Analysis of Urban Stormwater Best Management Practice Options for the St. Joseph River Watershed

Prepared for:

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Introduction

Although predominantly agricultural, the St. Joseph River Watershed has 19 of 217 subwatersheds with over 10% of the land area in urban uses (commercial, residential, industrial, or transportation) according to the 1992 land cover data from the U.S. Geological Survey (USGS) (http://www.stjoeriver.net/wmp/tasks/urban_lc.htm)). Major urban centers include South Bend-Mishawaka (IN), Benton Harbor-St. Joseph (MI), Elkhart (IN), and Goshen (IN). Nonpoint source (NPS) modeling work conducted by KIESER & ASSOCITES (K&A) revealed that in the 19 subwatersheds with over 10% urban areas, urban land uses contributed more than one-third of the total phosphorus (TP) loading from these subwatersheds (K&A, 2003). Therefore, while controling pollutant loadings from agricultural lands in the watershed is central in managing the overall water quality of the watershed, it is critical to reduce stormwater pollutant loadings from urban areas in order to protect and restore water quality in the streams draining urban subwatersheds.

From a regulatory perspective, USEPA's NPDES Phase II Stormwater Program (http://www.stjoeriver.net/wmp/tasks/npdesp2.htm) has put numerous urban communities in the watershed under regulatory obligation to develop stormwater pollution control and monitoring programs. As a result of this regulation and the predicted high pollutant loadings from urban lands, it is essential for watershed management planning efforts to examine stormwater pollutant loadings from urban subwatersheds. Planning must address solutions and associated costs of abating pollution from these urban sources. This report describes the work conducted by K&A to accomplish this.

This study is based on the empirical model used for estimating NPS pollutant loadings from various land cover types, including urban areas, that has been described by K&A in a report prepared for this 319 grant (K&A, 2003). In addition to updating the modeling work with newly available land cover data (2000), this study focused on the major urban centers in the St. Joseph River Watershed to explore: 1) the pollutant removal potential of select urban stormwater best management practices (BMPs); and 2) the costs associated with these BMPs. These efforts are meant to help the Watershed Management Plan being developed for the St. Joseph River to meet the required USEPA Nine Elements.

These analyses do not include pollutant loads from any combined sewer overflows (CSOs). Computations also assume there no current BMPs are in place and that predicted loads are solely associated with urban stormwater runoff. No additional mapping characterizations have been made which might also determine that select urban areas are isolated from surface waters either topographically or via stormsewer infrastructure. Budget and scope constraints precluded detailed deterministic modeling that would have been required for these consideration. Nevertheless, the findings of this report are still highly applicable as urban stormwater treatment and/or reduction will be necessary in these urban areas to realize water quality improvements.

Methods

The overall analysis procedure is represented in the flow chart shown in Figure 1. The 2000 land cover data for the St. Joseph River Watershed was downloaded from the National Oceanic and

Atmospheric Administration (NOAA)'s Coastal Change Analysis Program (http://www.csc.noaa.gov/crs/lca/greatlakes.html).

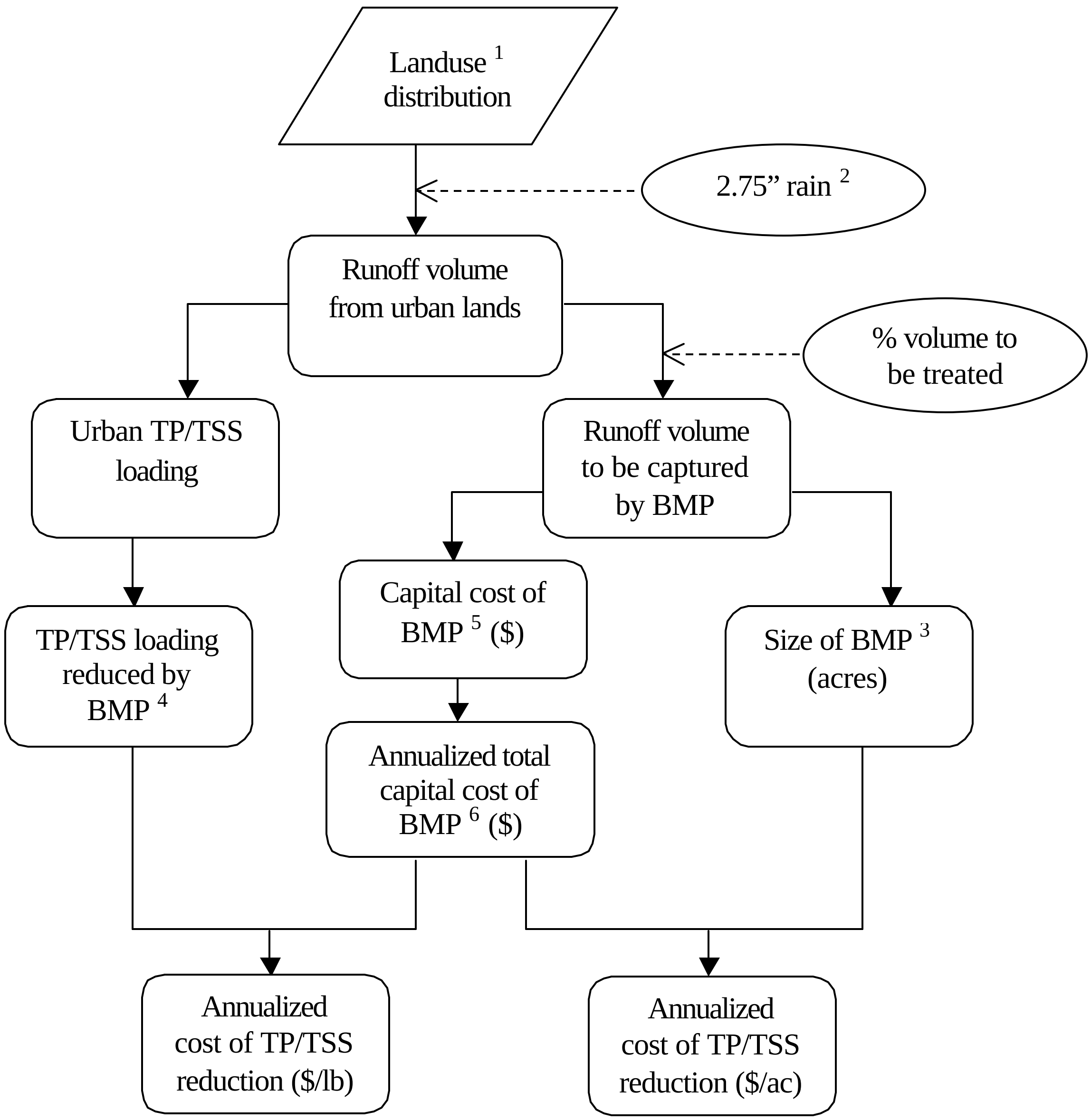

Figure 1. Flow Chart of Urban Stormwater BMP Cost Calculations.

[1] 2000 NOAA data.
[2] Equivalent to a one-hour 100-year or a 24-hour 2-year rain event for the St. Joseph River Watershed.
[3] General assumptions made for the physical dimensions of BMPs.
[4] Load reduction efficiencies of BMPs based on the Michigan Trading Rules and/or literature values.
[5] Cost based on Rouge River Watershed management plans and/or literature values.
[6] 30-year annualization with a 5% discount rate.

In the previous modeling effort (K&A, 2003), 1992 land cover data produced by USGS was used. Although NOAA and USGS use the same type of satellite image data for land cover/landuse classification and the classification process is also similar between the two agencies, they have different purposes for the data and hence different final classifications. NOAA's Coastal Change Analysis Program is interested in coastal habitat change and its land cover classification reflects this by giving more detailed sub-classes for wetlands and coastal lands but less for developed lands and agricultural lands, compared to the 1992 USGS land cover data. For this modeling purpose, however, these differences had minimal influence on data processing as the NPS model groups various land cover classes into five major categories: water and wetland, forest and open space, agricultural land, residential area (low intensity development), and commercial/industrial/transportation uses (high intensity development). Pollutant loading estimations were based on these five categories, and the combination of the latter two categories was considered urban in this study.

After processed and integrated into the St. Joseph River GIS database at K&A, land cover distribution for each of the 217 subwatersheds was tabulated and grouped into the five major categories. The grouping of land cover classes is shown in Table 1.

Table 1. Grouping of land cover classes.

Major Land Cover Groups	NOAA Land Cover Classes (2000)	USGS Land Cover Classes (1992)
Water and wetland	Open water, palustrine forest, palustrine scrub/shrub, palustrine emergent, unconsolidated shore, palustrine aquatic bed	Open water, woody wetlands, emergent herbaceous wetlands
Forest and open space	Deciduous forest, evergreen forest, mixed forest, scrub/shrub	Deciduous forest, evergreen forest, mixed forest, shrubland, grassland/ herbaceous
Agricultural land	Cultivated land, grassland, bare land	Pasture/hay, row crops, small grains
Residential area	Low density development	Low intensity residential, high intensity residential, urban/ recreational grasses
Commerical/industrial/ transportation uses	High density development	Commercial/industrial/transportation

To analyze urban pollutant loadings from the four major urban centers in the watershed, the land cover map was overlaid with the subwatershed delineation map (Figure 2). Subwatersheds containing these urban centers were then chosen for further analysis (Table 2). Because the purpose of this study is to analyze urban stormwater BMP options, it is assumed that only stormwater generated by the low density development and high density development land cover classes in the NOAA 2000 map are treated with the BMPs examined here.

Five widely used urban stormwater BMPs (wet retention ponds, dry detention ponds, vegetated swales, rain gardens, and constructed wetlands) were chosen in this study to evaluate pollution reduction opportunties and their cost-effectiveness in removing TP and TSS from urban stormwater runoff. These BMPs were selected because of their general applicability and the readily available information on their pollutant load reduction efficiencies (MI-ORR, 2002) and construction costs (Rouge River National Wet Weather Demonstration Project, 2001).

