrease total phytoplankton biomass as indicated in **Figure 7**. Correspondingly, total annual striped bass biomass both increased and decreased in relation to reductions in TDS over the 50-y simulated period. This nonlinear response reflects the complex food web interactions characterized for Lake Texoma by the original and revised CASM-LT. The incorporation of zebra mussels into the model seemed not to dramatically alter the response of striped bass to reductions in TDS. This result might be due in part to the model's underestimation of zebra mussel productivity. Further examination and revision of the model to better describe zebra mussel production should be undertaken to determine the apparently robust nature of striped bass responses to reductions in TDS in Lake Texoma.

6. Summary

The CASM-LT was revised to take advantage of more recent observations of golden algae production in Lake Texoma (Hambright 2007). Temperature tolerances and maximum growth rate were adjusted in the model based on this information and calibration to measured biomass of golden algae. The calibrations of the revised CASM-LT produced results that compared favorably with the available data. The revised model emphasized the potential production of this species in the Red River portions of the reservoir, with minimal production near Dennison Dam and the Washita areas include in the CASM-LT. These model results are also consistent with observations of golden algae abundance in Lake Texoma.

Three age-classes of zebra mussel (*D. polymorpha*) were added to the food web modeled by the revised CASM-LT. The model formulations and parameter estimates were based on previous modeling studies of this species in the Great Lakes (Schneider 1992, Madenjian 1995) and the Rhine River (Griebeler and Seitz 2007). The resulting revisions to the CASM-LT were used to simulate zebra mussel production within Lake Texoma. The model currently underestimates zebra mussel abundance compared to observations provided for several locations in Lake Texoma (Boeckman and Bidwell 2010). Further evaluation of the parameter values adopted from the previous modeling studies is required to determine the reason why the CASM-LT underestimates zebra mussel growth in Lake Texoma. However, the spatial patterns of production generated by the model are consistent with observations that the highest modeled and observed abundances are for locations near Dennison Dam (Boeckman and Bidwell 2010).

Despite the current bias in underestimation of zebra mussels, the revisions to the CASM-LT extend the model capabilities to examine the implications of management actions that might directly or indirectly influence zebra mussel growth and persistence in Lake Texoma. However, further refinements to the zebra mussel calibration should be undertaken to improve this aspect of model performance.

Importantly, the revisions to the parameter values for golden algae and the addition of zebra mussels to the modeled food web in the revised CASM-LT did not change the original model results in the examination of chloride management alternatives on total phytoplankton and striped bass production in Lake Texoma. Inter-annual variations in environmental factors other than TDS appear to exert greater influence on production of phytoplankton and striped bass. In the longer-term (i.e., 50-y), sedimentation will substantially reduce the overall productivity of Lake Texoma according to the original and revised versions of the CASM-LT.

7. Acknowledgement and Limitations

The revisions and modifications to the CASM-LT have been performed by Steve Bartell, Ph.D., from E2 Consulting Engineers, Inc. URS wishes to acknowledge his contribution to this project. URS has reviewed the basis for the revisions and modifications to the model and its results but it has not validated or verified the model itself.

This report is intended for the sole use of USACE. The Scope of Services performed during these analyses may not be appropriate to satisfy the needs of other users, and any use or re-use of this document or of the findings, conclusions, or recommendations presented here-in is at the sole risk of the said user.

Background information, design basis, and other data have been furnished to URS by the Tulsa District USACE, which URS has used in preparing this report. URS has relied on this information as furnished, and is neither responsible for nor has confirmed the accuracy of this information.

