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Technical Memorandum

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Subject: Detailed Assessment of Phosphorus Sources to Minnesota Watersheds – Urban Runoff

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The purpose of this memorandum is to provide a discussion of urban land use runoff as a source of phosphorus to Minnesota watersheds. This discussion is based on a review of the available literature, monitoring data and the results of phosphorus loading computations done for each of Minnesota's major watershed basins as part of this study. This memorandum is intended to:

- Provide an overview and introduction to this source of phosphorus
- Describe the results of the literature search and review of available monitoring data
- Discuss the characteristics of each watershed basin as it pertains to this source of phosphorus
- Describe the methodology used to complete the phosphorus loading computations and assessments for this study
- Discuss the results of the phosphorus loading computations and assessments
- Discuss the uncertainty of the phosphorus loading computations and assessment
- Provide recommendations for future refinements to phosphorus loading estimates and methods for reducing error terms
- Provide recommendations for lowering phosphorus export from this source

Overview and Introduction to Urban Runoff Sources of Phosphorus

The conversion of land areas to urban land uses leads to changes in watershed hydrology and pollutant load rates. The areal increase in impervious surfaces in urban areas over undeveloped rural and natural land uses leads to greater surface water runoff volumes. The increased runoff coupled with human activities increases the types of pollutants and delivery rate of these pollutants to surface waters. The impacts of the increased runoff volumes and pollutant mass to downstream waters often leads to declines in water quality and ecological function.

Urban land uses have higher percentages of impervious surfaces than natural land cover. The road and street infrastructure, parking lots and buildings all increase the area of hard surfaces. These impermeable surfaces shed water as surface runoff, lowering the infiltration and evapotranspiration components of the hydrologic cycle. Up to 90% of the annual precipitation may become surface runoff in high density urban environments (Center for Watershed Protection, 2003). This water is generally directed to storm sewers and other conveyance systems to rapidly move the large volumes to receiving waters and prevent flooding.

The intense human use in urban watersheds leads to a larger range of pollutants and large quantities of these pollutants when compared to natural vegetative land cover. Human activities related to automobiles, industrial uses, and the prevalence of turf grass as a groundcover provides a ready supply of pollutants. The storm water conveyance systems promote the rapid movement of water to receiving waters, increasing the efficiency of runoff water at entraining and removing pollutants from the landscape. The result is that urban landscapes generate a larger volume of surface runoff that transports a larger load of pollutants compared to pre-development conditions. This increase in runoff volumes reduces the infiltration volume and thus reduces stream base flows and shallow groundwater levels.

This resulting urban stormwater runoff channels large quantities of pollutants and water to lakes, streams and wetlands where the impact on ecological function is nearly always negative. The increased loading of nutrients, especially phosphorus, leads to eutrophication of lakes and wetlands, as well as stream systems. The resulting eutrophication leads to increased algal growth, decreased water clarity and loss of recreational uses, as well as human health concerns, increased periphyton growth and increased treatment costs for industrial uses of water. Remediation of the resulting water quality problems is costly and many times may not fully restore water to the pre-impacted conditions.

Results of Literature Search and Review of Available Monitoring Data

Initially, the literature review efforts attempted to document urban runoff studies within each of the basins in Minnesota, but it became readily apparent that the quality and quantity of the data available was insufficient for the use of quantifying basin-specific data for this assessment. See Table 1 for a listing and summary of the initial 31 data sets reviewed for this assessment. The need to quantify phosphorus loadings across basins with regard to three different hydrologic conditions (low, average and high flow conditions) required that a method be developed to model phosphorus loadings with regard to land use and hydrologic conditions. The scientific literature was thus reviewed to determine the hydrologic regimes, nutrient cycling mechanisms and phosphorus loading factors for each of the land use categories included in the Urban Runoff category. Phosphorus monitoring results for urban watersheds, the hydrologic and nutrient export relationships related to the urban land uses, runoff modeling techniques, and methods for assessing variability in stormwater modeling results were the main areas of investigation of the review.

Stormwater Runoff Monitoring

The variability in storm water runoff data is inherent in studies of this type, and storm water runoff data should always be subject to scrutiny to insure that the variability is not beyond the expected range. One recurring point noted during this review of the literature was agreement by all authors that runoff data is log-normally distributed and highly variable (Bannerman, 1983). In an attempt to determine the range of phosphorus concentrations in urban runoff, we reviewed summary data provided by investigators and wherever possible examined the site specific data from previous or ongoing monitoring studies. The monitoring data presented in Table 1 is a combination of flow-weighted mean concentrations, event mean concentrations, expressed as median geometric mean or arithmetic mean. The inconsistency in data reporting limited the use of many of the data sets found during the literature review process.

From all of the available published and unpublished urban runoff total phosphorus data that were assessed in the development of estimates of phosphorus concentrations in urban storm water runoff, only a limited number of data sets were used. The elimination of data from consideration was based upon information from various investigators related to bias and accuracy of load estimates (Schwartz and Naiman, 1999; Marsalek, 1991; Marsalek, 1990). Schwartz and Naiman (1999) reviewed the

Table 1. Storm event runoff total phosphorus concentrations (concentrations - mg P/L).*

Location	Concentration	Source of data	Notes:	
Nokomis/Hiawatha watersheds				
Hiawatha watersheds - 1996	0.510	Wenck/MCWD, 1998		
Minnehaha Creek 1997		Wenck/MCWD, 1998		
Storm event flows	0.380		[average] of overflows from MC to L.Nokomis following rain events	
Storm event flows	0.690		July 1, 1997 storm	
Minneapolis NPDES report (92 only)		City of Minneapolis, 1992		
Ave. EMC w/o Jimmy's	0.417			
White Bear Lake storm sewer FWMC	0.242	Schuler, 1998	arithmetic mean of annual FWMC for 12 years (1985-96)	
Metropolitan Area 208 Study	0.560	Oberts, 1983	median flow-weighted mean concentration	
Plymouth, MN	0.258	Barten, 1994	5 samples - July - Oct 1993	
TCMA - NURP site data		USGS, 1982 (from Brach, 1989)	mean FWMC values	
Yates watershed	0.630			
Iverson watershed	0.620			
Wisconsin storm-sewer samples	0.290	Bannerman *et al* , 1996	EMC median; n=204	
	0.450		EMC mean; n=204	
Madison, WI		Bannerman, *et al*, 1992	storm sewer outfalls - urban areas	
geometric mean	0.660		cv = 0.70	
arithmetic mean	0.860		cv = 0.70	
Michigan NPDES residential sites	0.380	Cave and Roesner, 1994	mean EMC 1992-93; n=34	
Marquette, MI	0.290	Steuer *et al* , 1997	geometric mean	
Minneapolis/St. Paul NPDES Monitoring				
Lake Harriet Parkway at W. 44th St., Minneap	0.541	MPRB 2002.	May-October	2001
Luella St. at Orange Ave, St. Paul, MN	0.652		May-October	2001
Vandalia St.-350 feet south of Capp Rd.,St. Pa	0.255		May-October	2001
Charles Ave-Mackubin to Arundel St., St. Pau	0.377		May-October	2001
E. 29th St. at 31st Ave. S., Minneapolis, MN	0.525		May-October	2001
Souix Falls SD		Niehus, 1997		
Site 1, Sioux Falls, SD	0.217		June 1995-July 1996	
Site 2, Sioux Falls, SD	0.613		June 1995-July 1996	
Site 3, Sioux Falls, SD	0.114		June 1995-July 1996	
Fish Lake Watershed - Eagan MN		City of Eagan, 1995		
I-2 inlet to Fish Lake Watershed, Eagan, MN	0.235		All Year	1993
I-3, Eagan, Fish Lake Watershed, MN	0.371		All Year	1993
Lake Harriet watershed, Minneapolis		MPRB unpublished		
Lake Harriet Parkway at W. 44th St., Minneap	0.934		April-October	1995
Lake Harriet Parkway at W. 44th St., Minneap	0.635		June-November	1996
Lake Harriet Parkway at W. 44th St., Minneap	0.466		June-August	1997
Lake Harriet Parkway at W. 44th St., Minneap	0.366		May-October	2002
Minneapolis/St. Paul NPDES Monitoring		MPRB 2003a		
Luella St. at Orange Ave, St. Paul, MN	0.344		May-October	2002
Vandalia St.-350 feet south of Capp Rd.,St. Pa	0.278		May-October	2002
Charles Ave-Mackubin to Arundel St., St. Pau	0.391		May-October	2002
E. 29th St. at 31st Ave. S., St. Paul, MN	0.305		May-October	2002
Tanners Lake Watershed, Maplewood, MN		Barr 1993		
G1AB, Tanners Lake Watershed, Maplewood,	0.240		All Year	1989
G4A, Tanners Lake Watershed, Maplewood, N	0.410		All Year	1989
G3, Tanners Lake Watershed, Maplewood, MN	0.340		All Year	1989
Minneapolis Chain of Lakes CWP project		Barr 1992		
LH1, Lake Harriet, Minneapolis, MN	0.224		April-October	1990-1991
LH8, Lake Harriet, Minneapolis, MN	0.213		April-October	1990-1991
LC15, Lake Calhoun, Minneapolis, MN	0.211		April-October	1990-1991
LC17, Lake Calhoun, Minneapolis,MN	0.179		April-October	1990-1991
LC20, Lake Calhoun, Minneapolis, MN	0.255		April-October	1990-1991
LC22, Lake Calhoun, Minneapolis, MN	0.224		April-October	1990-1991
LC26, Lake Calhoun, Minneapolis, MN	0.230		April-October	1990-1991
LI31, Lake of the Isles, Minneapolis, MN	0.232		April-October	1990-1991
CD36, Cedar Lake, Minneapolis, MN	0.211		April-October	1990-1991
CD37, Cedar Lake, Minneapolis, MN	0.173		April-October	1990-1991
TCMA golf course study		Barten 1995		
Baker Golf Course, Minneapolis, MN	0.479		April-October	1994
Meadowbrook Golf Course, Minneapolis, MN	0.892		April-October	1994
Woodhill Golf Course, Minneapolis, MN	0.476		April-October	1994
Plymouth MN		TRPD unpublished		
Three Rivers Park District	0.341		July-November	2001
Three Rivers Park District	0.195		April-October	2002
Three Rivers Park District	0.377		July-November	2001
Three Rivers Park District	0.254		April-October	2002
Three Rivers Park District	0.244		July-November	2001
Three Rivers Park District	0.219		April-October	2002
Three Rivers Park District	0.213		July-November	2001
Three Rivers Park District	0.249		April-October	2002
Three Rivers Park District	0.329		July-November	2001
Three Rivers Park District	0.290		April-October	2002
Tanners Lake Watershed, Maplewood, MN		Barr 2003		
G1AB Inlet (Dennys) to Tanners Lake, Oakdal	0.232		May-September	2002
G4A Inlet (Glenbrook) to Tanners Lake, Mapl	0.308		May-September	2002
G3 Inlet to Tanners Lake, Maplewood, MN	0.202		May-September	2002
Superior, WI		USGS 1996		
Urban Undeveloped Lot, Superior, WI	0.065		May-September	1996
Urban Undeveloped Lot, Superior, WI	0.115		July-September	1995
Golf Course, Superior, WI	0.247		June-October	1996
Madison WI		Waschbusch, etal 1999		
Monroe Neighborhood, Madison, WI	0.640		May-October	1994
Harper Neighborhood, Madison, WI	0.930		June-October	1995
Woodbury MN		RWMWD unpublished		
PFS Study Site, East Pond, Woodbury, MN	0.398		May-September	2001
PFS Study Site, East Pond, Woodbury, MN	0.332		May-September	2002
PFS Study Site, West Pond, Woodbury, MN	0.446		May-September	2001
PFS Study Site, West Pond, Woodbury, MN	0.322		May-September	2002
Minneapolis/St. Paul NPDES Monitoring		MPRB unpublished		
Lake Harriet Parkway at W. 44th St., Minneap	0.588		March-September	2003
Luella St. at Orange Ave, St. Paul, MN	0.539		May-September	2003
Vandalia St.-350 feet south of Capp Rd.,St. Pa	0.296		May-September	2003
Charles Ave-Mackubin to Arundel St., St. Pau	0.426		May-September	2003
St. Paul MN		Ramsey County Public Works, unpublished		
Como Lake Rain Water Garden, St. Paul, MN	0.253		April-September	2002
Hennepin County				
Storm Sewer at Torah School, St. Louis Park,	0.930		July-November	1989
Storm Sewer at Torah School, St. Louis Park,	0.470		April-October	1990
Keller Lake watershed		RWMWD unpublished		
Keller Lake Parkway and HWY 36, St. Paul, M	0.316		June-October	2002
Canadian Cities				
Sarnia, ON	0.299			
ult Ste. Marie, ON	0.309			
Windsor, ON	0.231			
		Marsalek, 1991		
Toronto, ON				
warm weather	0.280			
cold weather	0.230			
		Pitt and McLean, 1986		
Sault Ste. Marie, ON	0.246			
		Marsalek, 1990		
Summary statistics	**Mean**	**Standard deviation**		
	0.379	**0.195**		