The holding capacity or the design volume of a stormwater retention or detention pond is a function of the rainfall depth of the storm event that the pond is designed to treat. As a generally accepted rule, pond volume is designed to fully capture minimally the first inch of the rainfall in a storm event, because runoff from this first inch is believed to carry most of the pollutants from the watershed. To achieve a higher and more consistent pollutant removal, however, ponds with larger holding capacities are necessary. In this study, a 2.75-inch rain depth representing a 24-hour, 2-year or 1-hour, 100-year storm event in the St. Joseph River Watershed (Huff, 1992), was chosen to ensure the TP and TSS removal efficiencies quoted in the Michigan Water Quality Trading Rule (MI-ORR, 2002) and used in this study can be achieved (listed in Table 4). The runoff and pond volume associated with the 2.75-inch rainfall was calculated using the NPS loading model (K&A, 2003) based on the percent of the urban area to be treated by the stormwater facilities. Costs of constructing the ponds were then derived based on pond volume and area (assuming a depth of 5 feet).

For vegetated swales, generally agreed design criteria on the size in relation to treated area could not be found. According to a fact sheet produced by the Center for Watershed Protection (http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/Open%20Channel%20Practice/Grassed%20Channel.htm), vegetated swales should generally be used to treat drainage areas less than 5 acres. Optimum size of a swale may be 8 feet (width) by 200 feet (length), based on information available from the Low Impact Development Center (http://www.lowimpactdevelopment.org/epa03/LIDtrans/Ex_Swale.pdf). Using these design benchmarks (i.e., for every 5 acres of drainage, it will require a swale of 8ft ×200ft to reach expected treatment efficiencies), the total size of required swales to treat a certain percentage (e.g., 50%) of the targeted urban area was calculated.

A guidance manual produced by the University of Wisconsin-Extension Services (Bannerman and Considine, 2003) provides some detailed instructions on constructing a rain garden for average home owners. The manual suggests a range of size factors (fraction of the drainage area) for design of rain gardens based on soil types and distance from the downspout. Here, an average value of 0.19 from all the reported values across the entire range was used. In addition, it is assumed here that only runoff from the impervious portion of the urban landuses in a subwatershed is treated with rain gardens. This is a reasonable assumption because rain gardens are mostly used to treat runoff from parking lots, roadways, and rooftops in urban areas. Because of the restrictions on where rain gardens can be built in an urban watershed where private properties dominate, rain gardens can only achieve about 5-15% runoff flow reduction (K&A field data [http://www.kalamazooriver.net/pa319new/docs/handouts/downspout_survey.pdf] and Wade-Trim Detroit Study [http://www.wadetrim.com/resources/pub_conf_downspout.pdf]). Therefore, a maximum treatment coverage of 15% of the impervious area in a watershed was assumed in this study.

Figure 2. Major Urban Subwatersheds in the St. Joseph River Watershed

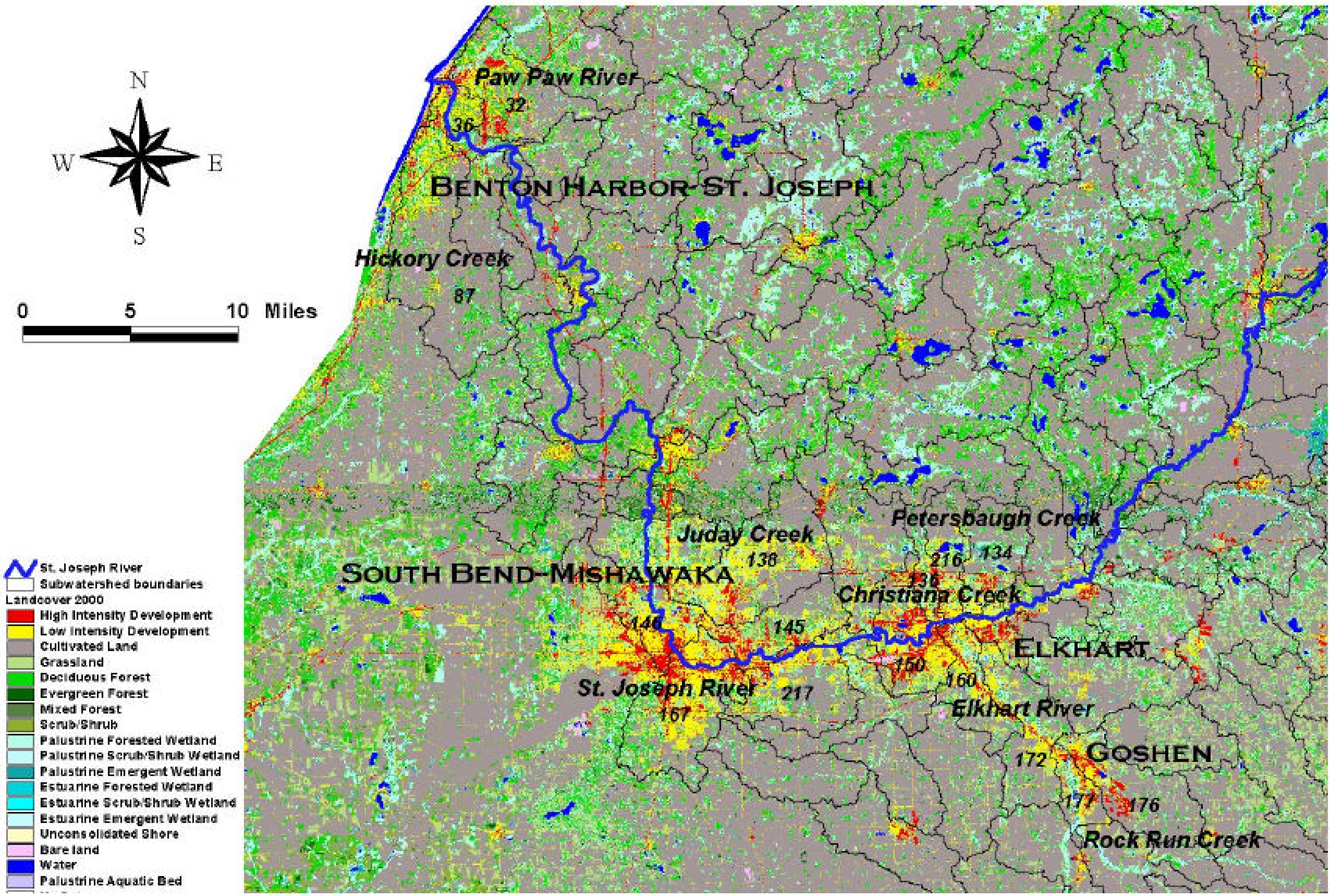

Table 2: Land cover distribution of urban subwatersheds.

Subwatershed			Water/Wetland		Forest/ Open Land		Agricultural		Residential		Commercial/Industrial /Transportation		Total
Urban center	Watershed number	Watershed name	acres	%[1]	acres	%	acres	%	acres	%	acres	%	acres
Benton Harbor – St. Joseph	32	Paw Paw River	1,215	7.5	2,677	16.6	7,868	48.8	2,684	16.6	1,681	10.4	16,125
	36	St. Joseph River at Lake Michigan	1,071	17.9	1,018	17.1	1,277	21.4	2,049	34.3	555	9.3	5,970
	87	Hickory Creek	1,550	4.8	4,700	14.6	21,762	67.6	3,405	10.6	798	2.5	32,215
South Bend – Mishawaka	138	Juday Creek	2,391	10.5	2,121	9.3	11,385	49.8	5,578	24.4	1,372	6.0	22,847
	145	St. Joseph River - Willow Creek	1,231	10.9	1,301	11.5	4,962	43.9	2,401	21.2	1,404	12.4	11,299
	146	St. Joseph River - Airport	1,256	10.5	898	7.5	3,706	31.0	3,715	31.1	2,385	19.9	11,961
	167	St. Joseph River - Auten Ditch	2,209	10.5	3,138	15.0	6,892	32.9	6,188	29.5	2,517	12.0	20,944
	217	St. Joseph River - Eller Ditch	2,401	13.6	1,776	10.0	9,258	52.4	3,320	18.8	918	5.2	17,674
Elkhart	134	Peterbaugh Creek	1,592	15.1	1,392	13.2	6,166	58.6	931	8.9	433	4.1	10,516
	136	Christiana Creek	725	17.6	502	12.2	1,823	44.2	606	14.7	469	11.4	4,126
	150	St. Joseph River - Elkhart West	1,491	12.3	792	6.5	3,324	27.4	3,792	31.2	2,749	22.6	12,148
	160	Elkhart River	1,194	13.4	733	8.2	4,046	45.5	2,040	22.9	882	9.9	8,894
	216	St. Joseph River - Osola Township Ditch	1,819	14.9	1,193	9.8	5,188	42.6	2,623	21.5	1,363	11.2	12,185
Goshen	172	Elkhart River - Leedy Ditch	1,605	11.1	1,502	10.3	8,912	61.4	2,171	15.0	328	2.3	14,518
	176	Rock Run Creek	1,042	7.2	978	6.8	10,102	69.9	1,237	8.6	1,089	7.5	14,448
	177	Elkhart River - Goshen	926	18.8	277	5.6	2,021	41.0	1,167	23.7	537	10.9	4,929

[1] Percent of the subwatershed total area.

According to Rouge River National Wet Weather Demonstration Project (2001), constructed wetlands typically require a size of 0.1 acres per impervious acre of the drainage area. This design criterion was used in this study to calculated required surface area of constructed wetlands. Though not specified in the Rouge River documentation, effective treatment wetlands generally require pre-treatment (sediment removal) in the form of forebays. In this analysis, costs and effectiveness implicitly assume these additional design elements would be constructed.

