URBAN BUILD-OUT AND STORMWATER BMP ANALYSIS IN THE PAW PAW RIVER WATERSHED

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TABLE OF CONTENTS

List of Tables

List of Figures

1. Introduction

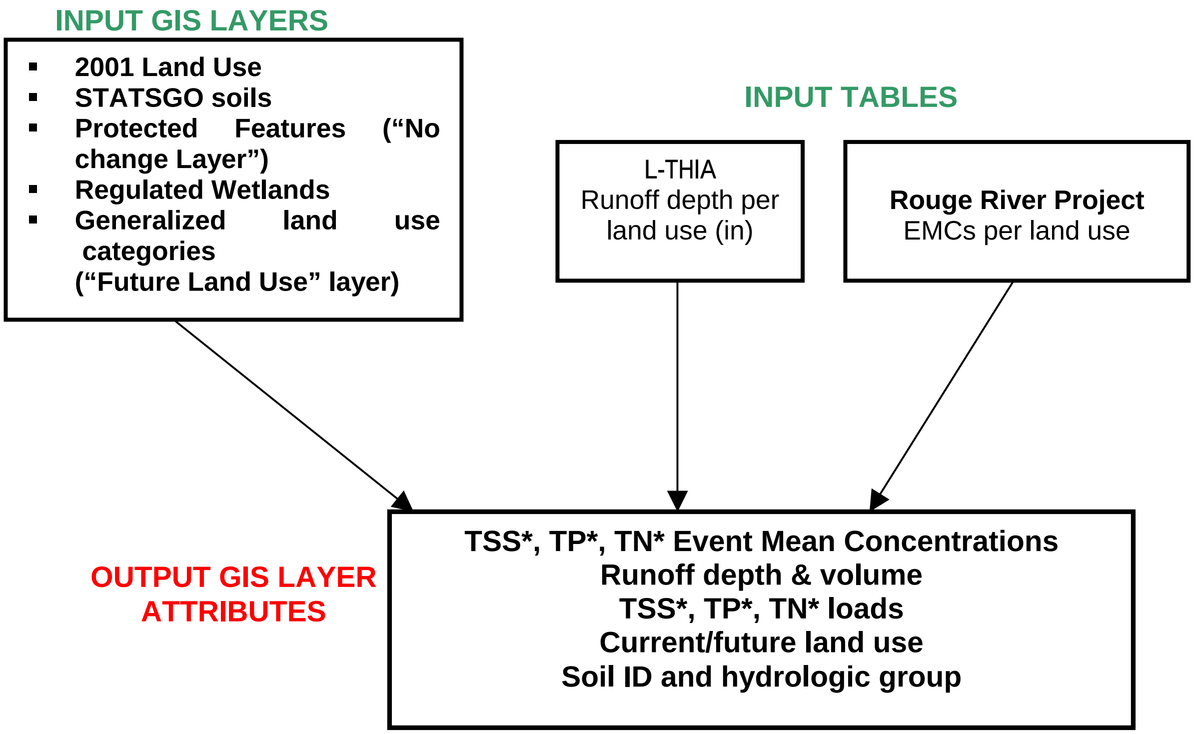
The Paw Paw River Watershed is predominantly agricultural; only two out of 17 subwatersheds have greater than 10% of their area in urban land uses (see Figure 1). However, development pressures exist that need to be documented and quantified. Although most of the nonpoint source pollution in the watershed is generated from agricultural areas, it has been shown that urban areas contribute significantly to pollutant loadings in urban watersheds (DeGraves, 2005). Understanding the impact of future urban development and urban best management practices (BMPs) on water quality is key to developing adequate land use management plans that meet watershed management goals.

The SWAT model used to simulate agricultural BMPs in the Paw Paw River Watershed (Kieser, 2008) is limited in its ability to simulate the impact of urban development and stormwater BMPs. A simple empirical approach, similar to the one used in the St Joseph Watershed Management Plan (DeGraves, 2005), was used to calculate nonpoint source pollutant loads and estimate the impact of stormwater BMPs. Pollutant loads and runoff volumes were calculated using average runoff depth values produced by the Long-term Hydrologic Impact Assessment model (L-THIA), and available pollutant event mean concentration values. Hypothetical build-out scenarios were defined to estimate the impact of urban development on water quality, and quantity. The impact and cost-effectiveness of five common stormwater best management practices were also modeled to support land use planning in the Paw Paw River Watershed.

2. Build-out Modeling Methods

2.1 Base GIS Build-out Layer

The build-out analysis is based on the development of a complex GIS layer where multiple data layers (land use, soils, political boundaries, etc.) were overlaid and each unique record (i.e., polygon) was assigned individual runoff and event mean concentration values as well as specific management characteristics. The conceptual design is presented on the next page.



The 2001 IFMAP land use/land cover layer[1] was reclassified into nine broad categories to match, as much as feasible, land use categories with known event mean concentration values and land use categories available in L-THIA (Table 1). The STATSGO soil data layer, provided through the BASINS interface and used in the SWAT modeling study, provided information on hydrologic soil group.

The Southwest Michigan Planning Commission (SWMPC) provided the following layers:

- 'No Change Layer' with protected/permanent features: lakes/river, conservation easements/ parks, utility easements, and cemeteries,
- 'Intermediate Layer' with MDEQ regulated wetlands,
- 'Future Land Use' layer with generalized future land use categories for several municipalities within the watershed (see Table 2) based on future land use maps and plans.

All layers (in shapefile format) were overlaid and processed through ESRI ArcGIS® to create one complex GIS layer with an extensive attribute table.

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[1] Available from the Michigan Geographic Data Library at http://www.mcgi.state.mi.us/mgdl/
* TSS: Total Suspended Solids, TP: Total Phosphorus, TN: Total Nitrogen

Table 1: Reclassification of IFMAP land use categories.

2001 IFMAP Classification		***Reclassified Values***	
Land Use Value	**Land Use Category**	***Reclassified Value***	***Reclassified Description***
1	Low intensity urban	1	Low density urban
2	High intensity urban	2	High density urban
3	Airport	3	Transportation
4	Road/parking lot	3	Transportation
5	Non-vegetated farmland	4	Agriculture
6	Row crops	4	Agriculture
7	Forage crops/non-tilled herbaceous agriculture	4	Agriculture
9	Orchard/vineyard/nursery	4	Agriculture
10	Herbaceous openland	5	Rural open
12	Upland shrub/low density trees	5	Rural open
13	Parks/golf courses	6	Urban open
14	Northern hardwood association	7	Forest
15	Oak association	7	Forest
16	Aspen association	7	Forest
17	Other upland deciduous	7	Forest
18	Mixed upland deciduous	7	Forest
19	Pines	7	Forest
20	Other upland conifers	7	Forest
22	Upland mixed forest	7	Forest
23	Water	8	Water
24	Lowland deciduous forest	9	Wetlands
25	Lowland coniferous forest	9	Wetlands
26	Lowland mixed forest	9	Wetlands
27	Floating aquatic	9	Wetlands
28	Lowland shrub	9	Wetlands
29	Emergent wetland	9	Wetlands
30	Mixed non-forest wetland	9	Wetlands
31	Sand/soil	5	Rural open
35	Other bare/sparsely vegetated	5	Rural open

Table 2: Dates of Future Land Use maps used in the build-out analysis.

Municipality	Master Plan Future Land Use Map Date
Alamo Twp	No Plan Available
Almena Twp	2006
Antwerp Twp	2002
Arlington Twp	No Plan Available
Bainbridge Twp	2003
Bangor Twp	2001
Benton Harbor, City of	1998
Benton Twp	2002
Bloomingdale Twp	No Plan Available
Coloma Twp	2001
Coloma, City of	1991
Covert Twp	2004
Decatur Twp	2001
Gobles, City of	2005
Hagar Twp	2001
Hamilton Twp	2001
Hartford Twp	1999
Hartford, City of	1999
Keeler Twp	2002
Lawrence Twp	2002
Lawrence, Village of	2002
Lawton, Village of	2004
Mattawan, Village of	1998
Oshtemo Twp	1993
Paw Paw Twp	2003
Paw Paw, Village of	1999
Pine Grove Twp	2006
Porter Twp	2005
Prairie Ronde Twp	No Plan Available
Sodus Twp	2004
Texas Twp	1999
Watervliet Twp	1998
Watervliet, City of	Plan Date Unknown (data from Berrien County GIS)
Waverly Twp	2006

2.2 Pollutant Load Calculations

Both land use and soil layers were processed using the L-THIA GIS ArcView® extension to calculate runoff depth. L-THIA is a simple rainfall-runoff model developed by Purdue University[2]. It uses the SCS Curve Number method and long term precipitation data to calculate average annual runoff depths for each unique combination of soil and land use. Standard curve numbers from TR-55 were selected for each land use based on land use definition and imperviousness (see Table 3).

Table 3: Curve numbers selected for L-THIA modeling.

	Curve Number for Hydrologic Soil Group			
Land Use Category	**A**	**B**	**C**	**D**
Agricultural	64	75	82	85
Forest	30	55	70	77
Rural Open	39	61	74	80
Urban Open	49	69	79	84
Transportation/Highways	89	92	94	95
Commercial	89	92	94	95
Industrial	81	88	91	93
Low Density Residential	54	70	80	85
Medium Density Residential	61	75	83	87
High Density Residential	77	85	90	92

The Rouge River National Wet Weather Demonstration Project conducted an extensive assessment of stormwater pollutant loading factors per land use class (Cave et al.,1994) and recommended event mean concentration (EMC) values for 10 broad land use classes (Table 4). These EMC values have since been incorporated into the Michigan Trading Rules (Part 30) to calculate pollutant loads from urban stormwater nonpoint sources. Runoff depth calculated through L-THIA, and event mean concentration values presented in Table 4, were added as attributes to the build-out layer and used to calculate current and future pollutant loads.

