Water Quality and Sediment Composition Study of the Lake Madison Watershed and Bourne Slough

Prepared for
Lake County Watershed Improvement Project
Madison, South Dakota

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Executive Summary

Introduction

This report describes the purpose, methods, and results of a study of phosphorus and suspended solids from the city of Madison storm sewers and phosphorus concentrations in the sediments and water of Bourne Slough. The study was a contribution to the overall goal of the Lake County Watershed Improvement Project (LCWIP), which is to reduce phosphorus loading to Lake Herman/Lake Madison/Brant Lake watershed by 50 percent. The objectives of this study are: (1) to measure and evaluate phosphorus loading from the City of Madison storm sewers during spring snowmelt and storm events, and (2) evaluate the Bourne Slough sediments for potential benefit of dredging of the slough. The City of Madison is the county seat for Lake County. Bourne Slough receives the inflow from Silver Creek and then drains directly into Lake Madison .

Stormwater Runoff in Madison

For this study, the urban area of Madison was delineated into 30 catchments (i.e., drainage areas) and 25 monitoring stations (11 storm sewer outlets; 14 in-stream) were sampled during a spring snowmelt and three storm events. Water samples were analyzed for total phosphorus, dissolved phosphorus, soluble reactive phosphorus, and total suspended solids. The spring snowmelt runoff contained primarily dissolved phosphorus, whereas the larger the storm event, the greater the proportion of particulate phosphorus. Overall, total phosphorus was highly correlated with total suspended solids.

The average total phosphorus concentration was 0.585 mg/L for all sites. The mean concentrations for each catchment ranged from 0.278 mg/L to 0.877 mg/L. Phosphorus concentrations from the storm sewer outlets were not significantly different from the concentrations in the receiving water, but the storm sewers did contribute a disproportionate amount of particulate phosphorus and suspended solids. The estimated phosphorus load from all catchments for a normal year of precipitation (24 inches) is 1445 pounds of phosphorus. On a per acre basis, the catchments with the greatest phosphorus were in the central part of the city, but are relatively small catchments.

Best management practices (BMPs) should be selected based on the site-specific conditions where phosphorus loads have been shown to be high. The city of Madison should also consider runoff pollution prevention measures, such as pavement management to reduce the runoff of solids that carry particulate phosphorus and other pollutants. Street sweeping and other reductions of particulate materials entering Silver and Memorial Creek can substantially reduce the phosphorus loading from the city.

Bourne Slough Phosphorus

Survey results from Bourne Slough show a surface area of 92 acres. A map of the Bourne Slough sediments was created that shows 410,000 cubic yards of sediment in the slough. Results from sediment core samples indicated the Bourne Slough sediments have high total phosphorus concentrations. Only about five percent of the phosphorus could potentially be released as dissolved phosphorus, although the remaining 95 percent could enter the water column as suspended sediments. The high proportion of particulate phosphorus in the water column is most likely a result of input from Silver Creek.

Excavating a portion of the sediments and rerouting the flow in the slough could potentially improve sedimentation in the basin, thereby reducing phosphorus entering Lake Madison. The flow path within the slough would need to be increased, most likely by building a barrier within the slough that would route the flow around the perimeter of the slough. Additional hydraulic modeling and engineering design would be needed to estimate the phosphorus removal efficiency with the adjusted slough depth and water flow.

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1.0 Introduction

1.1 Purpose

This study is intended to contribute to the overall goal of the Lake County Watershed Improvement Project (LCWIP), which is to reduce phosphorus loading to Lake Herman/Lake Madison/Brant Lake watershed by 50 percent. Phosphorus is the nutrient of interest in this study because it is generally the limiting factor that controls the growth of algae in lakes. If phosphorus is reduced by 50 percent, there will be a proportional decrease in algal concentration in the lakes. The lower the phosphorus concentration, the greater the reduction in algae per unit of phosphorus. A 50 percent reduction in tributary phosphorus loading to the lakes is expected to reduce algal concentration by 88 to 90 percent.

The objectives of this study are: (1) to measure and evaluate phosphorus loading from the City of Madison storm sewers during spring snowmelt and storm events, and (2) evaluate the Bourne Slough sediments for potential benefit of dredging of the slough. An earlier study of nutrient loading to Lake Madison and Brant Lake had measured runoff from the City of Madison, but the LCWIP initiated this study to acquire more detailed information on phosphorus loading from storm sewers within Madison to better determine where best management practices could be implemented. The earlier study had noted that the Bourne slough receives phosphorus from Silver Creek, but because the slough is shallow it has a limited capacity to retain phosphorus. Therefore, it was suggested that a small sediment removal project could increase the depth around the mouth of Bourne Slough and increase phosphorus retention. The methods and results for the two parts of this study—the storm sewer analysis and the sediment analysis—are divided into two sections within this report. The conclusions and recommendations address both parts of the study.

1.2 Site Description

The City of Madison is the county seat for Lake County; with a population of 6,650, it is the largest municipality in the county. The city has a surface area of about 3.5 square miles and is centrally located within the Lake Madison watershed, which drains 45.6 square miles within Lake County. Lake County is 528 square miles. Lake Madison is approximately three miles southeast of the city of Madison. Bourne Slough receives the inflow from Silver Creek and then drains directly into Lake Madison (Figure 1).

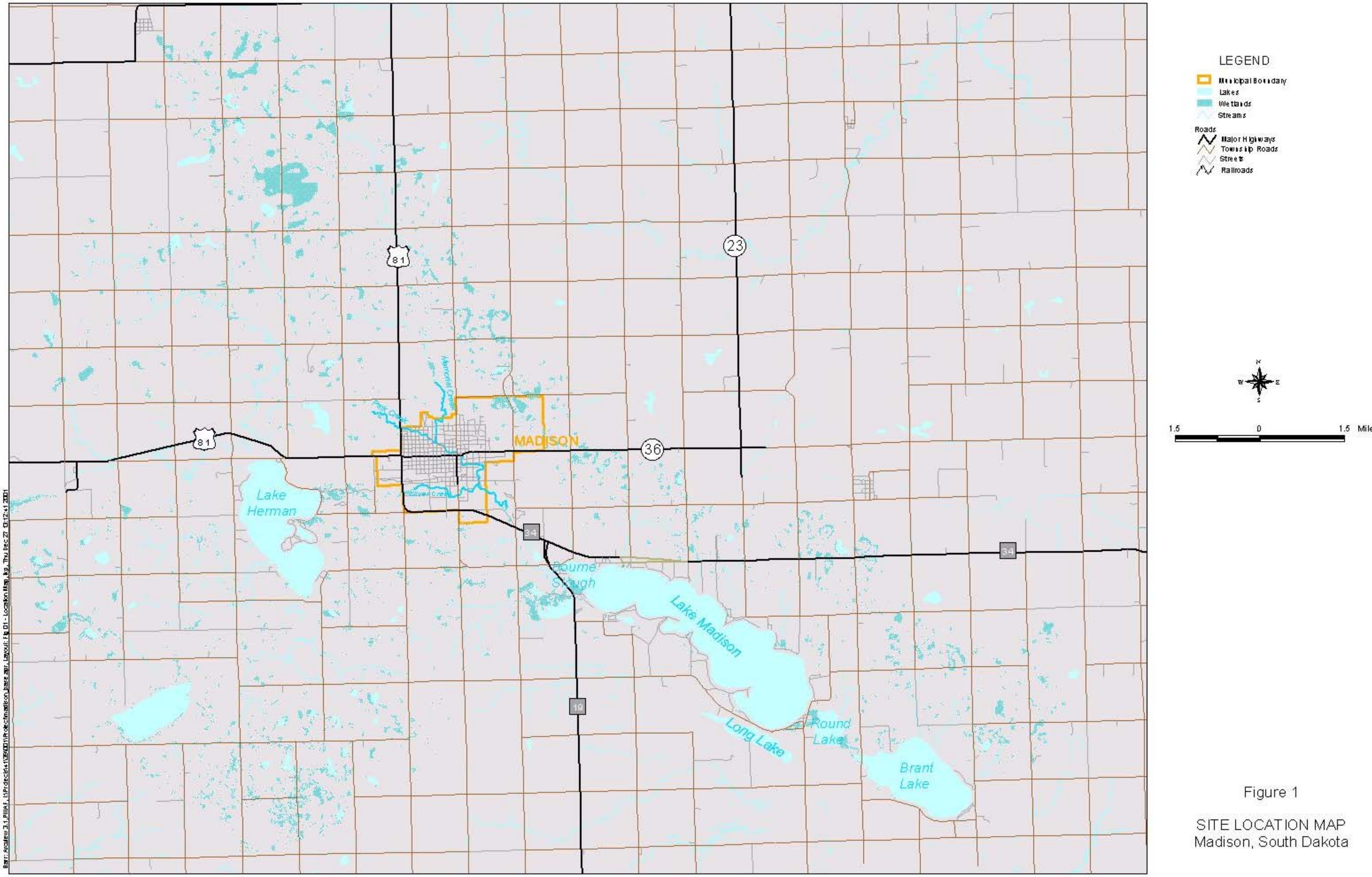

Figure 1

SITE LOCATION MAP
Madison, South Dakota

Memorial Creek is the main stream running through the center of Madison. Park Creek is a tributary to Memorial Creek, flowing from west to east in the northwest section of the city. Silver Creek runs west to east on the southern flank of the city and joins Memorial Creek at the city's southeast corner. The Memorial Creek and Silver Creek subwatersheds are part of the Big Sioux Basin. Brant Lake drains to Skunk Creek, which in turn drains to the Big Sioux River.

To control frequent flooding, which has historically been a deterrent to economic growth, Memorial Creek has been channelized and banks protected with a bulkhead throughout much of the city, beginning at Memorial Park. Memorial Park is downstream of the confluence of Park Creek and Memorial Creek and the park contains a pond with bulkhead extending along both shorelines.

The focus of water quality monitoring for this study was the city's storm sewer system, which drains the streets, residential, commercial, and light industrial areas of the city. Sanitary sewage is treated at Madison's wastewater treatment plant, which has a capacity of 1.75 MGD and treats an average of 0.8 MGD. The WWTP has secondary oxidation and uses infiltration lagoons, located north of Bourne Slough. There is no surface discharge from the WWTP.

Normal (1961-1990) annual precipitation in the Madison area is about 24 inches; 75 percent of the precipitation is during April through September (USDA 1972). Most of the precipitation (97%) returns to the atmosphere by evaporation and only one percent becomes streamflow (Hansen 1986). The mean annual temperature is 46 °F and the range is –30 to 110 °F.

Lake Madison and Brant Lake are included on the 1998 South Dakota 303(d) Waterbody List of impaired waters. They are listed for total phosphorus and exceedence the Carlson Trophic State Index threshold of 50. Because the two lakes are on the 303(d) list, a Total Maximum Daily Load (TMDL) study is required for the lakes. The Phase I Watershed Assessment Final Report (Witmuss and McIntire 1998) served as the TMDL for the lakes (http://www.state.sd.us/denr/DFTA/ WatershedProtection /TMDL/TMDLMADISONBRANT.htm). The TMDL goal for the watershed is a 50% reduction in total phosphorus. A 50% reduction in phosphorus load is expected to lead to an 88% drop in chlorophyll *a* concentration (from 52 µg/L to 6 µg/L).

2.0 Methods for Storm Sewer Analysis

2.1 Review of Historical Records and Reports

Several reports were provided by the Lake County Conservation District (LCWD), which were reviewed and water quality data was extracted for compilation in this report. The reports directly relevant to this study area are:

1. USDA, SCS. 1972. *Water and Related Land Resources Big Sioux Basin*

2. Hansen, D.S. 1986. *Water Resources of Lakes and Moody Counties, South Dakota*. USGS Water Resources Investigation Report 84-4209

3. Wittmuss, A. and M. McIntire. 1998. *Phase I Watershed Assessment Final Report Lake Madison/Brant Lake Lake County South Dakota.* South Dakota Watershed Protection Program, South Dakota Department of Environment and Natural Resource. October 1998.

The first two reports provided some general background on hydrology of the area, but contained no water quality data that could be used for comparison with this study. The third report, Wittmuss and McIntire (1998), was the source of previous water quality data and the basis for this follow up study. Because the report is often referenced in this report, the abbreviation WAFR (Watershed Assessment Final Report) is used throughout the remaining report. WAFR includes the results of a lake and watershed water quality study for Lake Madison and Brant Lake (the lakes). The assessment began in 1994 by establishing monitoring sites in the creeks (11), lakes (6), and storm sewers (3). The watershed modeling was primarily focused on the agricultural/rural area because it represented most of the 44,000-acre (17,807 ha) watershed. Water quality and quantity monitoring data during 1995 were used to estimate the hydrologic and phosphorus budgets for the lakes. Silver Creek (which includes Memorial Creek) contributed 92 percent of the annual phosphorus load to Lake Madison. The city accounted for 13 percent of the total phosphorus load to Lake Madison in 1995; thus, rural land use draining to Silver Creek accounted for another 79 percent of the phosphorus load to Lake Madison.

In 1995, six samples were collected within the city limits but were insufficient to assess urban runoff. Therefore, three automatic samplers were installed in 1997 to gather water quality data from the storm sewers. The location and water quality data from these sites are discussed in more detail below. Water quality data from the 1995 and 1997 monitoring are compared to results from this study in 2001.

2.2 Water Quality

2.2.1 Data Collection

A combination of in-stream and storm sewer outlet sample stations were selected to collect data to estimate the relative impacts among the city's storm sewer network to the phosphorus loading in Memorial and Silver Creeks. Water quality samples were collected during one spring snowmelt event and three storm events. The 25 monitoring sites are described in Table 1 and shown as a schematic in Figure 2. Sample sites were selected to represent key upstream and downstream locations relative to storm sewer outlets in Madison. Larger and representative storm sewers were selected for the outlet samples and the stream samples were selected based on the chosen outlets. The 25 monitoring stations consist of eleven storm sewer outlets and fourteen in-stream sites.

For this study, Memorial Creek was divided into four reaches; Park Creek and Silver Creek were assigned their own reach identifications (Figure 2). These reach identifications were used to provide a reference and to statistically evaluate the results.

A reconnaissance field trip of the sample sites was completed on March 19, 2001, and digital photographs were taken of the samples sites and provided to LCWIP for review prior to the first sample collection.

2.2.2 Precipitation

Precipitation data for this study are from Madison 2E Station (39509002), a National Weather Service cooperative station. The weather station is approximately two miles east of the city of Madison. The same station was used for precipitation data in the WAFR (see p 63 of the report). The data is subjected to the NWS quality control and the data is published.[1] Precipitation and temperature data for February through October, in the years 1995, 1997, and 2001, were downloaded from the NOAA web site and used for comparison among the three years (http://lwf.ncdc.noaa.gov/oa/ncdc.html).

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[1] Electronic communication with Al Bender, South Dakota State Climatologist. He recommended using precipitation data from Madison 2SE because of the quality control by NWS.