Baseline loadings of TP and TSS were calculated using the NPS loading model (K&A, 2003) for the runoff and pollutant loads associated with the 2.75-inch rainfall. Load reduction efficiencies achieved by the treatment ponds and swales were obtained from the Michigan Water Quality Trading Rule (MI-ORR, 2002) and are shown in Table 3. The total load reductions for a treated urban area were then calculated by multiplying the total annual loads from the treated area by the load reduction efficiencies in Table 3.

Table 3: Treatment efficiencies of stormwater BMPs.

	TP	TSS
Wet retention pond	90%	90%
Dry detention pond	30%	50%
Vegetated swale	40%	80%
Rain garden [1]	100%	100%
Constructed wetland [2]	90%	90%

[1] Assuming rain gardens absorb all pollutants contained in the runoff captured.
[2] Assuming to be the same as wet retention ponds (Rouge River National Wet Weather Demonstration Project, 2001).

Costs of construction and maintenance were derived from literature values, most of which can be found in the Rouge River National Wet Weather Demonstration Project (2001). These cost values were based either on the volume and surface area of stormwater ponds or the surface area of swales or rain gardens (Table 4).

Table 4. Costs of stormwater ponds.

	Construction [1]	Design & permits [1]	Maintenance
Wet retention pond	$0.50 – 1.00/cubic ft	30% construction	$4,152/ac/yr [2]
Dry detention pond	$0.40 – 0.80/cubic ft	30% construction	$4,152/ac/yr [3]
Vegetated swale	$0.30/sq. ft	--	$0.02/sq. ft/yr
Rain garden	$11/sq. ft [4]	--	--
Constructed wetland [1]	$40,500/acre	$10,500/acre	$850/acre.yr

[1] Source: Rouge River National Wet Weather Demonstration Project, 2001; Median values were used in calculations in this study.
[2] Source: Pitt, 2002; average pond depth of 5 feet assumed; adjusted to 2000 dollar value based on $1,500/acre/year in 1978 dollars with Consumer Price Index from Bureau of Labor Statistics of the U.S. Department of Labor (http://data.bls.gov/cgi-bin/surveymost?bls).
[3] Assumed to be the same as wet retention ponds.
[4] Bannerman and Considine (2003)

Results

Tables 5 and 6 show the annual TP and TSS loadings, respectively, from each of the five major land cover categories for the urban subwatersheds examined in this study. Loading distributions (percent of the total) of land cover categories are also shown in the tables. In addition, Figures 3 through 6 are pie charts of the land cover and TP and TSS loading distributions for the subwatersheds in each of the four major urban centers.

The general finding that can be drawn from these tables and figures is that urban lands (residential and commercial/industrial/transportation) contribute disproportionally high loads of TP and TSS compared to the area they occupy in the subwatersheds. This is especially true for TP loading. It is clear that to reduce TP and TSS loadings from these subwatersheds, it is crucial to treat stormwater from the urban areas of these subwatersheds.

Figure 7 illustrates pollutant loadings from urban lands and other land cover types of all the subwatersheds from each of the four urban centers. It shows that urban areas are the largest TP loading source in all the four urban centers. Not only does the South Bend-Mishawaka area have the largest urban TP and TSS loadings among the four urban centers, its urban lands account for 68.5% of the TP loading from all sources in the area, which is the highest among the four urban centers. This is a natural result of the highest portion (35.2%) of urban area in the South Bend-Mishawaka subwatersheds.

Table 7 shows the pond holding capacity (volume) that each subwatershed needs and the associated costs and load reductions if wet retention ponds are to be built to treat 50% of the runoff from urban areas in the subwatersheds of the urban centers. Table 8 shows the same set of results for dry detention ponds. Tables 9, 10, and 11 illustrate similar results (except pond volumes) for vegetated swales, rain gardens, and constructed wetlands, respectively. In terms of load reductions, wet retention ponds (Table 7) and constructed wetlands (Table 11) are the most effective, giving a total TP reduction of 21,454 lbs and TSS of over 5 million lbs for all the subwatersheds studied here.[1] Rain gardens, due to the limitations on treatment coverage typically being restricted to private lands in urban watersheds (10% areal coverage assumed in this study), yielded only 7,339 lbs of TP and less than 1.8 million lbs of TSS.

Due to the greater treatment efficiencies (Table 4) and comparable costs (Table 3), wet retention ponds are more cost-effective stormwater treatment structures than are dry detention ponds. On average for the 16 urban subwatersheds, it costs $325 to reduce one pound of phosphorus over a 30-year period (the assumed life of these structures) for wet retention ponds, compared to $804 for dry detention ponds. The cost-effectiveness for TSS is $1.32/lb for wet retention ponds and $2.02/lb for dry detention ponds.

[1] Due to the assumptions made on load reduction efficiencies (see the Method section and Table 3), constructed wetlands and wet retention ponds have the same load reductions.

Table 5: TP loading from urban subwatersheds.

Subwatershed			Water/Wetland		Forest/Open land		Agricultural		Residential		Commercial/Industrial /Transportation		Total
Urban center	Watershed number	Watershed Name	lbs/yr	%[1]	lbs/yr	%	lbs/yr	%	lbs/yr	%	lbs/yr	%	lbs/yr
Benton Harbor – St. Joseph	32	Paw Paw River	403	6.4	179	2.8	1,767	28.0	1,913	30.4	2,041	32.4	6,302
	36	St. Joseph River at Lake Michigan	357	12.5	68	2.4	288	10.1	1,467	51.3	677	23.7	2,858
	87	Hickory Creek	521	5.6	318	3.4	4,952	53.6	2,459	26.6	982	10.6	9,232
South Bend – Mishawaka	138	Juday Creek	698	8.7	125	1.6	2,249	28.0	3,496	43.5	1,465	18.2	8,032
	145	St. Joseph River - Willow Creek	352	8.1	75	1.7	960	22.2	1,473	34.0	1,468	33.9	4,328
	146	St. Joseph River - Airport	397	6.1	57	0.9	791	12.1	2,518	38.6	2,754	42.3	6,516
	167	St. Joseph River - Auten Ditch	656	7.4	187	2.1	1,384	15.5	3,943	44.3	2,732	30.7	8,902
	217	St. Joseph River - Eller Ditch	677	12.3	101	1.8	1,766	32.1	2,011	36.5	947	17.2	5,502
Elkhart	134	Peterbaugh Creek	444	16.5	78	2.9	1,162	43.3	557	20.8	442	16.5	2,683
	136	Christiana Creek	204	14.3	28	2.0	347	24.3	366	25.6	482	33.8	1,427
	150	St. Joseph River - Elkhart West	415	6.7	44	0.7	626	10.2	2,266	36.8	2,799	45.5	6,151
	160	Elkhart River	328	10.2	40	1.3	751	23.4	1,202	37.5	885	27.6	3,206
	216	St. Joseph River - Osola Township Ditch	507	11.2	67	1.5	979	21.7	1,570	34.8	1,390	30.8	4,513
Goshen	172	Elkhart River - Leedy Ditch	436	11.6	82	2.2	1,639	43.7	1,267	33.8	327	8.7	3,751
	176	Rock Run Creek	279	7.1	53	1.3	1,831	46.4	711	18.1	1,067	27.1	3,941
	177	Elkhart River - Goshen	260	13.6	16	0.8	384	20.0	703	36.7	551	28.8	1,913

[1] Percent of the subwatershed total TP load.

Table 6: TSS loading from urban subwatersheds.

Subwatershed			Water/Wetland		Forest/Open land		Agricultural		Residential		Commercial/Industrial/ Transportation		Total
Urban center	Watershed number	Watershed Name	lbs/yr	%[1]	lbs/yr	%	lbs/yr	%	lbs/yr	%	lbs/yr	%	lbs/yr
Benton Harbor – St. Joseph	32	Paw Paw River	30,248	1.4	82,852	3.9	1,031,340	48.3	351,419	16.5	637,782	29.9	2,133,641
	36	St. Joseph River at Lake Michigan	26,785	3.8	31,666	4.5	168,213	23.8	269,525	38.1	211,688	29.9	707,877
	87	Hickory Creek	39,112	1.0	147,413	3.8	2,890,674	75.4	451,720	11.8	306,811	8.0	3,835,729
South Bend – Mishawaka	138	Juday Creek	52,363	2.1	57,745	2.3	1,312,743	52.0	642,325	25.5	457,689	18.1	2,522,866
	145	St. Joseph River – Willow Creek	26,388	2.0	34,683	2.6	560,176	41.5	270,694	20.0	458,726	34.0	1,350,667
	146	St. Joseph River – Airport	29,744	1.6	26,424	1.4	462,020	25.1	462,570	25.1	860,498	46.7	1,841,256
	167	St. Joseph River – Auten Ditch	49,176	1.9	86,849	3.4	807,949	32.0	724,444	28.7	853,681	33.8	2,522,099
	217	St. Joseph River – Eller Ditch	50,800	2.8	46,706	2.6	1,031,235	57.5	369,376	20.6	295,976	16.5	1,794,094
Elkhart	134	Peterbaugh Creek	33,274	3.4	36,176	3.7	678,541	68.7	102,356	10.4	138,023	14.0	988,370
	136	Christiana Creek	15,298	3.4	13,170	2.9	202,429	45.1	67,177	15.0	150,632	33.6	448,708
	150	St. Joseph River – Elkhart West	31,127	1.8	20,557	1.2	365,496	21.4	416,360	24.4	874,664	51.2	1,708,204
	160	Elkhart River	24,577	2.5	18,757	1.9	438,460	44.8	220,757	22.5	276,481	28.2	979,032
	216	St. Joseph River – Osola Township Ditch	38,046	2.8	31,023	2.3	571,438	41.9	288,500	21.2	434,313	31.9	1,363,320
Goshen	172	Elkhart River – Leedy Ditch	32,721	2.4	38,062	2.8	956,738	70.2	232,819	17.1	102,048	7.5	1,362,387
	176	Rock Run Creek	20,939	1.3	24,431	1.5	1,068,710	67.7	130,714	8.3	333,477	21.1	1,578,272
	177	Elkhart River - Goshen	19,494	3.5	7,248	1.3	223,905	40.6	129,133	23.4	172,256	31.2	552,036

[1] Percent of the subwatershed total TSS load.

