Low Impact Development (LID)

in a Combined Sewer Overflow (CSO) District:

Evaluating the Effectiveness of LID in Reducing CSOs

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1. Executive Summary

Project Background

Many older communities have a drainage infrastructure which collects excess rainfall in addition to providing sanitary service to the public (i.e. Combined Sewer, or CS). This creates a problem when heavy rain events cause the system to overload or surcharge; often resulting in a discharge of excess wastewater being routed to local surface water. Federal Clean Water regulations and a public desire to prevent the Combined Sewer Overflows (CSO) during the past decades have initiated considerable effort from cities and industry. The City of Saginaw, in eastern mid-Michigan, is one example. Starting in the 1990's, the City's action to establish effective infrastructure did more than just meet regulations in the removal of pathogens and other nutrients before an overflow event. A post-construction study on the system found discharged wastewater to consistently meet Michigan's water quality standards for CSOs. In some of the events recorded, overflows were proven to meet or exceed certain treatment standards for the wastewater treatment plant.[i] Despite the advances, treated CSO wastewater still contains high levels of nutrients which negatively affect the downstream environment. New options should be investigated with the continued effort to eliminate CSOs. This is especially needed for cities like Saginaw, which has been economically depressed for several decades.

Low Impact Design (LID) is one option that has potential. LID, also called Low Impact Development, aims to deal with storm water "by using design techniques that infiltrate, filter, store, evaporate, and detain runoff close to its source."[ii] Some professional credit has recently been attributed to the usefulness of LID practices in dealing with CSOs, both in intercepting storm water and in removing harmful constituents. The City of Saginaw has good potential to implement LID, since it contains areas which are ripe for redevelopment.

In an effort to develop alternatives to combat the issue of CSOs, the Saginaw Bay Watershed Initiative (WIN) provided grant funding to study the use of Low Impact Design (LID) practices to mitigate CSO events. The study consisted of the creation of a computer model of a Combined Sewer District in the City of Saginaw. The model was used to develop scenarios where particular LID practices were implemented and the results of each simulation were compared. A more detailed explanation of the methods used, scenarios tested, and the results and findings of the study are included in the remainder of this report.

Method of Analysis

This study utilized a two-part analysis. The first part examined the reduction in volume to the CSO basin due to LID practices. It utilized the modeling software EPA SWMM to set up scenarios of LID Best Management Practices (BMPs) and estimate results. The second part used the web-based the Long-Term Hydrologic Impact Assessment (L-THIA) program to perform a scenario analysis on pollutant loading. L-THIA examined the affects of land use changes on the amount of pollutants in storm water runoff. This program was used to determine potential reductions in pollutants by utilizing LID.

Part I: CSO Volume Analysis

Hydrologic and hydraulic characteristics of the Fitzhugh CSO District were developed through field investigation and the study of digital resources. An EPA SWMM model was constructed to mimic existing conditions. It was calibrated by comparing the known CSO detention or discharge volume for a given rainfall event to the volume reported by the SWMM model; model adjustments were made to meet this criteria.

From the existing conditions model, nine scenarios were created to analyze various planning configurations and LID practices. These scenarios were each tested using four rain events. A total of thirty-six (36) model runs were executed. A brief description of each scenario is included below.

- Scenario 2a: Full build-out of residential areas in the form of ¼-acre parcels. Thirty (30) percent of residential areas redeveloped.
- Scenario 2b: Full build-out of residential areas in the form of ¼-acre parcels (similar to 2a). Each redeveloped parcel included a rain garden. Stormwater runoff from the roof of the house was routed to a rain garden, with the goal of increased infiltration or delay of peak runoff.
- Scenario 3a: Full build-out of residential areas in the form of 1/8-acre parcels (30% of residential areas redeveloped).
- Scenario 3b: Similar to 3a, but instead of complete build-out, half of the redeveloped areas consisted of open space. These green, open areas were designed to create runoff storage to delay peak flows and detain runoff volume.
- Scenario 4: Apartment buildings made up half of the redeveloped areas. The remaining area consisted of green. open areas, as in scenario 3b.
- Scenario 5: Redevelopment with ¼-acre parcels and rain gardens (as in Scenario 2b), plus retrofitted bio-swales for runoff from roads.
- Scenario 6: Redevelopment with apartment buildings and green areas (as in Scenario 4), plus retrofitted bio-swales for runoff from roads.
- Scenario 7: Implementation of vegetated roofing and bio-swales for parking lot runoff (specific sites selected).

Running each scenario under several runoff events allowed the comparison of LID practices based on hydrologic behavior. Conclusions were made as to the best LID practices for use in the Fitzhugh District. Implications for other CSO systems were also discussed.

Part II: Pollutant Loading Analysis

Existing land use characteristics (as determined in the EPA SWMM model) were utilized for the L-THIA analysis. The L-THIA model used a 30-year data set of rainfall to determine pollutant loadings with changing land use. Four scenarios were developed to model LID implementation in the Fitzhugh District.

Results and Conclusion

The City of Saginaw has the potential to effectively utilize Low Impact Development practices. The EPA SWMM scenario analysis of the Fitzhugh District estimated a potential decrease in CSO volume by as much as 20% (i.e. for 2- and 5-year storm events). The BMP which resulted in the largest offset of CSO events included routing storm water to large, open areas with storage capacity. Rain gardens were also effective in mitigating runoff from new residential developments. Other noteworthy gains were made through bio-swales, used for runoff from pavement surfaces, and green roofs in commercial districts.

Investing in LID in the City of Saginaw would result in a decrease in costs for the city as a return for a moderate investment of time (i.e. reduced costs in WWTP operation, life of infrastructure, and Retention Treatment Basin (RTB) maintenance and materials). Societal and monetary benefits, in addition to advances to the CSO system, make these methods beneficial and desirable.

In regard to future planning/development, construction and building ordinances, and improvements to the Combined Sewer Overflow system, the City of Saginaw should take into account various LID practices and goals. Some states have seen the publication of technical guides on Low Impact Design/Development for communities and professionals to use. Michigan is one such state and a well developed design manual and guidelines are available at:

http://www.semcog.org/LowImpactDevelopment.aspx

As determined in this study, such consideration has potential to be part of a comprehensive solution to meet environmental standards while contributing to community aesthetics, and improving the overall health of the watershed.

2. Introduction

Project Background and Location

Many older communities have a sewer infrastructure which collects excess rainfall in addition to providing sanitary service to the public (i.e. Combined Sewer, or CS). All contributing flows are ideally routed to the local wastewater treatment plant, however many rain events cause the system to overload. The overload results in the discharge of treated wastewater that meets the discharge criteria as set forth in the City of Saginaw's NPDES discharge permit. The growth of urbanized areas and consequently, increased impervious surfaces, cause increases in runoff volumes during precipitation events. The volume increase is related to little or no infiltration before stormwater runoff is collected. The flow of wastewater generated during storm events can exceed the capacity for treatment processes at the local wastewater treatment plant (WWTP). In the past, untreated excess flows would be discharged from the Combined Sewer system (CS) into a nearby body of water. Since the 1990's, regulation has spurred efforts to reduce and eliminate the amount of raw sewage being discharged. Billions of dollars in money and effort have been spent to curb this issue nationwide. Many innovative engineering solutions have been effective, both in reducing Combined Sewer Overflows (CSOs) and in treating overflows before they reach water bodies.

