MICHIGAN DEPARTMENT OF NATURAL RESOURCES & ENVIRONMENT

INTEROFFICE COMMUNICATION

TO: Whom It May Concern

FROM: Joe Rathbun, Nonpoint Source Unit, Water Bureau

DATE: March 10, 2010

SUBJECT: Updated Report on Phosphorus Load Data for Saginaw Bay

In March 2008, the Saginaw Bay Coastal Initiative Phosphorus Committee (Committee) was formed to develop recommended next steps that could be taken that would result in phosphorus reduction to the Saginaw Bay. As part of this effort, the Committee requested that DNRE develop an evaluation of potential sources and related loadings of phosphorus to the Bay.

Attached is the recently completed DNRE report entitled "UPDATE OF PHOSPHORUS LOAD DATA FOR SAGINAW BAY". In this report trends in phosphorus loads were assessed using data from several water quality monitoring studies starting in 1974 and running through 2005. Phosphorus sources were assessed using two models (L-THIA and SPARROW).

Trend analysis of phosphorus loads over the last three decades indicate that, when the data are adjusted for annual variation in river flow, loads declined 43 percent between 1974 and 2005. Most of this decline is probably due to waste water treatment plant upgrades and legislation that limited the phosphorus content of laundry detergents. Phosphorus loads to Saginaw Bay are larger in wet years when runoff from upland areas is higher.

The two source models both indicate that agriculture is the major source of phosphorus to Saginaw Bay. L-THIA predicted that 90 percent of the annual phosphorus load due to surface runoff is from agricultural lands, while the SPARROW model predicted that the major sources of phosphorus are fertilizer and livestock manure. Both models also indicate that, of the nine major subwatersheds draining to Saginaw Bay, four; the Pigeon-Wiscoggin, Flint, Shiawassee, and Cass River watersheds; contribute the most phosphorus to the Bay.

The attached report fulfills the Committee request for an updated summary of phosphorus loads to the Saginaw Bay. If you have questions regarding the report findings please contact Joe Rathbun at 517-373-8868 or rathbunj@michigan.gov for additional information.

Attachment

MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY
WATER BUREAU
January 8, 2010

UPDATE OF PHOSPHORUS LOAD DATA FOR SAGINAW BAY

Summary

In 1983 a phosphorus loading target of 440 metric tons per year was established for Saginaw Bay to help minimize algae-related odor problems in the Saginaw drinking water supply system and lower total phosphorus concentrations in the inner bay. Subsequent updates on progress towards achieving this target load, the last prepared in 1991, indicated that annual phosphorus loads exceeded this target, sometimes substantially. This report examined the results of four monitoring studies that spanned from 1974 to 2005 to assess trends in phosphorus loads to the Bay, and results of two models (L-THIA and SPARROW) that predicted the sources of the phosphorus loads. The monitoring studies demonstrated a strong relationship between river discharge and phosphorus load (wet years = higher loads), and indicated that the phosphorus loading target is only met during drier years. A trend analysis of time vs. discharge-normalized phosphorus loads found a 43 percent decline in annual loads between the time periods of 1974-1980 and 2001-2005. This reduction is presumably largely due primarily to waste water treatment plant upgrades and legislation that limited the phosphorus content of laundry detergent in the 1970s. The models both indicate that agriculture is the major source of phosphorus to Saginaw Bay. L-THIA predicted that 90 percent of the annual phosphorus load due to surface runoff to the Bay is from agricultural lands. SPARROW predicted that the major sources of phosphorus to the Bay are fertilizer (50 percent) and livestock manure (17 percent), while point sources account for 25 percent. Both models indicate that, of the nine subwatersheds draining to Saginaw Bay, the Pigeon-Wiscoggin, Flint, Shiawassee, and Cass River watersheds contribute the most phosphorus to the Bay.

Introduction

In the 1978 Great Lakes Water Quality Agreement, the United States and Canada affirmed their intentions to restore and maintain the chemical, physical and biological integrity of the Great Lakes Basin ecosystem. As part of this agreement, in 1983 the two parties finalized phosphorus load targets for each of the Great Lakes. The target total phosphorus load for the Saginaw Bay portion of Lake Huron is 440 metric tons per year. This target was established to minimize odor problems in the Saginaw drinking water supply system and lower total phosphorus concentrations in the inner bay to a target of 15 µg/L.

