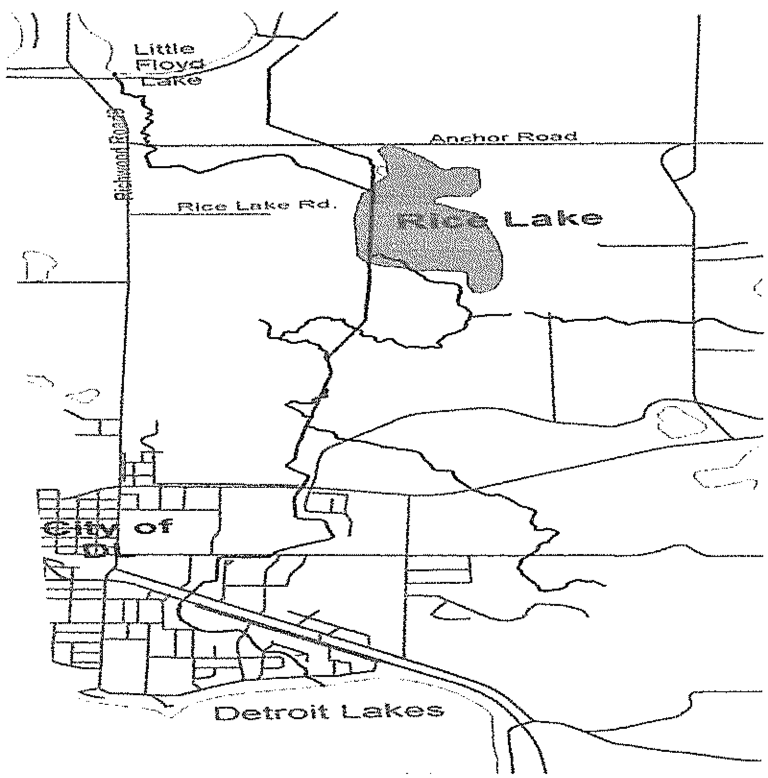
# Water Quality Assessment of the Upper Pelican River Watershed

## (North Floyd, Floyd, Little Floyd, Rice Wetland, Detroit Lake, Little Detroit Lake)

**Becker County, Minnesota**

**CLEAN WATER PARTNERSHIP PROGRAM**
**WORKING PAPER, 2002**

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# Executive Summary

The Upper Pelican River Watershed (drainage basin through Detroit Lakes' outlet) has been monitored over the past five years at six stream and five lake locations by the Pelican River Watershed District (PRWD), in conjunction with several partners including the Minnesota Pollution Control Agency (MPCA). The purpose of these diagnostic efforts has been to establish short and long-term water quality management goals and objectives.

Using the PRWD's database, stream and lake water quality was summarized using standard limnological assessments. This assessment is to aid future efforts to refine stream and lake management efforts of the Pelican River Watershed District.

In many respects, the water quality of the Upper Pelican River watershed is more similar to lakes and streams of the Northern Lakes and Forests (NLF) ecoregion than the North Central Hardwood Forests (NCHF) ecoregion. This is likely due of the number and placement of upland lakes and wetlands which function to trap nutrients and sediments along the flowage. There are, however, key stream locations exhibiting elevated average total phosphorus concentrations (a key plant nutrient that largely determines water quality), including: (1) the inlet to North Floyd Lake - Campbell Creek (CC1), with an average of 89 ppb total phosphorus; and (2) the outlet of Rice Lake Wetland, Pelican River 3 (PR3), with an average value of 95 ppb total phosphorus. Total phosphorus loading to North Floyd Lake from Campbell Creek, in turn, causes increased lake phosphorus and algal concentrations and reduced water clarity. The same is true for the Pelican River system draining via PR2 and PR3, which cause elevated total phosphorus loading to Big and Little Detroit Lakes. Recent (2002) additional stream monitoring of the inflow streams to the Rice Lake Wetland have shown extremely elevated nutrient and sediment concentrations. Target stream phosphorus concentrations, necessary to improve North Floyd and maintain Detroit Lakes are likely more on the order of 40 – 50 ppb total phosphorus. Over the 1998-2000 time period, which has annual precipitation exceeding average conditions, there is a general increase of about 2,000 kg P per year (or about 4,400 pounds) of loading coming through the Rice Lake Wetland. Hence, the Rice Lake Wetland should receive priority attention to better understand nutrient sources and processing occurring within the wetland and for priority rehabilitation management actions.

Accordingly, is recommended that a 50 percent reduction in total phosphorus and sediment loadings, relative to 1998-2000 conditions, be accomplished for Campbell Creek (CC1), and Pelican River outlet of Rice Lake Wetland (PR3). Otherwise, water quality for North Floyd Lake will continue to be impaired and the Rice Wetland outlet may threaten the quality of the Detroit Lakes over time due to cumulative impacts. Big Detroit and Little Detroit have exhibited better water quality than generally defined by lake simulation models using the measured stream values. It should be noted that internal P loading appears to be minimal in the Detroit Lakes in contrast to the continuing high internal loading that continues to be observed in Lake Sallie 15 + years after extensive changes in P loading to that lake realized by wastewater facility upgrades. It is recommended that additional watershed rehabilitation efforts are needed to minimize internal loading within the Detroit Lakes basins – both of which have optimal depths (e.g. shelf areas between 10 and 35 feet) for developing internal P loading. Hence, minimizing cumulative P loading impacts from watershed sources to these important lakes - will be an important management strategy.

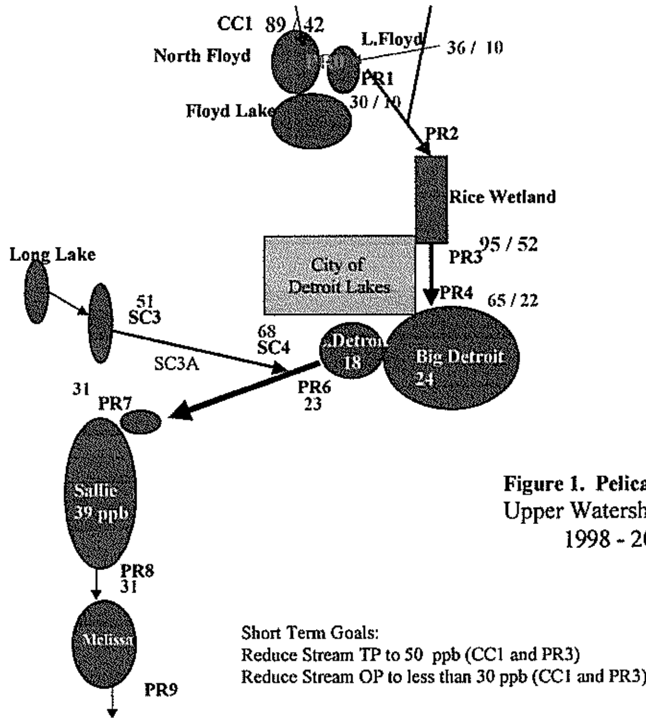
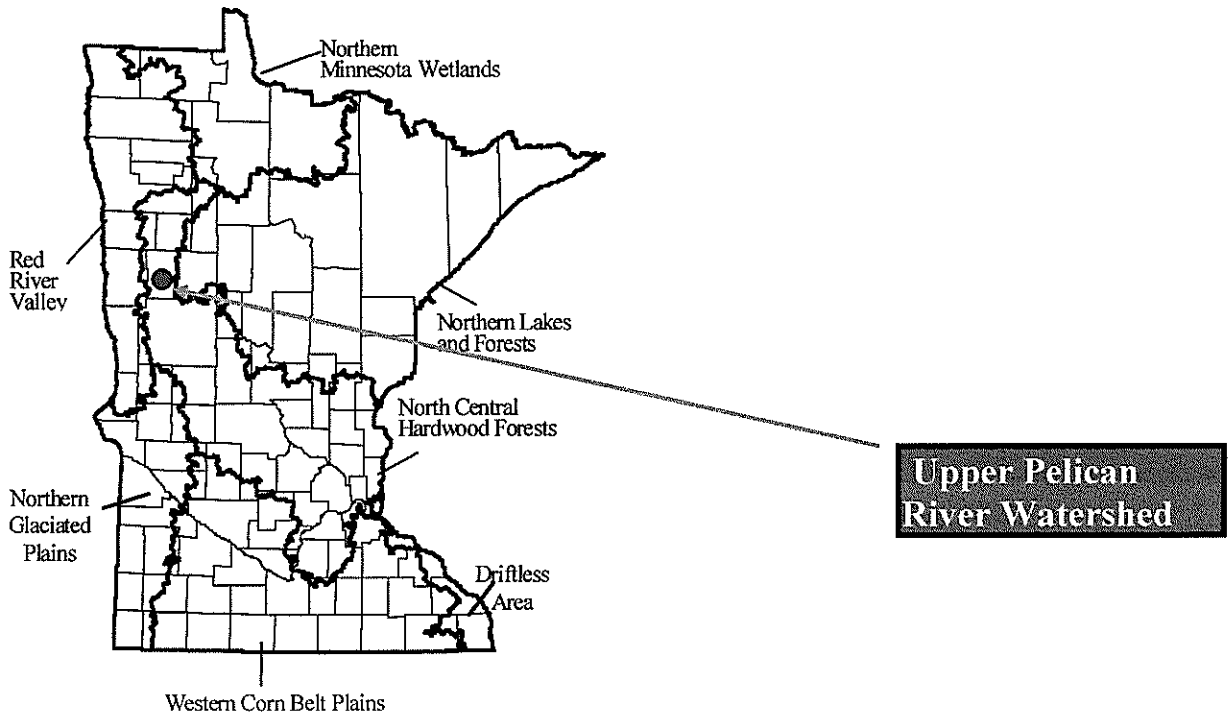



**Figure 1. Pelican River Watershed Distri**
Upper Watershed Monitoring Network
1998 - 2000 Averages

The lakes of the study area could exhibit declines in transparency and increases in the amount of algae with increases in in-lake total phosphorus. The Floyd Lake System and Detroit Lakes will be sensitive to changes (increases or decreases) in nutrient loading from watershed or in-lake sources. Increases of in-lake phosphorus will lead to increased degradation of the lake. It is essential, therefore, that all local government focus upon lake protection via land use/zoning authorities (e.g. Becker County, City of Detroit Lakes and the Pelican River Watershed District). Extra efforts to manage storm water quality from the urban and agricultural areas will have economic benefits.