*All values listed are for either mixed use urban watershed or urban residential, as provided by the author(s).

level and cause of uncertainty in planning level estimates of pollutant loads. They defined planning level estimates as methods that make use of an annual runoff volume and a representative pollutant concentration to estimate annual loads. The use of planning level estimates is widespread, but the authors note that very little work has been completed to measure the accuracy or confidence of these estimates. Schwartz and Naiman (1999) noted that errors in planning level pollutant loads have been reported to be in the range of 50 – 300%. Schwartz and Naiman (1999) suggest using the mean concentration as the representative concentration introduces significant bias into the annual load estimates and report that the use of flow-weighted mean concentration (FWMC) provides an unbiased estimate of annual load. They further note that the use of arithmetic means for event concentrations can yield a range of bias from -40% to 40%.

Data collected in the literature review, chosen for inclusion in the database, had to meet the following criteria:

1) phosphorus data was collected for the duration of individual storm events and was reported as Event Mean Concentration, (EMC)
2) numerous samples had to be collected at the same monitoring location throughout a given year,
3) land use was either reported in adequate detail or land use could be determined using ArcView with delineated watersheds and USGS National Land Cover Data (NLCD), and
4) a large fraction of the runoff generated from a monitored watershed was not routed through storm water treatment BMPs such as detention ponds.

With regard to criteria #4, the urban runoff dataset is intended to represent the concentration of phosphorus in untreated urban runoff. For a majority of the datasets (71 percent), the annual average total phosphorus concentration reported was weighted by the volume of runoff produced for each storm event (i.e. flow weighted mean concentration), the remainder of the annual total phosphorus concentrations reported were arithmetic averages. One study (Niehus, 1997) did not meet criterion #2 but was included in the dataset because of limited runoff data for small urban areas and the need to represent less populated urban areas in the dataset. All of the data included in this dataset are presented in Table 2. Precipitation data that is shown in Table 2 was gathered from the rain gage nearest to the monitoring site. Rain gage data was provided by the State Climatology Office Climatology Working Group web page.

Table 2. Dataset of flow-weighted annual total phosphorus concentration in urban runoff.

Location	Landuse[1]										
	% LIR	%CIT	%RG	%HIR	% Impervious	Watershed Size (ac)	Total Precipitation for Monitoring Year (in)	Monitoring Year	Sampling Period	Flow Weighted TP Concentration (ug/L)	Reference[2]
Lake Harriet Parkway at W. 44th St., Minneapolis,MN	100	0	0	0	32	143	36	2001	May-October	541	1
Luella St. at Orange Ave, St. Paul, MN	100	0	0	0	32	95	34	2001	May-October	652	1
Vandalia St.-350 feet south of Capp Rd.,St. Paul, MN	0	100	0	0	57	80	34	2001	May-October	255	1
Charles Ave-Mackubin to Arundel St., St. Paul, MN	60	40	0	0	42	63	34	2001	May-October	377	1
E. 29th St. at 31st Ave. S., Minneapolis, MN	50	45	5	0	43	100	36	2001	May-October	525	1
Site 1, Sioux Falls, SD	30	70	0	0	50	145	23	1995 to 1996	June 1995-July 1996	217	2
Site 2, Sioux Falls, SD	0	96	0	0	55	695	23	1995 to 1996	June 1995-July 1996	613	2
Site 3, Sioux Falls, SD	76	0	18	0	30	328	23	1995 to 1996	June 1995-July 1996	114	2
I-2 inlet to Fish Lake Watershed, Eagan, MN	80	20	0	0	37	124	34	1993	All Year	235	3
I-3, Eagan, Fish Lake Watershed, MN	100	0	0	0	32	40	34	1993	All Year	371	3
Lake Harriet Parkway at W. 44th St., Minneapolis, MN	100	0	0	0	32	143	26	1995	April-October	934	4
Lake Harriet Parkway at W. 44th St., Minneapolis, MN	100	0	0	0	32	143	26	1996	June-November	635	4
Lake Harriet Parkway at W. 44th St., Minneapolis, MN	100	0	0	0	32	143	34	1997	June-August	466	4
Lake Harriet Parkway at W. 44th St., Minneapolis, MN	100	0	0	0	32	143	39	2002	May-October	366	5
Luella St. at Orange Ave, St. Paul, MN	100	0	0	0	32	95	42	2002	May-October	344	5
Vandalia St.-350 feet south of Capp Rd.,St. Paul, MN	0	100	0	0	57	80	42	2002	May-October	278	5
Charles Ave-Mackubin to Arundel St., St. Paul, MN	60	40	0	0	42	63	42	2002	May-October	391	5
E. 29th St. at 31st Ave. S., St. Paul, MN	50	45	5	0	43	100	42	2002	May-October	305	5
G1AB, Tanners Lake Watershed, Maplewood, MN	0	82	18	0	53	65	27	1989	All Year	240	6
G4A, Tanners Lake Watershed, Maplewood, MN	0	83	17	0	53	43	27	1989	All Year	410	6
G3, Tanners Lake Watershed, Maplewood, MN	41	11	48	0	35	1354	27	1989	All Year	340	6
LH1, Lake Harriet, Minneapolis, MN	100	0	0	0	32	142	36	1991	April-October	224	7
LH8, Lake Harriet, Minneapolis, MN	82	18	0	0	37	50	36	1991	April-October	213	7
LC15, Lake Calhoun, Minneapolis, MN	81	12	7	0	35	232	36	1991	April-October	211	7
LC17, Lake Calhoun, Minneapolis,MN	26	42	25	0	40	1385	36	1991	April-October	179	7
LC20, Lake Calhoun, Minneapolis, MN	34	31	0	27	40	146	36	1991	April-October	255	7
LC22, Lake Calhoun, Minneapolis, MN	69	31	0	0	40	177	36	1991	April-October	224	7
LC26, Lake Calhoun, Minneapolis, MN	27	41	0	27	43	46	36	1991	April-October	230	7
LI31, Lake of the Isles, Minneapolis, MN	79	21	0	0	37	229	36	1991	April-October	232	7
CD36, Cedar Lake, Minneapolis, MN	100	0	0	0	32	115	36	1991	April-October	211	7
CD37, Cedar Lake, Minneapolis, MN	64	17	15	0	35	1714	36	1991	April-October	173	7
Baker Golf Course, Minneapolis, MN	0	0	100	0	32	47	30	1994	April-October	479	8
Meadowbrook Golf Course, Minneapolis, MN	0	0	100	0	32	94	30	1994	April-October	892	8
Woodhill Golf Course, Minneapolis, MN	0	0	100	0	32	31	30	1994	April-October	476	8
Three Rivers Park District	100	0	0	0	32	14	36	2001	July-November	341	9
Three Rivers Park District	100	0	0	0	32	14	41	2002	April-October	195	9
Three Rivers Park District	100	0	0	0	32	9	36	2001	July-November	377	9
Three Rivers Park District	100	0	0	0	32	9	41	2002	April-October	254	9
Three Rivers Park District	100	0	0	0	32	12	36	2001	July-November	244	9
Three Rivers Park District	100	0	0	0	32	12	41	2002	April-October	219	9
Three Rivers Park District	100	0	0	0	32	17	36	2001	July-November	213	9
Three Rivers Park District	100	0	0	0	32	17	41	2002	April-October	249	9
Three Rivers Park District	100	0	0	0	32	14	36	2001	July-November	329	9
Three Rivers Park District	100	0	0	0	32	14	41	2002	April-October	290	9
G1AB Inlet (Dennys) to Tanners Lake, Oakdale, MN	0	80	20	0	52	65	42	2002	May-September	232	10
G4A Inlet (Glenbrook) to Tanners Lake, Maplewood, MN	85	0	15	0	32	74	42	2002	May-September	308	10
G3 Inlet to Tanners Lake, Maplewood, MN	49	19	25	0	35	1368	42	2002	May-September	202	10
Urban Undeveloped Lot, Superior, WI	0	0	100	0	32	76	40	1996	May-September	65	11
Urban Undeveloped Lot, Superior, WI	0	0	100	0	32	76	32	1995	July-September	115	11
Golf Course, Superior, WI	0	0	100	0	32	12	40	1996	June-October	247	11
Monroe Neighborhood, Madison, WI	97	0	0	0	31	232	36	1994	May-October	640	12
Harper Neighborhood, Madison, WI	100	0	0	0	32	41	33.6	1995	June-October	930	12
PFS Study Site, East Pond, Woodbury, MN	100	0	0	0	32	21	36.0	2001	May-September	398	13
PFS Study Site, East Pond, Woodbury, MN	100	0	0	0	32	21	41.0	2002	May-September	332	13
PFS Study Site, West Pond, Woodbury, MN	100	0	0	0	32	15	36.0	2001	May-September	446	13
PFS Study Site, West Pond, Woodbury, MN	100	0	0	0	32	15	41.0	2002	May-September	322	13
Lake Harriet Parkway at W. 44th St., Minneapolis, MN	100	0	0	0	32	143	30.8	2003	March-September	588	14
Luella St. at Orange Ave, St. Paul, MN	100	0	0	0	32	95	26.8	2003	May-September	539	14
Vandalia St.-350 feet south of Capp Rd.,St. Paul, MN	0	100	0	0	57	80	26.8	2003	May-September	296	14
Charles Ave-Mackubin to Arundel St., St. Paul, MN	60	40	0	0	42	63	26.8	2003	May-September	426	14
Como Lake Rain Water Garden, St. Paul, MN	100	0	0	0	32	5	26.8	2002	April-September	253	15
Storm Sewer at Torah School, St. Louis Park, MN	100	0	0	0	32	31	26.8	1989	July-November	930	16
Storm Sewer at Torah School, St. Louis Park, MN	100	0	0	0	32	31	38.25	1990	April-October	470	16
Keller Lake Parkway and HWY 36, St. Paul, MN	27	53	20	0	45	53	42	2002	June-October	316	17

