# 3. UPPER MISSISSIPPI RIVER DATA SUMMARY

The Upper Mississippi River system has a rich set of water quality and biological data collected over the past 22 years by federal, state, and local government agencies. Within Pools 2 and 3, MCES has collected most of the monitoring data, while the USGS through the Long Term Resource Monitoring Program (LTRMP) has collected a majority of the data in Pool 4. Other agencies that regularly collect data within the UMR system include the USACE, MPCA, and the Minnesota DNR and Wisconsin DNR. Every effort was made to incorporate all of the available data into a water quality database, which was used to support the model calibration/confirmation process. The database was used to generate boundary conditions for the tributaries and to compare model results to available monitoring data within the system during calibration. This section provides a brief description of the data that were included in the database, including special studies that were conducted within the UMR system during the study period. A description of meteorological data and other data used for the modeling work is also provided in this chapter.

Due to the large number of figures in this chapter, they are provided at the end of the chapter.

## 3.1 DATA SOURCES AND PROCESSING

This section describes the available datasets used in the modeling study, and the water quality database that was compiled for the project. A table of available datasets is provided in Appendix A.

### 3.1.1 Metropolitan Council Environmental Services

The Metropolitan Council Environmental Services (MCES) routinely collects water samples from rivers, lakes and streams to assess long-term changes in water quality. Information on MCES's sampling locations, parameters, monitoring data, and protocols may be found online at http://www.metrocouncil.org. All of MCES' grab sample data are available online, while the daily-averaged automated data were obtained via e-mail from MCES. Data collected prior to 1997 were provided by MCES on CD.

An automated sampling network has been in place on the upper portions of the Mississippi River System since 1973. Dissolved oxygen, pH, temperature, and specific conductance are continuously monitored. Turbidity is also measured continuously at the mouth of the Minnesota River to assess the sediment load delivered to the Mississippi River. Automated stations are located on the Minnesota River near Fort Snelling (river mile 3.5), on the Vermillion River near Empire (15.6), and on the Mississippi River above the Metro WWTP (836.8), near Newport (831.0), Grey Cloud Island (826.7), and above Lock and Dam No. 2 (815.3).

MCES also maintains 23 conventional pollutant-monitoring sites within the UMR system. Data from 14 of the stations were either used to develop boundary conditions or as calibration sites during this study. Samples are collected on a weekly basis from March through October and on a semi-monthly basis from November through February. Data that were used for this study include ammonia, nitrite, nitrate, Kjeldahl nitrogen (total and particulate), dissolved oxygen, temperature, turbidity, Secchi depth, several BOD parameters, viable chlorophyll *a*, phosphorus (total, particulate, dissolved, and orthophosphate), dissolved silica, dissolved organic carbon, and suspended solids (total and volatile).

In 2006, additional water quality data were collected at part of a system-wide low flow survey (MCES 2006). This dataset provided a higher spatial and temporal resolution for key water quality parameters and locations throughout the UMR system. Samples were collected on a weekly basis at all MCES stations and bottom water grabs were also collected at many locations.

Results from a long-term BOD study on the major tributaries and the Metro WWTP were used to determine the split between labile and refractory organic nutrient fractions. An effluent study was also conducted in 2006 at the Metro WWTP to better quantify phosphorus and nitrogen loading components, and those data were used in the development of WWTP loadings.

MCES has also conducted numerous biological studies to assess phytoplankton and zooplankton speciation and biomass within the UMR system. For the phytoplankton data, LimnoTech received biomass estimates (mg/L) by species for particular locations and samples. For some samples, cell density (cells/ml) was converted to biomass using conversion values obtained from literature. A detailed inventory of all biological data collected by MCES and other agencies is found in Tables 3-1 and 3-2.

### 3.1.2 Long Term Resource Monitoring Program

In cooperation with the USGS, USACE, and five states (Illinois, Iowa, Minnesota, Missouri, and Wisconsin), the Long Term Resource Monitoring Program maintains the richest water quality and biological data collection program for the Upper Mississippi River system. Since 1990, the program has collected water quality data from 55 fixed sampling locations and over 6,000 random locations within Pool 4. The fixed locations provide a basis to compare long-term trends in water quality over time, while the random locations cover a vast area every year and capture spatial variability in water quality within Pool 4. Sampling frequency is semi-monthly from April through October and monthly from November to March, or as ice conditions permit. Relevant parameters include ammonia, viable chlorophyll *a*, dissolved oxygen, Secchi depth, suspended solids (total and volatile), temperature, nitrate, nitrite, total soluble nitrogen, phosphorus (total, dissolved, and orthophosphate), and turbidity. All of the relevant pre-2006 data were downloaded from the LTRMP website (http://www.umesc.usgs.gov/ltrmp.html). Data for 2006 were obtained directly from USGS on 2/13/07.

**Table 3-1. Phytoplankton Speciation Data Inventory**

| Agency | Date Range | Sampling Frequency | Sampling Locations | Agency Contact | Notes |
|---|---|---|---|---|---|
| MCES | 1981 - 1994 | One summer grab sample per year | Minnesota (2 sites; RM 3.5 and 39.4), Mississippi (20 sites from RM 800.4 to 871.6), St. Croix (5 sites from RM 1 to 24), Vermillion (RM 15.6) | Terrie O'Dea | Annual late summer grab sample for phytoplankton enumeration by species. Taxonomy for these data are not specific enough to be useful, especially with regards to diatoms. |
| MCES | 2003 - 2006 | Bi-weekly (apprx.) | Minnesota (2 sites; RM 3.5 and 39.4) | Terrie O'Dea | Bi-weekly grab sample for phytoplankton enumeration and biovolume estimation by species. |
| MCES | 1995, 1997 - 2003 | One summer grab sample per year | Minnesota (5 sites; RM 3.5 to 125), Mississippi (9 sites from RM 800.4 to 872), St. Croix (2 sites from RM 1.7 to 24), Vermillion (RM 15.6) | Terrie O'Dea | Annual late summer grab sample for phytoplankton enumeration by species. |
| MCES | 1996 | Bi-weekly (appx.) | Minnesota (5 sites; RM 3.5 to 125), Mississippi (9 sites from RM 800.4 to 872), St. Croix (2 sites from RM 1.7 to 24), Vermillion (RM 15.6) | Terrie O'Dea | Bi-weekly grab sample for phytoplankton enumeration and biovolume estimation by species. |
| MPCA | 1994 - 1998 | Approximately bi-weekly during the summer; otherwise monthly | Lake Pepin (6 sites; RM 766.3 to 784.3) 164 samples | Steve Heiskary | Seasonal phytoplankton enumeration data. We converted to biomass using conversion factors from the MCES data. |

**Table 3-1. Phytoplankton Speciation Data Inventory (Continued)**

| Agency | Date Range | Sampling Frequency | Sampling Locations | Agency Contact | Notes |
|---|---|---|---|---|---|
| LTRMP | 2000, 2002, 2005 | Monthly | Lake Pepin (3 sites; RM 771.2 to 786.2) - 90 samples total from 3 stations | Jeff Houser | Samples collected by the LTRMP, but recently sent to Howard Markus (MPCA) for estimating the percent biovolume for each functional group. |
| USACE | 1996 | Bi-weekly in the growing season | Lake Pepin (4 sites, RM 766, 771, 775, 781) | Cathy Larson/ Terrie O'Dea | Included as part of the MCES data from 1996 |
| MCES | 1988 | Several days in growing season | 18 stations in UMR, STC, and MN Rivers, samples collected on 6/18, 6/23, 6/28, 8/15, 8/17, and 8/19 | Terrie O'Dea | Collected during the low flow conditions at several stations |
| MCES | January to June 2005 | Bi-weekly | SC0.3, UM775.6, UM815.6, UM847.7, | Terrie O'Dea | Collected by MCES in anticipation of a low flow event |
| MCES | July to September 2006 | Bi-weekly | SC0.3, UM764.3, UM771.0, UM775.6, UM781.0, UM787.0, UM815.6, UM847.7, | Terrie O'Dea | Low Flow Survey |

# Table 3-2. Zooplankton Data Inventory by Study and Agency

| Agency | Date Range | Sampling Frequency | Sampling Locations | Agency Contact | Notes |
|---|---|---|---|---|---|
| LTRMP (MN DNR) | 1993 - 1994 | Bi-weekly during the growing season | Lake Pepin (stratified random sites and 4 fixed sited from PM 766.0 to 781.2) | Rob Burdis | Zooplankton species enumeration. No length was included, so biomass estimates are not available. |
| LTRMP (MN DNR) | 1995 - 2006 | Bi-weekly during the growing season | Lake Pepin (stratified random sites and 4 fixed sited from PM 766.0 to 781.2) | Rob Burdis | Zooplankton species enumeration with biomass estimates. |
| MCES | 1999 - 2002 | One summer grab sample per year | Minnesota (RM 3.5), Mississippi (7 sites from RM 800.4 to 848.0), St. Croix (RM 1.7), Vermillion (RM 15.6) | Terrie O'Dea | Zooplankton species enumeration with biomass estimates. |
| MCES | 1983 - 1995 | One summer grab sample per year | Minnesota, Mississippi, St. Croix, and Vermillion Rivers | Terrie O'Dea | Zooplankton species enumeration. No length was included, so biomass estimates are not available. |
| MCES | 1996 | Bi-weekly during the growing season (appx.) | Minnesota (RM 3.5), Mississippi (3 sites from RM 812 to 844), St. Croix (RM 0.4) | Terrie O'Dea | Zooplankton species enumeration with estimate of the total zooplankton biomass (not broken down by functional groups). |
| EPA | 2004 - 2005 | Twice during the growing season | Lake Pepin (exact locations are not clear) | Dave Bolgrein | Species enumeration of meso- and microzooplankton in Lake Pepin. |
| MCES | 1997 and 1998 | One summer grab sample per year | Minnesota, Mississippi, St. Croix, and Vermillion Rivers | Terrie O'Dea | Zooplankton species enumeration. No length was included, so biomass estimates are not available. |

### 3.1.3 Data Collected by Other Agencies

Several other state and federal agencies including the USGS, USACE, MPCA, and the Minnesota and Wisconsin DNR have collected water quality samples within the study area during the 1985-2006 period. Available data were used during the calibration process and cover various years, locations, and parameters.

In cooperation with MCES, the Minnesota DNR operates an automated water quality sampler in Lake Pepin near Lake City, MN. The instrument consists of an automatic profiling system and a multi-probe logger. The unit is attached to a cable mooring in roughly 9 meters of water and travels from the surface to the bottom once every 4 to 6 hours, recording dissolved oxygen, temperature, and conductivity at 1 meter intervals. This instrument was usually deployed from June through August in 2000, 2001, 2002, 2003, 2004, and 2006. The instrument provides information on the thermal stratification of Lake Pepin during the summer months and how dissolved oxygen is distributed throughout the water column.

The Minnesota Pollution Control Agency (MPCA) maintains several stations along the Mississippi River, which it monitors for conventional water quality parameters on a regular basis. Data were either received from MCES on CD for data prior to 1997 or downloaded from the MPCA webpage (http://www.pca.state.mn.us/) for data after 1996. Additional water quality data were obtained from a station at Lock and Dam No. 3, which was maintained by the Wisconsin DNR on a sporadic basis from 1985 to 1998.

The USACE has collected water quality, meteorological, and physical data throughout the UMR system from 1985 to 2006. Water quality data were collected at various locations from 1994 to 1996. At lock and dams 1, 2, and 3, USACE collected water surface elevation, flow over the dam structures, water temperature, air temperature, wind speed and direction, and information on ice cover. The water quality information was obtained from MCES on CD, while operational data was downloaded from the USACE – St. Paul district webpage (http://www.mvp.usace.army.mil/).

### 3.1.4 Water Quality Database

A water quality database was created using Microsoft Access as part of the data-gathering portion of this study to organize and store monitoring data from all of the agencies listed above. The database was used in the generation of boundary condition time series, model calibration, and model confirmation. The database includes all of the water quality data and some biological data from all of the agencies mentioned above. A summary of the database contents is provided in Table 3-3. The database provides the most comprehensive source of water quality data within the Upper Mississippi River system during the last 22 years. Data from MCES and the LTRMP represent a substantial portion of the available monitoring data.

**Table 3-3. Summary of UMR Water Quality Database Contents**

| Agency | Stations | Samples | Results | Start | End |
|---|---|---|---|---|---|
| MCES | 38 | 66,757 | 771,960 | 1985 | 2006 |
| MDNR | 1 | 13,604 | 54,416 | 2000 | 2006 |
| MPCA | 36 | 3,004 | 17,578 | 1985 | 2006 |
| USACE | 5 | 1,161 | 14,442 | 1994 | 1996 |
| LTRMP | 6,975 | 24,762 | 278,168 | 1990 | 2006 |
| WDNR | 1 | 170 | 3,406 | 1985 | 1998 |
| **Total** | **7,056** | **109,458** | **1,139,970** | **1985** | **2006** |

## 3.2 MODEL INPUTS

Monitoring data from the agencies listed above were used to generate boundary conditions and other input files necessary to run the ECOMSED and RCA components of the UMR-LP model. This section describes the development of key boundary condition and loading inputs for each model.

### 3.2.1 Hydrodynamic & Sediment Transport Model (ECOMSED)

In order to simulate hydrodynamic conditions, water temperature, and sediment transport behavior, a continuous input of discharge, water surface elevation, solids concentrations, and meteorological data is required at each ECOMSED boundary location. This section provides an overview of how these boundary condition inputs were developed using available data for the 1985-2006 period.

#### *3.2.1.a Tributary Flows*

Discharge data for each tributary were obtained from the USGS and USACE. USACE discharge data for the Mississippi River at Lock and Dam No. 1 were downloaded from the USACE website and used directly for the 1985-2006 period. For all other tributaries, data were downloaded from the USGS website for the station nearest to its confluence with the Mississippi River. To account for additional flow entering the system downstream of the measurement station, a ratio of the watershed area at the mouth to the watershed area at the gaging station was applied to all discharge data (i.e., drainage area ratio) in order to estimate discharge at the mouth. For small gaps in monitoring data (days to weeks), linear interpolation was used to estimate discharge for missing days. For large gaps in monitoring data (months to years), data from a station further upstream was used, and a new drainage area ratio was applied to this dataset. If no gages were located on the river, then a drainage area ratio was applied to discharge data from an appropriate monitored tributary. Table 3-4 provides information on gaging stations and watershed areas. A graph of the average annual flow for each of the major tributaries is provided in Figure 3-1, while the summer average (June-September) flow is shown in Figure 3-2.