Table 1. Sample Site Descriptions for Madison Storm Sewer and Stream Water Quality Monitoring

Table 1

#	ID	Comments	Reach	Stream/Outlet	Location
1	1	Memorial Creek inlet to City	1	Stream	Eighth St NW & Highland Ave (US 81)
2	2	Downstream of pond outlet	1	Stream	Eighth St NW & S Olive Ave
3	3	36" outlet; LMC-2 in 1997 study	1	**Outlet**	North of Sixth St NW, between Chicago & Liberty Aves
4	4	Creek sample before confluence with Park Creek Tributary	1	Stream	South of Seventh St NW & Blanche Ave N
5	5	Park Creek Tributary inlet to City	2	Stream	Spencer St & west of Vaneps Ave N
6	6a	Park Creek site, upstream of 30" outlet	2	Stream	Seventh St NW & west of Egan Ave N
7	6b	30" outlet	2	**Outlet**	Seventh St NW & west of Egan Ave N
8	7	Memorial/Park Creek downstream of confluence with Park Creek	3	Stream	Fifth St NW & west of Egan Ave N
9	8	Memorial/Park Creek downstream of Memorial Park	3	Stream	Fourth Ave NW & Egan Ave N
10	9a	Memorial Creek upstream of 24" outlet	3	Stream	Third St NE & Washington Ave N
11	9b	24" outlet	3	**Outlet**	Third St NE & Washington Ave N
12	10	36" outlet	3	**Outlet**	South of Second St NE & Lincoln Ave N
13	11	Memorial/Park Creek upstream of multiple storm sewer outlets	3	Stream	North of Center St & Lincoln Ave N
14	12a	Memorial/Park Creek upstream of 30" & 60" outlets	4	Stream	First St SE & Division Ave S
15	12b	30" outlet	4	**Outlet**	First St SE & Division Ave S
16	13	60" outlet	4	**Outlet**	First St SE & Division Ave S
17	14	72" outlet; LMC-3 in 1997 study	4	**Outlet**	Near railroad tracks between Garfield and Jefferson Aves S
18	15	36" outlet	4	**Outlet**	Third St SE & Jefferson Ave S
19	16	Memorial/Park Creek before confluence with Silver Creek	4	Stream	Fourth St SE & Jefferson Ave S
20	17	Silver Creek inlet to City	5	Stream	Seventh St SW & Highland Ave (US 81)
21	18	48" outlet	5	**Outlet**	South of Fourth St SW & Union Ave S
22	19	18" outlet	5	**Outlet**	South of Fourth St SW & Egan Ave S
23	20a	Silver Creek upstream of 36" outlet	5	Stream	South of Sixth St SE & Grant Ave S
24	20b	36" outlet	5	**Outlet**	South of Sixth St SE & Grant Ave S
25	21	Silver Creek downstream of confluence with Memorial/Park Creek	6	Stream	

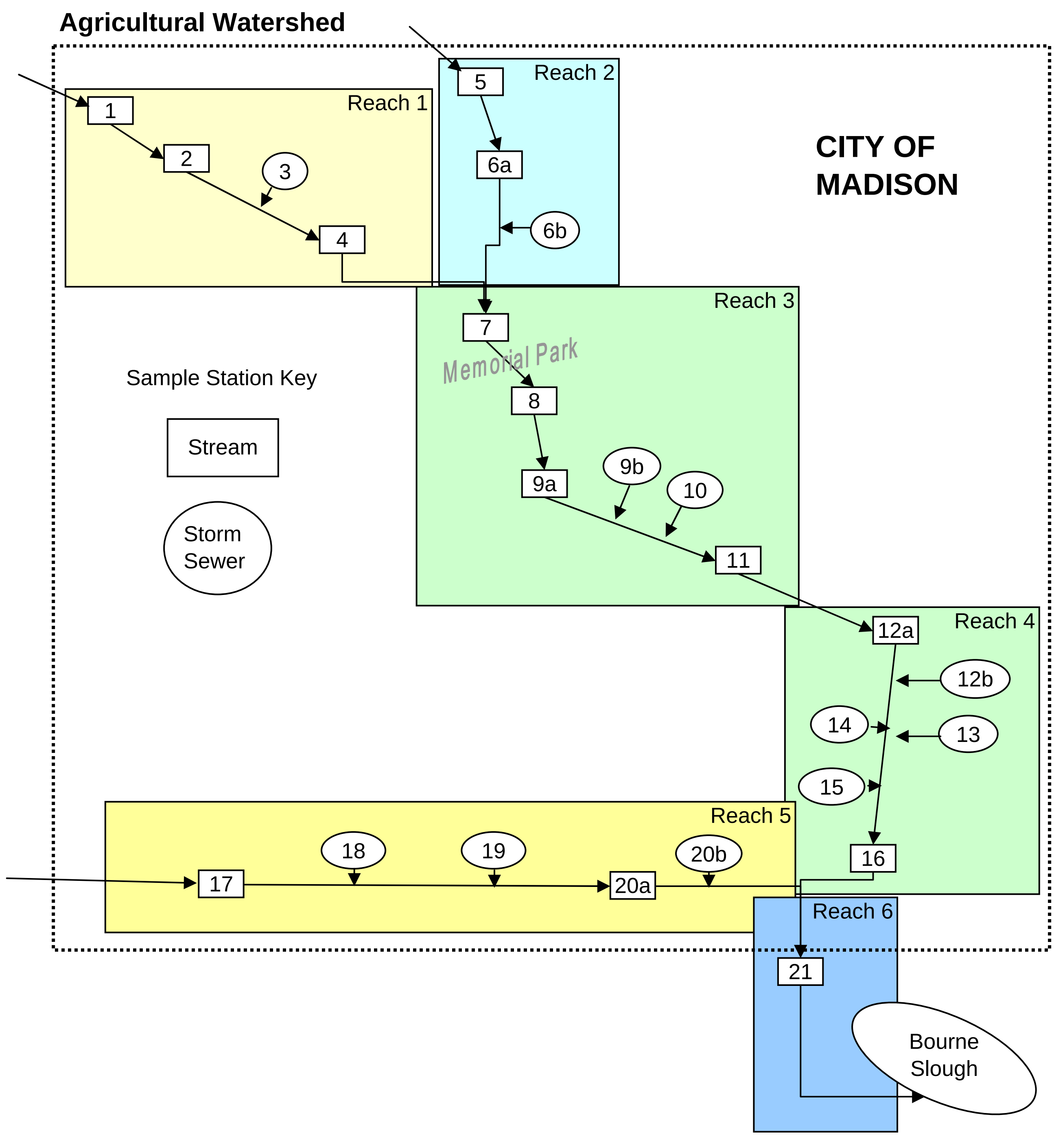


Figure 2
Sample Site Schematic for Madison Storm Sewer Water Quality Monitoring

2.3 Evaluation of Phosphorus Loading

Nutrient and solids data was collected during snowmelt and rain storms at 25 stations throughout the city of Madison to assess the relative contribution of the urban runoff via storm sewers to the phosphorus concentration in Memorial Creek and Silver Creek. The scale of this study limited the conclusions that can be made about the phosphorus loading from the urban area of Madison relative to the rural areas of the watershed. A more quantitative measure of the contribution to the annual mass loading of phosphorus would require continuous flow monitoring and automated sampling during storm events, as well as sampling during dry periods. From the nutrient and solids concentration data we can assess if the urban stormwater runoff from specific storm sewer outlets appear to significantly contribute to the phosphorus concentration in the creeks. The main point of assessing the concentration data is determining if the concentration of phosphorus in the urban runoff is significantly higher than upstream concentrations and if it appears to influence the concentration of phosphorus in the downstream receiving waters.

Annual phosphorus loading from drainage areas in Madison were estimated using the Simple Method (Schueler 1987). The method was used by WAFR to estimate urban runoff, based on samples that were collected in 1997 in three locations in Madison. The same method is used for this study to extrapolate from storm events to annual loading. The Simple Method is used specifically to estimate annual loading based on even mean concentrations for storm events, land cover, and annual rainfall. The two equations used in the Simple Method are:

$$Li = P \cdot f \cdot R_i \cdot C_i \cdot A_i \cdot 0.2267 \quad (1)$$

$$R_i = 0.05 + 0.009 \cdot I \quad (2)$$

Where:

Li = Annual pollutant load (lb/yr)

P = Annual precipitation (in/yr)

f = Correction factor for storms with no runoff = 0.9

R_i = Weighted-average runoff coefficient for land use area

C_i = Event-mean concentration (mg/L)

A_i = Catchment area (acres)

I = Percent imperviousness

In WAFR the annual precipitation for 1995 was used in the estimations of urban runoff, although the samples were collected in 1997. The event mean concentration for total phosphorus in 1997 was 0.995 mg/L. The annual precipitation in 1995 was 33.34 inches and in 1997 annual precipitation was 20.19 inches.

For this study, the average phosphorus concentration for the four sampling events was used as the event mean concentration for each station. Land use/cover was derived from GIS coverages, as described below, and percent imperviousness was applied to each land use. The total percent imperviousness for each drainage area was used in Equation 2 to determine the runoff coefficient. This approach differs somewhat from the way WAFR used the Simple Method. In the WAFR analysis land use categories were determined for the entire city and a runoff coefficient was calculated for each land use category. Furthermore, the WAFR used an average phosphorus concentration from all samples and applied it to the whole city, whereas in this study an average total phosphorus was applied to each catchment, based on sampling from the storm sewer outfall in the catchment or applying an average phosphorus concentration from a nearby catchment with similar land use. The objective in WAFR was to estimate urban runoff, as compared to rural runoff. The objective in this study was also to get an estimate of the urban runoff contribution to Silver Creek, but in addition, to evaluate the relative contributions of the subwatersheds within the city of Madison.

2.4 GIS Coverage

Digital information used in the analysis was obtained from several sources. Digital coverages of roads, creeks and the Madison municipal boundary were obtained from the South Dakota Department of Transportation. The land cover data was obtained from the United States Geological Survey National Land Cover Characterization Project. This data was created using satellite photography, and a variety of supporting information including topography, census, agricultural statistics, soil characteristics, other land cover maps, and wetlands data to determine and label the land cover type at 30 meter resolution. The data reflects land cover in the early 1990s.

The storm sewer information was digitized from the City's storm sewer maps. Watersheds to each of the separate storm sewer systems were estimated visually on the storm sewer map and digitized into the GIS database. Monitoring locations were also manually digitized into the database (Figure 3).

Land use/cover for each watershed was calculated in GIS. The land cover information was intersected with the watersheds and a table was created showing the area of each type of land use within each of the drainage areas.

Aerial Photo Source: USGS, 1998.

Figure 3

DELINEATED URBAN CATCHMENTS AND SAMPLE LOCATION MAP
Madison, South Dakota

3.0 Results and Discussion of Water Quality

3.1 Land Use and Cover

The City of Madison was delineated into 30 catchments based on storm sewer maps and USGS. 7.5 minute quadrangle maps of the area (Figure 2). The "ST" prefix identifies drainage areas to one of the in-stream monitoring stations and the "WS" identifies watersheds drained by storm sewers. Table 2 is a summary of the total area and land use/cover for each of the thirty catchments. The total area for of all catchments is 1645 acres. The northeast section of the city that includes the airport was not included in our analysis, because the area is not drained by storm sewers and is distinctly more rural land use than the areas of the city that were delineated for this study. The land use consists of 56% residential, 9% commercial/industrial, and 5% parks (Table 2). This delineation includes land cover as well as land use and, therefore, includes categories such as deciduous, mixed forest, and open water.

The percent imperviousness is shown in the top row of Table 2. Commercial and industrial land uses have the highest percentage of imperviousness (80%), excluding bare rock; whereas vegetated land cover has the lowest (5%).

3.2 Snowmelt and Storm Event Monitoring

3.2.1 Sample Events

Grab samples were collected during snowmelt on March 29, 2001. The maximum temperature on March 28 was 40 °F (4.4 °C) and minimum and maximum of March 29 were 32°C and 39°C. Freezing and thawing had occurred prior to this sample collection, but March 29 provided sufficiently warm temperatures for a period of time to generate snowmelt runoff.

The sampled storm event were April 11(Spring), June 13 (Summer), and November 24 (Fall), 2001. The first sampled storm event was on April 11, 2001, and was recorded at the Madison 2SE station as 0.51 inches of precipitation. A 0.73 inches were recorded on April 7, 2001, and on April 12th, 1.26 inches were recorded at the Madison 2SE station.

The second sampled storm event was on June 13, 2001, and was recorded at the Madison 2SE station as 1.88 inches of precipitation. This was the second largest recorded storm in 2001. The sampled storm was preceded by a 1.19 rainfall on June 10th. Prior to June 10th there were numerous small events (less than 0.5 inches).

Table 2. Summary Land Use/Cover for the City of Madison, S.D.

Watershed	Bare Rock	Commercial	Deciduous	Emergent	High Intensity	Low Intensity	Mixed Forest	Open Water	Pasture	Row Crops	Small Grains	Urban Recreation	Total	Imperv	% Imp	R
% Imperv. =	100%	80%	5%	75%	75%	25%	5%	100%	15%	15%	5%	15%				
ST-21	0.53	-	3.40	0.67	-	10.17	-	-	36.47	97.18	-	8.39	156.81	25.05	16%	0.194
ST-10	-	2.22	-	-	0.24	2.62	-	-	-	-	-	-	5.08	2.61	51%	0.513
ST-11	-	0.59	-	-	-	12.46	-	-	-	-	-	-	13.05	3.59	27%	0.297
ST-12	-	0.58	1.10	-	0.90	52.85	-	-	4.37	0.26	0.22	0.16	60.45	15.14	25%	0.275
ST-14	-	-	-	-	-	5.37	-	-	1.31	2.77	-	0.06	9.50	1.96	21%	0.236
ST-15	-	-	0.59	-	-	4.00	-	-	1.55	0.12	-	0.76	7.01	1.39	20%	0.229
ST-16	-	-	0.26	-	-	2.37	-	-	1.57	0.20	-	1.18	5.58	1.05	19%	0.219
ST-18	1.11	44.10	5.78	6.23	-	28.47	-	0.44	37.87	37.61	-	19.96	181.58	63.23	35%	0.363
ST-19	-	12.73	1.56	-	-	70.03	-	-	9.00	15.58	-	2.61	111.52	31.85	29%	0.307
St-2	-	1.49	0.21	-	-	11.01	-	-	-	0.42	-	2.83	15.96	4.44	28%	0.300
ST-20	0.22	13.85	7.91	0.67	-	51.38	-	3.56	25.39	33.13	0.22	20.03	156.36	40.40	26%	0.283
ST-3	-	0.22	0.71	-	3.90	30.24	-	-	-	1.41	-	2.74	39.22	11.32	29%	0.310
ST-4	-	-	-	-	1.10	34.99	-	-	-	-	-	0.16	36.26	9.60	26%	0.288
ST-6	-	0.94	0.63	0.06	4.82	48.68	-	-	1.92	6.58	-	0.32	63.96	17.94	28%	0.302
ST-7	-	0.96	-	-	0.31	6.27	-	-	-	-	-	3.04	10.58	3.02	29%	0.307
ST-8	-	0.00	0.08	0.47	-	5.97	0.02	-	-	-	-	0.26	6.81	1.89	28%	0.300
ST-9	-	3.89	-	-	3.97	24.26	-	-	-	-	-	1.47	33.58	12.37	37%	0.382
WS-10	-	9.14	-	-	2.00	69.35	-	-	-	-	-	1.19	81.67	26.33	32%	0.340
WS-11	-	0.39	-	-	0.47	9.17	-	-	-	-	-	-	10.03	2.96	29%	0.315
WS-12a	-	2.89	3.33	-	9.07	49.90	-	-	24.19	14.04	-	2.64	106.07	27.89	26%	0.287
WS-12b	-	1.78	6.21	0.67	-	-	-	-	39.95	3.72	-	-	52.35	8.79	17%	0.201
WS-14	-	17.58	0.22	-	6.31	57.97	-	-	1.52	2.47	0.04	0.14	86.27	33.93	39%	0.404
WS-15	-	1.63	0.23	-	-	22.28	-	-	2.99	1.73	0.19	-	29.04	7.60	26%	0.286
WS-18	-	12.83	0.89	-	0.55	112.76	-	-	12.21	2.93	-	1.80	143.96	41.45	29%	0.309
WS-19	-	5.34	-	-	-	5.67	-	-	-	2.53	-	-	13.53	6.07	45%	0.453
WS-3	-	0.69	-	-	4.54	62.50	-	-	-	-	-	0.61	68.35	19.67	29%	0.309
WS-6	-	8.86	0.22	0.15	13.93	47.03	-	-	-	1.57	-	7.80	79.55	30.82	39%	0.399
WS-7	-	1.11	0.89	0.22	0.05	16.68	-	-	-	-	-	1.59	20.54	5.54	27%	0.293
WS-8	-	1.66	0.81	0.42	0.66	5.24	0.20	-	-	-	-	0.34	9.32	3.54	38%	0.392
WS-9	-	1.70	0.67	-	3.75	18.95	-	-	-	-	-	5.76	30.83	9.81	32%	0.336
TOTALS	1.87	147.17	35.71	9.56	56.56	878.64	0.22	4.00	200.30	224.26	0.67	85.84	1,644.82	471.26	29%	0.308
Percentage		9%	2%	1%	3%	53%	0%	0%	12%	14%	0%	5%	100%			

The third sampled storm event was on November 24, 2001, and was recorded at the Madison 2SE station as 0.65 inches of precipitation. This storm followed an exceptionally dry antecedent period. The previous record precipitation of more than 0.01 inches, was 1.15 inches on October 10th and 0.22 inches on October 13th.

3.2.2 Precipitation

A comparison of monthly precipitation for February through September, for the Normal period (1961-1990), 1995, 1997, and 2001, indicates that 1995 was well above average, 1997 was well below normal, and 2001 was very close to normal (Table 3). The notable exceptions, by month, were the above normal precipitation in April (6.26”) and the below normal precipitation in August (0.4”).