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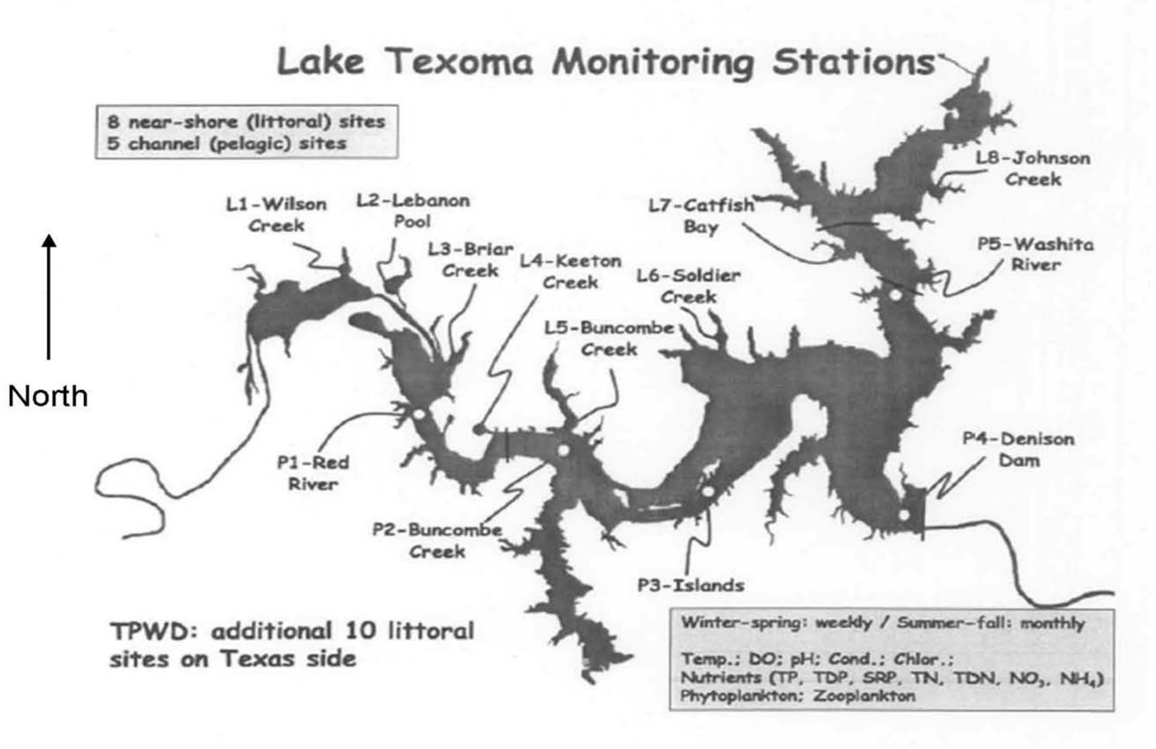
FIGURES



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Location of pelagic sampling stations (P1-P5) used to compare with simulated results for *P. parvum* production using the revised CASM-LT.

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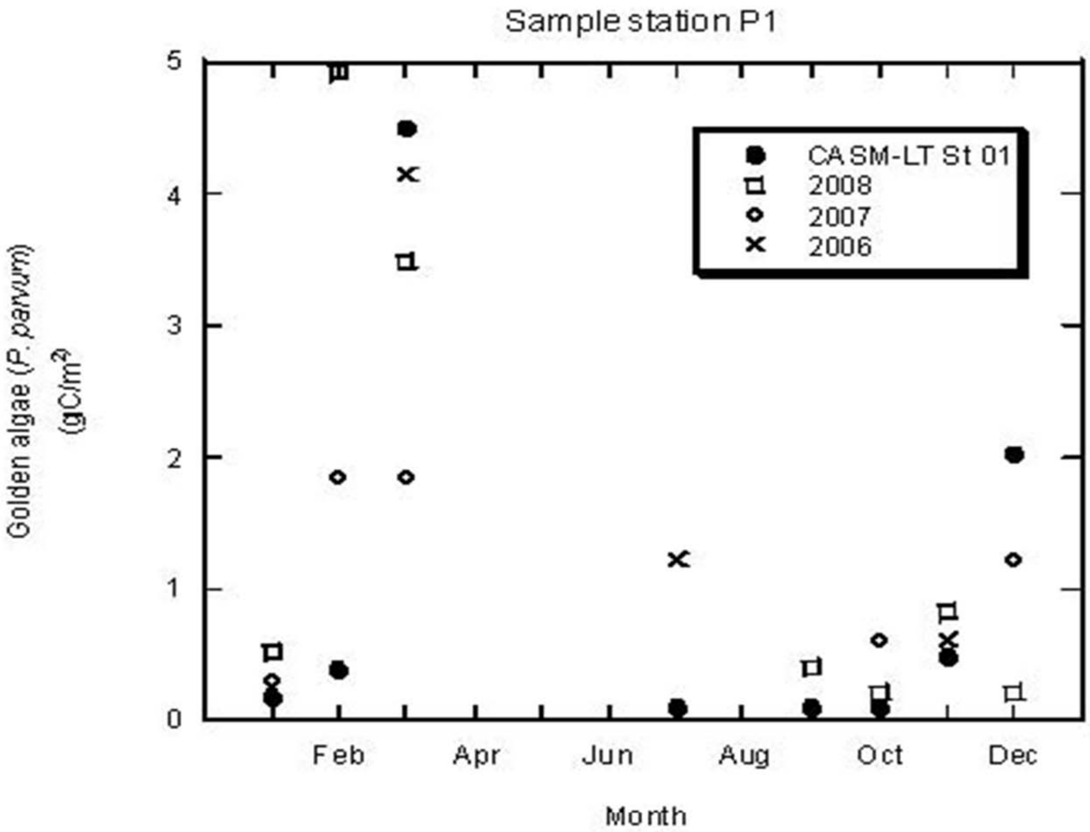
Figure No.
1