**Table 3-4. Location of USGS and USACE Gaging Stations and Watershed Areas**

| River System | Location | USGS Gage ID | River Mile | Drainage Area ($mi^2$) |
|---|---|---|---|---|
| Upper Mississippi River | Anoka | 05288500 | 864.8 | 19,100 |
| | LD1 | | 847.7 | 19,811 |
| | St. Paul | 05331000 | 839.1 | 36,701 |
| | LD2 | | 815.2 | 36,946 |
| | Prescott | 05344500 | 811.4 | 44,955 |
| | LD3 | | 797.0 | 45,087 |
| | LD4 | | 752.8 | 57,269 |
| Minnesota River | Jordan | 05330000 | 39.4 | 16,200 |
| | Mouth | | | 16,846 |
| St. Croix River | St. Croix Falls | 05340500 | 52.2 | 6,240 |
| | Mouth | | | 7,718 |
| Vermillion River | Empire | 05345000 | 15.6 | 110 |
| | Mouth | | | 257 |
| Cannon River | Welch | 05355200 | | 1,320 |
| | Mouth | | | 1,448 |
| Chippewa River | Durand (WI) | 05369500 | | 9,010 |
| | Mouth | | | 9,508 |

### *3.2.1.b Water Temperature and Meteorological Inputs*

Water temperature data for each of the tributaries were obtained from MCES grab samples and automated samplers. A linear interpolation procedure was used to fill small gaps in data coverage, while data from upstream stations or nearby tributaries were used to fill large gaps in data coverage. A discussion of large data gaps related to water temperature can be found in section 3.2.2.

Meteorological inputs including hourly air temperature, wind speed, wind direction, relative humidity, and solar radiation are discussed under the meteorological inputs section (3.2.4) below.

### *3.2.1.c Suspended Solids Boundary Condition*

The sediment transport portion of ECOMSED simulates the deposition, resuspension, and burial of non-volatile solids. The input of non-volatile suspended solids (NVSS) at the boundary conditions is calculated by subtracting MCES measurements of total suspended solids (TSS) from volatile suspended solids (VSS). This approach was used for the full simulation period for the Mississippi River at L&D 1 and the St. Croix River. Linear interpolation was used to fill gaps between sampling events. For the Cannon, Vermillion, and Chippewa rivers, available monitoring data for each tributary were used to calculate an average NVSS concentration for each month of the year (Figure 3-3). This monthly time series was repeated for each simulation year.

Daily variability in the observed NVSS concentration for the Minnesota River indicated that linear interpolation between weekly or bi-weekly sampling would result

in unreliable estimates of daily sediment load. To supplement the grab samples, daily measurements of turbidity at Fort Snelling (river mile 3.5) provided a means to calculate NVSS concentrations on a daily basis. Using over 10 years of paired NVSS and daily averaged turbidity, a relationship was developed between turbidity and NVSS specifically for the Minnesota River (Figure 3-4). Daily turbidity measurements are available from May 16, 1991 through 2006. Prior to 1991, NVSS concentrations were estimated using a relationship between NVSS and flow developed for the original UMR model. A more detailed explanation can be found in (HydroQual 2002c).

The major sources of NVSS to the UMR system in order of their loading magnitude are the Minnesota, Mississippi, Cannon, and St. Croix rivers. The annual average daily load for these locations for the 1985-2006 period is provided in Table 3-5 and shown graphically in Figure 3-5.

**Table 3-5. Annual daily average NVSS load for the major tributaries to the UMR system.**

| Year | NVSS Loads (million metric tons/day) | | | |
|---|---|---|---|---|
| | UMR at L&D 1 | Minnesota River | St. Croix River | Cannon River |
| 1985 | 551 | 1809 | 54 | 85 |
| 1986 | 687 | 2342 | 58 | 162 |
| 1987 | 117 | 1048 | 9 | 57 |
| 1988 | 58 | 194 | 7 | 35 |
| 1989 | 155 | 235 | 6 | 64 |
| 1990 | 214 | 962 | 9 | 79 |
| 1991 | 301 | 2328 | 37 | 59 |
| 1992 | 149 | 1660 | 18 | 111 |
| 1993 | 398 | 2492 | 16 | 309 |
| 1994 | 363 | 2642 | 49 | 111 |
| 1995 | 344 | 2059 | 53 | 86 |
| 1996 | 324 | 1558 | 31 | 86 |
| 1997 | 315 | 2345 | 64 | 153 |
| 1998 | 238 | 1927 | 31 | 166 |
| 1999 | 398 | 1991 | 33 | 136 |
| 2000 | 143 | 1245 | 23 | 138 |
| 2001 | 524 | 3481 | 42 | 166 |
| 2002 | 321 | 1448 | 22 | 115 |
| 2003 | 259 | 834 | 19 | 65 |
| 2004 | 182 | 1803 | 21 | 169 |
| 2005 | 330 | 1757 | 30 | 103 |
| 2006 | 197 | 1261 | 20 | 83 |
| **Average** | **299** | **1701** | **30** | **115** |

### 3.2.2 Water Quality Model (RCA)

The major inflows to the model domain are the Mississippi River at Lock and Dam No. 1, the Minnesota River, and the St. Croix River. (The Chippewa River also contributes a significant quantity of flow to the system; however, it enters below the Lake Pepin outlet.) Smaller inflows to the model domain include the Cannon, Vermillion, and Rush rivers. A complete time series for each actively simulated state variable for every tributary is required to run RCA model simulations. When monitoring data were not available for a particular state variable or tributary, reasonable assumptions were made to develop the boundary condition time series based on related datasets.

To generate boundary conditions for the Mississippi, Minnesota, and St. Croix Rivers, monitoring data were used from MCES stations UM 847.7, MN 3.5, and SC 0.3, respectively. Conventional water quality parameters were usually monitored semi-monthly to weekly during the growing season and semi-monthly during other periods. Linear interpolation was used to estimate daily concentrations between sampling events for every parameter. Algal speciation data collected by MCES were used to determine the fraction of algal biomass assigned to each algal group for each tributary, while algal biomass (mg-C/L) for each tributary was calculated from chlorophyll *a* concentrations. An annual zooplankton biomass time series was applied to all tributaries based on data from MCES. Table 3-6 lists all of the RCA state variables and indicates which water quality parameters were used in calculating the state variables.

**Table 3-6. RCA Upper Mississippi River Water Quality State Variables**

| System No | System ID | System Description | Units | Notes |
|---|---|---|---|---|
| 1 | SAL[1,2] | Salinity | ppt | Not simulated in RCA |
| 2 | PHYT1 | Blue-green phytoplankton | mg-C/L | Based on Chl-a |
| 3 | PHYT2 | Spring diatoms | mg-C/L | Based on Chl-a |
| 4 | PHYT3 | Summer phytoplankton | mg-C/L | Based on Chl-a |
| 5 | RPOP | Particulate Organic Phosphorus - refractory | mg-P/L | 0.85*(PTP-PIP) |
| 6 | LPOP | Particulate Organic Phosphorus - labile | mg-P/L | 0.15*(PTP-PIP) |
| 7 | RDOP | Dissolved Organic Phosphorus - refractory | mg-P/L | 0.85*(DTP-DIP) |
| 8 | LDOP | Dissolved Organic Phosphorus - labile | mg-P/L | 0.15*(DTP-DIP) |
| 9 | PO4T | Total Inorganic + Algal Phosphorus | mg-P/L | DIP+(algal-C)/40 |
| 10 | RPON | Particulate Organic Nitrogen - refractory | mg-N/L | 0.85*Particulate TKN |
| 11 | LPON | Particulate Organic Nitrogen - labile | mg-N/L | 0.15*Particulate TKN |
| 12 | RDON | Dissolved Organic Nitrogen - refractory | mg-N/L | 0.85*(diss TKN – NH4) |
| 13 | LDON | Dissolved Organic Nitrogen - labile | mg-N/L | 0.15*(diss TKN – NH4) |
| 14 | NH4T | Total Ammonia + Algal Nitrogen | mg-N/L | NH3+(algal-C)/5.68 |
| 15 | NO23 | Nitrite + Nitrate | mg-N/L | NO2+NO3 |
| 16 | BSI | Biogenic Silica | mg-Si/L | Not required for BC |
| 17 | SIT | Total Available Silica | mg-Si/L | Dissolved Si |
| 18 | RPOC | Particulate Organic Carbon - refractory | mg-C/L | 0.85*(0.3*VSS) |
| 19 | LPOC | Particulate Organic Carbon - labile | mg-C/L | 0.15*(0.3*VSS) |
| 20 | RDOC | Dissolved Organic Carbon - refractory | mg-C/L | 0.85*DOC or calculated |
| 21 | LDOC | Dissolved Organic Carbon - labile | mg-C/L | 0.15*DOC or calculated |
| 22 | EXDOC | Dissolved Organic Carbon - algal exudate | mg-C/L | Not required for BC |
| 23 | REPOC | Particulate Organic Carbon - reactive | mg-C/L | Not simulated in RCA |
| 24 | REDOC | Dissolved Organic Carbon - reactive | mg-C/L | Not required for BC |
| 25 | O2EQ | Aqueous SOD | mg-$O^2$/L | Not required for BC |
| 26 | DO | Dissolved Oxygen | mg-$O^2$/L | Measured directly |
| 27 | SS1 | Non-Volatile Suspended Solids, fine | mg/L | ECOMSED BC |
| 28 | SS2 | Non-Volatile Suspended Solids, coarse | mg/L | ECOMSED BC |
| 29 | ZOO1 | Cladoceran | mg-C/L | Repeated time series |
| 30 | ZOO2 | Copepods | mg-C/L | Repeated time series |
| 31 | ZOO3 | Microzooplankton | mg-C/L | Repeated time series |

### *3.2.2.a Boundary Conditions*

For each state variable, boundary conditions were either derived from a calculation involving several measurements, or used directly from measured values (e.g. dissolved oxygen). Phosphorus components initially measured at the boundary conditions included total (TP), particulate total (PTP), and dissolved orthophosphate (DIP). From these measurements, dissolved total phosphorus (DTP) was calculated as the difference between TP and PTP. When DTP measurements became available in 1990, they were used in place of the TP/PTP calculation. Dissolved organic phosphorus (DOP) was estimated as the difference between DTP and DIP, with particulate organic phosphorus (POP) remaining as the difference of PTP and algal phosphorus (algal P). Algal P is estimated by taking the total algal carbon and dividing it by the carbon: phosphorus ratio (40). Each of the organic phosphorus components is broken into refractory (85%) and labile (15%) fractions. These fractions were determined from the analysis of long-term BOD study results

conducted as part of the 2006 low-flow survey. From all of these calculations, DOP (labile and refractory), POP (labile and refractory), and inorganic phosphorus (DIP), and algal P are the parameters that are modeled as state variables within RCA.

The annual total phosphorus loadings for each tributary and from the four WWTPs represented in the calibration are presented in Table 3-7 and shown graphically in Figure 3-6. Phosphorus loading was at its lowest during the low-flow year of 1988 and highest in 1993, when record flow was recorded on the Minnesota River during the heavy spring runoff period. The largest contributor of phosphorus to the UMR system is the Minnesota River (Figure 3-7). From 1985 to around 2002/2003 the second largest source was either the Mississippi River at LD1 or the combined WWTP loads, depending on the year and flow conditions in the Mississippi River. However, the implementation of biological phosphorus removal at the Metro WWTP, which represents over 90% of the total WWTP load, greatly reduced the phosphorus load entering the UMR system post-2002/2003.

For the nitrogen components, ammonia (NH3), nitrite (NO2), nitrate (NO3), and total, dissolved, and particulate Kjeldahl nitrogen (TKN, DKN, PKN) were used as the basis for developing the model boundary conditions. Particulate Kjeldahl nitrogen was used directly as the particulate organic nitrogen (PON) fraction. Dissolved organic nitrogen (DON) was calculated as the difference between the DKN and NH3 concentrations. When measurements of DKN were not available, DKN was calculated by subtracting PKN from TKN. PON and DON were both divided into refractory and labile components using the same ratios developed for phosphorus.

Non-living particulate and dissolved organic carbon concentrations were estimated from volatile suspended solids (VSS) and 5-day carbonaceous biological oxygen demand (CBOD5) data. The non-living particulate organic carbon (POC) fraction was assumed to be 30% of the VSS less the calculated algal carbon (from above). Dissolved organic carbon (DOC) was either based on direct measurements or derived from CBOD5 data. Again, POC and DOC are broken into labile and refractory components using the same fractions used for phosphorus and nitrogen.

**Table 3-7. Annual Total Phosphorus Loadings From Major Tributaries and WWTPs (metric tons/year)**

| Year | UMR at L&D 1 | Minnesota River | St. Croix River | Cannon River | Vermillion River | WWTP |
|---|---|---|---|---|---|---|
| 1985 | 1,457 | 1,918 | 351 | 224 | 16 | 712 |
| 1986 | 1,671 | 2,872 | 533 | 434 | 28 | 618 |
| 1987 | 388 | 624 | 73 | 230 | 13 | 708 |
| 1988 | 324 | 390 | 112 | 166 | 13 | 914 |
| 1989 | 614 | 520 | 195 | 293 | 14 | 935 |
| 1990 | 942 | 981 | 212 | 259 | 14 | 866 |
| 1991 | 1,212 | 3,182 | 502 | 215 | 15 | 926 |
| 1992 | 553 | 2,143 | 178 | 291 | 30 | 728 |
| 1993 | 1,197 | 3,343 | 157 | 494 | 35 | 874 |
| 1994 | 858 | 2,134 | 503 | 326 | 27 | 951 |
| 1995 | 933 | 2,034 | 302 | 172 | 20 | 1,059 |
| 1996 | 866 | 1,418 | 315 | 147 | 29 | 1,044 |
| 1997 | 863 | 1,599 | 162 | 177 | 42 | 877 |
| 1998 | 697 | 1,386 | 206 | 219 | 52 | 908 |
| 1999 | 732 | 1,461 | 212 | 205 | 38 | 957 |
| 2000 | 422 | 738 | 174 | 218 | 31 | 967 |
| 2001 | 1,102 | 2,093 | 343 | 336 | 29 | 856 |
| 2002 | 1,161 | 1,110 | 342 | 200 | 50 | 755 |
| 2003 | 749 | 508 | 272 | 109 | 30 | 480 |
| 2004 | 614 | 1,482 | 298 | 220 | 30 | 315 |
| 2005 | 933 | 1,439 | 270 | 217 | 46 | 162 |
| 2006 | 513 | 1,162 | 137 | 162 | 19 | 155 |
| **Average** | **855** | **1,570** | **266** | **242** | **28** | **762** |

### *3.2.2.b Gaps in monitoring data*

Until dissolved silica measurements were available in 1996 from MCES, a constant value of 6 mg-Si/L was used for all boundary locations. This value represents the long-term average of dissolved silica for the Minnesota, Mississippi, and St. Croix rivers. Dissolved organic carbon (DOC) was originally estimated by HydroQual using a series of steps based on measurements of CBOD5. Direct measurements of DOC were used in place of this approach beginning in 1996. An analysis of DOC data for the 1996-2006 period revealed that earlier attempts to estimate DOC for 1985-1996 had been under-estimating DOC by several mg/L (Figure 3-8). A seasonal trend was noted in DOC concentrations using the recent data, and a recurring sinusoidal function was applied to the 1985-1996 period. The sinusoidal function was adjusted to match existing data as closely as possible for each tributary (Figure 3-8).