The City of Saginaw is located in eastern mid-Michigan. It is situated along the Saginaw River, which flows into the Saginaw Bay (i.e. Lake Huron). The city's sewer network is composed primarily of combined sewer, which currently serves about 56,000 residents[iii] in a 10,000 acre area. The City's sewers discharge to the Saginaw Wastewater Treatment Plant (WWTP), which is located north of the city. The current system is divided into seven CSO Districts, each of which has a CSO Facility, also referred to as a Retention Treatment Basin (RTB). Each CSO District represents a specific sewer drainage system (i.e. sewershed), which collects household sanitary waste, as well as stormwater runoff. The combined flow from each District is routed to

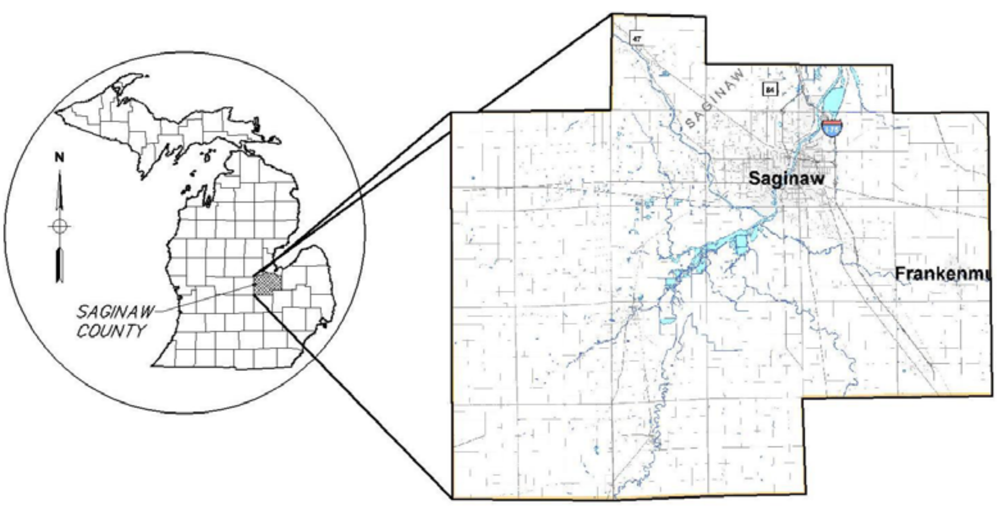

Figure 1: Location Map

the WWTP interceptor sewers, which are aided by pump stations located throughout the City.

When the capacity of interceptor sewers are exceeded during storm events, excess flow is routed to the respective district's RTB. Wastewater remaining in the RTB after a rain event is designed to re-enter the interceptor system and flow to the WWTP for treatment before discharge. Of course, the basin has a limited capacity and in the case of a large enough storm event, the RTB is designed to treat the excess volume and discharge the treated wastewater to the Saginaw River. The treated wastewater effluent from the City of Saginaw CSO system has been proven to meet primary treatment standards before being discharged, meaning that many constituents have been removed.[iv] Since its construction in the 1990s, the CSO system has helped remove large volumes of nutrients and sediment from reaching the Saginaw Bay and Lake Huron each year. In 1998, the City of Saginaw's efforts were nationally recognized by the USEPA as an "Outstanding CSO Control Program." There is still the need for a regional public education program to help citizens understand that treated wastewater is not raw sewage as is the popular perception.

The City of Saginaw's structural improvements to the combined sewer system have significantly reduced overflows into the river by creating detention storage at the distal end of each District. This was a way to implement controls within a well developed city, where the majority of parcels were occupied and a high level of infrastructure existed. The City's achievements should not be overlooked or discounted, however further options should be investigated to continue to reduce CSOs and improve the effectiveness of the system. This effort should not only be driven by the fact the Saginaw Bay is a U.S. EPA Area of Concern[v]. Citizens and professionals should push to improve water quality and continually reduce nutrient and pollutant loading of Saginaw Bay and ultimately Lake Huron. It should be noted that efforts to improve the function of the system will ultimately help in the delisting of some of the impaired Beneficial Uses of the Saginaw Bay.

Low Impact Development

The City of Saginaw CSO program represents one facet of a well-established paradigm to manage stormwater. During past decades, professionals have designed drainage networks to collect and move water downstream in a quick and efficient manner. As in the case of Saginaw, larger rainfall events have allowed for limited capacity before a backup takes place. Detention storage structures on commercial and platted residential sites are utilized to hold the water until the system has capacity to move it.

Low Impact Development (LID) practices represent a recently developing model of storm water management. LID aims to deal with water "by using design techniques that infiltrate, filter, store, evaporate, and retain / detain runoff close to its source." These activities attempt to maintain, restore, or mimic the pre-development hydrology of the land. For example, if houses are being constructed on a parcel, LID would attempt to keep the undeveloped site's method of routing and absorbing water without hindering the new use of the property. This method can involve physical components or structures to offset site grading and the construction of impervious surfaces and buildings, as well as other changes to the parcel. Conversely, ideals can be incorporated within the design or configuration of the particular property or area of development. Many Low Impact Development (LID) practices can be implemented within existing communities; some are simple enough for individual citizens to employ on their own without a major investment of money. Many LID practices also have the capacity to filter and treat pollutants from stormwater, unlike the older method of stormwater management. A large issue with stormwater is in the substances which are washed away with the runoff; these can include sediment, fertilizers, chemicals, oils, animal waste, and/or other nutrient-rich substances. The pollutants cause algae blooms, oxygen deficiency, and other problems which are detrimental to wildlife habitat, degrade river benthos and inhibit public recreational use of the watershed.

Some professional credit has also been to the usefulness of LID practices in mitigating CSOs, both in intercepting storm water and in removing harmful constituents. Initially, the idea of using LID seems to deviate from the existing overflow mitigation program. The potential, however, is in the ability of LID to complement and enhance the existing CSO infrastructure. For Saginaw, even more opportunity exists, since the City has substantial potential for redevelopment in many areas. The City has been economically depressed for a number of years. The state of housing and other structures has deteriorated as well, leaving many homes and structures abandoned and targets for arson. The City maintains a program for razing these decrepit structures, which translates into empty lots scattered throughout neighborhoods. These areas of the city are prime for redevelopment and rebuilding. If the opportunity presented itself, investments could spur new growth for Saginaw and at the same time assist in mitigating CSOs. Recently the City was named the recipient of a large multi-million dollar grant to address the vacant structures within its jurisdictional boundaries. This equates to an excellent opportunity for residential re-growth within the City limits. If this regrowth is managed properly and done with proven LID practices to enhance the aesthetics and social aspects of redevelopment Saginaw could become a choice place for young professionals to settle as the new techno / manufacturing industrial growth asserts itself in the Great Lakes Bay Region.