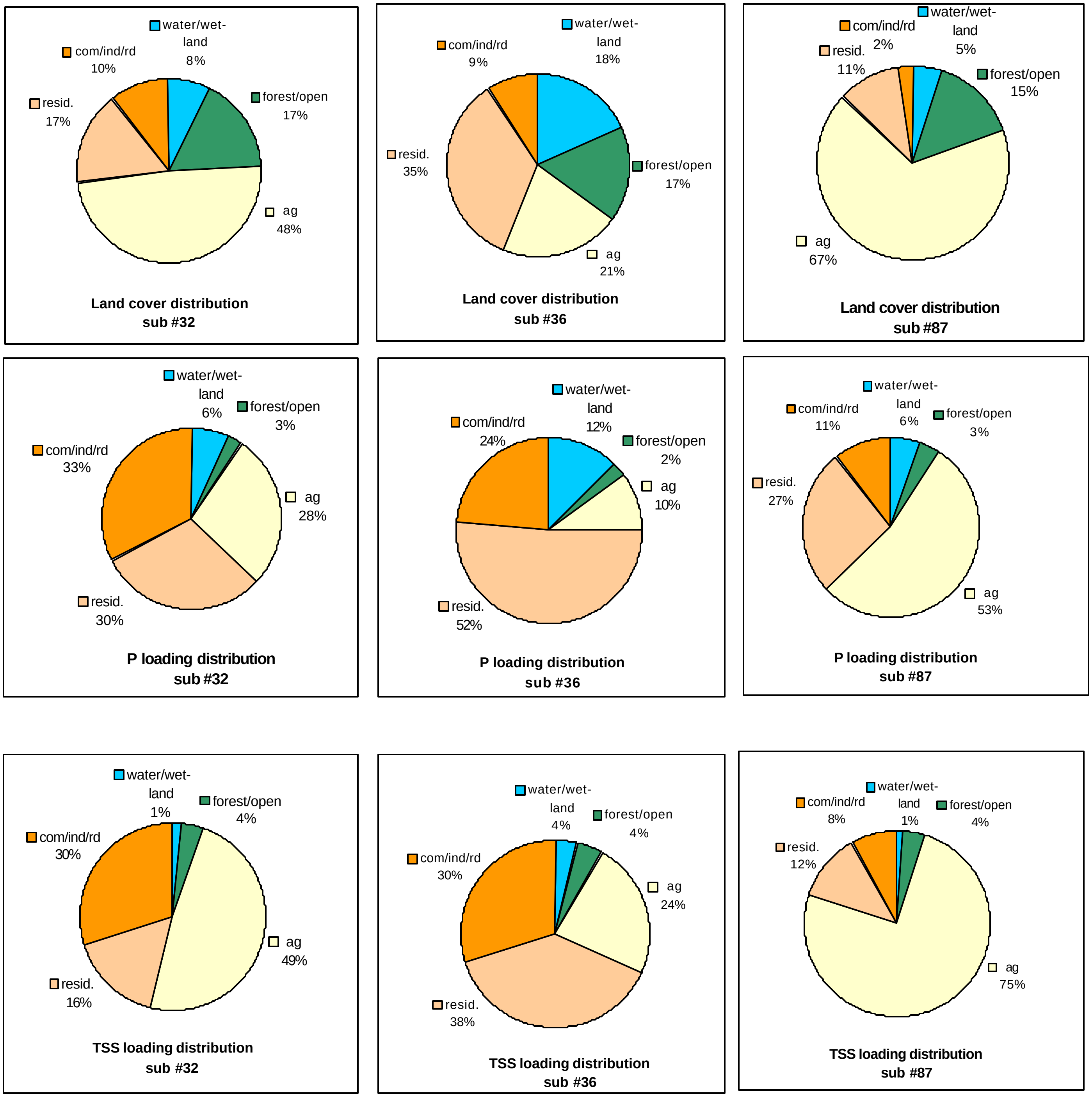

Figure 3. Land cover and TP and TSS loading distributions of subwatersheds in the Benton Harbor-St. Joseph (Michigan) area. (Note: ag: agricultural; resid.: residential; com/ind/rd: commercial/industrial/roads.)

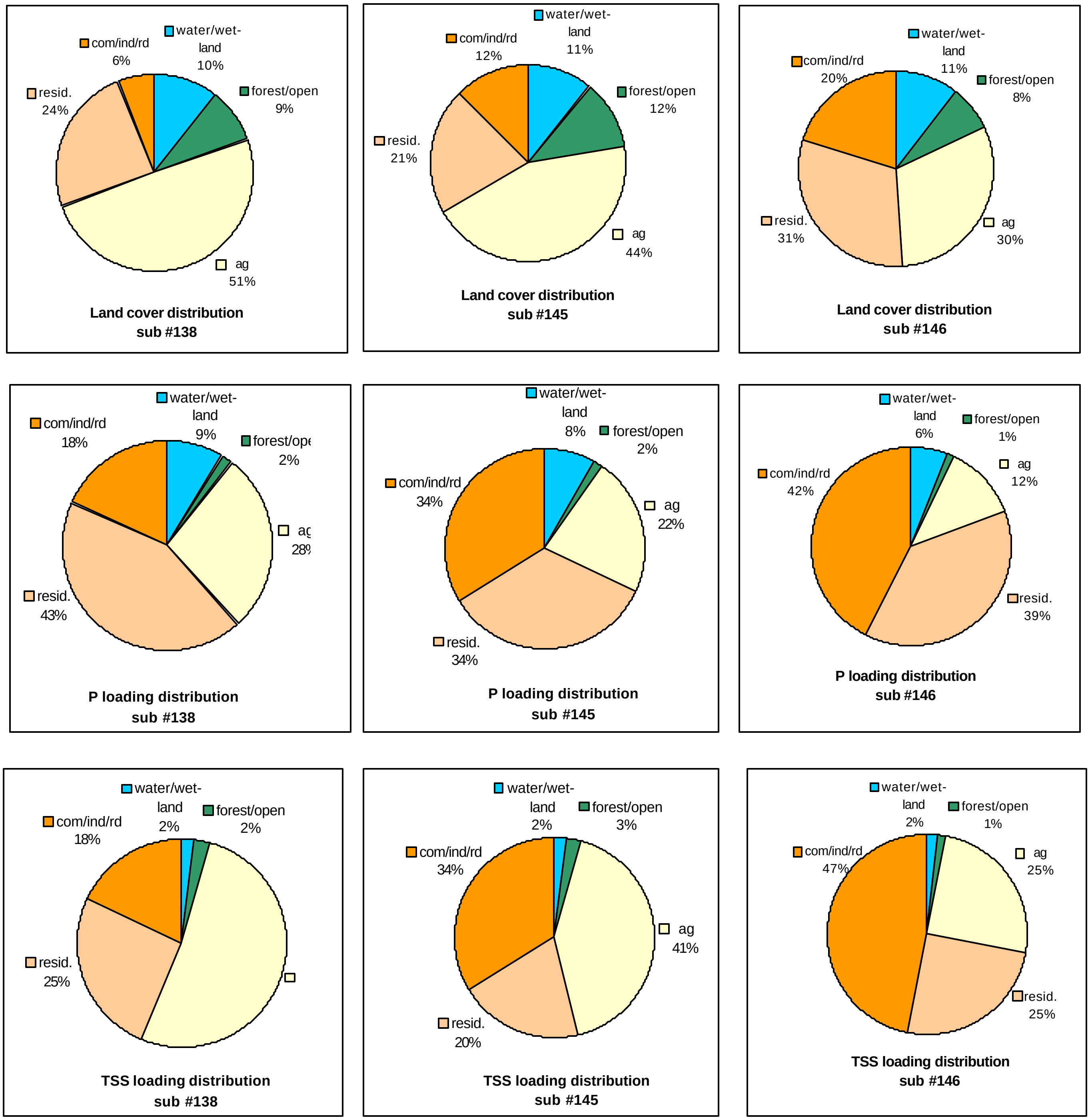

Figure 4: Land cover and TP and TSS loading distributions of subwatersheds in the South Bend-Mishawaka (Indiana) area.