### *3.2.2.c Minor Tributaries*

Although the Cannon and Vermillion Rivers account for less than 5% of the average flow that enters Lake Pepin, their proximity to Lake Pepin and phosphorus and solids loading contributions are potentially important factors in Lake Pepin water quality.

For this reason, every effort was made to develop accurate water quality boundary condition inputs for these tributaries in the RCA model.

MCES began monitoring the Cannon River for chlorophyll *a*, NH3, NO23, DIP, TP, and VSS in 1994 and added the full suite of parameters (similar to the other major tributaries) in 1996. A comparison of several key parameters (TP, DTP, DO, NVSS) between the Minnesota and Cannon Rivers using data after 1995 showed that water quality in the Cannon is very similar to that of the Minnesota River. Prior to 1994 and 1996 (depending on the parameter), concentration data from the Minnesota River were used to fill in the missing data for the Cannon River.

For the Vermillion River, some adjustments to phosphorus and chlorophyll *a* concentrations were necessary because the MCES monitoring station is located 15.6 miles upstream from the confluence with the Mississippi River. The station is located directly below the Empire WWTP, which has a treatment capacity of more than 15 MGD. The influence of the WWTP on water quality, especially for total and dissolved phosphorus, is apparent in the monitoring data. Limited data from the LTRMP and MCES at stations closer to the mouth (VM 0.1; 1990-2005 and MCES - VM 2.0; 1994-1996) revealed that the lower portions of the Vermillion River exhibit significantly lower TP concentrations. To reflect the net loss of phosphorus between river mile 15.6 and the mouth, TP concentrations from the upstream station were reduced by 75%, and DTP concentrations were reduced by 20% to estimate the actual Vermillion River loadings into the Mississippi River. In a similar analysis, chlorophyll *a* concentrations were found to be four times higher at the mouth when compared to the upstream station, and concentrations were adjusted accordingly for input into RCA.

In addition to the tributary sources discussed above, estimates of annual nutrient and solid loadings were developed for Minneapolis-St. Paul urban/suburban areas and the remaining small tributary areas between LD1 and the Lake Pepin outlet based on yield information provided by (Kloiber, 2006). The urban/suburban watersheds evaluated comprise an area of approximately 96,470 hectares (372 sq. miles)), including the Minnehaha Creek, Battle Creek, and Fish Creek watersheds. The smaller tributary areas evaluated include a total area of 117,750 hectares (455 sq. miles) within the following watersheds:

- *Watersheds on the Minnesota side*: Hay Creek, Bullard Creek, Wells Creek, Sugar Loaf Creek, Gilbert Creek, and Miller Creek; and
- *Watersheds on the Wisconsin side*: Trimbelle Creek and Isabelle Creek.

The total annual TP and TSS loadings from the urban/suburban watersheds were estimated to be 30 metric tons/year and 7,180 metric tons/year, respectively. The total annual TP and TSS loadings from the small tributary areas were estimated to be 24 metric tons/yr and 3,530 metric tons/yr, respectively. The TP loads from urban/suburban sources and small tributary watersheds represent approximately 0.8% and 0.6%, respectively, of the total phosphorus loading to the UMR between LD1 and the Lake Pepin outlet. Likewise, the urban/suburban and small tributary TSS loadings represent 0.8% and 0.4% of the total suspended solids loading to this reach.

Although the Chippewa River flows into the Mississippi River at the downstream end of Lake Pepin, the confluence is more than 10 miles upstream of Lock and Dam No. 4, and its contribution to water quality within the lower portion of Pool 4 is significant. USGS discharge data suggest that the Chippewa River contributes about 40% of the average flow to the lower portions of Pool 4. Unfortunately, a long-term record of water quality at the mouth of the Chippewa River does not exist. The LTRMP has measured water quality at the confluence of the Chippewa River, but it is unclear how backwater effects from the main stem of the Mississippi River affect water quality at this station. Due to lack of specific data and because the watershed of the Chippewa River remains relatively undeveloped, it was assumed that the Chippewa has the same water quality characteristics as the St. Croix River.

### 3.2.2.d Biological boundary conditions

Within the RCA model framework, three state variables are used to simulate algal dynamics: blue greens (PHYT1), winter diatoms (PHYT2), and summer assemblage (PHYT3). The grouping of phytoplankton species into three different classes allows the flexibility to specify kinetic constants that reflect the characteristics of each group algal group throughout the year. Zooplankton are represented in the model by two mesozooplankton groups (cladocerans – ZOO1, copepods – ZOO2) and one microzooplankton group (ZOO3). The development of tributary boundary conditions for phytoplankton and zooplankton is described separately below.

*Phytoplankton*

For the purposes of developing phytoplankton boundary conditions, the most useful datasets are those that cover the tributaries over an entire year. The MCES dataset from 1996 is the most rich, with bi-weekly samples collected at LD1 on the Mississippi (RM 847.7), at the mouth of the Minnesota (RM 3.5), and at the mouth of the St. Croix River (RM 0.3). The algal composition of the Minnesota and Mississippi Rivers (Figures 3-9 and 3-10) show similar trends, with diatoms dominating most of the year, blue-greens increasing during the warmer summer period, and other algae (i.e., greens) maintaining a fairly consistent percentage. The St. Croix River (Figure 3-11) demonstrates a much larger percentage of blue-greens in the growing season, but maintains a high percentage of diatoms in the late winter, spring, and late fall months.

Additional bi-weekly data are available for the Minnesota River (RM 3.5) from 2003 to 2006. These data are consistent with the 1996 data for the Minnesota River in that blue-greens comprise about 20% of the biomass in the summer, and the summer assemblage generally comprises 10% of the biomass. There are a few exceptions to these general trends, but the exceptions usually occur when overall algal biomass is low (spring 2005 and winter 2004), and any errors in percent abundance will not have a large impact on the overall loads of phytoplankton delivered to the system.

Several samples from 2005 (January through June) and 2006 (July through September) were collected on the Mississippi and St. Croix rivers. The algal

composition of these samples follow the same trends as the 1996 data, with a high percentage of blue-greens in the summer in the St. Croix River, and diatoms dominating during most of the year in the Mississippi River at L&D 1.

The algal speciation data show that diatoms dominate in the Mississippi and Minnesota Rivers for a majority of the year. This behavior is common in turbid river systems where adequate mixing and high nutrient concentrations are maintained. In the winter and early spring, larger diatoms species (large cyclotella, Nitzscia spp, and stephanodiscus) dominate, while in the summer and fall smaller diatoms species dominate the biomass (smaller cyclotella). To reflect this difference, summer diatoms were grouped with the summer assemblage algal class, while larger diatoms were assigned to the winter diatom group. The algal composition time series was modified to follow this behavior. The time series are presented in Figures 3-12 and 3-13, with a summary of the results in Table 3-8.

**Table 3-8. Percent Composition of Algal Species for the Minnesota, Mississippi, and St. Croix Rivers**

| Start Date | End Date | MN/UMR/VM/CN Rivers | | | St. Croix River | | |
|---|---|---|---|---|---|---|---|
| | | Blue-Green | Winter Diatoms | Summer Assem. | Blue-Green | Winter Diatoms | Summer Assem. |
| Jan-01 | Apr-30 | 5% | 85% | 10% | 5% | 75% | 20% |
| May-01 | Jun-30 | Linear Increase | | | Linear Increase | | |
| Jul-01 | Sep-30 | 20% | 5% | 75% | 50% | 5% | 45% |
| Oct-01 | Oct-31 | Linear Decrease | | | Linear Decrease | | |
| Nov-01 | Dec-31 | 5% | 85% | 10% | 5% | 75% | 20% |

Once the algal composition was determined for each tributary, the algal carbon loading to the RCA model was estimated by group by distributing the chlorophyll a measurements (an estimate of total algal biomass) using the fractions in Table 3-8, and then converting chlorophyll a to a carbon basis using an appropriate ratio. The C:Chl ratio is what ultimately determines the quantity of biomass carbon for each phytoplankton group entering the system at the tributary boundary locations. Some researchers have found that the C:Chl ratio can vary over an order of magnitude (20 to 300), with a higher C:Chl ratio in the late winter and spring months (Cerco and Noel, 2004; Cloern et al. 1995; Faure et al. 2006; Llewellyn et al. 2005). A plot of measured C:Chl from the Chesapeake Bay is shown in Figure 3-14. Several existing studies have also shown the C:Chl ratio of diatoms to be higher than for other algal species (Cerco et al. 2004; Llewellyn et al. 2005). Based on these literature sources, a C:Chla ratio of 50 mg-C/mg-Chla was selected for the winter diatom group, and a ratio of 33 was selected for the blue-green and summer assemblage groups.

In summary, phytoplankton biomass data obtained from MCES, primarily from 1996, were used to determine the composition of algae (% biomass of each group) at the tributary boundary locations. Additional phytoplankton data from 2003-2006 were used to validate the algal composition relationships. Algal carbon (mg C/L) for each subgroup was estimated by assigning a percentage of the measured chlorophyll *a* at each tributary to the three algal groups and applying the appropriate C:Chl conversion factor. A C:Chl ratio of 33 was used for blue-greens and the summer assemblage. The

C:Chl ratio for diatoms (50) was estimated by comparisons of VSS-inferred POC concentrations to algal carbon and measurements of chlorophyll *a* in Lake Pepin. Linear interpolation was used to fill in gaps between chlorophyll *a* grab samples to generate a daily time series of algal carbon concentrations.

For tributaries without chlorophyll *a* measurements (e.g., Chippewa River) or tributaries with missing chlorophyll *a* data for certain years (e.g., Vermillion and Cannon Rivers), chlorophyll *a* concentrations from an appropriate tributary were used. The Chippewa River was supplemented with chlorophyll *a* data from the St. Croix River. The Cannon River boundary condition was developed using chlorophyll *a* concentration data from the Minnesota River. A MCES station does exist on the Vermillion River at RM 15.6 where chlorophyll was monitored from 1985 to the present. However, when measurements of chlorophyll from this station are compared to paired data at the LTRMP station near the mouth (VM 0.1), chlorophyll concentrations are roughly four times higher at the downstream station. To adjust for higher chlorophyll at the mouth, chlorophyll data from the MCES station (RM 15.6) were multiplied by a factor of 4 to estimate the actual concentration at the mouth where the Vermillion enters the UMR system.

*Zooplankton*

Three zooplankton groups are used to simulate cladocerans (ZOO1), copepods (ZOO2), and microzooplankton (ZOO3) dynamics within the UMR-LP system. Table 3-2 lists the available zooplankton data that was used to guide the development of the boundary conditions. These dataset were used to develop a daily time series of biomass for each zooplankton class (Figure 3-15). Sufficient data did not exist to estimate the year-to-year variability or the spatial variability in zooplankton biomass (especially for microzooplankton); therefore, the time series was repeated for every year and applied to all tributary boundary locations. These time series adequately reflect the general patterns found in the zooplankton biomass data, and therefore are appropriate for use in the model.

### 3.2.3 Point Source Loads

Four wastewater treatment plants (WWTPs) that discharge directly to the pool 2, 3, or 4 were represented in the calibration/confirmation simulations. The largest of these plants is the Metro WWTP (located near UM 835.2), with an average daily discharge of 187 MGD in 2005. The remaining three WWTPs – Rosemont, Hastings, and Eagles Point – had an average daily discharge of 0.9 MGD, 1.6 MGD, and 2.3 MGD in 2005, respectively. For each WWTP, available nutrient and water quality data were used to calculate a daily loading (kg/d) that entered the model domain at the segment in closest proximity to the outfall.

Operational data for the four WWTPs from 1/1/1985 to 12/31/2006 were provided to LimnoTech by MCES via e-mail (Terrie O'Dea; 1985-1999) or downloaded directly from the EIMS website (http://es.metc.state.mn.us/eims/index.asp; 1999-2006). Table 3-9 lists the measured parameters and sampling frequency at each plant. Two special

effluent studies were conducted for all of the WWTPs from 1990 to 92 (weekly samples for one to two years) and for the Metro WWTP in 1996 by MCES (two samples per month). Additional effluent data were also collected from 1997 to 2006 (n=23) at the Metro Plant. The 1990-92 effluent study focused only on phosphorus, while the 1996 study included all parameters.

**Table 3-9. Sampling Frequency (times per week) for the WWTPs Represented in the RCA Model Calibration**

| WWTP | TP | DTP | TKN | NH3 | NO2 | NO3 | CBOD5 | DO | TSS |
|---|---|---|---|---|---|---|---|---|---|
| Metro | 7 | 7 | 5 to 7 | 7 | 5 | 5 | 7 | 7 | 7 |
| Rosemont | 1 to 3 | na | 1 to 3 | 1 | 1 | 1 | 3 | 7 | 3 |
| Eagles Point | 1 to 3 | na | 1 to 3 | 1 | 1 | 1 | 3 | 7 | 3 |
| Hastings | 1 to 3 | na | 1 to 3 | 1 | 1 | 1 | 3 | 7 | 3 |

It should be noted that the discussion in this section related to total phosphorus loadings is relevant only for the calibration/confirmation simulations. Total phosphorus loadings used for the model application were developed separately, as discussed in Chapter 6.

### *3.2.3.a Phosphorus*

The phosphorus parameters that are input to RCA include dissolved organic phosphorus (DOP), particulate organic phosphorus (POP), and total inorganic phosphorus (TIP). The DOP and POP fractions are divided into labile and refractory components. All four WWTPs measure total phosphorus (TP) on a daily or semi-weekly basis, and starting in November 1999, dissolved total phosphorus (DTP) was measured on a daily basis at the Metro WWTP. Using daily DTP and TSS data from 1999 through 2002 (pre-phosphorus biological removal), a relationship was developed (Figure 3-16) between monthly average particulate total phosphorus (PTP = TP - DTP) and total suspended solids (TSS). From this relationship, PTP was estimated on a daily basis for the 1985 to 1998 period using daily measurements of TSS. Data also exist for the other WWTPs from special studies conducted during 1990-92, and TSS is measured several times per week (Figure 3-17). A ratio of PTP to TSS of 0.038 is used for the Metro WWTP, while a ratio of 0.020 is used for the other three WWTPs.

Dissolved inorganic phosphorus (DIP) is assumed to be a constant fraction of the DTP. For the Metro plant, the 1996 and 1990-1992 datasets suggest that DIP comprises 92% of DTP (n=97; stdev. = 0.08). At the other WWTPs, the average ratio of DIP:DTP is 90% (n=135, stdev = 0.06). If DIP was greater than DTP, then DIP was assumed to comprise 100% of DTP. Once DIP has been estimated, DOP can be calculated as the difference between DIP and DTP.

A similar analysis was conducted for the particulate inorganic phosphorus (PIP) to PTP ratio. However, PIP is not measured directly, and the residual in the PIP calculation (TIP less DIP) was often negative. Therefore, an alternative method of calculating PIP was used. The effluent data suggest that TIP is a constant fraction of

TP. For the Metro WWTP this fraction is 0.89 (n=70, stdev=0.11) and for the other WWTPs this fraction is 0.86 (n=72, stdev = 0.08). The TIP:TP ratio was multiplied by total phosphorus to obtain TIP, and PIP was then calculated as the difference between TIP and DIP. The final calculation in the sequence was the subtraction of estimated PIP from PTP to obtain POP. Both organic fractions (DOP and POP) were broken into labile (25%) and refractory (75%) components based on 1996 long-term BOD study data. A diagram illustrating the calculation of the various phosphorus fractions is provided in Figure 3-18. Due to the implementation of biological phosphorus removal at the Metro WWTP, concentrations of total phosphorus have decreased to below 1 mg/L in the last several years (Figure 3-19).