Study Area

The Fitzhugh CSO District is one example of an area with this potential. As shown in Figure 1, it is situated in the northern end of the city and includes a portion of the downtown locale (see Appendix A for a larger image of the map). The drainage district is relatively small approximately 360 acres and is comprised of a mix of residential and commercial areas. The residential neighborhoods contain blocks where many of the houses have been demolished; some are nearly empty and contain pockets of trees and tall vegetation. These residential areas are ripe for redevelopment. Areas such as these types of landuse lend themselves easily for LID implementation. The commercial section of the Fitzhugh District generally contains a high percentage of impervious surfaces. To a lesser extent than residential, the commercial sections also contain empty lots.

Purpose and Scope of Study

The LID in a CSO study has two main components. The primary goal is to examine the ability of Low Impact Development to reduce overflows by storing and infiltrating storm water instead of sending it to the CSO Basin. Second, the study will analyze LID's affect on the amount of pollutants in stormwater runoff reaching the WWTP. The Saginaw Bay is a USEPA Area of Concern (AOC) and is an important element in Great Lakes water quality improvement. Because of the difficulty and costs associated with correcting the problem of CSOs, this information was of interest to the City of Saginaw (and other owners of CS systems), regulatory agencies, and other organizations. To this effect, support has been provided by the Saginaw Bay Watershed Initiative (WIN) in the form of a grant. Financial contributions towards this study were also made by the Saginaw Area Storm Water Authority (SASWA) and the Bay Area Storm Water Authority (BASWA). In-kind contributions were made by Spicer Group, Inc.

Part I: CSO Volume Analysis
To measure the reduction of overflows due to LID implementation, an Environmental Protection Agency Storm Water Management Model (EPA SWMM) representation of the Fitzhugh CSO District was developed. Characteristics of the district were determined through field investigation and the study of aerial imagery and other electronic sources. By constructing a model of the existing conditions and calibrating it according to known CSO events, the system could then be used to analyze various situations. Particular LID practices were discussed and then chosen for integration with the model to form new scenarios (and new models). The models were then examined under several storm events to gauge hydrologic behavior of the scenarios. These results were used to understand the performance of the various Low Impact Development practices.

The reduction in CSO volume was the primary concern in the simulation results. Rain gardens, bio-swales, and green roofs are some of the structural best management practices (BMPs) which were incorporated and studied. Some scenarios equally involved site configuration and planning in monitoring LID effectiveness. The scenarios were tested against four precipitation events which have a high recurrence interval. All events produce enough rainfall to cause a combined sewer overflow treatment and discharge event.

Part II: Pollutant Loading Analysis
For part two of the study, a Long-Term Hydrologic Impact Assessment and Non Point Source Pollutant Model (L-THIA NPS, or L-THIA) was developed. Land use information and historic rainfall data was gathered to investigate pollutant loading in Fitzhugh CSO events. Similar to part one, a model was constructed to describe existing conditions in the district. The initial model and LID practices were then used to form several scenarios. The scenarios, along with historical rainfall data, were simulated in L-THIA and the results of the simulations were then analyzed and discussed in terms of nitrogen and phosphorus reductions.

The results of both study components were analyzed for effectiveness with respect to cost, practicality, and comprehensiveness in addressing CSO mitigation.

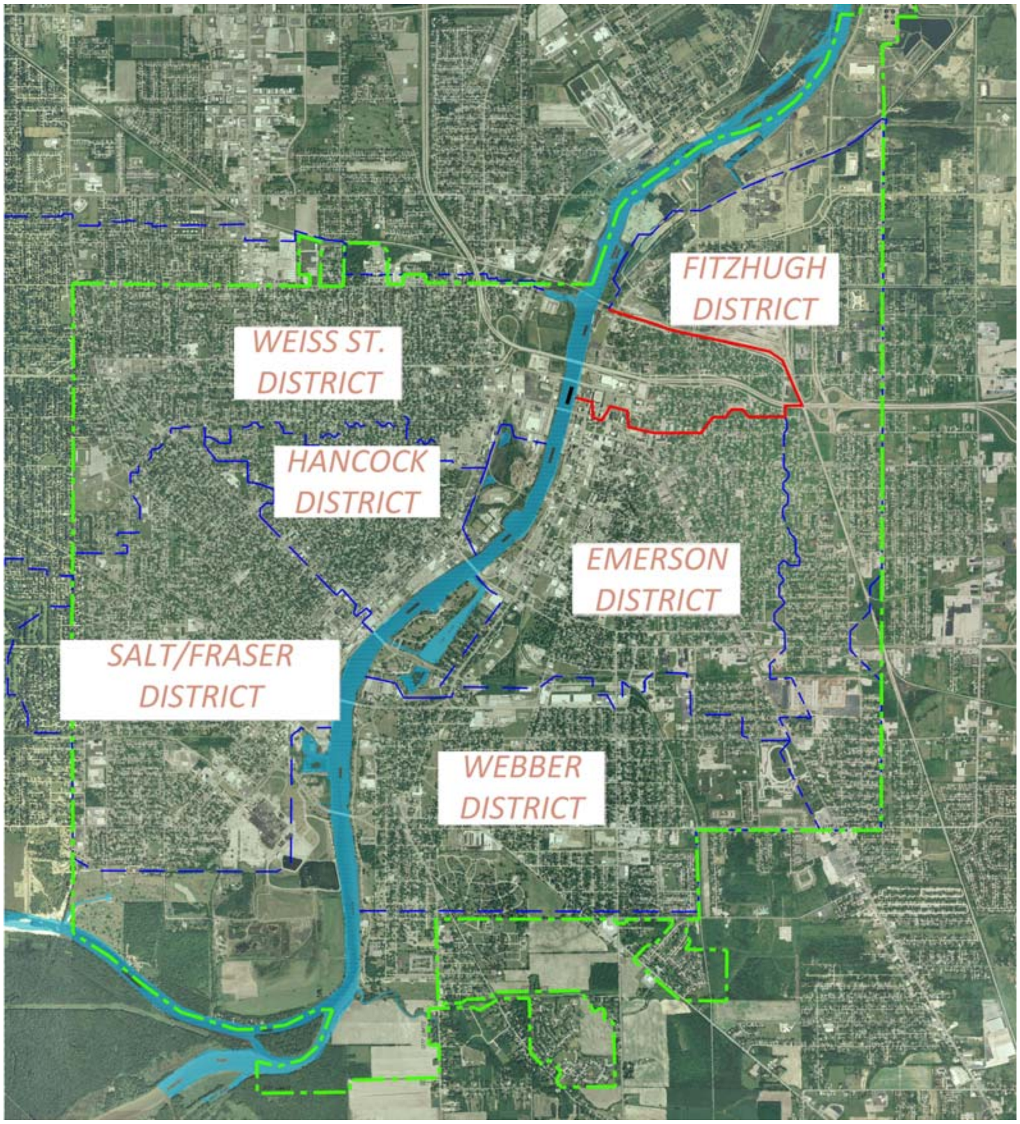

Figure 2: City of Saginaw Combined Sewer Overflow (CSO) Districts
Fitzhugh CSO District outlined in red

