D R A F T

Modeling

Three levels of lake modeling are discussed below as they relate to management of water quality in Jennings Bay and Lake Minnetonka in general. Specific data requirements vary, but are generally practical and compatible with hydrologic and water quality monitoring data typically collected in watershed and lake studies.

Estimates of flows and phosphorus loads from each subwatershed are the most critical input requirements, regardless of the lake model being used. In general, most of the time and cost of developing a lake model is invested in watershed monitoring and modeling. Watershed flows and loads would generally be derived from direct monitoring on major tributary streams (e.g., Painter Creek).

Watershed models of various levels of complexity can be used to estimate loads from unmonitored tributaries and to predict responses to changes in land use and/or BMP implementation. The simplest form of watershed model predicts yearly runoff and phosphorus export based upon land use and precipitation using regionally calibrated coefficients. Extensive data from other watershed in the Twin Cities area provide initial coefficient estimates, which can be refined based upon site-specific tributary monitoring data. Input values for more elaborate watershed models (land use, soil type, topography) can be extracted from GIS databases, as exemplified by EOR's modeling framework for Painter Creek. As recommended by EOR, additional spatially-distributed monitoring data are needed to support calibration of that framework, identification of critical source areas, and wetland functions.

Level 1 – One-Box Steady-State Model of Jennings Bay

The water column of Jennings Bay is represented as a single stirred-tank reactor at steady state. Water-balance terms include external inflow, rainfall, evaporation, turbulent exchange with the West Arm, and net outflow to the West Arm. Mass-balance terms include external inflow, atmospheric deposition, internal loading, and sedimentation, exchange with the West Arm, and net outflow to the West Arm. External inflows and load terms include Painter Creek, Dutch Lake, and local watersheds draining directly into the Bay. Sedimentation is predicted using an empirical phosphorus retention function, such as the Canfield-Bachman equation, which has been previously calibrated to data from other lakes (including shallow systems similar to Jennings Bay). Net effects of sediment-water interactions are reflected in the retention function. Water and phosphorus budget estimates similar to those presented by Wenck (1997, Table V-2) support this type of model. Turbulent exchange with the West Arm can be derived based upon morphometric information, but should be verified with drogue studies or other direct measurements. This type of model can be used to predict long-term-average responses of water quality in Jennings Bay to external and internal load controls. While it predicts flows and phosphorus loads leaving the Bay, it does not predict water quality changes in other lake segments likely to result from changes in loads leaving the Bay.

Level 2 – One-Box Dynamic Model of Jennings Bay

The Level 1 model is enhanced to allow prediction of seasonal and year-to-year variations in water quality within the Bay. The water and mass balance terms are identical, but are formulated on a daily (vs. yearly or long-term-average) basis. The model is driven by daily time series of flow and phosphorus loads to the Bay, which can be derived from tributary monitoring data and/or watershed modeling. Seasonal variations in phosphorus recycling from shallow and deep sediments are represented. The model can simulate increases in phosphorus and chlorophyll-a levels that are typically observed during the summer in Jennings Bay, in response to seasonal variations in tributary and internal loads. A preliminary version of this type of model is used below to evaluate potential responses to alternative management strategies.

Level 3 – Multi-Box Steady-State Model of Lake Minnetonka

The entire lake is represented as a network of interconnected segments, each with its own subwatershed and morphometry. Advective and turbulent exchange between adjacent lake segments is represented. The water and mass balance terms are similar to those used in the one-box model applied to individual segments. This type of model enables prediction of lake-wide spatial variations in eutrophication-related water quality conditions in response to loading controls applied to specific watersheds and/or lake segments.

BATHTUB, a model originally developed for simulating eutrophication-related water quality conditions in complex reservoirs, provides a framework for this level of modeling and does not have extensive data requirements. Bruce Wilson of the MPCA has developed a preliminary BATHTUB application to the Lake using available hydrologic, morphometric, and water-quality data. Although incomplete, the model appears to capture essential features of the phosphorus, chlorophyll-a, and transparency gradients that are observed between the shallow bays and downstream open-water segments. Estimates of average flows and loads from each subwatershed can be developed based upon watershed monitoring and/or modeling efforts. Data from the lake wide monitoring program currently being conducted by ?Parks/Barten? can be used for calibration purposes. Once the basic model framework is established, simulations of individual segments can be improved over time as additional data are available.