### *3.2.3.b Nitrogen*

The nitrogen parameters input to RCA include particulate and dissolved organic nitrogen (PON and DON), nitrate plus nitrite (NO23), and total ammonia (NH4T). Nitrate, nitrite, and ammonia are measured on a daily or semi-weekly basis at each of the WWTPs and are input directly to RCA. Total organic nitrogen (TON) is calculated as the difference between total Kjeldahl nitrogen (TKN) and ammonia (NH3). To estimate the split between PON and DON, HQI originally used a constant ratio of 60% dissolved and 40% particulate. However, PON concentrations tend to track TSS concentrations, and a strong relationship exists between TSS and PON (Figure 3-20). PON (expressed as mg-N/L) is approximately 7.3% of the TSS concentration (n=34, R2=0.75) based on data collected at the Metro WWTP during the 1996 study and a few data points in the 1996-2006 period (n=12). DON is then calculated as the difference of TON and PON. As for phosphorus, the dissolved and particulate organic concentrations are divided into labile (25%) and refractory (75%) components based on the 1996 long-term BOD study.

### *3.2.3.c Carbon*

The carbon parameters input to RCA include particulate and dissolved organic carbon (POC and DOC). The development of POC and DOC boundary conditions made use of the same approach used by HQI for the original UMR model (HydroQual, 2002a). A series of steps were followed using CBOD5 measurements in order to calculate POC and DOC. First, CBOD5 concentrations were multiplied by a factor of two to obtain an estimate of the ultimate CBOD. This was assumed to be oxygen demand from only labile total organic carbon (LTOC). The ultimate CBOD was converted from oxygen units to carbon units based on their stoichiometric ratios (12 mg C/ 32 mg O2), and then multiplied by four to obtain an estimate of the total organic carbon concentration (LTOC is 25% of TOC). The 1996 special effluent data from the Metro WWTP were then used to split the TOC into dissolved (90%) and particulate (10%) components. As for phosphorus and nitrogen, DOC and POC were split into labile (25%) and refractory (75%) components. The approach to calculate these parameters was not modified from the HQI approach because data are not available for any of the WWTPs to explicitly quantify total organic carbon (TOC), and subsequently divide TOC into dissolved and particulate components.

### 3.2.4 Environmental Parameters

ECOMSED requires the input of hourly air temperature, wind speed, wind direction, solar radiation, relative humidity, and barometric pressure to drive the calculation of surface heat fluxes and wind-induced surface water circulation. RCA uses the fraction of the day with daylight, total daily solar radiation (ly/day), and fractional ice cover to calculate the light available for algal growth during any time of the simulation. Wind speed and ice cover are used to determine the gas transfer coefficient at the air-water interface. This coefficient is used to compute the exchange of dissolved oxygen and carbon dioxide with the atmosphere.

#### *3.2.4.a Meteorological Data*

When selecting meteorological stations to support model development, it is ideal to use locations that are as close as possible to the model domain and that have a period of record covering the entire period of simulation. The model domain is nearly 100 river miles in length, so it is useful to utilize data from more than one station to capture local wind patterns and air temperature dynamics. The Minneapolis-St. Paul International Airport (MSP) is located adjacent to the Minnesota River and in close proximity to its confluence with the Mississippi River. The period of record for this station covers the entire simulation period (1985-2006) for wind speed, wind direction, air temperature, relative humidity, and barometric pressure. This station was used for all of the Pool 2 meteorological inputs and for relative humidity and barometric pressure for Pools 3 and 4 for the entire 1985-2006 simulation period. Meteorological stations at Red Wing, MN and Prairie Island, MN provided the air temperature and wind speed inputs for Pools 3 and 4. A summary of the inputs and their original data sources is provided below in Table 3-10. All recent meteorological data (1997-2006) from the MSP and Red Wing stations were obtained through the National Climatic Data Center (NCDC) website (http://www.ncdc.noaa.gov).

**Table 3-10. Meteorological Stations Used to Develop UMR-LP Model Boundary Conditions**

| 1997-2006 | | | |
|---|---|---|---|
| **Parameter** | **Pool 2** | **Pool 3** | **Pool 4** |
| Wind Speed | MSP | Red Wing | Red Wing |
| Wind Direction | MSP | Red Wing | Red Wing |
| Barometric Pressure | MSP | MSP | MSP |
| Relative Humidity | MSP | Red Wing | Red Wing |
| Air Temperature | MSP | Red Wing | Red Wing |
| Solar Radiation | UM-St. Paul | UM-St. Paul | UM-St. Paul |
| Vapor Pressure | MSP | Red Wing | Red Wing |
| **1985-1996** | | | |
| **Parameter** | **Pool 2** | **Pool 3** | **Pool 4** |
| Wind Speed | MSP | Prairie Island | Prairie Island |
| Wind Direction | MSP | Prairie Island | Prairie Island |
| Barometric Pressure | MSP | MSP | MSP |
| Relative Humidity | MSP | MSP | MSP |
| Air Temperature | MSP | Prairie Island | Prairie Island |
| Solar Radiation | UM-St. Paul | UM-St. Paul | UM-St. Paul |
| Vapor Pressure | MSP | Red Wing | Red Wing |

### *3.2.4.b Solar Radiation*

For the 1985-1995 period, HydroQual (2002) states that for ECOMSED it used solar radiation data estimated daily by the Midwest Climate Center based on meteorological data collected at the MSP airport, and in 1996 it used actual measurement data from the USDA-Rosemont. HydroQual also states that they obtained solar radiation data for the 1985-1996 period from the University of Minnesota, St. Paul Campus. For the1997-2006 period, Dave Ruschy at the University of Minnesota-St. Paul provided all solar radiation data to LimnoTech on an hourly basis. These datasets were applied to Pools 2, 3, and 4 (Figure 3-21). The fraction of daylight is used by RCA to determine the amount of time over which the solar radiation (ly/day) is distributed for each day. This information was obtained from the original RCA model inputs (1985-1996) and applied to the entire simulation period (1985-2006).

### *3.2.4.c Ice Cover*

The formation of surface ice during the winter months is represented in the ECOMSED and RCA models. Ice cover prohibits the free exchange of gases between the atmosphere and water, which include the process of reaeration. Ice cover also limits the amount of sunlight that is available to algae for photosynthesis. Within ECOMSED, the presence of ice prohibits wind from affecting surface water currents and thus inhibits sediment resuspension due to wind-wave activity. Very few agencies have monitored ice cover over the past 22 years. Limited measurements are available from the USACE at the lock and dams during normal operations, and the USGS has reported percent ice cover during the collection of water samples as part of the

LTRMP study. The measurements indicate that there is roughly 50% ice cover during December and March, and complete ice cover in January and February. Although annual variations exist in the “ice-in” and “ice-out” dates, a complete and accurate record of ice cover does not exist for the UMR system. Therefore, the percentages described above are specified in ECOMSED and RCA for the December through March winter period.

### 3.2.5 Turbidity

Although turbidity is not directly simulated in the UMR-LP model, it can be derived from relationships with non-volatile suspended solids (NVSS) and volatile suspended solids (VSS), which are simulated or calculated by the UMR-LP model. Within the UMR system, the USACE, MCES, and the USGS (LTRMP) have measured turbidity, total suspended solids, and volatile suspended solids at various locations. The following sections describe analyses of the datasets available from the LTRMP and MCES monitoring programs. As discussed in Chapter 6, these analyses served as the basis for computing turbidity results and metrics based on UMR-LP model calculations of NVSS and VSS.

#### *3.2.5.a Analysis of LTRMP Turbidity Data*

The LTRMP monitoring program collects water quality data, including turbidity, at multiple fixed stations in Lake Pepin and at LD3. In addition, the LTRMP program conducts random sampling throughout Lake Pepin, including monitoring of more than 5,000 unique stations during the past 15 years. A total of 8,388 LTRMP samples collected during 1991-2006 include measurements of turbidity, total suspended solids (TSS), and VSS, and these data serve as the basis for developing predictive relationships for turbidity (Table 3-11). Although NVSS concentrations are not directly measured, NVSS can be estimated simply by subtracting the VSS concentration from the TSS concentration for a given sample.

**Table 3-11. LTRMP Monitoring Summary for UMR-LP Turbidity, TSS, and VSS**

| Location | Fixed Stations | Random Stations | Total Samples |
|---|---:|---:|---:|
| Lock and Dam No. 3 | 400 | 0 | 400 |
| Upper Lake Pepin | 769 | 1,760 | 2,529 |
| Lower Lake Pepin | 1,815 | 3,644 | 5,459 |
| *All Locations* | *2,984* | *5,404* | *8,388* |

Samples taken at LD3 were used exclusively for the regression analysis because these observations are most representative for the reaches that are impaired for turbidity (i.e., Pools 2 and 3) under the current TMDL. Of the 400 paired turbidity-NVSS results available for LD3, five samples were excluded from the analysis because the TSS concentrations exceeded 100 mg/L. (Measured values greater than 100 are associated with dilution of the original sample, and therefore may not be

representative of the turbidity-solids relationships at lower concentrations.) The remaining 395 turbidity-NVSS data pairs were used to develop linear regressions based on 1) TSS as the only independent variable, and 2) VSS and NVSS (i.e., two independent variables). The regression based on TSS is depicted graphically in Figure 3-22.

When a multiple linear regression is performed for LD3 by explicitly representing VSS and NVSS as independent variables, the following regression is obtained:

$$Turb_{LTRMP} = 0.64 * NVSS + 0.90 * VSS \qquad R^2=0.91 \qquad (3\text{-}1)$$

where $Turb_{LTRMP}$ is the estimated LTRMP turbidity (NTU), and *NVSS* and *VSS* are expressed in units of mg/L. This regression is depicted graphically in Figure 3-23.

The turbidity values predicted using Equation 3-1 are compared to observed values in Figure 3-23. Because Equation 3-1 explicitly represents the unique contributions of VSS and NVSS to turbidity, it was adopted for calculating LTRMP turbidity based on UMR-LP model results.

### 3.2.5.b Analysis of MCES Turbidity Data

The MCES monitoring program collects water quality data, including turbidity, at multiple fixed stations in Pools 2, 3, and 4, and in major tributaries. A total of 3,149 MCES samples collected in the UMR system during 1985-2006 included measurements of turbidity, TSS, and VSS. These data serve as the basis for developing predictive relationships for turbidity relative to the MCES meter (Table 3-13). An additional 2,960 samples not included in Table 3-13 are available from monitoring of the tributaries, including the Minnesota, St. Croix, and Cannon Rivers, as well as UMR Pool 1.

**Table 3-12. MCES Monitoring Summary for UMR Turbidity, TSS, and VSS**

| Location | Total Samples |
|---|---:|
| Upper Pool 2 | 1,582 |
| Spring Lake | 32 |
| Lock and Dam No. 2 | 520 |
| Pool 3 | 14 |
| Lock and Dam No. 3 | 534 |
| Upper Pool 4 | 42 |
| Lake Pepin | 425 |
| *All Locations* | *3,149* |

The paired in-system turbidity/TSS/VSS data points available for Pools 2 and 3 were used to develop linear regressions based on 1) TSS as the only independent variable, and 2) VSS and NVSS. The regression based on TSS is depicted graphically in Figure 3-24. Of the total 2,682 paired turbidity-NVSS data, 313 data points were excluded from the analysis for the following reasons:

- 137 data points were excluded because either the TSS concentration exceeded 100 mg/l or the turbidity exceeded 100 NTU. Measured values greater than 100 mg/l or NTU are associated with dilution of the original sample, and therefore may not be representative of the turbidity-solids relationships at lower concentrations.

- 10 samples with associated turbidities greater than 40 NTU were excluded because they appeared to be outliers that were not representative of the turbidity-solids relationship below 40 NTU.

- 166 samples collected on or after March 20, 2006 were excluded because MCES changed its turbidity equipment and method on this date.

A comparison of the TSS-based regressions for the LTRMP (Figure 3-22) and MCES (Figure 3-24) datasets suggests that, for a given TSS concentration, the turbidity measured by the LTRMP meter will be approximately twice the turbidity measured by the MCES meter.

When a multiple linear regression is performed by explicitly representing VSS and NVSS as independent variables, the following regression is obtained:

$$Turb_{MCES} = 0.28 * NVSS + 0.62 * VSS \qquad R^2 = 0.82 \qquad (3\text{-}2)$$

where $Turb_{MCES}$ is the estimated MCES turbidity (NTU), and *NVSS* and *VSS* are expressed in units of mg/L. The turbidity values predicted using Equation 3-2 are compared to observed values in Figure 3-25. Because Equation 3-2 explicitly represents the unique contributions of VSS and NVSS to turbidity, it was adopted for calculating MCES turbidity based on UMR-LP model results.

### 3.2.6 Water Transparency

A subset of MCES water quality samples collected during 1996-2006 included analysis of the key parameters required for developing a predictive multiple linear regression for Secchi depth and subsequently the light extinction coefficient represented in the UMR-LP model. These parameters include:

- Secchi depth;
- Chlorophyll *a*;
- Total suspended solids (TSS);
- Volatile suspended solids (VSS); and
- Dissolved organic carbon (DOC).

As described previously, the difference between observed total suspended solids (TSS) and volatile suspended solids (VSS) can be used to estimate the non-volatile solids (NVSS) concentration. The algal (ALGS) and non-algal (NLOS) components

of VSS can be calculated by converting chlorophyll *a* measurements to an estimate of algal dry weight biomass (mg/L d.w.):

$$ALGS = \frac{Chla * (C : Chla)}{R_{C:DW}} \tag{3-3}$$

where *Chla* is chlorophyll *a* concentration (mg/L), *C:Chla* is the carbon-to-chlorophyll ratio (assumed to be 40 mg-C/mg-Chla), and $R_{C:DW}$ is the ratio of algal carbon to dry weight biomass (assumed to be 0.4). Once an estimate of algal VSS is obtained, the non-algal VSS (*NLOS*) is calculated as the difference between VSS and algal VSS (*ALGS*).