Periodic reports updating Michigan's progress towards achieving this loading target were published in 1985, 1987, 1988, and 1991. The last of these reports (MDNR et al., 1991) estimated the average annual load of total phosphorus to Saginaw Bay at that time to be 665 metric tons.

The intentions of this report are to:

- Update the status of phosphorus loads to Saginaw Bay.
- Present information on the sources of phosphorus to the Bay

Methods

Phosphorus loading data were obtained from the reports listed in Table 1. All data are presented in Appendix A. Phosphorus load estimates in all four of these reports are based on water sampling programs, not land use-based models. The monitored location representing phosphorus loads to the Bay in each of the four studies was the mouth of the Saginaw River. Consequently, the phosphorus loads in these data sets represent the summed loads of the tributaries making up the Saginaw River watershed (the Tittabawassee, Pine, Chippewa, Shiawassee, Flint, Cass, and Saginaw Rivers) and do not include the tributaries along the eastern and western portions of Saginaw Bay (the Au Gres, Rifle, Kawkawlin, Pigeon, and Pinnebog Rivers, and smaller streams).

Two phosphorus loading models were also used to identify phosphorus sources to the Bay; the Long-Term Hydrologic Impact Assessment (L-THIA) model (Engle et. al., 2005) and the Spatially Referenced Regressions On Watershed attributes (SPARROW) model (Smith et. al., 1997). L-THIA estimates long-term average annual runoff loads from multiple land use categories, and its application to Saginaw Bay phosphorus loads has been previously reported (Vincent, 2009). Phosphorus loads were calculated for seven land use categories:

- Agriculture
- Commercial
- Forest
- Grass/Pasture
- High density residential
- Low density residential
- Water/Wetland

Land use data from 2001 was used as input to L-THIA. Note that since L-THIA is a land-use based model it does not include point source loads. L-THIA was applied to the nine 8-digit hydrologic unit codes (HUCs), or watersheds, that make up the Saginaw Bay drainage area (Figure 1).

SPARROW correlates stream nutrient (phosphorus and nitrogen) concentrations at previously monitored locations with known upstream sources and land surface characteristics, and predicts loadings for locations at unmonitored locations. SPARROW considers four nutrient sources:

- Point source discharges
- Fertilizer sales
- Manure production
- Runoff from “nonagriculture” lands (urban, forest, and range lands)

Note that, unlike L-THIA, SPARROW includes point source loadings.

Most of the input data for SPARROW is from the mid-1980s. Results were calculated for 8-digit HUCs nationwide, including the nine 8-digit HUCs making up the Saginaw Bay drainage.

Results and Conclusions

Trends in Phosphorus Loads

Taken together, the four available data sets listed in Table 1 provide good temporal coverage over the last three-plus decades (Figure 2), including two important periods in the Bay’s recent history:

- The mid to late 1970s, when Michigan's waste water treatment plants upgraded from primary treatment to secondary treatment, and the law limiting the phosphorus content of laundry detergents was passed (1977).
- The early 1990s, when zebra mussels first colonized the Bay.

Phosphorus loads have varied substantially during the period of record, by up to a factor six. Phosphorus loads appear to have declined in recent years (2001 to 2005) compared to the 1970s and 1980s, although this pattern is partly obscured by the annual variability in phosphorus load and river discharge, and the strong relationship between discharge and phosphorus load (Figure 3). This issue is addressed further, below.
As noted in the Methods section, comparing recent phosphorus loads to the 1983 target of 440 metric tons per year is complicated by the fact that monitoring data are only available for the Saginaw River watershed, and not for the smaller tributaries along the east and west sides of the Bay. Approximately three-quarters of the overall Saginaw Bay phosphorus load is attributable to the Saginaw River watershed (Table 2), so a 'correction factor' of 25 percent should be added to the Saginaw River load data in Figure 2 to account for the loads from the other tributaries to the Bay. After this correction factor is applied, the overall phosphorus loads to Saginaw Bay in the most recent monitoring period (2001 to 2005) were below the 1983 target in the two drier years, 2003 and 2005, and exceeded the target in the other three, wetter, years (Table 3).