Table 3 Monthly Precipitation at Madison 2SE Weather Station

Month	Normal (61-90)	1995	1997	2001
February	0.75	0.11	0.96	0.84
March	1.84	2.95	0.5	0.94
April	2.37	6.77	2.3	6.26
May	2.96	4.59	2.51	2.59
June	3.63	3.3	1.31	4.11
July	3.07	5.2	1.92	1.88
August	2.93	4.69	2.99	0.4
September	2.37	3.11	4.12	2.78
8-mth Total	19.92	30.72	16.61	19.8
Annual (Jan-Dec)	24.12	33.34	20.19	---

The daily precipitation record for the Madison 2SE station from February 1 to November 27, 2001 is shown in Figure 4. Rainfall in April 2001 was 3.89 inches above normal (monthly mean for 1961-1990), but below the April 1995 monthly total of 6.77 inches. June 2001 monthly total precipitation was 0.48 inches above normal monthly means and 0.81 inches above the April 1995 monthly total. March, May, June, and August in 2001 were below normal precipitation, especially in August when drought conditions left only 0.4” of total rain at the Madison station; the normal for August is 2.93 inches. The largest storm event in 2001 was on April 23, 2001, with a 24 hour total of 2.36 inches.

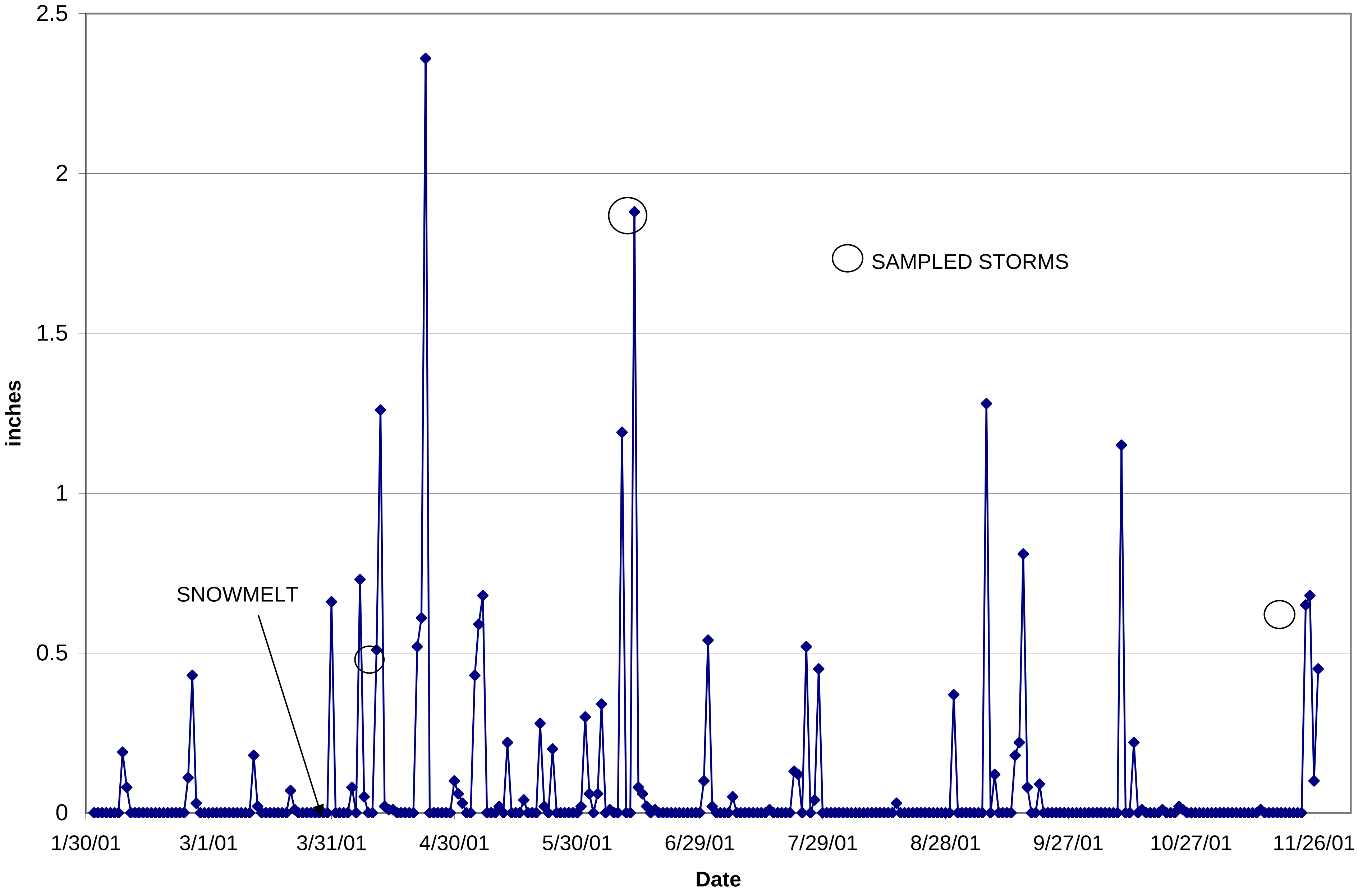


Figure 4
Daily Precipitation at Madison 2SE Station

3.3 Snowmelt and Storm Event Water Quality

The concentrations of phosphorus, for each of the sampling events, are shown in Figures 5, 6, 7, and 8. The data are tabulated in Appendix C. Some general observations are as follows:

- Snowmelt runoff was mostly dissolved phosphorus in the upper reaches of Memorial Creek before receiving substantial contributions from storm sewers. The particulate phosphorus concentrations in the upper branch of Silver Creek before the confluence with Memorial Creek. The concentration at the station 21, the downstream station, was relatively low (total phosphorus less than 0.2 mg/L) compared to the concentrations upstream (total phosphorus concentrations from 0.3 to 1.7 mg/L).

- During the April storm event, total phosphorus concentrations were in a range similar to the spring snowmelt, but there was proportionately more particulate phosphorus in the April storm compared to the snowmelt runoff.

- During the June storm event, which was the biggest precipitation event of all the sampling periods, the total phosphorus concentrations were approximately twice the concentrations of the snowmelt and April storm, but the dissolved phosphorus concentrations were similar to the previous sample events. In other words, the particulate phosphorus concentrations were relatively high during the June storm.

- During the November storm event, the total phosphorus concentrations were generally the lowest of all the sampling periods. A noticeable exception was total phosphorus from Station 13, a storm sewer outlet on the east side of Madison, which had the highest total phosphorus concentration of all stations in November (1.2 mg/L) and the highest concentration recorded for that station. Nearly all the phosphorus was in the particulate form.

All the phosphorus data were combined to evaluate the statistical relationships among the measured parameters. Total, dissolved, and soluble reactive phosphorus concentrations in the stream and in the storm sewer outlets were compared using two-sample t-tests. The means and distribution of the three phosphorus species were not significantly different between the stream sites and the storm sewer sites. Figure 9 is a box-whisker plot of total phosphorus and total dissolved phosphorus grouped by in-stream and storm sewer outfall. This simple comparison illustrates the similarity in the two groups.