A total of 453 samples collected by MCES during 1996-2006 included measurement of all of the necessary parameters listed above. These included several samples in the Minnesota River (33) and St. Croix River (16), with the remaining samples taken from locations in Pools 2, 3, and 4. These 49 tributary samples were excluded from the regression analysis. A multiple linear regression analysis was conducted by specifying the reciprocal of Secchi depth ($Secchi^{-1}$, 1/meter) as the dependent variable and NVSS, algal VSS (ALGS), non-algal VSS (NLOS), and DOC as the independent variables. An intercept of 0.01 was assumed in the regression to represent the intrinsic light extinction coefficient of water. The following regression was generated based on these specifications:

$$Secchi^{-1} = \begin{Bmatrix} 0.125 * ALGS + 0.106 * NLOS + 0.023 * NVSS \\ + 0.080 * DOC + 0.01 \end{Bmatrix} \tag{3-4}$$

The predictions for $Secchi^{-1}$ based on Equation 3-4 are compared to the individual observations of reciprocal Secchi depth in Figure 3-26. The comparison in Figure 3-26 indicates that the fit to observed data is very good ($R^2$ = 0.63, slope = 0.95). As described in Chapter 2, Equation 3-4 was implemented in the RCA model code for predicting the light extinction coefficient ($K_e$, $m^{-1}$) by multiplying $Secchi^{-1}$ by a factor of 1.5.