Assessing phosphorus loading trends is also complicated by more-or-less simultaneous occurrence of the law limiting phosphorus in laundry detergents (1977) and a series of consecutive dry years between 1977 and 1980 (Figure 2). Given the strong correlation between discharge and phosphorus load in the Saginaw River, for trend assessment it is appropriate to normalize each year's mean load to its corresponding mean discharge. The results are illustrated in Figure 4; note that the fixed station data (MDNR, 1993) included in Figure 2 were omitted from this analysis because the sampling frequency is unclear from the available documentation. Linear regression of time vs. discharge-normalized phosphorus load indicates a significant decline in loads over the period of record ($p = 0.007$); phosphorus loads declined by 43 percent between the 1974-1980 and 2001-2005 time periods. This decline is presumably due to a combination of waste water treatment plant upgrades and the lower phosphorus content of laundry detergents dating to the 1970s, although changing agricultural practices may have also played a role. Despite this decline in phosphorus loads since the 1970s, however, the 1983 phosphorus load target has only been met recently in dry years (Figure 2).

Phosphorus Sources

The loading data discussed above does not identify the source(s) of the phosphorus loads to Saginaw Bay. Sources of phosphorus were assessed using two models, L-THIA and SPARROW, and point source discharge data for NPDES-permitted facilities.

The L-THIA model, which calculates phosphorus export from different land use types, estimated that runoff from agricultural lands, which constitute about 45 percent of the overall Saginaw Bay drainage area, accounts for 90 percent of the surface runoff phosphorus load (Table 4). Results were similar for each of the nine 8-digit HUCs making up the Saginaw Bay drainage area, with agriculture accounting for greater than 70 percent of the phosphorus loads even in watersheds where it was not the dominant land use (Table 5). It should also be noted that commercial and high density residential land uses, though small in total area, are predicted to have the highest phosphorus loads pre acre (Table 5).

Results of the SPARROW model, which estimates phosphorus loads from known potential sources and landscape characteristics rather than land uses, were generally similar to those of the L-THIA model, in that agricultural sources account for most of the phosphorus loads to Saginaw Bay. The SPARROW model estimated that fertilizer accounts for about 51 percent of the phosphorus load to Saginaw Bay (Figure 5), the large majority of which is presumably agricultural fertilizer. Livestock manure (based on livestock numbers) accounted for an additional 17 percent, so agricultural sources combined accounted for a total of about two-thirds of the total load to the Bay. As of the mid-1980s, when the SPARROW calculations were performed, point sources accounted for about 24 percent of the total annual loadings, while runoff from nonagricultural lands (urban, forest, and range lands) was less than 10 percent of the total. The relative contributions of point and nonpoint source phosphorus loads to the Bay have apparently changed over time. Nonpoint source loads increased from 60 percent of the total load to the Bay in the early 1970s to 77 percent by 1980 (MDNR, 1994) – identical to the results of the SPARROW model reported here, which represent conditions in the mid-1980s. This change is presumably due to the decline of point source phosphorus loadings resulting from wastewater treatment plant upgrades and the laundry detergent phosphorus ban during the 1970s.

Results of the SPARROW and L-THIA models also generally identified the same subwatersheds as major and minor sources of phosphorus to Saginaw Bay (Table 6). For example, both models found that the Flint River and Shiawassee River together account for over one-third of the phosphorus loadings to the Bay, while the Au Gres-Rifle, Kawkawlin-Pine, and Saginaw subwatersheds each account for five to seven percent of the total phosphorus load. This information should be useful for prioritizing subwatersheds for remedial actions.

Phosphorus Load Estimates: Measured vs. Modeled

Although the four sampling-based loading studies (listed in Table 1) and the two modeling studies (L-THIA and SPARROW) all compute phosphorus loads to Saginaw Bay, comparisons between them are problematic for several reasons:

- The sampling-based studies are 1-year 'snap shots' of phosphorus loadings and the L-THIA model's predictions are based on land uses from a single year (2001), while the SPARROW model uses input data from more than one year (mid-1980s, mostly, though the output is assigned to 1987 [Smith et. al., 1997]).
- The sampling-based studies and the SPARROW model include both point sources and nonpoint sources, while the L-THIA model does not include point sources.
- The two models calculate loads for all nine of the 8-digit HUCs that drain into Saginaw Bay, while the sampling-based studies include only the six HUCs that combine to form the Saginaw River drainage (although it is possible to adjust the sampling-based study data sets to account for the other tributaries; see Table 3).

With those caveats, Table 7 compares the two modeled phosphorus loads and the sampling-based loads (extrapolated to the entire Saginaw Bay watershed) for the appropriate year. The SPARROW model load estimate greatly exceeded the measured load in 1987, while the L-THIA model load estimate was slightly lower than the measured load in 2001.