It is hoped that this working paper will help refine future management actions for these important water resources.

**Figure 2. Upper Pelican River Watershed and Ecoregions Map**




## Introduction

This assessment of the Upper Pelican River watershed (Floyd Lake – Rice Lake – Detroit Lakes) Becker County, was conducted at the request of the PRWD. The PRWD has monitored stream and lake water quality though out the Floyd Lake- Detroit Lake – Sallie/Melissa Lake watershed from 1995 through 2000 for diagnostic and management purposes. This present evaluation of the Upper Pelican River watershed is intended to summarize this data and to establish short and long term stream and lake water quality management goals and objectives.

Richard Heckok and Tera Guetter of the PRWD, supervised watershed district technicians performing fieldwork for this assessment. Mark Evenson, North Central Regional MPCA office, assisted in the installation and operation of the stream flow-monitoring network. Tim James, Detroit Lakes Regional MPCA office, helped facilitate this effort up through 2000 with the PRWD. Bruce Wilson, Policy and Planning Division, MPCA, St. Paul conducted this data assessment and report.

### Diagnostic Effort

This report summarizes the results of an intensive watershed data gathering effort undertaken by the PRWD, the Minnesota Department of Natural Resources, the Minnesota Pollution Control Agency in cooperation with the Natural Resources Conservation Service (NRCS); through the Clean Water Partnership Program (CWP). Specific objectives of the monitoring program include:

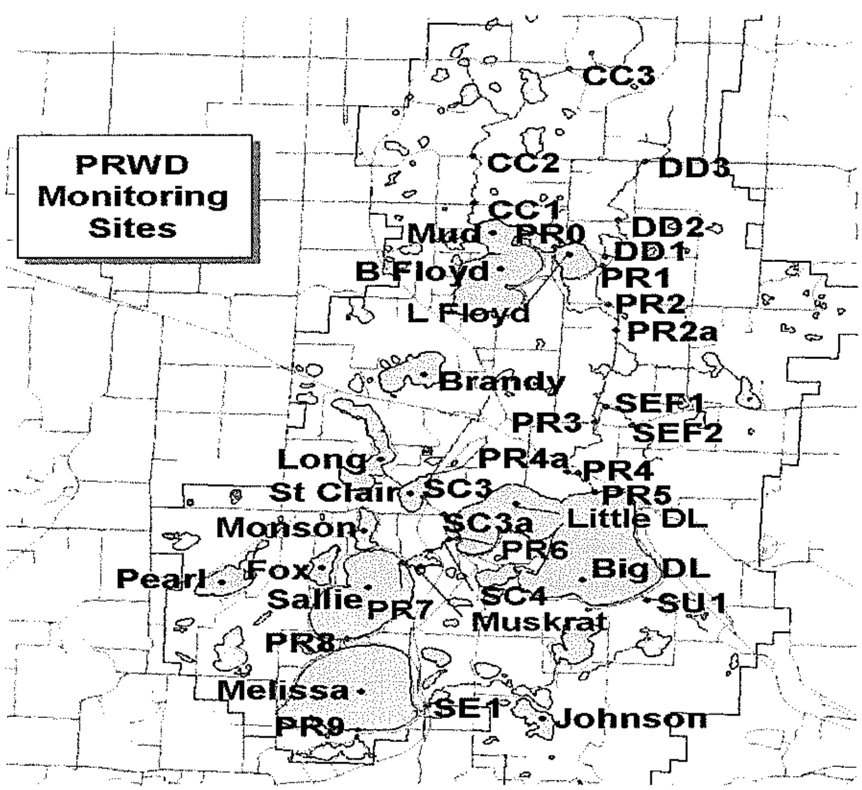
- To quantify runoff, nutrient and sediment loadings from the major tributaries and along main stem river sites.
- To assess watershed characteristics by river subdrainage basin;
- To define short and long-term stream and lake management goals; and
- To accomplish this task a network of stream and river monitoring stations were established beginning in 1995, which were expanded upon and operated through the summer of 2002.

**Sampling Design**

Six stream sampling stations (Sites CC!, PRO, PR1, PR3, PR4 and PR6 - Figure 1) were located throughout the river and tributaries representing discharges along the Upper Pelican River system. Two of the stations were automated by the use of Campbell Scientific CR10 data loggers to obtain continuous flows. The remaining two stations were secondary sites equipped with staff gauges or bridge down measures of water elevation, and stage-discharge relationships, and are operated manually by the PRWD – labeled as Periodic Flows in Table 1.

Lake monitoring stations were established for two sites on North Floyd (e.g. west and east basins), and one station each for Floyd, Little Floyd, Big and Little Detroit Lakes as depicted in Figure 3.

**Figure 3. PRWD Monitoring Sites**



Stream grab samples were collected at mid-depth and mid-stream at the monitoring sites on each date by the PRWD following Clean Water Partnership Program sampling protocols and procedures. Two sampling sites were sampled on North Floyd Lake and one site on Floyd, Little Floyd, Big Detroit and Little Detroit Lakes. [Map from PRWD needed here showing lake site locations and depths.] No automated flow pacing of stream sampling was conducted because the loading estimates generally had good statistical coverage as determined by usage of the software FLUX (e.g. CV of means less than 0.2).

Lake samples were collected once per month from May through September. Lake surface samples were collected with an integrated sampler, which is a PVC tube 6.6 feet in length with an inside diameter of 1.24 inches.

Laboratory analyses were performed by the laboratory of the City of Detroit Lakes using U.S. Environmental Protection Agency (EPA) approved methods. Lake samples were analyzed for total phosphorus and chlorophyll-a. Temperature and dissolved oxygen profiles and Secchi transparency measurements were also taken.

Stream flows were gauged by the PRWD on multiple occasions and regressed against staff gauge readings. Equations obtained were used to define flows over the range of seasons and years. (Attach regressions in the Appendix). Streams were sampled approximately 25 to 40 times each year during the non-ice time period according to the summary table for each site included in the Appendix.

**Table 1. Upper Pelican River Watershed Database Summary**

| Station | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 |
|---|---|---|---|---|---|---|---|
| CC1 | | *S CF* | *S CF* | *S CF* | *S CF* | *S CF* | *S CF* |
| PR0 | | | | *S PF* | *S PF* | *S PF* | *S PF* |
| PR1 | *S* | *S PF* | *S PF* | *S PF* | *S PF* | *S PF* | *S PF* |
| PR2 | *S* | | | | | | |
| PR3 | | *S PF* | *S F* | *S PF* | *S PF* | *S PF* | *S PF* |
| PR4 | | *S* | *S CF* | *S CF* | *S CF* | *S CF* | *S CF* |
| PR6 | *S PF* | *S PF* | *S PF* | *S PF* | *S PF* | *S PF* | *S PF* |

**S = Stream sampling**
**CF = Continuous stream flows**
**PF = Periodic stream flows**

**Loading and Modeling Software**

The data reduction techniques presented include estimates of 1) subwatershed mass loadings using FLUX software (Walker, 1986); 2) hydrologic and phosphorus routing through the main stem and tributary sites; 3) main stem and tributary water and mass balances; and 4) estimated total phosphorus loadings along the river system. Lake simulations were accomplished using BATHTUB software (Walker, 1986), employing natural lake phosphorus, chlorophyll-a and Secchi transparency models.

The master files used for FLUX have been labeled PRMSTR_Q.wk1 (flows) and FLUX_s.wk1 (sampling data). The master files used for BATHTUB analyses were labeled DETROIT0.bin and FLOYD00.bin.

**Results and Discussion**

The Upper Pelican River watershed lies in the North Central Hardwoods Forest ecoregion in west central Minnesota and flows generally south and west into the Red River Valley. Rivers in the NCHF ecoregion have an typical range of average annual total phosphorus concentrations of 50 – 90 ug P/L while just to the east in the Northern Lakes and Forests ecoregion is more typified by a total phosphorus range of 10 – 40 ug P.

**Land use**

Since land use affects water quality, it has proven helpful to divide the state into regions where land use and water resources are similar. Minnesota is divided into seven regions, referred to as ecoregions, as defined by soils, land surface form, natural vegetation and current land use. Data gathered from representative, minimally impacted (reference) lakes within each ecoregion serve as a basis for comparing the water quality and characteristics of other lakes. The Upper Pelican River Watershed is located in the North Central Hardwood Forests ecoregion (Figure 1).
Big Detroit Lake's watershed is about 43,314 acres (or about 68 square miles) including the lake.

Figure 4. Landuses by Watershed

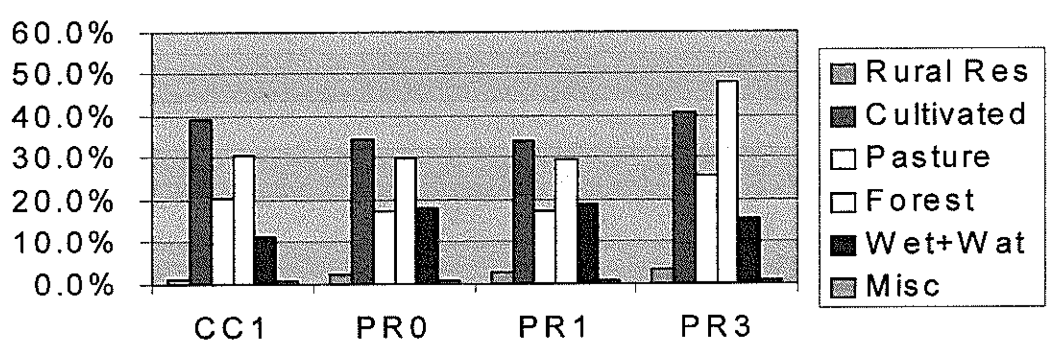


**Table 2. Watershed Areas**

| | Watershed Acres | Watershed Sq. Km |
|---|---|---|
| CC1 | 8230 | 33.3 |
| PR0 | 15066 | 61.0 |
| PR1 | 15407 | 62.4 |
| PR2 | 23102 | 93.5 |
| PR3 | 25471 | 103.1 |
| W. N. Floyd | 1333 | 5.4 |
| E. N. Floyd | 716 | 2.9 |
| Big Floyd | 4869 | 19.7 |
| Little Floyd | 341 | 1.4 |
| PR4/5 | 34000 | 133.9 |
| Sucker Crk | 2635 | 10.7 |
| East side DL | 1729 | 7.0 |
| DL SW Immed. | 2248 | 9.1 |
| Big Detroit Outlet | 43314 | 175.4 |

In general, land uses within the study area for forests ranged from about 30 percent to 40 percent, pastured lands averaged about 20 percent, water plus wetlands ranged 12 percent to 19 percent with rural residential in the 2 percent to 4 percent range (see Figure 2 Land uses by Watershed). Cultivated lands typically were about 32 percent to 41 percent of the study area, with higher percentages being noted in the CC1 and PR3 subwatersheds.