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Comparison of model and measured values of P. parvum for sampling station P1 and modeled location St 01.

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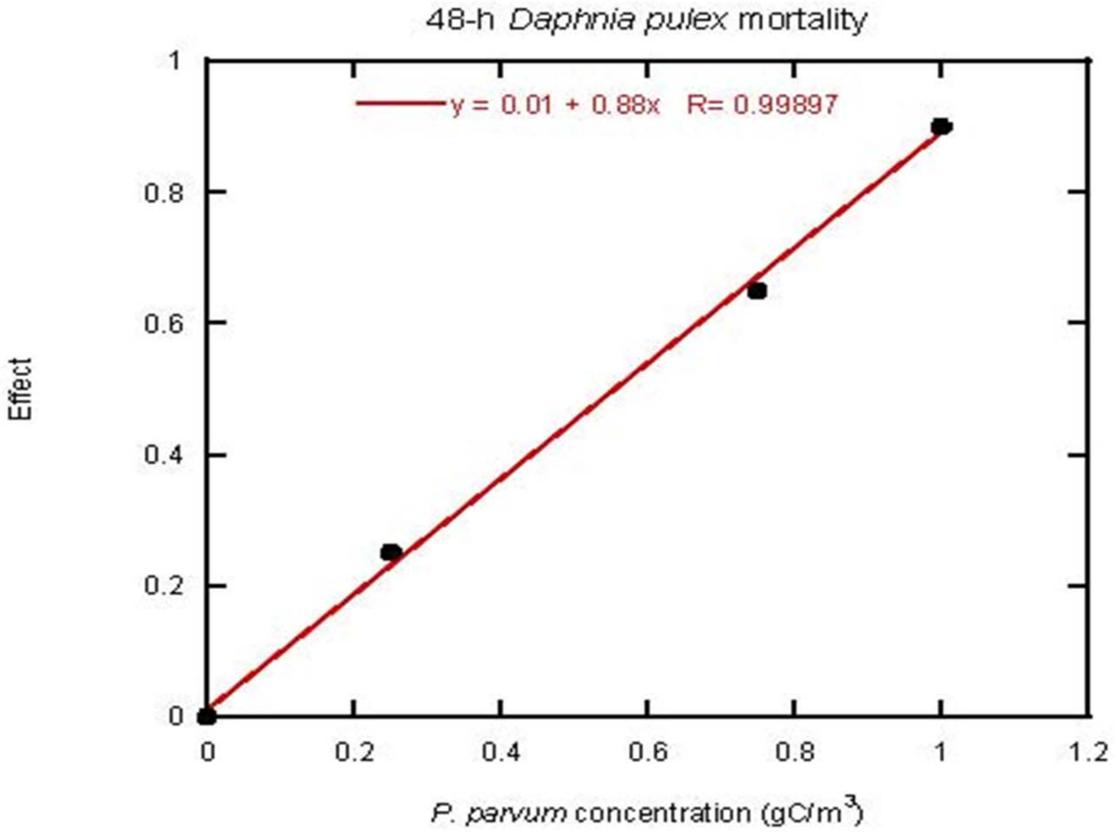
Figure No.
2



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Relationship between abundance of P. parvum and mortality of Daphnia pulex derived from data provided in Kohmescher (2007).