Pollutant loads were calculated using the simple equation:

$$EMC_L \times R_L \times A_L \times 0.2266 = L_L$$

Where:

- EMC_L = Event mean concentration for land use L in mg/L (Table 4).
- R_L = Runoff per land use L from L-THIA in inches/year.
- A_L = Area of land use L in acres
- 0.2266 = Unit conversion to convert mg-in-ac/yr to lbs/ac-yr.
- L_L = Annual load per land use L in lbs/ac.

[2] For more information, visit L-THIA website at: http://www.ecn.purdue.edu/runoff/lthianew/Index.html

Table 4: Event mean concentrations for land use categories used in the build-out analysis.

Original Land Use Categories (Rouge River)	2001 Reclassified Land Use Categories	Future Land Use Category	Percent Impervious	TSS (mg/L)	TP (mg/L)	TN (mg/L)
Forest/rural open	Forest/rural open	N/a	0.5% (1)	51	0.11	1.74
Urban open	Urban open	Urban open	0.5%	51	0.11	1.74
Agricultural	Agricultural	Agricultural	3% (2)	145	0.37	5.98
Low density residential	Low density urban	Low density residential	10%	70 (3)	0.52 (3)	5.15 (3)
N/a	N/a	Rural residential (4)	varies	varies	varies	varies
Medium density residential	N/a	Medium density residential	30%	70	0.52	5.15
N/a	High density urban (5)	N/a	85%	120 (5)	0.31 (5)	3.54 (5)
High density residential	N/a	High density residential	85% (6)	97	0.24	3.29
Commercial	N/a	Commercial	90%	77	0.33	2.97
Industrial	N/a	Industrial	80%	149	0.32	3.97
Highways	Transportation	Highways	90%	141	0.43	2.65
Water/ wetlands	Water and Wetlands	Water/ Wetlands	0%	6	0.08	1.38

N/a: not applicable

Notes:

(1) Imperviousness for forest/rural open is considered similar to the Urban Open category value as it includes forested/open space areas where roads have been assigned to the Highways category.

(2) This value is based on density of farm roads, field access roads and farmsteads in the agricultural land use category.

(3) Low density residential category values will be applied to smaller parcel single family dwellings of less than two acres in size.

(4) This category includes parcels greater than 2 acres. The EMC value for Low Density Residential will be used to calculate the loading and runoff for 33% of the area of these polygons (corresponding to the homestead and associated acreage developed). The loading and runoff for the remaining 67% should be calculated using the EMC value of the current land cover (IFMAP) category in the polygon. If more than one IFMAP land cover type exists in the polygon, a proportion of the land cover categories equal to the original should be used to calculate the remaining 67% of the polygon.

(5) This land use was defined as 60% industrial, 25% commercial and 15% high density residential in the Paw Paw River Watershed. This ratio was determined by comparing areas identified in IFMAP as High Intensity Urban to 2003 & 2005 digital orthophotos and the 1978 MIRIS Land Use dataset. Event mean concentration values were re-calculated by weighting High Density Urban land use area using the above ratio.

(6) The High Density Residential land use range nationwide is from 50–100 percent imperviousness: the land use category determined from the Rouge River study defined it as high-rise apartment and condominium buildings that are four or more stories in height. These structures when combined with adequate parking reflect commercial or industrial land use category values.

3. Baseline Results for Urban Areas

3.1 Urban Areas in the Paw Paw River Watershed

Figure 1 shows that only two out of 17 subwatersheds may be considered urban, with urban land use being greater than 10% of the area. These subwatersheds are centered around the cities of St Joseph/Benton Harbor and Coloma/Watervliet. Three additional subwatersheds (around the Village of Paw Paw, and on the outskirts of Benton Harbor and Coloma) may be classified as urbanizing, with urban land uses representing between 8 and 10% of the area. Land use breakdowns, by subwatershed, are shown in Table 5.

Figure 1: Percentage of urban land use per 14-digit HUC subwatershed (based on 2001 IFMAP land use).

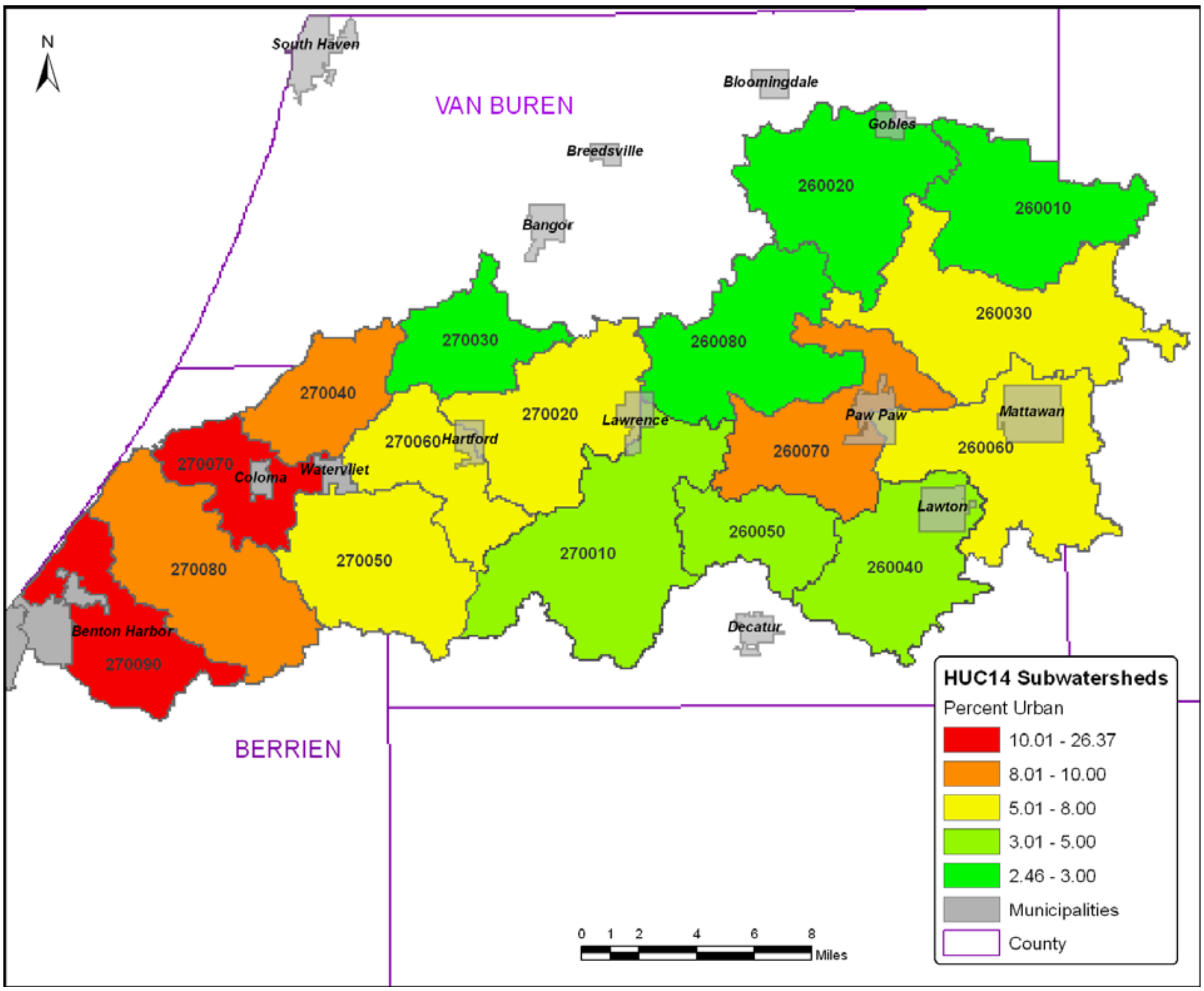


Table 5: 2001 land use breakdown (%) per subwatershed.

HUC	Watershed Name	Low Density	High Density	Transport.	Urban Open	Total Urban	Forest	Rural Open	Agriculture	Wetlands	Water
260080	Paw Paw River	0.28	0.00	2.63	0.00	**2.91**	17.88	8.94	46.92	22.59	0.76
260020	Brandywine Creek	0.47	0.13	1.86	0.00	**2.46**	16.42	9.77	57.05	13.83	0.47
260010	N. Br. Paw Paw River	0.84	0.15	1.84	0.00	**2.83**	29.69	9.56	32.21	24.71	0.99
270010	Brush Creek	1.05	0.75	2.66	0.00	**4.46**	16.04	8.72	55.74	14.44	0.60
260050	Eagle Lake Drain	1.07	0.27	2.28	0.00	**3.62**	14.77	3.62	66.31	7.25	4.43
270030	Mud Lake Drain	1.31	0.26	1.05	0.00	**2.62**	17.06	6.56	56.17	14.44	3.15
260040	S. Br. Paw Paw River	1.34	0.71	1.89	0.00	**3.93**	19.97	9.12	53.54	13.44	0.00
270050	Mill Creek	1.35	0.28	4.47	0.00	**6.11**	10.58	7.10	64.56	11.58	0.07
270020	Paw Paw River	1.54	0.44	3.82	0.00	**5.80**	20.56	10.57	46.33	16.30	0.44
260060	E. Br. Paw Paw River	1.65	1.34	4.45	0.00	**7.43**	33.82	12.74	35.16	10.18	0.67
260030	N. Br. Paw Paw River	1.65	0.72	2.97	0.00	**5.34**	32.60	12.28	37.61	12.00	0.17
260070	S. Br. Paw Paw River	2.10	1.25	5.85	0.00	**9.20**	18.39	7.87	44.58	16.91	3.04
270060	Paw Paw River	2.64	0.77	3.85	0.00	**7.26**	12.76	8.03	54.13	17.82	0.00
270080	Paw Paw River	2.66	0.63	5.01	1.33	**9.63**	16.60	10.27	53.30	10.20	0.00
270040	Paw Paw Lake	3.44	1.02	4.72	0.00	**9.18**	19.39	11.35	35.71	16.33	8.04
270070	Paw Paw River	5.37	2.42	5.50	0.00	**13.29**	17.18	10.87	45.23	13.42	0.00
270090	Paw Paw River	8.11	5.97	12.29	0.00	**26.37**	18.43	16.13	30.89	8.19	0.00

3.2 Pollutant Load and Runoff Results

Figures 2 to 5 show sediment, TP and TN baseline loading, and runoff volume, for each subwatershed. While these results should not be directly compared to the SWAT modeling results (as explained in box below), results from this analysis highlight similar subwatersheds with relatively high loading values. These results reflect the importance of soils and land uses (in particular row crops and urban) in pollutant load export.