The SPARROW model point source load predictions can also be compared to National Pollutant Discharge Elimination System (NPDES) data for permitted point source dischargers, although this comparison is problematic for several reasons:

- Point source data inputs to the SPARROW model are from the period 1977-1981, while the most readily available NPDES data are from 2008.

- The input data to the SPARROW model includes waste water treatment plants (WWTPs), industrial dischargers, small sanitary waste dischargers and other point sources, while the most readily available NPDES data are for WWTPs and retention treatment basins (RTBs; i.e., treatment facilities for combined sewerage) only. (Note that there are no untreated combined sewerage overflows [CSOs] in the basin.)
- 1977 to 1981 was a period of transition for point sources in Michigan; many WWTPs were being upgraded and installing phosphorus controls, the laundry detergent phosphorus limit came into effect in 1977, there were many more CSOs than RTBs, and the CSOs were not monitored.
- It is unknown whether any RTBs were permitted in 1977-1981, and so it is not known if they were included in the SPARROW input data set.

With those caveats, Table 8 compares the older but presumably more complete SPARROW model point source load predictions from approximately thirty years ago with the sum of the reported WWTP and RTB discharges from 2008. The historic model point source loads are over three times higher than the recently reported WWTP and RTB loads. Assuming the model load estimates are correct, this 72 percent decline over 3 decades may be partly due to the waste water treatment plant upgrades and laundry detergent phosphorus ban that occurred in the 1970s. It should also be noted that phosphorus loads from the RTBs are only a small fraction (approximately 2 percent) of the loads from WWTPs.

Finally, the sum of the phosphorus loads from commercial and high density land uses calculated by the L-THIA model (Table 4) can be considered roughly equivalent to the point source loads from the MS4 storm water communities (although the calculated figure may be biased high by an undetermined amount by inclusion of certain urban nonpoint source loads). Consequently, it is possible to roughly compare the modeled point source loads for MS4 communities with the measured phosphorus loads from WWTPs and RTBs for the entire Saginaw Bay watershed. These data indicate that, among these three point source categories, loads from the 39 waste water treatment plants in the watershed are approximately four times larger than loads from the 44 MS4 communities, and approximately 50 times larger than loads from RTBs (Figure 6). It should be noted that Figure 6 does not include other, presumably small point source phosphorus loads, such as industrial storm water dischargers, waste water sewage lagoons, drinking water treatment plants, and noncontact cooling water.

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Appendix

Total phosphorus loads and average annual discharge from the Saginaw River, 1974-2005

Year	P Load Bierman et. al., 1984 (metric tons/year)	P Load MDNR, 1993 (metric tons/year)	P Load WCMP* (metric tons/year)	P Load Snell, 1986 (metric tons/year)	Mean Annual Discharge (m^3/sec)
1974	1,044	1692			165
1975	1,267	1171			191
1976	937	1459			191
1977	511	492			81
1978	595	588			94
1979	409	621			97
1980	472	562			104
1981		596			135
1982		1772			165
1983		620		561	150
1984		517		664	135
1985		1365			203
1986		1211			222
1987		516			128
1988		420			112
1989		743			127
1990		304			112
1991		1390			207
1992-2000	Phosphorus load data not available for these years				
2001			642		126
2002			513		128
2003			227		74
2004			724		162
2005			288		98

(* MDEQ Water Chemistry Monitoring Program annual reports)

Tables

Table 1. Sources of phosphorus loading data cited in this report.

Citation	Years with Data
Bierman et. al, 1984	1974-1980
Snell Environmental Group, 1986	1983 and 1984
Michigan Department of Natural Resources, 1993	1974-1990
MDEQ Water Chemistry Monitoring Program annual reports (Aiello 2003, 2004, 2005, 2006, & 2008)	2001-2005

Table 2. Contribution of the Saginaw River watershed to the total phosphorus load to Saginaw Bay.

Information Source	Percent of the Total Load to Saginaw Bay
Chapra, 1979	86
MDNR, 1994	66
SPARROW model	78
Average	77

Table 3. Measured Saginaw River and estimated Saginaw Bay phosphorus loads.

Year	Measured Saginaw River Load (metric tons/year)	Estimated Saginaw Bay Load, including unmonitored tributaries (metric tons/year)
	1983 load target = 440 metric tons/year	
2001	642	803
2002	513	641
2003	227	284
2004	724	905
2005	288	360

Table 4. Phosphorus loads from different land uses in the Saginaw Bay drainage area, according to the L-THIA model.

