SPECIAL PUBLICATION SJ2007-SP20

ESTIMATING THE SPATIAL DISTRIBUTION OF STORMWATER BEST MANAGEMENT PRACTICES IN THE ST JOHNS RIVER WATER MANAGEMENT DISTRICT

SPECIAL PUBLICATION SJ2007-SP20

Estimating the Spatial Distribution of Stormwater Best Management Practices in the St Johns River Water Management District

by
Xiaoqing Huang*, Zhulu Lin and Yanbing Jia

BCI Engineers & Scientists, Inc.

* Corresponding author: xhuang@sjrwmd.com

St. Johns River Water Management District
Department of Water Resources
Division of Engineering
Palatka, Florida 32178
2007

Acknowledgements

The authors would like to thank Dale R. Smith for his supervision and guidance of this project and his many constructive suggestions that led to the successful completion of this project and the report. Thanks also are extended to Tom Ziegler and Chris Basci for reviewing the manuscripts, whose efforts had significantly improved the report. The authors would like to give special thanks to Ed Carter and Marc Adkins for manuscript review, and their efforts to follow the appended GIS procedures to reproduce the estimated stormwater best management practices coverage map in the Lake Jesup basin and in the Indian River Lagoon Basin, respectively.

Executive Summary

This report describes and documents the methodology and geographic information system (GIS) procedures used to estimate the stormwater best management practices (BMPs) distribution in the St Johns River Water Management District (SJRWMD). Stormwater programs were adopted in Florida since the early 1980s. Under the frameworks of the *Clean Water Act*, in 1987 US Environmental Protection Agency (US EPA) designated BMPs as the primary mechanism for offsetting water quality impacts due to the land development in the United States. BMPs play an important role in the rainfall-runoff process, not only do they reduce the runoff volumes and peak flows, but also they can remove sediments and nutrients associated with the runoff. Hence, BMPs need to be incorporated into the watershed hydrologic and water quality models. The objectives of this project are to map the spatial distribution of BMPs in the SJRWMD in a more efficient manner and to document the step-by-step GIS procedures used to complete this mapping effort. The total BMPs-treated area in the Lake Jesup basin estimated by our method was compared with the estimate by a traditional method developed by PBS&J, Inc., and the difference was less than 10%. The comparison between these two methods also demonstrated that over 57% of the BMP-treated area was spatially matched. In conclusion, our method is relatively accurate, detailed, efficient, and reproducible, suitable for our purpose, i.e., to estimate the spatial distribution of BMPs in the SJRWMD in order to facilitate the modeling of hydrology and water quality in the SJRWMD watersheds.

Table of Contents

List of Figures

List of Figures (Con't)

List of Tables

Introduction

Stormwater management programs in Florida have been being enacted since the early 1980s. Stormwater Best management practices (BMPs) have been designated as the primary countermeasures to achieve the post-development water quality standards by US EPA and Floridian Legislature and regulatory agencies. Since then, BMPs have played a critical role in protecting Florida's rivers, coastal areas, and other waterbodies. BMPs are one of the components simulated with the Hydrologic Simulation Program – Fortran (HSPF) models developed by the St Johns River Water Management District's Division of Engineering. However, the available information on BMPs spatial distribution in the St Johns River Water Management District (SJRWMD) is either non-existent or only sparsely available. The traditional way to map BMPs distribution is through field investigation and manual digital delineation, which is time-consuming and costly. The objectives of this report are to document an alternative method to estimate this information in an efficient and low-cost way by taking advantage of the extensive available data in the SJRWMD including regulatory permits, land use, soils, and groundwater table depth using our state-of-the-art information technology; and to compare the estimated results with that obtained through traditional method.

Stormwater is generated by runoff from land, pavements, building rooftops and other urban surfaces during rainfall or snow events. It is of concern for two reasons: the first is its volume and peak flow rate; and the other is related to the concentrations of contaminants such as oil and grease, organic or inorganic chemicals, nutrients, metals, bacteria, etc, that accumulate in the stormwater as it travels across land surfaces. This stormwater runoff can adversely affect the water quality of the receiving waterbodies. Numerous investigations over the last forty years have demonstrated that stormwater could be as great a source of pollution as wastewater (Butler and Davies 2004). In Florida, stormwater is one of the primary sources of pollution, contributing 80-95 percent of heavy metals (lead, copper, cadmium) loadings into Florida's streams and other waterbodies (SJRWMD 2006). Florida has remained the hot state for domestic migration or immigration for the past forty years. Florida's population has increased dramatically since then and the pace has accelerated in the recent years, adding 1,000 people per day from 2000 to 2006 (US Census Bureau 2006). Coupled with the rapid growth of the state's economy, many of Florida's open or natural lands have been developed for residential, commercial, or industrial uses. The State of Florida and Federal Government have implemented strong stormwater programs to control the quantity and quality of runoff through various local, regional, state, and national agencies. These programs not only require controlling runoff from new development but also the reduction of pollutants from existing development.

BMPs are structural or nonstructural control measures taken to mitigate post-development adverse environmental effects at a minimal cost. In this report, BMPs refer to structural measures unless otherwise noted. They are designed to reduce stormwater quantity and quality through evapotranspiration, detention, retention, filtration, infiltration, and other physical, chemical or biological reactions. BMPs play a critical role in the rainfall-runoff process. Not only do they reduce the runoff volumes and peak flows, and but also they can remove sediments and other water quality elements associated with the runoff. Some of the regulatory programs such as Total Maximum Daily Load (TMDL) also require the determination of watershed pollution loadings by using computer model as a tool. To better understand the impacts of stormwater runoff and the benefits derived from areas that have stormwater BMPs treatment, BMPs spatial distribution need to be quantified and their effects on water quality need to be simulated using hydrologic and water quality models.

Hence, it is important to incorporate the BMPs into the Hydrologic Simulation Program – Fortran (HSPF) models, used by and for SJRWMD, which model hydrology and water quality in the watershed. The objectives of this project are to efficiently map the spatial distribution of BMPs in the SJRWMD and to provide this information to the HSPF modelers in the SJRWMD's Division of Engineering to facilitate improved modeling of the hydrology and water quality in the SJRWMD. Obviously, the estimated BMPs coverage map is far from being perfect, but is sufficient for watershed-scale modeling. If your projects require precise and detailed BMPs coverage data, certainly this estimated BMPs coverage is not suitable.

Florida's climate, hydrology and geomorphology are well suited for a variety of BMPs such as swales, dry detention and wet detention ponds. They mimic the natural ecosystems well, which can be seen everywhere in Florida. In this report, a method was developed to differentiate these three types of BMPs.

Swales

Swales are one of the most common stormwater BMPs used in Florida. They are usually situated adjacent to highways, major roads, or residential streets. Typically, they are very shallow, have gentle side slopes (Figure 1), and are typically stabilized with suitable local vegetation. This vegetation slows down stormwater flowing through the swale, allows for temporary ponding, and allows the vegetation to filter the stormwater, and to remove sediment, heavy metals and other pollutants. Swales also allow stormwater to infiltrate into the ground hence reducing peak flows.

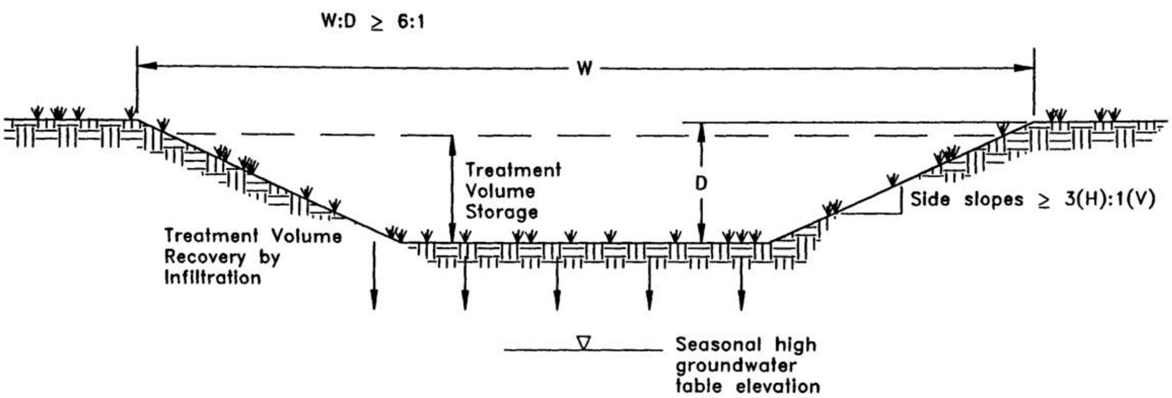


Figure 1. Cross-section of a typical swale (SJRWMD 2005, used with permission of the St. Johns River Water Management District).

Dry Detention Ponds

As its name implies, dry detention ponds "are normally dry storage areas that are designed to store a defined quantity of runoff and slowly release the collected runoff through an outlet structure to adjacent surface waters. After drawdown of the stored runoff is completed, the storage basin does not hold any water" (Figure 2, SJRWMD 2005). This type of BMPs primarily removes sediments in the stormwater and a fraction of pollutants associated with the sediments. Hence, its pollutant removal efficiencies are very limited. Therefore, SJRWMD limits its application areas where other types of BMPs are not feasible due to soil or hydrologic conditions such as low ground water tables and/or high soil infiltration rates (SJRWMD 2005).

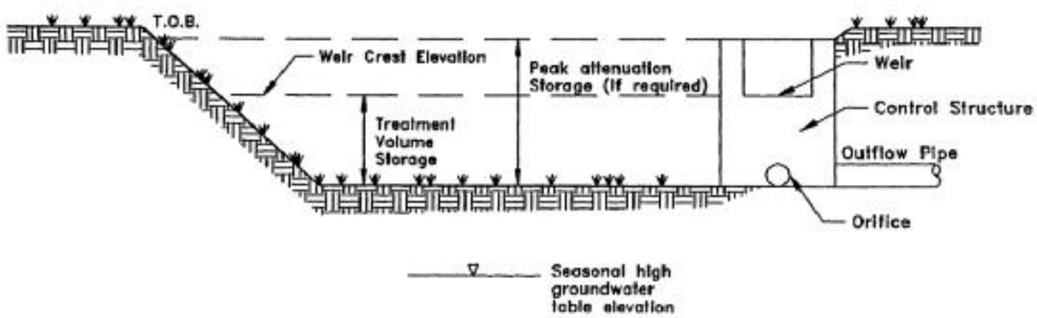


Figure 2. Cross-section of a typical dry detention pond (SJRWMD 2005, used with permission of the St. Johns River Water Management District).

Wet Detention Ponds

Wet detention ponds (Figure 3) are one of the most popular and recognizable stormwater BMPs in the SJRWMD. As their name implies, these systems hold a permanent "wet" pool, which, in SJRWMD, is usually less than 12 feet deep. The extra storage capacities above the permanent pool can attenuate the stormwater peak flow rate and the collected stormwater runoff is then slowly released through the pond's outlet structures. This allows sediments and contaminants to have more time to be involved in the physical, chemical, and biological processes within the pond (CDM 1985), which includes: uptake of nutrients by algae, adsorption of nutrients and heavy metals onto bottom sediments, biological oxidation of organic materials, and sedimentation (CDM 1985). Hence, wet detention systems can efficiently remove both dissolved and suspended pollutants/sediments. Moreover, wet detention ponds are easy to maintain and do not have the complexity of other BMPs, such as under-drains etc (SJRWMD 2005). Furthermore, they can provide flood attenuation and pleasing aesthetics to the nearby properties and hence increase the property values. Overall, wet detention systems are one of the most successful mimics of natural systems. Hence, SJRWMD highly recommends wet detention ponds as the preferred stormwater treatment for sites with a moderate to high ground water table and/or a low soil infiltration rate (SJRWMD 2005).

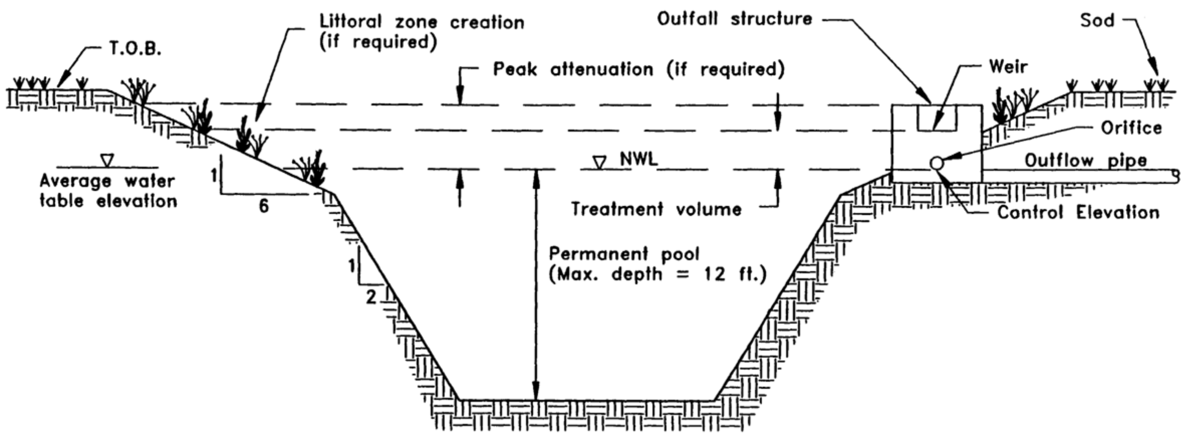


Figure 3. Cross-section of a typical wet detention pond (SJRWMD 2005, used with permission of the St. Johns River Water Management District).

BMPs' Pollutant Removal Efficiencies

As Table 1 indicates, all these three types of BMPs offer some levels of pollutant removal, including sediments, nutrients as well as heavy metals. All three of these BMPs have similar removal rates for total suspended solids, up to 85%, which is excellent (CDM 2002). They also have similar removal rates of biochemical oxygen demand (BOD), around 25%. However, they differ significantly in nutrient removal efficiencies.

Wet detention ponds offer the best removal efficiencies for dissolved and total phosphorus (P), 65% and 45%, respectively; swales are second to wet ponds, 15% and 40%, respectively; while dry ponds provide minimal removal rates, 5% to 25%, respectively. On the other hand, all three types of BMPs have similar total heavy metals (Copper, Lead, and Zinc) removal rates, i.e., between 35% and 75%. Therefore, wet detention ponds stand out as the most efficient BMPs among these three types of BMPs. Coupled with the advantage of their processing volume, SJRWMD strongly encourages the use of wet detention ponds where natural conditions permit (SJRWMD 2005).

Table 1. Pollutant removal efficiencies (%) for stormwater treatment BMPs: dry detention pond, wet detention pond and swale in the SJRWMD.

Pollutants	**Dry Detention**		**Wet Detention**		**Swales**	
	Range	Average	Range	Average	Range	Average
BOD	20-30	25	20-40	30	20-40	30
TSS	80-90	85	80-90	85	70-90	80
Dissolved P	0-10	5	60-70	65	0-30	15
Total P	20-30	25	40-50	45	30-50	40
NOx	0-10	5	30-40	35	0-30	15
Total N	10-20	15	20-30	25	20-40	30
Total Cu	50-60	55	60-70	65	40-60	50
Total Pb	70-80	75	70-80	75	60-90	75
Total Zn	30-40	35	40-50	45	40-50	45

1. Data source: prep. by CDM for SJRWMD 2002.
2. Abbreviations: BOD: biochemical oxygen demand; NOx: nitrate and nitrite; TSS: total suspended solids.

Data Sources

The following is a list of the data sources used to develop this methodology:

1. SJRWMD Environmental Resource Permit (ERP) boundaries data (polygons) from the SJRWMD GIS database: since the most recent land use/ land cover data are from the aerial images taken at the end of 2003, hence we can estimate BMPs coverage only for the period ending in 2003. So, any permit applications received after December 31, 2003 will not be included in the ERP boundaries data;
2. ERP stormwater data (points) from the SJRWMD GIS database: similar to ERP boundaries data, we need to include only stormwater points (permits) that were received before December 31, 2003. We also need to convert the points to polygon coverage by drawing circular buffers around each of the points based on its project size;
3. Groundwater table depth data (Grid format) from SJRWMD , Dept of Resource Management, Division of Ground Water Programs: the grid resolution is 115 X 115 meters;
4. 2004 and 1990 land cover/land use data from the SJRWMD GIS database;
5. Hydrologic soil groups data from the SJRWMD GIS database: Soil SSURGO 24K data. The soil scientists at Natural Resources Conservation Services, U.S. Department of Agriculture (NRCS-USDA 1986) have classified soils into hydrologic groups A, B, C, and D based on their infiltration rates:

   Group A soils have soil textures of sand, loamy sand, or sandy loam, and have low runoff potential and high infiltration rates even when thoroughly wetted.

They consist chiefly of deep, well to excessively drained sand or gravel and have a high rate of water transmission (greater than 0.30 in/hr).

Group B soils have soil textures of silt loam or loam, and have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (0.15-0.30 in/hr).

Group C soils have soil textures of sandy clay loam, and have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine-to-fine texture. These soils have a low rate of water transmission (0.05-0.15 in/hr).