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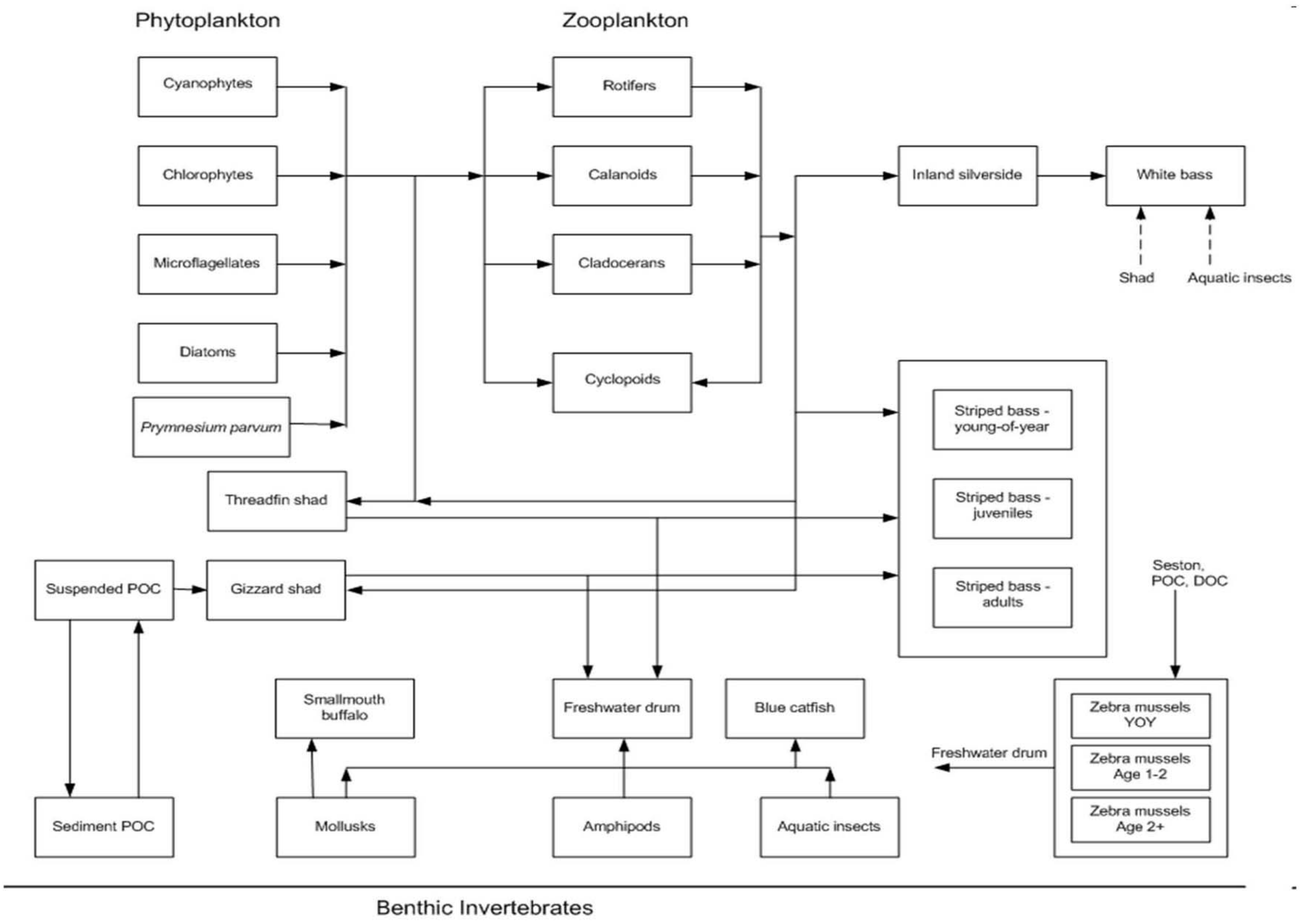
Figure No.
3



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Revised food web that adds zebra mussels to the CASM-LT and indicates that P. parvum is subject to zooplankton grazing.