**Precipitation/Evaporation**

The long-term annual precipitation averages about 23.07 inches with values ranging from 20.28 through 34.03 inches since 1990 (see Appendix for a listing). Over the study period of this assessment, annual precipitation has ranged from 24.71 inches (2001) to 34.03 inches (1998). Annual evaporation has been estimated to be on the order of 34 inches per year with about 27 inches occurring May through October. The long-term average runoff for this area of the state is on the order 3.5 inches (State Climatologist – see map in the Appendix.)

**Table 3. Upper Pelican River Watershed Lake Morphometry and Characteristics Summary**

| | B. Floyd | N.Floyd | L. Floyd | B. Detroit | L. Detroit |
|---|---|---|---|---|---|
| Surface Acres (GIS) | 862 | 298 | 217 | 2076 | 941 |
| DNR Acres | 812 | | 231 | 3089 | w/B.Det. |
| Shoreline Length (feet) | 29005 | 18850 | 11740 | 40900 | 25295 |
| Shoreline length (miles) | 5.5 | 3.6 | 2.2 | 7.7 | 4.8 |
| Shoreline Ratio (acres/mile) | 157 | 83 | 98 | 268 | 196 |
| Watershed Area | 14,892 | See Big Floyd | | 40,017 | see big detroit |
| Watershed area/DNR acres | 18.3 | See Big Floyd | | 13.0 | see big detroit |
| Basin Area | 8352 | See Big Floyd | | 5800 | see big detroit |
| Lake Area | | | | | |
| % less than 15 feet deep | 70 | w/BF | 47 | 40 | 90 |
| % less than 10 feet | 65.6% | 44.5% | 43.0% | 37.5% | 73.2% |
| Volume (PRWD) in acre feet | 9869.8 | 4776.5 | 3259.3 | 37589.2 | 8003.1 |
| Volume (PRWD) in million cubic meters | 12.2 | 5.9 | 4.0 | 46.3 | 9.9 |
| % more than 20 feet | 12.0% | 25.8% | 14.9% | 25.5% | 0.0% |
| % more than 30 feet | 1.5% | 9.5% | 0.8% | 9.0% | 0.0% |
| Average Depth (PRWD) | 11.8 | 16 | 14.6 | 18.4 | 8.5 |
| Outlets | 1 | 1 | 2 | 1 | 2 |
| Inlets | 1 | 2 | 1 | 4 | 1 |
| Inflow (annual acre feet) | NA | 6428 | 11478 | 6000 | 6000 |
| Inflow (annual millions of cubic meters) | MA | 7.9 | 14.2 | 7.4 | 7.4 |
| Residence time in days | NA | 271 | 104 | 2287 | 487 |
| Shoreline with moderate or major modification (%) | 1997 | 1997 | 1997 | 1998 | 1998 |
| Vegetation | 89% | 22% | 79% | 80% | 93% |
| Land | 83% | 34% | 70% | 24% | 13% |
| Littoral | 15% | 14% | 36% | 66% | 87% |
| Shoreline with no modification (%) | 10% | 61% | 17% | 19% | 6% |
| Shore Impact Zone structures (%) | 34 | 2 | 4 | 42 | 18 |
| Retaining Walls | 101 | 3 | 14 | 80 | 35 |
| Weed Rollers | 2 | 0 | 0 | 8 | 4 |
| Sand blanketed shoreline (%) | 18% | 2% | 7% | 10% | 14% |
| Rip-Rapped shoreline (%) | 19% | 4% | 11% | 34% | 21% |
| Boats | 361 | 16 | 60 | 337 | 270 |
| Personal Watercraft | 33 | 2 | 2 | 64 | 48 |
| Lake acres per boat | 2.4 | 18.6 | 3.6 | 6.2 | 3.5 |
| First Tier Residence (including RV's) | 183 | 21 | 80 | 236 | 158 |
| Second Tier Residences | 65 | 6 | 28 | 96 | 320 |
| Estimated Seasonal Residences | | 40.0% | 15.0% | 10.0% | 10.0% |
| Est Impervious Coverage in basin | | 20.0% | 22.0% | 24.0% | 25.0% |
| Number of Septic System (1st tier) | | 80 | 2 | 0 | 30 |

**Table 4. Average Summer Total Phosphorus and Secchi Transparency by Lake**

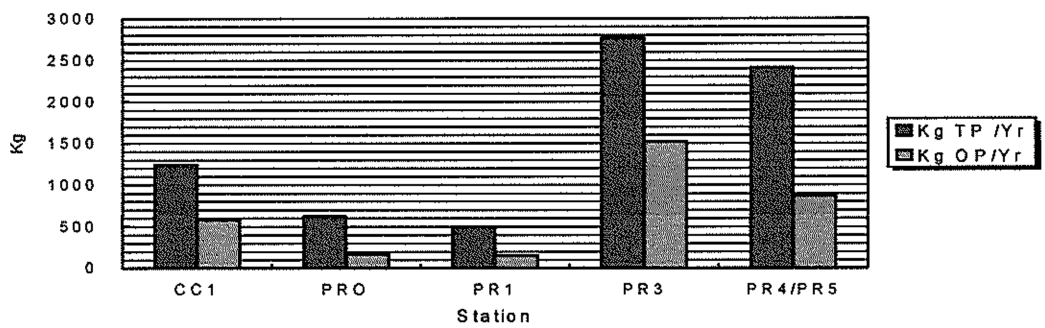
| Total Phosphorus | B. Floyd | N.Floyd | L. Floyd | B. Detroit | L. Detroit |
|---|---|---|---|---|---|
| 1995 | 23 | 40 | | 26 | 28 |
| 1996 | 15 | 25 | | 20 | 16 |
| 1997 | 20 | 35 | 20 | 23 | 29 |
| 1998 | 16 | 37 | 30 | 37 | 35 |
| 1999 | 17 | 30 | 27 | 24 | 20 |
| 2000 | 14 | 37 | 19 | 24 | 18 |
| 2001 | 19 | 27 | 22 | 30 | 25 |
| Average 1995-2000 | 18 | 33 | 24 | 26 | 24 |
| **Secchi** | **B. Floyd** | **N.Floyd** | **L. Floyd** | **B. Detroit** | **L. Detroit** |
| 1995 | 10 | 9.4 | | 8.3 | 8.6 |
| 1996 | 7.9 | 7 | | 10.9 | 11.3 |
| 1997 | 11.5 | 6.5 | 6.9 | 8.5 | 9.2 |
| 1998 | 11.8 | 6.2 | 7.1 | 7.3 | 8.8 |
| 1999 | 13.5 | 7.6 | 9.2 | 6.3 | 9.7 |
| 2000 | 12.3 | 6.5 | 9.1 | 9.5 | 11.7 |
| 2001 | 11.4 | 8.6 | 11 | 9.8 | 10.7 |
| Average 1995-2000 | 11.2 | 7.4 | 8.7 | 8.7 | 10.0 |

Stream Morphometry – to be added.

**Flow Equations.**
Flows were determined by site and by year based upon flow-stage relationships for each site. In general, flow-stage relationships were based upon a minimum of 10 to 20 measurements per site which are summarized in the Appendix.

Flow-weighted mean concentrations (FWM) estimated by FLUX (Walker, 1996) are summarized by station and by year in the Appendix along with graphics. Calendar years were used for calculation purposes. For simple graphic comparisons, an arithmetic average of the three years of flow-weighted mean concentrations for TP, OP and TSS have been summarized along the flow monitoring network and listed in the below figure.

Figure 5. 1998-2000 Estimated Yearly Phosphorus Loss Rates




## Total Phosphorus

The primary emphasis has been to define the stream and lake phosphorus dynamics as this is usually the dominant nutrient factor affecting lake enrichment or eutrophication. Beginning at the headwaters and proceeding downstream at Campbell Creek Site 1 (CC1) average total phosphorus for the study period was on the order of 89 ppb with 42 ppb noted in ortho phosphorus. The corresponding total suspended solids value was noted to be about 12.7 mg/L.

The drainage system flows into North Floyd Lake and on through Little Floyd Lake. In between these two lakes, the next station identified as Pelican River Site 0 or PR0 was found to have very consistent year-to-year values around 36 ppb TP with about 10 ppb OP. Further sedimentation within Little Floyd lake dropped these values to 30 ppb TP and 10 ppb noted at Pelican River Site 1 or PR1, which enters into the Rice Wetland at PR2. Limited summer data were available for PR2 from 1995 only and these values averaged 107 ppb versus an average value for the same time period from the PR3 site of 77 ppb (see Appendix for the data). This would indicate that at least some of the phosphorus loading from the Rice Wetland was due to loading sources upstream of the PR1 monitoring site. Additional monitoring is being conducted during 2002 at sites DD1, DD2, DD3, SEF1, SEF2 and SE1(see map PRWD Monitoring Sites). Data from the partial dataset from 2002 from site DD1, SEF1 and SEF2 strongly indicate that watershed loading into the Rice Wetland is continuing. It is recommended that continuous flow recorders be installed in a suitable flow site near DD1/DD2 and SEF1/SEF2 to further refine the magnitude of upstream loading into Rice Lake.

Monitoring conducted at PR3 over the study period shows consistent and elevated total and ortho phosphorus FWM's on the order of 95 and 52 ppb, respectively. These values are about three times those values noted at the Little Floyd Lake outlet and represent the highest values monitored in the 1998-2000 study.

FWM phosphorus values were noted to drop in concentration between PR3 and PR4/5 concurrent with a general increase of about 30 percent in water volumes. The mass balances between these two sites need to be examined more closely and include the effects of ground water as well as storm water from the City of Detroit Lakes. Using the available flows and substantial sampling record, it was estimated over the study period that phosphorus mass increased by about 2,000 kg P/year going through the Rice Wetland drainage area as FWM's for total and ortho phosphorus tripled.

## Concentration Flow Dynamics

Plots of total phosphorus concentrations versus flow were examined in FLUX and plotted in the Appendix.