Group D soils have soil textures of clay loam, silty clay loam, sandy clay, silty clay, or clay, and have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission (0-0.05 in/hr).

Methodology

The straightforward method to map the stormwater BMPs is to collect information about BMPs implementation from different governmental entities, such as cities, counties, districts, Florida Department of Environmental Protection, Florida Department of Transportation, etc., which all have some levels of authority to issue land development permits. After that, field trips are required to corroborate or correct this information, and then manually delineate the project boundaries on the map. This is possibly the most accurate method; it is, however, very time-consuming and costly. According to Mr. Joe Walker, the project manager from the consulting firm PBS&J who oversaw the BMPs distribution mapping using this method in Lake Jesup watershed, they spent about 5 months of manpower on this project (personal communication). The area of Lake Jesup watershed is only about 1% of the SJRWMD's total area. At this speed, it would take over forty years of manpower to finish mapping the BMPs in all the SJRWMD area using this method. This does not take into account any changes that may occur to previously mapped areas during this effort. The development of an efficient and relatively accurate method is needed to provide input data for the modeling of hydrology and water quality. To expedite the mapping process, GIS information available through the SJRWMD various departments was utilized, including Environmental Resources Permits (ERP) regulatory data, land cover/land use, groundwater table, hydrologic soil groups. As the result, the production of a reasonably accurate BMPs distribution map for all of the SJRWMD's 2,000 square mile area can be accomplished within two days.

GIS Approach to estimate BMPs coverage in the SJRWMD

Three BMPs types, i.e., swales, dry and wet detention ponds, were mapped in this estimated BMPs coverage map since these three types of BMPs are the most common and recognizable practices in Florida. In this project, we do not consider non-structural BMPs such as street sweeping, educational efforts, etc. as these are very difficult to quantify; nor did we consider agricultural BMPs, as they are quite different from residential, industrial or commercial BMPs. However, we could add agricultural BMPs later if there is a need for such information and more information becomes available.

First, we have to identify the locations where BMPs had been installed. This information is based on two sources of data:

1. ERP boundaries data (polygons) and ERP stormwater data (points): the SRJWMD Permit Data Service delineated the properties contained in the permit applications and put this information into two GIS files, ERP boundaries (polygons) and ERP stormwater data (points). The former typically contains large projects that are under the regulations of Chapters 40C-4, 40C-40 and 40C-42 F.A.C., which is already in the format of polygons; the latter contains smaller projects, usually under the regulation of Chapter 40C-42 F.A.C.. However, the latter is in point format and had to be converted into polygon format by creating a circular buffer around the point based on its project size. We then combine these two GIS layers into one GIS layer. However, cautions should be exercised: some permit applications may be a primary permit application, which are followed by a series of sub-applications when the developers start to develop various phases of the

property. This means some open lands may have been included in the permits but have not been developed yet. Therefore, we need to limit the ERP permitted area to the urban/industrial/commercial area. This information represents the most reliable information regarding BMPs locations since it comes directly from the permit application;

2. Urban land cover/use changes between 1990 and 2004. Although the SJRWMD Division of Regulatory Information Management has tried very hard to delineate all the proposed development contained in the permits applications, due to the large number of permits some older permits have not yet been delineated. In addition, there might be some areas where the SJRWMD does not have authority to issue permits. Since stormwater programs were adopted in Florida in the early 1980s, it is a reasonable assumption that any urban land use changes will be treated with some types of BMPs. Therefore, we did a GIS comparison between 1990 and 2004 LU/LC layers, any land cover changes of residential densities or changes from rural to urban will be extracted to complement the regulatory source. Later, regulatory data and urban land cover changes data indicating BMPs treatment will be unioned and dissolved into one GIS layer.

After we produced the GIS layer of where BMPs were located, we needed to separate the data into types of BMPs for each location.

Swales: all swales-treated areas come from the permitting data. It is a common phenomenon that major roads, including interstate highways, state, and county roads are treated by swales, as it is the most appropriate BMPs for road stormwater treatment. Although it is not unusual that some sections of roads may be treated by multiple BMPs or BMPs treatment chain, nevertheless, since swales are the most common BMPs for roads, all the road features from the regulatory data source were assumed to be treated by "swales".

Dry/wet detention ponds: dry/wet detention ponds separation is totally based on the groundwater depth and hydrologic soil group data. Groundwater depth and soil types are the most important factors in designing dry/wet detention ponds. For example, a dry pond constructed at a site with a shallow groundwater table and/or low infiltration rate will not function as a dry pond, but rather as a wet pond. On the other hand, a wet pond constructed in an area with a very deep groundwater table and/or high soil infiltration rate cannot hold a permanent pool, and hence it will function as dry pond instead. Therefore, our separation of dry/wet ponds is based on functional types rather than designed types. Our assumptions are:

a. If the groundwater depth is less than 5 feet, it will be a wet pond regardless of the soil hydrologic condition;
b. If the groundwater depth is greater than 10 feet, it will be a dry pond regardless of the soil hydrologic condition;
c. If the groundwater depth is between 5 and 10 feet, then it depends on the soil hydrologic condition: if it is an "A" soil (high infiltration rate) then this site most likely will be treated by dry detention pond; otherwise, it will be a wet detention pond.

Method used to compare our results with the PBS&J method

There is very limited information regarding BMPs spatial distribution in the SJRWMD. To the best of our knowledge, so far the only information available is the Lake Jesup watershed BMPs coverage developed by PBS&J, Inc in 2004. PBS&J's BMPs coverage also includes agricultural BMPs, nursery BMPs, and conservation wetland areas as well as urban/industrial BMPs, but our results include only urban/industrial BMPs. Hence, it is necessary to adjust PBS&J results to include only urban/industrial BMPs. Furthermore, the PBS&J method had 4 more BMPs types than our method, i.e., swales/dry detention ponds, lake drainage wells, Orlando private BMPs and Orlando 100% detention (Table 4), in addition to swales, dry and wet detention ponds. Orlando private BMPs and Orlando 100% detention was ignored due to their limited usage (39 combined acres) (Table 4). Swales/dry detention ponds were lumped into swales while lake drainage wells were lumped into wet detention ponds due to their similarities. After that, the results of the BMPs coverage in the Lake Jesup watershed estimated from our method (estimated BMPs layer) were compared with those developed by PBS&J (adjusted PBS&J BMPs layer) through GIS operations. The estimated BMPs layer was unioned with adjusted PBS&J BMPs layer within ESRI ArcMap and then were compared on 1) the total BMPs-treated area; 2) the percentage of BMPs-treated area where two methods agrees on; and 3) the area where the two methods do not match at all.

Results and Discussions

Map Production

Following the method discussed in this report and the GIS procedures in the Appendix I, the BMPs distribution maps were estimated for the whole District (Figure 4), and for all nine of the major basins within the SJRWMD (Figures 5 through 13). As Table 2 indicates, in the whole SJRWMD area, only 6.5% of the total area receives urban/industrial BMPs treatment. Among the three types of BMPs, the majority of BMPs were wet detention ponds, with their area occupying about 4.55% of the total SJRWMD area, or 70% of the total BMPs-treated area. Swales comprised only a small fraction of the BMPs, about 0.2% of the total SJRWMD area or 3% of the total BMPs-treated area. The rest were occupied by dry detention ponds, about 1.7% of the total SJRWMD area or 26.8% of the BMPs-treated area (Table 2). All of these values were in line with observations that wet detention ponds are the most adopted BMPs in Florida. Although swales are one of the most recognizable BMPs in Florida, due to its nature, however, it cannot treat large-scale developed areas. Hence, the total area treated by swales is limited and mostly distributed along the major roads (Figure 4). As Figure 4 demonstrates, wet detention ponds were distributed across the whole SJRWMD area, especially in the coastal regions, and in the northern and southern portions of the SJRWMD. Dry detention ponds were more concentrated in the middle west of the SJRWMD. These results agreed very well with the distribution of hydrologic soil groups and the depths to groundwater table in the SJRWMD, i.e., the soils in middle west are mostly group “A” with high infiltration rates and the depths to groundwater table are deep (Figures 18 & 19).

Table 2. Distribution of swales, dry and wet detention ponds in the SJRWMD.

BMPs Types	Area (acres)	% of Total SJRWMD Area
Swales	15,808	0.20%
Dry Detention Ponds	135,406	1.74%
Wet Detention Ponds	354,309	4.55%
Total BMPs-treated Area	505,523	6.50%
Total SJRWMD Area	7,782,104	

Relationship between urbanization rate and BMPs-treated rate

In this report, urbanization rate and BMPs-treated rate are defined as total urban area and BMPs-treated area, respectively, divided by the total area of the basin or watershed and then multiplied by 100. The SJRWMD has a total area of 7,782,104 acres with 1,089,123 acres of urban area, around 14% urbanization rate based on 2004 land use/cover data. More than 45% of the urban area was treated by BMPs. However, the BMPs-treated rate was only about 6.5% (Table 3). Out of the nine SJRWMD's major basins, Upper St Johns River Basin (USJRB) and St Mary's River Basin had the lowest urbanization rates; both basins were 4.2% urbanized and both had very low BMPs-treated rates, 2.1% and 1.8%, respectively (Table 3). On the other hand, Middle St. Johns River Basin (MSJRB) was the most urbanized basin with a 25.7% urbanization rate: out of its total area of 753,886 acres, 193,911 acres was urban area, and 45% of the urban area was treated by BMPs (Table 3). Correspondingly, the MSJRB had the highest BMPs-treated rate in the SJRWMD, about 11.6% (Table 3). Therefore, it was clear that there was a relationship between BMPs-treated rate and urbanization rate. This trend was demonstrated in Figure

17 where the BMPs-treated rate was significantly and positively correlated with urbanization rate with a linear relationship: Y (BMPs-treated rate) = 0.483 * X (urbanization rate) - 0.001 ($p < 0.001$ and $R^2 = 0.95$), which means the higher the urbanization rate; the higher the BMPs-treated rate in the basin.

Table 3. Major basin's urban and BMPs-treated areas (acres) and their respective percentages.

Basins	Total Area	Urban Area	Urban % of Total Area	BMPs-treated Area	BMPs-treated % of Total Area	BMPs-treated % of Urban Area
SJRWMD	7,782,104	1,089,123	14.0%	505,523	6.5%	45.2%
USJRB	1,104,826	46,802	4.2%	22,658	2.1%	48.4%
St Mary's River	609,394	25,837	4.2%	10,952	1.8%	42.4%
Ocklawaha River	1,353,468	162,763	12.0%	82,032	6.1%	50.4%
Northern Coastal	468,875	94,680	20.2%	54,129	11.5%	57.2%
Nassau River	271,458	24,266	8.9%	11,566	4.3%	47.7%
MSJRB	753,886	193,911	25.7%	87,250	11.6%	45.0%
Lake George	522,256	32,411	6.2%	11,634	2.2%	35.9%
LSJRB	1,763,317	284,449	16.1%	129,300	7.3%	66.7%
Indian River Lagoon	743,651	138,973	18.7%	57,884	7.8%	41.7%

Comparison between this method and PBS&J method

PBS&J results: the BMPs map developed by PBS&J has a few more BMPs types than our method besides the three common BMPs types, i.e., swales, dry detention ponds and wet detention ponds. In addition, PBS&J picked up some local, specific BMPs types, such as Orlando 100% detention, and Orlando private BMPs, which was specific for the Orlando area. These two local BMPs types covered a combined area of 39 acres, which was less than 0.04% of total area of Lake Jesup watershed (Table 4). In addition, PBS&J had lake drainage wells as special BMPs in Lake Jesup watershed, which was located at the southwest of the watershed draining about 3,074 acres, about 3.15% of the total watershed area (Table 4). Although this was a major BMPs feature in the Lake Jesup watershed that could retain stormwater and pollutants, however, there are concerns over their effects on groundwater quality (Gao 2005). Hence, future application or application outside Lake Jesup watershed is discouraged and will not be permitted any more. PBS&J also included a combination of swale/dry detention ponds as independent BMPs although it only covered 311 acres, or about 0.32% of the watershed area. Hence, swales, dry detention ponds and wet detention ponds were the more universal and common BMPs types. Also, the PBS&J method included agricultural, nursery, pasture BMPs in addition to urban/industrial BMPs (Table 4 & 5).

Our results: on the other hand, our method maps only urban/industrial BMPs, i.e., BMPs in residential, industrial and commercial areas (Table 6). Hence, PBS&J results had to be adjusted to urban/industrial area as well as lumping swales/dry detention ponds and lake drainage wells into swales and wet detention ponds, respectively, as described in the *Methodology* section before being compared with our estimated results. After adjustment, PBS&J recorded 1,200 acres, 6,973 acres and 11,807 acres, in comparison with our results, 1,014 acres, 5,556 acres and 11,531 acres for swales, dry detention ponds, and wet detention ponds, respectively (Table 7). Our results compared favorably with

PBS&J's, especially for wet detention ponds, where the difference was less than 1.6%. The total BMPs-treated area estimated by our method was 18,101 acres, or 18.55% of the total Lake Jesup watershed area in comparison with the adjusted PBS&J total of 19,980 acres, or 20.48% of the total watershed area (Table 7). The difference between the total BMPs-treated areas by these two methods was less than 10%. The match study between these two methods demonstrated that 10,352 acres, out of 18,101 acres total BMPs-treated area matched on the locations, which was roughly 57% (Table 7 & 8). Half of this match, or 5,753 acres, was exact match, i.e., swale to swale, dry detention pond to dry detention pond, and wet detention pond to wet detention pond (Table 8).

Frequency study at sub-watershed level at selected basins

To further study the distribution of BMPs in the SJRWMD, several representative basins were selected for further studies at the sub-watershed level, i.e., Lake Jesup basin, and three other major basins, namely, Lower St. Johns River Basin (LSJRB), Upper St. Johns River Basin (USJRB), and Indian River Lagoon Basin. The Lake Jesup basin is an example of a highly urbanized basin with the highest urbanization rate, 46.8%, while the USJRB is an example for the least developed area with the least urbanization rate, 4.2% (Table 3). For each basin, there are three histograms for the frequency distribution of urbanization rate, BMPs to urban area percentage, and BMPs-treated rate. The X-axis represents the percentage range for urbanization rate, BMPs to urban area, and BMPs-treated rate. For example, 10 represents 0 to 10%, 20 represents 10 to 20%, etc. The left Y-axis is the frequency percentage, which is calculated as the number of sub-watersheds falling into each incremental 10% range on X-axis divided by the total number of sub-watersheds in that basin. The right Y-axis is the cumulative frequency distribution. The table following each histogram displays the same information as the histogram.

In the highly urbanized Lake Jesup basin, at least 18.6% of the total area was treated by BMPs (Table 7). Out of its 39 sub-watersheds, 64% of the sub-watersheds had below a 20% BMPs-treated rates while 36% of the sub-watersheds had above a 20% BMPs treated rates (Figure 22). On the other hand, the least urbanized USJRB had the least BMPs-treated rate, i.e., 2.1%; out of its total 110 sub-watersheds, 92.7%, or 102 sub-watersheds had less than a 10% BMPs-treated rate; 5 sub-watersheds had a 10% to 20% BMPs-treated rate; and the remaining 3 sub-watersheds had a 20% to 30% BMPs-treated rate (Figure 25). The other two basins had BMPs-treated rates between these two extremes (Figures 26, 27, 28, 29, 30 and 31).

Conclusions

Overall, our method produced reasonably accurate and detailed information regarding BMPs spatial distribution in the SJRWMD. The difference of the total BMPs-treated area in the Lake Jesup watershed between these two methods was less than 10%, which was very good considering that our method can reproduce the spatial distribution of BMPs in the SJRWMD within two days, while it will take 40 man years to finish the same task using the PBS&J method. Our estimated results were also in line with our and other SJRWMD engineers' observations. What is more important, our method's accuracy depends upon the source data's accuracy, especially regulatory data. Once more accurate data becomes available, our method can be used to reproduce more accurate BMPs distribution maps for the whole SJRWMD area within two days.

Future Directions

In the future, we can improve our product (the estimated BMPs spatial distribution in the SJRWMD) as more data become available. The staff at Division of Regulatory Information Management at the SJRWMD is striving to digitize all the most recent or older permits or permit applications and then update the permit GIS database every week. In addition, they are converting the stormwater GIS layer from points feature to polygon feature. Furthermore, at our request, they are adding a new attribute to the GIS layer: stipulating in their coverage data, which BMPs are going to be implemented once the lands have been developed. As a result, more BMPs types will be delineated in the estimated map, including BMPs treatment chains, infiltration trenches, etc, as well as the three BMPs discussed in this report. What is more important, the separation of the BMPs types will not be based on the assumptions described in this report, but based on the real data. This will tremendously improve our result; it will be more accurate and detailed in the future. Furthermore, with our method automatic GIS processes can be enabled by Visual Basic for Application codes. In this case the whole GIS calculation described in Appendix I can be finished within a few hours.

Table 4. BMPs distributions in the Lake Jesup watershed estimated by PBS&J method.