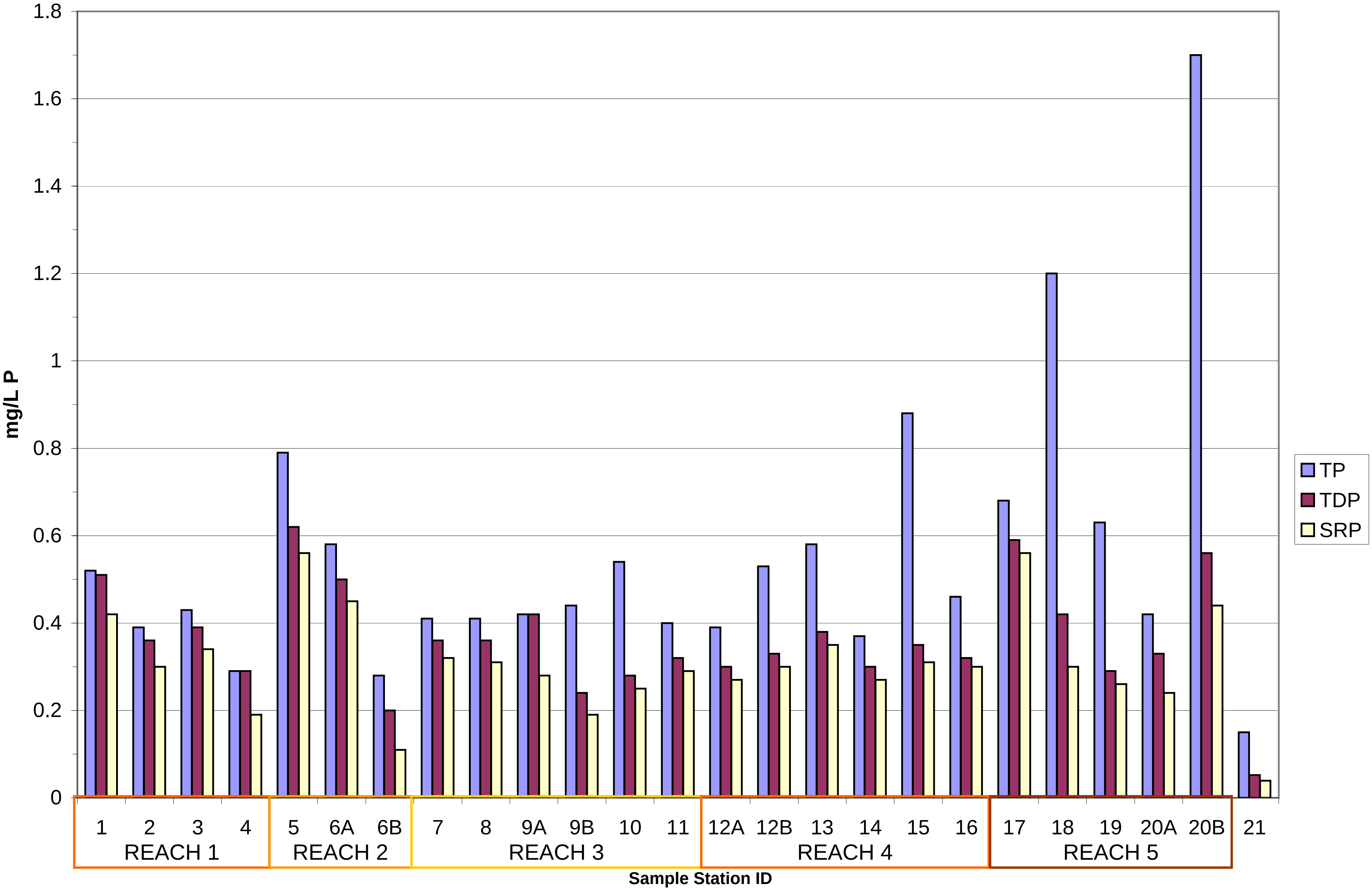


Figure 5
Phosphorus Concentrations During Spring Snowmelt: March 29, 2001

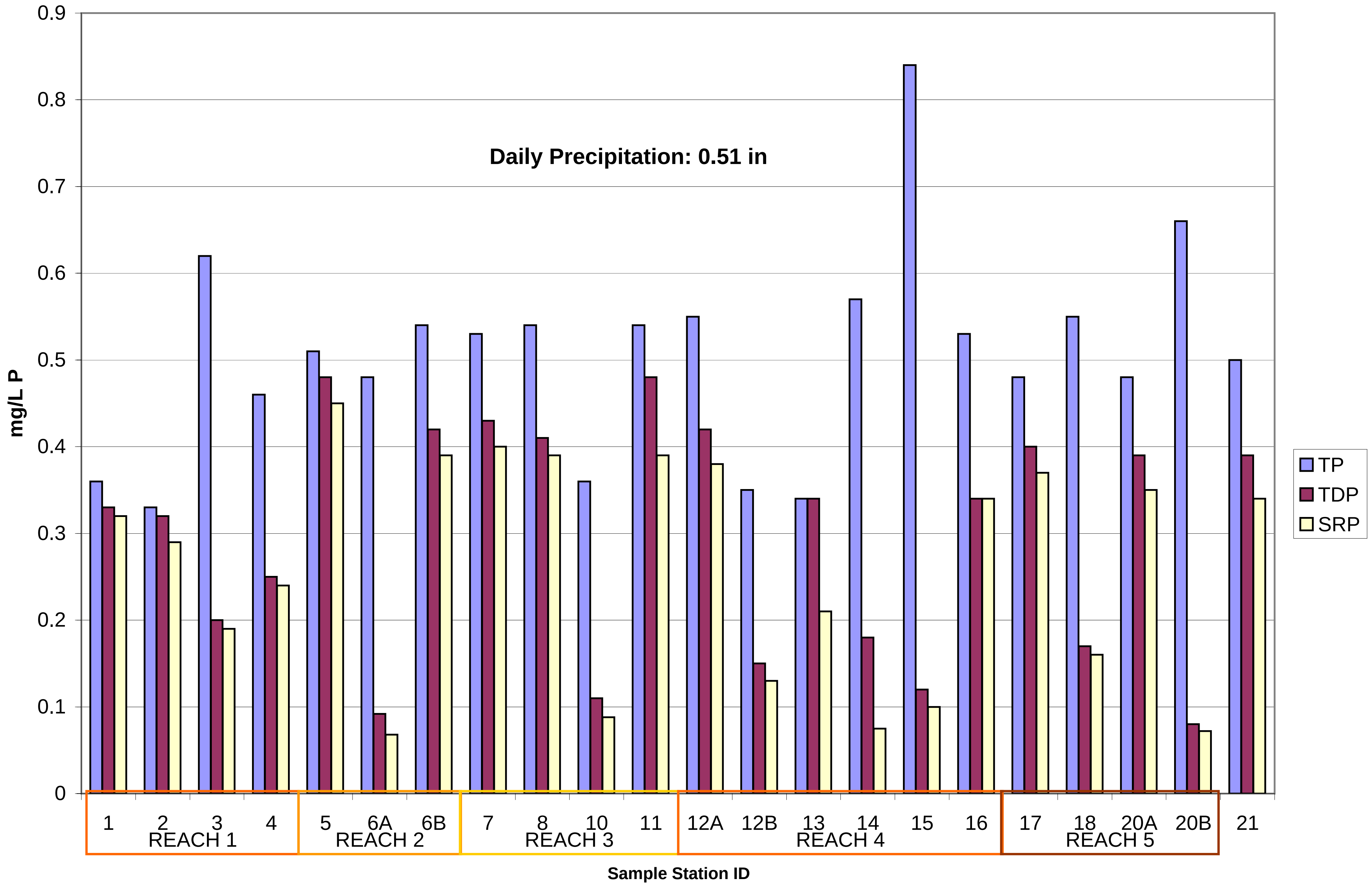


Figure 6
Phosphorus Concentrations During Spring Storm: April 11, 2001

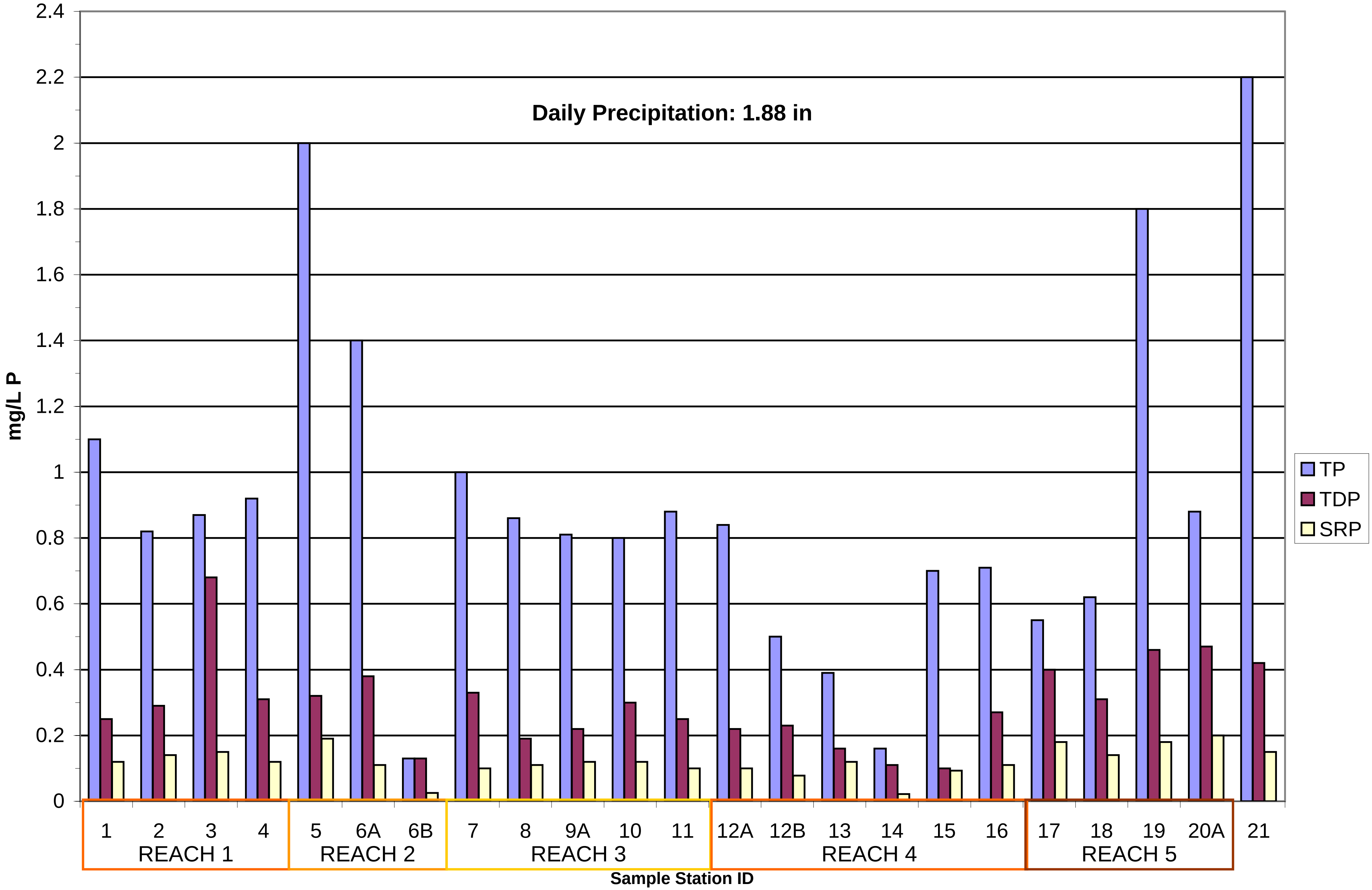


Figure 7
Phosphorus Concentrations During Summer Storm: June 13, 2001

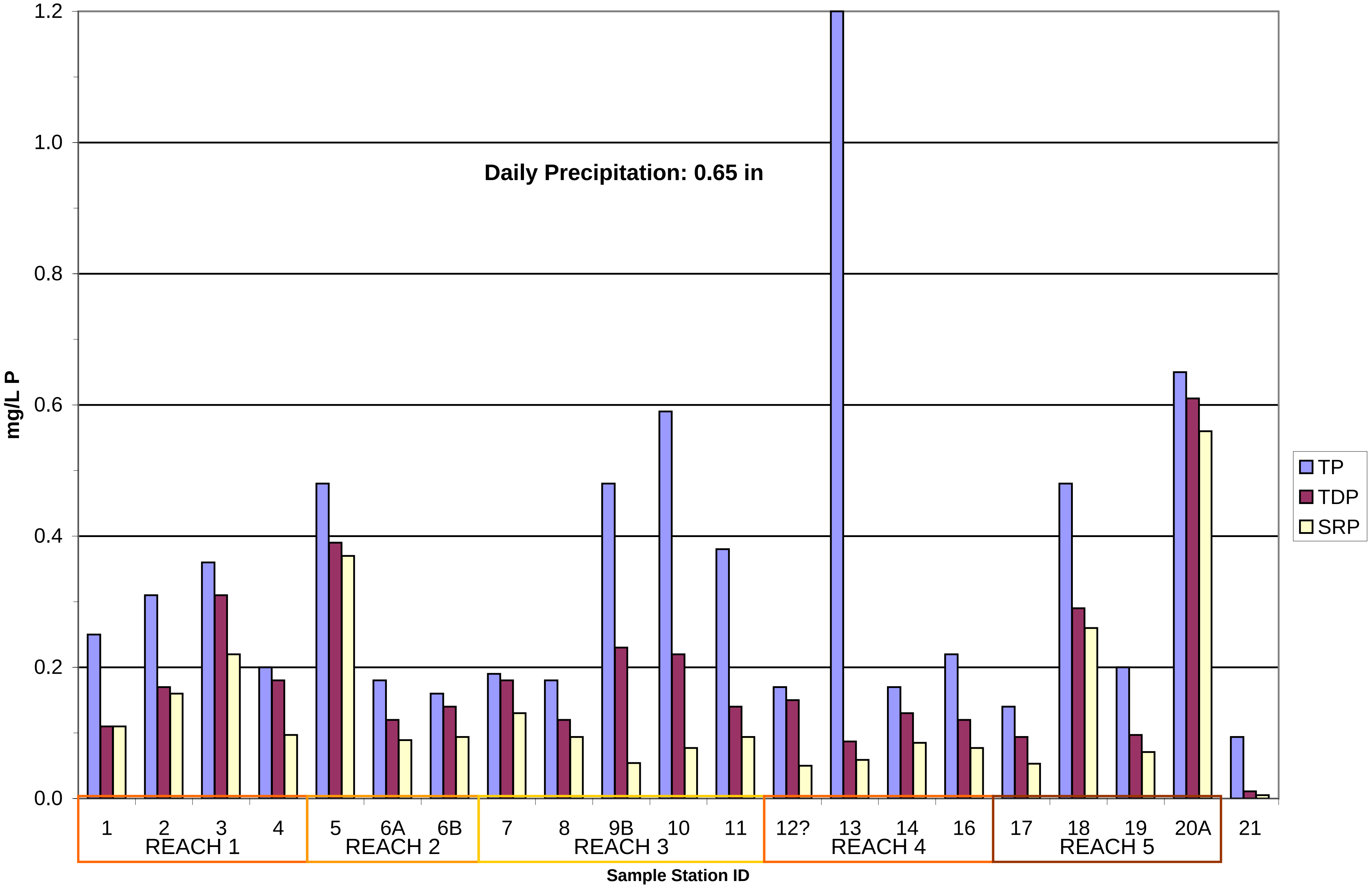


Figure 8
Phosphorus Concentrations During Autumn Storm: November 24, 2001

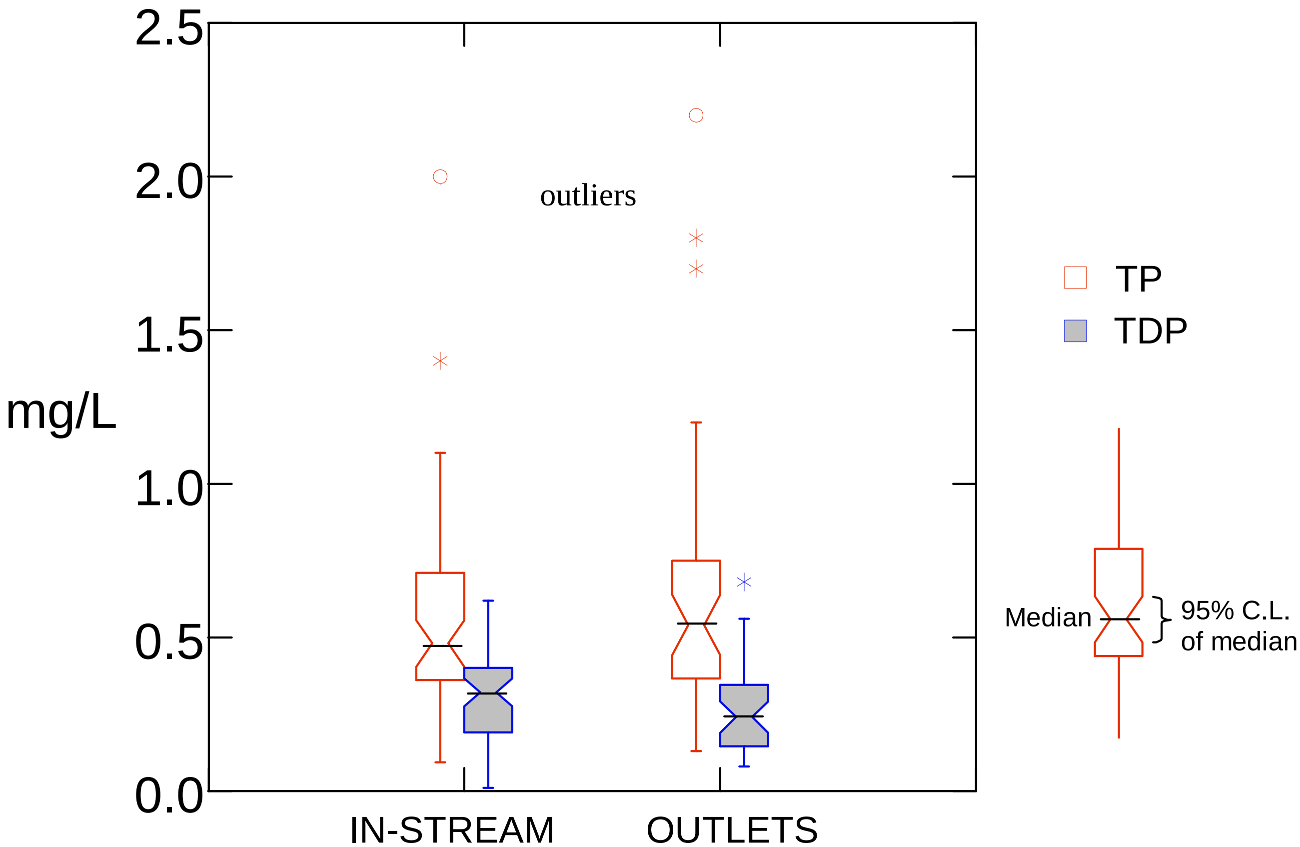


Figure 9
Comparison of TP and TDP in Storm Sewer Outlets and In-stream

There was a significant difference in the fraction of dissolved phosphorus between in-stream and storm sewer outfall. The stream total phosphorus concentrations averaged 73 percent dissolved, whereas the storm sewer outlets had an average dissolved fraction of 43 percent. This is informative for evaluating best management practices to reduce phosphorus in runoff because it indicates that most of the phosphorus in the urban runoff is in the particulate form, which can be removed in properly designed wet detention basins, or other methods of removing solids. This is further supported by the strong correlation between total phosphorus and total suspended solids. The Pearson correlation coefficient for total suspended solids and total phosphorus is 0.789. A linear regression gave the following result:

$$TP = 0.002\ TSS + 0.426 \qquad R^2 = 0.618 \qquad (3)$$

Where TP and TSS are in mg/L. This regression and the other statistics do not include the data from November 24, 2001.

3.4 Comparison of 1995/1997 and 2001 Results

The results of event sampling in 2001 demonstrate the impact of runoff on the water quality of Silver Creek. A number of comparisons can be made between the results from 1995 and 2001 (Table 4). In 1995, the LMT5 station was located at approximately the same place as Station 21 in the 2001 monitoring. Continuous monitoring data from 1995 showed a phosphorus concentration ranging from 0.167 to 0.402 mg/L, with a mean of 0.310 mg/L. This monitoring included mostly dry weather periods; therefore, it may be representative of baseflow conditions. In contrast, the 2001 monitoring was snowmelt and storm events. The total phosphorus concentration at Station 21 ranged from 0.50 to 2.20 mg/L during the spring and summer storms, but was only 0.150 mg/L during the spring snowmelt. Clearly, wet weather periods contributed higher flows and concentrations, resulting in greater nutrient and sediment loading to Lake Madison.

Two of the urban runoff monitoring stations in 1997, LMC-2 and LMC-3, correspond to the 2001 outlet stations 3 and 14. The third urban runoff station, LMC-1 was located in the center of the catchment that drains to station 18. The descriptive statistics of these stations for 1997 and 2001 are compared in Table 5. Certainly differences are to be expected given the different precipitation conditions of the two years (1995 was considerably drier than normal, while 2001 appears be close to normal). Furthermore, the 1997 samples were collected with automated samplers and composited samples throughout a storm event, whereas the 2001 samples were single grab samples during snowmelt and two storm events. Noteworthy similarities between the two years are:

- LMC-2 and 3 showing similar total phosphorus concentrations (means of 0.65 mg/L and 0.57 mg/L)

- LMC-3 and 14 had identical total dissolved phosphorus concentrations (means of 0.18 mg/L)

Noteworthy differences between the two years are:

- TSS concentrations were considerably higher in 1997 than in 2001. This could be caused by longer antecedent periods in 1995, given that it was drier year. The higher TSS in 1995 could also be the result of more complete sampling throughout the storm event.

- TDP was generally higher in the 2001 samples and represented a much higher fraction of TP. The higher TDP fraction is undoubtedly related to the lower TSS in 2001.

- LMC-3 and Station 14 were quite different in the mean and range of TP concentrations. Unfortunately, we do not have similar comparisons for the downstream outlet, Station 15, which appears to drain the same catchment as station 14; and station 15 was shown to be have some of the highest TP concentrations in 2001 among the outlets.

Table 4 Descriptive Statistics for Phosphorus and Suspended Solids at Paired Stations from 1995 and 2001 Monitoring of Silver Creek

ID-1995	ID-2001	Statistic	TP 1995	TP 2001	TDP 1995	TDP 2001	TSS 1995	TSS 2001
LMT2	2	**Mean**	**0.31**	**0.46**	**0.13**	**0.28**	**35**	**69**
		Median	0.32	0.36	0.15	0.17	34	37
		Maximum	0.40	0.82	0.22	0.36	80	200
		Minimum	0.16	0.31	0.05	0.29	4	<4
		Standard Dev	0.06	0.24	0.06	0.08	26	91
LMT3	1	**Mean**	**0.16**	**0.56**	**0.14**	**0.30**	**9**	**104**
		Median	0.16	0.44	0.12	0.29	7	37
		Maximum	0.42	1.10	0.35	0.51	24	340
		Minimum	0.05	0.25	0.07	0.11	2	<4
		Standard Dev	0.10	0.38	0.08	0.17	7	159
LMT4	5	**Mean**	**0.32**	**0.94**	**0.26**	**0.45**	**22**	**200**
		Median	0.31	0.65	0.25	0.44	17	14
		Maximum	0.53	2.00	0.41	0.62	76	770
		Minimum	0.13	0.48	0.09	0.32	6	<4
		Standard Dev	0.12	0.72	0.10	0.13	20	380
LMT5	21	**Mean**	**0.31**	**0.74**	**0.15**	**0.24**	**39**	**98**
		Median	0.32	0.50	0.13	0.35	35	61
		Maximum	0.40	2.20	0.25	0.42	72	200
		Minimum	0.17	0.09	0.08	0.01	7	11
		Standard Dev	0.07	0.86	0.06	0.20	21	90

Table 5 Descriptive Statistics for Phosphorus and Suspended Solids at Paired Stations from 1997 and 2001 Monitoring of Urban Runoff

ID-1997	ID-2001	Statistic	TP 1997	TP 2001	TDP 1997	TDP 2001	TSS 1997	TSS 2001
LMC-1	18*	**Mean**	**1.15**	**0.71**	**0.18**	**0.30**	**661**	**208**
		Median	1.04	0.58	0.17	0.30	550	173
		Maximum	1.96	1.20	0.31	0.42	1636	440
		Minimum	0.72	0.48	0.07	0.17	192	45
		Standard Dev	0.41	0.33	0.06	0.10	426	184
LMC-2	3	**Mean**	**0.65**	**0.57**	**0.14**	**0.40**	**463**	**125**
		Median	0.62	0.52	0.15	0.35	304	114
		Maximum	1.34	0.87	0.21	0.68	1376	270
		Minimum	0.17	0.36	0.06	0.20	12	<4
		Standard Dev	0.41	0.23	0.05	0.20	466	122
LMC-3	14	**Mean**	**1.00**	**0.32**	**0.18**	**0.18**	**538**	**70**
		Median	0.91	0.27	0.16	0.16	407	13
		Maximum	2.07	0.57	0.42	0.30	1512	250
		Minimum	0.34	0.16	0.08	0.11	70	6
		Standard Dev	0.63	0.19	0.11	0.09	431	120

*LMC-1 was located in the center of the catchment that drained to outlet station 18

3.5 Comparison to Urban Runoff in other Cities

The following information is provided as a general comparison of phosphorus concentrations. The data are limited, but provide an indication of the relative phosphorus levels in the city of Madison storm sewers, as well as Memorial and Silver Creeks.

The USGS measured stormwater runoff in the city of Sioux Falls in 1995 and 1996 (Niehus 1997). Three sites were selected to represent commercial, industrial, and residential land uses. Results for TP and TDP are shown in Table 6. Runoff from industrial land use appeared to have higher phosphorus concentrations than commercial or residential. The phosphorus concentrations are similar to the 2001 data for Madison.