The discrepancies between SWAT baseline loading values and the empirical model results can be explained by different modeling characteristics:

- *The empirical model represents land use distributions accurately while SWAT omits land uses covering less than 13% of each subwatershed. In particular, small urban areas were often not simulated using SWAT. The empirical model allows direct comparison of pollutant loads by land use between subwatersheds.*
- *SWAT incorporates additional parameters in loading equations such as slope, groundwater flow, land management practices, and pollutant uptake and deposition. Calculated loads include both particulate and dissolved forms. SWAT more accurately simulates the hydrologic cycle and the fate and transport of pollutants. The empirical model can only account for loads delivered from surface runoff.*
- *SWAT was calibrated for flow, and coarsely assessed for nutrients. The empirical model was not calibrated; event mean concentrations used in this analysis are averages used for Michigan that may not accurately describe conditions within the Paw Paw River Watershed.*

Figure 2: Sediment loading (lbs/ac) per subwatershed.

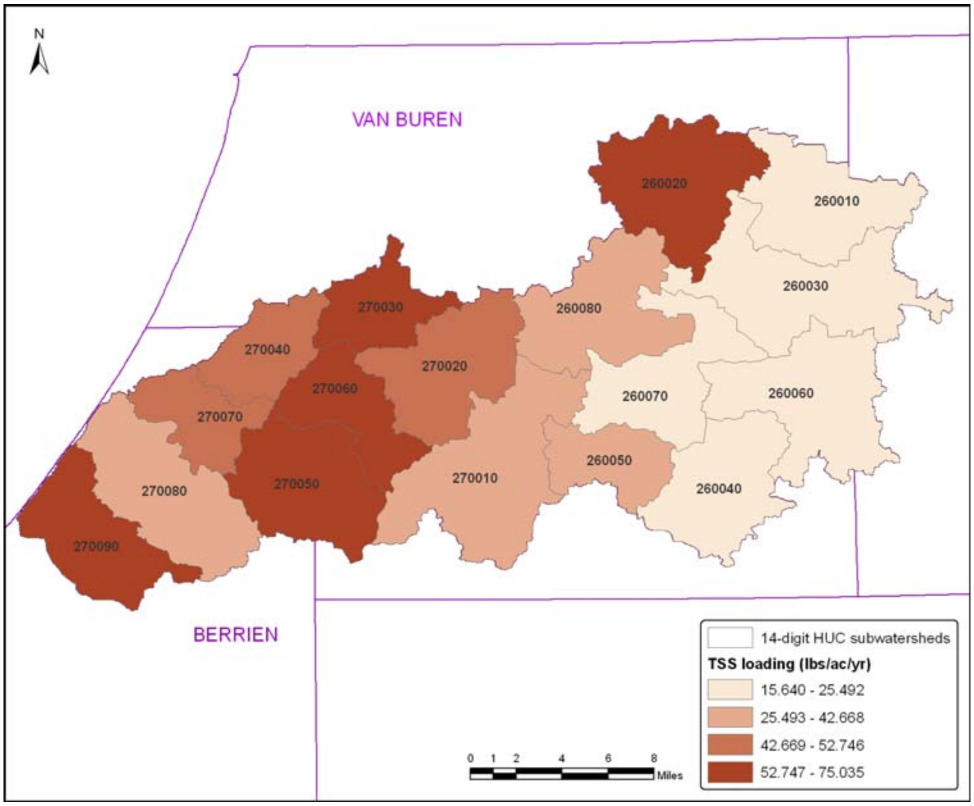


Figure 3: Total phosphorus loading (lbs/ac) per subwatershed.

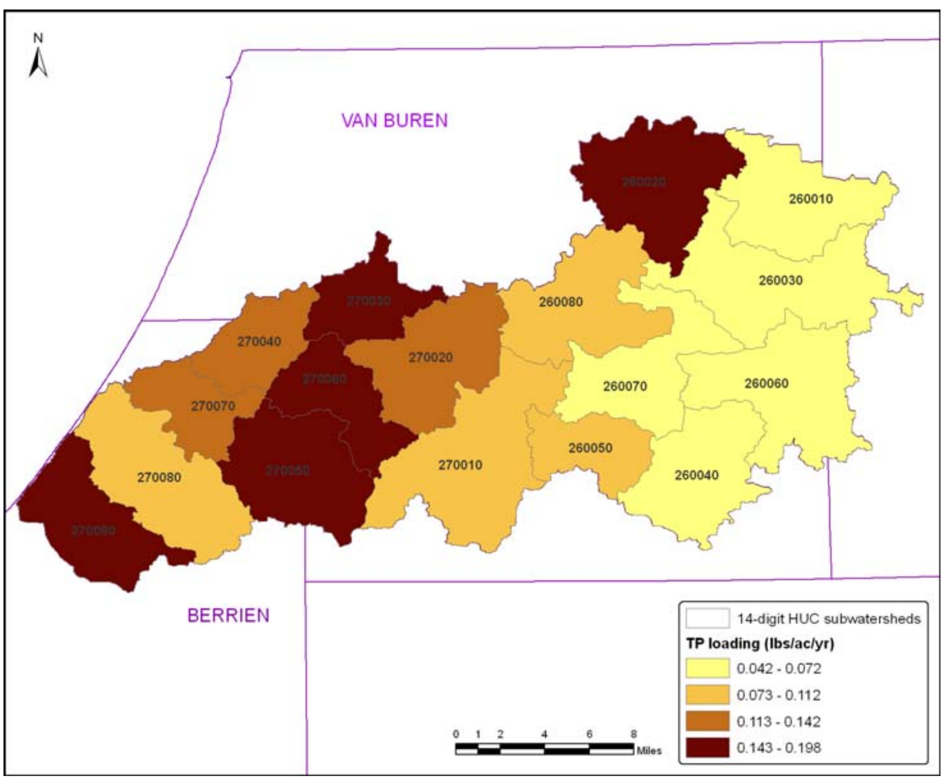


Figure 4: Total nitrogen loading (lbs/ac/year) per subwatershed.

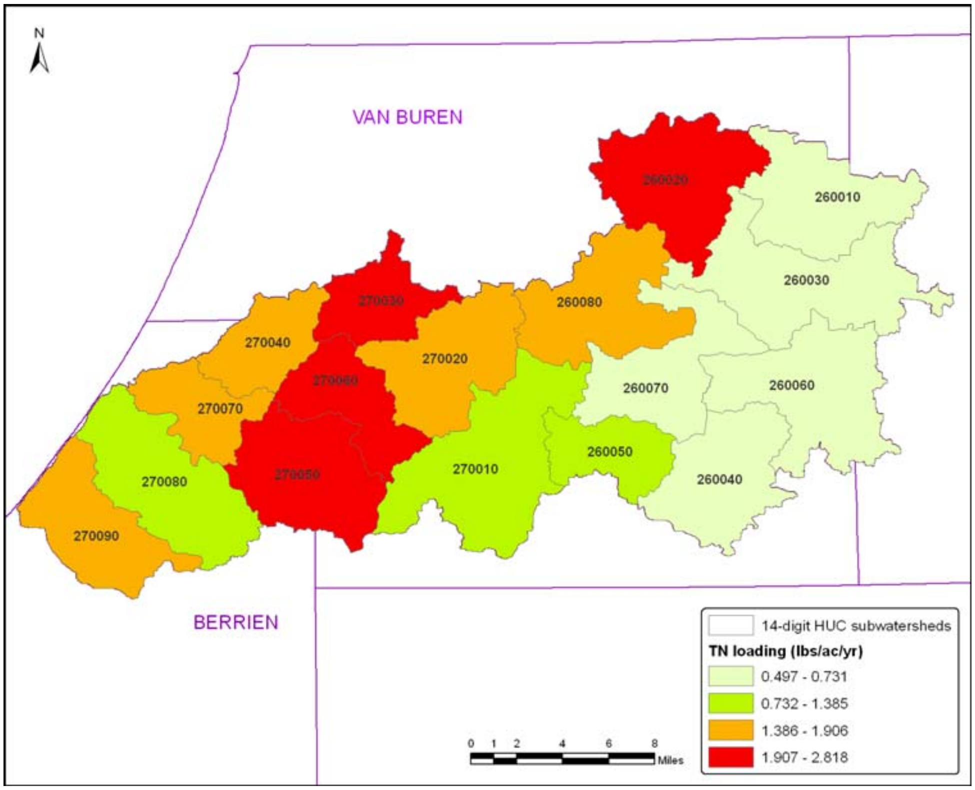


Figure 5: Runoff volume (in acre-feet/year) per subwatershed.