BMPs Types	Area (acre)	% Basin Area
Swales	1,214	1.24%
Swales/Dry Detention Ponds	311	0.32%
Dry Detention Ponds	11,040	11.31%
Wet Detention Ponds	12,156	12.46%
Lake Drainage Wells	3,074	3.15%
Orlando 100% Detention	33	0.03%
Orlando Private BMPs	6	0.01%
Total BMPs-treated Area	27,833	28.53%
Total Lake Jesup Watershed Area	97,569	

Table 5. The relationship between 2004 land cover and BMPs distribution estimated by PBS&J method.

BMPs Types	2004 Land Cover Types	Area (acres)
Swales	N/A	22
Swales	Low Residential Density	144
Swales	Medium Residential Density	13
Swales	High Residential Density	49
Swales	Industrial and Commercial	6
Swales	Animal Production	9
Swales	Forest	30
Swales	Water	2
Swales	Wetlands	35
Dry Detention Ponds	N/A	43
Dry Detention Ponds	Low Residential Density	1,417
Dry Detention Ponds	Medium Residential Density	2,487
Dry Detention Ponds	High Residential Density	793
Dry Detention Ponds	Industrial and Commercial	2,268
Dry Detention Ponds	Mining	7
Dry Detention Ponds	Open Land and Barren Land	272
Dry Detention Ponds	Animal Production	344
Dry Detention Ponds	Agricultural General	193
Dry Detention Ponds	Agricultural Tree Crop	42
Dry Detention Ponds	Rangeland	195
Dry Detention Ponds	Forest	518
Dry Detention Ponds	Water	492
Dry Detention Ponds	Wetlands	1,968
Swales/Dry Detention Ponds	N/A	20
Swales/Dry Detention Ponds	Low Residential Density	89
Swales/Dry Detention Ponds	Medium Residential Density	531
Swales/Dry Detention Ponds	High Residential Density	35
Swales/Dry Detention Ponds	Industrial and Commercial	332
Swales/Dry Detention Ponds	Open Land and Barren Land	30
Swales/Dry Detention Ponds	Animal Production	0
Swales/Dry Detention Ponds	Agricultural General	36

BMPs Types	2004 Land Cover Types	Area (acres)
Swales/Dry Detention Ponds	Agricultural Tree Crop	4
Swales/Dry Detention Ponds	Rangeland	3
Swales/Dry Detention Ponds	Forest	45
Swales/Dry Detention Ponds	Water	26
Swales/Dry Detention Ponds	Wetlands	63
Wet Detention Ponds	N/A	70
Wet Detention Ponds	Low Residential Density	200
Wet Detention Ponds	Medium Residential Density	5,682
Wet Detention Ponds	High Residential Density	2,165
Wet Detention Ponds	Industrial and Commercial	1,529
Wet Detention Ponds	Mining	6
Wet Detention Ponds	Open Land and Barren Land	306
Wet Detention Ponds	Animal Production	8
Wet Detention Ponds	Agricultural General	214
Wet Detention Ponds	Agricultural Tree Crop	34
Wet Detention Ponds	Rangeland	110
Wet Detention Ponds	Forest	285
Wet Detention Ponds	Water	595
Wet Detention Ponds	Wetlands	952
other BMPs	Medium Residential Density	2
other BMPs	Industrial and Commercial	36
other BMPs	Water	2
Lake Drainage Area	N/A	30
Lake Drainage Area	Medium Residential Density	1,261
Lake Drainage Area	High Residential Density	97
Lake Drainage Area	Industrial and Commercial	868
Lake Drainage Area	Open Land and Barren Land	21
Lake Drainage Area	Agricultural General	95
Lake Drainage Area	Rangeland	36
Lake Drainage Area	Forest	21
Lake Drainage Area	Water	623
Lake Drainage Area	Wetlands	23

Table 6. The relationship between 2004 land cover and BMPs distribution estimated by our method

BMPs Types	2004 Land Cover Types	Area (acres)
Swales	Industrial and Commercial	1,014
Dry Detention Ponds	Low Residential Density	265
Dry Detention Ponds	Medium Residential Density	2,584
Dry Detention Ponds	High Residential Density	1,029
Dry Detention Ponds	Industrial and Commercial	1,678
Dry Detention Ponds	Mining	0
Wet Detention Ponds	Low Residential Density	837
Wet Detention Ponds	Medium Residential Density	4,951
Wet Detention Ponds	High Residential Density	2,831
Wet Detention Ponds	Industrial and Commercial	2,905
Wet Detention Ponds	Mining	7

Table 7. Comparison of BMPs distribution in the Lake Jesup watershed between our method and adjusted PBS&J method. The result of BMPs distribution from PBS&J method was adjusted to urban areas, excluding any agriculture, forestry, nursery, water or wetland areas.

BMPS Types	Area (acre)	% Basin area	Area (acres)	% Basin Area
	This Method		Adjusted PBS&J Method	
Swales	1,014	1.04%	1,200	1.23%
Dry Detention Ponds	5,556	5.69%	6,973	7.15%
Wet Detention Ponds	11,531	11.82%	11,807	12.10%
Total BMPs-treated Area	18,101	18.55%	19,980	20.48%
Total Lake Jesup Watershed Area	97,569			

Table 8. BMPs Match study between our method and adjusted PBS&J method.

BMPs Distribution Estimated by		Areas (acre)	% Basin Area
Our Method	**PBS&J Method**		
No BMPs	BMPs	17,478	17.91%
BMPs	No BMPs	7,746	7.94%
Swales	Swales	17	0.02%
Swales	Dry Detention Ponds	36	0.04%
Swales	Wet Detention Ponds	189	0.19%
Dry Detention Ponds	Swales	176	0.18%
Dry Detention Ponds	Dry Detention Ponds	968	0.99%
Dry Detention Ponds	Wet Detention Ponds	1,699	1.74%
Wet Detention Ponds	Swales	99	0.10%
Wet Detention Ponds	Dry Detention Ponds	2,400	2.46%
Wet Detention Ponds	Wet Detention Ponds	4,768	4.89%
Total Exact Match		5,753	5.90%
Total Dry/Wet Ponds Match		9,835	10.08%
BMPs/BMPs Match		10,352	10.61%
Total Lake Jesup Watershed Area		97,569	17.91%

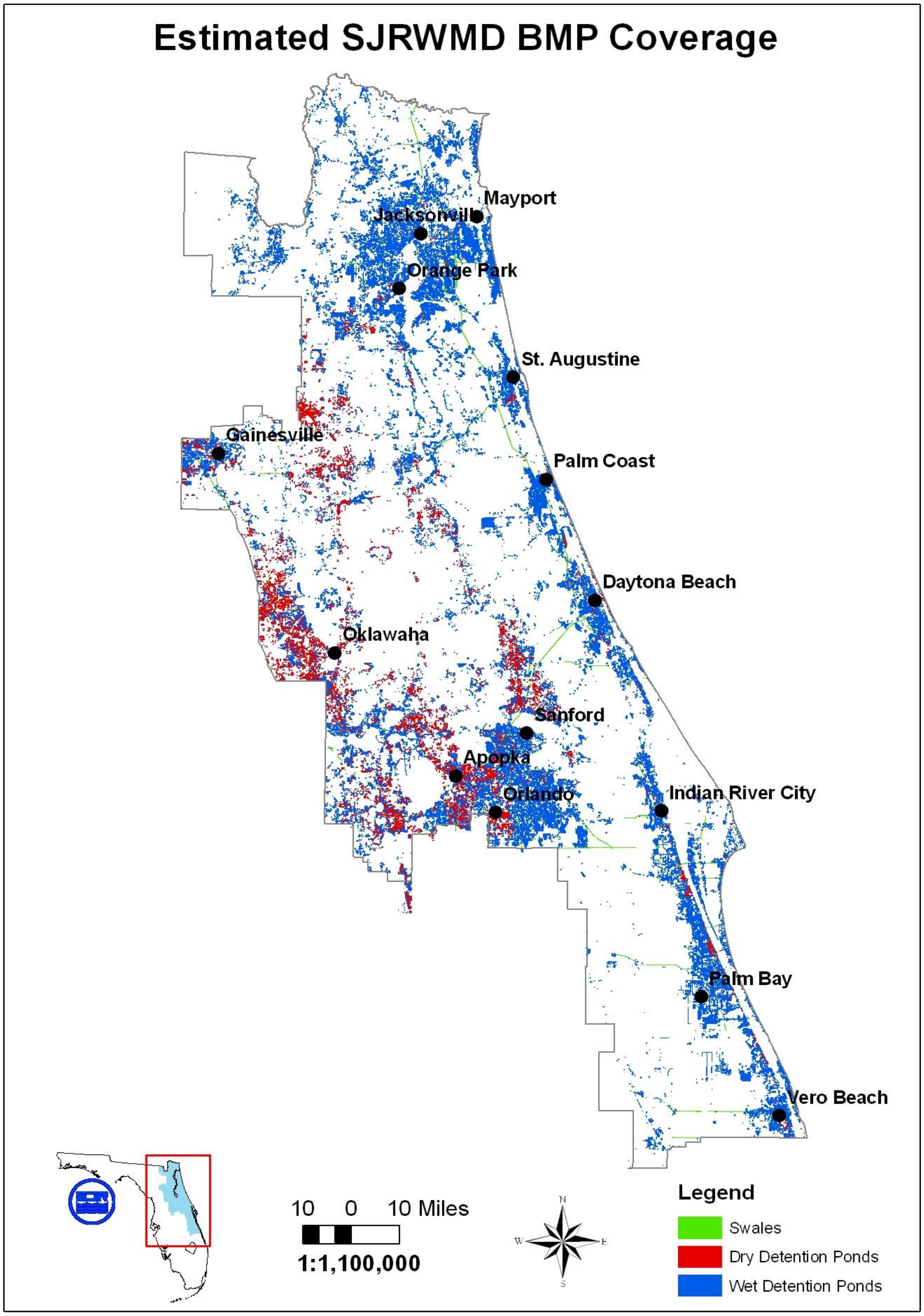


Figure 4. Spatial distribution of the stormwater best management practices in the St Johns River Water Management District.

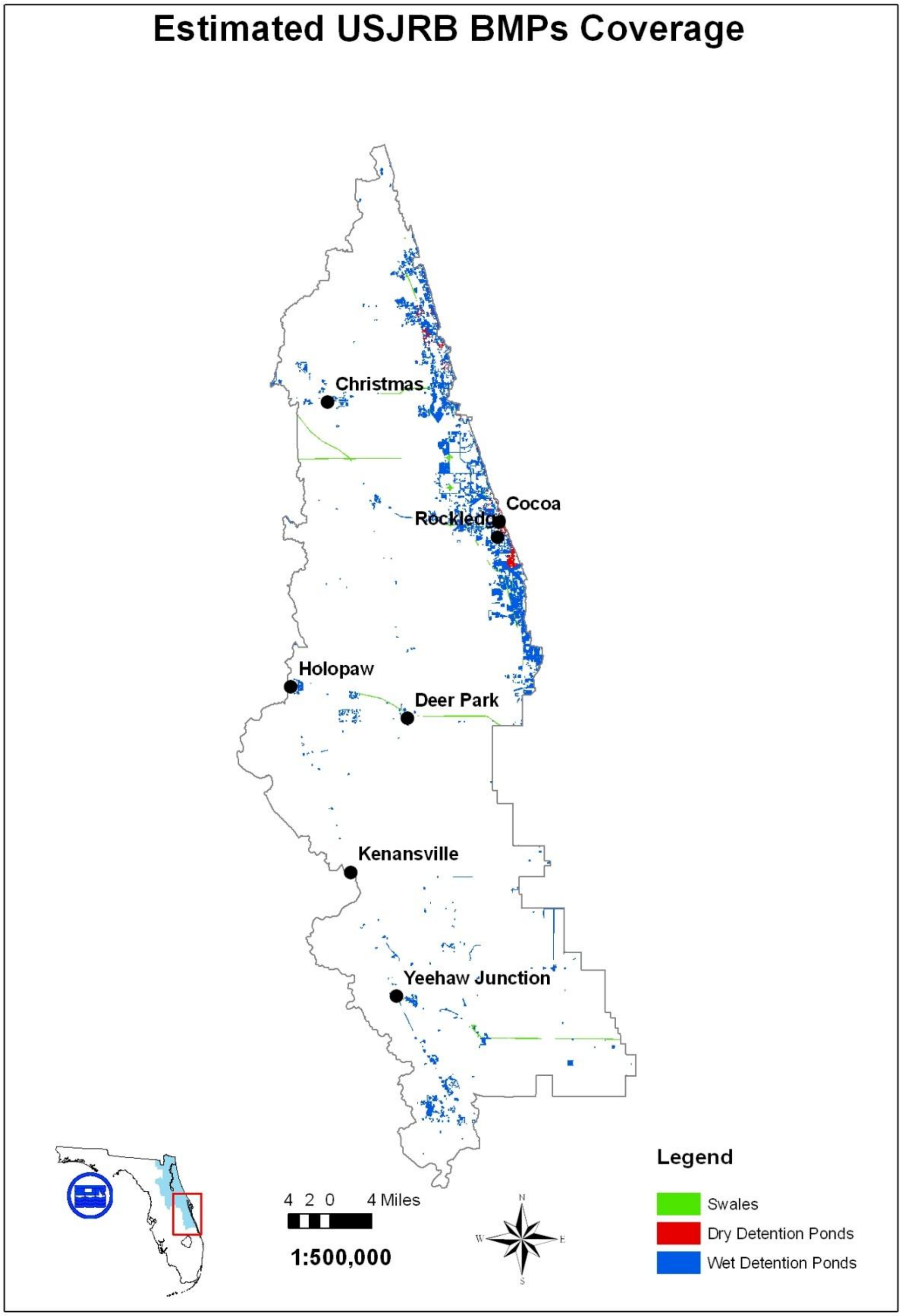


Figure 5. Spatial distribution of the stormwater best management practices in the Upper St. Johns River Basin (USJRB).

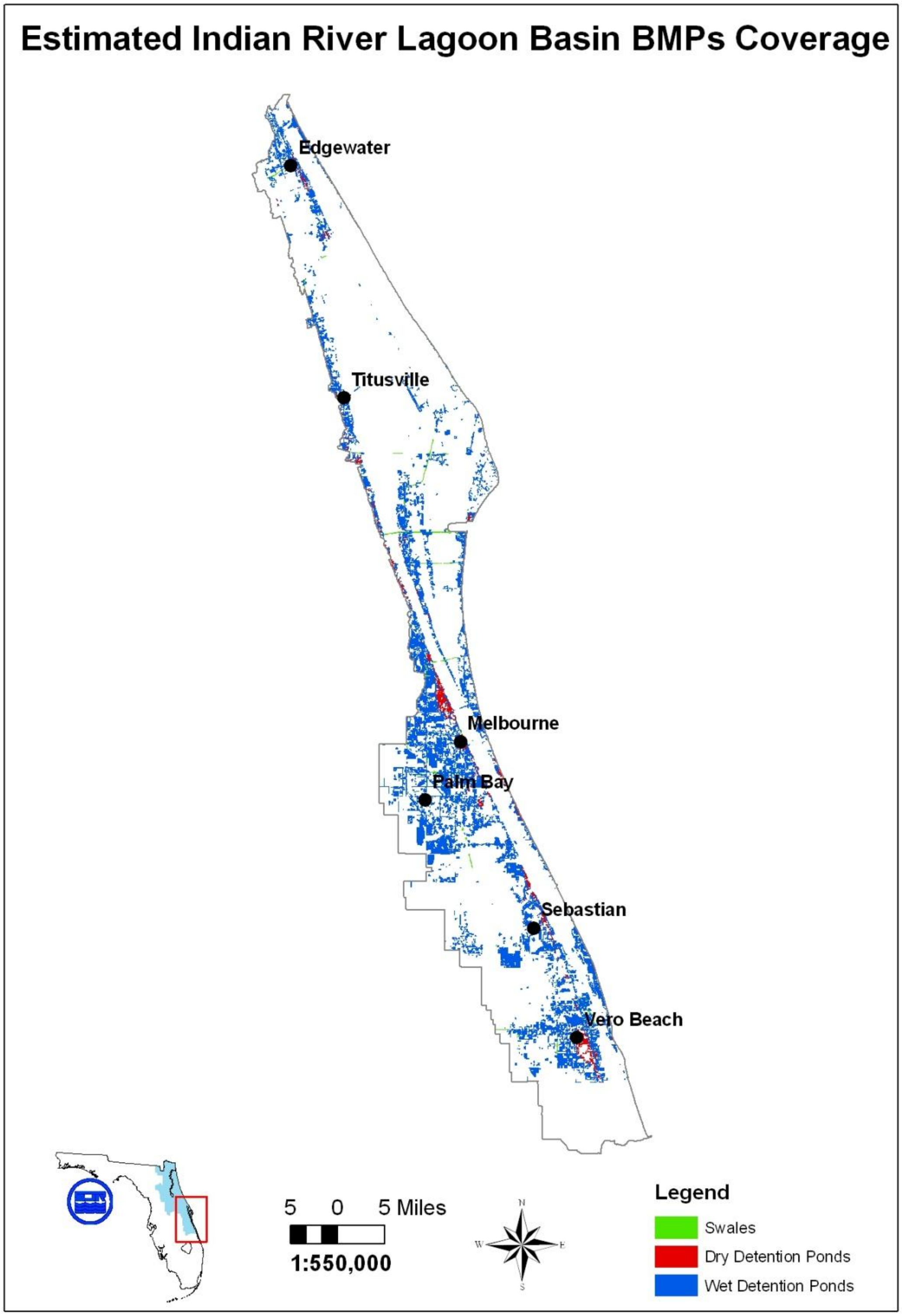


Figure 6. Spatial distribution of the stormwater best management practices in the Indian River Lagoon Basin.