## Modeling Summary

Numerous complex mathematical models are available for estimating nutrient and water budgets for lakes. These models can be used to relate the flow of water and nutrients from a lake's watershed to observed conditions in the lake. Alternatively, they may be used for estimating changes in the quality of the lake as a result of altering nutrient inputs to the lake (e.g. changing land uses or influent stream quality). To analyze the in-lake water quality of Floyd Lake system as well as Big and Little Detroit Lakes, the models MINLEAP (Wilson and Walker, 1989) and BATHTUB (Walker, 1996) were used. The "Minnesota Lake Eutrophication Analysis Procedure " (MINLEAP) was developed by MPCA staff based on an analysis of data collected from the ecoregion reference lakes. It is intended to be used as a screening tool for estimating lake conditions with minimal data input and is described in greater detail in Wilson and Walker (1989).

BATHTUB is a series of empirical eutrophication models that perform water and nutrient balance calculations and estimates water quality related conditions (total phosphorus, chlorophyll-a, transparency and numerous diagnostic measures as well). For this report, the model was used in conjunction with the FLUX, a program for reducing tributary monitoring data.

The first model, MINLEAP, predicted average in-lake total phosphorus, chlorophyll-a and Secchi transparencies as indicated below, using default stream concentrations for the Northern Lakes and Forests ecoregion rather than the North Central Hardwood Forests Ecoregion. Measured values have been included from 2000 for comparison, where data values existed. The PRWD has add chlorophyll-a to their field measures over the summer of 2002, which should help further refine in-lake responses.

**Table 5. MINLEAP Modeling Results.**

| Name | TP +/- | Chl-a +/- | Secchi Ft +/- | |
|---|---|---|---|---|
| North Floyd | 32 +/- 8 (37) | 11 +/- 5 (na) | 6.2 +/- 2 (na) | |
| Little Floyd | 26 +/- 8 (na) | 8 +/- 4 (na) | 7.5 +/- 2.6 (9.5) | |
| Big Floyd | 20 +/- 7 (14) | 6 +/- 3 (na) | 9.5 +/- 3.6 (12.3) | |
| Detroit Lakes | 23+/- 7 (24) | 6 +/- 4 (na) | 8.5+/- 3.3 (9.5) | |

**BATHTUB** simulations of the water quality of the Upper Pelican River Watershed were accomplished for the Floyd Lake system (Big Floyd into North Floyd into Little Floyd Lake in FLOYD00.bin) and for the Detroit Lakes (Big Detroit into Little Detroit in Detroit0.bin) for the year 2000. Additional years of data can also be processed using these two lake system formats prepared for this analysis.

The Floyd Lake system was segmented into four lake segments: Big Floyd (segment 3) flowing into West North Floyd (1), then into East North Floyd (2), and finally into Little Floyd (4) Lake. Measured phosphorus and Secchi values from 2000 were used in the simulations along with artificially generated chlorophyll-a values, which were necessary to run some of the subroutines.

In general, the BATHTUB simulations of water quality generally agreed with available measured values for total phosphorus and Secchi transparency for the lake segments as defined. No data calibrations were employed in the use of BATHTUB.

For the Floyd Lake System, the dominant source of water (e.g. 72 percent) and phosphorus (92 percent) was from Campbell Creek (CC1). Accordingly, the western basin of North Floyd Lake showed elevated phosphorus concentrations relative to the eastern basin.

**Table 6. Floyd Lakes BATHTUB Output Summary**

SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
COMPONENT: TOTAL P — SEGMENT: 1 West N Floyd

| ID | T | LOCATION | FLOW HM3/YR | FLOW % | LOAD KG/YR | LOAD % | CONC MG/M3 |
|---|---|---|---|---|---|---|---|
| 1 | 1 | CC1 | 11.65 | 72.0 | 990.2 | 91.6 | 85.0 |
| 7 | 1 | Septics NFloyd | .00 | .0 | .0 | .0 | .0 |
| 11 | 1 | West N Floyd | 1.00 | 6.2 | 25.0 | 2.3 | 25.0 |
| | | PRECIPITATION | .61 | 3.8 | 15.8 | 1.5 | 26.0 |
| | | TRIBUTARY INFLOW | 12.65 | 78.2 | 1015.2 | 93.9 | 80.3 |
| | | ADVECTIVE INFLOW | 2.92 | 18.0 | 49.7 | 4.6 | 17.1 |
| | | ***TOTAL INFLOW | 16.17 | 100.0 | 1080.8 | 100.0 | 66.8 |
| | | ADVECTIVE OUTFLOW | 15.49 | 95.8 | 697.4 | 64.5 | 45.0 |
| | | NET DIFFUSIVE OUTFLOW | .00 | .0 | 56.5 | 5.2 | .0 |
| | | ***TOTAL OUTFLOW | 15.49 | 95.8 | 753.8 | 69.7 | 48.7 |
| | | ***EVAPORATION | .68 | 4.2 | .0 | .0 | .0 |
| | | ***RETENTION | .00 | .0 | 327.0 | 30.3 | .0 |

RESID. TIME = .255 YRS, OVERFLOW RATE = 19.6 M/YR, DEPTH = 5.0 M

SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
COMPONENT: TOTAL P — SEGMENT: 2 East N Floyd

| ID | T | LOCATION | FLOW HM3/YR | FLOW % | LOAD KG/YR | LOAD % | CONC MG/M3 |
|---|---|---|---|---|---|---|---|
| 2 | 4 | PRO | .00 | .0 | .0 | .0 | 37.5 |
| 5 | 1 | East N Floyd Dir | .58 | 3.5 | 29.0 | 3.9 | 50.0 |
| 6 | 1 | Septic Big Floyd | .00 | .0 | .0 | .0 | .0 |
| | | PRECIPITATION | .32 | 1.9 | 8.2 | 1.1 | 26.0 |
| | | TRIBUTARY INFLOW | .58 | 3.5 | 29.0 | 3.9 | 50.0 |
| | | ADVECTIVE INFLOW | 15.49 | 94.5 | 697.4 | 94.9 | 45.0 |
| | | ***TOTAL INFLOW | 16.39 | 100.0 | 734.6 | 100.0 | 44.8 |
| | | ADVECTIVE OUTFLOW | 16.04 | 97.8 | 602.2 | 82.0 | 37.5 |
| | | NET DIFFUSIVE OUTFLOW | .00 | .0 | 33.3 | 4.5 | .0 |
| | | ***TOTAL OUTFLOW | 16.04 | 97.8 | 635.5 | 86.5 | 39.6 |
| | | ***EVAPORATION | .35 | 2.2 | .0 | .0 | .0 |
| | | ***RETENTION | .00 | .0 | 99.1 | 13.5 | .0 |

RESID. TIME = .089 YRS, OVERFLOW RATE = 39.1 M/YR, DEPTH = 3.5 M

SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
COMPONENT: TOTAL P SEGMENT: 3 Big Floyd

| ID | T | LOCATION | FLOW HM3/YR | FLOW % | LOAD KG/YR | LOAD % | CONC MG/M3 |
|---|---|---|---|---|---|---|---|
| 4 | 1 | Big Floyd Direct | 3.00 | 80.6 | 75.0 | 75.0 | 25.0 |
| | | PRECIPITATION | .72 | 19.4 | 18.8 | 18.8 | 26.0 |
| | | TRIBUTARY INFLOW | 3.00 | 80.6 | 75.0 | 75.0 | 25.0 |
| | | NET DIFFUSIVE INFLOW | .00 | .0 | 6.2 | 6.2 | .0 |
| | | ***TOTAL INFLOW | 3.72 | 100.0 | 100.0 | 100.0 | 26.9 |
| | | ADVECTIVE OUTFLOW | 2.92 | 78.3 | 49.7 | 49.7 | 17.1 |
| | | ***TOTAL OUTFLOW | 2.92 | 78.3 | 49.7 | 49.7 | 17.1 |
| | | ***EVAPORATION | .81 | 21.7 | .0 | .0 | .0 |
| | | ***RETENTION | .00 | .0 | 50.3 | 50.3 | .0 |

RESID. TIME = 1.515 YRS, OVERFLOW RATE = 3.1 M/YR, DEPTH = 4.7 M

SEGMENT BALANCE BASED UPON ESTIMATED CONCENTRATIONS
COMPONENT: TOTAL P SEGMENT: 4 Little Floyd

| ID | T | LOCATION | FLOW HM3/YR | FLOW % | LOAD KG/YR | LOAD % | CONC MG/M3 |
|---|---|---|---|---|---|---|---|
| 3 | 4 | PR1 | 13.60 | 79.8 | 401.1 | 56.4 | 29.5 |
| 10 | 1 | L Floyd Direct | .30 | 1.8 | 7.5 | 1.1 | 25.0 |
| | | PRECIPITATION | .70 | 4.1 | 18.2 | 2.6 | 26.0 |
| | | TRIBUTARY INFLOW | .30 | 1.8 | 7.5 | 1.1 | 25.0 |
| | | ADVECTIVE INFLOW | 16.04 | 94.1 | 602.2 | 84.6 | 37.5 |
| | | NET DIFFUSIVE INFLOW | .00 | .0 | 83.5 | 11.7 | .0 |
| | | ***TOTAL INFLOW | 17.04 | 100.0 | 711.4 | 100.0 | 41.8 |
| | | GAUGED OUTFLOW | 13.60 | 79.8 | 312.8 | 44.0 | 23.0 |
| | | ADVECTIVE OUTFLOW | 2.66 | 15.6 | 78.3 | 11.0 | 29.5 |
| | | ***TOTAL OUTFLOW | 16.26 | 95.4 | 391.1 | 55.0 | 24.1 |
| | | ***EVAPORATION | .78 | 4.6 | .0 | .0 | .0 |
| | | ***RETENTION | .00 | .0 | 320.3 | 45.0 | .0 |

RESID. TIME = .263 YRS, OVERFLOW RATE = 17.9 M/YR, DEPTH = 4.7 M

CASE: Floyd Lake Chain
T STATISTICS COMPARE OBSERVED AND PREDICTED MEANS
USING THE FOLLOWING ERROR TERMS:
1 = OBSERVED WATER QUALITY ERROR ONLY
2 = ERROR TYPICAL OF MODEL DEVELOPMENT DATA SET
3 = OBSERVED AND PREDICTED ERROR