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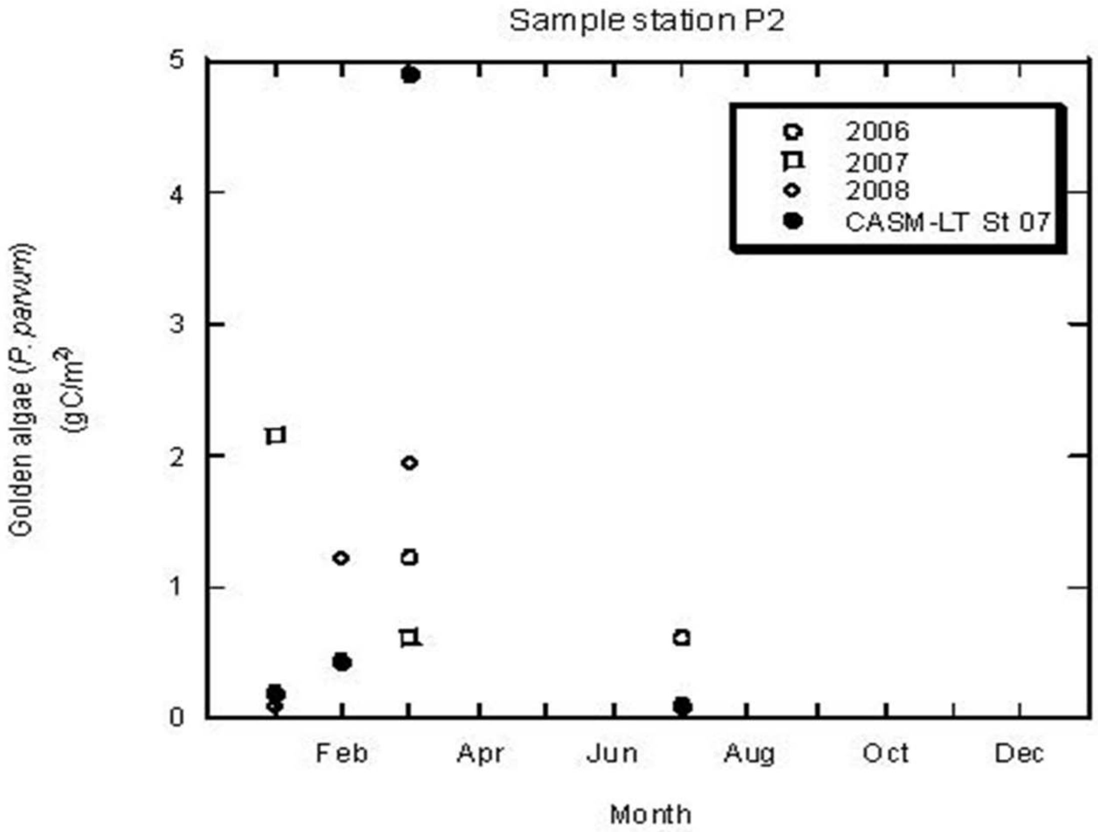
Figure No.
4



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Comparison of model and measured values of P. parvum for sampling station P2 and modeled location St 07.