Land Use Type	Land Use (% of drainage area)	Phosphorus Load (metric tons/year)	Phosphorus Load (% of total)	Phosphorus Load per Unit Area (pounds/acre)
Agriculture	45.0	619	90.2	0.55
Commercial	0.4	8	1.1	0.79
Forest	21.7	0.6	0.1	< 0.01
Grass/Pasture	5.9	0.3	0.04	< 0.01
High density residential	1.1	18	2.7	0.69
Low density residential	10.2	41	5.9	0.16
Water/Wetland	15.8	0	0	0
Total		686.9		

Table 5. Phosphorus loads from the agricultural portions of the subwatersheds of the Saginaw Bay drainage area, according to the L-THIA model.

HUC/Watershed	Percent of Drainage Area in Agriculture	Phosphorus Load from Agricultural Lands (% of total for HUC)
Pigeon-Wiscoggin	80.4	96.9
Flint	46.3	81.1
Shiawassee	57.4	93.3
Cass	57.1	96.1
Chippewa-Pine	43.7	93.0
Tittabawassee	21.6	88.5
Kawkawlin-Pine	46.2	90.1
Au Gres-Rifle	15.7	88.7
Saginaw	61.0	70.6

Table 6. Percent of annual phosphorus load to Saginaw Bay from each HUC/subwatershed in the drainage area.

HUC/Watershed	HUC Land Area – Percent of Overall Saginaw Bay Drainage Area	Phosphorus Load – SPARROW (% of total to the Bay)	Phosphorus Load – L-THIA (% of total to the Bay)
Pigeon-Wiscoggin	10.4	12.6	18.7
Flint	15.4	21.1	17.4
Shiawassee	14.6	16.4	17.1
Cass	10.5	14.4	10.8
Chippewa-Pine	11.9	10.6	9.7
Tittabawassee	16.8	7.3	9.6
Kawkawlin-Pine	5.6	6.4	6.4
Au Gres-Rifle	11.9	4.1	5.7
Saginaw	2.9	7.0	4.6

Table 7. Comparison of modeled and sampling-based phosphorus loads for Saginaw Bay.

Year	Sampling-Based Load (metric tons/year)*	Modeled Load (metric tons/year)
1987	645	1,690 (SPARROW)
2001	803	687 (L-THIA**)

(* Adjusted to include tributaries outside the Saginaw River drainage basin.)
(** L-THIA does not include point source loads.)

Table 8. Comparison of point source loads predicted by the SPARROW model (for 1977-1981) and reported by NPDES-permitted dischargers (for 2008) in the Saginaw River subwatersheds.

River	SPARROW Predicted Load (Kg/yr)	WWTP Reported Load (Kg/yr)*	RTB Reported Load (Kg/yr)**
Pine	29,940	6,535	
Flint	176,229	42,659	
Cass	11,776	3,074	
Saginaw	75,302	24,981	1,697
Tittabawassee	41,771	13,424	363
Shiawassee	31,153	8,397	
Total Point Source Loads	366,171	101,130	

(* WWTP = Waste Water Treatment Plant)
(** RTB = Retention Treatment Basin [a.k.a. treatment facility for Combined Sewerage])

Figures

Figure 1. The 8-digit hydrologic unit codes (HUCs) making up the Sagniaw Bay drainage area.

Figure 2. Total phosphorus loads from the Saginaw River, 1974-2005.