3. Method of Analysis

Data Collection

Existing information on the City of Saginaw CSO system and sewer network were utilized for this project. Sources included past studies, maps, CAD drawings, older computer models, and in-house files concerning the City's infrastructure. Data can be found in Appendix A. Information including aerial imagery, soil characteristics, parcel locations, land use and zoning records were collected from various technical web sites, Spicer Group data files, and from the City of Saginaw (i.e. WWTP, Saginaw GIS, and other). This data was analyzed and examined in order to estimate hydrologic and hydraulic characteristics of the area composing the Fitzhugh CSO District.

Field Inspection

Spicer Group personnel performed field investigation to estimate particular hydrologic characteristics of the Fitzhugh District. The percent of impervious area was visually evaluated on a block by block basis for EPA SWMM hydrology. Other parameters were noted in a similar fashion in order to construct the model. Field data, in combination with investigation using electronic information were utilized to describe the CSO District. Collected data can be found in Appendix A.

Part I: CSO Volume Analysis

The Fitzhugh District encompasses approximately 0.5 square mile and is divided into three areas for analysis (see Figure 3) for the purpose of this study. It is composed mainly of residential and commercial land use, with some industrial zoning. Residential areas make up the majority of acreage in the District, especially in the upper reaches (i.e. the eastern end). The commercially zoned area is primarily located at the downstream end of the district (i.e. to the southwest, along the Saginaw River). A few businesses and other institutions are also located to the north of I-675. Figures numbered 4 through 6 depict the land use composition of each sub-catchment; pavement is included as a separate category.

An EPA SWMM model of the Fitzhugh District was developed to analyze the effectiveness of LID in reducing CSOs. EPA Storm Water Management Model (SWMM) is a rainfall and runoff scenario-based modeling software developed by the U.S. Environmental Protection Agency for analyzing urban watersheds. This software was chosen for this study for several reasons. First, it is freely available for download from the EPA web site.[vi] More advanced modeling software would exceed needs of the project scope and budget. SWMM also has advantages in modeling capability. SWMM hydrology will accept input data from outside sources; these include output from TR-55 or other hydrologic modeling procedures or programs. Conversely, the user can assign values directly into the program to define watershed parameters. Hydrologic characteristics of the Fitzhugh subcatchments were developed based on existing land use, soils, imperviousness, and other characteristics of the sewershed (see Table 1, for the range of values used for subcatchment parameters).

Curve Numbers were determined based on these criteria and inputted as part of SWMM's determination of infiltration/abstractions and ultimately, runoff. The SCS Curve Number (CN) method for determining runoff has been widely used because of its simplicity and application ease on major watershed parameters. It was used in this application because of the availability of information on the watershed and land use categories. Curve Numbers and the other subcatchment parameters were used directly in EPA SWMM to predict runoff behavior and

Figure 3: Subcatchments in the Fitzhugh CSO District

amounts. This method was chosen over the use of pre-determined hydrologic inputs because of the ability to represent LID implementation within the subcatchments. For example, rain gardens were represented in subcatchment *S1* by modifying certain parameters of the area. Weighting subcatchment characteristics attempts to show how rain gardens would change the total hydrologic behavior of the area in the EPA SWMM model; this allowed for examination of the LID practices in mitigating CSO events.

Precision in modeling requires extensive study and effort. For the City's combined sewer system this involves the interrelation of many parameters, it includes runoff timing in the CSO District (plus the other districts), a large volume of data involved with modeling the hydraulic arrangement of the CSS (e.g. interceptor sewer, pump stations, throttling valves, restrictor plates, etc), the hydraulics of the particular CSO facility, and capacity and treatment time at the WWTP. This study focused on the volume of CSO during certain rain events. For these reasons, hydraulic conditions of the Fitzhugh District were simplified in order to construct the EPA SWMM model.

The Fitzhugh SWMM model was constructed as an isolated system ending in an outfall, which represents the CSO outlet to the Saginaw River (see Appendix B, for a visual of the model). An additional outlet was added to simulate flows routed to the WWTP. The EPA SWMM district is divided into three areas, or subcatchments, which are based on layouts of existing sewer systems. During storm events, trunk sewers (i.e. one in each subcatchment) collect all excess flows from smaller piping and direct them to the RTB. In the model however, runoff is collected at one point from overland flow for the entire subcatchment area. All pipes were modeled to route flows via gravity. Runoff from all areas of the district flows towards and through a single junction, where it is diverted towards the WWTP outfall or the Fitzhugh CSO Retention Treatment Basin, based on limiting pipe capacity. In the real-world system, flow routed to the Fitzhugh system enters the basin through a series of pumps and is either treated and discharged as an overflow event, or reenters the sewer when capacity is available. The EPA SWMM Fitzhugh RTB is represented as a simple tank with an inlet and orifice. Again, since the primary goal is CSO volume, hydraulic conditions could be simplified.

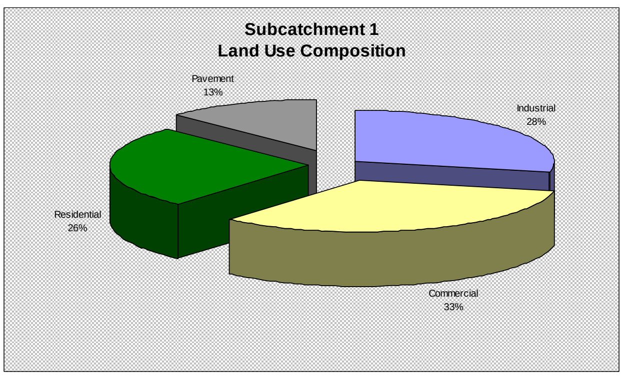

Figure 4

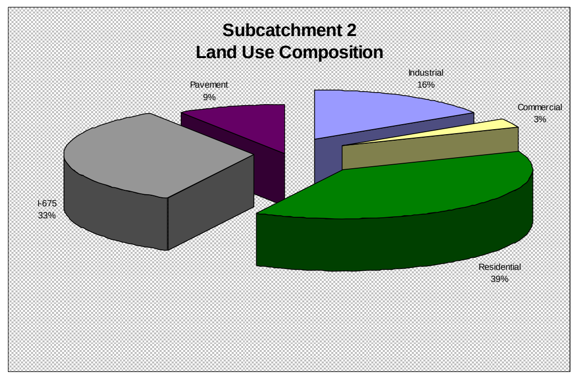

Figure 5

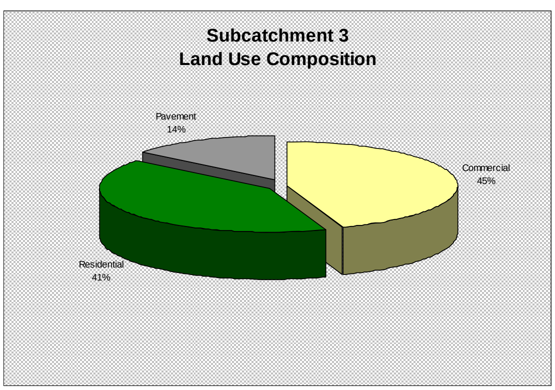

Figure 6

Figures 3 – 5: Land use composition of the Fitzhugh CSO District, Subcatchments S1-S3