[1] LIR= Low Intensity Residential, CIT= Commercial, Industrial, Transportation, RG= Urban Recreation Grasses, HIR=High Intensity Residential

[2] References

1)Minneapolis Park and Recreation Board, 2002. National Pollutants Discharge Elimination System (NPDES) Monitoring
2)Niehus, C.A. 1997. Characterization of stormwater runoff in Sioux Falls, South Dakota, 1995-1996. USGS Water-Resources Investigations Report 97-4070.
3)City of Eagan. 1995. Diagnostic/feasibility study of Fish Lake, Eagan, MN.
4) Minneapolis Park and Recreation Board, 1997. Unpublished Data.
5)Minneapolis Park and Recreation Board, 2003a. National Pollutants Discharge Elimination System (NPDES) Monitoring
6)Barr Engineering. 1993. Diagnostic/feasibility study of water quality problems and restorative measures for Tanner's Lake. Prepared for the Ramsey Washington Metro Watershed District.
7)Barr Engineering. 1992. Minneapolis chain of lakes clean water partnership project. Prepared for Minneapolis Park and Recreation Board.
8)Barten, J. 1995. Quantity and quality of runoff from four golf courses in the twin cities metropolitan area. Suburban Hennepin Regional Park District.
9)Three River Park District, unpublished data
10) Barr Engineering. 2003. Tanners Lake CIP Performance Evaluation. Prepared for Ramsey-Washington Metro Watershed District.
11) USGS. 1996. Water resources data Wisconsin Water Year 1996. U.S. Geological Survey Water-Data Report WI-96-1.
12) Waschbusch, R.J., etal. 1999. Sources of phosphorus in stormwater and street dirt from two urban residential basins in Madison, Wisconsin. 1994-95. USGS Water-Resources Investigation Report 99-4021.
13) Ramsey Washington Metro Watershed District. Unpublished Data.
14) Minneapolis Park and Recreation Board, 2003b. Unpublished monitoring data for the 2003 NPDES permit.
15) Ramsey County Public Works. 2003. Unpublished data.
16) Hennepin Conservation District. 1991. Toxic and hazardous substances in urban runoff. February 1991.
17) Ramsey Washington Metro Watershed District. 2003. Unpublished data.

Hydrologic and nutrient export relationships

Driver and Tasker (1990) found that, in developing linear regression equations for the estimation of storm water loads, the total storm rainfall, and total contributory drainage area were the most significant factors, while impervious area, land-use and mean annual climatic characteristics were also significant.

The high level of correlation between land use type and effective impervious area has also been noted by many investigators (Schueler, 1987; Driver and Tasker, 1990; Beaulac and Rechkow, 1982). Likewise nutrient loadings increase with increasing impervious surface area, most likely due to the ease of washoff and transport in curb and gutter systems and on other hard surfaces (Brezonik, *et al*, 2002; Schueler, 1994). Higher impervious percentage watersheds yield lower phosphorus concentrations, but the larger volume of water leads to the higher phosphorus loading rates (Bannerman, *et al*, 1992; Swenson, 1998; Beaulac and Rechkow, 1982). Schwartz and Naiman (1999) propose that in small watersheds the pollutant and buildup functions may dominate the pollutant delivery patterns. Thus precipitation patterns can move the pollutant delivery between supply-limited and transport-limited conditions depending upon rainfall amounts. These conditions make the correlation of flow and concentration difficult. This transition between supply-limited conditions and transport-limited is also helpful in explaining the observed concentration and loading differences with annual rainfall amounts. Walker (1992) found similar relationships for runoff data for the Vadnais Lake watershed and noted that antecedent flow conditions are important, with high loads in years following drought. The regression analysis preformed for this assessment supports this theory, in that during wet years the phosphorus storm FWMC are lower and the annual loadings are higher.

Clesceri, et al, (1986) report that years (and seasons) that are wetter or dryer than average, or generally abnormal, can cause large deviations in the annual export rate. They suggest that more accurate loading estimates can be calculated if export rates used were determined from watersheds having similar watershed characteristics or at least from the same regions. Beaulac and Rechkow (1982) also suggest that there is wide variability in loading estimates due to watershed characteristics that influence runoff rates, pollutant sources and delivery. US EPA (1997) and Brezonik, *et al* (2002) provide information on the use of regression analysis for evaluating non-point source pollutant loads. Brezonik *et al* (2002) presented Walker's (1987) regression relationship between phosphorus export and percent urban cover, and the regression relationships between percent urban and percent impervious surface from Twin Cities watershed studies.

Runoff modeling techniques

Marsalek (1991) noted that the simplest methods for estimating annual loads is made by applying monitoring data expressed as annual unit loads to unmonitored watersheds, with the use of summary statistics from larger data bases, regression models and simulation models being progressively more complex. He felt that the best load estimates would be obtained through runoff sampling programs, and that the correlation between runoff volumes and event mean concentrations were critical to the accuracy of the estimates.

Export coefficients are commonly reported according to land use and are developed during a given year under a particular hydrologic condition, such as a wet year (Beaulac and Reckhow, 1982: Reckhow, et al, 1980; Panuska and Lillie, 1995; Clesceri, et al, 1986a; Clesceri, et al, 1986b; McFarland and Hauck, 2001). In some cases the export coefficient is adjusted to reflect a normal climatic year. The most common approach to estimating loads is based upon Schueler's (1987) regression of rainfall runoff volume and percentage imperviousness of a watershed combined with a flow-weighted mean concentration. The equation is widely used for loading estimates and is used in this assessment to determine runoff coefficient based upon impervious fraction:

$$\text{Runoff coefficient } (R_v) = 0.05 + 0.009\ (I)$$

where I = the percentage of site imperviousness.

Using the direct average method, the pollutant load is calculated by multiplying runoff volume with the pollutant concentration to obtain a mass load (Marsalek, 1990). The phosphorus export coefficients used for urban areas assume 100% of phosphorus transported from land will reach surface water due to developed conditions. The mass per unit area derived from the pollutant can be used to calculate the areal loading rate or export coefficient.

The phosphorous export coefficient is part of the total phosphorous loading equation:

$$L = \sum_{i=1}^{m} c_i \bullet A_i$$

> L is total phosphorus loading from land (in kilograms per year), m is number of land use types, c_i is the phosphorus export coefficient for land use i (in kilograms per hectare per year), and A_i is area of land use i (in hectares).

Over large watershed areas, the phosphorus export may not be proportional to watershed area and some attenuation of phosphorus occurs, especially in natural plant communities that have low runoff rates (Soranno, et al, 1996). Panuska and Lillie (1995) report that watershed phosphorus export rates are highly variable and are affected by many factors. Among the factors sited are watershed size, land use, soil types, annual rainfall and the drainage system efficiency.

Walker (1986) developed the FLUX program for the US Army Corps of Engineers (ACOE) to estimate watershed loads from monitoring data sets. The FLUX program allows for the estimation of tributary loadings from sample concentration data and continuous flow records. Five estimation methods are available and potential errors in estimates are quantified. This software is widely used where both flow and concentration data are available. FLUX was used by the Minneapolis Chain of Lakes Clean Water Partnership (and many other monitoring efforts) to estimate annual loads (MPRB, 1993). This data was examined and used in the development of the regression equations (see Approach and Methodology for Phosphorus Loading Computations section) and was used in the assessment of loading variability and uncertainty analysis undertaken for this assessment (see Phosphorus. Loading Variability and Uncertainty section).