SEGMENT: 1 West N Floyd

| VARIABLE | | OBSERVED MEAN | OBSERVED CV | ESTIMATED MEAN | ESTIMATED CV | RATIO | T STATISTICS 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|---|---|
| TOTAL P | MG/M3 | 40.0 | .00 | 45.0 | .19 | .89 | .00 | -.44 | -.62 |
| CHL-A | MG/M3 | 20.0 | .00 | 20.0 | .31 | 1.00 | .00 | .00 | .00 |
| SECCHI | M | 1.7 | .00 | 1.7 | .27 | 1.00 | .00 | .00 | .00 |
| ORGANIC N | MG/M3 | .0 | .00 | 619.2 | .25 | .00 | .00 | .00 | .00 |
| TP-ORTHO-P | MG/M3 | .0 | .00 | 33.6 | .36 | .00 | .00 | .00 | .00 |

SEGMENT: 2 East N Floyd

| VARIABLE | | OBSERVED MEAN | OBSERVED CV | ESTIMATED MEAN | ESTIMATED CV | RATIO | T STATISTICS 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|---|---|
| TOTAL P | MG/M3 | 35.0 | .00 | 37.5 | .24 | .93 | .00 | -.26 | -.29 |
| CHL-A | MG/M3 | 12.0 | .00 | 18.1 | .54 | .66 | .00 | -1.18 | -.76 |
| SECCHI | M | 2.5 | .00 | 1.8 | .46 | 1.38 | .00 | 1.15 | .70 |
| ORGANIC N | MG/M3 | .0 | .00 | 576.6 | .40 | .00 | .00 | .00 | .00 |
| TP-ORTHO-P | MG/M3 | .0 | .00 | 30.4 | .59 | .00 | .00 | .00 | .00 |

SEGMENT: 3 Big Floyd

| VARIABLE | | OBSERVED MEAN | OBSERVED CV | ESTIMATED MEAN | ESTIMATED CV | RATIO | T STATISTICS 1 | T STATISTICS 2 | T STATISTICS 3 |
|---|---|---|---|---|---|---|---|---|---|
| CONSERVATIVE SUB | | 9.2 | .00 | 9.2 | .00 | 1.00 | .00 | .00 | .00 |
| TOTAL P | MG/M3 | 15.0 | .00 | 17.1 | .40 | .88 | .00 | -.48 | -.33 |
| CHL-A | MG/M3 | 7.0 | .00 | 6.3 | .64 | 1.11 | .00 | .30 | .16 |
| SECCHI | M | 3.9 | .00 | 4.2 | .44 | .93 | .00 | -.25 | -.16 |
| ORGANIC N | MG/M3 | 780.0 | .00 | 307.1 | .32 | 2.54 | .00 | 3.73 | 2.90 |
| TP-ORTHO-P | MG/M3 | .0 | .00 | 9.1 | .80 | .00 | .00 | .00 | .00 |

SEGMENT: 4 Little Floyd

| VARIABLE | | OBSERVED MEAN | OBSERVED CV | ESTIMATED MEAN | ESTIMATED CV | RATIO | T STATISTICS 1 | T STATISTICS 2 | T STATISTICS 3 |
|---|---|---|---|---|---|---|---|---|---|
| TOTAL P | MG/M3 | 21.0 | .00 | 29.5 | .32 | .71 | .00 | -1.26 | -1.06 |
| CHL-A | MG/M3 | 12.0 | .00 | 13.0 | .58 | .92 | .00 | -.23 | -.14 |
| SECCHI | M | 3.0 | .00 | 2.5 | .48 | 1.21 | .00 | .69 | .40 |
| ORGANIC N | MG/M3 | .0 | .00 | 459.0 | .39 | .00 | .00 | .00 | .00 |
| TP-ORTHO-P | MG/M3 | .0 | .00 | 20.9 | .66 | .00 | .00 | .00 | |

The predicted in-lake TP for Little Floyd was greater than the observed by the largest amount estimated for the Floyd Lake system with an estimated value of 30 versus the observed value of 21 ug P/L. Further refinement of the water balances will likely improve future simulation capabilities.

A similar process was used to simulate the quality of Big and Little Detroit Lakes using the flows from station PR4/PR5 as the inflow to these lakes along with the estimated FWM's for 2000. Approximately 82 percent of the water was from PR4/PR5 which also accounted for about 90 percent of the TP income to the lakes. The remaining subwatersheds draining into the Detroit Lakes were estimated based upon surface areas, but additional work is recommended to improve estimates of runoff from these areas. For conditions monitored in 2000, the lake's water residence time is on the order of 1.2 years and 0.4 years, respectively for Big and Little Detroit Lakes. Future assessments should also include assessment of the impacts of storm water, especially into Little Detroit from municipal drainage areas.

In general, the simulations using measured flows and concentrations for the largest drainage areas, agreed with measured conditions for 2000, especially for Little Detroit (e.g. estimated 20 versus 18 ug P/L). The models suggested that Big Detroit should have slightly worse quality than observed (e.g. 30 versus 25 ug P/L measured in 2000). Additional refinements of the water flows at the inlet and outlet stations will likely improve simulation capabilities.

It is important to note that reduction of the PR4/PR5 total phosphorus FWM values to 40 to 50 ug P/L was predicted to reduce in-lake values on the order of 20 – 25 ug P/L average surface water summer concentrations. Increasing the PR4/PR5 FWM values to 100 ug P/L was predicted to increase average summer TP values to near 40 ug P/L – or similar to conditions measured over the past few years in Lake Sallie. Additionally, if internal loading occurs within the Detroit Lakes, dramatic declines of water quality can be expected to be observed over most summers. For example, if a relatively modest level internal P recycling were to occur (e.g. 50 percent of the measured Lake Sallie level), then in-lake concentrations (using the 2000 PR4/PR5 value of 69 ug P/L) would be on the order of 40 ug P/L. Again, conditions within the Detroit Lakes would mimic water quality conditions observed in Lake Sallie. Year 2000 water quality of the Detroit Lakes is very similar to conditions observed in Lake Bemidji – and lake management efforts there have focused upon protecting the lakes by nondegradation [e.g. goal of less than 25 ug P/L over most flow conditions, Hrubes (1995)].

## Table 7. Detroit Lakes BATHTUB Output Summary

COMPONENT: TOTAL P

| ID | T | LOCATION | LOADING KG/YR | LOADING %(I) | VARIANCE KG/YR**2 | VARIANCE %(I) | CV | CONC MG/M3 | EXPORT KG/KM2 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | PR4/PR5 | 2263.0 | 82.4 | .148E+06 | 90.5 | .170 | 68.0 | 16.9 |
| 2 | 1 | Sucker | 65.0 | 2.4 | .000E+00 | .0 | .000 | 50.0 | 6.1 |
| 3 | 2 | New Devel | .0 | .0 | .000E+00 | .0 | .000 | .0 | .0 |
| 4 | 1 | East Side | 90.0 | 3.3 | .729E+01 | .0 | .030 | 100.0 | 12.9 |
| 5 | 4 | Outlet PR6 | .0 | .0 | .000E+00 | .0 | .000 | 19.0 | .0 |
| 6 | 1 | Detroit SW Immed | 80.0 | 2.9 | .000E+00 | .0 | .000 | 100.0 | 8.8 |
| | | PRECIPITATION | 249.6 | 9.1 | .156E+05 | 9.5 | .500 | 33.3 | 20.0 |
| | | TRIBUTARY INFLOW | 2498.0 | 90.9 | .148E+06 | 90.5 | .154 | 68.9 | 15.6 |
| | | ***TOTAL INFLOW | 2747.6 | 100.0 | .164E+06 | 100.0 | .147 | 62.8 | 15.9 |
| | | ADVECTIVE OUTFLOW | 623.8 | 22.7 | .349E+04 | 2.1 | .095 | 18.0 | -270.1 |
| | | ***TOTAL OUTFLOW | 623.8 | 22.7 | .349E+04 | 2.1 | .095 | 18.0 | 3.6 |
| | | ***STORAGE INCREASE | -17.0 | -.6 | .613E+02 | .0 | .460 | 27.3 | .0 |
| | | ***RETENTION | 2140.8 | 77.9 | .168E+06 | 103.0 | .192 | .0 | .0 |

| OVERFLOW RATE M/YR | HYDRAULIC RESIDENCE TIME YRS | TOTAL P POOL CONC MG/M3 | TOTAL P RESIDENCE TIME YRS | TOTAL P TURNOVER RATIO - | TOTAL P RETENTION COEF - |
|---|---|---|---|---|---|
| 2.73 | 1.6653 | 22.9 | .4725 | 2.1163 | .7792 |

T STATISTICS COMPARE OBSERVED AND PREDICTED MEANS
USING THE FOLLOWING ERROR TERMS:
1 = OBSERVED WATER QUALITY ERROR ONLY
2 = ERROR TYPICAL OF MODEL DEVELOPMENT DATA SET
3 = OBSERVED AND PREDICTED ERROR

SEGMENT: 1 Big Detroit

| VARIABLE | | OBSERVED MEAN | OBSERVED CV | ESTIMATED MEAN | ESTIMATED CV | RATIO | T STATISTICS 1 | T STATISTICS 2 | T STATISTICS 3 |
|---|---|---|---|---|---|---|---|---|---|
| TOTAL P | MG/M3 | 25.0 | .00 | 30.1 | .46 | .83 | .00 | -.69 | -.41 |
| CHL-A | MG/M3 | 7.0 | .00 | 8.4 | .53 | .83 | .00 | -.54 | -.35 |
| SECCHI | M | 3.0 | .00 | 2.7 | .31 | 1.11 | .00 | .37 | .33 |
| ORGANIC N | MG/M3 | .0 | .00 | 361.3 | .31 | .00 | .00 | .00 | .00 |
| TP-ORTHO-P | MG/M3 | .0 | .00 | 14.7 | .56 | .00 | .00 | .00 | .00 |

SEGMENT: 2 Little Detroit

| VARIABLE | | OBSERVED MEAN | OBSERVED CV | ESTIMATED MEAN | ESTIMATED CV | RATIO | T STATISTICS 1 | T STATISTICS 2 | T STATISTICS 3 |
|---|---|---|---|---|---|---|---|---|---|
| TOTAL P | MG/M3 | 18.0 | .00 | 20.6 | .46 | .87 | .00 | -.51 | -.30 |
| CHL-A | MG/M3 | 3.6 | .00 | 5.8 | .53 | .62 | .00 | -1.37 | -.90 |
| SECCHI | M | 3.6 | .00 | 3.0 | .25 | 1.20 | .00 | .64 | .72 |
| ORGANIC N | MG/M3 | .0 | .00 | 302.9 | .26 | .00 | .00 | .00 | .00 |
| TP-ORTHO-P | MG/M3 | .0 | .00 | 10.6 | .53 | .00 | .00 | .00 | .00 |

**Goal Setting**

Since the lakes of the Upper Pelican River Watershed share more in common with the Northern Lakes and Forests than the North Central Hardwood Forest ecoregion, more reliance has been placed upon characteristics of the former than the later for goal setting purposes. The current phosphorus criteria value for lakes in the Northern Lakes and Forests ecoregion for support of swimmable use, is less than 30 µg/L (and 40 ug P/L for the North Central Hardwoods Forest ecoregion) (Heiskary and Wilson, 1990). At or below 40 µg P/L, "nuisance algal blooms" (chlorophyll a > 20 µg/L ) should occur less than 25 percent of the summer.