The EPA SWMM software allows the user to choose different methods of flow routing within conduits. Kinematic Wave Routing was utilized in this study. This approach conserves volume in the system (i.e. in the case of surcharging or surface ponding), in contrast to the most simple routing method. Dynamic Wave Routing was determined to be unnecessary; it was assumed that the behavior of the model would not largely include pressurized flows or backwater affects. Additionally, the time step interval and level of calibration needed for kinematic routing matches the scope of the model (as opposed to Dynamic Routing, which requires a detailed setup).

The details of several Fitzhugh CSO events were supplied by the WWTP plant; this data included precipitation amount, RTB inflow volume/duration, and CSO discharge volume/duration. Three events were chosen to calibrate the existing system. The rainfall events' intensities and durations were programmed into a rain gauge in order to replay this event in the model. Running the model produced a bench mark from which to adjust the system and simulate the correct overflow amount in the district.

Table 1: Model parameters for the EPA SWMM version of the Fitzhugh CSO District

Basis of Design				
Hydraulic Width	ranges from	952 ft	to	1048 ft
% Slope	ranges from	0.10%	to	0.50%
% Impervious	ranges from	56%	to	74%
Manning's N (Impervious areas)	ranges from	0.015	to	0.015
Manning's N (Pervious areas)	ranges from	0.17	to	0.17
Depression Storage (Impervious areas)	ranges from	0.07	to	0.08
Depression Storage (Pervious areas)	ranges from	0.161	to	0.196
% of Impervious area with Zero Storage	ranges from	15	to	25
Subarea Routing	to	Impervious Areas (all cases)		
Percent Routed	ranges from	80	to	85
Curve Number	ranges from	93	to	94

EPA SWMM Scenarios

Seven scenarios were developed to study LID practices in the Fitzhugh District. Scenarios #1 through #6 involve 30% redevelopment (by area) in the residential sections of each subcatchment. These scenarios utilize rain gardens, bio-swales, and planning configurations within each redevelopment type. Scenario #7 describes selective commercial redevelopment in the form of vegetated roofs and bio-swales. Each scenario was incorporated into the SWMM system by modifying various subcatchment properties to reflect the hydrologic behavior of the particular LID practice. The scenarios are briefly outlined below; a more detailed description and visual representation of the scenarios can be found in Appendix B.

- Scenario 2a: Full build-out of residential areas in the form of ¼-acre parcels. Thirty (30%) percent of residential areas redeveloped.

- Scenario 2b: Full build-out of residential areas in the form of ¼-acre parcels (similar to 2a). Each redeveloped parcel included a rain garden. Runoff from the roof of the house routed to the rain garden, with the goal of increased infiltration or delay of peak runoff.

- Scenario 3a: Full build-out of residential areas in the form of 1/8-acre parcels (30% of residential areas redeveloped).
- Scenario 3b: Similar to 3a, but instead of complete build-out, half of redeveloped areas consisted of open space. These green areas were aimed to create runoff storage.
- Scenario 4: Apartment buildings made up half of redeveloped areas. Remaining area consisted of green areas, as in scenario 3b.
- Scenario 5: Redevelopment with ¼-acre parcels and rain gardens (as in Scenario 2b), plus retrofitted bio-swales for runoff from roads.
- Scenario 6: Redevelopment with apartment buildings and green areas (as in Scenario 4), plus retrofitted bio-swales for runoff from roads.
- Scenario 7: Implementation of vegetated roofing and bio-swales for parking lot runoff (specific sites selected).

Each scenario was tested under four precipitation events. These include the 2- and 5-year recurrence interval events. The storms represent rainfall which would cause a CSO event (i.e. each produce well over 1-inch of rainfall). Cumulatively, these events also represent a larger percentage of yearly rainfall on average in contrast with a lower recurrence event, like the 100-yr storm. Since this study monitored volume as the key parameter, these were the correct rainfall events to use in evaluating a potential reduction of discharge amount. A larger event, like the 100-year storm, could have also been used to test the scenarios, except that the Fitzhugh RTB is well within the flood plain for this event magnitude. As previously mentioned, the model was examined under isolated single events as opposed to a long-term cycle of events. This allows for a focused look at the differences between LID practices.

Table 2: EPA SWMM Scenario Analysis; Rain Events[vii]

2-Year Recurrence Interval

Duration	Rainfall (inches)	Intensity (in/hr)
6 Hour	1.61	0.268
24 Hour	2.14	0.089

5-Year Recurrence Interval

Duration	Rainfall (inches)	Intensity (in/hr)
6 Hour	1.99	0.332
24 Hour	2.65	0.110

Part II: Pollutant Loading Analysis
The Long-Term Hydrologic Impact Assessment (L-THIA) program was developed by Purdue University, and is available for use at no cost on the internet.[viii] This program used land use and soil characteristics from the user along with thirty years of precipitation data to quantify the impact of land use on the quantity and quality of the receiving water. This project used the web-based version of L-THIA. The advanced input option was used because it allowed for custom land use types, which was necessary to model the impact of the rain gardens. In this way, the models could be defined and used to simulate potential future scenarios.

The following assumptions were made for the L-THIA program:

- The curve number used for the custom rain garden areas was determined by using a *Composite CN with Connected Impervious Areas* chart.
- A rain garden was assumed to be in the land use category *Meadow*.
- HD Residential land use assumed to be 1/4 acre lots.

Electronic data sources were utilized to define model parameters for L-THIA (see EPA SWMM section). Subcatchment parameters closely followed the EPA SWMM model. Precipitation data for Saginaw County, Michigan was supplied by the L-THIA website; it contains the daily precipitation amounts from October 1, 1965 to September 30, 1997. It was reviewed and determined to be acceptable for the study.

Five different scenarios were run in the L-THIA program. The impact of the rain gardens was modeled as a decrease in the percent impervious area for the land use type. Table 3 shows the percent of impervious area for each scenario. Rain gardens only apply to the areas that are ripe for redevelopment; thus, only areas identified as such were modeled under the custom rain garden land use category in the L-THIA program.