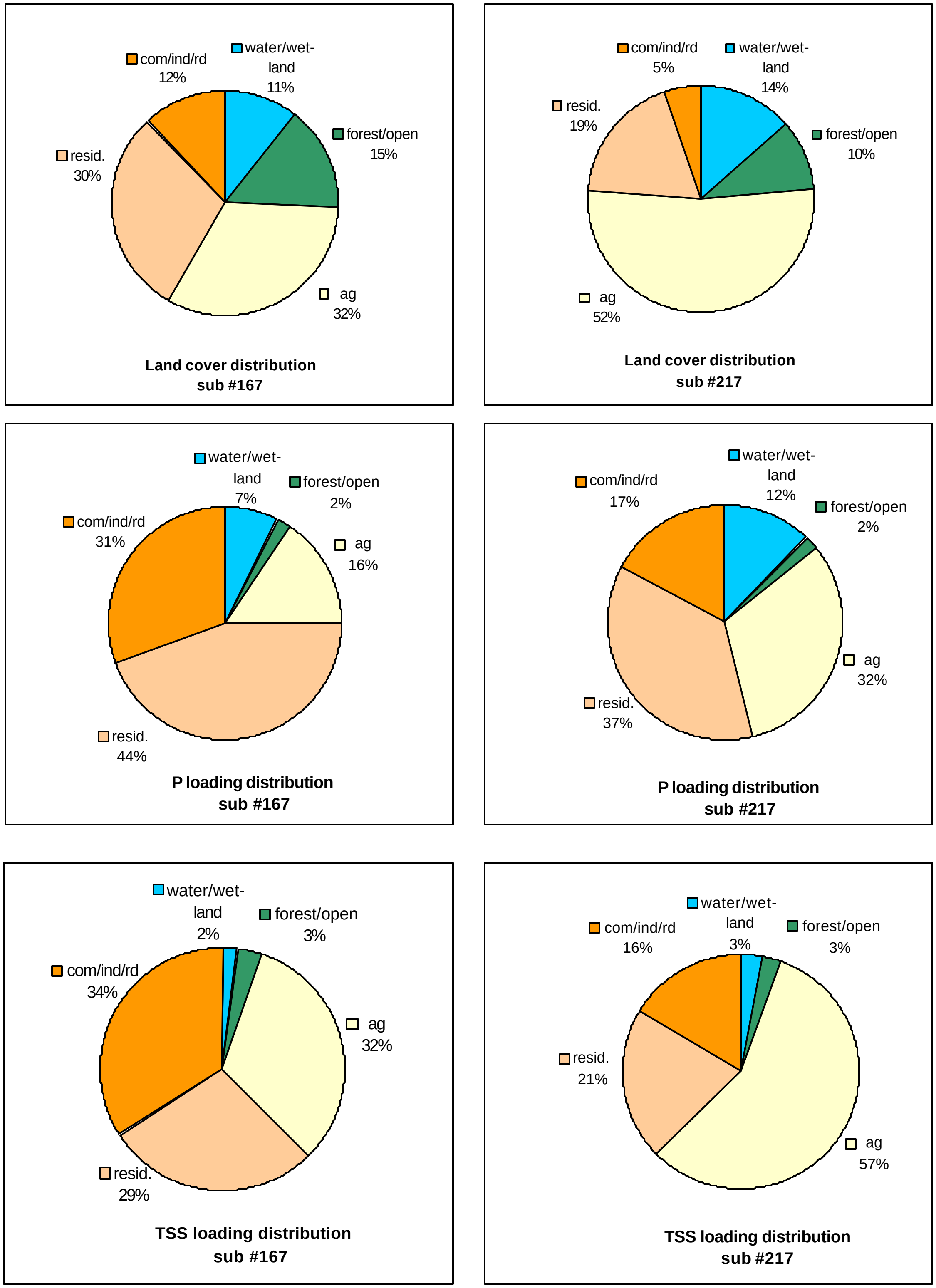

Figure 4 (cont'd): Land cover and TP and TSS loading distributions of subwatersheds in the South Bend-Mishawaka (Indiana) area.

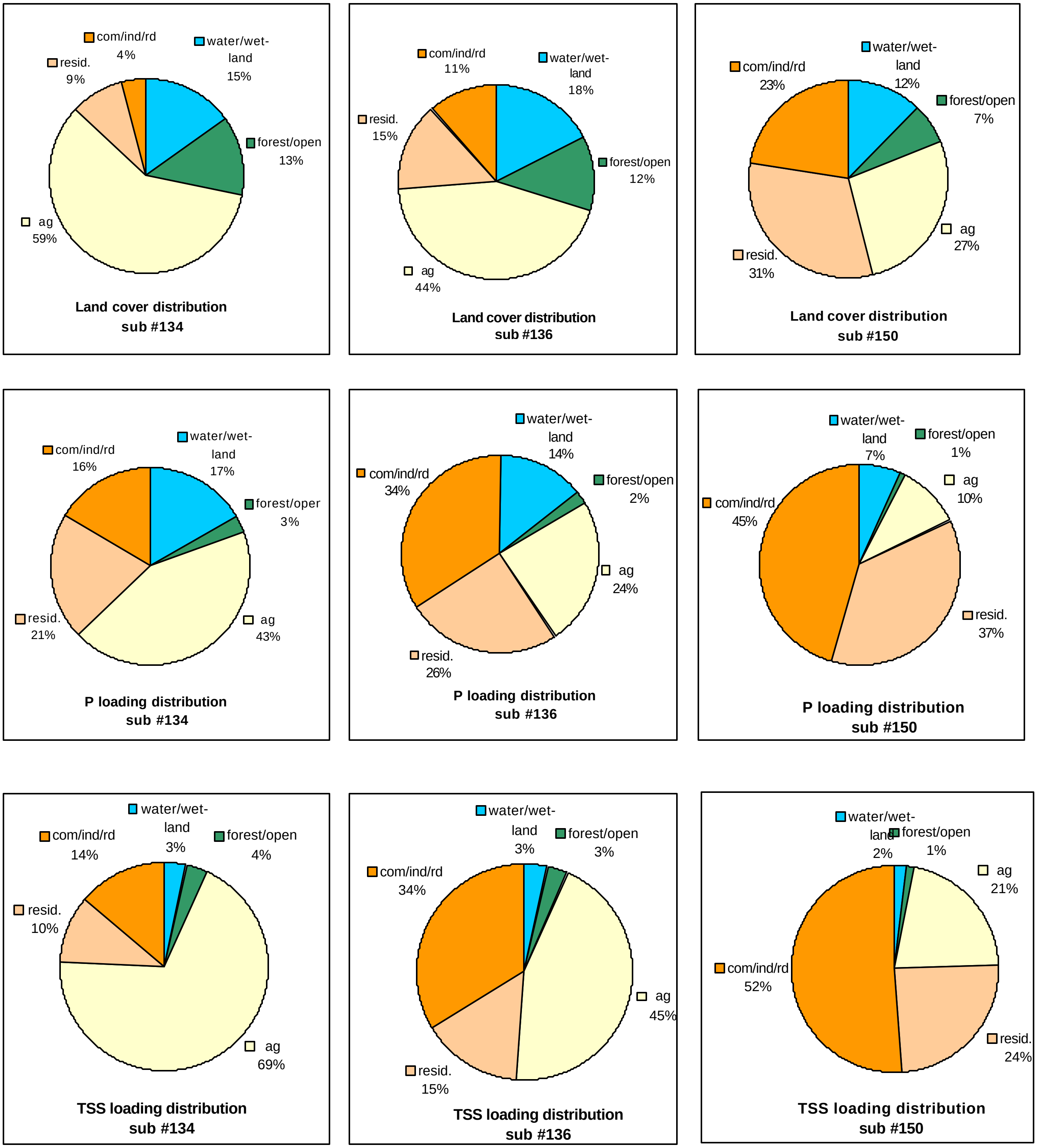

Figure 5: Land cover and TP and TSS loading distributions of subwatersheds in the Elkhart (Indiana) area.

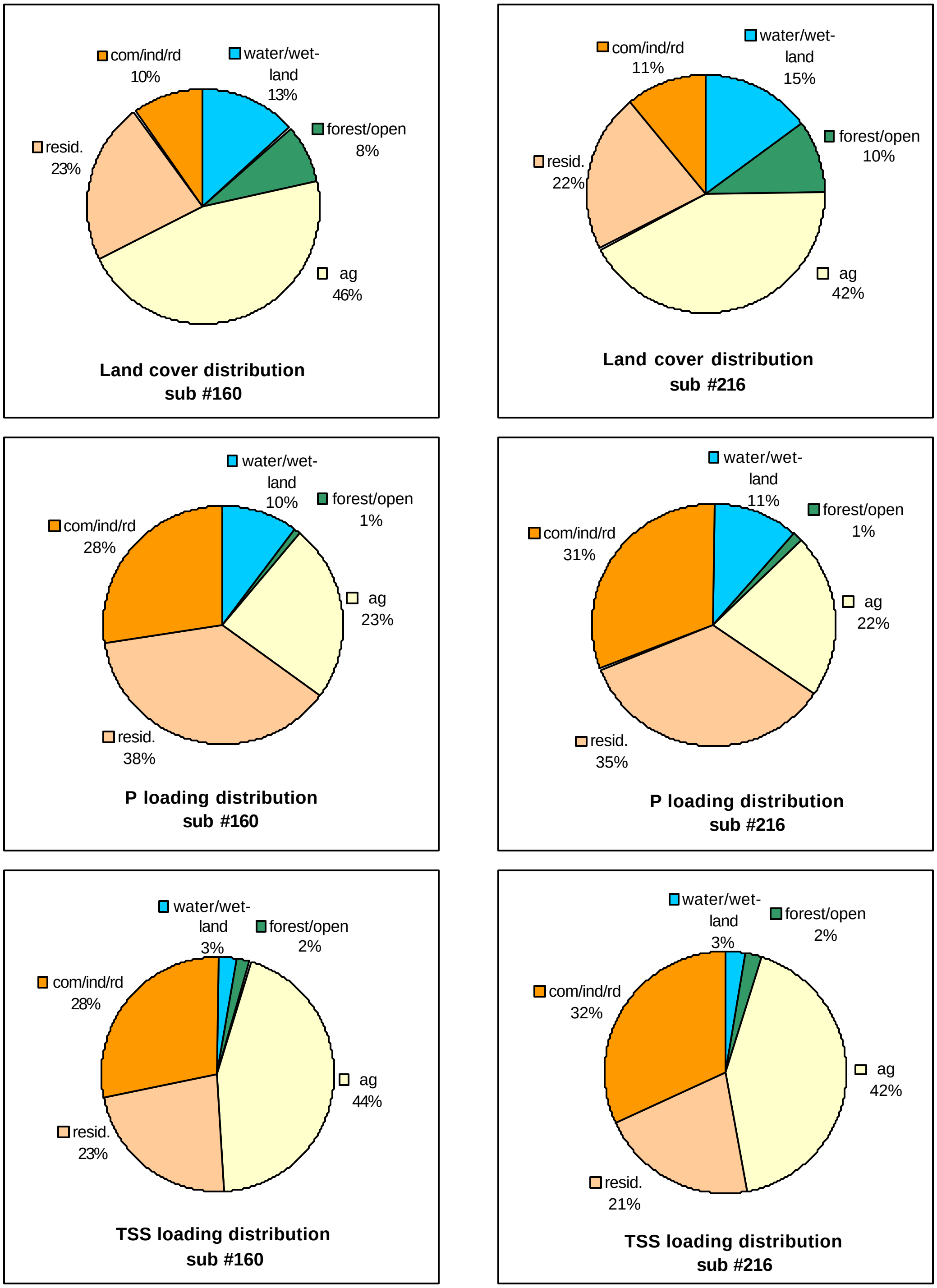

Figure 5 (cont'd): Land cover and TP and TSS loading distributions of subwatersheds in the Elkhart (Indiana) area.