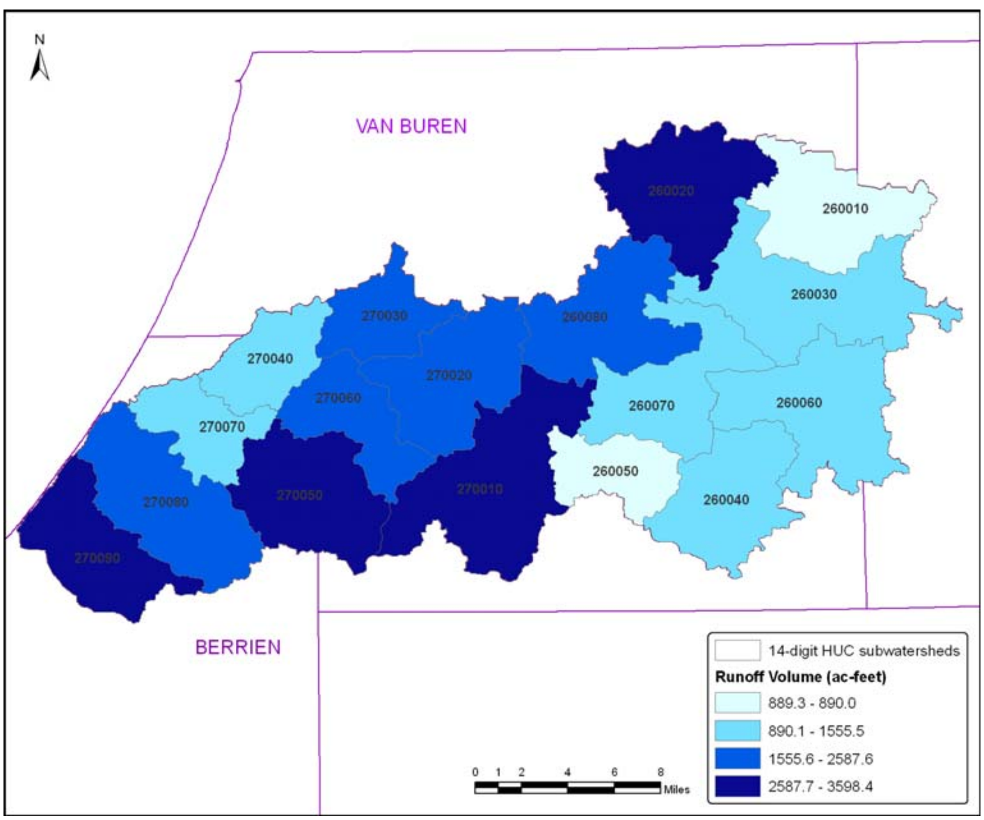
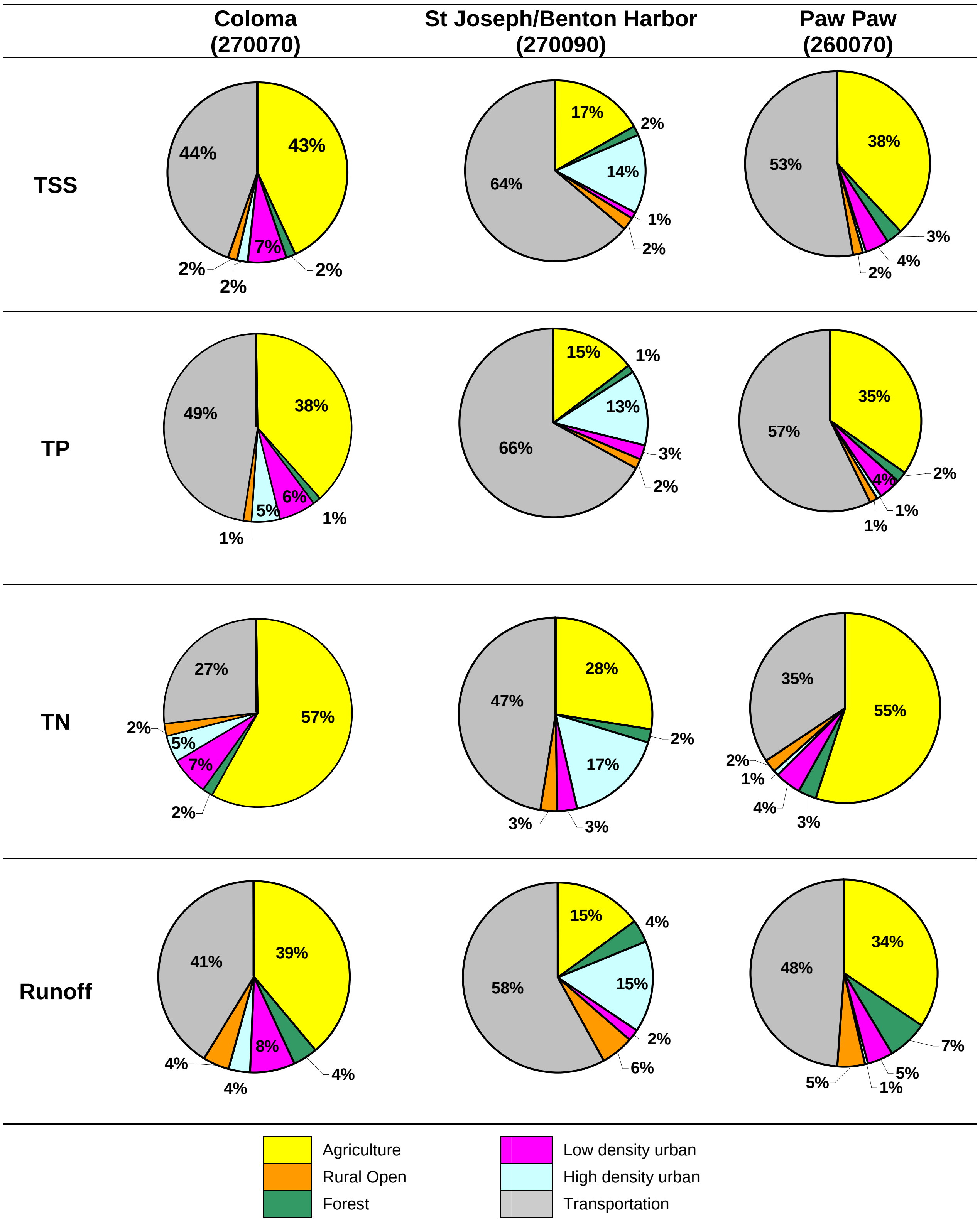


Figure 6 shows pollutant loading and runoff volume distributions per land use category for the urban subwatersheds in the Paw Paw River Watershed. The charts clearly indicate that urban land uses (in particular transportation) contribute disproportionately high loads of TP, TN and TSS when compared to the fraction of the area they occupy. In fact, urban areas contribute greater than 50% of TP load in all three subwatersheds but only occupy between 9 to 26% of the total acreage. In the St Joseph/Benton Harbor subwatershed (the most urban of the three), transportation accounts for 66% of the TP load and only 12% of the acreage. It is clear that treatment of urban stormwater runoff is crucial for reducing TP and TSS loadings in these subwatersheds.

Figure 6: Total load (in lbs/yr) and runoff volume per land use per urban subwatershed



4. Build-out Modeling Tool and Scenarios

4.1 Build-out Rules

The build-out analysis was based on detailed Future Land Use maps compiled by SWMPC from township masterplans when available. Four build-out scenarios were defined to simulate increasing rates of urban development (25%, 50%, 75% and 100%) and were based on the zoned land use category (called Future Land Use). Within each scenario, SWMPC specified rules based on current and future land uses that either: allowed, prohibited or limited development (see narrative below and Table 6).

<u>Build-out rules narrative</u>

For each build-out scenario, and within a defined polygon (subwatershed, township, village, etc.):

- Certain land uses cannot be changed (i.e., be built-out): water, protected lands, utility easements, cemeteries.
- Regulated wetlands will be built out at a lower rate than the scenario's rate (as defined by SWMPC - 25% in complete build-out – see Table 6).
- When two rules apply to a defined polygon (e.g., Rural Residential or Agricultural Future Land Use within a wetland), the build-out rates will be compounded, e.g., 6.25% (wetland rate) x 6.25% (agricultural rate) = 0.0039% (final build-out rate).
- Build-out change (for instance, increase in low density residential) will be distributed equally among the remaining land use categories (except when wetlands are present – see item 2). The total area changed will correspond to 25%, 50%, 75%, and 100% of the area of Future Land Use polygons.
- Build-out can only occur from a non-urban or lower urban category to a higher urban category (see classes and rules in Table 6). For instance, highways or high density residential cannot be changed to low density residential, but low density residential can be changed to high density residential.

Table 6: Future Land Use build-out rules defined by SWMPC.

Class		Scenario 1	Scenario 2	Scenario 3	Complete Build Out
	NO CHANGE LAYER: Hydro, SWMPC Protected Lands, Cemeteries, Utility Easements	**25.00%**	**50.00%**	**75.00%**	
	Water	100% IFMAP	100% IFMAP	100% IFMAP	100% IFMAP
	Protected Lands	100% IFMAP	100% IFMAP	100% IFMAP	100% IFMAP
	Utility Easements	100% IFMAP	100% IFMAP	100% IFMAP	100% IFMAP
	Cemeteries	100% IFMAP	100% IFMAP	100% IFMAP	100% IFMAP
	INTERMEDIATE LAYER:				
	Regulated Wetlands	6.25% FLU; 93.75% IFMAP	12.5% FLU; 87.5% IFMAP	18.75% FLU; 81.25% IFMAP	25% FLU; 75% IFMAP
Class	**FUTURE LAND USE (FLU)**				
1	Urban Open	25% Urban Open; 75% IFMAP	50% Urban Open; 50% IFMAP	75% Urban Open; 25% IFMAP	100% Urban Open
1	Agricultural	6.25% LD Res; 93.75% IFMAP	12.5% LD Res; 87.5% IFMAP	18.75% LD Res; 81.25% IFMAP	25% LD Res; 75% IFMAP
1	Rural Res	8.25% LD Res; 91.75% IFMAP	16.5% LD Res; 83.5% IFMAP	24.75% LD Res; 75.25% IFMAP	33% LD Res; 67% IFMAP
2	Low Density Residential	25% LD Res; 75% IFMAP	50% LD Res; 50% IFMAP	75% LD Res; 25% IFMAP	100% LD Residential
2	Medium Density Residential	25% MD Res; 75% IFMAP	50% MD Res; 50% IFMAP	75% MD Res; 25% IFMAP	100% MD Residential
2	High Density Residential	25% HD Res; 75% IFMAP	50% HD Res; 50% IFMAP	75% HD Res; 25% IFMAP	100% HD Residential
2	Commercial	25% Commercial; 75% IFMAP	50% Commercial; 50% IFMAP	75% Commercial;25% IFMAP	100% Commercial
2	Industrial	25% Industrial; 75% IFMAP	50% Industrial; 50% IFMAP	75% Industrial; 25% IFMAP	100% Industrial
2	Highways	25% Highways; 75% IFMAP	50% Highways; 50% IFMAP	75% Highways; 25% IFMAP	100% Highways
2	Transportation Corridor	100% IFMAP	100% IFMAP	100% IFMAP	100% IFMAP

Class	**IFMAP LAND COVER**
1	Water/Wetlands
1	Forest/Rural Open
1	Urban Open/Parks
1	Agricultural
2	Low Intensity Urban
3	High Intensity Urban
3	Transportation/Highways

RULES (apply in ALL scenarios):

When NO CHANGE LAYER features are present, loading values are based on IFMAP land cover.
When INTERMEDIATE LAYER features are present, build-out occurs at rates specified above.
When FLU is Class 1 and IFMAP land cover Class is >= 2, loading values are based on IFMAP land cover.
When IFMAP land cover is Class 3 loading values are based on IFMAP land cover.