McFarland and Hauck (2001) used a multiple regression approach to determine nutrient export coefficients for the Bosque River. They advise that the use of regression analysis using measured flows and water quality data for heterogeneous land uses allows the estimation of loads that represent average conditions accurately.

Methods for Assessing Variability

Schwartz and Naiman (1999) reviewed bias in planning level estimates of pollutant loads. They defined planning level estimates as methods that make use of an annual runoff volume and a representative pollutant concentration (literature derived or monitoring-based measure of central tendency) to estimate annual loads. The use of planning level estimates is widespread, but the authors note that very little work has been completed to measure the accuracy or confidence of these estimates. They noted that errors in planning level pollutant loads have been reported to be in the range of 50 – 300%. Schwartz and Naiman (1999) suggest using the mean event concentration as the representative concentration introduces significant bias into the annual load estimates and report that the use of flow-weighted mean concentration (FWMC) provides an unbiased estimate of annual load. They further note that the use of arithmetic means for EMCs can yield a range of bias from -40% to 40%.

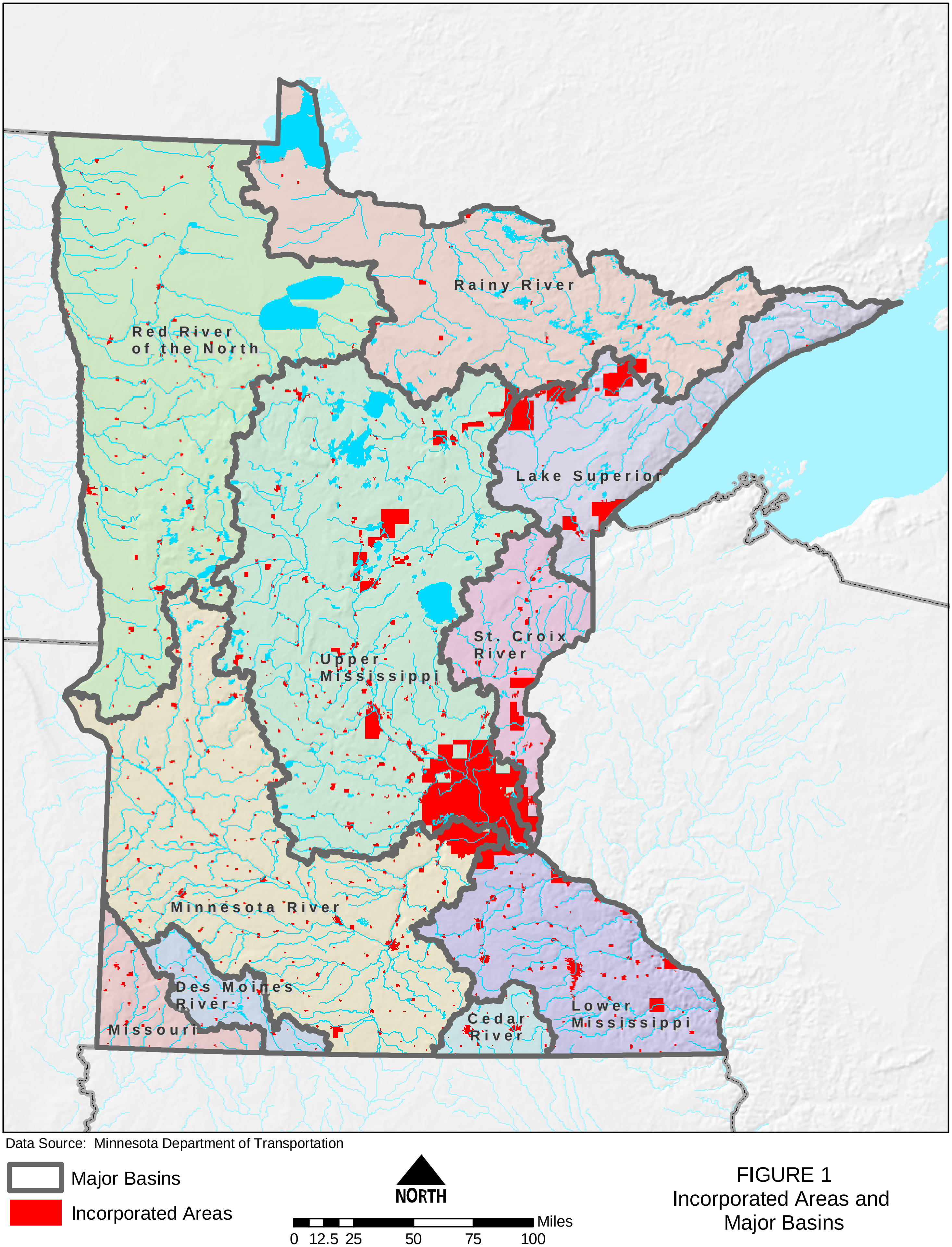
Watershed Basin Characteristics

For the purposes of defining and quantifying the phosphorus loads to Minnesota basins, the land uses within incorporated areas were classified and enumerated using the USGS National Land Cover Data (NLCD). Figure 1 shows the locations of the incorporated areas included in this assessment in relation to the basin boundaries. The National Land Cover Data Set for the Conterminous United States is derived from the Landsat thematic mapper data system (Vogelmann, 2001). The NLDC cover classes included in the land uses within incorporated areas assessed are:

- Urban Developed Areas
    - Low intensity residential
    - High intensity residential
    - Commercial/Industrial/Transportation
- Deciduous Forest
- Evergreen Forest
- Mixed Forest
- Shrubland
- Grasslands/Herbaceous
- Urban / Recreational Grasses
- Agricultural lands
    - Pasture/Hay
    - Row Crops
    - Small Grains
- Other
    - Quarries/Strip Mines/Gravel Pits
    - Transitional (new development)

Tables 3 and 4 provide an overview of the basin characteristics and basin hydrology for each of the ten basins.

Tables 5 and 6 present an overview of the land cover distribution within incorporated areas across the Minnesota basins. Table 5 provides a breakout of all the land cover classes found in the incorporated area boundaries, while Table 6 provides a detailed breakdown of only the urban land cover classes assessed for phosphorus loads.



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Data Source: Minnesota Department of Transportation

FIGURE 1
Incorporated Areas and
Major Basins

Table 3. Basin watershed areas, precipitation, runoff and land cover percentages.

Basin	Area (Sq Miles)	Average Precipitation (1979-2002)	Average Runoff (1979-2002)	Land Cover Percentages*					
				Urban	Forested	Tilled Agricultural	Pasture/ Grassland	Wetland/Open Water	Other
Cedar River	1,028	32.06	9.80	3.4%	3.3%	83.4%	6.2%	3.7%	0.0%
Des Moines River	1,535	27.98	5.68	1.8%	1.8%	79.9%	11.0%	5.5%	0.0%
Lake Superior	6,149	29.11	12.44	1.4%	57.1%	2.6%	3.5%	33.3%	2.1%
Lower Mississippi	6,317	33.29	10.28	2.4%	15.4%	52.2%	24.8%	5.1%	0.1%
Minnesota River	14,943	28.14	5.61	2.2%	4.6%	72.7%	12.6%	7.8%	0.1%
Missouri	1,782	27.16	5.25	1.5%	1.0%	78.9%	16.0%	2.6%	0.0%
Rainy River	11,236	26.20	8.01	0.4%	41.4%	2.0%	2.3%	52.5%	1.3%
Red River	17,741	23.29	3.42	0.7%	12.0%	54.6%	8.8%	23.8%	0.2%
St. Croix River	3,528	30.61	9.71	1.3%	36.8%	10.8%	20.6%	30.1%	0.2%
Upper Mississippi	14,943	28.07	6.87	3.5%	29.1%	20.2%	16.7%	29.7%	0.7%
State Wide	**79,202**	**27.39**	**6.83**	**1.9%**	**22.7%**	**38.1%**	**12.0%**	**24.7%**	**0.6%**

*Based on USGS National Land Cover Database (1992)

Table 4. Basin hydrologic conditions for assessment scenarios.

			Dry Conditions		Average Conditions		Wet Conditions	
Basin	Total Watershed Area - Square Miles (at discharge point from State)	Minnesota Watershed Area	Rainfall (inches)	Runoff (inches)	Rainfall (inches)	Runoff (inches)	Rainfall (inches)	Runoff (inches)
Cedar River	1,028	1,028	27.5	5.6	32.1	9.8	41.3	17.5
DesMoines River	1,535	1,535	22.0	1.4	28.0	5.7	36.8	13.4
Lake Superior	6149*	6,149	25.5	7.9	29.1	12.4	35.1	16.7
Lower Mississippi	21,073	6,317	27.0	7.1	33.3	10.3	39.8	15.6
Minnesota River	16,879	14,933	22.1	1.9	28.1	5.6	34.8	11.2
Missouri River	1,782	1,782	21.1	1.0	27.2	5.3	35.6	12.8
Rainy River	>22,000*	11,236	22.4	4.8	26.2	8.0	32.1	11.4
Red River	38,183	17,741	18.6	1.1	23.3	3.4	28.9	6.1
St. Croix River	7,728	3,528	23.7	5.6	30.6	9.7	37.6	14.3
Upper Mississippi River	20,100	20,100	22.6	3.6	28.1	6.9	34.3	10.4

Table 5. All land use cover classes, total coverage (acres) and percent of land area for all urban land uses within incorporated areas.