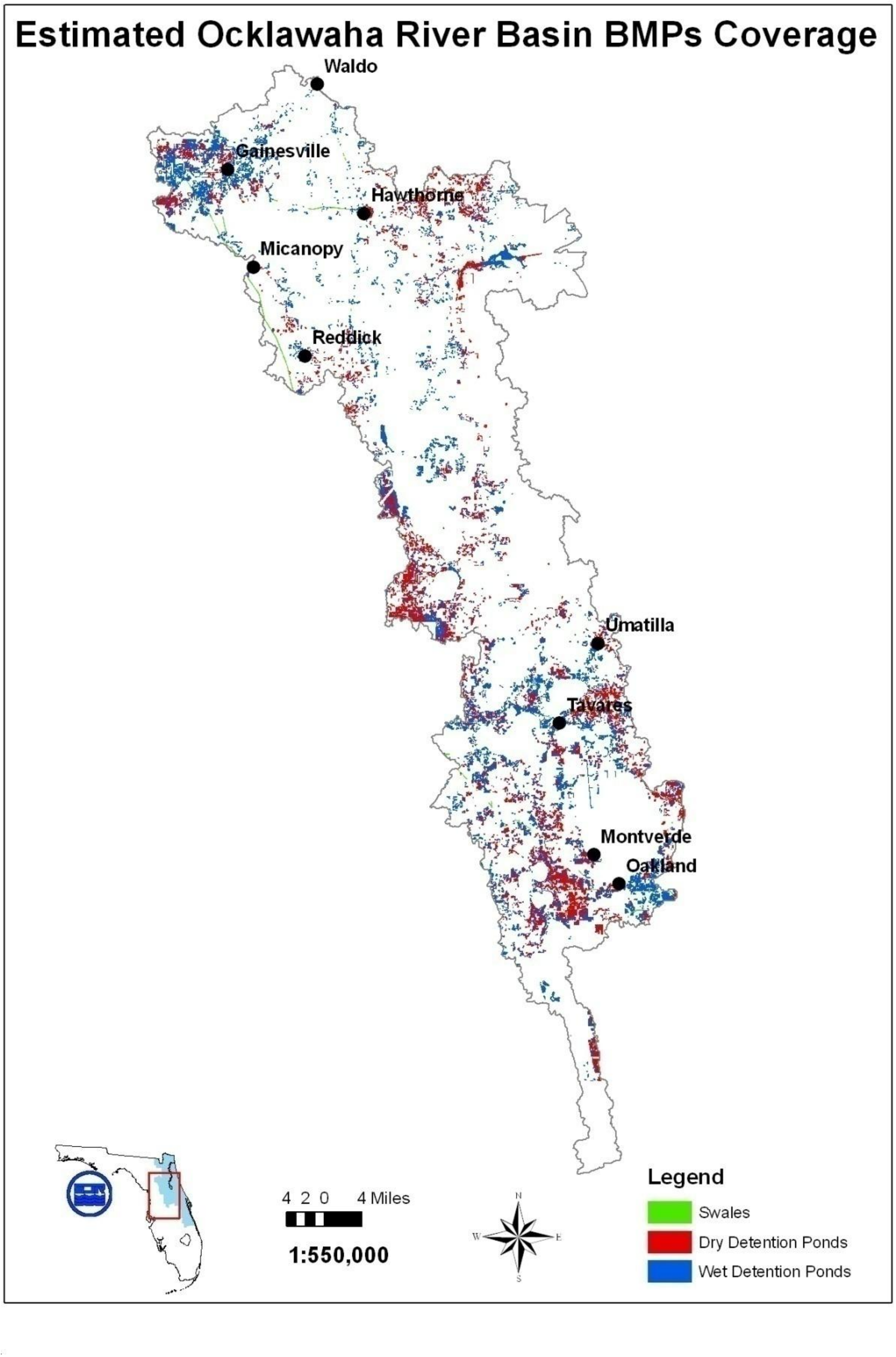


Figure 7. Spatial distribution of the stormwater best management practices in the Ocklawaha River Basin.

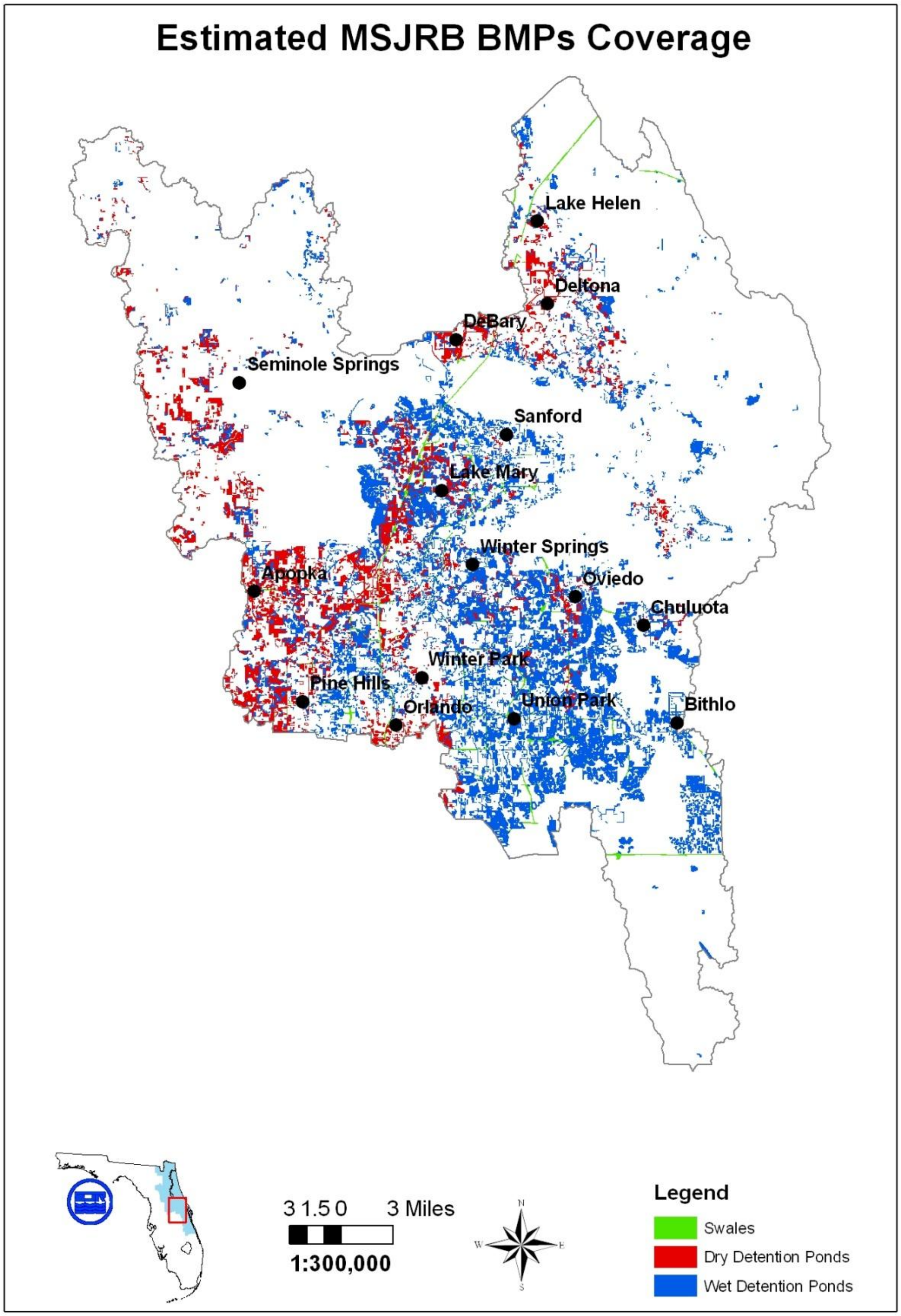


Figure 8. Spatial distribution of the stormwater best management practices in the Middle St. Johns River Basin (MSJRB).

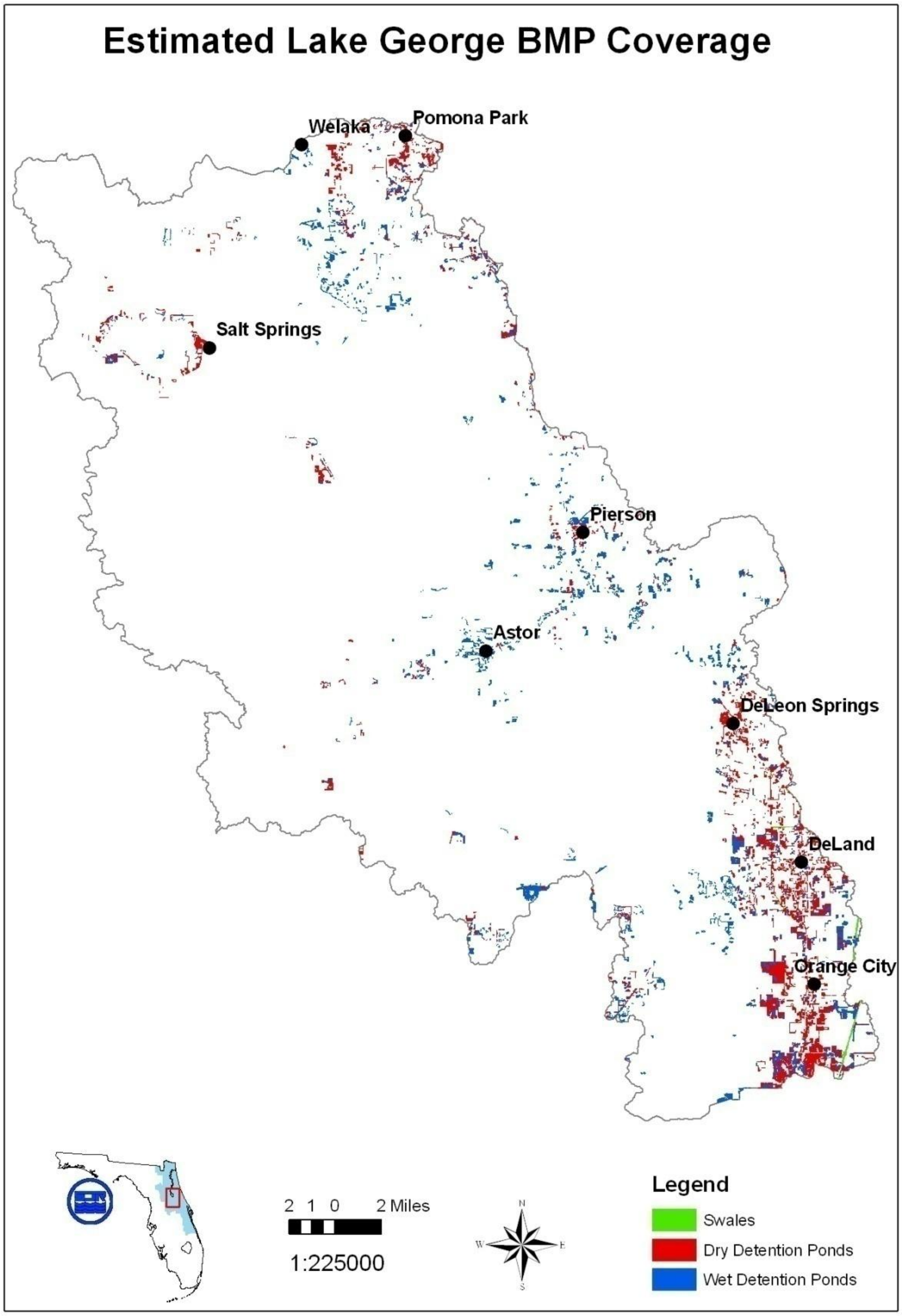


Figure 9. Spatial distribution of the stormwater best management practices in the Lake George Basin.

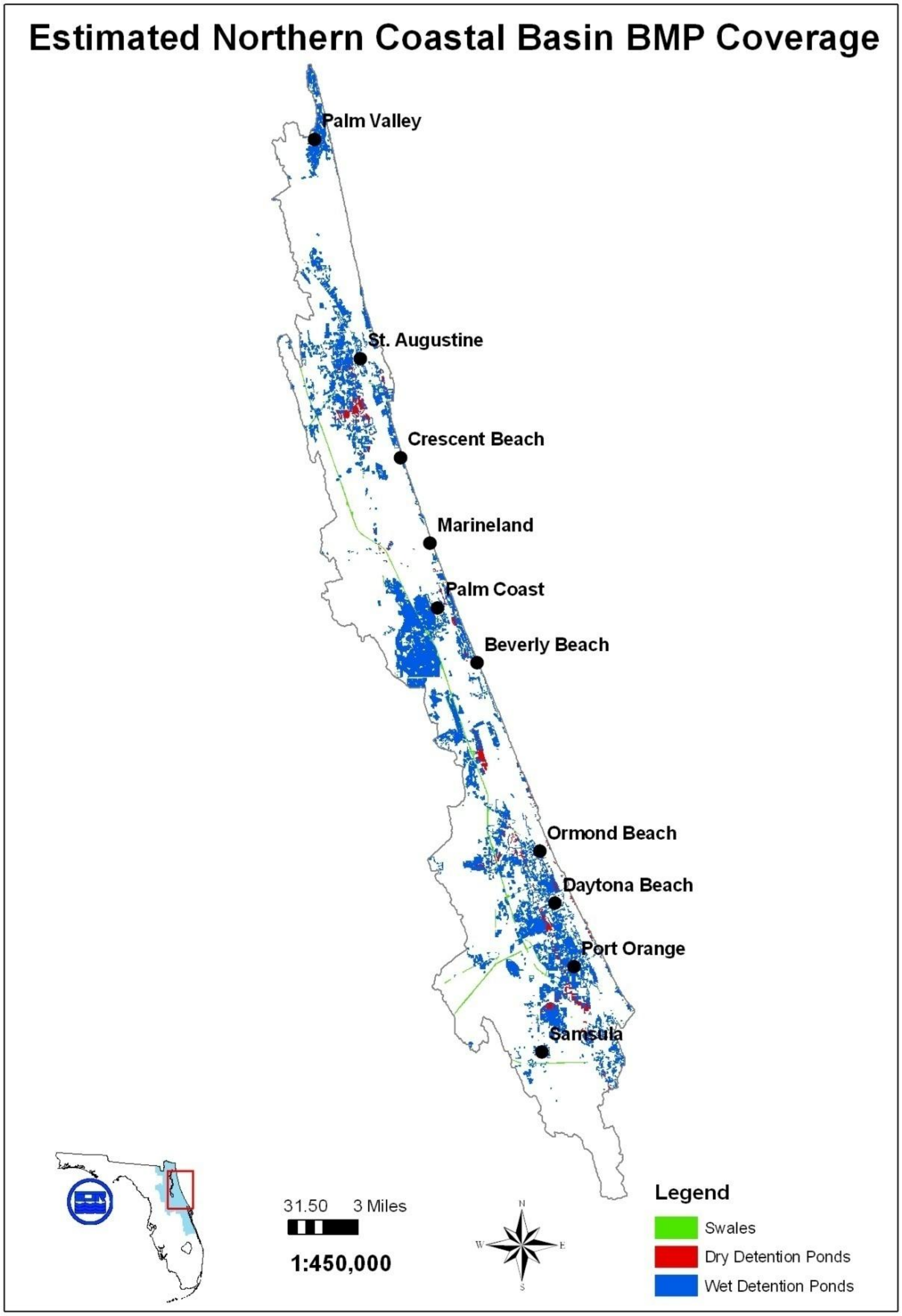


Figure 10. Spatial distribution of the stormwater best management practices in the Northern Coastal Basin.