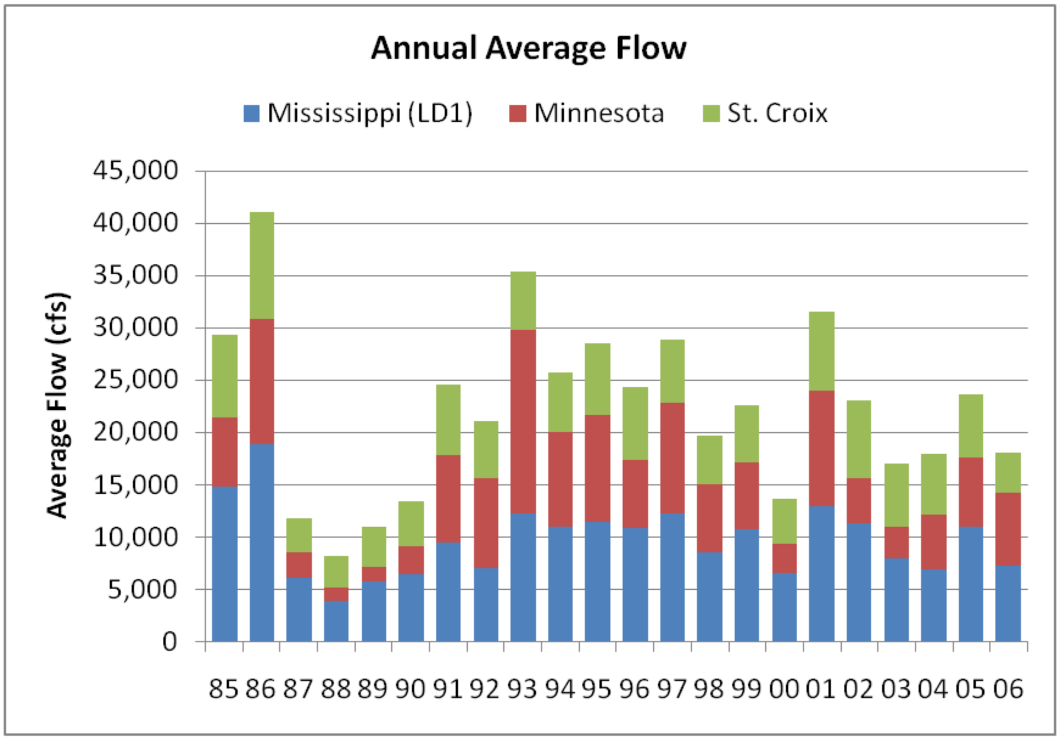


**Figure 3-1. Average Annual Daily Discharge for Major UMR Tributaries**

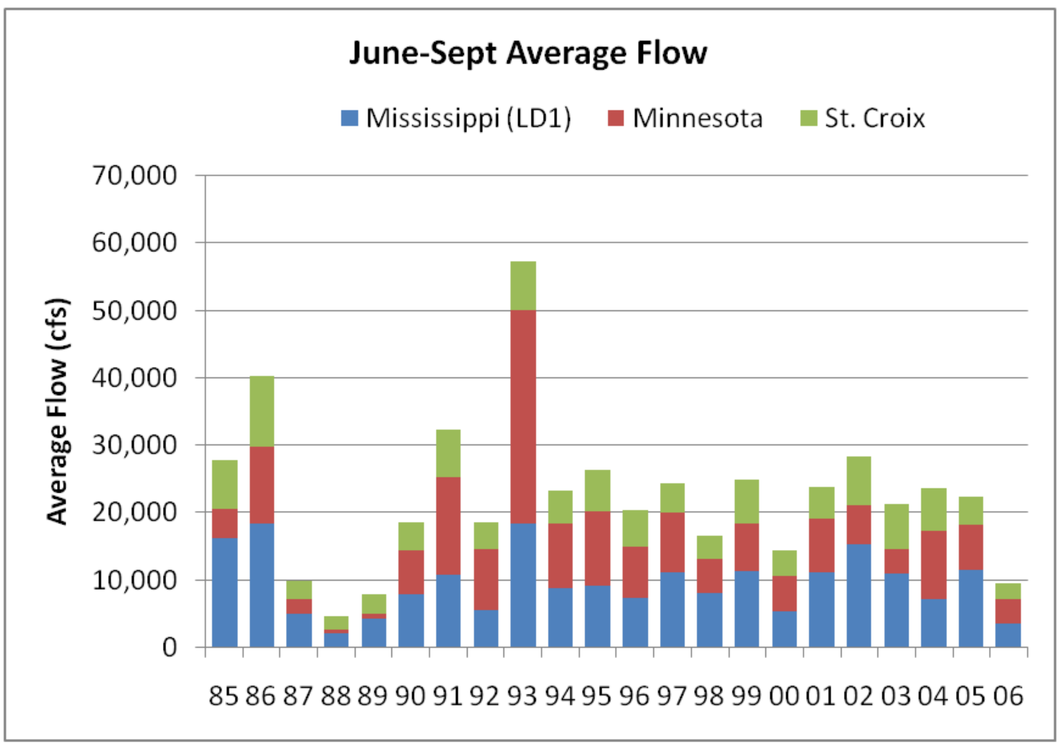


**Figure 3-2. Average Summer (June-September) Daily Discharge for Major UMR Tributaries**

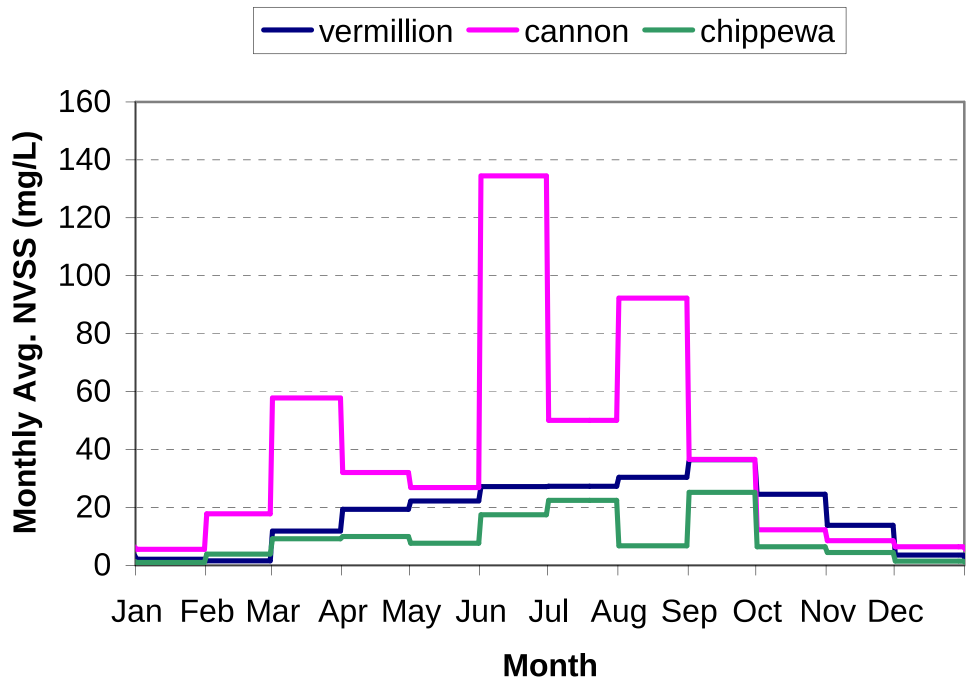


**Figure 3-3. Monthly Average NVSS Concentrations for the Cannon, Chippewa and Vermillion Rivers**

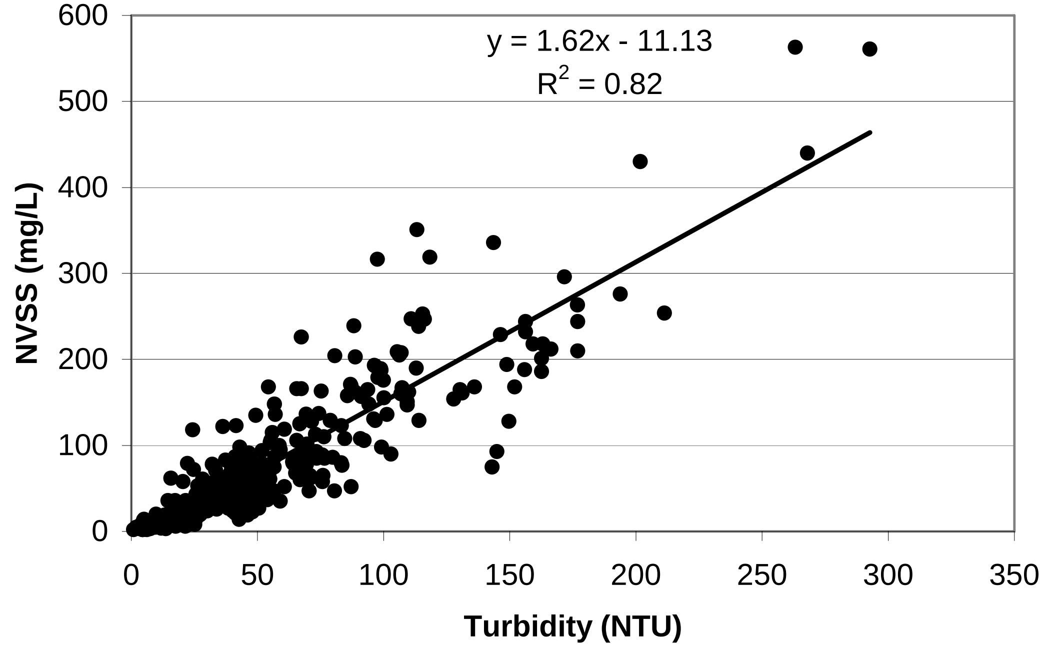


**Figure 3-4. Paired Daily Average Turbidity and NVSS Observations for the Minnesota River at River Mile 3.5**

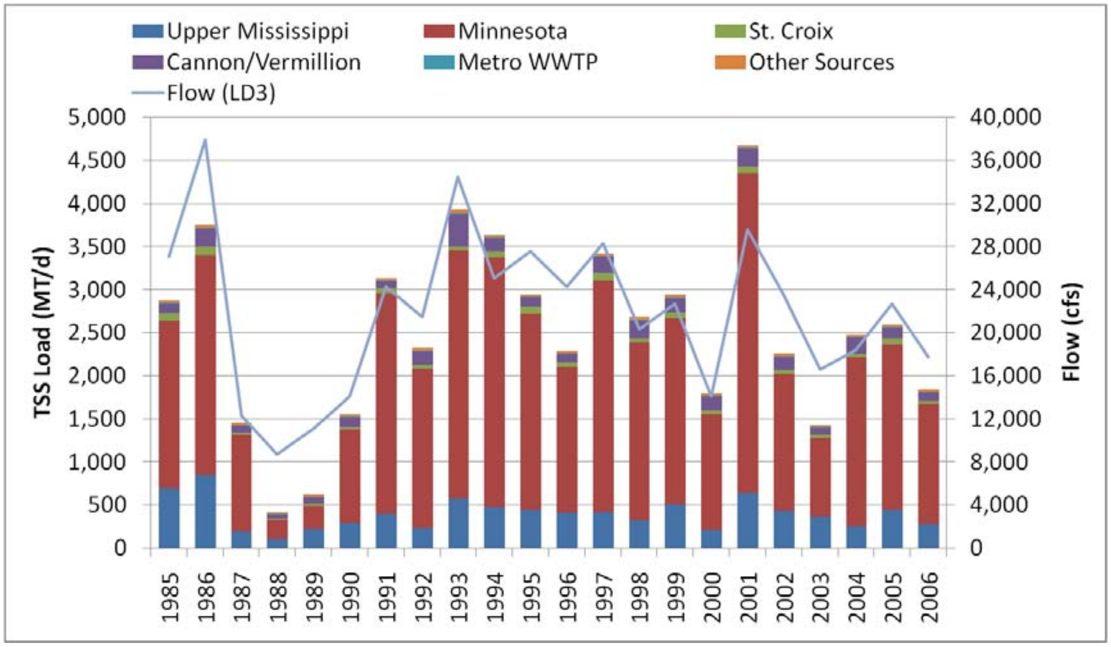


**Figure 3-5. Average Daily Loading of NVSS to the UMR System from Major Tributaries**

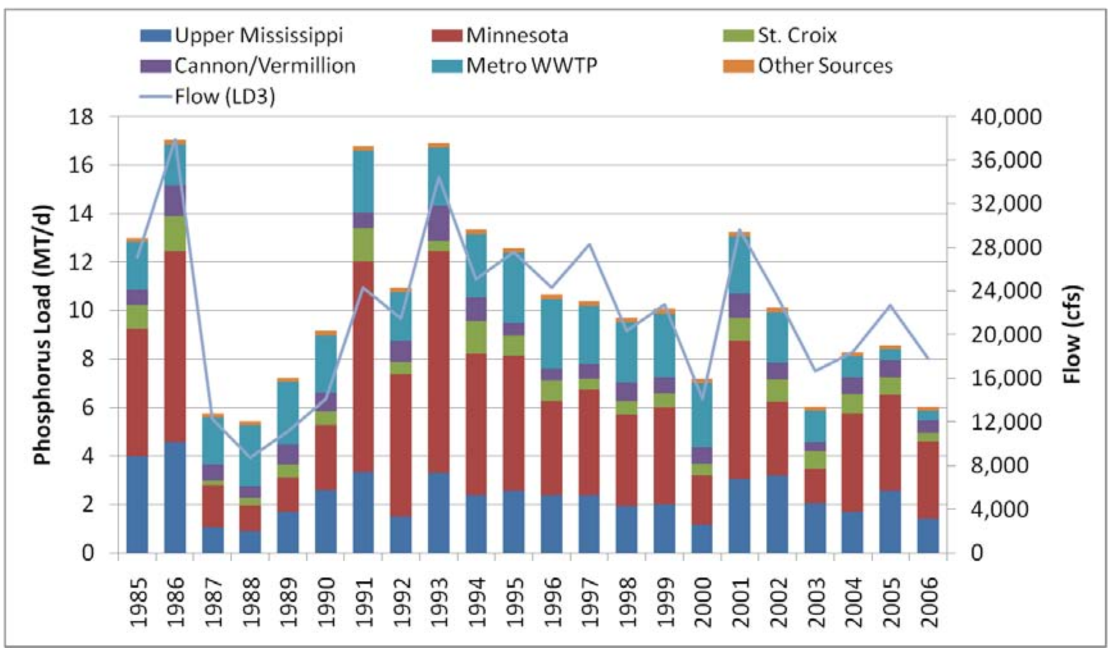


**Figure 3-6. Annual Total Phosphorus Load to the UMR from Major Tributaries and the Metro WWTP**

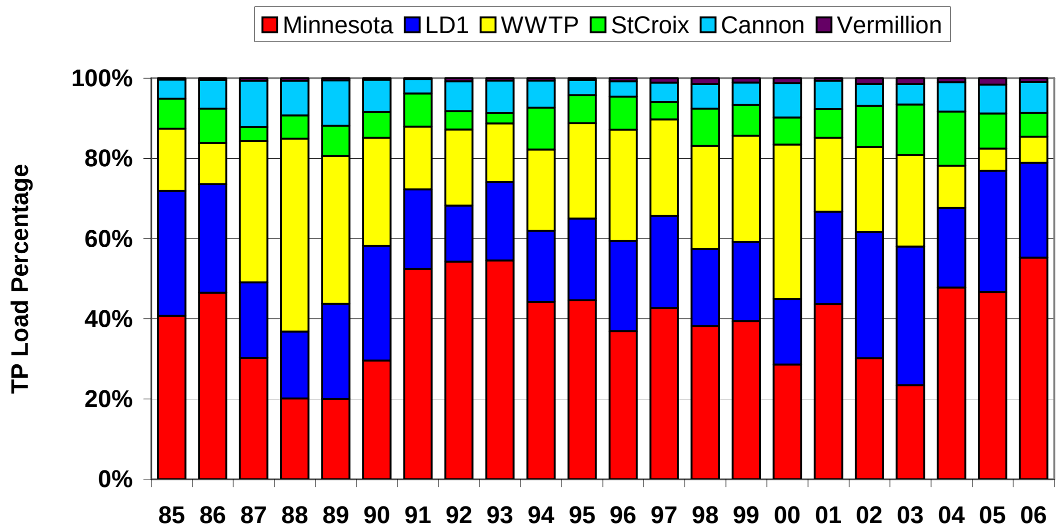


**Figure 3-7. Annual total phosphorus load contribution from the major tributaries and the Metro WWTP.**

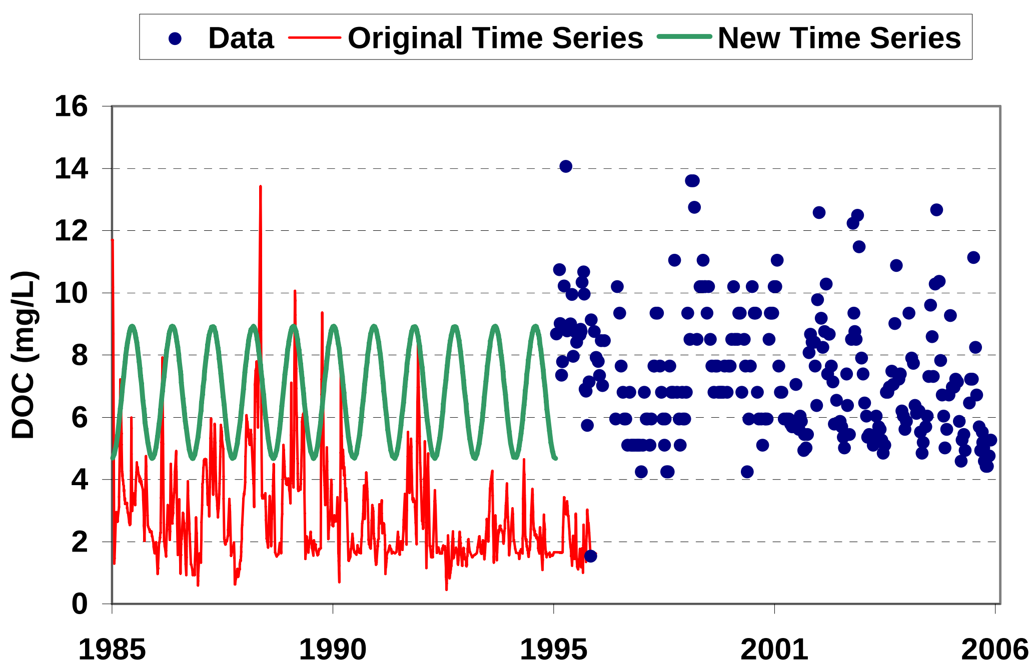


**Figure 3-8. Comparison of DOC Data and the Sinusoidal Function Developed for the 1985-1995 Simulation Period**

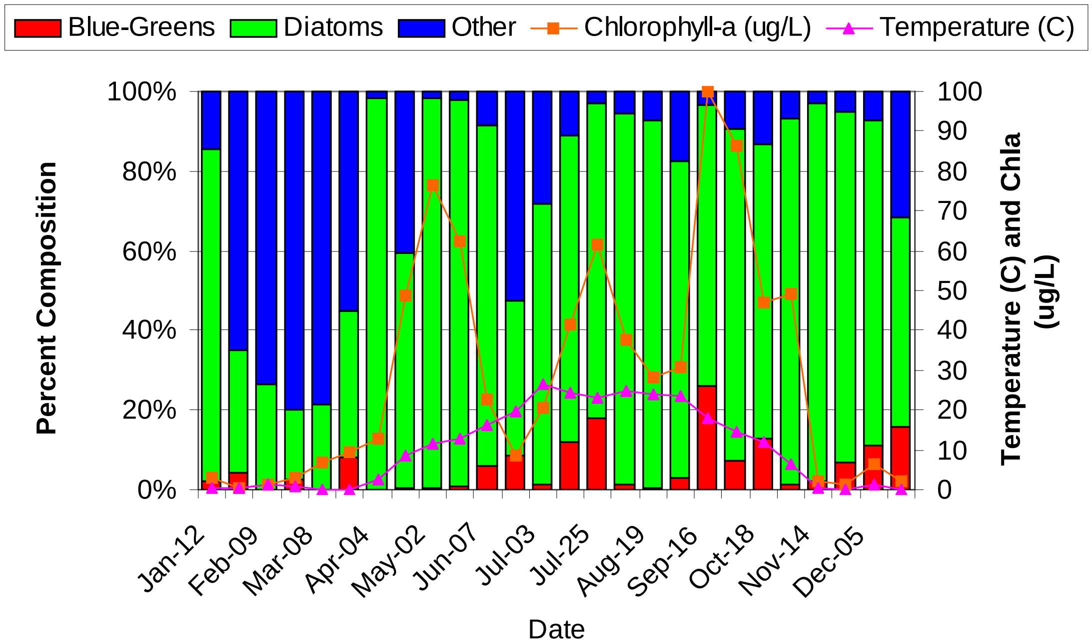