Table 6 Phosphorus Concentrations in Urban Runoff from Sioux Falls, SD

	TP/TDP (mg/L) by Representative Land Use		
Date	**Commercial**	**Industrial**	**Residential**
9/18/95	0.12 / 0.083	0.55 / 0.27	0.3 / 0.12
5/3/96	0.06 / ---	0.38 / ---	0.097 / ---
7/3/96	0.14 / ---	--- / ---	0.12 / ---

Source: Niehus 1997

Long term water quality monitoring of the Minnesota River upstream of the Twin Cities Metropolitan Area has shown a ten year average total phosphorus concentration of 0.25 mg/L. This watershed is predominately agricultural. The comparable ten year average for the Mississippi River, upstream of the Twin Cities is 0.10 mg/L. The Minnesota River average is similar to the upstream concentrations measured in 1995 (see Table 5a: LMT3, LMT4).

The nationwide Urban Runoff Program (NURP) studied urban runoff throughout the U.S. and found a wide range in pollutant concentrations (USEPA 1983). The mean concentrations from the NURP study for total phosphorus and dissolved phosphorus by land use were:

	Residential	**Mixed**	**Commercial**	**Open**
Total P	0.46	0.33	0.24	0.23
Dissolved P	0.16	0.07	0.098	0.06

The overall average total phosphorus concentration in Madison was 0.585 mg/L and, therefore, was slightly higher than the mean concentrations from the NURP study.

3.6 Outlet Evaluations

A survey and comparison of phosphorus concentrations in the outlets for the four sample events provides the following insights.

- **Station 3** – 36” outlet north of Sixth Street NW, between Chicago and Liberty Avenues – samples were collected during all three events. This outlet had relatively high loading of particulate phosphorus during the April storm, which appeared to influence downstream particulate phosphorus concentrations (Station 4). Concentrations of phosphorus were comparable to instream concentrations during the snowmelt and June storm events. Therefore, the Station 3a outlet appears to contribute additional particulate loading during the spring, but is similar to upstream runoff during the summer.

- **Station 6b** – 30” outlet at Seventh Street NW, west of Egan Avenue N – samples were collected during all three events. The concentrations from this outlet were comparable to the upstream Station 5 during the April storm event, but phosphorus concentrations were relatively low during the snowmelt and June storm events. Thus, the runoff at Station 6b appears to be similar to upstream concentrations.

- **Station 9b** – 24” outlet at Third Street NE and Washington Avenue N – was a problematic site in that there was no flow during the snowmelt, the pipe was under water during the April storm, and there was no flow during the June storm.

- **Station 10** – 36” outlet south of Second Street NE and Lincoln Avenue N – samples were collected during all three events, although the flows very low in the snowmelt and only a trickle during the storm events. Phosphorus concentrations were relatively low in the April storm event and comparable to instream concentrations during the storm events. Thus, the runoff at Station 10 appears to be similar to upstream concentrations..

- **Station 12b –** 30” outlet at First Street SE and Division Avenue S – samples were collected during all three events. Total phosphorus concentrations were below upstream concentrations during the snowmelt and June storm event. The concentration of total phosphorus in April storm was higher than the immediate upstream stations (11 and 12a). Overall, it does not appear that the runoff from Station 12b represents a substantial contribution to phosphorus loading to Memorial Creek.

- **Station 13 –** 60" outlet at First Street SE and Division Avenue S – samples were collected during all three events. The phosphorus concentrations at the outlet and in the downstream station (16) compared to the upstream stations (11 and 12a) indicate this storm sewer outlet has runoff similar to upstream concentrations.

- **Station 14 –** 72" outlet near railroad tracks, between Garfield and Jefferson Avenues S – samples were collected during all three events. The total phosphorus concentration during the snowmelt was similar to the upstream stations (11 and 12a), although total dissolved phosphorus and soluble reactive phosphorus was substantially lower in the outlet than upstream. Phosphorus concentrations in the April and June storms were comparable or lower than the upstream concentrations. Therefore, Station 14 runoff concentrations are similar to upstream concentrations.

- **Station 15 –** 36" outlet at Third Street SE and Jefferson Avenue S – samples were collected during all three events. Station 15 had one of the highest total phosphorus concentrations during the spring snowmelt and it had the highest total phosphorus concentration during the April storm. The phosphorus concentration in the June storm was not as remarkable, because it was similar to instream concentrations, although Station 15 had higher TP concentrations than outlets at Stations 12B, 13 and 14, immediately upstream. Station 15 appears to be outstanding in its contribution of phosphorus and sediment to Memorial Creek.

- **Station 18 –** 48" outlet to Silver Creek, south of Fourth Street SW and Union Avenue S – the most upstream outlet sampled on Silver Creek, downstream of Lake Herman. Samples were collected during all three events. Compared to the upstream station (17), this outlet appeared to contribute a disproportionate particulate phosphorus load to Silver Creek during snowmelt and the April Storm event.

- **Station 19 –** 18" outlet to Silver Creek, south of Fourth Street SW and Egan Avenue S – a sample was not collected during the April storm because the pipe was submerged. The snowmelt sampling did showed the phosphorus concentration from this outlet was similar to or lower than the upstream station (17). In the June storm event, Station 19 had a remarkably high particulate phosphorus load; however, there was no flow from the pipe during this sampling and the sample was actually collected downstream of the outlet. Therefore, the results are inconclusive for this outlet.

- **Station 20b –** 36” outlet to Silver Creek, upstream of the confluence with Memorial Creek. This outlet was not sampled during the June storm event because there was no flow in the pipe. This outlet had the highest total phosphorus concentration in the spring snowmelt and two-thirds of the total phosphorus was in the particulate form. This outlet had the second highest phosphorus concentration in the April storm event, and 88 percent of the total phosphorus was in the particulate form. Therefore, runoff from this drainage are appears to disproportionately contribute particulate phosphorus to the receiving water.

The conclusion from this survey of phosphorus concentrations in the storm sewers is that runoff from most of the outlets appear to be similar to upstream concentrations and therefore do not contribute a disproportionate amount of phosphorus to the creek. The exceptions – those outlets that do contribute a disproportionate concentration of phosphorus – are Stations 20b, 15, and 18. Based on this water quality sampling, these three drainage areas should receive the highest priority for consideration of best management practices.

3.7 Estimated Phosphorus Loadings

Total phosphorus loads were estimated for each catchment to determine the areas of the city that appear to have the largest contributions to phosphorus loading on an annual basis. The mean total phosphorus concentration by catchment, based on the 2001 sampling results, ranged from 0.278 mg/L to 0.877 mg/L, with a grand mean of 0.585 mg/L (Table 7). The results of the estimated annual total phosphorus yield calculations are shown in Figure 10 as pounds per acre per year (lb/ac/yr). The absolute load will vary with the selected year because of difference in precipitation. As indicated above, the rainfall for 2001 was very close to normal. Therefore the normal annual precipitation of 24 inches was used for this comparison. The average unit area loading was 0.88 lb P/ac/year. The highest unit area phosphorus loadings were from ST-10 and WS-19 (1.45 and 1.96 lb/ac/yr).

The estimated annual phosphorus load from the city for a normal precipitation year was 1445 pounds. This estimate is considerably less than WAFR estimates of 4,889 lbs using 1995 rainfall data (33 inches) or 2,961 lbs using the 1997 rainfall data (20 inches). The lower estimate in this study can be attributed to the smaller delineated surface area (1645 acres in this study compared to 2215 acres in WAFR) and to the lower phosphorus concentrations (WARF used a single mean concentration of 0.995 mg/L). The higher measured phosphorus concentrations in 1997 could be due to numerous factors, including differences in sampling and/or longer antecedent periods (i.e., dry periods between storms).

The results of this analysis based on the Simple Method were compared to an estimate of phosphorus loading based on phosphorus land use export coefficients. The export coefficients are estimates of annual phosphorus loads for a give land use. The source of most of the export coefficients is Schueler (1987), the same reference cited for the Simple Method. As seen in Figure 10 and compared to the previous figure, the export coefficients appear to underestimate phosphorus loading for the city of Madison. The export coefficient approach again shows ST-10 and WS-19 with the highest unit area phosphorus loads. An interesting difference between the two approaches is the estimated phosphorus load for WS-14, which covers the central commercial area of Madison. The Simple Method estimate shows WS-14 ranked as one of the lower per unit loads at 0.63 lb/ac/yr, while the export coefficient estimate show WS-14 ranked as one the higher per unit loads at 0.62 lb/ac/yr.

Table 7
Annual Phosphorus Loading by Catchment

Catchment	Outlet ID	Area (ac)	% Imp	R	Simple Method L (lb/yr)	Simple Method lb/ac/yr	Export Coefficient L (lb/yr)	Export Coefficient lb/ac/yr
ST-21		156.8	16%	0.19	94	0.60	111	0.70
ST-10		5.1	51%	0.51	7	1.45	4	0.77
ST-11		13.1	27%	0.30	11	0.81	6	0.43
ST-12		60.5	25%	0.28	47	0.78	24	0.40
ST-14		9.5	21%	0.24	7	0.73	5	0.55
ST-15		7.0	20%	0.23	5	0.71	2	0.31
ST-16		5.6	19%	0.22	4	0.68	2	0.29
ST-18		181.6	35%	0.36	214	1.18	112	0.62
ST-19		111.5	29%	0.31	111	1.00	61	0.55
ST-2		16.0	28%	0.30	13	0.84	7	0.43
ST-20	20B	156.4	26%	0.28	143	0.92	80	0.51
ST-3		39.2	29%	0.31	34	0.87	18	0.46
ST-4		36.3	26%	0.29	29	0.81	15	0.42
ST-6		64.0	28%	0.30	54	0.85	33	0.51
ST-7		10.6	29%	0.31	9	0.86	4	0.40
ST-8		6.8	28%	0.30	6	0.84	2	0.36
ST-9		33.6	37%	0.38	40	1.18	19	0.55
WS-10	10	81.7	32%	0.34	78	0.96	41	0.50
WS-11		10.0	29%	0.32	9	0.88	5	0.46
WS-12a	12b	106.1	26%	0.29	69	0.65	53	0.50
WS-12b	13	52.3	17%	0.20	33	0.62	15	0.29
WS-14	14	86.3	39%	0.40	55	0.63	53	0.62
WS-15	15	29.0	26%	0.29	33	1.13	13	0.46
WS-18	18	144.0	29%	0.31	156	1.08	67	0.46
WS-19	19	13.5	45%	0.45	26	1.96	11	0.82
WS-3	3	68.3	29%	0.31	59	0.87	31	0.45
WS-6	6b	79.6	39%	0.40	43	0.55	46	0.58
WS-7		20.5	27%	0.29	17	0.82	8	0.40
WS-8		9.3	38%	0.39	6	0.61	5	0.52
WS-9	9B	30.8	32%	0.34	32	1.04	14	0.46
TOTALS		1644.8	29%	0.31	1445		866	0.53

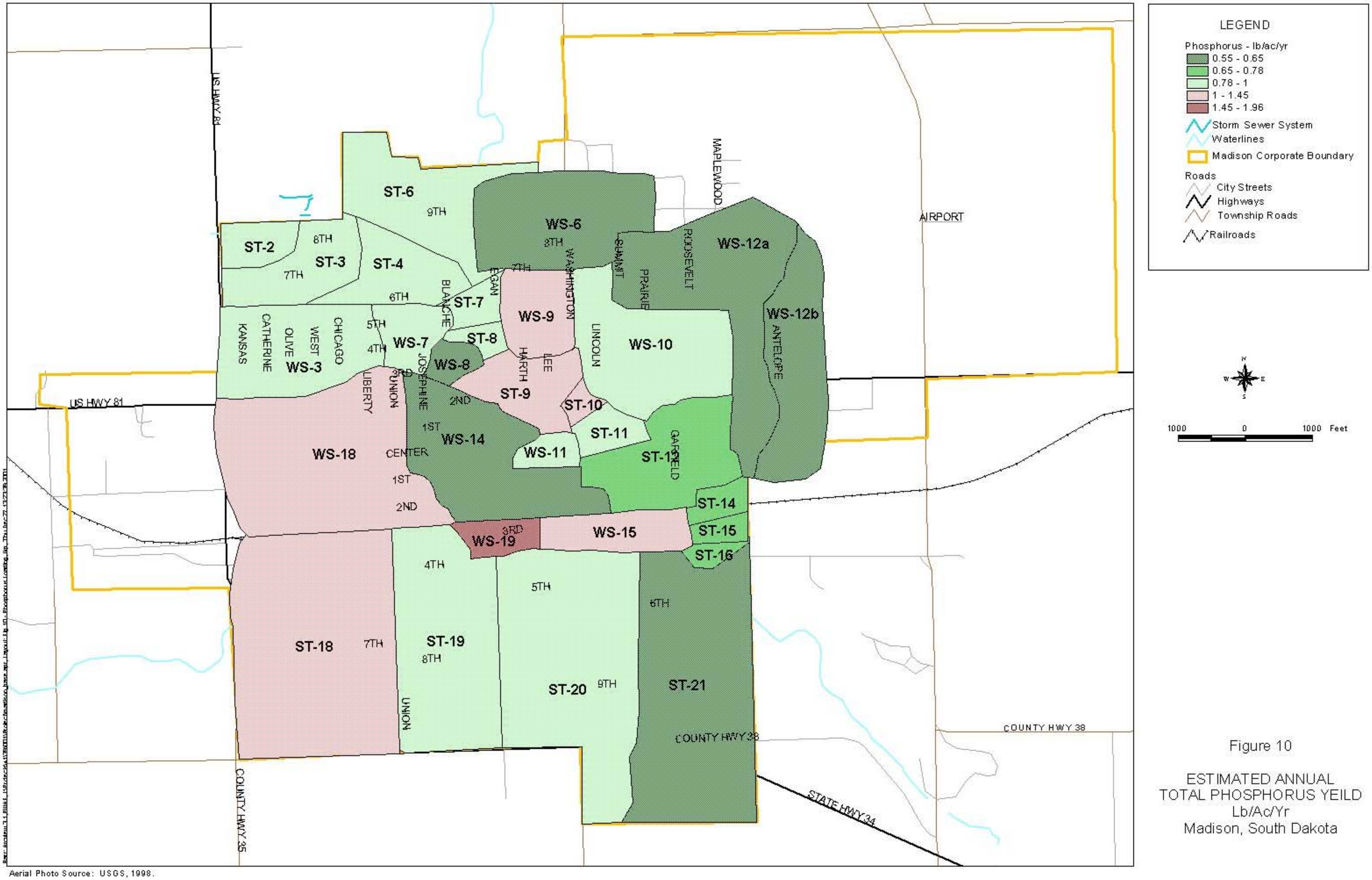


Figure 10

ESTIMATED ANNUAL TOTAL PHOSPHORUS YEILD Lb/Ac/Yr Madison, South Dakota

3.8 Urban Best Management Practices

Constructed urban best management practices (BMPs) are selected for site-specific conditions. Site-specific design is beyond the scope of this study, but the Stormwater Treatment BMP Selection Matrix (Appendix D) provides a stepwise process for selecting BMPs for specific sites. For example, the Step 1 Matrix shows infiltration and bioretention filtration as the most effective processes for removing nutrients. Step 2 Matrix shows the physical feasibility factors, such as needed soil conditions and surface area, needed for each of the 16 BMPs. Step 3 Matrix shows the community and environmental factors to consider for the BMPS, such as community acceptance, cost, and wildlife habitat. The developing areas around the perimeter of the city are best suited for this selection process because of the availability of land for siting BMPs.

For the city, in general and especially for areas of the city where land for constructed BMPs are unavailable, the runoff pollution prevention BMPs should be considered. These include pavement management (i.e., street sweeping, alternative product and application rates) and erosion control practices. Appendix D includes a discussion of pavement management.

Housekeeping BMPs include:

- Fertilizer management – soil test for phosphorus: no phosphate fertilizer needed if over 50 lb P/acre
- Litter control (leaves and lawn clippings) – a study of storm runoff into Minneapolis lakes found P-levels reduced 30-40% when street gutters kept free of leaves and lawn clippings (Shapiro and Pfannkuck 1973).
- Catch basin cleaning – clean catch basins can remove pollutant loads during the first flush of a storm event
- Street sweeping – best done in spring and fall
- De-icing chemical use – cover salt piles and prevent runoff
- Proper construction site erosion and sediment control

4.0 Methods for Sediment Analysis

4.1 Bourne Slough and Round Lake Sediments

The three parts of the Bourne Slough sediment study were (1) survey of sediment depth, to estimate sediment volume, (2) collect sediment samples, to determine the concentration of phosphorus in the sediments, and (3) assess the amount of particulate phosphorus in the water column. Conventional survey methods were used to survey the perimeter of the slough and each point of sediment depth measurement. Sediment depth was determined by first measuring water depth to top of sediment, using a delineated rope and weight, and then pressing a one inch diameter steel pipe (with a cap on the end) into the sediment and measuring the distance the pipe penetrated into the sediment. The survey data was compiled in AutoCAD and, along with the sediment depth measurements, a map of sediment depth was prepared and the volume of sediment was estimated.