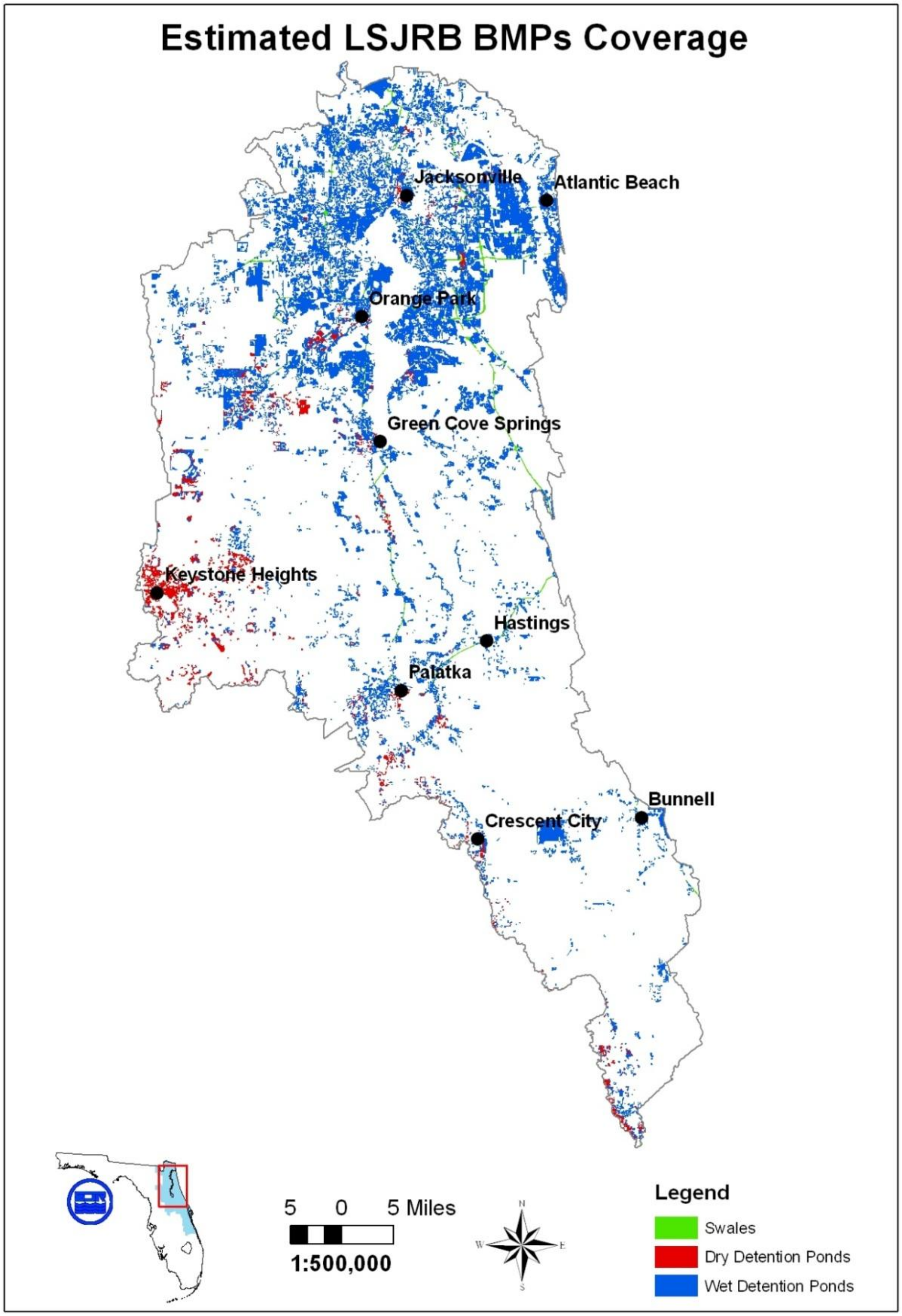


Figure 11. Spatial distribution of the stormwater best management practices in the Lower St. Johns River Basin (LSJRB).

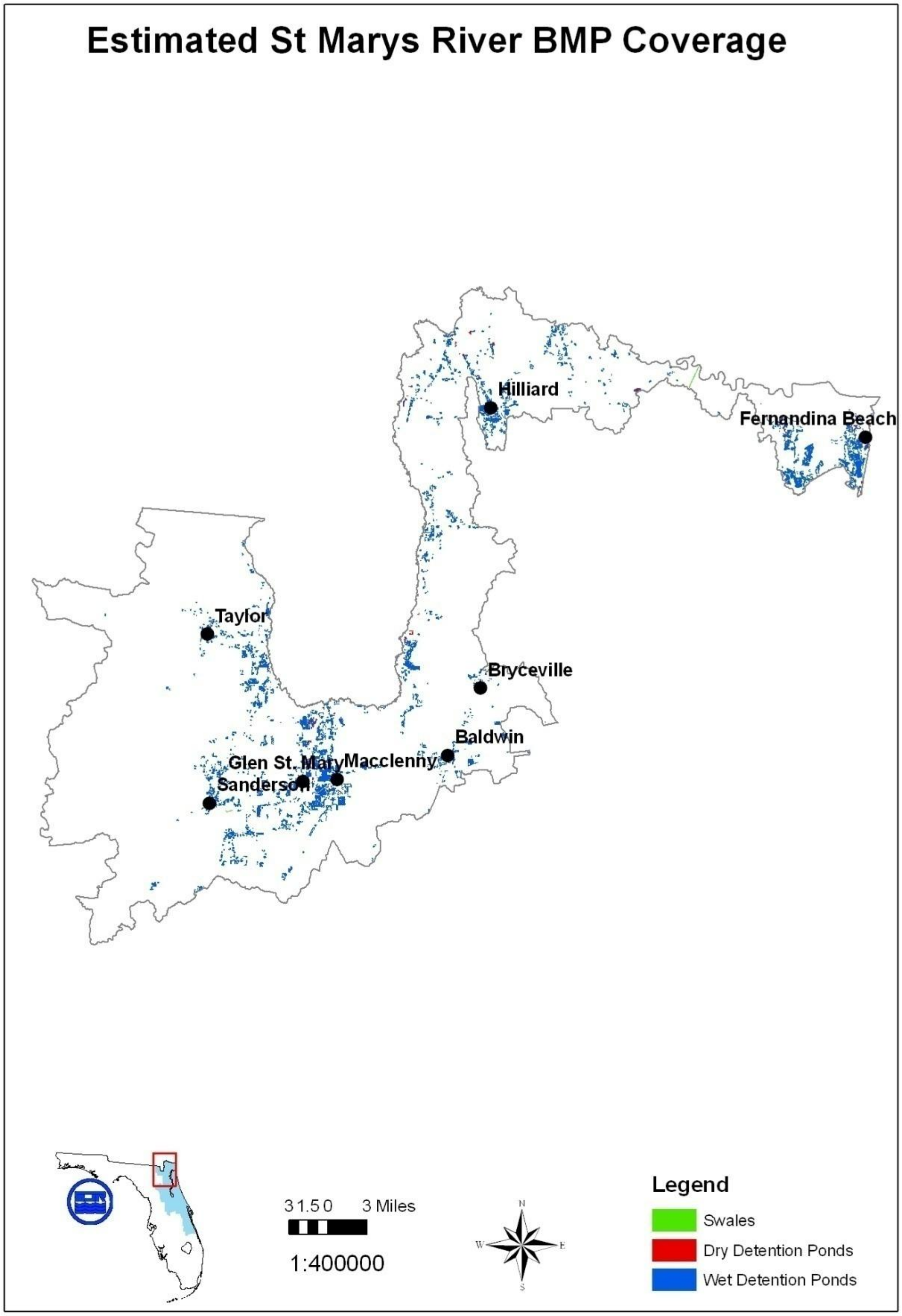


Figure 12. Spatial distribution of the stormwater best management practices in the St Marys River Basin.

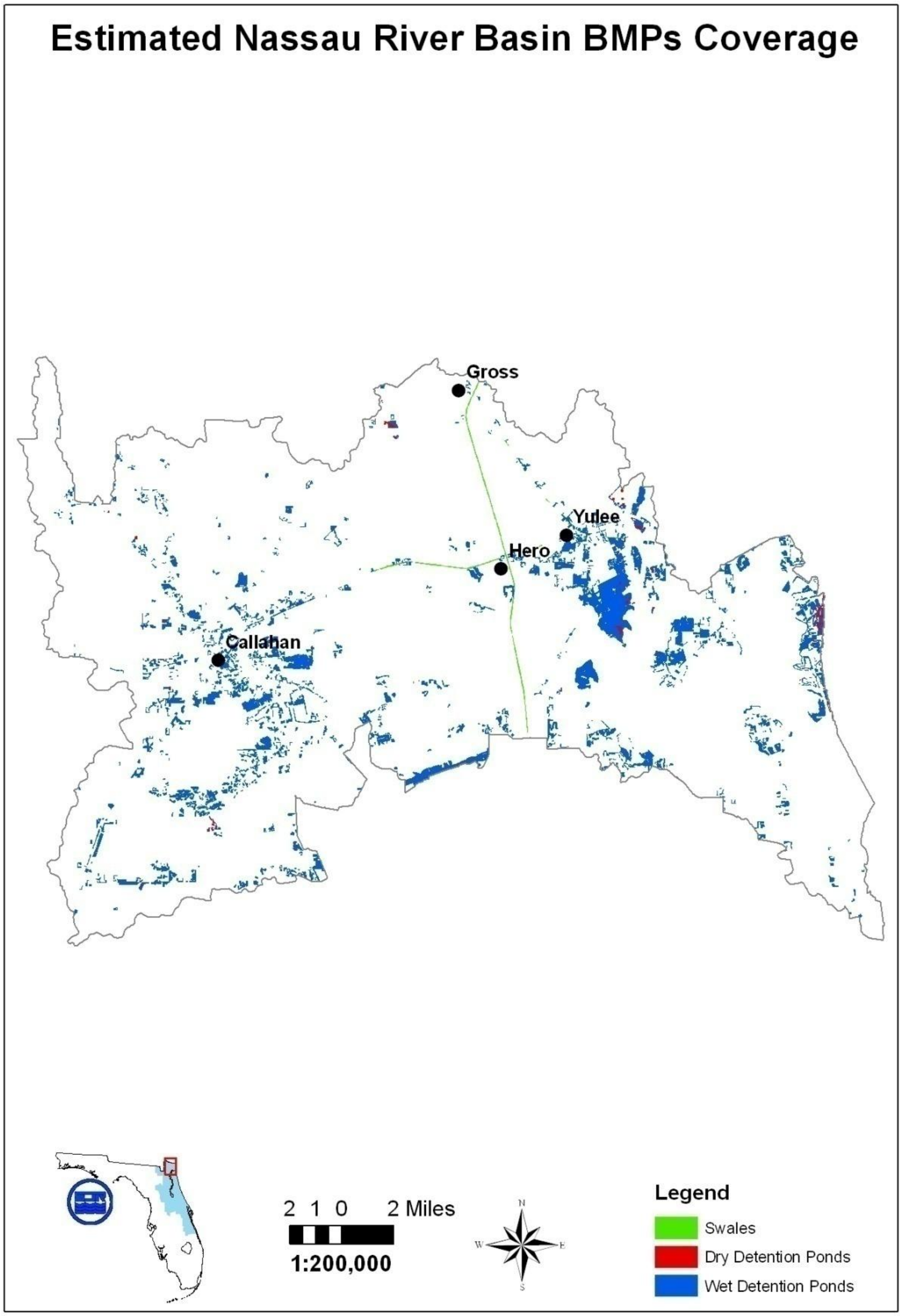


Figure 13. Spatial distribution of the stormwater best management practices in the Nassau River Basin.

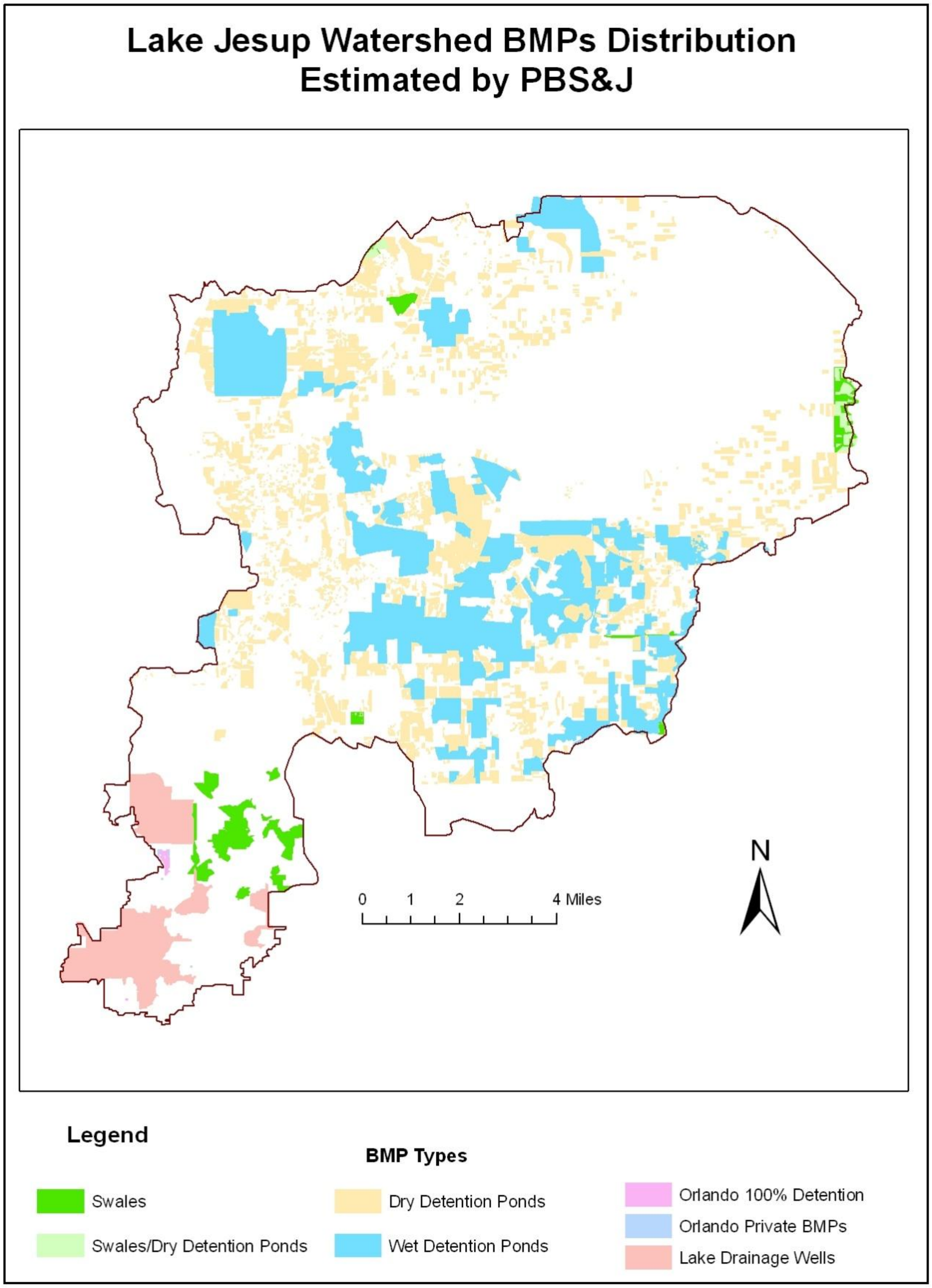


Figure 14. Lake Jesup watershed stormwater best management practices distribution developed by PBS&J, Inc.

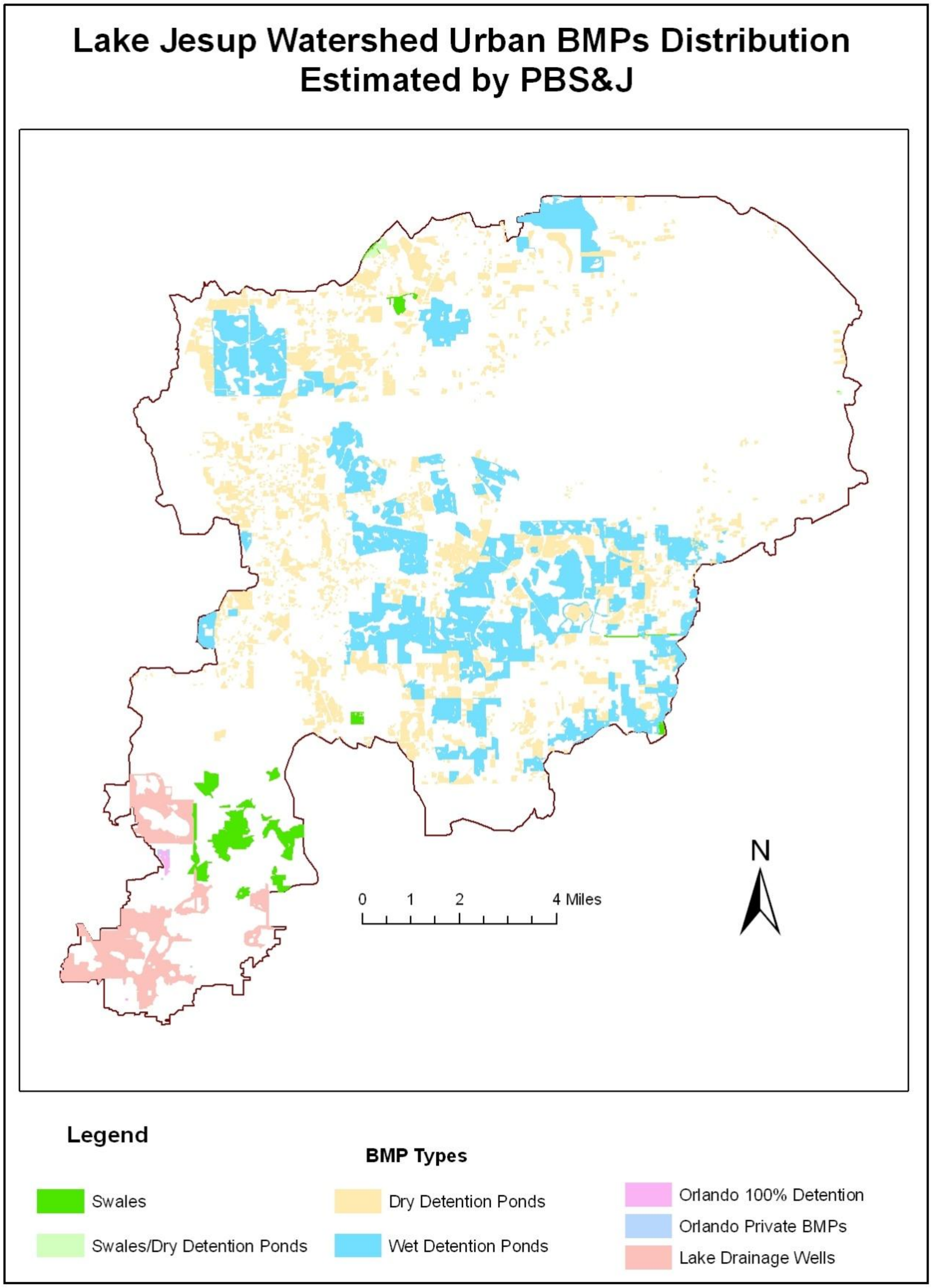


Figure 15. Lake Jesup watershed stormwater best management practices urban distribution developed by PBS&J, Inc.