4.2 Build-out Modeling Results

The build-out analysis for the 25, 50, 75, and 100% scenarios were conducted using the statistical program "R", an open-source code-based language. All records from the base build-out GIS layer were imported into R. For each scenario, new fields were created for: new land use acreage, remaining land use acreage, new TP/TN/TSS loads, and new runoff volume. The land use from each unique record (i.e., polygon in the GIS layer) was converted to the identified, zoned future land use as reported by SWMPC and according to the build-out rules. New and remaining land use acreage were calculated based on the build-out rules and the percent build-out scenario. Regulated wetlands were treated differently from other land use categories and were built out at lower rates than the specified scenario build-out percentage (see build-out rules). Similarly, agricultural and rural residential future land use categories were built out at lower rates than other land use categories. If the future land use category was either agricultural or rural residential, but also a regulated wetland according to the 2001 land use, build-out rates were compounded to result in an even lower build-out rate. For each record, loading and runoff values were calculated for both the amount of land in the new land use category, and the amount of land remaining in the original land use category. All new fields and results created in R were joined to the original GIS layer to allow analysis at different geographical scales. In the following example, loads and runoff volumes were summed, per subwatershed, for the hypothetical 25% build-out scenario. Total pollutant load and runoff results per 14-digit HUC subwatershed are presented in Appendix A.

Figure 7 to 10 present the impact of a 25% build-out rate on runoff and pollutant loads per subwatershed. The results clearly show that subwatersheds with the greatest percentage of urban areas are, in general, experiencing the highest increase in nutrient and sediment loads, and runoff volume. Overall, most subwatersheds will experience some varying amount of increase in loading and runoff volume. A few of the subwatersheds (#260050 and #260040, to the south of the Village of Paw Paw) do not experience increases in loads or runoff volume and may have reduced loading and runoff volume. This result can be explained by: 1) the presence of dual hydrologic soil group (A/D) which are modeled as D soil group (i.e., high runoff potential) for undeveloped land uses (e.g., forest) and as A soil group (i.e., high infiltration) for developed land uses (e.g., agriculture or residential)[3], and 2) build-out from agricultural land use to rural residential or low density residential land use (these land use categories have lower curve numbers than agricultural land use).

[3] See Michigan Department of Environmental Quality "Calculating Runoff Curve Numbers with GIS" available at: http://www.michigan.gov/deq/0,1607,7-135-3313_3684_3724-112833--,00.html

Figure 7: Percentage change in TSS load per subwatershed under the 25% build-out scenario.

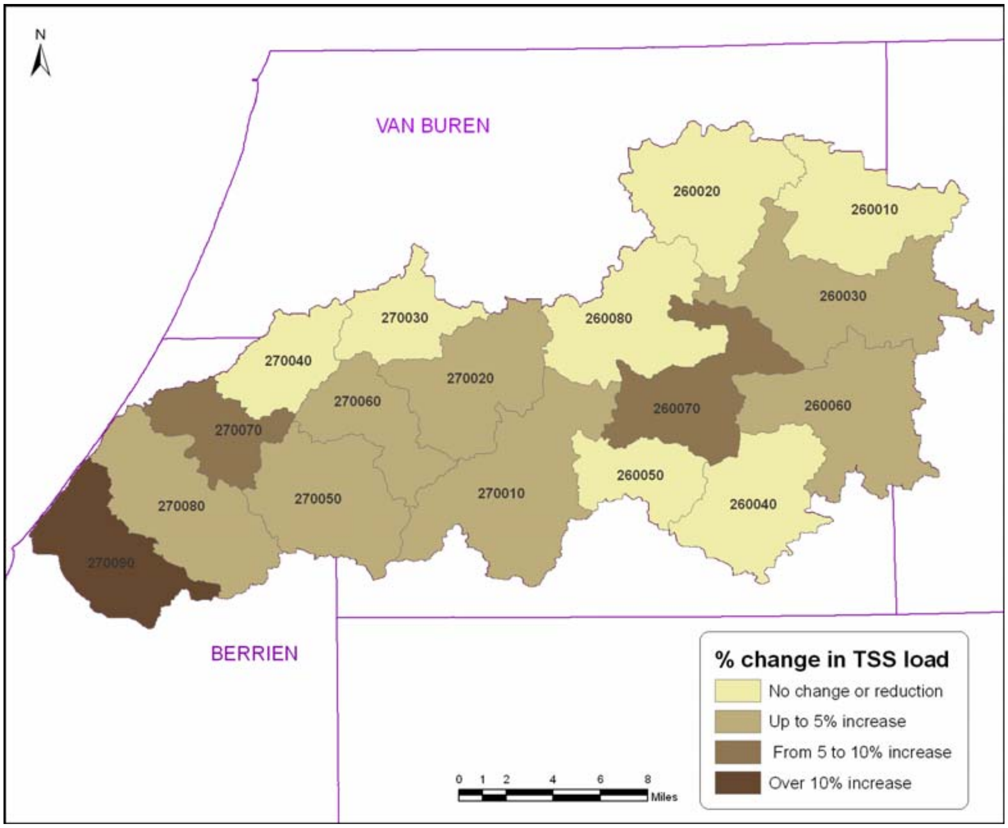


Figure 8: Percentage change in TP load per subwatershed under the 25% build-out scenario.

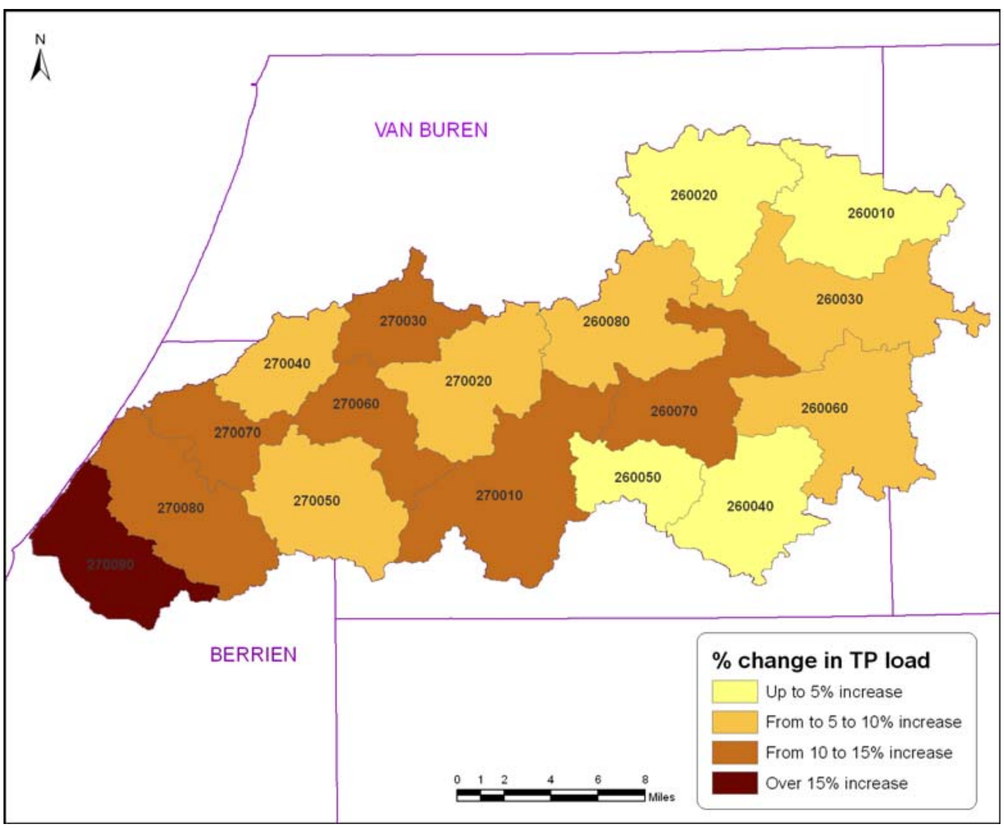


Figure 9: Percentage change in TN load per subwatershed under the 25% build-out scenario.