**Table 8. Minnesota Lake Phosphorus Criteria**
**(Heiskary and Wilson, 1988)**

| Ecoregion | Most Sensitive Use | P Criteria |
|---|---|---|
| **Northern Lakes and Forests** | drinking water supply<br>cold water fishery<br>primary contact recreation and aesthetics | **< 15 µg/L**<br>**< 15 µg/L**<br>**< 30 µg/L** |
| **North Central Hardwood Forests** | drinking water supply<br>primary contact recreation and aesthetics | **< 30 µg/L**<br>**< 40 µg/L** |

While Big Detroit and North Floyd and Little Floyd stratify thermally over the summer, they do experience top to bottom mixing during strong storm events. Hence, average total phosphorus by lake mixis types were examined (Table 9) where it may be seen that the 50$^{th}$ percentile for (1) the Northern Lakes and Forests range from 20 to 29 ug P/L and (2) 39 to 89 ug P/L - for dimictic, intermictic and polymictic lakes, respectively. The greater P values observed in the North Central Hardwoods Forests are the result of higher stream P concentrations, increased bottom temperatures and P internal recycling. Hence, this suggests that goal setting should focus upon maintaining in-lake TP values in the 20-30 ug P/L range for Big Floyd, Little Floyd, Big Detroit, and Little Detroit.

For North Floyd Lake, it would be desirable to reduce in-lake P concentration. An in-lake P goal (whole lake) on the order of 30 – 40 µg/L may be appropriate based on data from 2000, and model results, especially with reduction of Campbell Creek to less than 50 ug P/L. Attaining an in-lake average P concentration of 30 – 40 µg/L or lower should keep chlorophyll-a concentrations at or below 20 µg/L about 75 to 90 percent of the summer and Secchi at or above 2 meters 60 to 80 percent of the summer. Improvement of North Floyd will have downstream beneficial effects on Little Floyd, likely dropping average summer TP to values less than 25 ug P/L. Strong nondegradation policies should be encouraged for all of these lakes, especially for Big Floyd Lake and the Detroit Lakes. The longer elevated phosphorus loading occurs via Campbell Creek into North Floyd Lake and from the outlet of Rice Lake into Big Detroit, the greater the likelihood of internal P recycling from lake sediments, especially for lakes with significant shelf depths of 10 and 35 feet.

Maintaining a summer-mean P concentration of about 30 µg/L or lower over the long term, would require that P loading into the lake be reduced. The PRWD and its partners have a long history of achieving nutrient loading reductions from watershed sources and have plans in place for further P loading. The details of their efforts will be presented in their Phase II Clean Water Partnership Workplan, which will have Best Management Practices (BMPs) defined for these watersheds.

**Table 9. Distribution of Total Phosphorus (µg/L) Concentrations by Mixing Status and Ecoregion (Heiskary and Wilson, 1988).**
**D** = Dimictic, **I** = Intermittent, **P** = Polymictic

| | Northern Lakes and Forests | | | North Central Hardwood Forest | | |
|---|---|---|---|---|---|---|
| Mixing Status: | D | I | P | D | I | P |
| Percentile value for [TP] | Ppb | | | | | |
| **90 %** | **37** | **53** | **57** | **104** | **263** | **344** |
| **75 %** | **29** | **35** | **39** | **58** | **100** | **161** |
| **50 %** | **20** | **26** | **29** | **39** | **62** | **89** |
| **25 %** | **13** | **19** | **19** | **25** | **38** | **50** |
| **10 %** | **9** | **13** | **12** | **19** | **21** | **32** |
| | | | | | | |
| # of obs. | 257 | 87 | 199 | 152 | 71 | 145 |

## Conclusions and Recommendations

Recommended lake management goals were identified for the Floyd Lake and Detroit Lakes systems. From these lake goals, inflow stream phosphorus management goals were then assessed to allow nondegradation and/or restoration of the lakes.

Watershed restoration is recommended for the Campbell Creek and Rice Lake Wetland drainage areas with a 25 percent short-term and 50 percent long-term phosphorus reduction. Downstream of this area, the Rice Wetland complex is discharging excess P concentrations and mass to the Detroit Lakes. It is unclear whether Rice Lake is recycling historical loading and/or upstream P loading is continuing to this date. Additional monitoring of inflows to the Rice Wetland being conducted during 2002 will help clarify P sources – especially the SEF 1 and DDD1 monitoring sites. Nonetheless, it recommended that the Rice Lake Wetland phosphorus loading to Detroit Lakes be reduced by about 50 percent.

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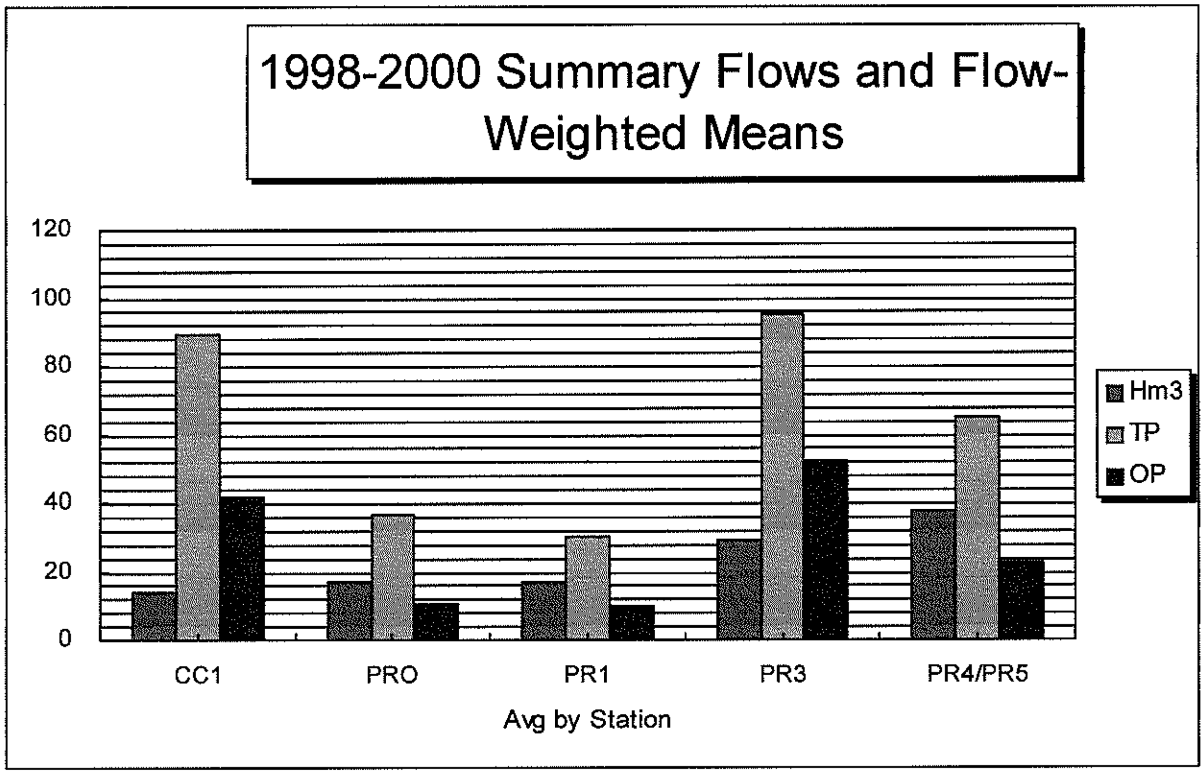
# Appendix

## Stream Summary by Stream Site and Year
## (Means with Number of Samples)

| Site | Year | TP | OP | TSS | Number |
|---|---|---|---|---|---|
| *CC1* | 1996 | 0.098 | | 13.084 | 26 |
| *CC1* | 1997 | 0.094 | 0.052 | 7.843 | 43 |
| *CC1* | 1998 | 0.081 | 0.049 | 8.783 | 30 |
| *CC1* | 1999 | 0.093 | 0.038 | 19.290 | 31 |
| *CC1* | 2000 | 0.074 | 0.034 | 9.333 | 28 |
| *PRO* | 1998 | 0.037 | 0.012 | 3.400 | 39 |
| *PRO* | 1999 | 0.037 | 0.037 | 17.984 | 35 |
| *PRO* | 2000 | 0.035 | 0.007 | 2.957 | 35 |
| *PR1* | 1998 | 0.034 | 0.012 | 1.500 | 39 |
| *PR1* | 1999 | 0.033 | 0.011 | | 35 |
| *PR1* | 2000 | 0.023 | 0.006 | | 27 |
| *PR3* | 1997 | 0.058 | | 4.654 | 26 |
| *PR3* | 1998 | 0.085 | 0.032 | 4.994 | 35 |
| *PR3* | 1999 | 0.087 | 0.051 | | 14 |
| *PR3* | 2000 | 0.098 | 0.064 | 8.071 | 11 |
| *PR4* | 1998 | 0.066 | 0.035 | 6.363 | 41 |
| *PR4* | 1999 | 0.055 | 0.025 | 6.792 | 24 |
| *PR4* | 2000 | 0.069 | 8.427 | 5.000 | 30 |