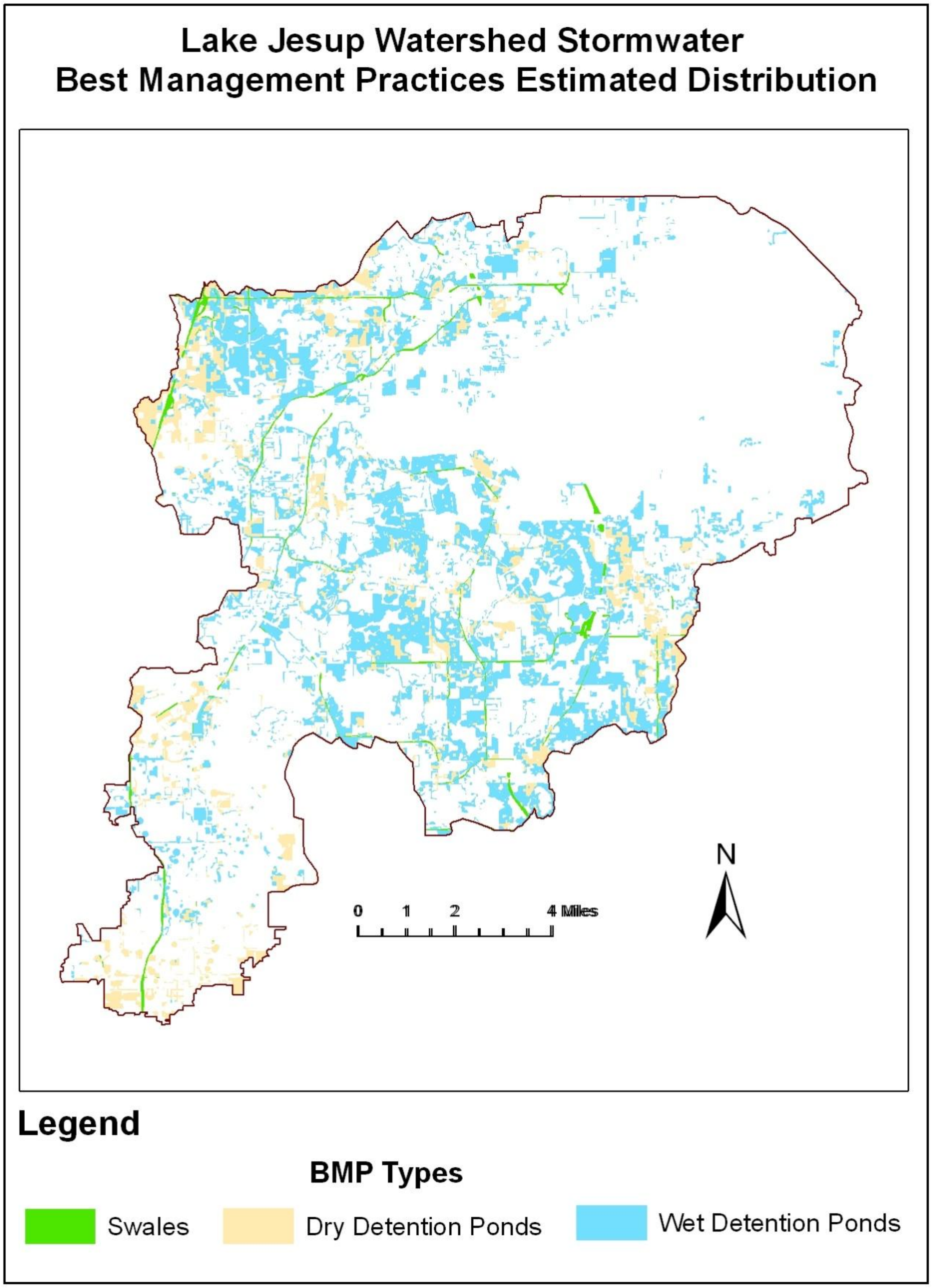


Figure 16. Lake Jesup watershed stormwater best management practices distribution estimated by the reported method.

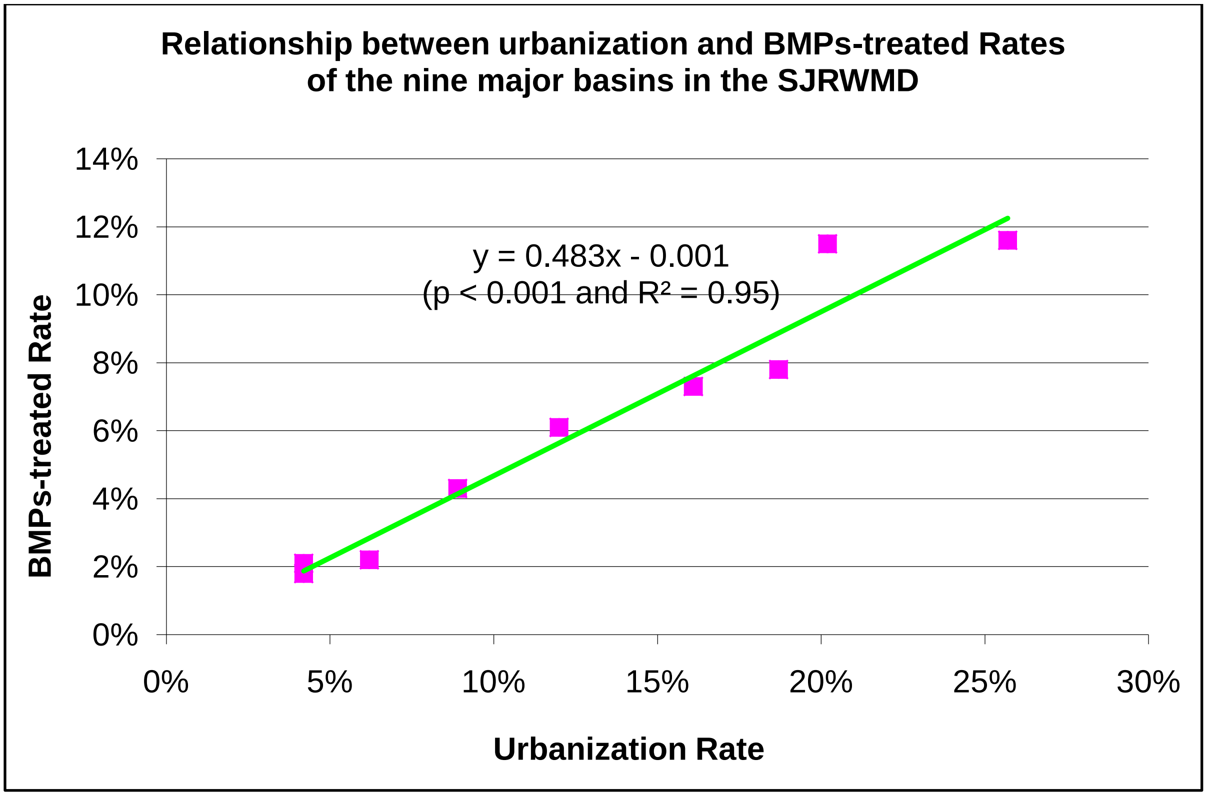


Figure 17. Relationship between urbanization and BMPs-treated rates of the nine major basins in the SJRWMD.

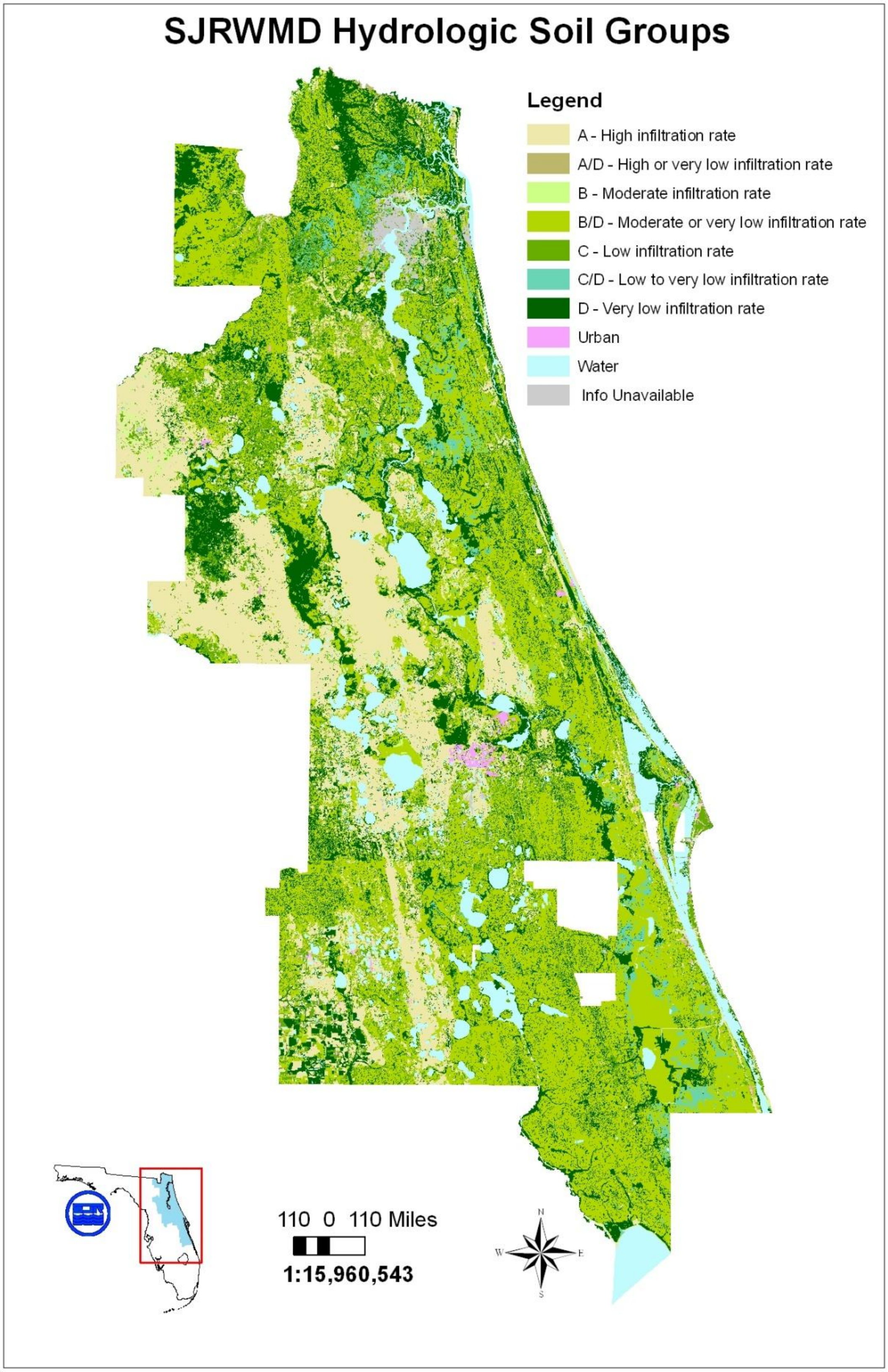


Figure 18. Distribution of hydrologic soil groups in the St Johns River Water Management District.

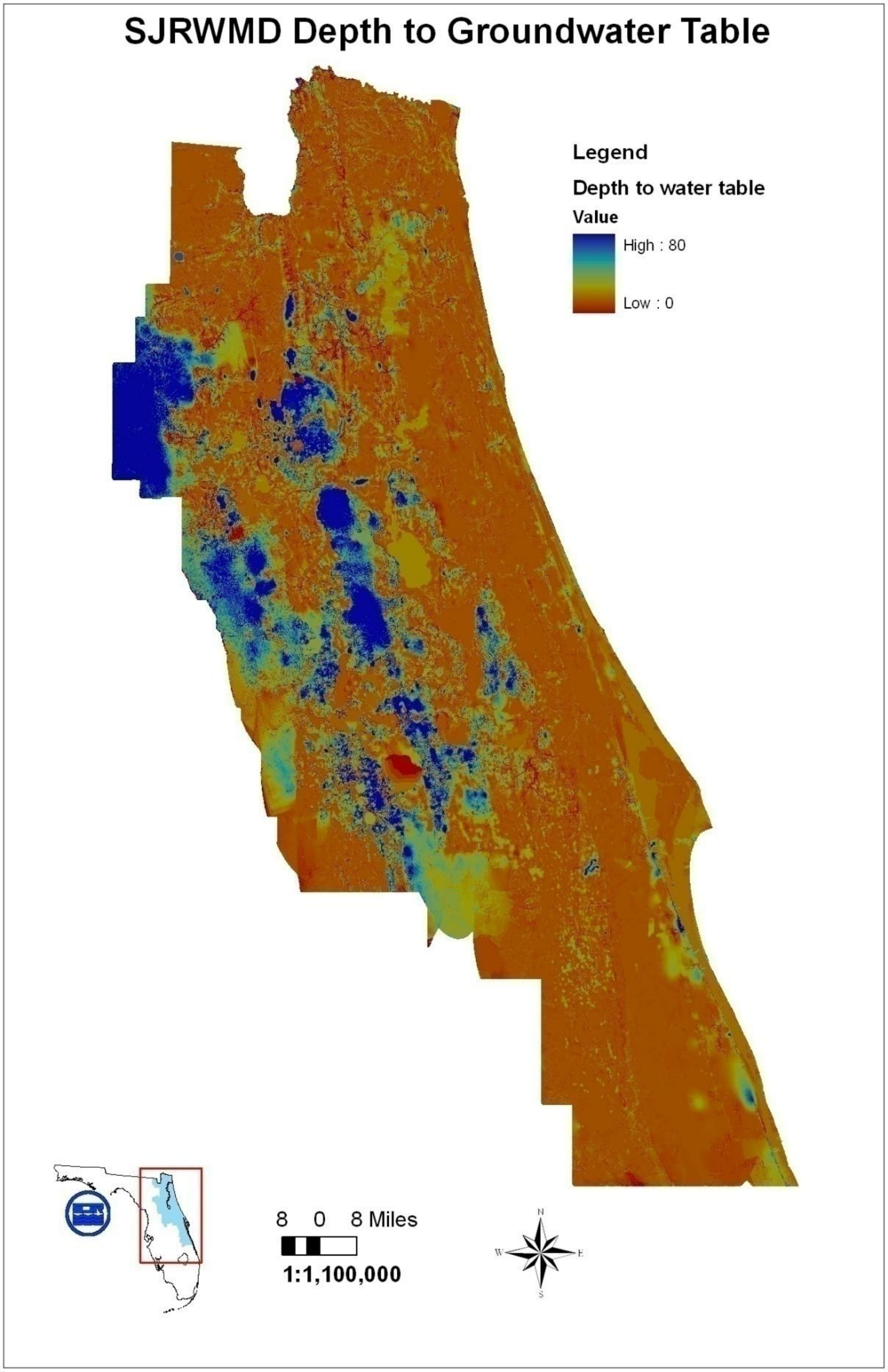
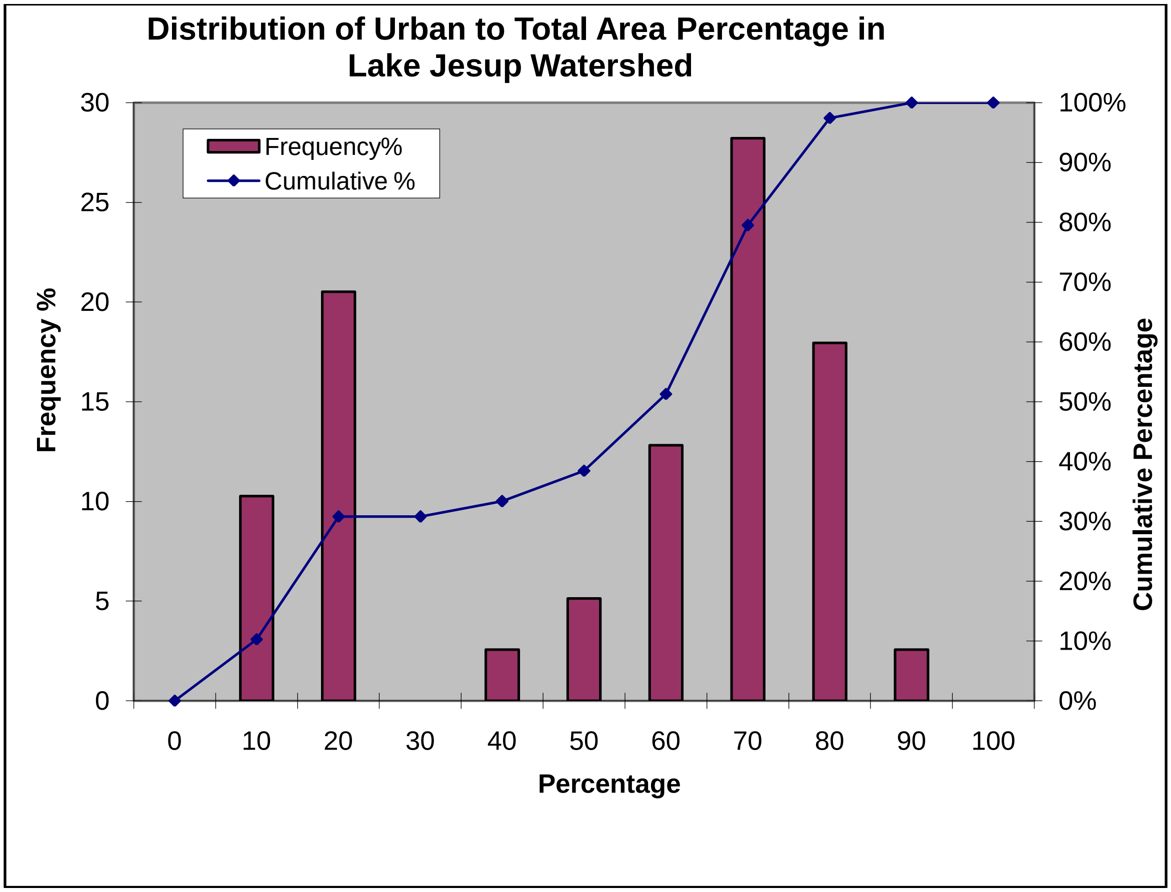