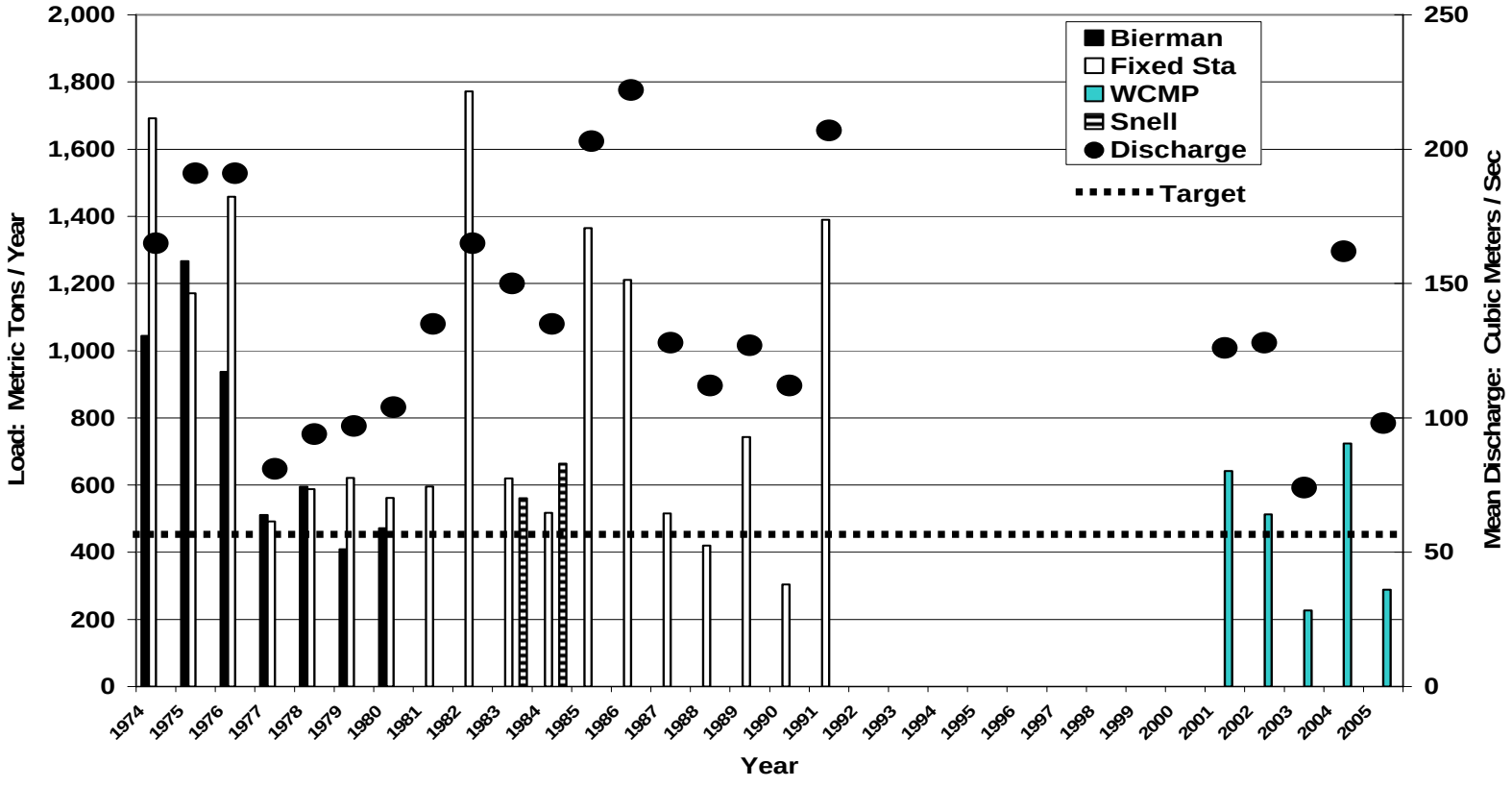

Figure 3. Correlation between Saginaw River discharge and total phosphorus load.