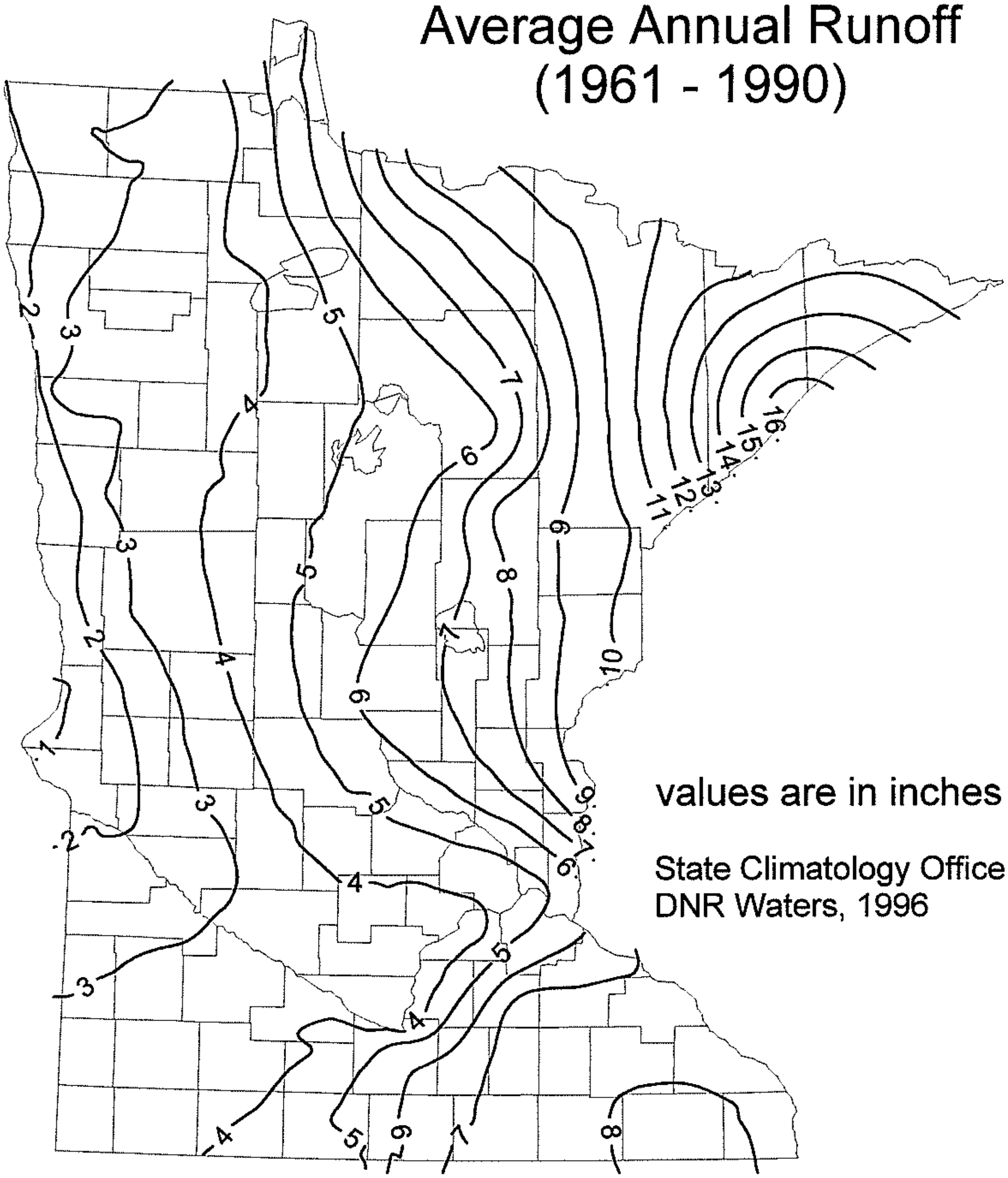

**Becker County Average Precipitation Quanitities**

| *Year* | *Annual* | *Grow Season* |
|---|---|---|
| *1990* | 20.28 | 11.25 |
| *1991* | 26.39 | 15.89 |
| *1992* | 23.29 | 16.82 |
| *1993* | 32.66 | 23.6 |
| *1994* | 24.57 | 16.5 |
| *1995* | 28.99 | 17.52 |
| *1996* | 26.03 | 15.53 |
| *1997* | 29.26 | 19.48 |
| *1998* | 34.03 | 22.26 |
| *1999* | 27.43 | 22.88 |
| *2000* | 30.18 | 18.47 |
| *2001* | 24.71 | 14.53 |
| **Quartiles** | | |
| **Min** | 20.28 | 11.25 |
| **25%** | 25.37 | 16.195 |
| **75%** | 27.43 | 17.52 |
| **Max** | 34.03 | 23.6 |
| **Mean** | 23.07 | 12.86 |

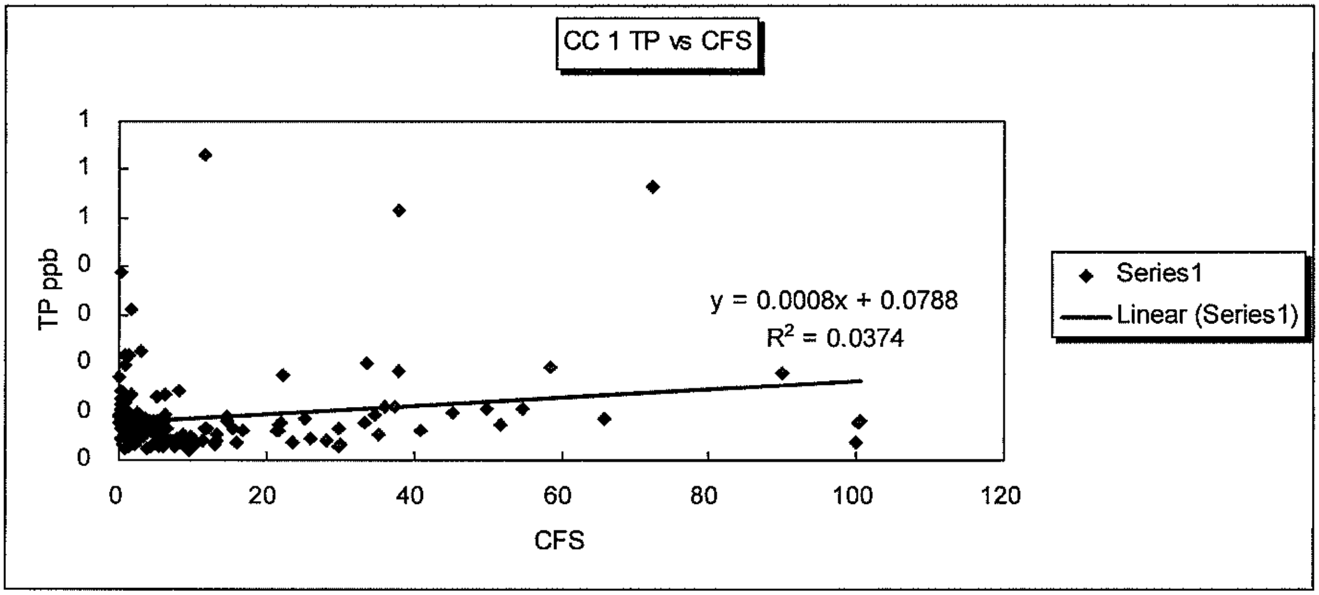
**1995 Data from PR3 and PR2.**

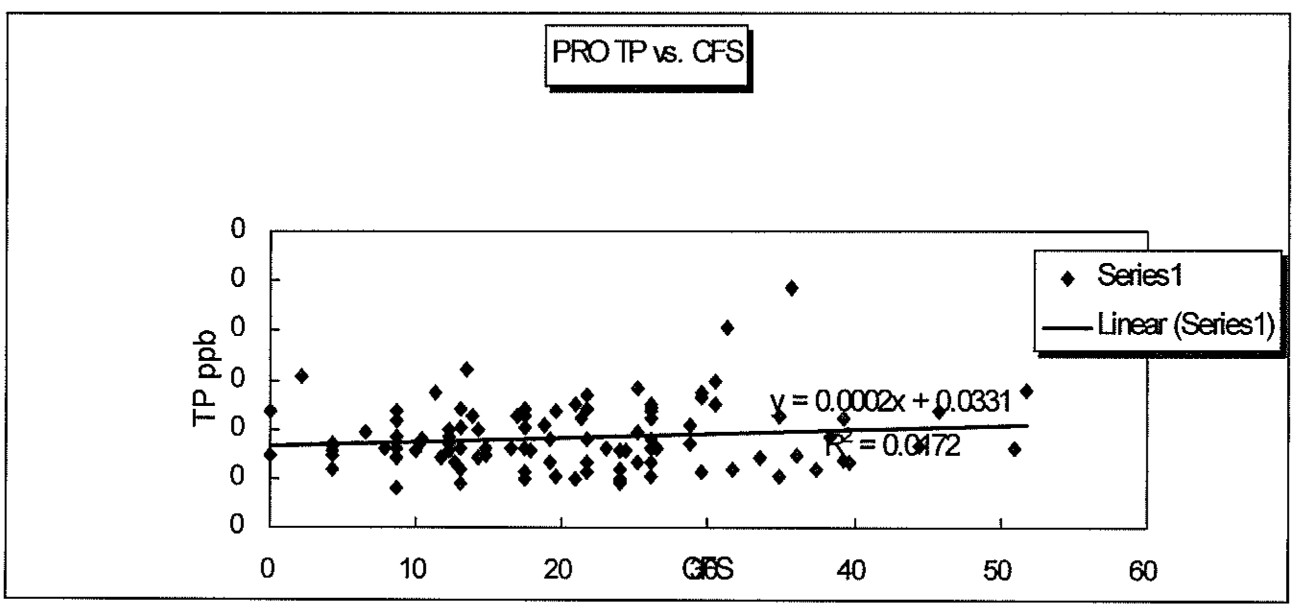
| | | P3 | P2 |
|---|---|---|---|
| | Staff | TP | TP |
| June6 | 2.04 | 0.085 | 0.106 |
| June13 | 2.06 | 0.047 | 0.052 |
| June20 | 1.94 | 0.088 | 0.113 |
| June27 | 1.78 | 0.11 | 0.183 |
| July3 | 1.78 | 0.082 | 0.1 |
| | | 0.119 | |
| July11 | 1.9 | 0.072 | 0.075 |
| July18 | 1.9 | 0.0111 | 0.08 |
| July25 | 1.9 | 0.086 | 0.099 |
| Aug1 | 1.7 | 0.053 | 0.09 |
| Aug8 | 1.54 | 0.04 | 0.123 |
| Aug15 | 1.39 | 0.034 | 0.119 |
| Aug22 | 1.24 | 0.035 | 0.125 |
| | | 0.188 | |
| Aug29 | 1.78 | 0.103 | 0.121 |
| **Averages** | | **0.077** | **0.107** |