A piston core, consisting of a Plexiglas sleeve and a rubber plug attached to steel rod, was used to extract three sediment cores from the Bourne Slough and one sediment core from Round Lake. The only surveying on Round Lake was to identify the location of the sediment core, which was generally in the center of the lake. The three cores in Bourne Slough were aligned in a transect down the length of the longest axis of the slough (approximately northwest-southeast direction), which included the areas of greatest sediment accumulation.

A sediment sub-sample was collected from the top five centimeters of the sediment core, because it represents the sediment directly exposed to the water column and most likely subject to resuspension from wind-driven turbulence. The sediment samples were analyzed for extractable phosphorus and total phosphorus at Braun Intertec Laboratory, Minneapolis. The total phosphorus method is EPA Method 365.3, which is the standard method for total phosphorus analysis. The extractable phosphorus is a measure of the phosphorus that is bound to iron or sorbed phosphorus that is available for release to the water column under reducing (i.e., anaerobic) conditions. The method was first reported by Psenner (1984) and more recently by Rydin and Welch (1998).

5.0 Results and Discussion for Bourne Slough and Round Lake

5.1 Sediments in Bourne Slough and Round Lake

The surface area, bottom depth, and sediment depth of Bourne Slough were surveyed on February 26 through 28, 2001. A total of 68 sediment depth measurements were recorded to provide an estimate of the amount of sediment in the slough. A sediment depth contour map was created from these measurements (Figure 11). The surface area of the slough is 92 acres and it has an estimated sediment volume of 410,000 cubic yards. Maximum depth in the slough is about 8.5 feet.

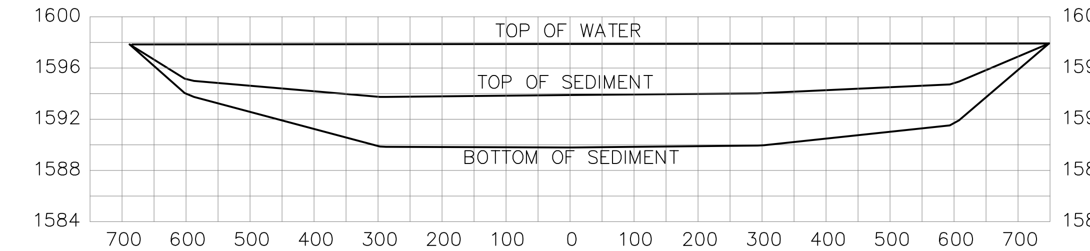
During the sediment survey, three sediment cores were collected (locations shown in Figure 11). A sediment core was also collected from Round Lake and the same procedure was followed for sample collection and analysis. The remaining four sediment cores have been kept in a freezer for potentially later analysis of other parameters. Sediment samples from the cores were extruded in the field.

Phosphorus analysis indicates the fraction of total phosphorus that is extractable phosphorus is fairly consistent among the three cores: approximately 5-6% (Table 8). Comparing the northwest end (Station 48) of the slough with the southeast end (Station 54) shows about a 25% higher total phosphorus concentration in the southeast end sediments. The higher concentration corresponds to the inflow from Silver Creek, which enters the slough on the south side.

5.2 Water Sample Collection in Bourne Slough

A grid of eleven water samples were collected from Bourne slough on October 28, 2001, and an additional sample was collected in Lake Madison. The sampling grid of water is shown in Figure 12. Samples were analyzed for total phosphorus and dissolved phosphorus.

1 PLAN: WATER SAMPLE LOCATIONS



2 SECTION: A–A

LEGEND

⌖ SEDIMENT CORE LOCATION

NOTE: BASED ON 68 SURVEY POINTS COLLECTED. THE SLOUGH AREA IS APPROXIMATELY 92 ACRES AND THE ESTIMATED SEDIMENT VOLUME IS 410,000 CUBIC YARDS.

Figure 11
SEDIMENT DEPTH CONTOURS

NO.	BY	CHK.	APP.	DATE	REVISION DESCRIPTION

34

RELEASED TO/FOR	A	B	C	0	1	2	3
CLIENT							
BID							
CONSTRUCTION							
	DATE RELEASED						

BARR
Corporate Headquarters: Minneapolis, Minnesota Ph: 1-800-632-2277

Project Office: BARR ENGINEERING CO. 4700 WEST 77TH STREET MINNEAPOLIS, MN. 55435-4803 Ph: 1-800-632-2277 Fax: (612) 832-2601 www.barr.com

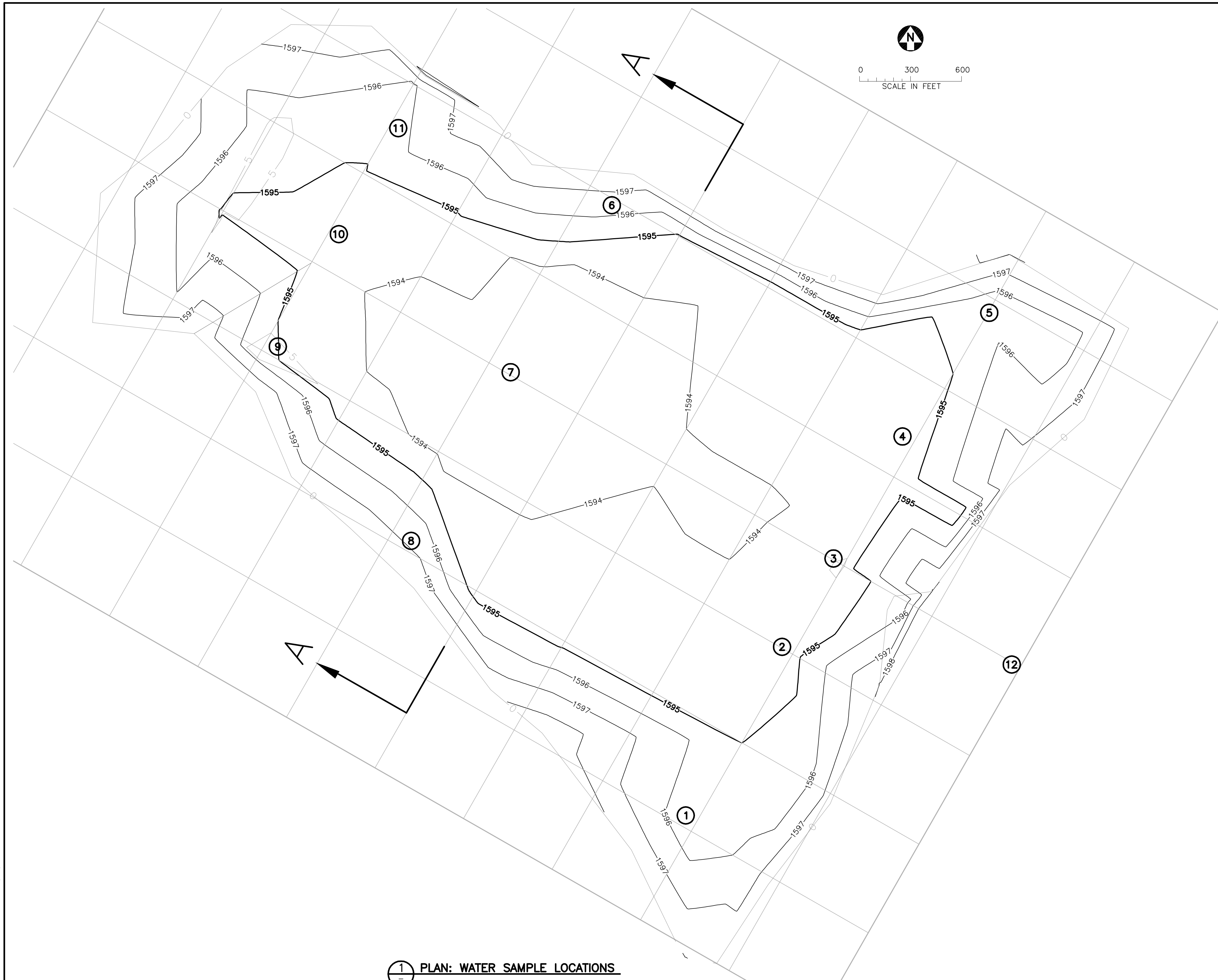
Scale	AS SHOWN
Date	12/27/2001
Drawn	BJH
Checked	
Designed	
Approved	

CITY OF MADISON
MADISON, SOUTH DAKOTA

LAKE COUNTY WATERSHED IMPROVEMENT PROJECT

BOURNE SLOUGH SEDIMENT DEPTH CONTOURS

BARR PROJECT No. 41/39-001-BAM
CLIENT PROJECT No.
DWG. No.
REV. No.



1 PLAN: WATER SAMPLE LOCATIONS

LEGEND

(12) WATER SAMPLE LOCATION

NOTE: BASED ON 68 SURVEY POINTS COLLECTED. THE SLOUGH AREA IS APPROXIMATELY 92 ACRES AND THE ESTIMATED SEDIMENT VOLUME IS 410,000 CUBIC YARDS.

Figure 12
WATER SAMPLE LOCATIONS

NO.	BY	CHK.	APP.	DATE	REVISION DESCRIPTION

RELEASED TO/FOR	A	B	C	0	1	2	3
CLIENT							
BID							
CONSTRUCTION							
DATE RELEASED							

BARR
Corporate Headquarters: Minneapolis, Minnesota Ph: 1-800-632-2277

Project Office:
BARR ENGINEERING CO.
4700 WEST 77TH STREET
MINNEAPOLIS, MN.
55435-4803
Ph: 1-800-632-2277
Fax: (612) 832-2601
www.barr.com

Scale	AS SHOWN
Date	12/27/2001
Drawn	BJH
Checked	
Designed	
Approved	

CITY OF MADISON
MADISON, SOUTH DAKOTA

LAKE COUNTY WATERSHED IMPROVEMENT PROJECT

BOURNE SLOUGH
WATER SAMPLE LOCATIONS

BARR PROJECT No. 41/39-001-BAM
CLIENT PROJECT No.
DWG. No.
REV. No.

Xrefs in Drawing - 15165_1.DWG
Images in Drawing - J:\Civil2\Land Projects R2\20019506 - Lake Madison\dwg\madison.tif J:\Civil2\Land Projects R2\20019506 - Lake Madison\dwg\madison5.bmp
BJH M:\cad\41\39\001\16087_1.DWG Plot at 200 12/27/2001 17:24:39

Table 8 Sediment Phosphorus in Bourne Slough and Round Lake

Analyte*	Round Lake	Bourne Slough		
		Station 48**	Station 51**	Station 54**
Extractable Phosphorus	15.38	17.13	15.09	19.12
Total Phosphorus	300	280	290	350
Extractable P as Percentage of TP	5.1%	6.1%	5.2%	5.5%

Units: mg/Kg
* 0-5 cm sediment samples
Braun Intertec laboratory reported results on April 12, 2001
**See Figure 12 (Bourne Slough Sediment Map) for station locations

Among the seven lakes that Barr has extractable phosphorus and total phosphorus concentrations, the average ratio of releasable to total P is 0.12; The extractable phosphorus concentrations in Bourne Slough and Round Lake are similar for the concentrations in five Minnesota lakes, where the releasable P concentration ranged from 5.1 to 19.28 mg/kg (wet wt.), but the total P concentrations in Bourne Slough and Round Lake were much higher than these same lakes. Total P ranged from 77 to 140 mg/kg. This comparison indicates that most of the phosphorus in the sediments of Bourne Slough and Round Lake is non-extractable phosphorus which is probably bound to calcium and not likely to be released as a bioavailable form of phosphorus.

5.3 Water in Bourne Slough

Wind speeds in the days prior to sampling had been in excess of 20-30 mph. When the samples were collected the wind was out of the south-southwest at 8-15 mph. Dissolved oxygen, temperature, and specific conductivity were vertically and horizontally uniform, indicating the slough was well mixed (see Appendix E). Total phosphorus concentrations in the slough were high (average 0.355 mg/L), and only varied from 0.32 to 0.39 mg/L (Table 9). Despite the small range in phosphorus concentrations, there appeared to be a trend of higher concentrations near the mouth of Silver Creek and decreasing with distance from the mouth. Approximately 90 percent of the total phosphorus was in the particulate form. One sample was collected from Lake Madison on the same day and it had a total phosphorus concentration of 0.239 mg/L, and only six percent was particulate phosphorus.

Table 9 Total and Dissolved Phosphorus Concentrations in Bourne Slough Water

Sample	TDP (mg/L)	TP (mg/L)	TDP/TP (%)
1	0.035	0.388	9%
2	0.032	0.369	9%
3	0.031	0.368	8%
4	0.032	0.375	9%
5	0.032	0.364	9%
6	0.031	0.353	9%
7	0.031	0.347	9%
8	0.036	0.362	10%
9	0.035	0.336	10%
10	0.031	0.330	9%
11	0.031	0.318	10%
12	0.224	0.239	94%
Statistics for Samples 1-11 (Bourne Slough)			
Mean	0.032	0.355	
Minimum	0.031	0.318	
Maximum	0.036	0.388	
St. Dev.	0.0019	0.0210	
C.V.	6%	6%	

5.4 Management of Bourne Slough for Phosphorus Reduction

These results demonstrate that phosphorus in the Bourne Slough is primarily in the particulate fraction, which suggests that detention with sufficient settling time could remove a large portion of the phosphorus from the water column. The results of this sampling did not indicate that the particulate phosphorus is generated from suspension of sediments from wind action; instead, the results show the highest TP concentrations near the inflow from Silver Creek and the lowest TP concentrations are on the north end of the slough—farthest from the inflow.

To effectively use the slough as a detention basin for removal of suspended solids, and most of the phosphorus, sediments could be excavated to create a horseshoe-shaped channel to maximize the length of flow path within the slough. This would route the flow coming in from Silver Creek in a northwest direction toward the upper end of the slough and then back down in a southeasterly direction toward the outlet to Lake Madison. Dredged sediments could be piled to create a barrier wall between the inlet and outlet of the slough. The barrier wall would need to be armored with rock to reduce erosion. To create the channel, at least 100,000 cubic yards of sediment would be dredged, some of dredge spoils would most likely need to be placed outside of the slough. The actual treatment efficiency expected from this conceptual design could be determined from modeling, but would require more specific dimensions and water flow through the slough.

6.0 Conclusions

6.1 Urban Runoff Quality

For this study, the urban area of Madison was delineated into 30 catchments (i.e., drainage areas) and 25 monitoring stations (11 storm sewer outlets; 14 in-stream) were sampled during a spring snowmelt and three storm events. Water samples were analyzed for total phosphorus, dissolved phosphorus, soluble reactive phosphorus, and total suspended solids. The spring snowmelt runoff contained primarily dissolved phosphorus, whereas the larger the storm event, the greater the proportion of particulate phosphorus. Overall, total phosphorus was highly correlated with total suspended solids.

The estimate from this study of total phosphorus load from the city of Madison is lower than his estimate from the WAFR. The difference can be partially attributed to the WAFR study occurring during a relative wet year (33 inches of precipitation compared to 24 inches for a normal year) and to the larger area considered in the WAFR (2215 acres compared to 1645 acres in this study). The reason for this difference is not known. The average total phosphorus concentration in the WAFR was 0.995 mg/L and was applied to the entire city. In this study, the average total phosphorus concentration was 0.585 mg/L, but mean concentrations were applied to each catchment and ranged from 0.278 mg/L to 0.877 mg/L. Despite these differences between the phosphorus loading estimated in WAFR and this study, they are relatively similar when compared to the estimated 23,351 lbs of phosphorus transported to Lake Madison from Silver and Memorial Creek Watersheds (WAFR, p 14).

The WAFR concluded that Silver Creek contributed 92% of the phosphorus load to Lake Madison and the City of Madison contributed 13% of the total load to Lake Madison in 1995. If BMPs could be installed in the City of Madison that removed 60% of the phosphorus, that would reduce the phosphorus loading to Lake Madison by approximately 8%, leaving 42% to be removed from other sources to meet the 50% reduction goal. Although the phosphorus loading estimates were lower in this study than were estimated in the WAFR, the relative contributions of urban runoff compared to rural nonpoint source contributions appear to hold.