This type of model provides a basis for long-term management of lake water quality, particularly if specific phosphorus targets are adopted for each region of the Lake. It would serve as a framework for integrating water quality and hydrologic data collected throughout the watershed, designing monitoring programs to fill specific data needs, interpreting water quality data, and developing control strategies to achieve water quality goals in each region of the lake.

Evaluating Potential

Projections of Bay responses to alternative control measures can be derived from any of the modeling approaches discussed above. Development and use of a time-variable phosphorus balance model (Level 2) are demonstrated below. Given the limited time frame and data resources for this effort, it has been undertaken more to demonstrate a viable modeling approach than to support specific management decisions.

Water and phosphorus budget components are listed in Table 1. Seasonal distributions are shown in Figure ?. Estimates of annual tributary flows are derived from Table V-2 of Wenck (1997). The seasonal distribution of inflow volumes and loads from Painter Creek is derived from paired concentration and flow data collected between 1995 and 2001. These values have been rescaled so that the average annual values are approximately equal to those reported by Wenck. Similar seasonal distributions are used for Dutch Lake inflows and local watershed runoff. To reflect urban land uses, the phosphorus concentration in runoff from shoreline areas is increased by 50% relative to the Painter Creek values. Precipitation and evaporation are assumed to be equal.

Phosphorus cycling within the lake is represented by three terms:

1. Gross sedimentation from the water column (calibrated settling rate = 36 m/day)

2. A constant internal load term (calibrated rate of 1 mg/m2-day applied to the entire lake bottom) to reflect recycling from shallow sediments; this term is assumed to be proportional to annual external loading.

3. A seasonal internal load term (25 mg/m2-day applied to 20% of the lake area in June-September) to reflect releases from anaerobic sediments; this is scaled so that the total annual release (786 kg) approximates the value estimated by Wenck (1997, Table V-2) for summer and fall overturn internal loads (770 kg).

The Bachman-Jones regression model is used to predict chlorophyll-a as a function of phosphorus between May and September. A calibration factor of 0.66 is applied based upon 1996-2000 lake monitoring data. Transparency is predicted from chlorophyll-a using the empirical model incorporated in BATHTUB.

Figure ? shows predicted average seasonal variations in phosphorus, chlorophyll-a, and transparency in relation to values observed in the surface waters of the Bay on individual dates between 1996 and 2000. The predicted values appear to capture basic seasonal patterns in the data. Variations in observed values on any julian day reflect year-to-year variations in hydrology and in the timing of internal loading events. The model inputs and predictions reflect the average seasonal pattern in an average hydrologic year. Although the model is capable of simulating year-to-year variations, substantial additional effort would be required to develop the required continuous flow and load time series from the intermittent flow and concentration data.

The model has been applied to predict responses to the following management scenarios:

1. 1979-1986 Conditions – Based upon limited phosphorus data collected in Painter Creek during those years (Predicted TP = 104 ppb, May-September)
2. 1995-2001 Conditions (TP = 90 ppb)
3. 50% Reduction in Painter Creek Loads vs. 1995-2001 (TP = 64 ppb)
4. 70% Reduction in Redox-Mediated Internal Loads from Anaerobic Sediments, Alum Treatment (TP = 71 ppb)
5. 25% Reduction in Painter Creek+ 70% Reduction in Internal (TP = 58 ppb)
6. 50% Reduction in Painter Creek + 70% Reduction in Internal (TP = 45 ppb)

Results for other variables are listed in Table ? and displayed in Figure ?.