WATERSHED	Open Water	Low Intensity Residential	High Intensity Residential	Commercial/ Industrial/ Transportation	Bare Rock/Sand/ Clay	Quarries/ Strip Mines/Gravel Pits	Transitional	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrubland	Grasslands/ Herbaceous	Pasture/Hay	Row Crops	Small Grains	Urban/ Recreational Grasses	Woody Wetlands	Emergent Herbaceous Wetlands	Total
Cedar River	1,420	2,721	3,645	4,088	0	57	0	1,118	0	5	0	0	1,644	6,719	0	965	202	575	23,161
Des Moines River	880	3,712	657	2,038	0	0	0	497	9	6	0	0	1,759	6,248	0	1,558	87	309	17,762
Lake Superior	12,500	12,465	6,773	11,558	438	31,536	1,086	105,427	20,564	28,412	1,829	1,243	13,003	12,207	121	4,696	61,323	5,607	330,787
Lower Mississippi	11,364	26,611	11,619	13,993	0	803	324	39,953	583	1,957	4	1,026	52,126	72,531	21	14,634	8,125	6,887	262,562
Minnesota River	19,097	79,112	22,044	29,134	15	726	402	30,006	1,070	1,087	139	17	36,206	75,097	2,450	26,042	6,548	20,458	349,650
Missouri	874	3,102	601	1,458	2	45	0	380	0	4	0	25	3,529	9,065	193	1,323	16	320	20,938
Rainy River	2,578	2,883	1,054	2,073	174	8,154	418	17,004	5,305	7,896	513	45	4,148	1,939	493	818	13,491	2,192	71,179
Red River	7,046	15,745	6,701	10,168	0	196	32	7,348	219	130	10	0	14,212	31,002	4,604	6,178	1,782	3,497	108,869
St. Croix River	9,656	8,839	1,737	3,857	0	389	42	31,342	2,842	2,877	6	310	62,842	44,247	1,873	4,994	11,352	10,919	198,126
Upper Mississippi	112,290	172,383	82,717	61,800	50	17,791	2,293	203,942	15,688	19,224	2,476	859	218,513	152,854	15,440	55,046	64,030	103,844	1,301,239
Total Area in Acres by Category for All Basins (1)	177,705	327,573	137,548	140,168	679	59,698	4,598	437,017	46,280	61,598	4,978	3,526	407,981	411,910	25,196	116,253	166,956	154,609	2,684,274
Area Expressed as a Percent of Total Urban Land Use (1)	6.62%	12.20%	5.12%	5.22%	0.03%	2.22%	0.17%	16.28%	1.72%	2.29%	0.19%	0.13%	15.20%	15.35%	0.94%	4.33%	6.22%	5.76%	100.00%

Notes: (1) Sum of each land use acreage within incorporated areas by cover class across all basins in Minnesota.
(2) Individual land use category expresses as a percent of the total statewide land use within incorporated areas.

Table 6. Land cover classifications, total land area coverage (acres) and percent of land area for all land areas within incoprorated areas included in Urban Runoff Sources.

WATERSHED	Low Intensity Residential	High Intensity Residential	Commercial/ Industrial/ Transportation	Bare Rock/Sand/ Clay	Quarries/ Strip Mines/ Gravel Pits	Transitional	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrubland	Grasslands/ Herbaceous	Pasture/ Hay	Row Crops	Small Grains	Urban / Recreational Grasses	Total
Cedar River	2,721	3,645	4,088	0	57	0	1,118	0	5	0	0	1,644	6,719	0	965	20,964
Des Moines River	3,712	657	2,038	0	0	0	497	9	6	0	0	1,759	6,248	0	1,558	16,485
Lake Superior	12,465	6,773	11,558	438	31,536	1,086	105,427	20,564	28,412	1,829	1,243	13,003	12,207	121	4,696	251,358
Lower Mississippi River	26,611	11,619	13,993	0	803	324	39,953	583	1,957	4	1,026	52,126	72,531	21	14,634	236,186
Minnesota River	79,112	22,044	29,134	15	726	402	30,006	1,070	1,087	139	17	36,206	75,097	2,450	26,042	303,547
Missouri River	3,102	601	1,458	2	45	0	380	0	4	0	25	3,529	9,065	193	1,323	19,728
Rainy River	2,883	1,054	2,073	174	8,154	418	17,004	5,305	7,896	513	45	4,148	1,939	493	818	52,918
Red River	15,745	6,701	10,168	0	196	32	7,348	219	130	10	0	14,212	31,002	4,604	6,178	96,544
St. Croix River	8,839	1,737	3,857	0	389	42	31,342	2,842	2,877	6	310	62,842	44,247	1,873	4,994	166,199
Upper Mississippi River	172,383	82,717	61,800	50	17,791	2,293	203,942	15,688	19,224	2,476	859	218,513	152,854	15,440	55,046	1,021,075
Land Uses within Incorporated Areas - Land Use Category Total in Acres for All Basins (1)	327,573	137,548	140,168	679	59,698	4,598	437,017	46,280	61,598	4,978	3,526	407,981	411,910	25,196	116,253	2,185,004
Land Uses within Incorporated Areas expressed as Percent of State Total for Each Land Use Category (2)	91.29%	97.06%	42.79%	33.96%	55.10%	2.37%	5.14%	2.86%	3.33%	1.79%	19.97%	6.38%	2.19%	2.03%	67.68%	4.10%
Land Uses within Incorporated Areas expressed as Percent of All Incorporated Area Land Uses Statewide (3)	14.99%	6.30%	6.42%	0.03%	2.73%	0.21%	20.00%	2.12%	2.82%	0.23%	0.16%	18.67%	18.85%	1.15%	5.32%	100.00%

Notes: (1) Sum of each land use acres by land cover category across all basins in the state of Minnesota.
(2) Individual land use category area expressed as percent total statewide coverage for that land use category, i.e., a percentage of all low intensity residential land use, both urban and rural.
(3) Incorporated land use area total in (1) expressed as a precent of the state total area for all urban lands uses, including natural vegetation, agricultural, surface waters and developed areas.

The NLCD system of land cover classification defines each of these land use categories as follows:

Developed areas characterized by a high percentage (30 percent or greater) of constructed materials (e.g. asphalt, concrete, buildings, etc).

21. Low Intensity Residential - Includes areas with a mixture of constructed materials and vegetation. Constructed materials account for 30-80 percent of the cover. Vegetation may account for 20 to 70 percent of the cover. These areas most commonly include single-family housing units. Population densities will be lower than in high intensity residential areas.

22. High intensity residential urban areas - Includes highly developed areas where people reside in high numbers. Examples include apartment complexes and row houses. Vegetation accounts for less than 20 percent of the cover. Constructed materials account for 80 to 100 percent of the cover. Population densities will be higher than in low intensity residential areas.

23. Commercial/Industrial/Transportation - Includes infrastructure (e.g. roads, railroads, etc.) and all highly developed areas not classified as High Intensity Residential. Phosphorus in gasoline (1.2 – 2.0 ppm) and the resulting automobile emissions can contribute to the phosphorus load from roads. This load is included in the Atmospheric Deposition Technical Memorandum (Barr, 2003c)) and likewise would be reflected in the urban loads as part of the runoff concentration. Based upon an annual gasoline consumption in Minnesota of 6.8 million gallons the resulting phosphorus input would be 34 kilograms per year (Mike Hensel, personal communication, 2003).

Barren - Areas characterized by bare rock, gravel, sand, silt, clay, or other earthen material, with little or no "green" vegetation present regardless of its inherent ability to support life. Vegetation, if present, is more widely spaced and scrubby than that in the "green" vegetated categories; lichen cover may be extensive.

32. Quarries/Strip Mines/Gravel Pits - Areas of extractive mining activities with significant surface expression. Runoff from these sites is either covered under NPDES permitted discharges under the point source category, or any overland runoff has been considered to be internal and thus does not leave the site.

33. Transitional - Areas of sparse vegetative cover (less than 25 percent of cover) that are dynamically changing from one land cover to another, often because of land use activities. Examples include forest clear cuts, a transition phase between forest and agricultural land, the temporary clearing of vegetation, and changes due to natural causes (e.g. fire, flood, etc.). This land use classification has been treated in the same manner as the Commercial/Industrial/Transportation class for loading calculations, as in most urban areas this class represents land undergoing development. Only 2% of the land use in this category is found within incorporated areas.

Undeveloped areas with forested upland - Areas characterized by tree cover (natural or semi-natural woody vegetation, generally greater than 6 meters tall); tree canopy accounts for 25-100 percent of the cover.

41. Deciduous Forest - Areas dominated by trees where 75 percent or more of the tree species shed foliage simultaneously in response to seasonal change.

42. Evergreen Forest - Areas dominated by trees where 75 percent or more of the tree species are coniferous, i.e., they maintain their leaves all year. Canopy is never without green foliage in most locations.

43. Mixed Forest - Areas dominated by trees where neither deciduous nor evergreen species represent more than 75 percent of the cover present. Clear-cut and burned areas are classified as “Transitional Bare” areas,

Shrubland - Areas characterized by natural or semi-natural woody vegetation with aerial stems, generally less than 6 meters tall, with individuals or clumps not touching to interlocking. Both evergreen and deciduous species of true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions are included.

51. Shrubland - Areas dominated by shrubs; shrub canopy accounts for 25-100 percent of the cover. Shrub cover is generally greater than 25 percent when tree cover is less than 25 percent. Shrub cover may be less than 25 percent in cases when the cover of other life forms

(e.g. herbaceous or tree) is less than 25 percent and shrubs cover exceeds the cover of the other life forms.

Herbaceous upland areas characterized by natural or semi-natural herbaceous vegetation; herbaceous vegetation accounts for 75-100 percent of the cover.

71. Grasslands/Herbaceous - Areas dominated by upland grasses and forbs. In rare cases, herbaceous cover is less than 25 percent, but exceeds the combined cover of the woody species present. These areas are not subject to intensive management, but they are often utilized for grazing.

Planted/Cultivated - Areas characterized by herbaceous vegetation that has been planted or is intensively managed for the production of food, feed, or fiber; or is maintained in developed settings for specific purposes. Herbaceous vegetation accounts for 75-100 percent of the cover.

81. Pasture/Hay - Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops.

82. Row Crops - Areas used for the production of crops, such as corn, soybeans, vegetables, tobacco, and cotton.

83. Small Grains - Areas used for the production of graminoid crops such as wheat, barley, oats, and rice.

85. Urban / Recreational Grasses – Vegetation (primarily grasses) planted in developed settings for recreation, erosion control, or aesthetic purposes. Examples include parks, lawns, golf course, airport grasses and industrial grass sites.