A comparison of the relative phosphorus loading from catchments within the city of Madison indicate that several small drainage areas contribute a disproportionately high phosphorus load. These drainage areas should be evaluated for BMPs to reduce the phosphorus loading.

Overall, the BMPs most likely to suit the conditions of the city of Madison are runoff pollution prevention measures, such as pavement management. Street sweeping and other reductions of particulate materials entering Silver and Memorial Creek can substantially reduce the phosphorus loading from the city.

6.2 Bourne Slough

The Bourne Slough sediments have high total phosphorus concentrations. Only about five percent of the phosphorus could potentially be released as dissolved phosphorus, although the remaining 95 percent could be enter the water column as suspended sediments. The high proportion of particulate phosphorus in the water column is most likely a result of input from Silver Creek.

The slough contains approximately 400,000 cubic yards of sediment. Excavating a portion of the sediments and rerouting the flow in the slough could potentially improve sedimentation in the basin, thereby reducing phosphorus entering Lake Madison. The flow path within the slough would need to be increased, most likely by building a barrier within the slough that would route the flow around the perimeter of the slough. Additional hydraulic modeling and engineering design would be needed to estimate the phosphorus removal efficiency with the adjusted slough depth and water flow.

7.0 Recommendations

The following sections of this report describe recommendations pertaining to the following three topics:

1. Detention Ponding of Runoff from the Urbanized Area of Madison, SD
2. Streambank Erosion Concerns Within the City of Madison, SD
3. Retention of Suspended Sediments on Bourne Slough

7.1 Detention Ponding of Runoff

Because detention ponding will both reduce the rate of runoff and improve its quality, Barr Engineering Co. makes the following recommendations about the technical feasibility and costs of installing runoff detention basins at strategic locations within the urbanized area of the City of Madison.

The Madison storm sewer drainage system is shown in Figure 13. Also shown on this figure are six locations where we fell it is possible to construct runoff detention ponds. Five of these pond locations are within the city proper, while the sixth location is downstream from the city, on the creek leading to Bourne Slough. The five in-city ponding locations were chosen because they provide sufficient room to construct ponds sized to meet Nationwide urban Runoff Program (NURP) design criteria, and because ponds constructed there would intercept and detain runoff from a significant fraction of the urban watershed.

The sixth runoff detention pond is intended to be a regional pond that operates as an off-channel, low-flow capture device, located adjacent to Silver Creek. As such, creek flows up to a specified maximum discharge rate (determined by pond size and stream channel discharge capacity) would be diverted through the detention pond, while higher flows would bypass the diversion and pass into the slough through the normal stream channel. This pond would treat the “first flush” of urban runoff, before upstream runoff reached the off-channel ponding location.

The following Figures (14 through 16) illustrate the estimated phosphorus budgets for Lake Madison:

1. Currently (based on 2001 runoff monitoring results)
2. Assuming construction of the five recommended in-city runoff detention ponds.
3. Assuming construction of the regional off-channel, low-flow capture pond, respectively.

City of Madison runoff phosphorus contributions comprise 7.2, 6.3, and 2.8 percent of the annual phosphorus load estimates, respectively, we estimate, for these three scenarios.

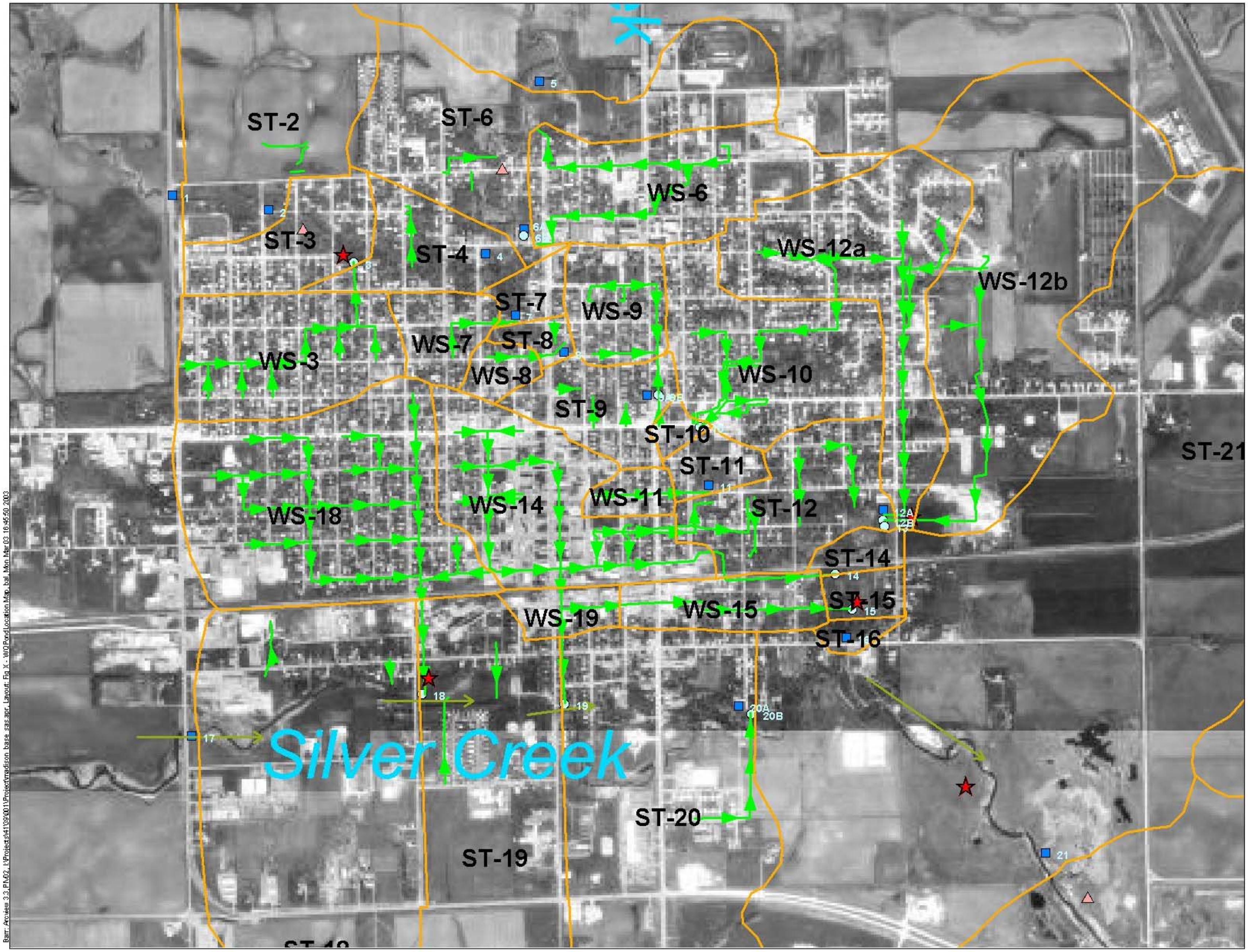


Figure 13

WATER QUALITY (WQ) POND LOCATION MAP
Madison, South Dakota

Figure 14

Lake Madison
Annual Total Phosphorus Budget (2001/Normal PPTN)

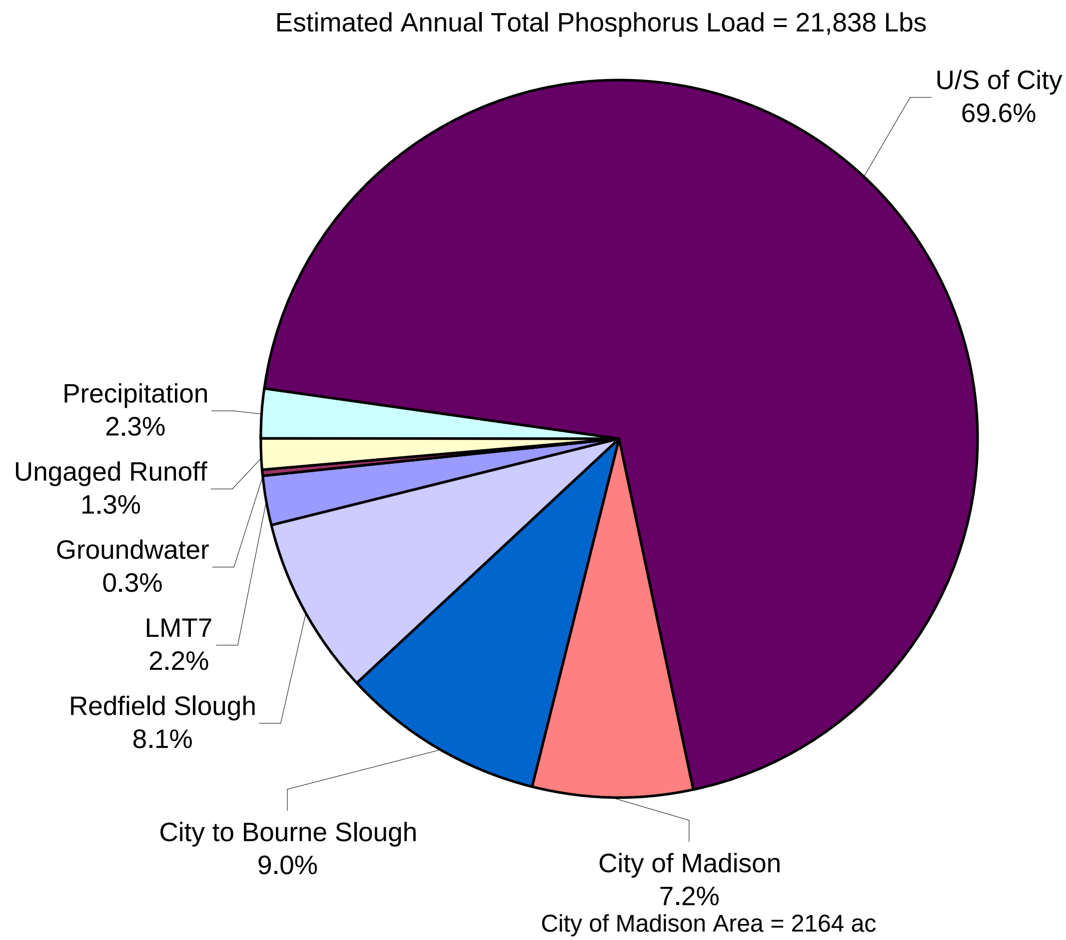
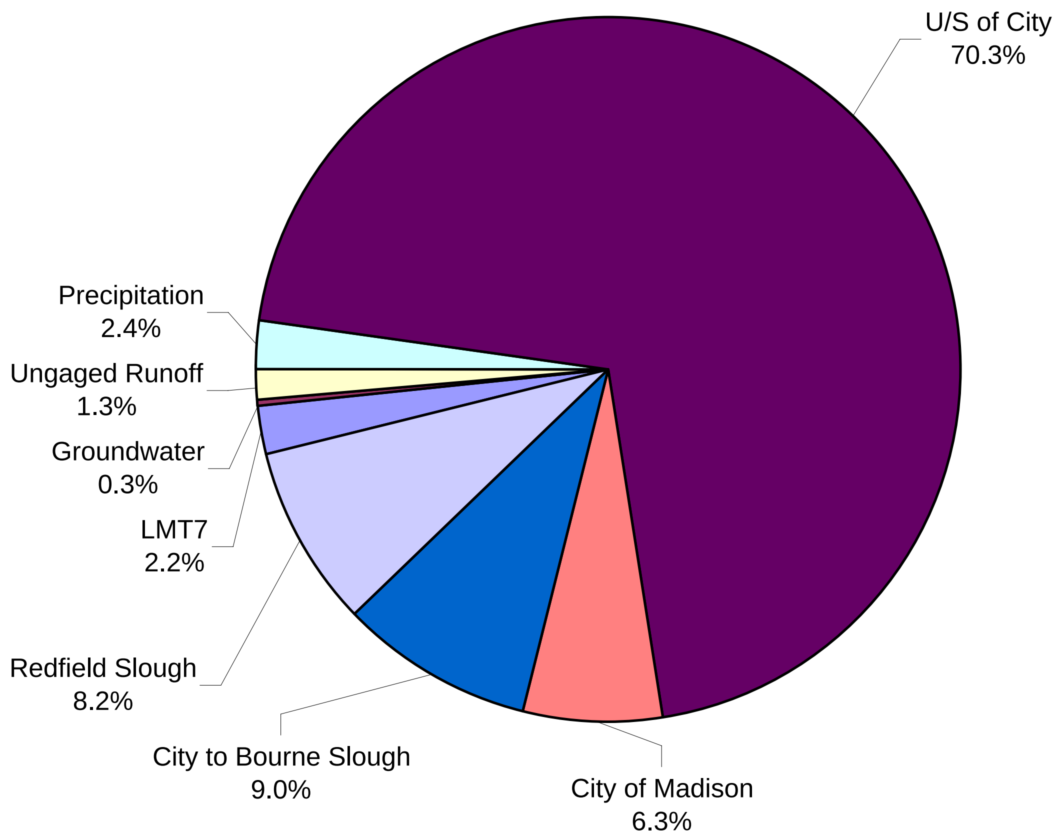


Figure 15

Lake Madison
Annual Total Phosphorus Budget (2001/Normal PPTN)
Assuming Wet Detention Ponds in
Watersheds WS-3, WS-12a&b, WS-15, & WS-18

Estimated Annual Total Phosphorus Load = 21,614 Lbs



City of Madison Area = 2164 ac

Figure 16

Lake Madison
Annual Total Phosphorus Budget (2001/Normal PPTN)
Assuming One Wet Detention Pond
Sized to Treat 1645 acres of Low Flow City Runoff

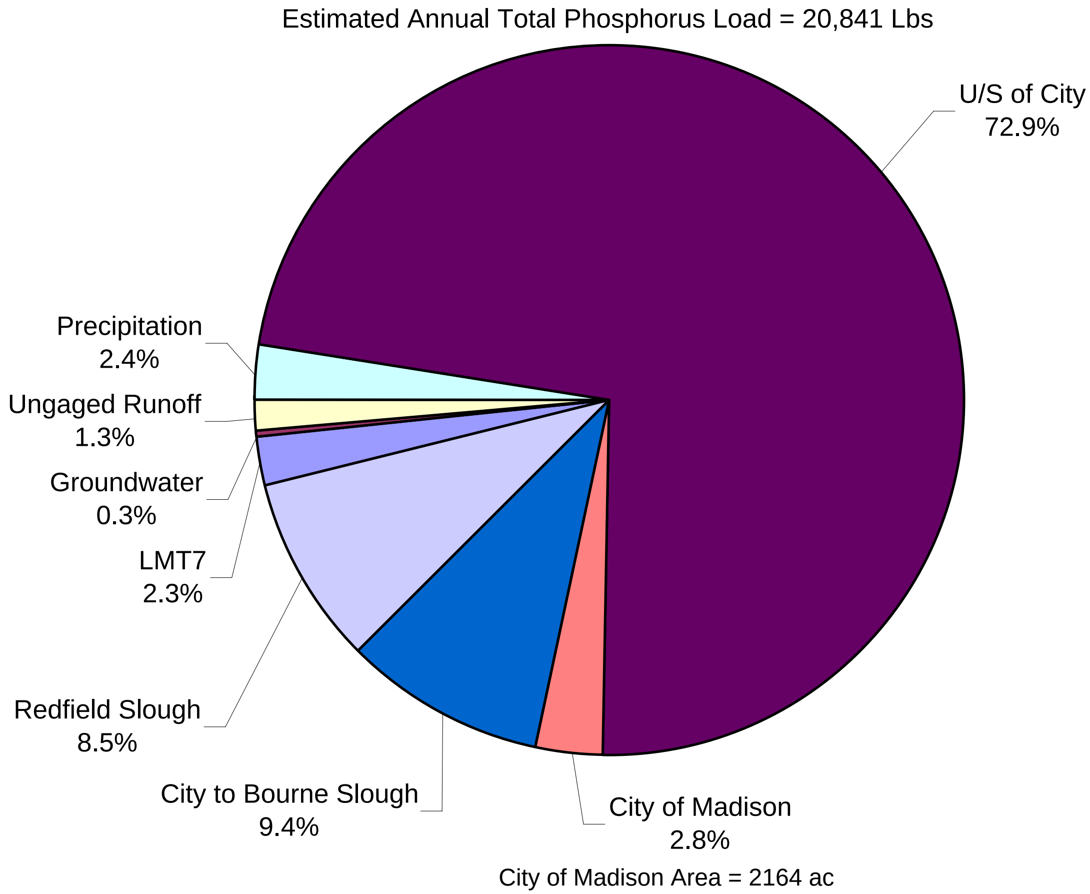


Table 10 presents construction cost estimates for the six recommended runoff detention ponds. These costs range from $34,000 for constructing a pond in subwatershed WS-15, to $984,000 for building the off-channel, low-flow capture pond between the city and Bourne Slough.