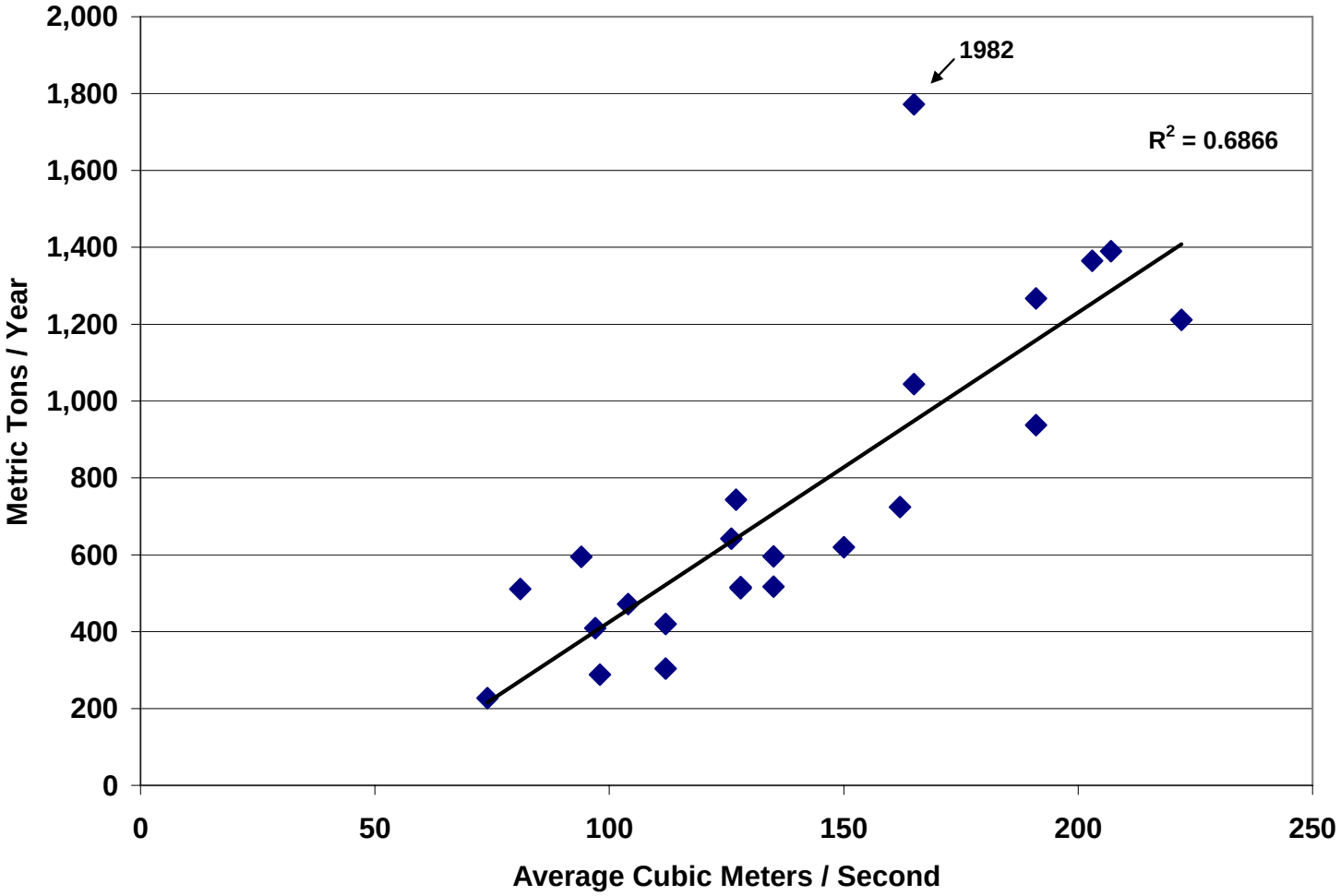

Figure 4. Trend in discharge-normalized phosphorus loads from the Saginaw River.