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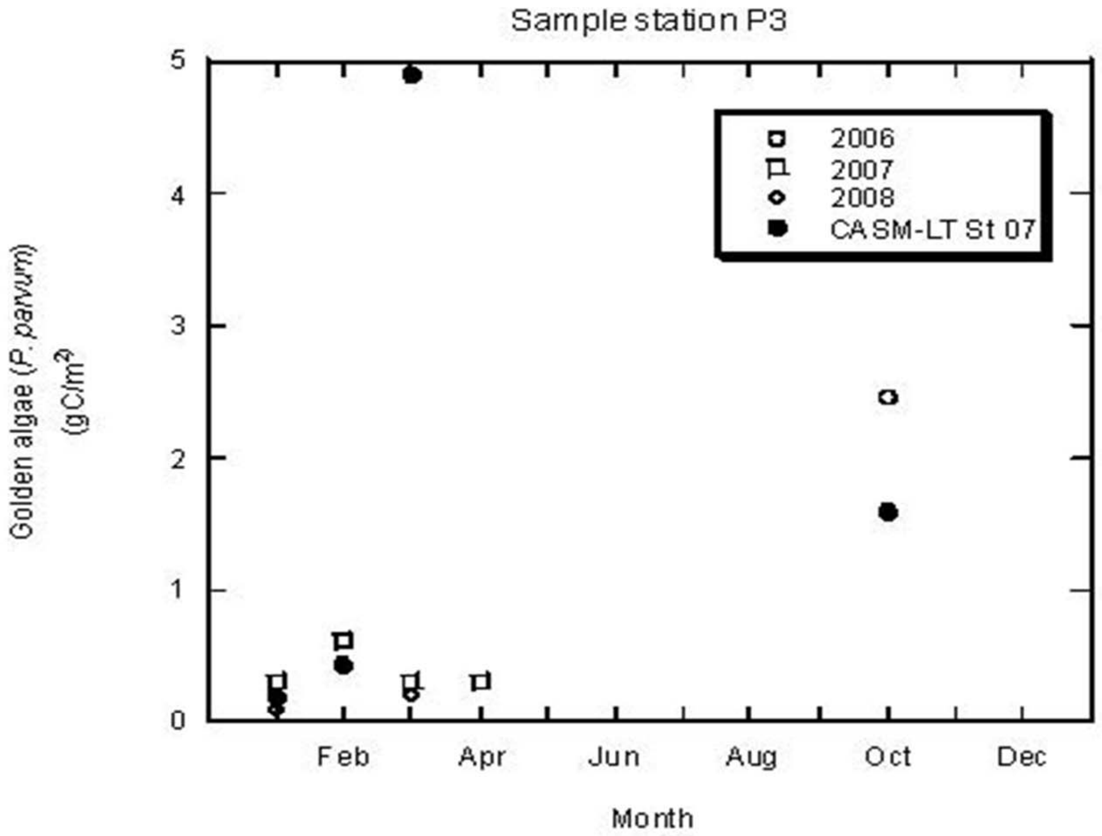
Figure No.

5



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Comparison of model and measured values of P. parvum for sampling station P3 and modeled location St 07.

Project No.

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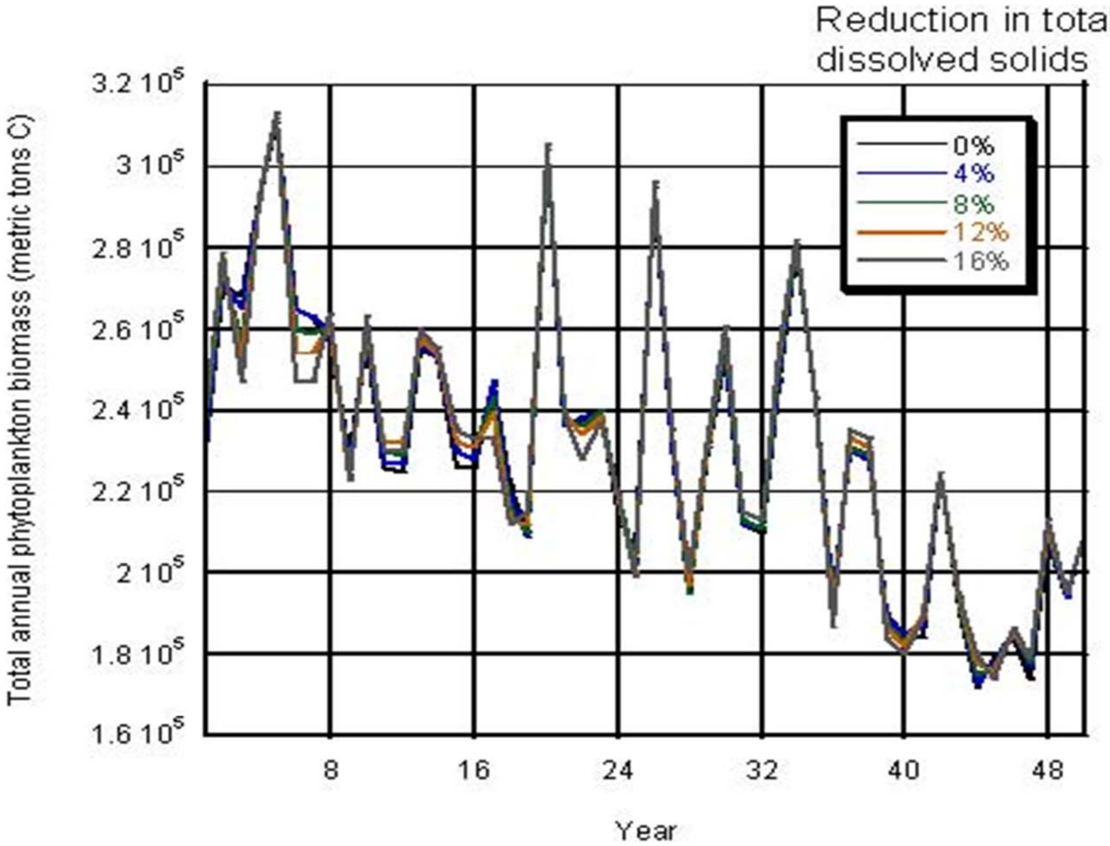
Figure No.