Figure ? shows predicted seasonal variations in phosphorus, chlorophyll-a, and transparency for Scenarios 2, 4, and 6. The alum treatment alone (Scenario 4) reduces the average summer phosphorus concentration from 90 to 71 ppb and the seasonal maximum chlorophyll-a concentration from 51 to 33 ppb, slightly above the 30 ppb level often use to distinguish nuisance algal blooms. The combination of alum treatment and 50% reduction in Painter Creek loads (Scenario 6) reduces the average phosphorus concentration from 90 to 45 ppb and the seasonal maximum chlorophyll-a from 51 to 17 ppb. Scenario 6 may approach the limits of what is practically achievable.

A goal of 60 ppb for summer phosphorus concentration appears to be technically achievable with an alum treatment and 25% reduction in Painter Creek loads. Achieving this goal would reduce the frequency of summer algal blooms. Results suggest that goal of 40 ppb Total P (thought to be consistent with full recreational use) would be difficult to achieve.

Caveat – caveat – caveat.

Figure - ? Long-Term Trends in Jennings Bay Water Quality

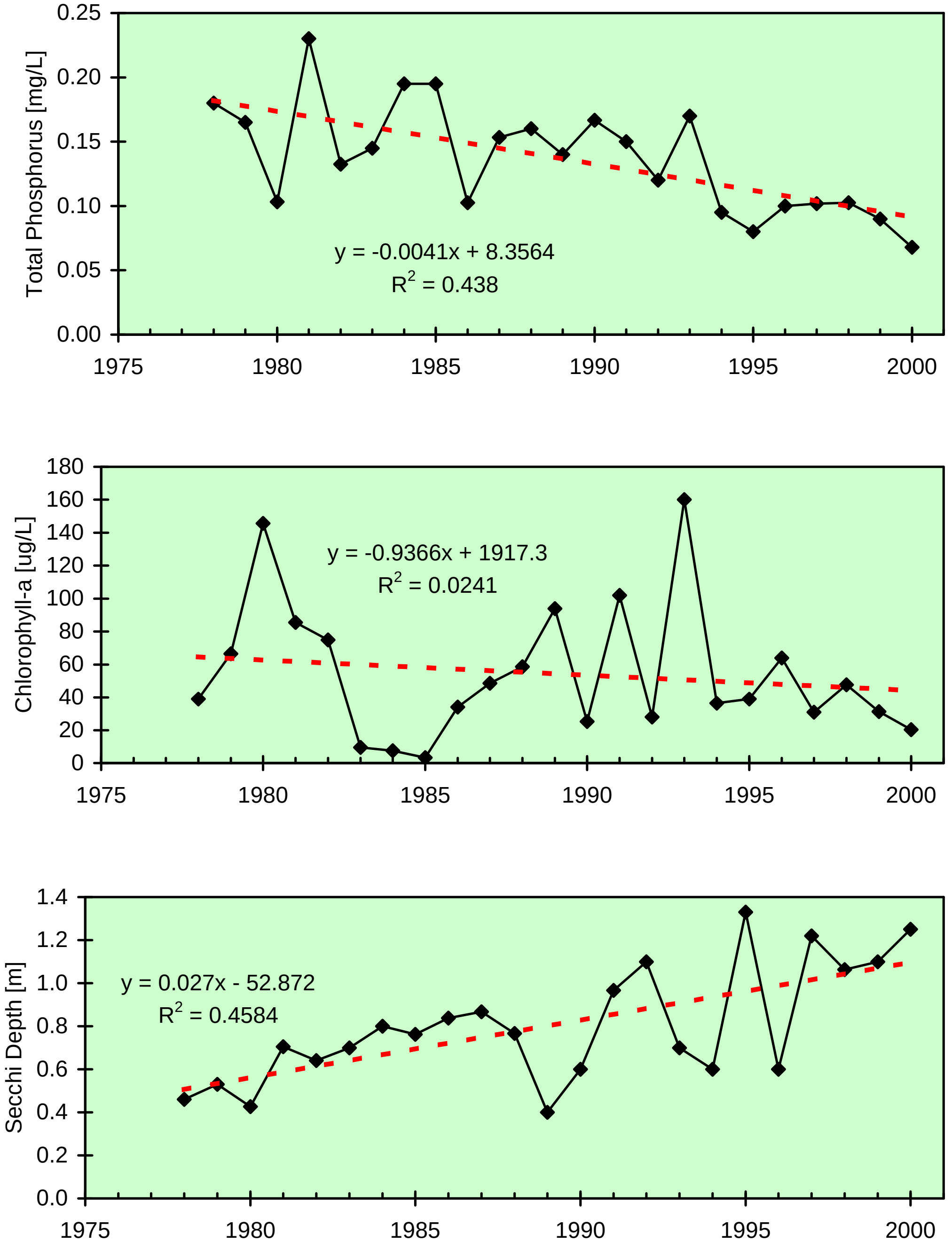

Figure ? – Observed & Predicted Seasonal Variations in Jennings Bay, 1996-2000

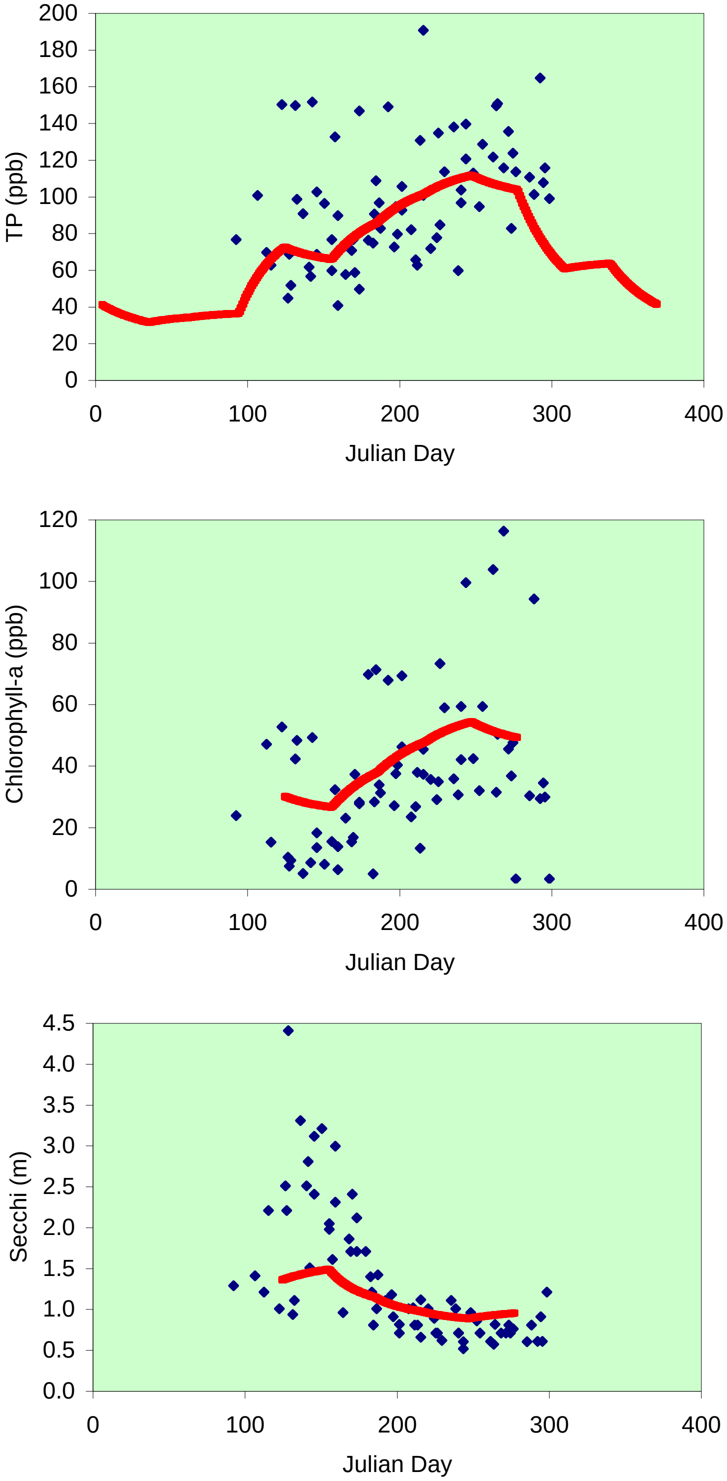

Figure ? – Predicted Reponses to Alternative Management Scenarios

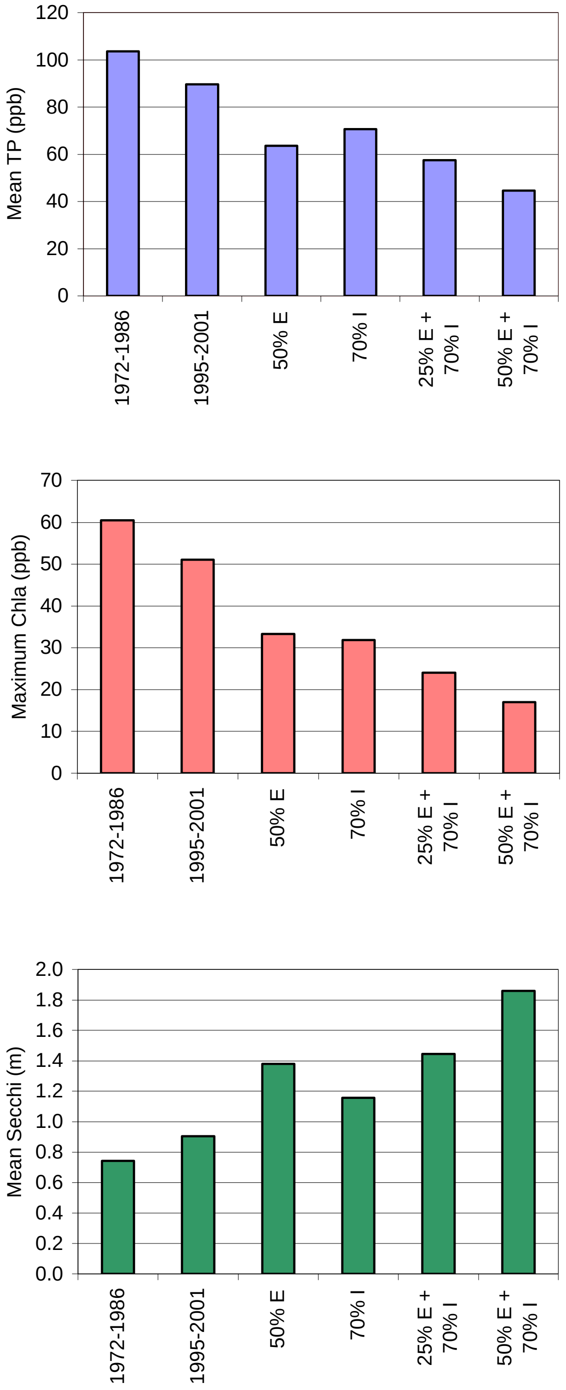

Figure ? - Predicted Seasonal Responses to Reductions in External & Internal Load