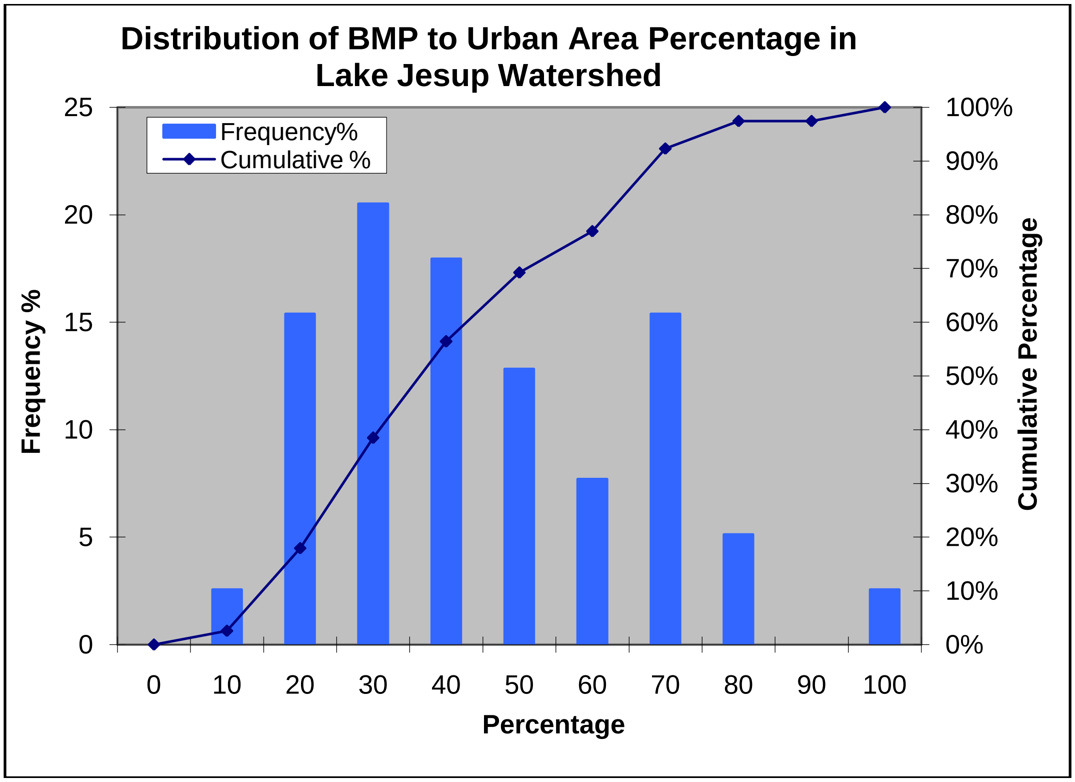
Figure 19. Distribution of the depth to groundwater table in the SJRWMD.

Figure 20. Lake Jesup Watershed: urbanization rate (%).



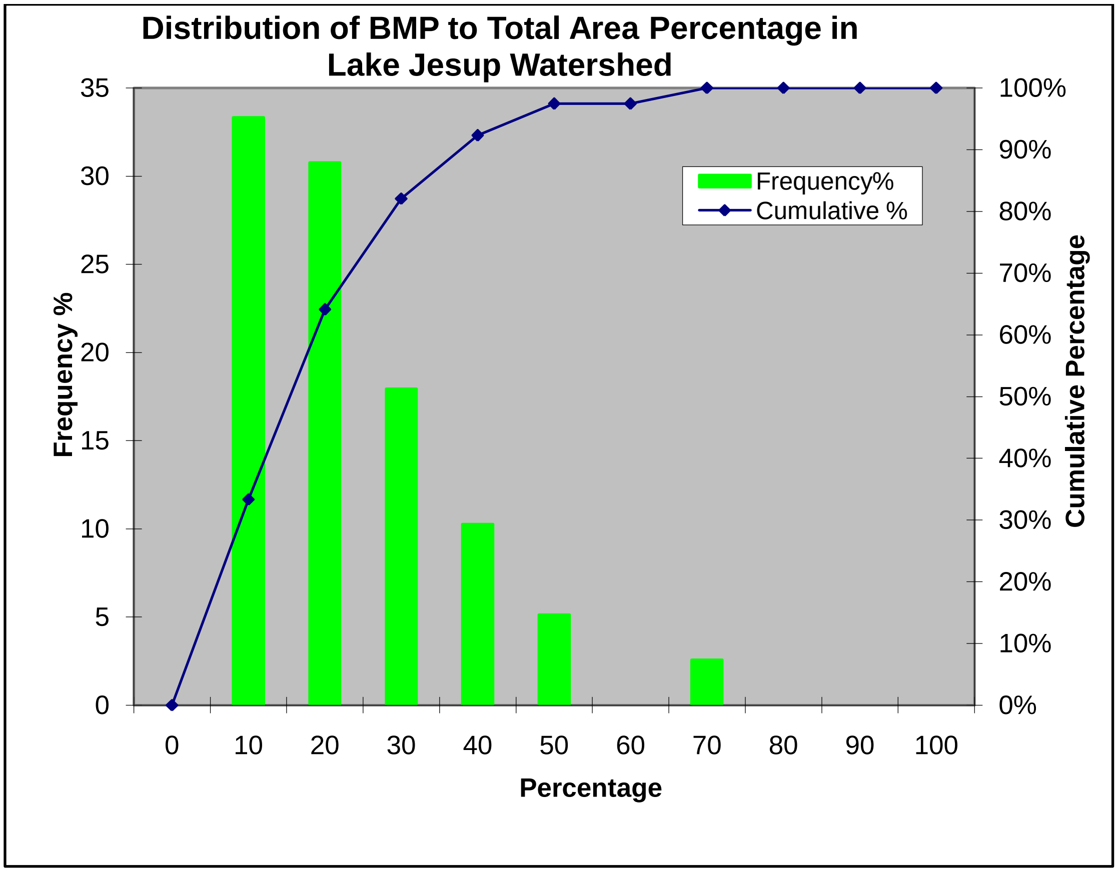
Percentage	*Frequency*	*Frequency%*	*Cumulative %*
0	0	0.00	0.00%
10	4	10.26	10.26%
20	8	20.51	30.77%
30	0	0.00	30.77%
40	1	2.56	33.33%
50	2	5.13	38.46%
60	5	12.82	51.28%
70	11	28.21	79.49%
80	7	17.95	97.44%
90	1	2.56	100.00%
100	0	0.00	100.00%
total sub-watershed	39		

Figure 21. Lake Jesup Watershed: BMPs-treated area to urban area (%).



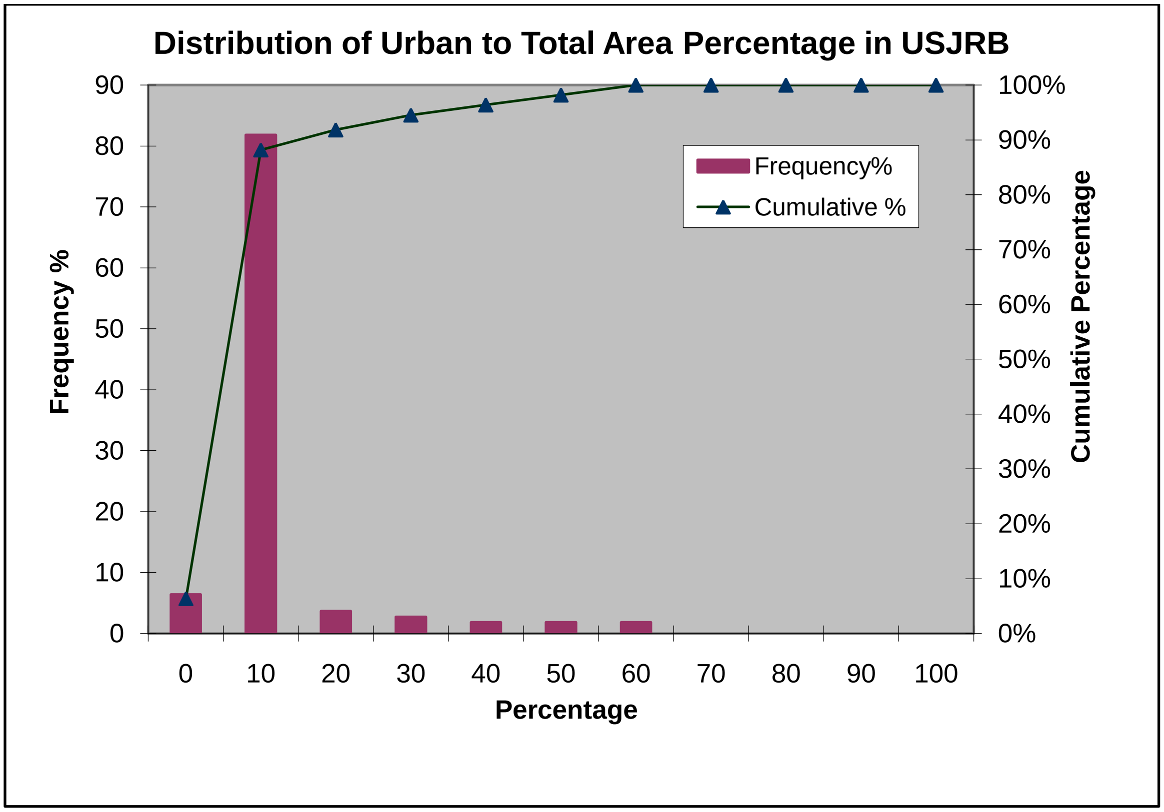
Percentage	Frequency	Frequency%	Cumulative %
0	0	0.00	0.00%
10	1	2.56	2.56%
20	6	15.38	17.95%
30	8	20.51	38.46%
40	7	17.95	56.41%
50	5	12.82	69.23%
60	3	7.69	76.92%
70	6	15.38	92.31%
80	2	5.13	97.44%
90	0	0.00	97.44%
100	1	2.56	100.00%
total sub-watershed	39		

Figure 22. Lake Jesup Watershed: BMPs-treated rate (%).



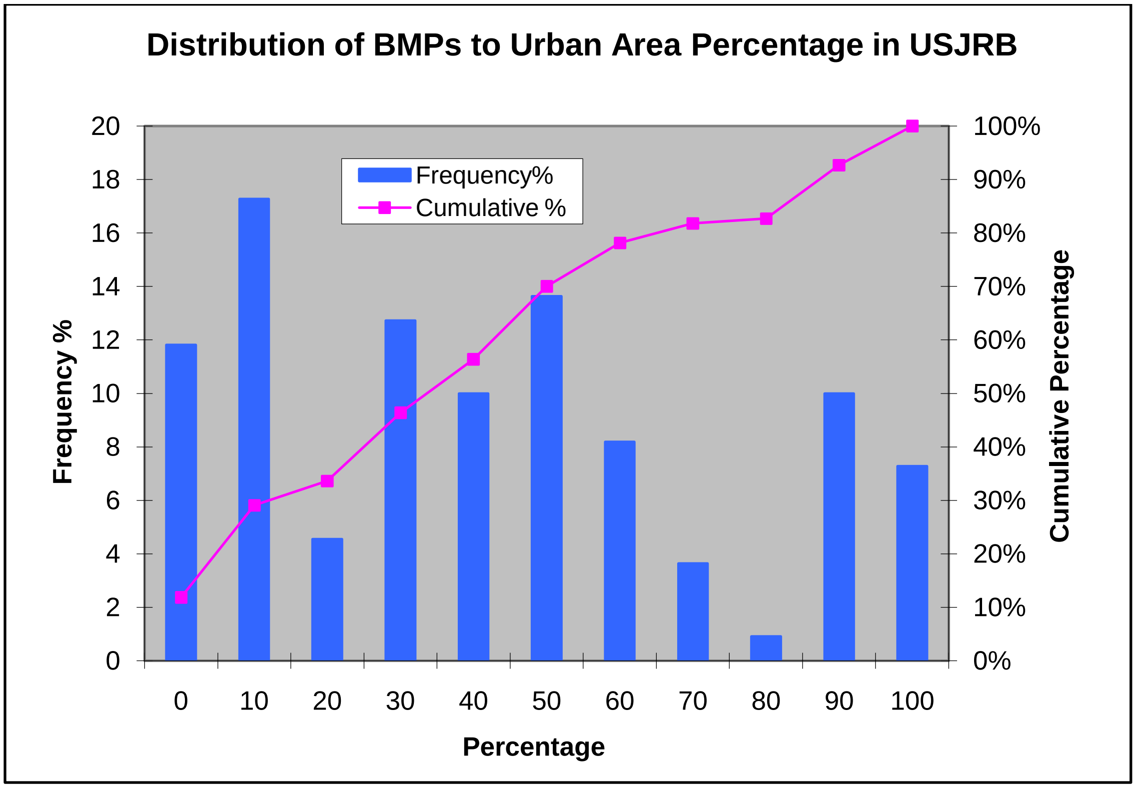
Percentage	*Frequency*	*Frequency%*	*Cumulative %*
0	0	0.00	.00%
10	13	33.33	33.33%
20	12	30.77	64.10%
30	7	17.95	82.05%
40	4	10.26	92.31%
50	2	5.13	97.44%
60	0	0.00	97.44%
70	1	2.56	100.00%
80	0	0.00	100.00%
90	0	0.00	100.00%
100	0	0.00	100.00%
total sub-watershed	39		

Figure 23. USJRB: urbanization rate (%).