The percent imperviousness applied to each of these urban land uses and then used in calculation of the runoff coefficient for this assessment are as follows:

Land cover class	Percent impervious
Low intensity residential	32%
High intensity residential	42%
Commercial/Industrial/Transportation	57%
Urban / Recreational Grasses	32%
Transitional	57%

(adapted from Zielinski, 2002 and analysis of TCMA GIS coverage)\

Approach and Methodology for Phosphorus Loading Computations for Incorporated (Urban) Areas

The development of nutrient loading estimates in the absence of direct monitoring has generally been completed by applying areal based nutrient export rates to the watershed area to calculate the annual nutrient mass (Beaulac and Reckhow, 1982: Reckhow, et al, 1980; Panuska and Lillie, 1995; Clesceri, et al, 1986a; Clesceri, et al, 1986b; McFarland and Hauck, 2001). Inherent in the export coefficient is the climatic condition under which the coefficient was developed and the difficulty lies in trying to adjust this export coefficient to reflect loading under dry, normal, and wet climatic conditions because it is not known for a particular site what the relationship is between precipitation and runoff. The phosphorus export coefficients used for land uses within incorporated area boundaries assume 100% of phosphorus transported from land will reach surface water due to developed conditions. The phosphorous export coefficient is part of the total phosphorous loading equation:

$$L = \sum_{i=1}^{m} c_i \bullet A_i$$

where: L is total phosphorus loading from land (in kilograms per year),
m is number of land use types,
c_i is the phosphorus export coefficient for land use i (in kilograms per hectare per year),
A_i is area of land use i (in hectares).

Over large watershed areas, the phosphorus export may not be proportional to watershed area and some attenuation of phosphorus occurs, especially in natural plant communities that have low runoff rates. Recently, authors who have examined the nutrient export issue on landscape level scales have raised concerns over the applicability of export coefficients across large watershed areas (Birr and Mulla, 2001; Cammermeyer, et al, 1999; Johnson and gage, 1997; Jones, et al, 2001; Mattson and Isaac, 1999; McFarland and Hauck, 1998; Richards, et al, 2001; Sharpley, et al, 1993; Soranno, et al, 1996; Worrall and Burt, 1999). The underlying issue related to this concern is that not all areas in a large watershed contribute nutrients and sediment equally. For this assessment, all of the developed urban uses are assumed to have storm water conveyance systems in place – minimally drainage ditches and conveyance channels up to full curb and gutter with piping.

An alternative approach is to estimate the phosphorus load from urban sources using annual estimates of the average flow-weighted total phosphorus concentration in urban runoff. There are several variables that may potentially affect the concentration of phosphorus in storm water runoff, however, development of a relationship between phosphorus concentration and these variables is limited by the variables that are typically reported. The most common variables are land use and precipitation.

For this assessment of monitoring data an evaluation was completed for data that were collected at the same location for multiple years and under different hydrologic conditions. These data shows that the concentration of phosphorus in stormwater at the same site is often higher during dry years compared to an average year, and is lower during a wet year compared to an average year (Table 2). From the available studies that had multiple years of monitoring data, a ratio was developed by dividing the concentration of total phosphorus in runoff for a wet year by the average year, and by dividing the concentration of total phosphorus in runoff for a dry year by the average year (Table 7). Overall, the wet to average ratio was 0.8 and the dry to average ratio was 1.18. This qualitatively shows that less precipitation leads to higher total phosphorus concentrations in runoff, and more precipitation leads to lower phosphorus concentrations in runoff.

To quantify the relationship between annual precipitation, land use (the four urban NLCD land uses: low intensity residential, high intensity residential, commercial-industrial-transportation, and urban recreational grasses), percent impervious area, and the annual flow-weighted total phosphorus concentration, single variable and multivariate linear regressions were performed. The percent impervious area for the watershed that contributed runoff to each monitoring point was calculated from the land use data collected for each watershed (see Table 2), based on a 32 percent impervious area for low density residential, 47 percent for high density residential, 42 percent for commercial-industrial-transportation, and 32 percent for urban/recreational grasses. There was a significant relationship ($P<0.1$ for each variable, $R^2=0.19$ for the overall model) between annual flow-weighted mean total phosphorus concentration, percent impervious area, and annual precipitation (Table 8). Although the overall R^2 was slightly greater for the regression that included annual precipitation and land use composition expressed as a percent, no single land use variable was significant when considered as a separate variable. This may have been because many of the watersheds that were tributary to the monitoring locations reported for each study were not uniform or singular land uses. The land use was often mixed resulting in the effective “canceling out” of one land use versus another. It was determined that the only way to determine the aggregate effect of land use on phosphorus concentration for a particular watershed was to express that land use as percent impervious.

Table 7. Effect of precipitation on annual total phosphorus EMC

Location	Flow-Weighted Average Annual Concentration (ug/L)	Year	Annual Precipitation	Wet,Dry, or Average Precipitation Year	Ratio (Wet/Average, or Dry/Average)	Reference	
G3 Inlet to Tanners Lake, Maplewood, MN	340	1989	27	Dry	0.83	1	0.80
G3 Inlet to Tanners Lake, Maplewood, MN	411	2001	32	Average	--	2	1.18
G3 Inlet to Tanners Lake, Maplewood, MN	202	2002	42	Wet	0.49	2	
G4A, Tanners Lake Watershed, Maplewood, MN	410	1989	27	Dry	--	1	
G4A, Tanners Lake Watershed, Maplewood, MN	308	2002	42	Wet	0.75[1]	2	
Lake Harriet Parkway at W. 44th St., Minneapolis,MN	245	1991	37	Wet	0.49	3	
Lake Harriet Parkway at W. 44th St., Minneapolis,MN	935	1995	26	Dry	1.86	4	
Lake Harriet Parkway at W. 44th St., Minneapolis,MN	635	1996	26	Dry	1.26	4	
Lake Harriet Parkway at W. 44th St., Minneapolis,MN	466	1997	34	Average	--	4	
Lake Harriet Parkway at W. 44th St., Minneapolis,MN	541	2001	34	Average	--	5	
Lake Harriet Parkway at W. 44th St., Minneapolis,MN	373	2002	39	Wet	0.74	6	
Lake Harriet Parkway at W. 44th St., Minneapolis,MN	588	2003	31	Dry	1.17	7	
MG1, Three Rivers Park District, Maple Grove, MN	341	2001	36	Average	--	8	
MG1, Three Rivers Park District, Maple Grove, MN	223	2002	41	Wet	0.65	8	
MG2, Three Rivers Park District, Maple Grove, MN	329	2001	36	Average		8	
MG2, Three Rivers Park District, Maple Grove, MN	252	2002	41	Wet	0.77	8	
P1, Three River Park District, Plymouth, MN	238	2001	36	Average	--	8	
P1, Three River Park District, Plymouth, MN	219	2002	41	Wet	0.92	8	
P2, Three River Park District, Plymouth, MN	213	2001	36	Average	--	8	
P2, Three River Park District, Plymouth, MN	245	2002	41	Wet	1.15	8	
P3, Three River Park District, Plymouth, MN	256	2001	36	Average	--	8	
P3, Three River Park District, Plymouth, MN	233	2002	41	Wet	0.91	8	
Luella St. at Orange Ave, St. Paul, MN	652	2001	34	Average	--	5	
Luella St. at Orange Ave, St. Paul, MN	344	2002	42	Wet	0.53	6	
Luella St. at Orange Ave, St. Paul, MN	539	2003	27	Dry	0.83	7	
Vandalia St.-350 feet south of Capp Rd.,St. Paul, MN	255	2001	34	Average	--	5	
Vandalia St.-350 feet south of Capp Rd.,St. Paul, MN	278	2002	42	Wet	1.09	6	
Vandalia St.-350 feet south of Capp Rd.,St. Paul, MN	296	2003	27	Dry	1.16	7	
Charles Ave-Mackubin to Arundel St., St. Paul, MN	377	2001	34	Average	--	5	
Charles Ave-Mackubin to Arundel St., St. Paul, MN	391	2002	42	Wet	1.04	6	
Charles Ave-Mackubin to Arundel St., St. Paul, MN	426	2003	27	Dry	1.13	7	
E. 29th St. and 31st Ave. S., Minneapolis, MN	525	2001	36	Average	--	5	
E. 29th St. and 31st Ave. S., Minneapolis, MN	305	2002	39	Wet	0.58	6	
PFS Study Site, East Pond, Woodbury, MN	398	2001	32	Average	--	9	
PFS Study Site, East Pond, Woodbury, MN	332	2002	42	Wet	0.83	9	
PFS Study Site, West Pond, Woodbury, MN	446	2001	32	Average	--	9	
PFS Study Site, West Pond, Woodbury, MN	322	2002	42	Wet	0.72	9	

[1] Ratio of wet/dry year.

[2] References

1)Barr Engineering. 1993. Diagnostic/feasibility study of water quality problems and restorative measures for Tanner's Lake. Prepared for the Ramsey Washington Metro Watershed District.
2) Barr Engineering. 2003. Tanners Lake CIP Performance Evaluation. Prepared for Ramsey-Washington Metro Watershed District.
3)Barr Engineering. 1992. Minneapolis chain of lakes clean water partnership project. Prepared for Minneapolis Park and Recreation Board.
4) Minneapolis Park and Recreation Board, 1997. Unpublished Data.
5)Minneapolis Park and Recreation Board, 2001. NPDES permit application monitoring report.
6)Minneapolis Park and Recreation Board, 2002. NPDES permit application monitoring report.
7) Minneapolis Park and Recreation Board, 2003. Unpublished monitoring data for the 2003 NPDES permit.
8)Three River Park District: Lawn Fertilizer Experiment, unpublished data
9) Ramsey Washington Metro Watershed District. Unpublished Data.

Table 8. Regression results between flow-weighted TP concentration in runoff and land use, percent imperviousness, and total preciptiation recorded during the monitoring year.