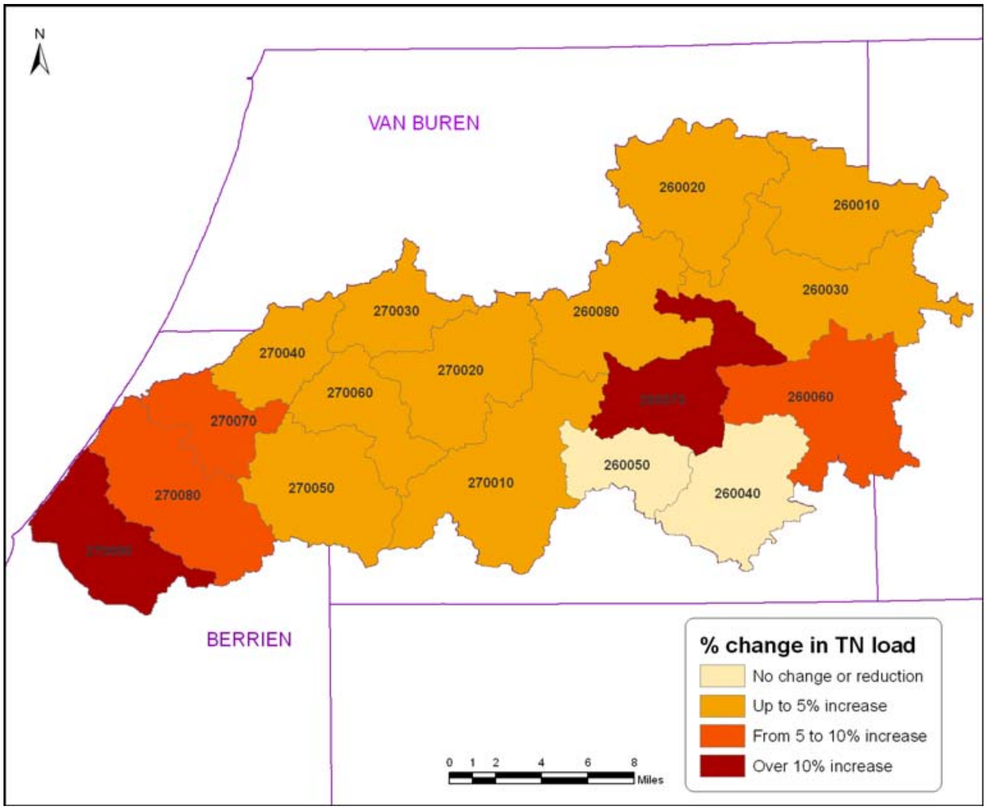
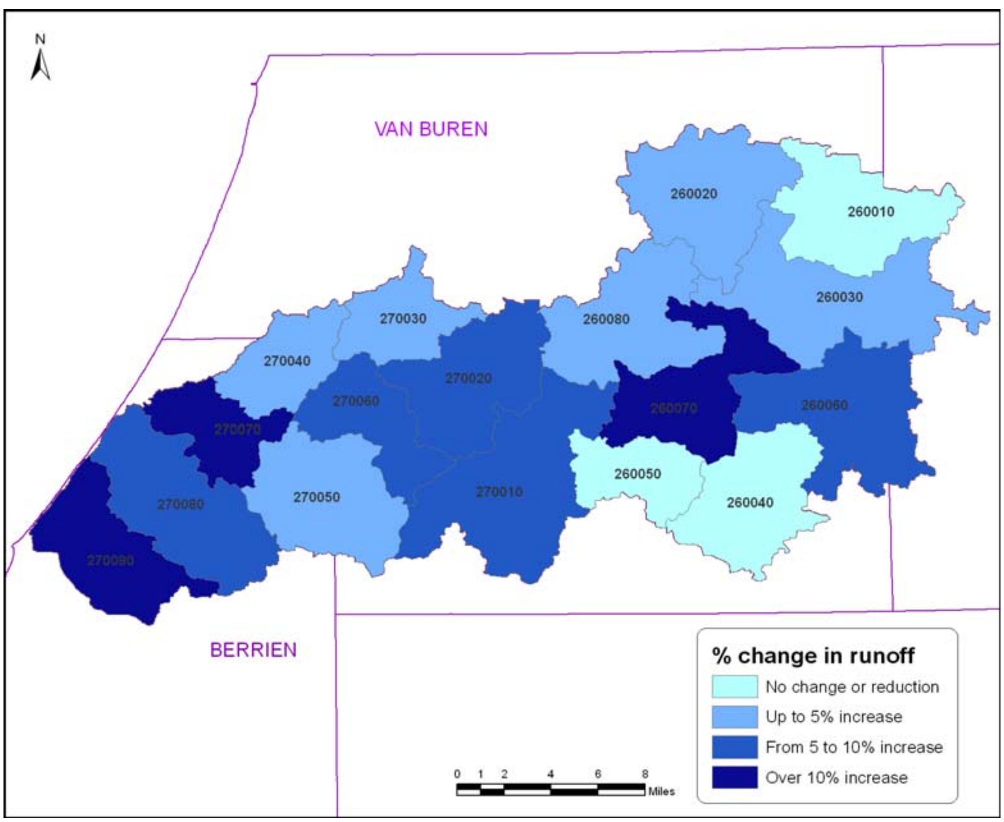


Figure 10: Percentage change in runoff volume per subwatershed under the 25% build-out scenario.

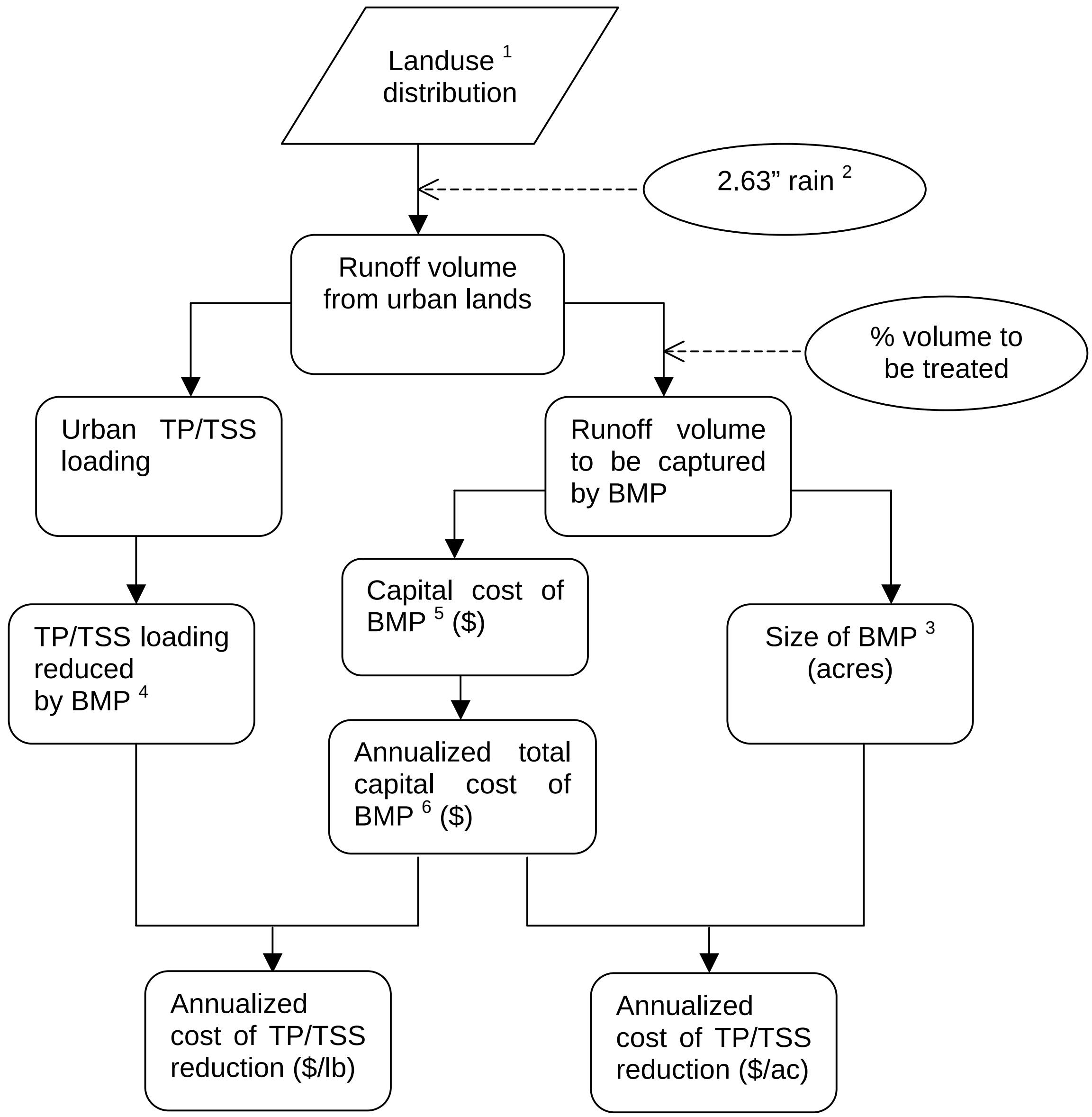


5. Modeling Urban Stormwater Best Management Practices

5.1 Methods

The overall analysis methodology is represented in the flow chart below.

Figure 11. Flow Chart of Urban Stormwater BMP Cost Calculations.



[1] 2001 IFMAP
[2] Equivalent to a one-hour 100-year or a 24-hour 2-year rain event for the Paw Paw 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.

5.2 Selected Stormwater Best Management Practices

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 opportunities 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).

- Retention/detention pond: 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 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. However, to achieve a higher and more consistent pollutant removal, ponds with larger holding capacities are necessary. In this study, a 2.63-inch rain depth representing a 24-hour, 2-year or 1-hour, 100-year storm event in the Paw Paw 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. The runoff associated with the 2.63-inch rainfall was calculated using L-THIA and the pond volume was calculated using MI Trading Rules 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).

- Vegetated swales: Generally agreed design criteria for the size of a swale in relation to treated area could not be found. According to a fact sheet produced by the Center for Watershed Protection[4], 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.