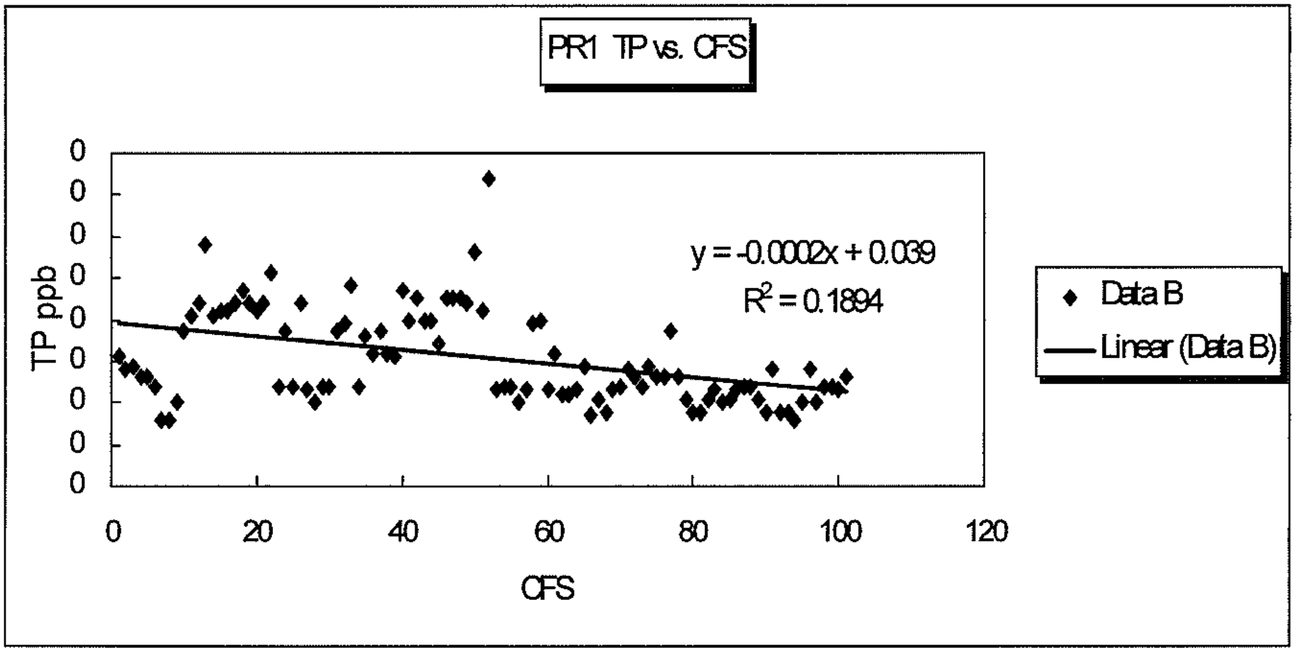
# Average Annual Runoff
# (1961 - 1990)

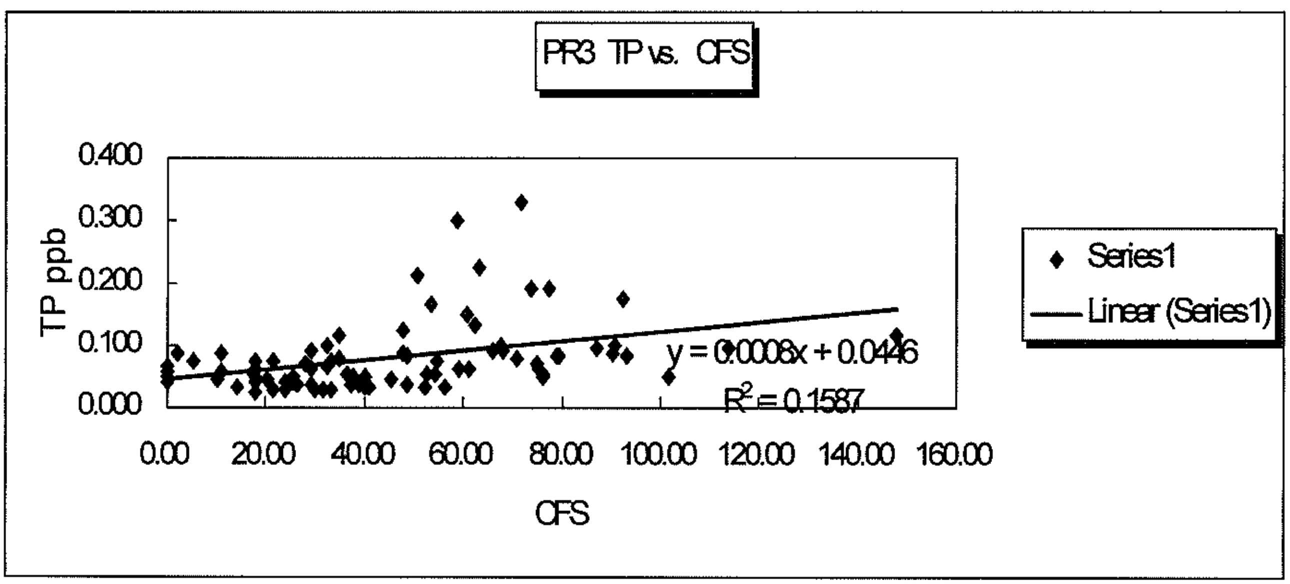


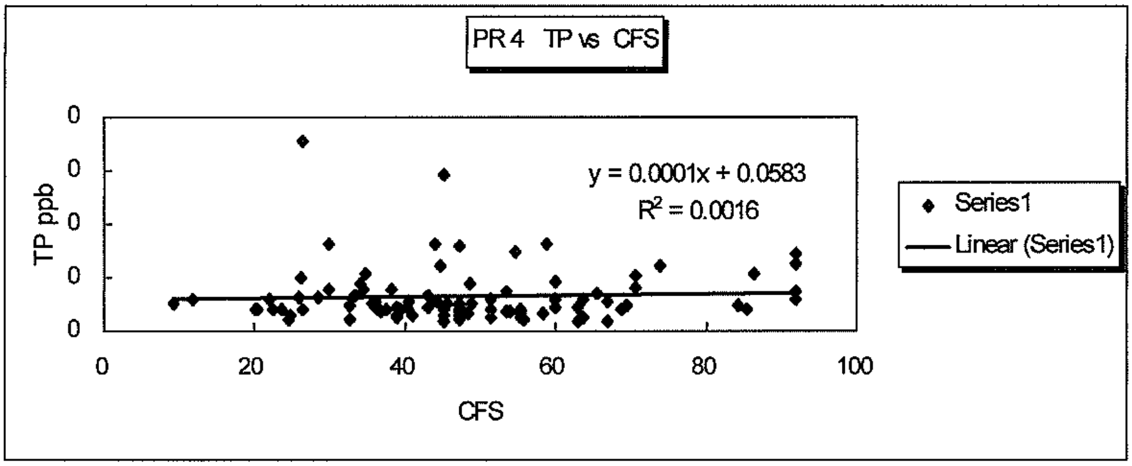

runoff derived from streamflow data provided by the U.S. Geological Survey

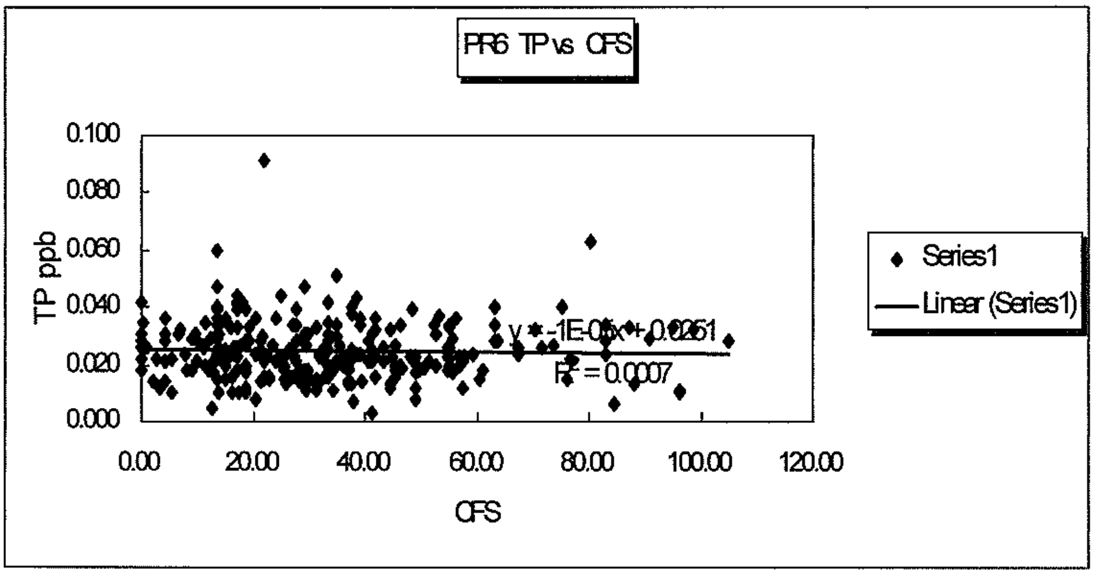

CC 1 TP vs CFS
TP ppb
1
1
1
0
0
0
0
0
0
20
40
60
80
100
120
CFS
y = 0.0008x + 0.0788
R2 = 0.0374
Series1
Linear (Series1)


PRO TP vs. CFS
TP ppb
0
0
0
0
0
0
0
0
10
20
30
40
50
60
CFS
y = 0.0002x + 0.0331
R2 = 0.0472
Series1
Linear (Series1)


PR1 TP vs. CFS
TP ppb
0
0
0
0
0
0
0
0
0
0
20
40
60
80
100
120
CFS
y = -0.0002x + 0.039
$R^2$ = 0.1894
Data B
Linear (Data B)


PR3 TP vs. CFS
TP ppb
0.400
0.300
0.200
0.100
0.000
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
CFS
y = 0.0008x + 0.0446
$R^2$ = 0.1587
Series1
Linear (Series1)


PR 4 TP vs CFS
y = 0.0001x + 0.0583
$R^2$ = 0.0016
TP ppb
0
0
0
0
0
0
0
20
40
60
80
100
CFS
Series1
Linear (Series1)


PR6 TP vs CFS
TP ppb
0.100
0.080
0.060
0.040
0.020
0.000
0.00
20.00
40.00
60.00
80.00
100.00
120.00
CFS
Series1
Linear (Series1)