Table 3: Scenarios modeled in the L-THIA program

	Percent Impervious				
Land Use	**Current**	**Future 1**	**Future 2**	**Future 3**	**Future 4**
HD Residential	45%	35%	25%	35%	25%
Commercial	85%	85%	85%	70%	70%
Industrial	72%	72%	72%	72%	72%
Pavement	95%	95%	95%	95%	95%

4. Results

Part I: Results of CSO Volume Analysis

Existing Conditions and Model Verification

Including the model of existing conditions, nine scenarios (i.e. and nine models) were developed in all. The four precipitation events mentioned earlier were carried out on each of the nine models; a total of thirty-six (36) model runs were executed.

Verification of the model was performed by comparing CSO volumes in the EPA SWMM model with actual system data provided by City of Saginaw WWTP. Three known storm events were carried out with the existing conditions model of the CSO District. Table 4 shows the results, after adjustments were made.

Table 4: EPA SWMM Calibration Results

	Reported CSO Volume	
Event	**Model**	**Actual**
October 4, 2006	3.37 MG	3.46 MG
June 27, 2007	1.65 MG	2.17 MG
August 17, 2008	1.45 MG	1.50 MG

Caution should be taken in the model's ability to project scenario results. Despite calibration procedures, model results will vary from actual conditions due to spatial and time variation in weather patterns, conditions of the combined sewer system, and in the limited scope of the model structure. A variety of scenarios were tested in order to compare LID performance under well defined parameters.

EPA SWMM Scenario Analysis

A summary of the scenario analysis is displayed in Table 5; a full set of results can be viewed in Appendix B. CSO and runoff reduction vary between storm events since the total amount of precipitation and the intensity of the rainfall affect the CS system differently.

The two scenarios with the greatest reduction in CSO volume include Scenarios 5 and 6. These are based on the LID practices in Scenarios 3b and 4 (which make up the bulk of the reduction), only adding bio-swales to make 5 and 6. Scenarios 3b and 4 utilize high density housing configurations combined with open space areas, which are used for stormwater storage. The scenario which made the least improvements on average is #3a; this scenario actually increased the volume of overflow during storm events. Scenarios 2a and 7 also made minor impacts to the system. Results of each scenario are discussed below.

Table 5: Summary of Scenario Results

		Scenario Results: 2 Year-6 Hour Precipitation Event							
		2a	2b	3a	3b	4	5	6	7
		Full Build-Out (1/4 parcels)	Full Build-Out (w/ Rain Gardens)	Full Build-Out (1/8 ac parcels)	Full Build-Out (w/ open space)	Apartment Buildings (w/ open space)	Scen #2b with Bio-Swales along roads	Scen #4 with Bio-Swales along roads	Commercial: Green Roof & Bio-Swales
CSO Reduction	Volume (MG)	0.058	0.316	-0.165	0.566	0.536	0.387	0.549	0.091
	Percent	2.04%	11.11%	5.80%	19.89%	18.84%	13.60%	19.30%	3.20%
Runoff Reduction	Volume (MG)	0.427	1.033	-0.483	1.788	1.589	1.204	1.618	0.629

		Scenario Results: 2 Year-24 Hour Precipitation Event							
		2a	2b	3a	3b	4	5	6	7
		Full Build-Out (1/4 parcels)	Full Build-Out (w/ Rain Gardens)	Full Build-Out (1/8 ac parcels)	Full Build-Out (w/ open space)	Apartment Buildings (w/ open space)	Scen #2b with Bio-Swales along roads	Scen #4 with Bio-Swales along roads	Commercial: Green Roof & Bio-Swales
CSO Reduction	Volume (MG)	-0.029	0.154	-0.057	0.455	0.462	0.211	0.508	0.026
	Percent	0.39%	2.07%	0.77%	6.13%	6.22%	2.84%	6.84%	0.35%
Runoff Reduction	Volume (MG)	0.381	1.154	-0.500	2.573	2.383	1.397	2.487	0.727

		Scenario Results: 5 Year-6 Hour Precipitation Event							
		2a	2b	3a	3b	4	5	6	7
		Full Build-Out (1/4 parcels)	Full Build-Out (w/ Rain Gardens)	Full Build-Out (1/8 ac parcels)	Full Build-Out (w/ open space)	Apartment Buildings (w/ open space)	Scen #2b with Bio-Swales along roads	Scen #4 with Bio-Swales along roads	Commercial: Green Roof & Bio-Swales
CSO Reduction	Volume (MG)	0.041	0.340	-0.152	0.629	0.608	0.418	0.641	0.056
	Percent	1.27%	10.56%	4.72%	19.53%	18.88%	12.98%	19.90%	1.74%
Runoff Reduction	Volume (MG)	0.514	1.291	-0.544	2.347	2.115	1.496	2.189	0.718

		Scenario Results: 5 Year-24 Hour Precipitation Event							
		2a	2b	3a	3b	4	5	6	7
		Full Build-Out (1/4 parcels)	Full Build-Out (w/ Rain Gardens)	Full Build-Out (1/8 ac parcels)	Full Build-Out (w/ open space)	Apartment Buildings (w/ open space)	Scen #2b with Bio-Swales along roads	Scen #4 with Bio-Swales along roads	Commercial: Green Roof & Bio-Swales
CSO Reduction	Volume (MG)	-0.067	0.100	-0.035	0.258	0.272	0.149	0.310	0.003
	Percent	0.85%	1.27%	0.44%	3.27%	3.45%	1.89%	3.93%	0.04%
Runoff Reduction	Volume (MG)	0.430	18.102	-0.525	2.777	2.555	1.539	2.682	0.747

Scenarios 2a and 3a

All scenarios reduced the overflow amount, except for cases 2a and 3a. Both portrayed full build-out conditions in the Fitzhugh CSO district with no LID practices implemented during development. Redeveloped areas with ¼-acre and 1/8-acre parcels would likely mimic the past, since the Fitzhugh District probably contained a similar make-up during historical build-out conditions. Since these scenarios added impervious area to the district and removed storage provided by empty lots and dense vegetation, the fact that some rain events cause a larger CSO event was not a surprise. Scenario 2a averaged a slight decrease in CSO volume with respect to all four rain events. Scenario 3a caused an increase in CSO volume when considering all precipitation events. This described partial redevelopment of the district without incorporating any LID practices. Despite the CSO program and infrastructure, a greater level of impervious area will create more CSO events and/or discharge volume. Over a yearly average of varying rainfall events, these scenarios would most likely increase the amount and number of overflow events.

Scenario 2b

Scenario 2b used rain gardens at each new residential lot in the redevelopment. This scenario was developed from the configuration of 2a. The rain gardens were implemented with the hypothesis of providing storage capacity and facilitating a higher level of infiltration for runoff from the house. This practice seemed to be effective in reducing CSO volume, given a 1 to 11% decrease between the four runoff events. In the case of redevelopment in the Fitzhugh District, implementation of residential rain gardens would be an effective way to reduce CSOs by volume and number of events.