Multple Variable Regressions:

Set 1: R^2=0.23

Variables	Coefficient	P-Value
Intercept	-978	0.49
%LIR	19.0	0.18
%CIT	17.5	0.22
%RG	18.3	0.20
%HIR	19.9	0.27
Total Precipitation (in) in Monitoring Year	-14.7	0.001

Set 2: R^2=0.19

Variables	Coefficient	P-Value
Intercept	1075	0.000001
% Impervious	-14.4	0.06
Total Precipitation (in) in Monitoring Year	-5.7	0.001

Single Variable Regression

Set 1: R^2=0.13

Variable	Coefficient	P-Value
Intercept	802.3	0.000001
Total Precipitation (in) in Monitoring Year	-12.6	0.003

The number of acres for each of the four developed urban land uses was determined for the incorporated areas in each of the ten basins. In the incorporated areas the total area of each land cover was considered to be contributory. To calculate the expected concentration of total phosphorus in urban runoff for each basin, the average percent imperious area for the four developed urban land uses (high and low intensity residential, commercial/industrial/transportation and urban/recreational grasses) in each basin and the annual precipitation for the dry, average, and wet year were used as inputs to the regression model.

Phosphorus loading from the four developed urban land uses in each basin was then calculated according to the following equation:

*Basin load = Concentration * Contributory area * Runoff coefficient * Annual Rainfall Depth*

where: concentration is based upon the concentration regression equations developed for urban runoff in each of the basins,
contributory area is equal to the total area for each land use class,
runoff coefficient = 0.05 + 0.009 * impervious percentage,
annual rainfall depth is the annual precipitation for the loading flow condition scenario by basin.

The phosphorus load for each of the other non-agricultural land uses within incorporated areas (natural vegetation within incorporated areas) were calculated by multiplying the phosphorus export coefficient by the contributory area and basin runoff factor. The basin runoff factor is based upon the percent differences between the wet and dry precipitation scenarios compared to the average conditions for each basin (Barr Engineering, 2003a). The basin runoff factor was developed to account for the changes in runoff volumes due to increased precipitation and higher loadings due to longer overland flow lengths and thus larger contributory areas. This information was generated from the basin hydrology technical memorandum (Barr Engineering, 2003b). The basin hydrology technical memorandum reported significant variability of runoff and precipitation across the state. That technical memorandum examined the precipitation patterns and developed the basin-wide precipitation conditions used for each of the loading scenarios assessed. The basin runoff factor used for each of the three scenarios for natural areas within incorporated areas is present in Table 9 of the Non-Agricultural Rural Land use Technical Memorandum (Barr Engineering, 2003a).

The calculation formula for the natural areas was:

*Basin natural area load (kg) = Export rate (kg/ha/yr) * Contributory area (ha) * Runoff factor*

Phosphorus loads from agricultural land uses within incorporated areas were calculated using the same methodology as for other agricultural areas statewide as per Mulla (2003).

The export rates used for natural areas within the incorporated area boundaries are listed in Table 9.

Table 9. Natural vegetation ecoregion and agricultural land use export coefficients for phosphorus load calculations applied to urban areas.

Watershed	Land Use Export Coefficient - kg/ha/yr				
	Deciduous Forest (3)	Evergreen Forest (3)	Mixed Forest (3)	Shrubland (3)	Grasslands/ Herbaceous (3)
Cedar River	0.119	0.114	0.130	0.129	0.151
Des Moines River	0.119	0.114	0.130	0.129	0.151
Lake Superior	0.155	0.123	0.130	0.129	0.146
Lower Mississippi River	0.075	0.114	0.130	0.129	0.151
Minnesota River	0.119	0.114	0.130	0.129	0.151
Missouri River	0.119	0.114	0.130	0.129	0.151
Rainy River	0.155	0.123	0.130	0.129	0.146
Red River	0.075	0.123	0.130	0.129	0.151
St. Croix River	0.075	0.123	0.130	0.129	0.169
Upper Mississippi River	0.075	0.123	0.130	0.129	0.169

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(1) Beaulac, M. N., and Reckhow, K. H. 1982. An examination of land use-nutrient export relationships. Water Resour. Bull. 18(6):1013-24.

(2) Panuska, J.C. and Lillie, R.A. 1995. Phosphorus loadings from Wisconsin watersheds: Recommended phosphorus export coefficients for agricultural and forested watersheds. Research Management Findings, Number 38. Wisconsin Department of Natural Resources.

(3) Barr Engineering Company. 2003a. Detailed Assessment of Phosphorus Sources to Minnesota Watersheds – Non-Agricultural Rural Runoff. Prepared for the Minnesota Pollution Control Agency.

Results of Phosphorus Loading Computations and Assessments

The percentage of imperviousness and export rates, as applicable for urban land use for each of the basins are listed on page 19 and in Table 9, respectively.

Land use totals for the basins and the phosphorus contributory areas for each basin were previously listed in Table 6.

The results of the basin loading calculations for each basin and state-wide totals are listed in Table 10.

Table 10. Phosphorus loading results from incorporated urban areas for Minnesota basins and state-wide totals for three hydrologic scenarios; loads in kg/yr.

Basin	Hydrology Scenario	Low Intensity Residential	High Intensity Residential	Commercial/ Industrial/ Transportation	Bare Rock/Sand/ Clay	Quarries/ Strip Mines/ Gravel Pits	Transitional	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrubland	Grasslands/ Herbaceous	Urban/ Recreational Grasses	Agricultural Lands in Incorporated Areas	Total Kg P
Cedar River	Dry Year	738.7	1,251.5	1,827.8	0.0	Not Calculated	0.0	46.2	0.0	0.2	0.0	0.0	262.1	413	4,539
	Avg Year	782.3	1,325.3	1,935.6	0.0	Not Calculated	0.0	53.9	0.0	0.3	0.0	0.0	277.5	1,002	5,377
	Wet Year	800.6	1,356.4	1,981.0	0.0	Not Calculated	0.0	69.4	0.0	0.3	0.0	0.0	284.0	1,278	5,770
Des Moines River	Dry Year	1,097.6	245.8	992.7	0.0	Not Calculated	0.0	18.8	0.3	0.2	0.0	0.0	460.6	351	3,167
	Avg Year	1,272.8	285.0	1,151.1	0.0	Not Calculated	0.0	23.9	0.4	0.3	0.0	0.0	534.1	537	3,805
	Wet Year	1,433.5	321.0	1,296.4	0.0	Not Calculated	0.0	31.5	0.6	0.4	0.0	0.0	601.6	1,042	4,727
Lake Superior	Dry Year	3,598.6	2,472.8	5,495.7	320.0	Not Calculated	516.4	5,794.7	896.9	1,309.8	83.7	64.3	1,355.6	1,060	22,969
	Avg Year	3,846.7	2,643.3	5,874.5	342.1	Not Calculated	552.0	6,613.3	1,023.6	1,494.8	95.5	73.4	1,449.0	1,824	25,832
	Wet Year	4,117.2	2,829.2	6,287.6	366.1	Not Calculated	590.8	7,966.8	1,233.2	1,800.7	115.0	88.5	1,550.9	3,134	30,080
Lower Mississippi River	Dry Year	9,032.4	4,987.8	7,823.2	0.4	Not Calculated	181.1	983.8	21.8	83.5	0.2	50.9	4,967.4	5,291	33,423
	Avg Year	10,028.5	5,537.9	8,685.9	0.4	Not Calculated	201.1	1,212.7	26.9	103.0	0.2	62.7	5,515.2	10,535	41,909
	Wet Year	10,615.5	5,862.0	9,194.3	0.5	Not Calculated	212.8	1,449.9	32.2	123.1	0.2	74.9	5,838.0	12,809	46,212
Minnesota River	Dry Year	24,477.9	8,625.8	14,846.9	11.6	Not Calculated	205.0	1,135.2	38.8	44.9	5.7	0.8	8,057.5	5,723	63,173
	Avg Year	28,467.9	10,031.9	17,267.0	13.5	Not Calculated	238.4	1,445.1	49.4	57.2	7.2	1.1	9,371.0	11,275	78,225
	Wet Year	31,583.3	11,129.8	19,156.6	15.0	Not Calculated	264.5	1,786.3	61.0	70.7	8.9	1.3	10,396.5	16,541	91,015
Missouri River	Dry Year	913.6	223.8	707.4	1.8	Not Calculated	0.0	14.2	0.0	0.2	0.0	1.2	389.7	614	2,866
	Avg Year	1,075.3	263.4	832.6	2.1	Not Calculated	0.0	18.3	0.0	0.2	0.0	1.6	458.7	1,000	3,652
	Wet Year	1,222.7	299.5	946.7	2.3	Not Calculated	0.0	24.0	0.0	0.3	0.0	2.0	521.5	1,859	4,878
Rainy River	Dry Year	800.7	370.1	948.4	122.1	Not Calculated	191.4	913.8	226.2	355.9	23.0	2.3	227.1	218	4,399
	Avg Year	879.4	406.5	1,041.6	134.1	Not Calculated	210.2	1,066.6	264.1	415.4	26.8	2.7	249.5	502	5,199
	Wet Year	968.7	447.8	1,147.4	147.7	Not Calculated	231.6	1,305.2	323.1	508.3	32.8	3.3	274.8	874	6,265
Red River of the North	Dry Year	3,978.4	2,141.3	4,231.8	0.0	Not Calculated	13.2	177.9	8.7	5.4	0.4	0.0	1,561.0	1,229	13,347
	Avg Year	4,640.4	2,497.6	4,936.0	0.0	Not Calculated	15.4	223.0	10.9	6.8	0.5	0.0	1,820.7	3,599	17,750
	Wet Year	5,248.4	2,824.8	5,582.7	0.0	Not Calculated	17.5	277.1	13.5	8.5	0.7	0.0	2,059.3	5,101	21,133
St. Croix River	Dry Year	2,888.4	718.1	2,076.0	0.0	Not Calculated	22.8	735.7	109.4	117.1	0.3	16.4	1,631.9	3,397	11,713
	Avg Year	3,357.8	834.7	2,413.3	0.0	Not Calculated	26.6	951.3	141.5	151.4	0.3	21.2	1,897.1	7,309	17,104
	Wet Year	3,662.7	910.5	2,632.5	0.0	Not Calculated	29.0	1,168.2	173.7	185.9	0.4	26.1	2,069.3	13,421	24,279
Upper Mississippi River	Dry Year	53,550.4	32,497.7	31,620.6	38.9	Not Calculated	1,173.4	4,982.4	628.5	814.1	104.1	47.3	17,099.9	21,243	163,800
	Avg Year	61,278.5	37,187.6	36,183.9	44.5	Not Calculated	1,342.7	6,190.1	780.9	1,011.4	129.3	58.8	19,567.7	38,038	201,813
	Wet Year	67,579.4	41,011.4	39,904.5	49.1	Not Calculated	1,480.8	7,560.0	953.7	1,235.2	157.9	71.8	21,579.7	68,981	250,565