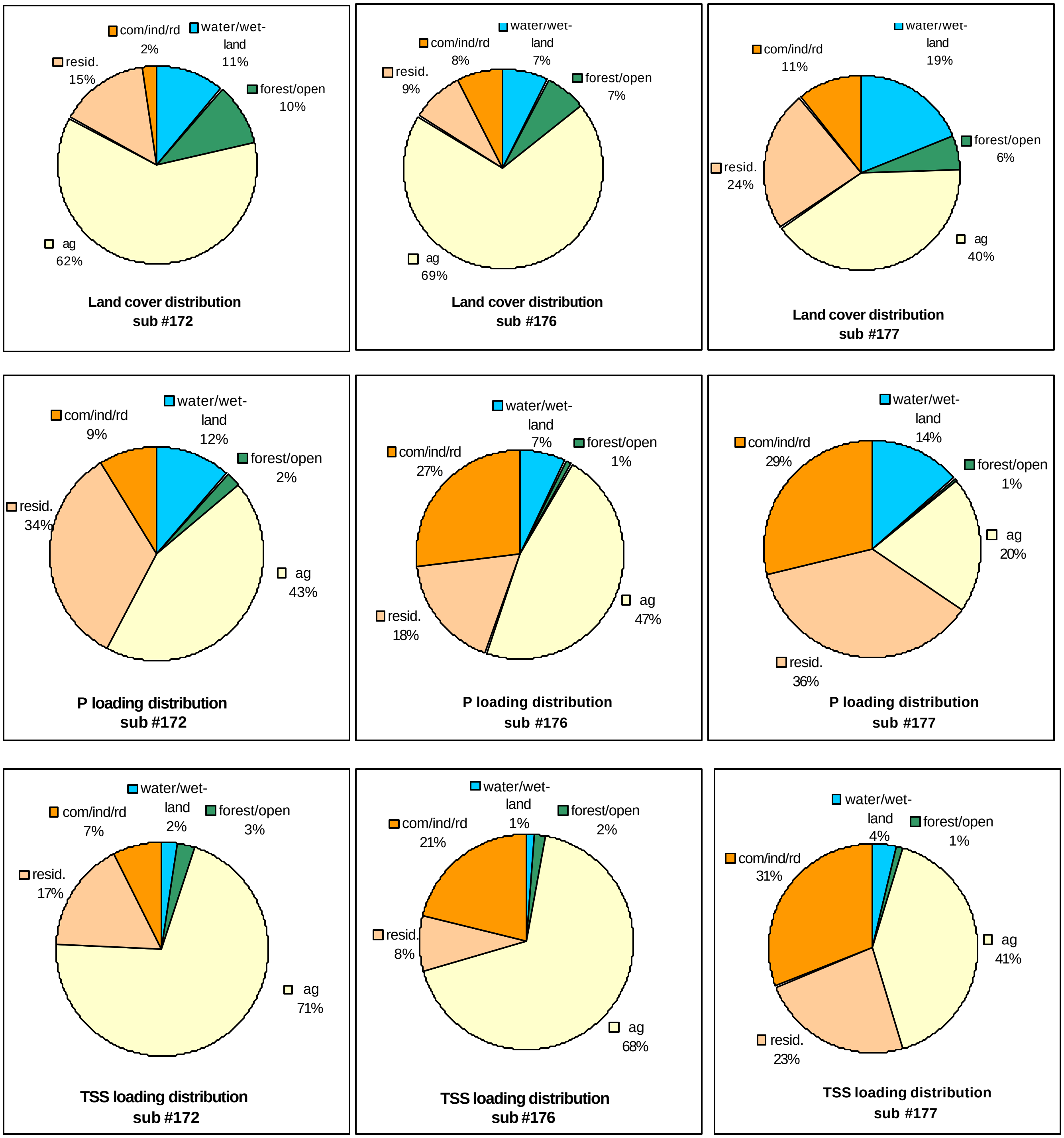

Figure 6: Land cover and TP and TSS loading distributions of subwatersheds in the Goshen (Indiana) area.

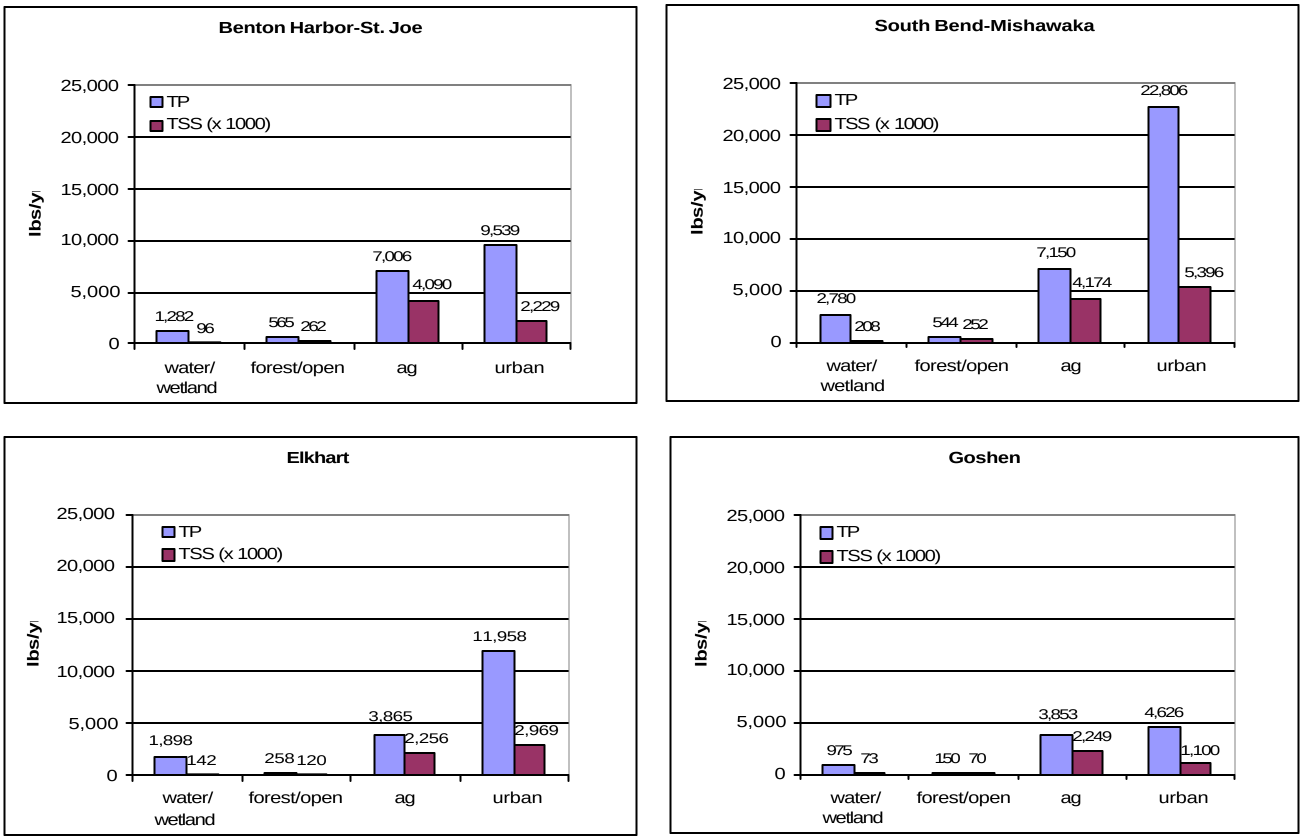

Figure 7: Total TP and TSS loadings from subwatersheds of the urban centers. (Note: TSS values shown in the graphs are in 1000 lbs.)

Compared to detention ponds, vegetated swales, at averages of $41/lb TP and $0.09/lb TSS, show a distinctly higher cost-effectiveness (Table 9) over stormwater ponds (Tables 7 and 8). Clearly, the lower per unit cost of constructing swales ($0.30/sq. ft. construction plus $0.02/sq. ft. maintenance) and comparable TP and TSS load reduction efficiencies (40% and 80% respectively) make this BMP an attractive option for high investment returns.

Cautions should be taken in using these per pound reduction cost values in the context of watershed pollutant load reduction planning, and particularly in comparison with other BMPs such as stormwater ponds. This is because of: 1) the uncertainties on the required size of vegetated swales (see the Methods section on Page 6 of this report); 2) the non-specific nature of the load reduction efficiency values used in this study (MI-ORR, 2002) [2]; and 3) the fact that vegetated swales are often used as a pretreatment or conveyance device for stormwater ponds in stormwater management designs, indicating the intermediate nature of vegetated swales as a stormwater BMP. Moreover, swales require additional right of way and therefore are not always practical in and of themselves as a primary stormwater treatment strategy. They also have limited capabilities for recharge. The ability to construct ponds in select areas as regionalized treatment devices, a smaller overall footprint and groundwater recharge capabilities, make ponds attractive in many instances especially considering their effectiveness for pollutant and hydraulic mitigation. A treatment train combining these options can also be considered.