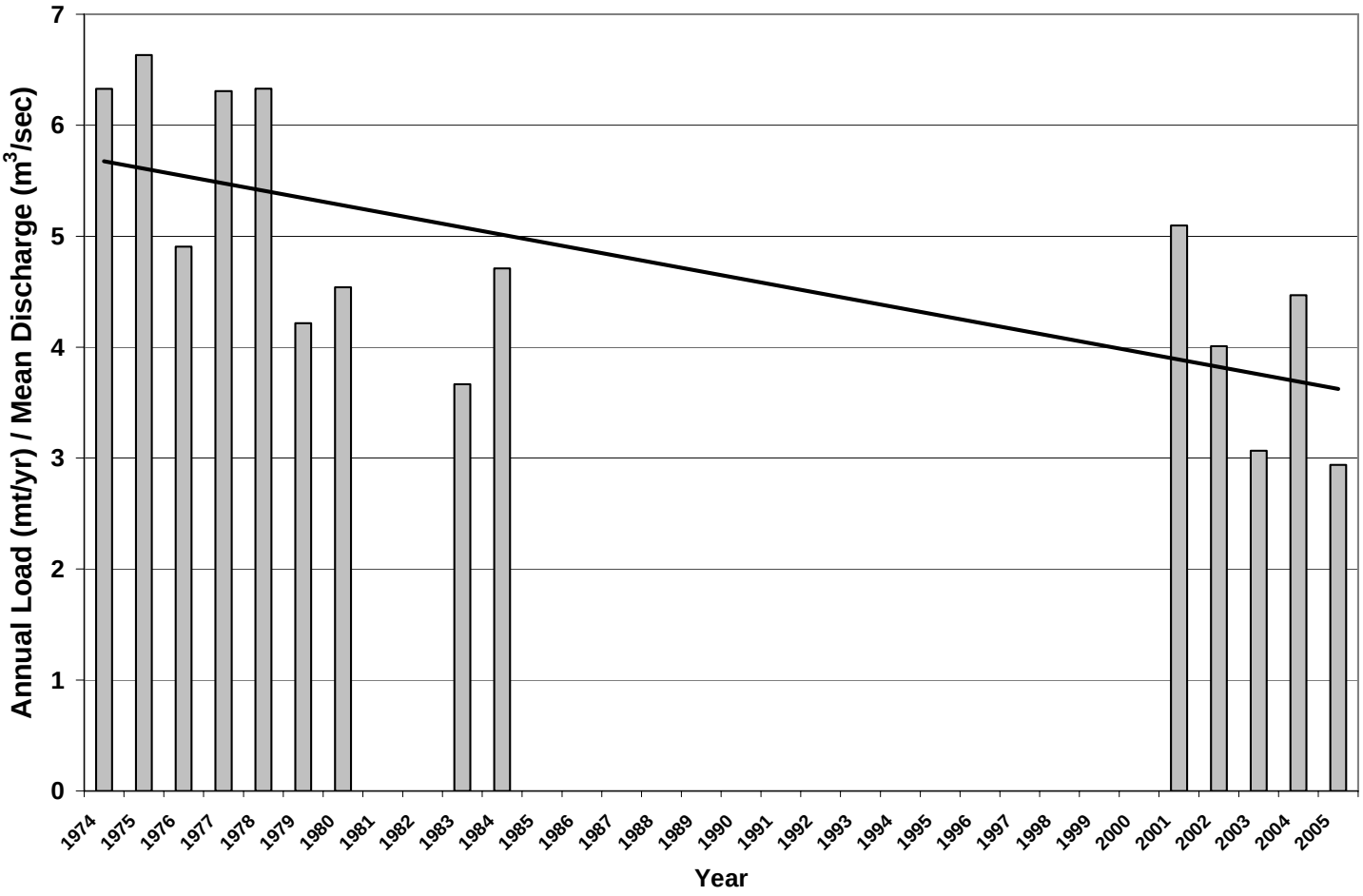

Figure 5. Phosphorus Loads (percent of total load) from different potential sources in the Saginaw Bay watershed, according to the SPARROW model.

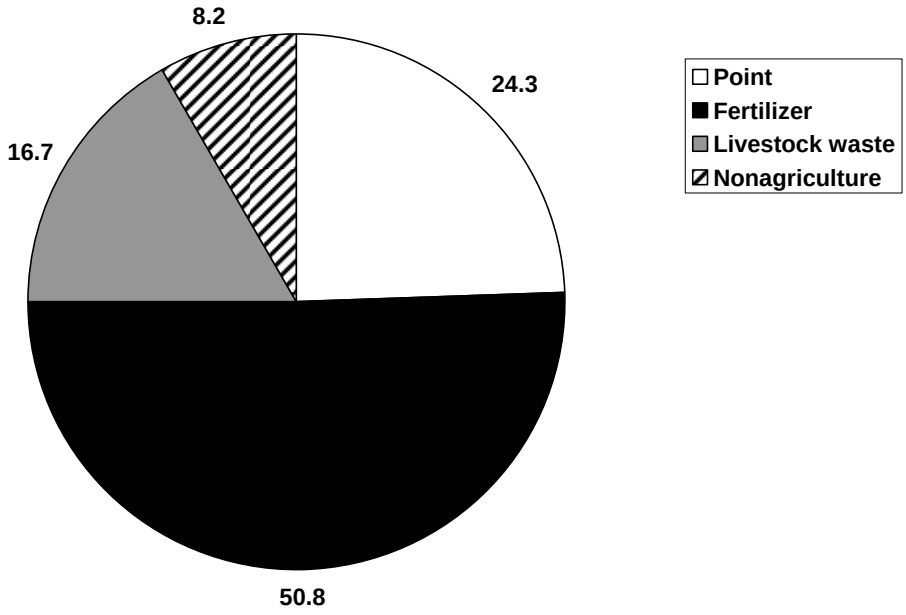

Figure 6. Relative contributions of phosphorus from waste water treatment plants (WWTPs), retention and treatment basins (RTBs), and MS4 storm water communities (MS4s) across the Saginaw Bay watershed to the total point source loads to the Bay. WWTP and RTB data are from the 2008 NPDES permit records; MS4 data are from the loads for commercial and high density land uses calculated by the L-THIA model, based on 2001 land use data.