- Rain garden: 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 that only runoff from the impervious portion of urban land uses in a subwatershed is treated with rain gardens. This is a reasonable assumption since rain gardens are mainly used to treat runoff from parking lots, roadways, and rooftops in urban areas. Because of restrictions on where rain gardens can be built in an urban watershed where private properties dominate, rain gardens can only achieve about 5-15% in runoff flow reduction[5]. Therefore, a maximum treatment coverage of 15% of the impervious area in a watershed was assumed in this study.

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[4] Available at: http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/Open%20Channel%20Practice/Grassed%20Channel.htm

[5] See K&A field data at: http://www.kalamazooriver.net/pa319new/docs/handouts/downspout_survey.pdf, and Wade-Trim Detroit Study at: http://www.wadetrim.com/resources/pub_conf_downspout.pdf

- Constructed Wetlands: 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 to calculate 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 calculated in section 3b were used. Load reduction efficiencies achieved by treatment ponds and swales were obtained from the Michigan Water Quality Trading Rule (MI-ORR, 2002) and are shown in Table 7. Total load reductions for a treated urban area were then calculated by multiplying total annual loads from the treated area by load reduction efficiencies in Table 7.

Table 7: Treatment efficiencies of stormwater BMPs.

	TP	TSS
Wet retention pond	90%	90%
Dry detention pond	30%	90%
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 8).

Table 8: Costs of stormwater treatments.

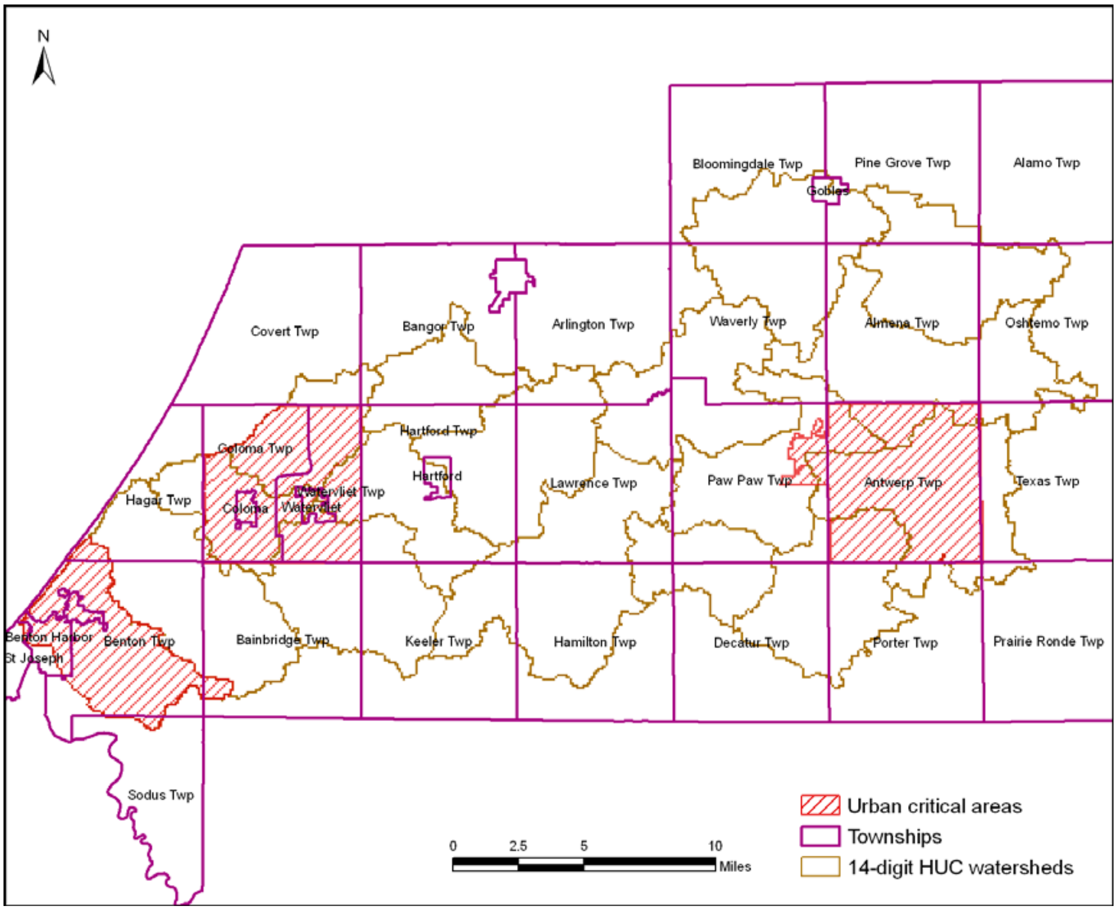
	Construction [1]	Design & Permits [1]	Maintenance
Wet retention pond	$0.50 – 1.00/cubic ft	30% construction	$4,825/ac/yr [2]
Dry detention pond	$0.40 – 0.80/cubic ft	30% construction	$4,825/ac/yr [3]
Vegetated swale	$0.30/sq. ft	--	$0.02/sq. ft/yr
Rain garden	$11/sq. ft [4]	--	--
Constructed wetland [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 2007 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)

Best management practices were applied to the three most urban areas in the watershed (Figure 12) defined as follows:

- Ox Creek Area: corresponds to subwatershed 270090 (Benton Harbor/St Joseph).
- Paw Paw Lake Area: includes the townships of Coloma and Watervliet, the village of Watervliet and the city of Coloma.
- Antwerp township and the village of Paw Paw.

Figure 12: Selected urban areas for stormwater best management practices.



5.3 *Results*

Table 9 shows the pond holding capacity (volume) that each subwatershed would need and the associated costs and load reductions if wet retention ponds were built to treat 50% of the runoff from selected urban areas. Table 10 shows the same set of results for dry detention ponds. Table 11, 11, and 12 illustrate similar results (except pond volumes) for vegetated swales, rain gardens, and constructed wetlands, respectively. In terms of load reductions, wet retention ponds (Table 9) and constructed wetlands (Table 13) are the most effective, giving total TP reductions of almost 5,000 lbs and TSS of over 1.5

million lbs for all areas selected[6]. Rain gardens, due to the limitations on treatment coverage (15% of impervious area), yielded reductions of 814 lbs of TP and less than 300,000 lbs of TSS.

Due to the greater treatment efficiencies (Table 7) and comparable costs (Table 8), **wet retention ponds** are more cost-effective stormwater treatment structures than **dry detention ponds**. It costs on average $55 to reduce one pound of phosphorus over a 30-year period (the assumed life of these structures) for wet retention ponds, compared to $140 for dry detention ponds. The cost-effectiveness for TSS is $0.17/lb for wet retention ponds and $0.26/lb for dry detention ponds.

Compared to detention ponds, **vegetated swales**, with average costs of $56/lb TP and $0.09/lb TSS, have the highest cost-effectiveness for TSS (Table 11) of all the BMPs, and are as cost-effective as wet retention ponds for TP. Clearly, the lower per unit cost of constructing swales makes this BMP an attractive option for high investment returns. Caution should be taken in using these per pound reduction costs in the context of watershed pollutant load reduction planning, and particularly in comparison with other BMPs such as stormwater ponds. This is mainly due to: 1) the uncertainties on the required size of vegetated swales (see the Methods section); 2) the non-specific nature of the load reduction efficiency values used in this study (MI-ORR, 2002) [7]; and 3) the fact that vegetated swales are often used as a pretreatment or conveyance device for stormwater ponds in stormwater management designs which indicate the intermediate nature of vegetated swales as a stormwater BMP. Moreover, swales require additional right of way and therefore, are not always practical as a primary stormwater treatment strategy. Vegetated swales also have limited capabilities for groundwater recharge. The ability to construct ponds in select areas as a regionalized treatment device combined with a smaller overall footprint and groundwater recharge capabilities, make ponds an attractive option especially when considering their effectiveness for pollutant and hydraulic mitigation. A treatment train combining these options could also be considered.

Calculations for **rain gardens** suggest that this practice is very expensive (Table 12) compared with other BMPs. At an average per pound cost of $6,936 for TP and $21.24 for TSS, to achieve the same level of treatment would cost over a hundred times more than wet retention ponds and vegetated swales for TP, and several times higher for TSS. Only reducing the installation cost of rain gardens to $3/sq. ft.[8], can lower the per pound cost to $1,836 for TP and $5.64 for TSS. These values 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. 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.

[6] Due to the assumptions made on load reduction efficiencies (see the Method section and Table 7), constructed wetlands and wet retention ponds have the same load reductions.

[7] 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.

[8] 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).

Rain garden applications will be most effective with new construction. Retrofit requirements with existing infrastructure make it a difficult to sell this approach to sufficient number of private landowners.

At $542/lb of TP and $1.66/lb of TSS, **constructed wetlands** (Table 13) show lower per pound costs than wet retention ponds but much higher costs than vegetated swales. The cost differences between constructed wetlands and wet retention ponds lie mainly on the much lower maintenance cost for wetlands ($850/ac/yr compared to $4,825/ac/yr for wet retention ponds). On the other hand, wet retention ponds occupy a much smaller area (7 acres in total for all selected areas) than constructed wetlands (308 acres) due to the greater depth of the ponds (up to 5 feet vs <1 ft).

Because land purchase expenses were not considered in calculations for Table 9 through 13, 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 footprint for wetlands must ultimately be considered for any stormwater treatment strategy.

Table 9: Wet retention pond pollutant treatment costs with a 50% treatment coverage of urban lands.