[2] Load reductions by swales very much on the conditions and properties of underlying soils. The efficiency values quoted in the Michigan's Water Quality Trading Rule (MI-ORR, 2002) do not specify the applicability of these efficiency values with respect to soil types.

Table 7: Wet retention pond pollutant treatment costs with a 50% treatment coverage of urban lands.

Subwatershed			Pond volume	Area [1]	TP load reduction	TSS load reduction	Capital cost [2]	30-year annualized cost [3]	TP load reduction cost	TSS load reduction cost
Urban center	Watershed number	Watershed name	ft^3	acre	lbs/yr	lbs/yr	$	$/yr	$/lbs/yr	$/lbs/yr
Benton Harbor – St. Joseph	32	Paw Paw River	6,237,599	28.6	1,779	445,141	6,081,659	514,526	289	1.16
	36	St. Joseph River at Lake Michigan	3,169,786	14.6	965	216,546	3,090,542	261,469	271	1.21
	87	Hickory Creek	4,995,635	22.9	1,548	341,339	4,870,744	412,079	266	1.21
South Bend – Mishawaka	138	Juday Creek	8,323,977	38.2	2,232	495,006	8,115,878	686,627	308	1.39
	145	St. Joseph River – Willow Creek	5,361,441	24.6	1,324	328,239	5,227,405	442,254	334	1.35
	146	St. Joseph River – Airport	8,761,103	40.2	2,372	595,380	8,542,075	722,685	305	1.21
	167	St. Joseph River – Auten Ditch	11,408,686	52.4	3,004	710,156	11,123,469	941,078	313	1.33
	217	St. Joseph River – Eller Ditch	5,177,420	23.8	1,331	299,408	5,047,985	427,074	321	1.43
Elkhart	134	Peterbaugh Creek	1,836,623	8.4	449	108,171	1,790,707	151,499	337	1.40
	136	Christiana Creek	1,603,040	7.4	381	98,014	1,562,964	132,231	347	1.35
	150	St. Joseph River – Elkhart West	9,629,349	44.2	2,279	580,961	9,388,615	794,305	348	1.37
	160	Elkhart River	3,874,136	17.8	939	223,757	3,777,283	319,569	340	1.43
	216	St. Joseph River – Osola Township Ditch	5,482,251	25.2	1,332	325,266	5,345,195	452,219	339	1.39
Goshen	172	Elkhart River – Leedy Ditch	2,791,213	12.8	717	150,690	2,721,433	230,241	321	1.53
	176	Rock Run Creek	3,561,994	16.4	800	208,886	3,472,945	293,821	367	1.41
	177	Elkhart River – Goshen	2,288,696	10.5	564	135,625	2,231,478	188,790	335	1.39
Total/Average	--	--	*84,502,950*	*388.0*	*22,018*	*5,262,586*	*82,390,377*	*6,970,470*	*325*	*1.32*

[1] Ponds are assumed to have an average depth of 5 feet.
[2] Construction cost + design and permits.
[3] Assuming a 5% interest rate and including a $4,152/acre/year maintenance cost.

Table 8: Dry detention pond pollutant treatment costs with a 50% treatment coverage of urban lands.

Subwatershed			Pond volume	Area [1]	TP load reduction	TSS load reduction	Capital cost [2]	30-year annualized cost [3]	TP load reduction cost	TSS load reduction cost
Urban center	Watershed number	Watershed name	ft^3	acre	lbs/yr	lbs/yr	$	$/yr	$/lbs/yr	$/lbs/yr
Benton Harbor – St. Joseph	32	Paw Paw River	6,237,599	28.6	593	247,300	4,865,327	316,496	734	1.76
	36	St. Joseph River at Lake Michigan	3,169,786	14.6	322	120,303	2,472,433	160,835	688	1.84
	87	Hickory Creek	4,995,635	22.9	516	189,633	3,896,596	253,478	676	1.84
South Bend – Mishawaka	138	Juday Creek	8,323,977	38.2	744	275,004	6,492,702	422,358	781	2.11
	145	St. Joseph River – Willow Creek	5,361,441	24.6	441	182,355	4,181,924	272,039	848	2.05
	146	St. Joseph River – Airport	8,761,103	40.2	791	330,767	6,833,660	444,538	773	1.85
	167	St. Joseph River – Auten Ditch	11,408,686	52.4	1,001	394,531	8,898,775	578,876	795	2.02
	217	St. Joseph River – Eller Ditch	5,177,420	23.8	444	166,338	4,038,388	262,702	815	2.17
Elkhart	134	Peterbaugh Creek	1,836,623	8.4	150	60,095	1,432,566	93,190	856	2.13
	136	Christiana Creek	1,603,040	7.4	127	54,452	1,250,371	81,338	880	2.05
	150	St. Joseph River – Elkhart West	9,629,349	44.2	760	322,756	7,510,892	488,593	885	2.08
	160	Elkhart River	3,874,136	17.8	313	124,310	3,021,826	196,574	864	2.18
	216	St. Joseph River – Osola Township Ditch	5,482,251	25.2	444	180,703	4,276,156	278,169	862	2.12
Goshen	172	Elkhart River – Leedy Ditch	2,791,213	12.8	239	83,717	2,177,146	141,626	815	2.33
	176	Rock Run Creek	3,561,994	16.4	267	116,048	2,778,356	180,735	932	2.14
	177	Elkhart River – Goshen	2,288,696	10.5	188	75,347	1,785,183	116,128	849	2.12
Total/Average	--	--	*84,502,950*	*388.0*	*7,339*	*2,923,659*	*65,912,301*	*4,287,676*	*804*	*2.02*

[1] Ponds are assumed to have an average depth of 5 feet.
[2] Construction cost + design and permits.
[3] Assuming a 5% interest rate and including a $4,152/acre/year maintenance cost.

Table 9: Vegetated swale pollutant treatment costs with a 50% treatment coverage of urban lands.

Subwatershed			Area [1]	TP load reduction	TSS load reduction	Capital cost [2]	30-year annualized cost [3]	TP load reduction cost	TSS load reduction cost
Urban center	Watershed number	Watershed name	acre	lbs/yr	lbs/yr	$	$/yr	$/lb/yr	$/lb/yr
Benton Harbor – St. Joseph	32	Paw Paw River	16.0	791	395,681	209,542	27,600	35	0.07
	36	St. Joseph River at Lake Michigan	9.6	429	192,485	124,989	16,463	38	0.09
	87	Hickory Creek	15.4	688	303,412	201,749	26,574	39	0.09
South Bend – Mishawaka	138	Juday Creek	25.5	992	440,006	333,580	43,939	44	0.10
	145	St. Joseph River – Willow Creek	14.0	588	291,768	182,642	24,057	41	0.08
	146	St. Joseph River – Airport	22.4	1,054	529,227	292,836	38,572	37	0.07
	167	St. Joseph River – Auten Ditch	32.0	1,335	631,250	417,813	55,034	41	0.09
	217	St. Joseph River – Eller Ditch	15.6	592	266,141	203,457	26,799	45	0.10
Elkhart	134	Peterbaugh Creek	5.0	200	96,152	65,510	8,629	43	0.09
	136	Christiana Creek	3.9	170	87,124	51,580	6,794	40	0.08
	150	St. Joseph River – Elkhart West	24.0	1,013	516,410	313,971	41,356	41	0.08
	160	Elkhart River	10.7	417	198,895	140,211	18,468	44	0.09
	216	St. Joseph River – Osola Township Ditch	14.6	592	289,125	191,288	25,196	43	0.09
Goshen	172	Elkhart River – Leedy Ditch	9.2	319	133,947	119,993	15,805	50	0.12
	176	Rock Run Creek	8.5	356	185,677	111,667	14,709	41	0.08
	177	Elkhart River – Goshen	6.3	251	120,556	81,810	10,776	43	0.09
Total/Average	--	--	*232.8*	*9,786*	*4,677,854*	*3,042,638*	*400,770*	*41*	*0.09*

[1] Total area of vegetated swales in the subwatershed. Assuming for every 5 acre of drainage area, an 8×200 sq ft swale is needed.
[2] Construction cost
[3] Assuming a 5% interest rate and including a $0.02/sq ft/yr maintenance cost.

Table 10: Rain garden pollutant treatment costs with a 10% treatment coverage of urban lands.

Subwatershed			Area [1]	TP load reduction	TSS load reduction	Capital cost [2]	30-year annualized cost [3]	TP load reduction cost	TSS load reduction cost
Urban center	Watershed number	Watershed name	acre	lbs/yr	lbs/yr	$	$/yr	$/lb/yr	$/lb/yr
Benton Harbor – St. Joseph	32	Paw Paw River	66.1	593	148,380	31,659,991	2,059,521	3,473	13.88
	36	St. Joseph River at Lake Michigan	31.8	322	72,182	15,217,750	989,933	3,078	13.71
	87	Hickory Creek	49.6	516	113,780	23,759,115	1,545,560	2,995	13.58
South Bend – Mishawaka	138	Juday Creek	82.9	744	165,002	39,710,284	2,583,203	3,471	15.66
	145	St. Joseph River – Willow Creek	56.5	441	109,413	27,093,664	1,762,476	3,995	16.11
	146	St. Joseph River – Airport	93.0	791	198,460	44,538,091	2,897,257	3,664	14.60
	167	St. Joseph River – Auten Ditch	117.5	1,001	236,719	56,280,075	3,661,088	3,657	15.47
	217	St. Joseph River – Eller Ditch	51.9	444	99,803	24,888,853	1,619,050	3,649	16.22
Elkhart	134	Peterbaugh Creek	19.1	150	36,057	9,142,676	594,742	3,970	16.49
	136	Christiana Creek	17.2	127	32,671	8,243,442	536,246	4,217	16.41
	150	St. Joseph River – Elkhart West	102.9	760	193,654	49,323,077	3,208,527	4,223	16.57
	160	Elkhart River	40.0	313	74,586	19,190,054	1,248,337	3,989	16.74
	216	St. Joseph River – Osola Township Ditch	57.4	444	108,422	27,490,894	1,788,316	4,028	16.49
Goshen	172	Elkhart River – Leedy Ditch	27.0	239	50,230	12,932,765	841,292	3,519	16.75
	176	Rock Run Creek	38.5	267	69,629	18,455,725	1,200,568	4,500	17.24
	177	Elkhart River – Goshen	23.8	188	45,208	11,384,842	740,598	3,937	16.38
Total/Average	--	--	*875.1*	*7,339*	*1,754,195*	*419,311,296*	*27,276,715*	*3,716*	*15.55*

[1] Total area of rain gardens in the subwatershed. Assuming rain garden area of 19% of the drainage area, which in turn is assumed to be 10% of impervious urban lands.
[2] Construction cost.
[3] Assuming a 5% interest rate.