	Hydrology Scenario	Low Intensity Residential	High Intensity Residential	Commercial/ Industrial/ Transportation	Bare Rock/Sand/ Clay	Quarries/ Strip Mines/ Gravel Pits	Transitional	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrubland	Grasslands/ Herbaceous	Urban/ Recreational Grasses	Agricultural Lands in Incorporated Areas	Total Kg P
Statewide Totals	Dry Year	101,077	53,535	70,570	495	Not Calculated	2,303	14,803	1,931	2,731	217	183	36,013	39,539	323,397
	Avg Year	115,630	61,013	80,321	537	Not Calculated	2,586	17,798	2,298	3,241	260	221	41,140	75,621	400,667
	Wet Year	127,232	66,992	88,130	581	Not Calculated	2,827	21,638	2,791	3,933	316	268	45,176	125,040	484,924

Phosphorus Loading Variability and Uncertainty

In an effort to define the accuracy of the pollutant loading estimates derived from the regression equations, a comparison was completed using FLUX calculated loads for the Minneapolis Chain of Lakes watershed. This assessment was completed on the residential watersheds that had direct storm water flow from the 1991 monitoring stations. All of the sites had continuous flow measurement and flow-composite runoff samples; the data was reduced to a flow-weighted mean concentration using FLUX (MPRB, 1993; Walker, 1986). Not all of the watersheds assessed in the Chain of Lakes project are included in Table 11, as a number of them had upstream wetlands or large areas of natural land cover that attenuated the phosphorus loadings.

For purposes of this loading variability and uncertainty discussion, the loading regression equation developed for this assessment was used to calculate loads to the eight watersheds. All of the load estimates were calculated using the 1991 monitored flow volumes. The 1991 FLUX-derived loadings based upon FWMC concentrations are, for this discussion considered, the baseline loadings. Annual loadings were also estimated using the mean 1991 EMC for each specific watershed, using a national EMC for residential watersheds of 320 ug/L (Center for Watershed Protection, 2003) and the regression equation result of 326 ug/L.

The results of those calculations and assessments are presented in Table 12. The loads calculated with the national EMC for residential watersheds and the regression equation were 100.6% and 102.5% of the FLUX model loadings, respectively. The results of the regression equation are very similar to the monitored loads.

Stormwater monitoring results are highly variable and the 102.5% average variance from the 1991 monitored loads is quite good. The variance range for the Minneapolis 1991 FWMC and EMC stormwater data of 168% to 456% reflects that variability. The regression equation developed for the urban land use loads estimation explains 19% of the variance for stormwater using precipitation and impervious percentage (see Table 8).

Table 11. Chain of Lakes CWP project monitored watersheds, FLUX loadings and comparisons for alternative load estimate methodologies.

	1991 Flow Weighted Mean Concentrations (MPRB, 1993) FLUX - UNSTRATIFIED				1991 Flow Weighted Mean Concentrations (MPRB, 1993) FLOW - 2 STRATA				1991 Subwatershed Event Mean Concentrations (MPRB, 1993)				Literature Values - Residential Land Uses Mean EMC (Center for Watershed Protection, 2003)			Regression Equation Based Values Assessment of Phosphorus Sources (Barr 2003)		
Subwatershed	Q	FWMC	CV	LOAD - P kg	Q	FWMC	CV	MASS-P kg	Q	FWMC	CV	MASS-P kg	Q	EMC	LOAD kg	Q	FWMC	LOAD kg
S57-020	0.019	245	0.640	4.7	**0.019**	**338**	**0.376**	**6.4**	0.019	559	0.33	10.6	0.019	320	6.1	0.019	326	6.2
S57-100	**0.252**	**694**	**0.168**	**174.9**	0.252	688	0.299	173.4	0.252	480	0.25	121.0	0.252	320	80.6	0.252	326	82.2
S57-120	**0.041**	**219**	**0.456**	**9.0**	0.041	182	0.291	7.5	0.041	267	0.41	10.9	0.041	320	13.1	0.041	326	13.4
S54-080	0.171	263	0.407	45.0	**0.171**	**343**	**0.158**	**58.7**	0.171	413	0.33	70.6	0.171	320	54.7	0.171	326	55.7
S54-040	0.162	225	0.398	36.5	**0.162**	**156**	**0.305**	**41.5**	0.162	1360	0.38	220.3	0.162	320	51.8	0.162	326	52.8
S53-120	**0.085**	**320**	**0.303**	**27.2**	0.085	320	0.353	27.2	0.085	633	0.35	53.8	0.085	320	27.2	0.085	326	27.7
S53-160	0.212	194	0.444	41.1	**0.212**	**285**	**0.413**	**63.6**	0.212	359	0.35	76.1	0.212	320	67.8	0.212	326	69.1
S53-150	0.082	350	0.453	28.7	**0.082**	**345**	**0.434**	**28.3**	0.082	555	0.35	45.5	0.082	320	26.2	0.082	326	26.7

Notes: Q = hm3/yr, FWMC = ug/L; Watershed land uses = mixed urban residential
Center for Watershed Protection. 2003. Impacts of Impervious Cover on Aquatic Systems. Watershed Protection Research Monograph No. 1. Center for Watershed Protection, Ellicott City, MD. Table 16.
Minneapolis Park and Recreation Board, 1993. Minneapolis Chain of Lakes Clean Water Partnership Project Phase I – Diagnostic Report. Minneapolis Park & Recreation Board, Minneapolis, MN
1991 was an wet year based upon Barr Engineering, 2003b.
Bold values used in 1991 modeling results for Chain of Lakes Phase I CWP Project

Table 12. Comparison of percent difference for FLUX derived (FWMC) loads and other load estimation methods.

SITE	FLUX LOAD - P kg	1991 EMC LOAD - P kg	% Difference vs. FLUX Load	CWP, 2003 LOAD - P kg	% Difference vs. FLUX Load	Regression LOAD - P kg	% Difference vs. FLUX Load
S57-020	6.4	10.6	165.4%	6.1	94.7%	6.2	96.4%
S57-100	174.9	121.0	69.2%	80.6	46.1%	82.2	47.0%
S57-120	9.0	10.9	121.9%	13.1	146.1%	13.4	148.9%
S54-080	58.7	70.6	120.4%	54.7	93.3%	55.7	95.0%
S54-040	41.5	220.3	531.3%	51.8	125.0%	52.8	127.3%
S53-120	27.2	53.8	197.8%	27.2	100.0%	27.7	101.9%
S53-160	63.6	76.1	119.7%	67.8	106.7%	69.1	108.7%
S53-150	28.3	45.5	160.9%	26.2	92.8%	26.7	94.5%
	Mean % Difference for Method		185.8%		100.6%		102.5%

Recommendations for Future Refinements

Refinement of the load estimate for phosphorus in urban runoff will require that additional, long-term monitoring sites be established across the state. Most of the long-term monitoring locations used for the regression equation development were located within the Twin Cities metropolitan area or other large cities. There were some out-state sites but most lacked multiple years of data or were quite old and therefore were not usable in this assessment. The lack of data for out-state sites could introduce some bias into the results due to differing watershed conditions and characteristics.

Recommendations for Lowering Phosphorus Export

The design, construction and maintenance of watershed BMPs will help reduce pollutant loads to surface waters. However, the current dependence of watershed managers and regulators upon "NURP-type" ponds will not prevent the degradation of surface water resources due to increased phosphorus loadings. While the NURP-style ponds can remove particulate phosphorus, they are relatively ineffective at removing soluble phosphorus (which can comprise up to 50% of the phosphorus in urban runoff). The phosphorus removal efficiency of ponds are also only in the 40 – 50% range, so that in many urban developments, the phosphorus load increase exceed the removal effciency of ponds. The ponds required by regulators to mediate the increased runoff therefore do not fully mitigate the increases in runoff loads. In essence the BMP treatment, whether ponds or otherwise, never keeps the post-development loadings at pre-development levels once impervious area surpasses 40 – 50% (Schueler, 1995). Another critical flaw is that many urban planners assume that urban turf grass is an effective infiltrator of runoff, when in actuality most urban turf grows on highly compacted soils and can have a runoff rate of up to 45% during large storm events (Schueler, 1996a, 1996b; Legg, *et al*, 1996). Urban soils need to be protected from compaction during development/construction activities and likewise need to be actively managed to reduce compaction and increase infiltration over the long term.

Water quality protection requires that all urban development design use a water budget approach, where the preservation of the infiltration and evapotranspiration components of the hydrologic cycle are primary considerations. Site planning that reduces impervious surface area and preserves infiltration will help attain water quality protection. Caraco, et al (1998) recommends that site design in urban areas create urban spaces that:

- reduce impervious cover
- spread runoff over pervious areas
- utilize open channel drainage
- conserve forests and natural areas
- reduce the amount of managed turf and lawn
- create more effective stream buffers and riparian areas

A number of stormwater management and urban best management practices manuals are available that provide design guidance for controlling the impacts of urban runoff and promoting infiltration (Metropolitan Council, 2001; Schueler, 1995; Brach, 1989; US EPA. 2001)

The National Pollutant Discharge Elimination System (NPDES) permit administered by the MPCA regulates runoff from construction sites, industrial facilities and municipal separate storm sewer systems to reduce the pollution and ecological damage. Phase I focused on large construction sites, 11 categories of industrial facilities, and major metropolitan MS4s. Phase II broadened the program to include smaller construction sites, small municipalities (populations of less than 100,000) that were exempted from Phase I regulations, industrial activity, and MS4s.

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