Table 10 Preliminary Construction Cost Estimates for Runoff Detention Ponds—June 27, 2002

A. Cost Estimate for Wet Detention Pond to Treat Runoff from WS-18—June 27, 2002

Item	Description	Units	Qty.	Unit Cost	Extension
1	Mobilization/Demobilization (15%)	LS	1	$10,000.00	$10,000.00
2	Site Preparation/Clearing/Grubbing	AC	1.2	$5,000.00	$6,000.00
3	Common Excavation	CY	10,003	$4.00	$40,000.00
4	Outlet Control Structure	LS	1	$10,000.00	$10,000.00
5	Restoration	AC	1.2	$10,000.00	$12,000.00
				Project Total	$78,000.00
	Contingency		25%		$20,000.00
	Engineering/Permitting/Administration		25%		$20,000.00
				Total	$118,000.00

B. Cost Estimate for Wet Detention Pond to Treat Runoff from WS-12a&12b—June 27, 2002

Item	Description	Units	Qty.	Unit Cost	Extension
1	Mobilization/Demobilization (15%)	LS	1	$10,000.00	$10,000.00
2	Site Preparation/Clearing/Grubbing	AC	1.1	$5,000.00	$6,000.00
3	Common Excavation	CY	9,357	$4.00	$37,000.00
4	Outlet Control Structure	LS	1	$10,000.00	$10,000.00
5	Restoration	AC	1.1	$10,000.00	$11,000.00
				Project Total	$74,000.00
	Contingency		25%		$19,000.00
	Engineering/Permitting/Administration		25%		$19,000.00
				Total	$112,000.00

C. Cost Estimate for Wet Detention Pond to Treat Runoff from WS-3—June 27, 2002

Item	Description	Units	Qty.	Unit Cost	Extension
1	Mobilization/Demobilization (15%)	LS	1	$6,000.00	$6,000.00
2	Site Preparation/Clearing/Grubbing	AC	0.7	$5,000.00	$4,000.00
3	Common Excavation	CY	4,840	$4.00	$19,000.00
4	Outlet Control Structure	LS	1	$10,000.00	$10,000.00
5	Restoration	AC	0.7	$10,000.00	$7,000.00
				Project Total	$46,000.00
	Contingency		25%		$12,000.00
	Engineering/Permitting/Administration		25%		$12,000.00
				Total	$70,000.00

D. Cost Estimate for Wet Detention Pond to Treat Runoff from WS-15—June 27, 2002

Item	Description	Units	Qty.	Unit Cost	Extension
1	Mobilization/Demobilization (15%)	LS	1	$3,000.00	$3,000.00
2	Site Preparation/Clearing/Grubbing	AC	0.4	$5,000.00	$2,000.00
3	Common Excavation	CY	1,936	$4.00	$8,000.00
4	Outlet Control Structure	LS	1	$5,000.00	$5,000.00
5	Restoration	AC	0.4	$10,000.00	$4,000.00
				Project Total	$22,000.00
		Contingency	25%		$6,000.00
		Engineering/Permitting/Administration	25%		$6,000.00
				Total	$34,000.00

E. Cost Estimate for Wet Detention Pond to Treat Runoff from Area Entire to City—June 27, 2002

Item	Description	Units	Qty.	Unit Cost	Extension
1	Mobilization/Demobilization (15%)	LS	1	$86,000.00	$86,000.00
2	Site Preparation/Clearing/Grubbing	AC	8.8	$5,000.00	$44,000.00
3	Common Excavation	CY	114,708	$4.00	$459,000.00
4	Inlet and Outlet Control Structures	LS	1	$60,000.00	$60,000.00
5	Restoration	AC	0.7	$10,000.00	$7,000.00
				Project Total	$656,000.00
		Contingency	25%		$164,000.00
		Engineering/Permitting/Administration	25%		$164,000.00
				Total	$984,000.00

7.2 Streambank Erosion Concerns

Concern about streambank erosion was expressed by Lake Improvement Committee members, especially as it might have been exacerbated by the recent construction of new bridges within the city. Barr staff examined this issue and evaluated the situation. We have concluded, based on site conditions and conversations with City and State DOT engineers, that the new bridges with their increased discharge capacities actually served to reduce streambank erosion by reducing the peak rates and durations of high flows downstream of bridges. Our evaluation is summarized in the following paragraphs along with recommendations to reduce and minimize future streambank erosion.

7.3 Retention of Suspended Sediments in Bourne Slough

During periods of elevated discharge rates, inflows from Silver Creek that enter Bourne Slough now flow into Lake Madison via a highly short-circuited route. This is because previous high flows eroded a channel through the berm separating the land and slough. Correcting this short-circuiting problem to increase hydraulic residence time in, and solids retention by the slough is feasible, we believe, and was evaluated to determine likely costs. Depending on underlying soil conditions and expected flows through the slough, restoration of the existing berm would require its restoration to a height of either 5- to 10-feet above the normal water level (Alternatives 1A and 1B), as shown in Figure 17. Such a project would cost between $689,000 and $1,591,000 to complete, we estimate (Table 11).

Table 11 Preliminary Construction Cost Estimates for Bourne Slough Berm Restoration Options—June 10, 2002

ALTERNATIVE 1A: RESTORE 5-ft. BERM AT BOURNE SLOUGH

Item	Description	Units	Qty.	Unit Cost	Extension
1	Mobilization/Demobilization (15%)	LS	1	$60,000.00	$60,000.00
2	Site Preparation/Clearing/Grubbing	LS	1	$10,000.00	$10,000.00
3	Geotextile Filter Fabric	SY	10,000	$3.00	$30,000.00
4	Embankment Fill	CY	3,000	$15.00	$45,000.00
5	Filter Material	CY	800	$30.00	$24,000.00
6	Riprap	CY	3500	$80.00	$280,000.00
7	Restoration	LS	1	$10,000.00	$10,000.00
				Project Total	$459,000.00
	Contingency	25%			$115,000.00
	Engineering/Permitting	25%			$115,000.00
				Total	$689,000.00

(1) Mobilization includes erosion control features
(2) Site Preparation includes clearing, preliminary grading, as necessary
(3) Geotextile fabric placed beneath berm
(4) Place 10' wide embankment with 3:1 side slopes
(5) Place 6" granular filter material beneath riprap
(6) Place 2' riprap along each side of berm
(7) Restoration includes topsoil, erosion control blanket along top of berm, seeding and mulching.
(Notes) Assume new 1,500 ft. berm between Bourne Slough and Lake

ALTERNATIVE 1B: RESTORE 10-ft. BERM AT BOURNE SLOUGH

Item	Description	Units	Qty.	Unit Cost	Extension
1	Mobilization/Demobilization (15%)	LS	1	$138,000.00	$138,000.00
2	Site Preparation/Clearing/Grubbing	LS	1	$20,000.00	$20,000.00
3	Geotextile Filter Fabric	SY	15,000	$3.00	$45,000.00
4	Embankment Fill	CY	20,000	$12.00	$240,000.00
5	Filter Material	CY	1,600	$30.00	$48,000.00
6	Riprap	CY	7,000	$80.00	$560,000.00
7	Restoration	LS	1	$10,000.00	$10,000.00
				Project Total	$1,061,000.00
	Contingency	25%			$265,000.00
	Engineering/Permitting	25%			$265,000.00
				Total	$1,591,000.00

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Aerial Photo Date: 4/29/1998

N W E S

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Figure 17
Berm Restoration and
Possible Stream Relocation Routes

Also, in connection with recommended berm restoration, Barr staff previously evaluated the feasibility and cost of dredging a portion of Bourne Slough to provide an area into which runoff-borne suspended sediments could be directed and captured, thereby preventing their entry into Lake Madison. After further analyses, however, we have concluded that relocation of the Silver Creek inflow to the slough would result in greater long-term solids retention than would a dredging project. That is because the sediments in the slough are highly resuspendable by wind and wave action, a fact that would likely limit the longevity of any relatively deep water area(s) excavated by dredging. Relocation of the Silver Creek inflow to provide greater flow-path length for runoff entering Bourne Slough would, we believe, result in greater suspended solids removal by the slough. Two potential relocations to Sites 2A and 2B in Figure 17, were evaluated and preliminarily cost-estimated (Table 12). However, the feasibility of constructing either of these creek relocations will depend on numerous factors related to land ownership, regulatory permitting conditions and soil conditions.

Table 12 Preliminary Construction Cost Estimates for Silver Creek Relocation Options—June 10, 2002

ALTERNATIVE 2A: RELOCATE SILVER CREEK—NORTH—June 10, 2002

Item	Description	Units	Qty.	Unit Cost	Extension
1	Mobilization/Demobilization (15%)	LS	1	$58,000.00	$58,000.00
2	Site Preparation/Clearing/Grubbing	AC	3	$5,000.00	$15,000.00
3	Common Excavation	CY	60,000	$4.00	$240,000.00
4	Drop Structure & Culvert Crossing	LS	1	$100,000.00	$100,000.00
5	Restoration	AC	3	$10,000.00	$30,000.00
				Project Total	$443,000.00
		Contingency	25%		$111,000.00
		Engineering/Permitting/Administration	25%		$111,000.00
				Total	$665,000.00

(1) Mobilization includes erosion control features
(2) Site Preparation includes clearing, grubbing, stripping and stockpiling topsoil, as necessary
(3) Common Ex. includes excavating new channel (5 ft. wide w/ 3:1 side slopes), on-site soil disposal
(4) Due to decreased channel length, install drop structure is anticipate at new channel crossing
(5) Restoration incl. topsoil, erosion control blanket along new channel slopes, seeding and mulching

(Notes) Assume new 1,000-ft. channel between Silver Creek and Bourne Slough along the south side of the north boundary of Section 21. Preliminary cost estimate does not include easement or or property acquisition.

Table 12 Preliminary Construction Cost Estimates for Silver Creek Relocation Options—June 10, 2002 (Continued)

ALTERNATIVE 2B: RELOCATE SILVER CREEK – SOUTH—June 10, 2002

Item	Description	Units	Qty.	Unit Cost	Extension
1	Mobilization/Demobilization (15%)	LS	1	$7,000.00	$7,000.00
2	Site Preparation/Clearing/Grubbing	AC	2	$5,000.00	$10,000.00
3	Common Excavation	CY	3,500	$5.00	$17,500.00
4	Drop Structure & Culvert Crossing	LS	0	$100,000.00	$0.00
5	Restoration	AC	2	$10,000.00	$20,000.00
				Project Total	$54,500.00
	Contingency		25%		$14,000.00
	Engineering/Permitting/Administration		25%		$14,000.00
				Total	$82,500.00

(1) Mobilization includes erosion control features
(2) Site Preparation includes clearing, grubbing, stripping and stockpiling topsoil, as necessary
(3) Common Ex. includes excavating new channel (5 ft. wide w/ 3:1 side slopes), on-site soil disposal
(4) Due to decreased channel length, install drop structure is anticipate at new channel crossing
(5) Restoration incl. topsoil, erosion control blanket along new channel slopes, seeding and mulching

(Notes) Assume new 1,000-ft. channel between Silver Creek and Bourne Slough along the east boundary of Section 21. Preliminary cost estimate does not include easement or property acquisition. This Alternative may not be feasible, creek would discharge into Bourne Slough approx midway between existing berm and the location assumed for Alternative 2A. May need to add berm at south side of creek to prevent short circuiting.

7.4 Background

Silver Creek is the primary mode of transport for suspended solids and phosphorus that are carried to Bourne Slough. Areas of streambank erosion along the creek contribute excessive amounts of suspended solids and phosphorus to the streamflow. To date, this contribution has not been quantified, but it is thought to be significant. Although streambank erosion probably exists at random places along the entire length of Silver Creek, this discussion is directed toward the City of Madison. The following is a discussion of various causes of streambank erosion and recommendations for management of Silver Creek within the City of Madison. It should be noted that a detailed study of the causes of streambank erosion in the City of Madison has not been performed.

7.5 Causes of Streambank Erosion

Many factors can contribute to increased streambank erosion in the City of Madison. These contributing factors can originate both within the city and upstream of the city. Upstream contributors in an agricultural setting typically include drain tiles and drainage ditches, which carry runoff much more efficiently to the stream and result in higher discharges and increased stream velocities.

Within the City, contributors can include floodplain development, channel crossings (bridges and culverts), vegetation management, stormwater management, and maintenance of erosion areas. A brief discussion of each of these contributors follows.

7.5.1 Floodplain Development

Natural streams are typically able to carry up to a two-year flood event within their channel banks. Larger floods tend to spill into overbank area on either side of the channel. This area is known as the floodplain. Floodplains are important because they allow large floods to be carried at a lower velocity than if the entire flow were contained within the channel. Generally, any loss of floodplain results in a higher water level and higher velocity for a given flood event. This increases the potential for streambank erosion.

7.5.2 Channel Crossings

Roadway or railroad crossings of the stream channel tend to concentrate flow from the floodplain into the channel, resulting in higher water levels and higher flow velocities during flood events. Typically, increased channel and bank erosion is evident at and directly downstream of these structures. Larger bridge or culvert openings and/or the addition of culverts in the floodplain area can reduce the impact of channel crossings. Floodplain culverts would be placed at the floodplain elevation, which is higher than the channel crossing elevation.

7.5.3 Vegetation Management

Vegetation management along the stream corridor plays a key role in maintaining stability of the streambanks. A buffer strip consisting of shrubs and native plants can greatly improve the stability of the streambanks. Shrubs and native plants may have rooting depths on the order of six to eight feet deep, while typical Kentucky Bluegrass turf has a rooting depth of only several inches. Plants with deeper roots are much more resistant to erosion when exposed to high flow velocities, and can better serve to maintain the stability of the streambanks. The buffer strip should be a minimum of 50-feet on either side of the channel.

7.5.4 Stormwater Management

Cities typically produce much more runoff per acre than rural areas due to the large amount of impervious surface. Draining this runoff directly to the creek tends to increase the total creek discharge for a given flood event. Detention of runoff in stormwater detention ponds and releasing the runoff slowly can reduce the flowrate increase, thereby reducing the flow velocity and streambank erosion. Detention of stormwater has other water quality benefits, discussed elsewhere in this report.

7.5.5 Maintenance of Erosion Areas

Repair and maintenance of eroded areas along the creek is necessary to reduce their contribution of sediment to the creek. Many techniques are available for stabilizing eroded streambanks. These can include bank riprap, bioengineering, directing flow away from the bank using natural materials, and establishment of bank vegetation. Modification of bridges or culverts may be necessary if they are contributing to the eroded area. Each site presents a unique set of circumstances and needs to be addressed on an individual basis.

7.6 Future Work Recommendations

Although the City of Madison appears to be a relatively small contributor of TSS and Phosphorus to Bourne Slough, steps can be taken to reduce existing bank erosion and prevent future bank erosion. This would serve to reduce the City's contribution of TSS and Phosphorus to Silver Creek and Bourne Slough.

The magnitude and extent of the stream erosion has not been determined. A detailed study should be considered, including site surveys of eroded areas, and hydraulic modeling of the stream to determine the impact of channel crossings and other modifications to the channel and floodplain or the course, current, and erosive potential of the stream. An inventory of channel erosion upstream of the city would also be useful.

References

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Appendix A
South Dakota Water Quality Standards

Silver Creek has been assigned the beneficial uses of

- Warmwater Marginal Fish Life Propagation (6)
- Limited Contact Recreation (8)
- Wildlife Propagation and Stock Watering (9)
- Irrigation Waters (10)

Criteria for warmwater marginal fish life propagation waters (SDECR 74:51:01:49) includes total suspended solids 30-day average of ≤150 mg/L and daily maximum of ≤263 mg/L. There is no water quality criteria for phosphorus; the TSI of 50 is used as a guideline for establishing the impairment of SD lakes.

Appendix B
Climate Data from Madison 2SE

Appendix C
Madison Storm Sewer and Stream Water Quality Data

Appendix D
BMPS: Stormwater Treatment Suitability Matrix and Pavement Management

Appendix E
Bourne Slough and Round Lake Sediment and Water Quality Data