Table 11: Constructed wetland treatment costs with a 50% treatment coverage of urban lands.

Subwatershed			Area [1]	TP load reduction	TSS load reduction	Capital cost [2]	30-year annualized cost [3]	TP load reduction cost	TSS load reduction cost
Urban center	Watershed number	Watershed name	acre	lbs/yr	lbs/yr	$	$/yr	$/lb/yr	$/lb/yr
Benton Harbor – St. Joseph	32	Paw Paw River	116	1,779	445,141	5,911,879	483,106	272	1.09
	36	St. Joseph River at Lake Michigan	56	965	216,546	2,841,615	232,211	241	1.07
	87	Hickory Creek	87	1,548	341,339	4,436,546	362,545	234	1.06
South Bend – Mishawaka	138	Juday Creek	145	2,232	495,006	7,415,113	605,947	271	1.22
	145	St. Joseph River – Willow Creek	99	1,324	328,239	5,059,208	413,428	312	1.26
	146	St. Joseph River – Airport	163	2,372	595,380	8,316,610	679,616	287	1.14
	167	St. Joseph River – Auten Ditch	206	3,004	710,156	10,509,195	858,789	286	1.21
	217	St. Joseph River – Eller Ditch	91	1,331	299,408	4,647,503	379,784	285	1.27
Elkhart	134	Peterbaugh Creek	33	449	108,171	1,707,215	139,510	310	1.29
	136	Christiana Creek	30	381	98,014	1,539,300	125,788	330	1.28
	150	St. Joseph River – Elkhart West	181	2,279	580,961	9,210,112	752,631	330	1.30
	160	Elkhart River	70	939	223,757	3,583,364	292,825	312	1.31
	216	St. Joseph River – Osola Township Ditch	101	1,332	325,266	5,133,383	419,489	315	1.29
Goshen	172	Elkhart River – Leedy Ditch	47	717	150,690	2,414,939	197,344	275	1.31
	176	Rock Run Creek	68	800	208,886	3,446,243	281,620	352	1.35
	177	Elkhart River – Goshen	42	564	135,625	2,125,895	173,724	308	1.28
Total/Average	--	--	*1,535*	*22,018*	*5,262,586*	*78,298,119*	*6,398,357*	*291*	*1.22*

[1] Total area of constructed wetlands in the subwatershed. Assuming constructed wetlands to have 10% of the impervious drainage area.
[2] Construction cost + design and permits.
[3] Assuming a 5% interest rate and including a $850 /acre/year maintenance cost.

Calculations for rain gardens suggest that this practice is very expensive (Table 10) compared with other BMPs (Tables 7-10). At an average per pound cost of $3,716 for TP and $15.55 for TSS, these values are several times higher than wet retention ponds and vegetated swales for TP, and hundreds of times higher for TSS. Only lowering the installation cost of rain gardens to $3/sq. ft.[3], can one bring down the per pound cost to $1,014 for TP and $4.24 for TSS. These costs still do not compare favorably with stormwater ponds and swales. This is a direct result of the high per square foot cost ($11) for rain gardens and the high surface area required (19% of the drainage area) for rain gardens to work properly. Moreover, it is assumed here that rain gardens will only be applied to 10% of the urban land cover. Typically, these are applied to individual properties making it difficult to achieve significant stormwater treatment benefits or broad scale adoption and implementation given the vast number of property owners required to construct such features.

Again, caution should be taken in interpreting these numbers, especially when comparing rain garden applications to other BMPs. The value of rain gardens goes well beyond treating stormwater runoff. Effective for source control, rain gardens also provide habitat to native plants and animals, enhance the aesthetics of urban lands, and raise the awareness of stormwater issues among the general public. Rain garden applications will be most effective with new construction. Retrofit requirements with existing infrastructure make it a difficult to sell this approach to an effective number of private landowners.

At $291/lb of TP and $1.22/lb of TSS, constructed wetlands (Table 11) show lower per pound cost values than wet retention ponds but much higher costs than vegetated swales. The differences between constructed wetlands and wet retention ponds mainly lie on the much lower maintenance cost for wetlands ($850/ac/yr compared to $4,152/ac/yr for wet retention ponds). On the other hand, wet retention ponds occupy a much smaller area (388 acres in total for all the subwatersheds) than constructed wetlands (1,535 acres) due to the greater depth of the ponds (up to 5 feet) vs. wetlands (<1 ft).

Because land purchase expenses were not considered in calculations for Tables 7 through 11, cost differences were not factored into the per pound costs. These two BMP applications show similar load reduction capabilities and comparable long-term (30 years) cost-effectiveness, however, additional land costs to accommodate the necessary footprint for wetlands must ultimately be a consideration for any stormwater treatment strategy.

General equations can be derived from the calculations that lead to the outputs in Tables 7 and 8 for the reduction capacity and cost of urban stormwater ponds for any area in the St. Joseph River Watershed. Due to the uncertainties involved in calculations for swales, rain gardens, and wetlands, equations for these BMPs are not presented in this report.

<u>Equation 1:</u> TP load reduction (lbs/yr):

$$(0.01864*A_L + 0.03175*A_H)*R*T\%*E_p\%$$

[3] Assuming no professional assistance is needed for designing and constructing a rain garden. Only expenditure is for purchasing plants (http://natsci.edgewood.edu/wingra/management/raingardens/rain_build.htm).

where: A_L: Area of low intensity development (acre);
A_H: Area of high intensity development (acre);
R: Annual rainfall total (inch);
T%: Percent of urban area ($A_L + A_H$) treated; and
E_p%: TP load reduction efficiency of the stormwater pond (90% for wet retention ponds and 30% for dry detention ponds).

Equation 2: TSS load reduction (lbs/yr):

$$(3.4245*A_L + 9.9228*A_H)*R*T\%*E_s\%$$

where: E_s% is the TSS load reduction efficiency of the stormwater pond (90% for wet retention ponds and 50% for dry detention ponds).

Equation 3: Wet retention pond capital cost ($):[4]

$$9732.94*(0.1913*A_L + 0.4379*A_H)*T\%$$

Equation 4: Dry detention pond capital cost ($):[5]

$$7786.35*(0.1913*A_L + 0.4379*A_H)*T\%$$

Equation 5: Wet retention pond 30-year annualized unit TP reduction cost ($/lb/yr):[6]

$$\frac{823.44*(0.1913*A_L + 0.4379*A_H)}{(0.01864*A_L + 0.03175*A_H)*R*E_p\%}$$

Equation 6: Dry detention pond 30-year annualized unit TP reduction cost ($/lb/yr):[7]

$$\frac{696.81*(0.1913*A_L + 0.4379*A_H)}{(0.01864*A_L + 0.03175*A_H)*R*E_p\%}$$

Equation 7: Wet retention pond 30-year annualized unit TSS reduction cost ($/lb/yr):[8]

$$\frac{823.44*(0.1913*A_L + 0.4379*A_H)}{(3.4245*A_L + 9.9228*A_H)*R*E_s\%}$$

Equation 8: Dry detention pond 30-year annualized unit TSS reduction cost ($/lb/yr):[9]

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[4] Construction cost + cost of design and permits.
[5] See Note 4.
[6] Assuming a 5% interest rate and an average pond depth of 5 feet, and including a $4,152/acre/year maintenance cost
[7] See Note 6.
[8] See Note 6.

$$\frac{696.81*(0.1913*A_L + 0.4379*A_H)}{(3.4245*A_L + 9.9228*A_H)*R*E_s\%}$$

These equations require five inputs that either are readily available (A_L, A_H, and R), can be assumed (T%) or are obtained from the literature (E_p or E_s). Therefore, these equations can be used to quickly determine the cost-effectiveness of stormwater ponds in removing urban TP and TSS loadings for any area in the St. Joseph River Watershed. It should be noted that these equations, their parameters and factors are based on the NPS model that was calibrated specifically for the St. Joseph River Watershed (K&A, 2003). Applying these equations to areas outside of the watershed may require calibration specific to the targeted geographic area.

Conclusions

This study shows that in the St. Joseph River watershed, urban storm runoff is a significant source of TP and TSS loads in subwatersheds with the substantial presence of urban landuses. It is important to control this source of loading when water quality in local waterways is to be improved. Among the five urban BMPs examined here (wet retention ponds, dry detention ponds, vegetated swales, rain gardens, and constructed wetlands), wet retention ponds and constructed wetlands provide the highest load reductions for TP and TSS while vegetative swales show the highest cost-effectiveness (lowest per pound cost of load reduction). Cautions should be taken, however, in interpreting these results due to the uncertainties in design parameters of vegetative swales and rain gardens.

This study has also provided some easy-to-use equations for calculating load reductions and cost-effectiveness of stormwater ponds. Overall, site-specific engineering will be required in all cases to effectively apply urban stormwater BMPs. Groundwater recharge and restored natural flow regimes should be the ultimate goal of any BMP strategy.

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[9] See Note 6.

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