The basic idea behind using rain gardens, and other LID practices, is to prevent all runoff from being routed to a stormwater drainage system. Some community programs have been effective in educating and motivating local citizens to act on their own on issues related to stormwater. Downspout disconnection has been helpful in recorded cases. Residents can easily store rainfall by routing gutter downspouts to a large barrel, cistern or specially placed landscaping. In this way, many gallons of water can be saved for use in lawn and garden applications instead of overloading infrastructure and polluting local water bodies.

Scenarios 3b and 4

In addition to using rain gardens to handle runoff, Scenarios 3b and 4 utilized open space. High density housing was used to provide the same or greater living capacity as Scenario 2b, while more community space was created. Half of the redeveloped area consisted of housing, and the other half was green space. The open space provided storage in these areas as well as potential locations for parks and other recreational investments. Scenario 3b reduced CSO discharge between 3 - 20%; this is the largest reduction. Scenario 4 resulted in a reduction of 4 to 19%. Since the two cases utilize the same LID planning method, this was proven to be an effective way to reduce overflows, as well as runoff in general.

Scenarios 5 and 6

As described previously, Scenarios 5 and 6 were extensions of cases 3b and 4. Bio-swales were added to handle runoff from roads in redeveloped areas. The bio-swales added storage capacity and infiltration of runoff which would normally be routed directly to the storm sewer. Scenario 5 provided an additional 0.8 – 2.5% reduction (in addition to #2b). Scenario 6 further reduced overflow events by 0.5 - 1%.

As shown by this scenario, retrofitted bio-swales store and infiltrate runoff to reduce overflows. Excess storm water, which would otherwise be routed directly to the sewer, has more opportunity to infiltrate into the ground. Another practice with similar goals includes pavement material which has pores and gaps (porous concrete or porous asphalt) which allows water to travel through the surface and into the ground.

Scenarios 7

Scenario 7 deviated from the LID in previous cases and was more difficult to compare. LID was implemented in commercial areas through the use of bio-swales and vegetated roofing. Redevelopment was limited to subcatchment S3 and specific sites were chosen based on standard criteria for these practices. In contrast with other scenarios, less Low Impact Development was implemented by area. Despite this fact, it resulted in a 0.1 – 3.2% decrease in CSO volume.

The potential for implementing vegetated roofing and bio-swales should be investigated further, especially in the event of new business investments in the city. Commercial areas in the City of Saginaw make up a large portion of the impervious area in the form of buildings and pavement. Additional green space (e.g. bio-swales) in lieu of concrete can improve aesthetics, reduce costs, and of course, allow for the infiltration and storage of storm water. As mentioned earlier, pervious pavement is another viable option. Green roofs have been shown to provide other benefits in addition to CSO mitigation, such as a reduction in the costs of heating and cooling a facility. The above options have the potential to be implemented in cases of new construction, redevelopment, or even for current establishments.

Part II: Results of Pollutant Loading Analysis

Pollutant runoff was studied in each scenario with respect to annual average rainfall data. A summary of the results are shown in Tables 6 and 7. The percent reduction in pollutant amounts was calculated by comparing the future scenarios with the current scenario. The output from the L-THIA program was used to create tables and graphs, which describe pollutant contribution from each land use type. The full set of information can be found in Appendix C.

For the scenarios tested, the L-THIA program estimated a 5-11% reduction in the average annual nitrogen amount and a 9-17% reduction in average annual phosphorus amount. Figures 8 and 9 show the same results in a chart.

Table 6: Projected L-THIA Pollutant Reduction by Weight

Load Type	*Discharged Pollutant by Weight*				
	Current	**Future 1**	**Future 2**	**Future 3**	**Future 4**
Runoff (ac-ft)	184.8	175.7	171.9	168.8	165.1
Nitrogen (lbs)	825.0	779.0	760.0	754.0	735.0
Phosphorus (lbs)	158.0	143.8	137.7	136.8	130.7

Table 7: Projected L-THIA Pollutant Reduction by Volume

Load Type	*Pollutant Reduction by Percent*				
	Current	**Future 1**	**Future 2**	**Future 3**	**Future 4**
Runoff	N/A	5.0%	7.0%	8.7%	10.7%
Nitrogen	N/A	5.6%	7.9%	8.6%	10.9%
Phosphorus	N/A	9.0%	12.9%	13.4%	17.3%

Little explanation is required since it is a direct relationship; the more rain gardens implemented correlates with a greater reduction in pollutants in storm water runoff. These results do provide a valuable estimate of the magnitude of impact rain gardens could make on water quality. The Retention Treatment Basins are known to remove a significant percentage of nitrogen and phosphorus from reaching downstream water. Even a 6% reduction due to rain gardens, a low projection by this model, would be an effective complement to CSO infrastructure. This study omits other substances which may be retained by rain gardens or other LID practices. These include eroded soils, oils and fuels from pavement surfaces, and yard waste debris.

With respect to CSO Districts, these reductions mean preventing more of the pollutants from even reaching the storm sewer system. Increasing the amount of pervious area, or implementing rain gardens and other LID structural practices infiltrates and stores these nutrients with the storm water. An obvious benefit is a reduction of pollutants (i.e. nitrogen, phosphorus, as well as others) reaching downstream water bodies. As discussed in the previous section with excess runoff volume, less of these chemicals would reach the wastewater treatment plant. This means less effort in the treatment of wastewater. The Saginaw Bay could also realize gains in recreational use.