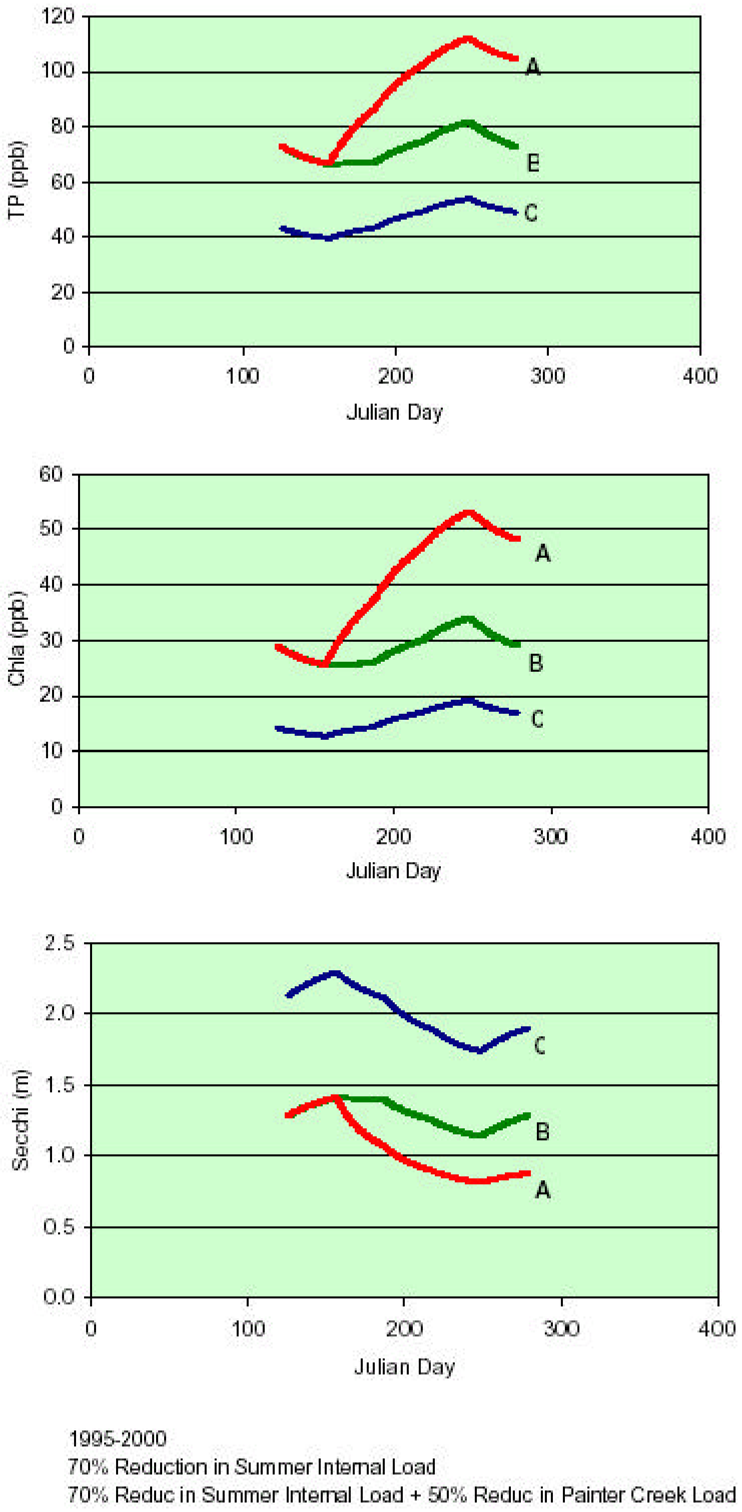

Table ? – Average Annual Phosphorus Budget for Current Conditions

	Flow	Load	Conc	Load%
Source	hm3	kg	ppb	
Painter	5.37	1662	310	52%
Dutch	1.03	134	130	4%
Local	0.35	161	465	5%
Total External	6.75	1958	290	61%
Internal - Shallow		428		
Internal - Deep		786		
Internal - Total		1214		38%
Atmospheric		35		1%
Total In	6.75	3206	475	100%
Outflow	6.75	440	65	14%
Retention		2766		86%

Table ? – Predicted Responses To Management Scenarios

Scenario	Units	1972-1986 1	1995-2001 2	50% E 3	70% I 4	25%E+70% I 5	50%E + 70%I 6
External Load Redu	%	0%	0%	50%	0%	25%	50%
Internal Load Reduc	%	0%	0%	0%	70%	70%	70%
External Load	kg/yr	2106	1958	1127	1958	1542	1127
Internal Load	kg/yr	1214	1214	1002	714	608	502
Total Load	kg/yr	3355	3206	2163	2707	2185	1664
Outflow Load	kg/yr	469	440	294	389	316	243
Mean Total P	ppb	104	90	64	71	58	45
Max Total P	ppb	123	110	82	80	66	52
Mean Chl-a	ppb	47	38	23	27	20	14
Max Chla	ppb	60	51	33	32	24	17
Mean Secchi	m	0.74	0.91	1.38	1.16	1.44	1.86