	Pond Volume	**Pond 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	ft^3	acre	lbs/yr	lbs/yr	$	$/yr	$/lbs/yr	$/lbs/yr
Ox Creek Area (Benton Harbor)	749,559	3.4	1,086	358,988	730,820	64,147	59	0.18
Paw Paw Lake Area (Watervliet/Coloma)	432,260	2.0	827	260,349	421,454	36,992	45	0.14
Antwerp Twp/Village of Paw Paw	375,987	1.7	529	174,787	366,588	32,177	61	0.18
Total/Average	*1,557,807*	*7*	*2,441*	*794,124*	*1,518,862*	*133,316*	*55*	*0.17*

[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 10: **Dry detention pond pollutant treatment costs with a 50% treatment coverage of urban lands.**

	Pond Volume	Pond 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	ft^3	acre	lbs/yr	lbs/yr	$	$/yr	$/lbs/yr	$/lbs/yr
Ox Creek Area (Benton Harbor)	749,559	3.4	362	199,438	584,656	38,033	151	0.27
Paw Paw Lake Area (Watervliet/Coloma)	432,260	2.0	276	144,639	337,163	21,933	114	0.22
Antwerp Twp/Village of Paw Paw	375,987	1.7	176	97,104	293,270	19,078	156	0.28
Total/Average	*1,557,807*	*7*	*814*	*441,180*	*1,215,089*	*79,043*	*140*	*0.26*

[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 $4,825/acre/year maintenance cost.

Table 11: Vegetated swale pollutant treatment costs with a 50% treatment coverage of urban lands.

	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	acre	lbs/yr	lbs/yr	$	$/yr	$/lbs/yr	$/lbs/yr
Ox Creek Area (Benton Harbor)	15.0	483	319,101	196,498	25,882	54	0.08
Paw Paw Lake Area (Watervliet/Coloma)	9.7	367	231,422	126,293	16,635	45	0.07
Antwerp Twp/Village of Paw Paw	9.2	235	155,366	120,672	15,895	68	0.10
Total/Average	*34*	*1,085*	*705,888*	*443,462*	*58,412*	*56*	*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 12: Rain garden pollutant treatment costs with a 15% treatment coverage of urban lands

	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	acre	lbs/yr	lbs/yr	$	$/yr	$/lbs/yr	$/lbs/yr
Ox Creek Area (Benton Harbor)	80.9	362	119,663	38,758,220	2,521,270	6,967	21.07
Paw Paw Lake Area (Watervliet/Coloma)	46.1	276	86,783	22,103,183	1,437,839	5,218	16.57
Antwerp Twp/Village of Paw Paw	48.8	176	58,262	23,360,056	1,519,600	8,624	26.08
Total/Average	*176*	*814*	*264,708*	*84,221,459*	*5,478,709*	*6,936*	*21.24*

[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 15% of impervious urban lands.
[2] Construction cost.
[3] Assuming a 5% interest rate

Table 13: Constructed wetland treatment costs with a 50% treatment coverage of urban lands.

	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 enter	acre	lbs/yr	lbs/yr	$	$/yr	$/lbs/yr	$/lbs/yr
Ox Creek Area (Benton Harbor)	141.9	1,086	358,988	7,237,334	591,420	545	1.65
Paw Paw Lake Area (Watervliet/Coloma)	80.9	827	260,349	4,127,334	337,277	408	1.30
Antwerp Twp/Village of Paw Paw	85.5	529	174,787	4,362,030	356,456	674	2.04
Total/Average	*308*	*2,441*	*794,124*	*15,726,697*	*1,285,153*	*542*	*1.66*

[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.

General equations can be derived from the calculations that lead to the outputs in Table 9 and 10 for the reduction capacity and cost of urban stormwater ponds for any area in the Paw Paw 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):

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

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).

<u>Equation 2:</u> 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) and all other parameters are as above.

<u>Equation 3:</u> Wet retention pond capital cost ($):[9]

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

<u>Equation 4:</u> Dry detention pond capital cost ($):[10]

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

<u>Equation 5</u>: Wet retention pond 30-year annualized unit TP reduction cost ($/lb/yr):[11]

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

[9] Construction cost + cost of design and permits.
[10] See Note 9.
[11] Assuming a 5% interest rate and an average pond depth of 5 feet, and including a $4,825/acre/year maintenance cost

Equation 6: Dry detention pond 30-year annualized unit TP reduction cost ($/lb/yr):[12]

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

Equation 7: Wet retention pond 30-year annualized unit TSS reduction cost ($/lb/yr):[13]

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

Equation 8: Dry detention pond 30-year annualized unit TSS reduction cost ($/lb/yr):[14]

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

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 of the Paw Paw River Watershed.

[12] See Note 11.
[13] See Note 11.
[14] See Note 11.

6. Conclusion

A GIS build-out tool was developed to allow analysis at any specified build-out rate and at any defined geographic scale within the Paw Paw River Watershed. Under the current land use, this study shows that urban storm runoff is the largest source of nutrient and sediment loads in urban subwatersheds. In addition, the analysis of a hypothetical 25% build-out scenario showed that urban subwatersheds would experience the greatest increase in pollutant loads and runoff volume. Therefore, it is important to control this source of loading if water quality in the Paw Paw River Watershed is to be maintained or improved.

Among the five urban BMPs examined (wet retention ponds, dry detention ponds, vegetated swales, rain gardens, and constructed wetlands), wet retention ponds and constructed wetlands provide the greatest load reductions for TP and TSS while vegetative swales are the most cost-effective (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. Other considerations should be evaluated, including limitations of vegetated swales and rain gardens for runoff flow reduction, and the feasibility of installing the required acreage in residential or high density urban areas.

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.

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APPENDIX A

Pollutant loads and Runoff Volume
per Subwatershed
under Build-out Scenarios

Table A- 1:Pollutant loads (in lbs/year) per subwatershed under build-out scenarios

	Baseline			25% buildout			50% buildout			75% buildout			100% buildout		
HUC14	TN	TP	TSS	TN	TP	TSS	TN	TP	TSS	TN	TP	TSS	TN	TP	TSS
4050001260010	8,545	721	268,881	8,607	757	261,109	8,684	794	253,525	9,137	861	253,530	10,097	979	261,072
4050001260020	48,354	3,472	1,312,343	49,060	3,633	1,306,265	49,793	3,796	1,300,500	51,033	4,004	1,308,918	53,008	4,293	1,332,171
4050001260030	12,299	1,111	403,855	12,682	1,202	404,912	13,074	1,293	406,061	14,318	1,457	429,448	16,619	1,724	477,462
4050001260040	12,133	1,013	374,936	11,833	1,041	361,917	11,534	1,070	348,912	11,955	1,150	356,930	13,057	1,290	383,244
4050001260050	12,135	899	336,942	11,640	899	316,620	11,148	900	296,314	11,015	921	285,542	11,159	964	280,484
4050001260060	13,268	1,323	467,520	14,031	1,449	479,880	14,794	1,575	492,242	16,495	1,783	530,224	19,346	2,105	596,988
4050001260070	12,342	1,210	430,317	13,638	1,384	462,617	14,940	1,559	494,982	17,197	1,832	554,495	20,700	2,245	648,048
4050001260080	29,447	2,112	806,022	29,858	2,232	794,074	30,305	2,355	782,573	31,428	2,536	788,038	33,489	2,815	811,112
4050001270010	36,438	2,740	1,025,122	38,230	3,039	1,037,190	40,049	3,341	1,049,577	42,846	3,743	1,086,159	47,081	4,310	1,151,434
4050001270020	34,100	2,517	943,853	35,318	2,759	947,712	36,550	3,003	951,694	38,734	3,336	982,654	42,204	3,811	1,043,612
4050001270030	28,283	1,989	752,997	28,571	2,217	702,258	28,868	2,447	651,612	30,191	2,748	630,660	32,678	3,164	630,401
4050001270040	16,058	1,412	503,656	16,858	1,548	499,820	17,665	1,684	496,017	18,918	1,863	501,115	20,777	2,111	514,685
4050001270050	49,293	3,536	1,328,626	50,219	3,736	1,333,351	51,181	3,941	1,338,447	52,670	4,185	1,363,238	55,002	4,513	1,411,300
4050001270060	29,711	2,221	826,373	31,026	2,478	838,681	32,357	2,737	851,178	34,446	3,075	886,447	37,627	3,544	948,382
4050001270070	14,819	1,376	481,769	16,285	1,575	512,563	17,760	1,775	543,449	19,762	2,037	589,495	22,549	2,396	655,771
4050001270080	24,765	2,204	787,027	26,267	2,441	797,861	27,776	2,680	808,754	30,187	3,010	840,223	33,767	3,479	893,958
4050001270090	25,474	2,930	1,006,625	29,564	3,388	1,121,486	33,655	3,846	1,236,352	39,445	4,494	1,404,262	47,684	5,421	1,646,028
Total	*407,464*	*32,786*	*12,056,863*	*423,688*	*35,778*	*12,178,315*	*440,132*	*38,793*	*12,302,190*	*469,776*	*43,036*	*12,791,377*	*516,846*	*49,164*	*13,686,153*

A- 2: Runoff volume (in acre-feet/year) per subwatershed under build-out scenarios

HUC14	Baseline	25%	50%	75%	100%
4050001260010	889	886	883	905	958
4050001260020	3,598	3,692	3,786	3,918	4,112
4050001260030	1,209	1,268	1,326	1,459	1,690
4050001260040	1,132	1,119	1,105	1,162	1,291
4050001260050	890	871	852	851	865
4050001260060	1,269	1,368	1,466	1,650	1,943
4050001260070	1,213	1,381	1,549	1,827	2,256
4050001260080	2,387	2,423	2,460	2,554	2,726
4050001270010	2,830	3,031	3,234	3,513	3,913
4050001270020	2,588	2,760	2,932	3,192	3,579
4050001270030	2,063	2,111	2,158	2,242	2,375
4050001270040	1,555	1,607	1,658	1,729	1,828
4050001270050	3,536	3,662	3,789	3,951	4,176
4050001270060	2,211	2,422	2,633	2,925	3,340
4050001270070	1,355	1,543	1,731	1,977	2,309
4050001270080	2,222	2,371	2,519	2,727	3,019
4050001270090	2,883	3,325	3,767	4,403	5,312
Total	*33,833*	*35,837*	*37,847*	*40,987*	*45,690*