6



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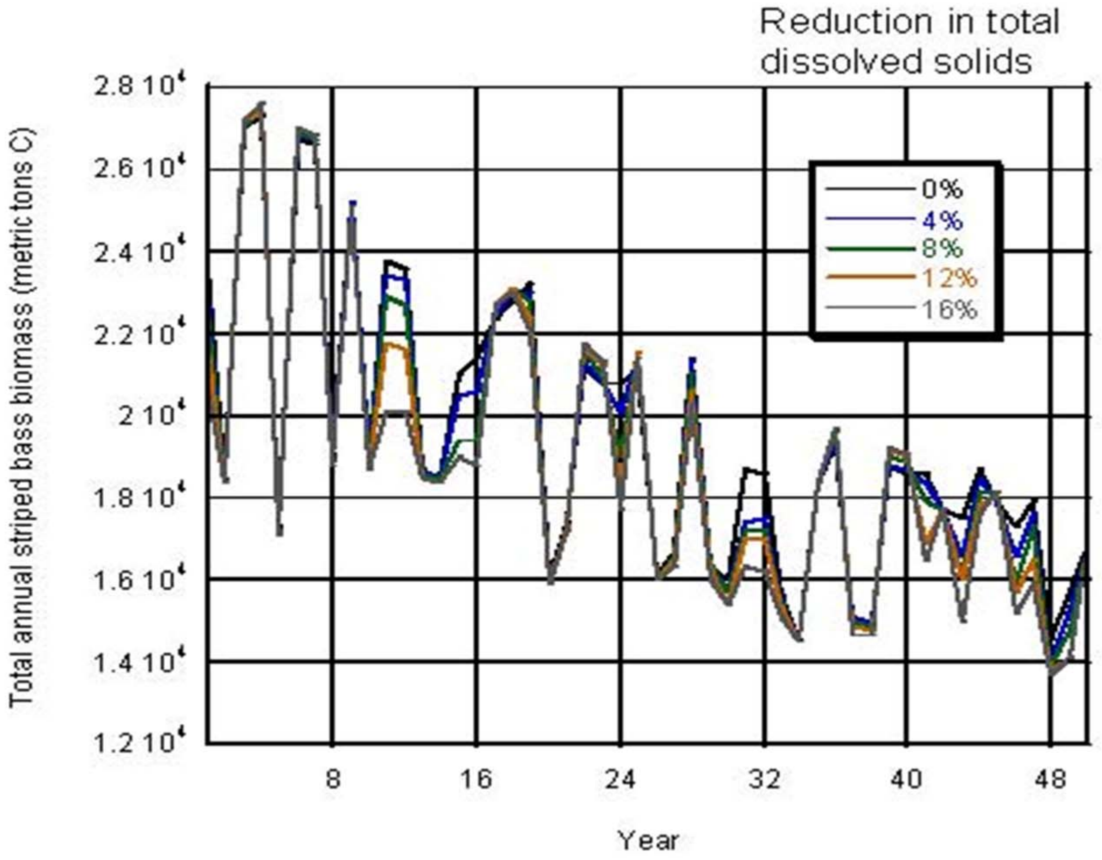
Combined modeled effects of sedimentations, environmental variability, and chloride management on Lake Texoma total phytoplankton.

Project No.

25334506

Figure No.

7



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Combined modeled effects of sedimentation, environmental variability, and chloride management on Lake Texoma and striped bass.

Project No.

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Figure No.

8