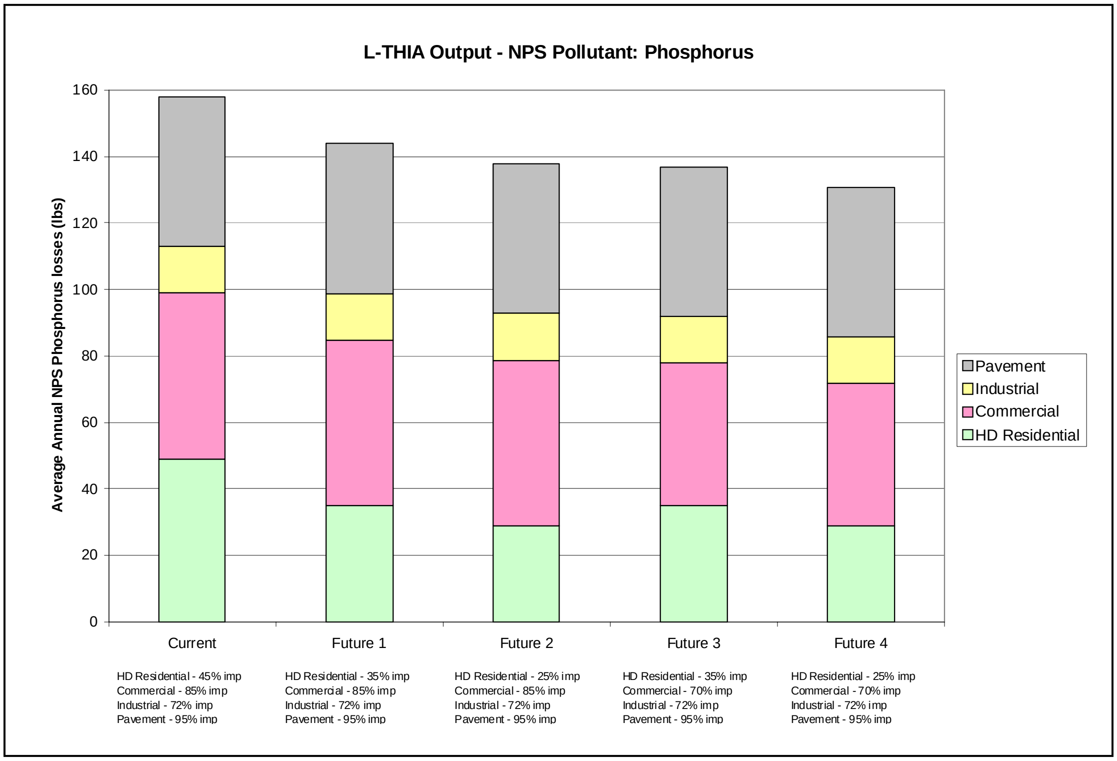

Figure 7: L-THIA Results for NPS Phosphorus

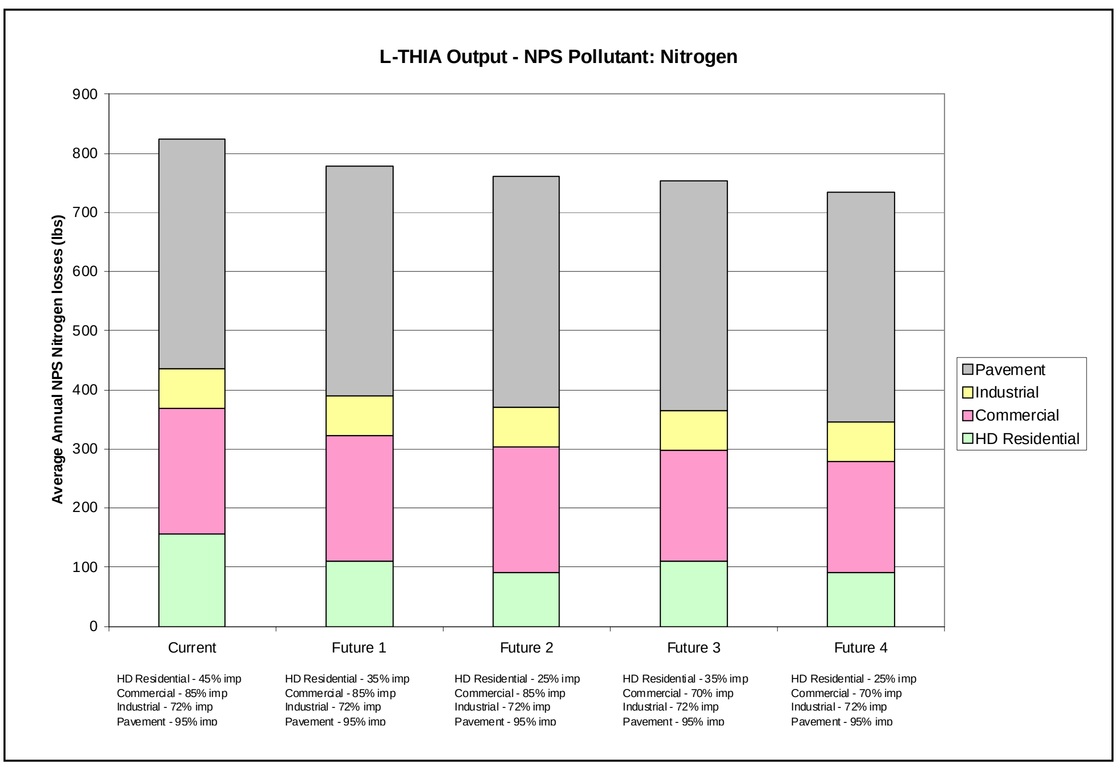

Figure 8: L-THIA Results for NPS Nitrogen

Other Implications for CSO systems

A reduction in the amount of storm water runoff would have a direct affect on Combined Sewer Overflows. It could also provide positive affects for the wastewater treatment plant. Storm water dilutes sanitary flows; less runoff in the CS system would mean more concentrated sanitary flows, which are less expensive to treat. Although it was not a primary goal of this study, LID implementation may also affect the peak flow rate during storm events, which could diminish backups at the WWTP.

As discussed previously, LID can be an alternative to costly and intensive infrastructure additions to CS systems. It may also increase the life span of the system by lowering average flows and mitigating loading on a system due to further development or build-out. Further impacts may include cost savings at the Retention Treatment Basins in CSO Districts; fewer overflows mean less chemicals being used in RTB treatment, and a reduction in maintenance.

5. Conclusion

Aging sewer systems in large cities and the push for environmental improvements reinforce the need for a solution to Combined Sewer Overflows. While separation of existing combined sewer systems is very expensive there are alternatives to consider. Mitigation through infrastructure is becoming a less attractive option due to its cost. Low Impact Development can provide a decentralized source solution to urban storm water, as opposed to infrastructure, which attempts to control it downstream. It can be implemented in older developed cities, or as part of construction in growing or redevelopment areas.

The City of Saginaw has extensive potential for redevelopment, as well as the implementation of Low Impact Development practices. The EPA SWMM scenario analysis of the Fitzhugh District estimated a potential decrease in CSO volume by as much as 20% (i.e. for 2- and 5-year storm events). The BMP which resulted in the largest offset of CSO events included routing storm water to large, open areas with storage capacity. Rain gardens were also effective in mitigating runoff from new residential developments. Other noteworthy gains were made through bio-swales, used for runoff from pavement surfaces, and green roofs in commercial districts.

Investing in LID in the City of Saginaw would likely result in a decrease in costs for the city as a return for a moderate investment of time (i.e. reduced costs in WWTP operation, life of infrastructure, and RTB maintenance and materials). In a situation where redevelopment will take place, these best management practices can be employed both in planning and structural improvements without upsetting progress or cost. As opposed to installing new storm sewer and curb and gutter in redevelopment areas, some of this space could be retrofitted with rain gardens, and open green areas for recreation. Societal and monetary benefits, in addition to advances to the CSO system, make these methods beneficial and desirable.

In regard to future planning/development, construction and building ordinances, and improvements to the Combined Sewer Overflow system, the City of Saginaw should take into account various LID practices and goals. Some states have seen the publication of technical guides on Low Impact Design/Development for communities and professionals to use. Training for some City of Saginaw employees may be beneficial; reference to the LID guides is an alternative. Some situations, such as design or implementation may warrant the services of a LID professional. As shown in this study, such consideration has potential to be part of a comprehensive solution to meet environmental standards while contributing to aesthetics, and improving the overall health of the watershed.

References

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