**Figure 3-9. Composition of the Major Algal Groups During 1996 for the Minnesota River (RM 3.5)**

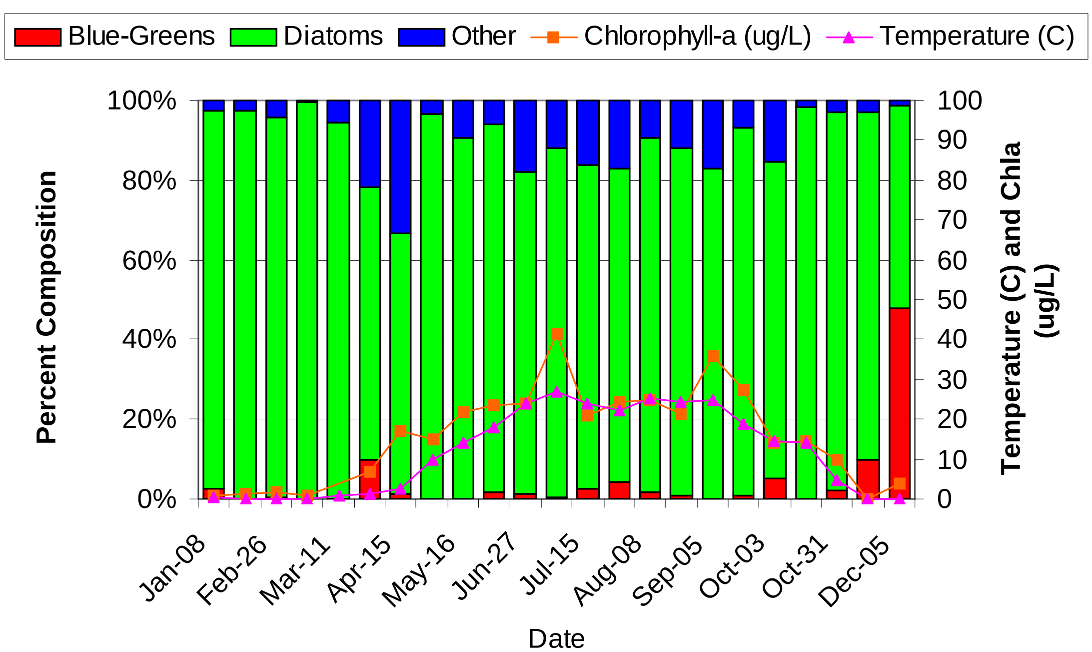


**Figure 3-10. Composition of the Major Algal Groups During 1996 for the Upper Mississippi River (RM 847.7)**

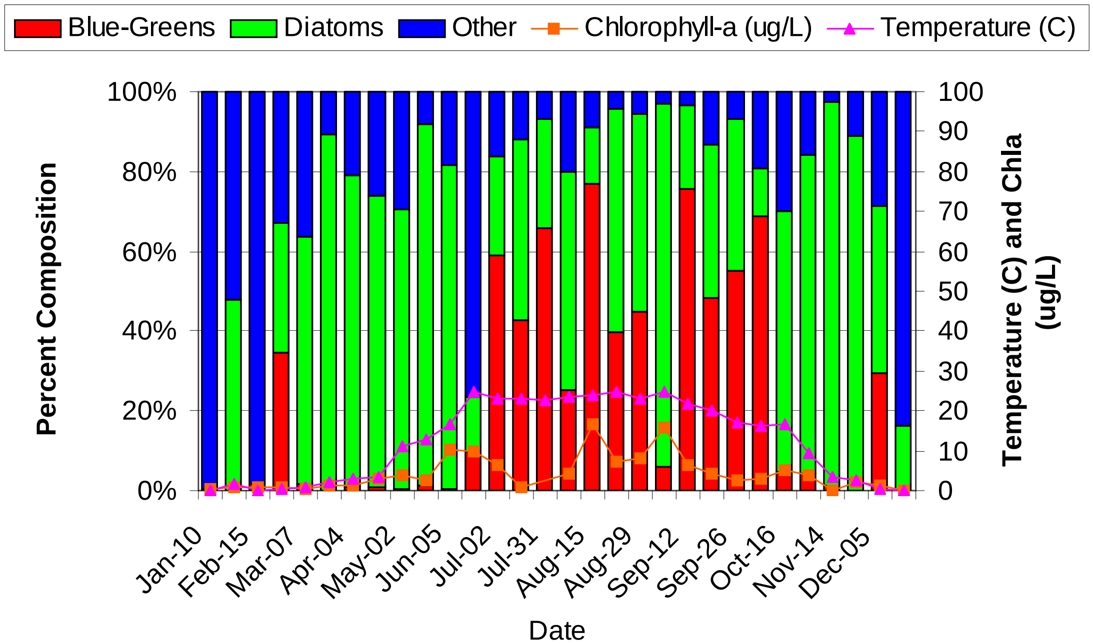


**Figure 3-11. Composition of the Major Algal Groups During 1996 for the St. Croix River (RM 0.3).**

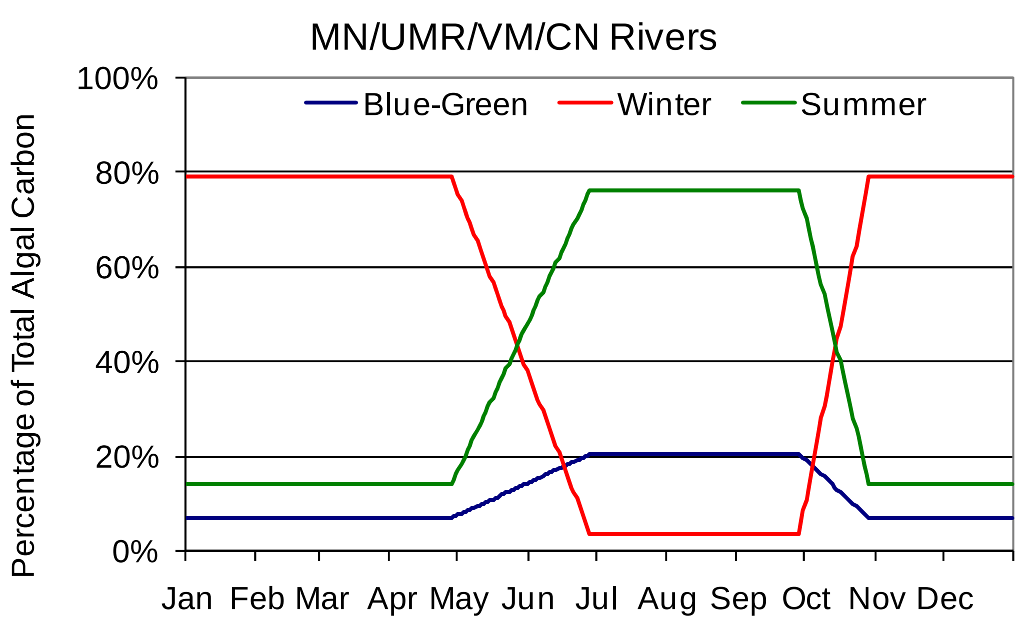


**Figure 3-12. Seasonal Distribution of Algal Biomass for Tributary Boundary Conditions (excluding St. Croix River)**

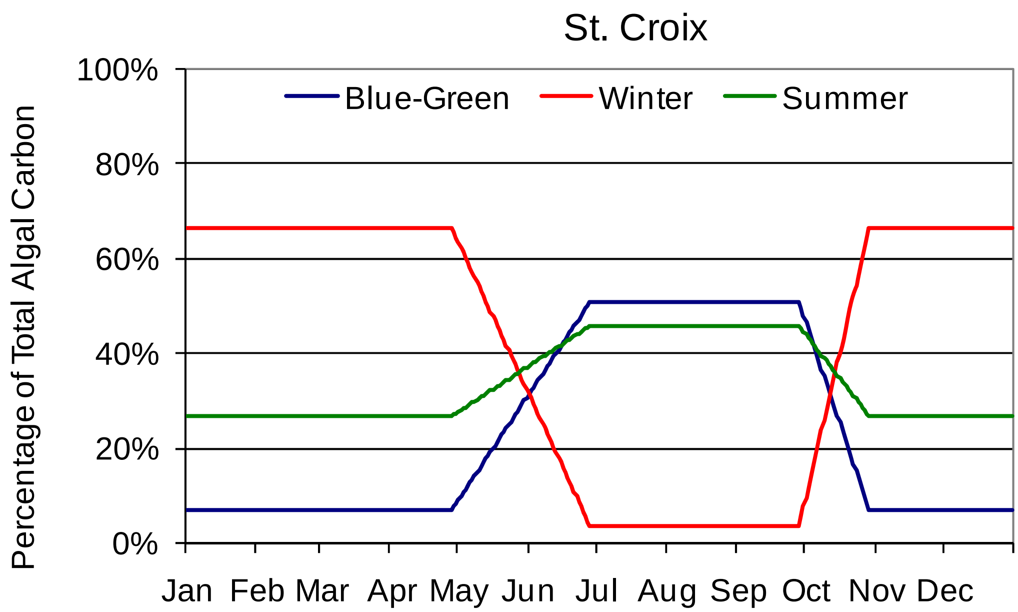


**Figure 3-13. Seasonal Distribution of Algal Biomass for St. Croix River Boundary Conditions**

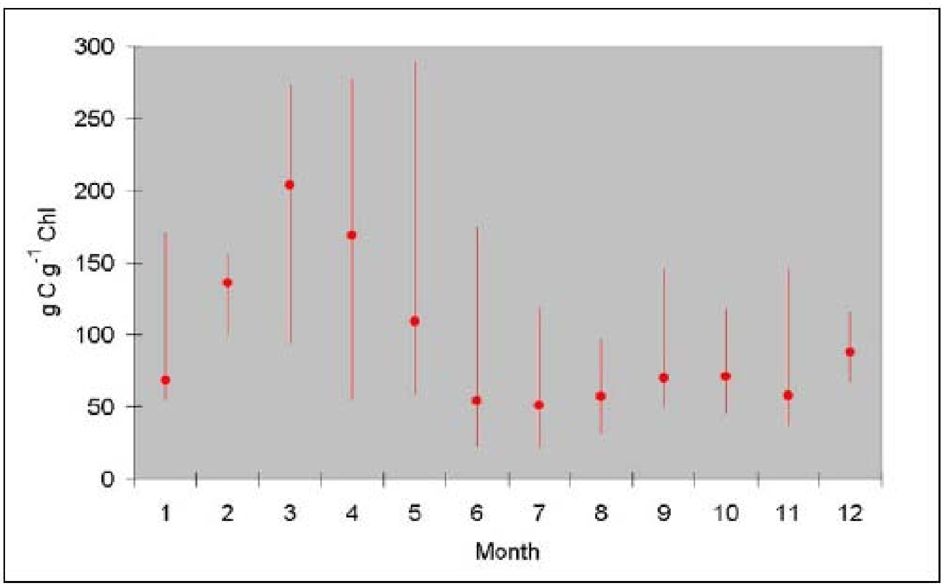


**Figure 3-14. Monthly Average Carbon-to-Chlorophyll Ratios from the Chesapeake Bay Model**

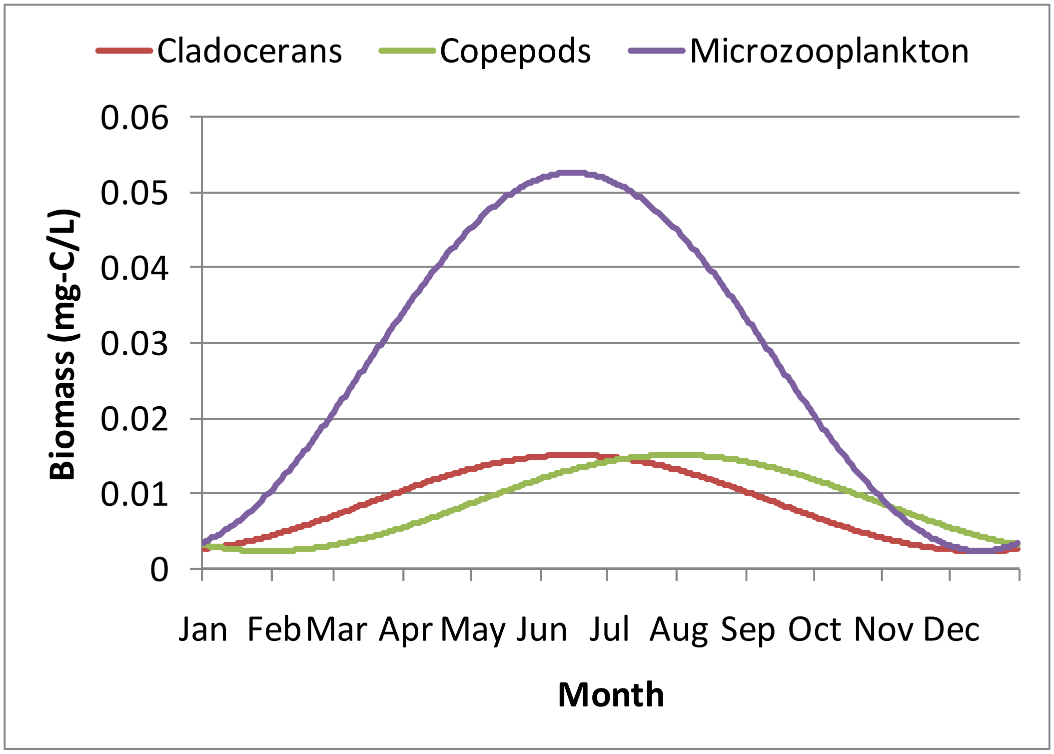


**Figure 3-15. Zooplankton Biomass Time Series Used for Tributary Boundary Conditions**

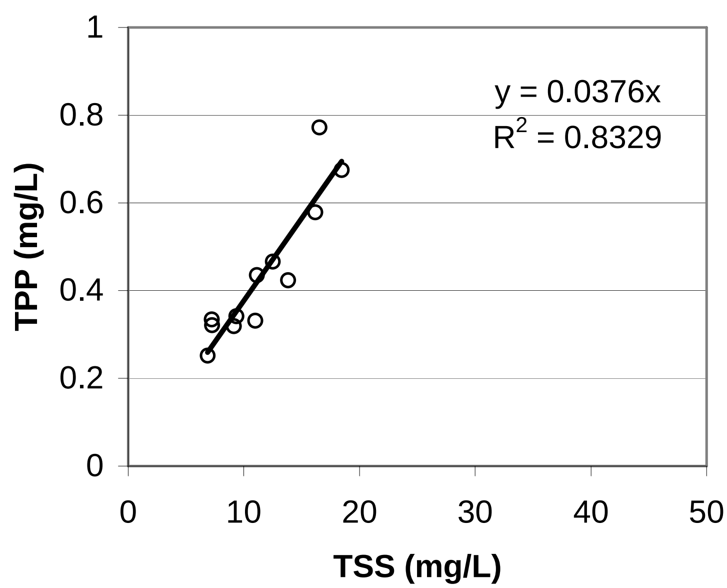


**Figure 3-16. Relationship between Monthly-Averaged Total Particulate Phosphorus and Total Suspended Solids for the Metro Plant (1999-2002)**

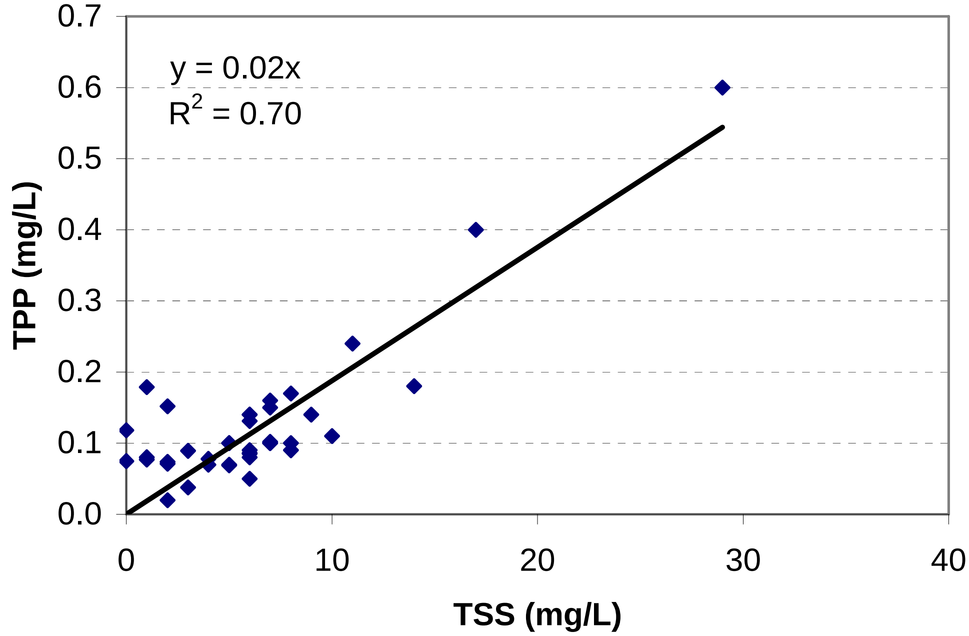


**Figure 3-17. Relationship between Total Particulate Phosphorus and Total Suspended Solids at Non-Metro WWTPs**

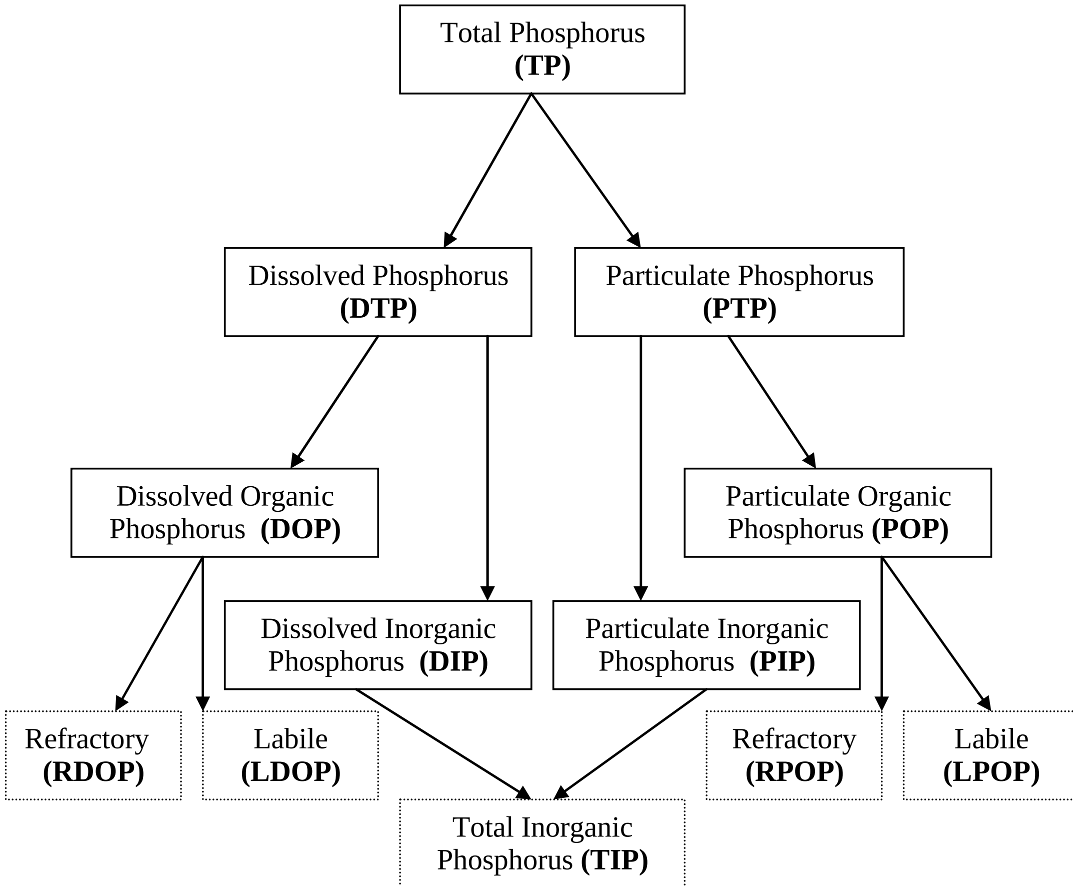


**Figure 3-18. Description of Phosphorus Fractions for WWTPs**

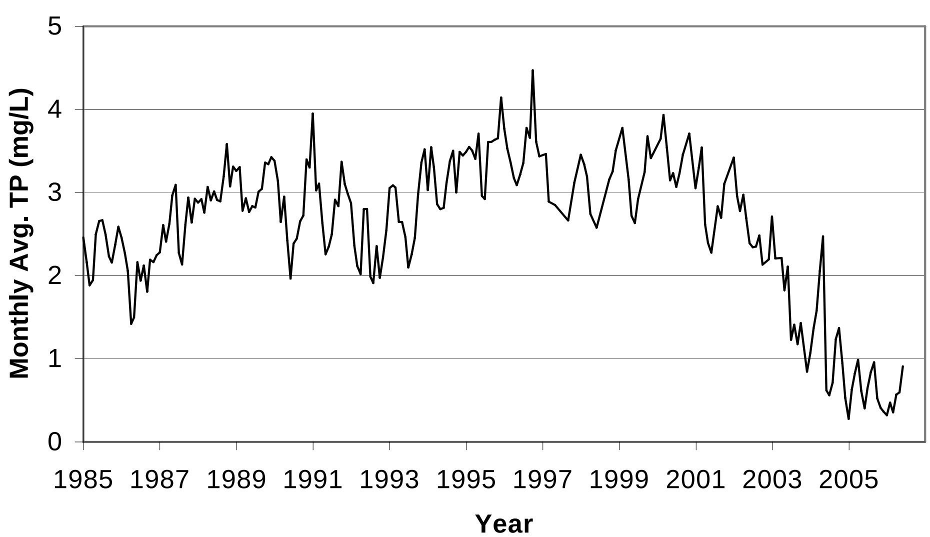


**Figure 3-19. Monthly Average Time Series of Total Phosphorus Concentration at the Metro WWTP**

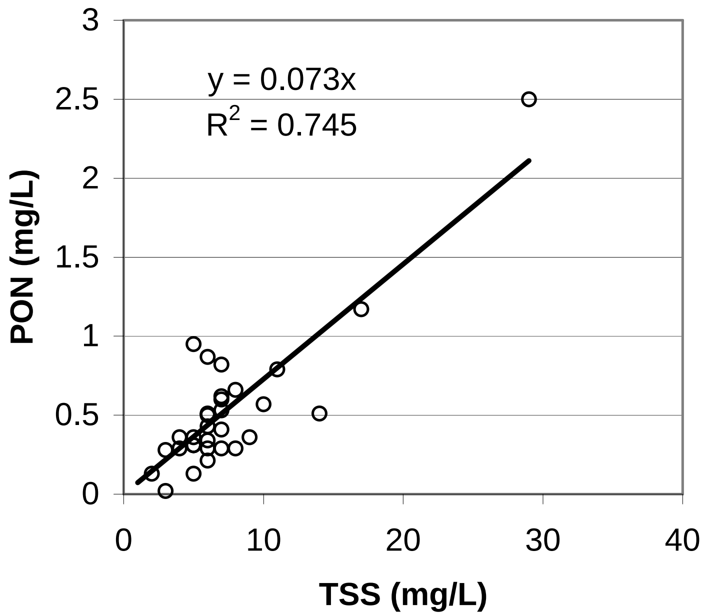


**Figure 3-20. Relationship between Particulate Organic Nitrogen and Total Suspended Solids for the Metro Plant.**

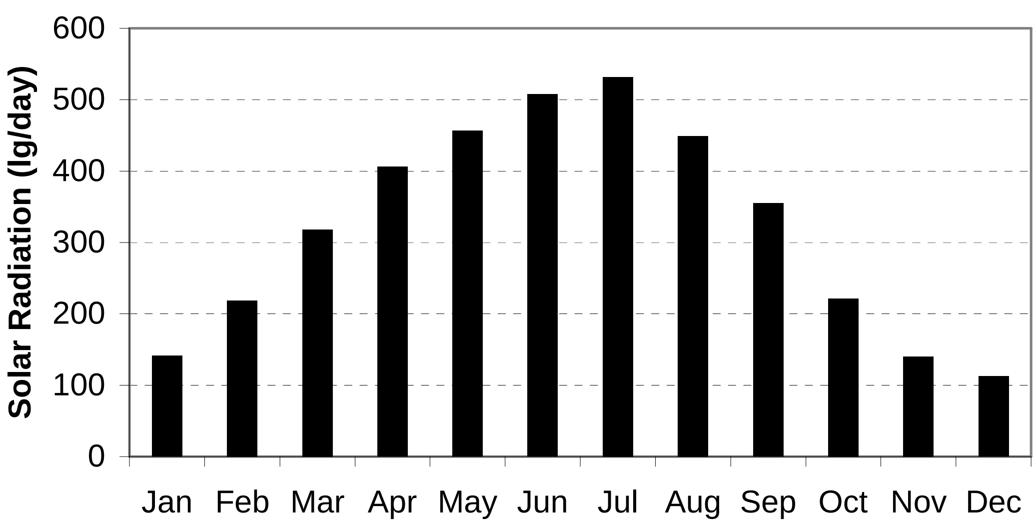


**Figure 3-21. Average Monthly Solar Radiation Based on University of Minnesota Data for 1997-2006**

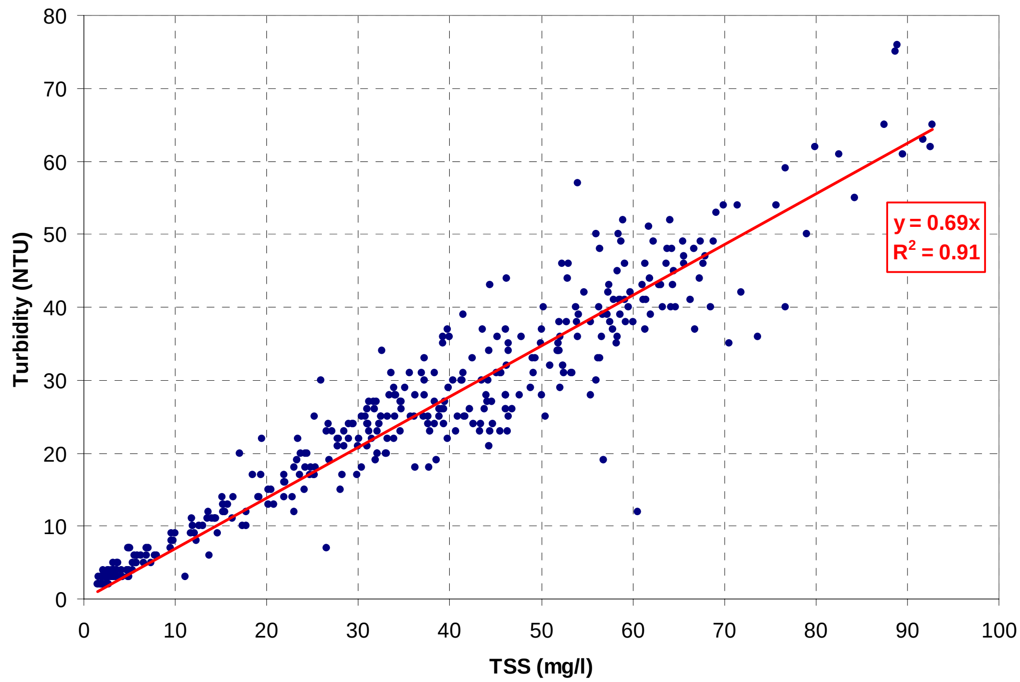


**Figure 3-22. LTRMP Turbidity Regression for Lock and Dam No. 3 (based on TSS only)**

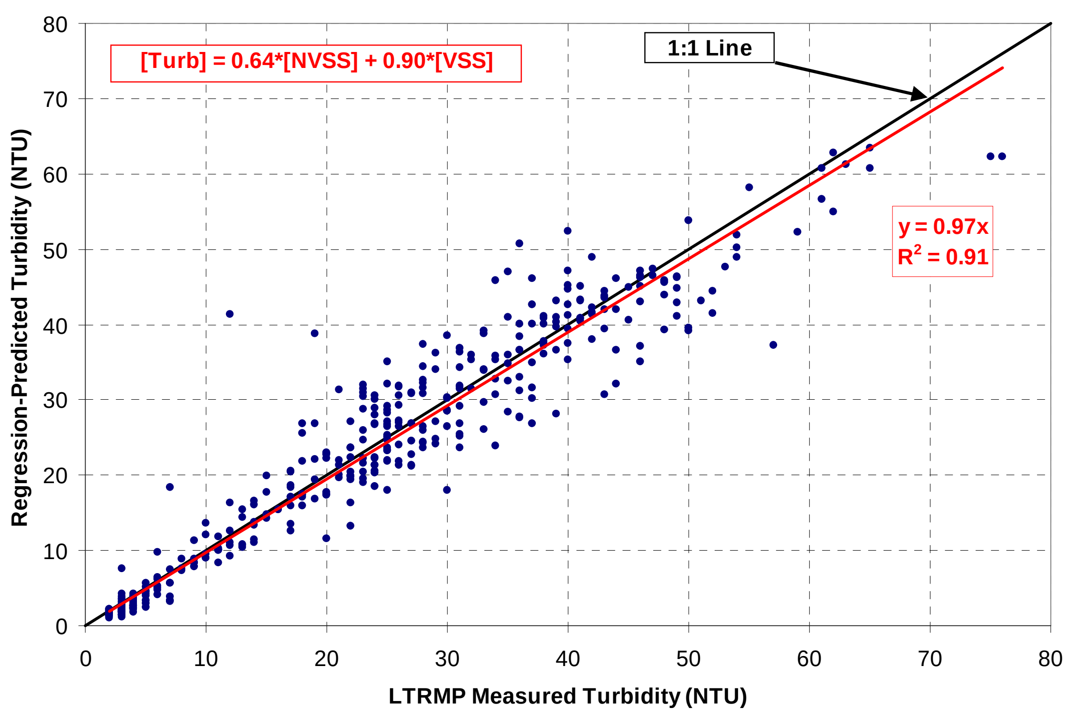


**Figure 3-23. LTRMP Turbidity Regression Based on VSS/NVSS**

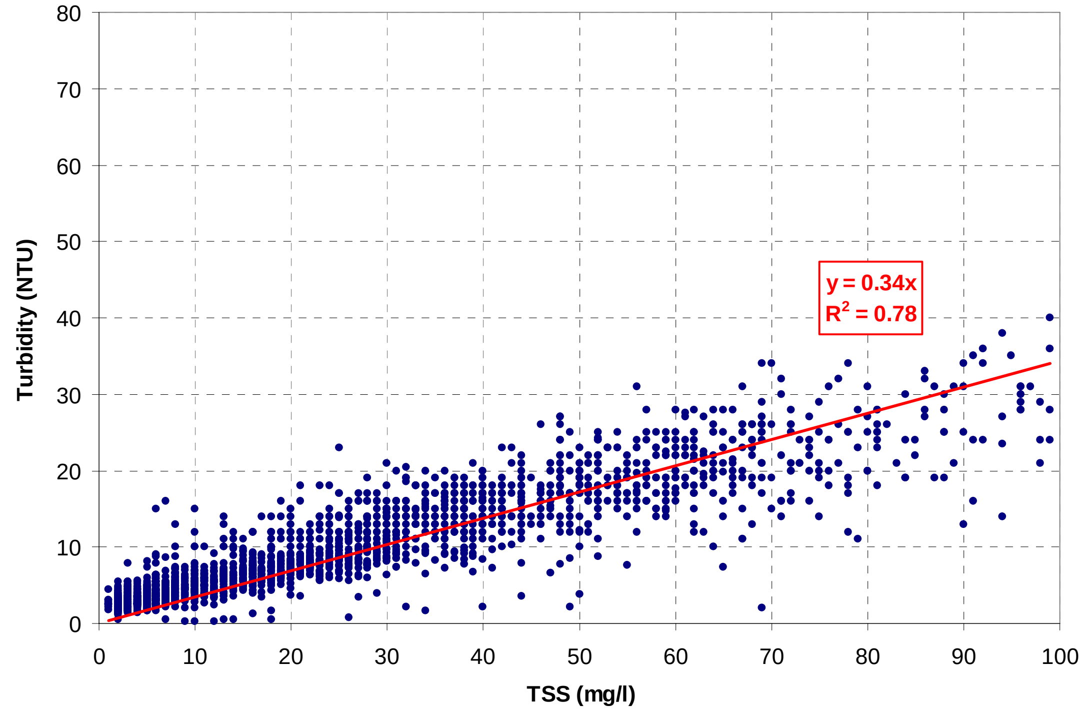


**Figure 3-24. MCES Turbidity Regression for Pools 2-3 (based on TSS only)**

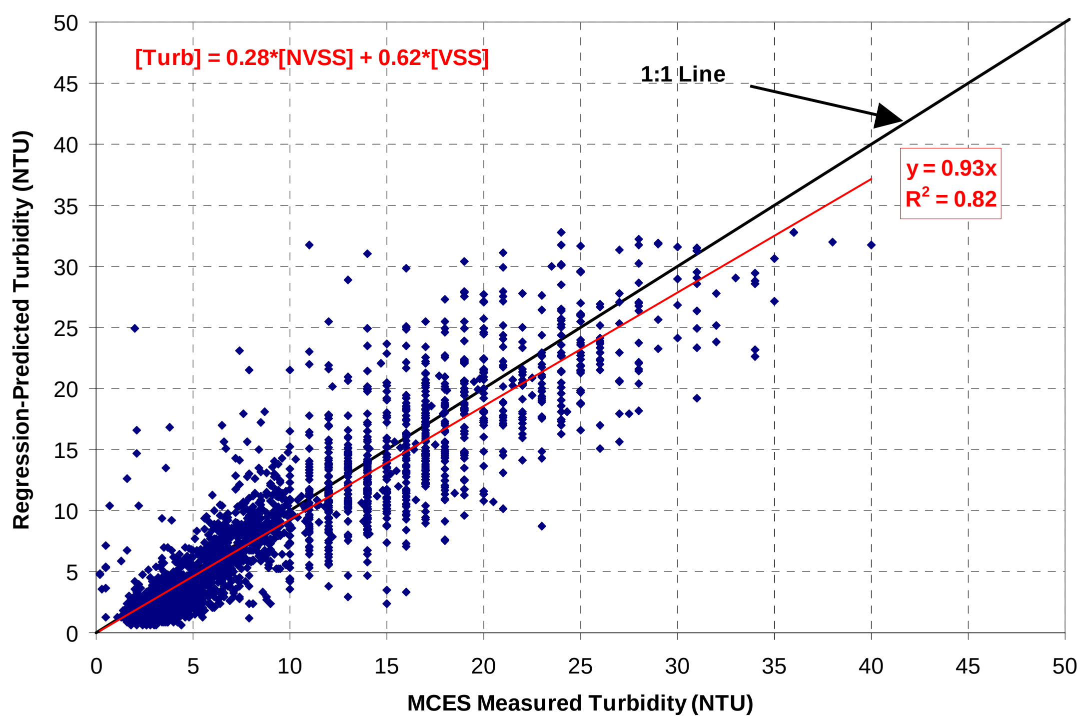


**Figure 3-25. MCES Turbidity Regression Based on VSS/NVSS**

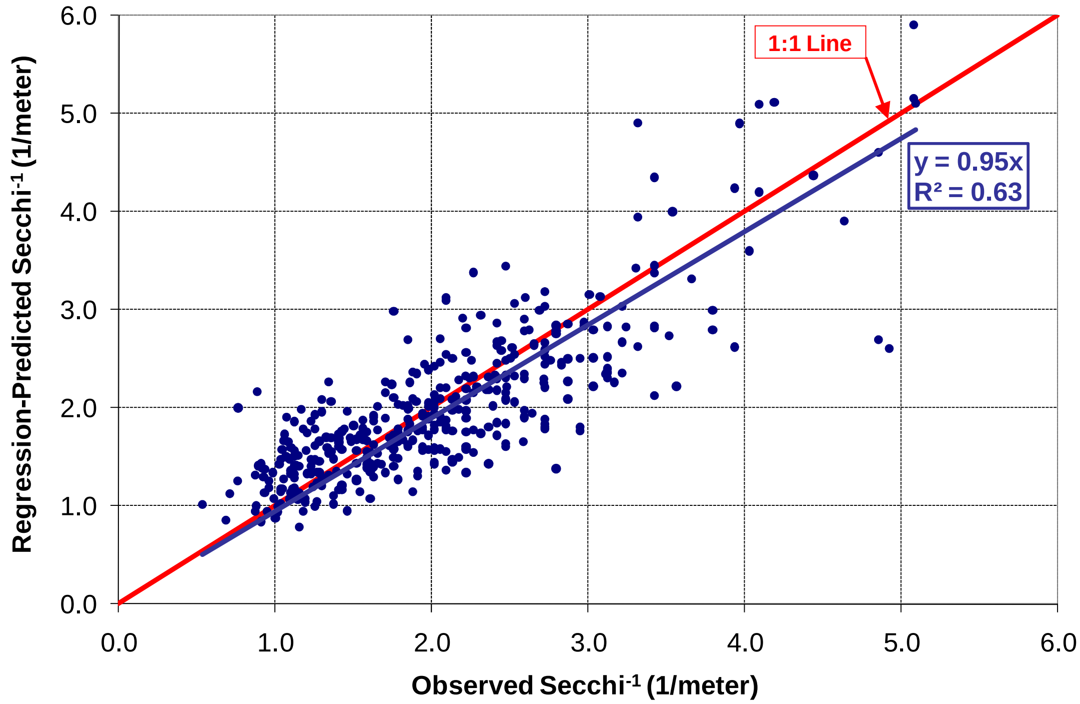


**Figure 3-26. MCES Regression Fit for Secchi Depth Reciprocal**

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