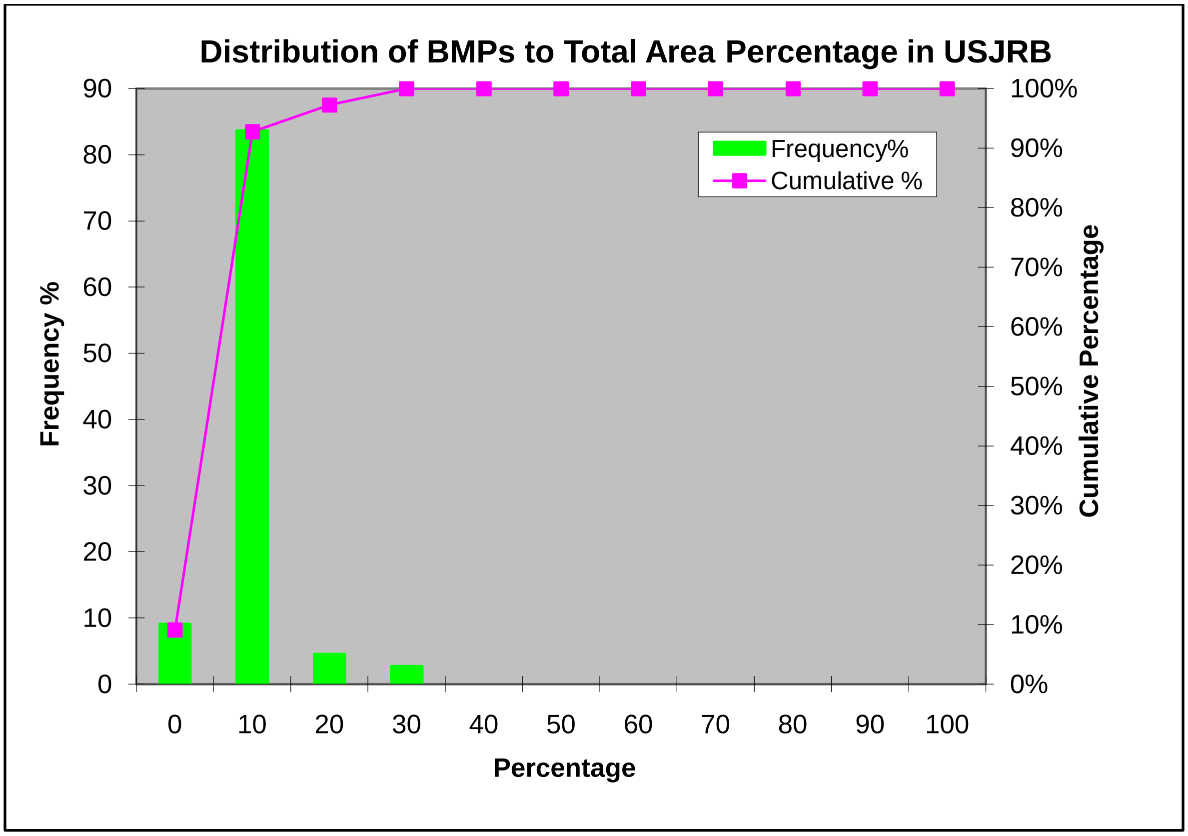
Percentage	Frequency	Frequency%	Cumulative %
0	7	6.36	6.36%
10	90	81.82	88.18%
20	4	3.64	91.82%
30	3	2.73	94.55%
40	2	1.82	96.36%
50	2	1.82	98.18%
60	2	1.82	100.00%
70	0	0.00	100.00%
80	0	0.00	100.00%
90	0	0.00	100.00%
100	0	0.00	100.00%
total sub-watershed	110		

Figure 24. USJRB: BMPs-treated area to urban area (%).



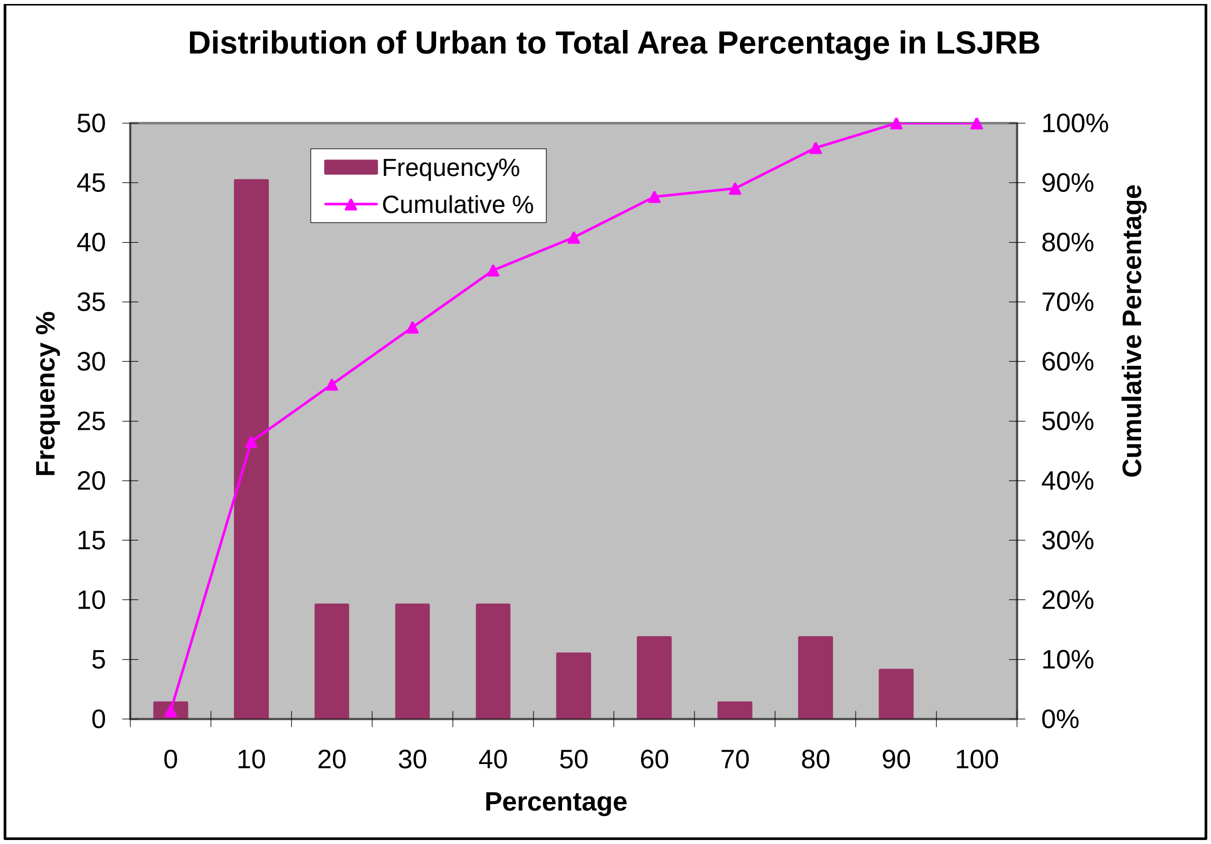
Percentage	*Frequency*	*Frequency%*	*Cumulative %*
0	13	11.82	11.82%
10	19	17.27	29.09%
20	5	4.55	33.64%
30	14	12.73	46.36%
40	11	10.00	56.36%
50	15	13.64	70.00%
60	9	8.18	78.18%
70	4	3.64	81.82%
80	1	0.91	82.73%
90	11	10.00	92.73%
100	8	7.27	100.00%
total sub-watershed	110		

Figure 25. USJRB: BMPs-treated rate (%).



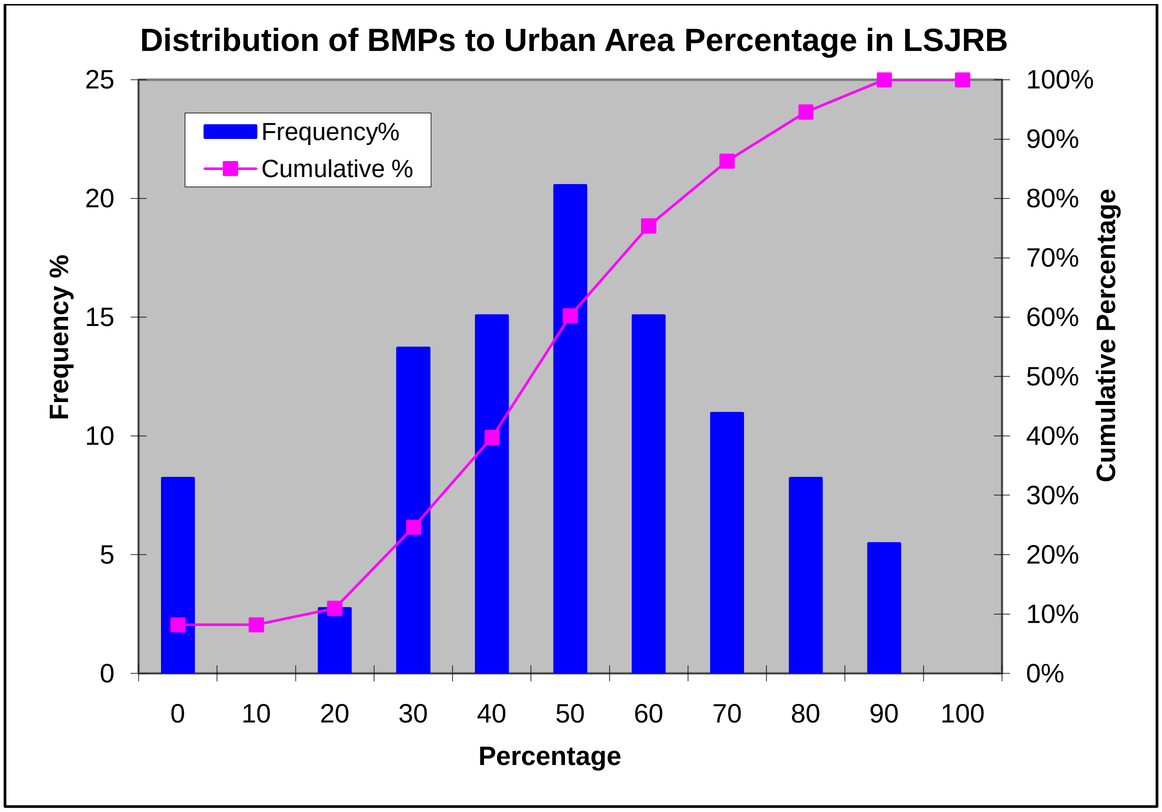
Percentage	*Frequency*	*Frequency%*	*Cumulative %*
0	10	9.09	9.09%
10	92	83.64	92.73%
20	5	4.55	97.27%
30	3	2.73	100.00%
40	0	0.00	100.00%
50	0	0.00	100.00%
60	0	0.00	100.00%
70	0	0.00	100.00%
80	0	0.00	100.00%
90	0	0.00	100.00%
100	0	0.00	100.00%
total sub-watershed	110		

Figure 26. LSJRB: urbanization rate (%).



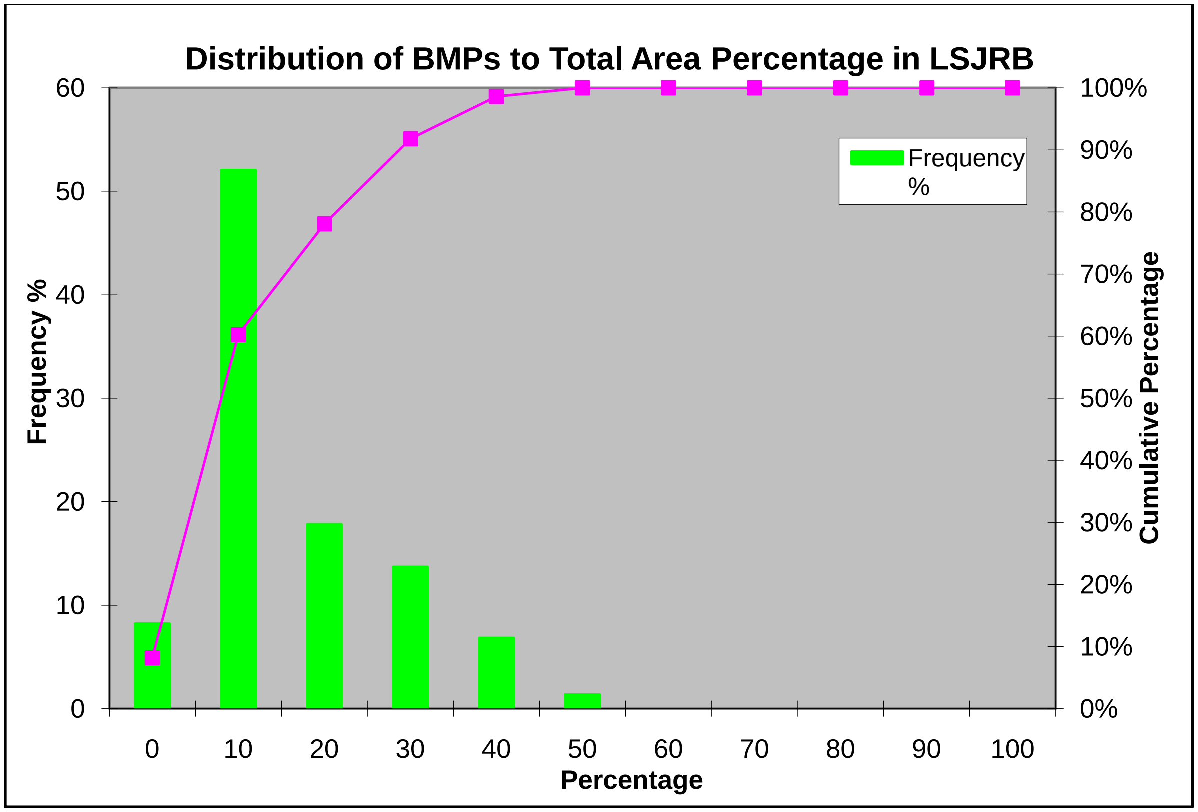
Percentage	*Frequency*	*Frequency%*	*Cumulative %*
0	1	1.37	1.37%
10	33	45.21	46.58%
20	7	9.59	56.16%
30	7	9.59	65.75%
40	7	9.59	75.34%
50	4	5.48	80.82%
60	5	6.85	87.67%
70	1	1.37	89.04%
80	5	6.85	95.89%
90	3	4.11	100.00%
100	0	0.00	100.00%
total sub-watershed	73		

Figure 27. LSJRB: BMPs-treated area to urban area (%).



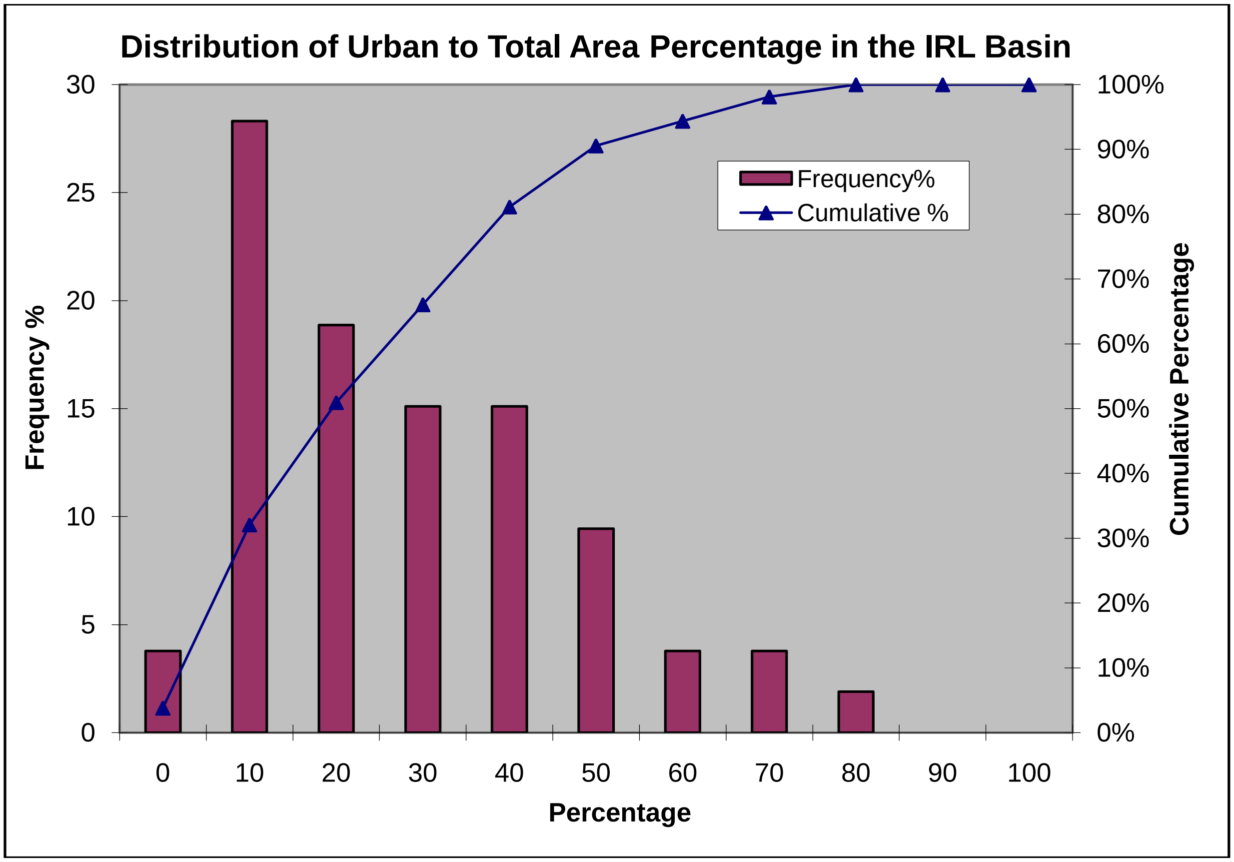
Percentage	*Frequency*	*Frequency%*	*Cumulative %*
0	6	8.22	8.22%
10	0	0.00	8.22%
20	2	2.74	10.96%
30	10	13.70	24.66%
40	11	15.07	39.73%
50	15	20.55	60.27%
60	11	15.07	75.34%
70	8	10.96	86.30%
80	6	8.22	94.52%
90	4	5.48	100.00%
100	0	0.00	100.00%
total sub-watershed	73		

Figure 28.LSJRB: BMPs-treated rate (%)



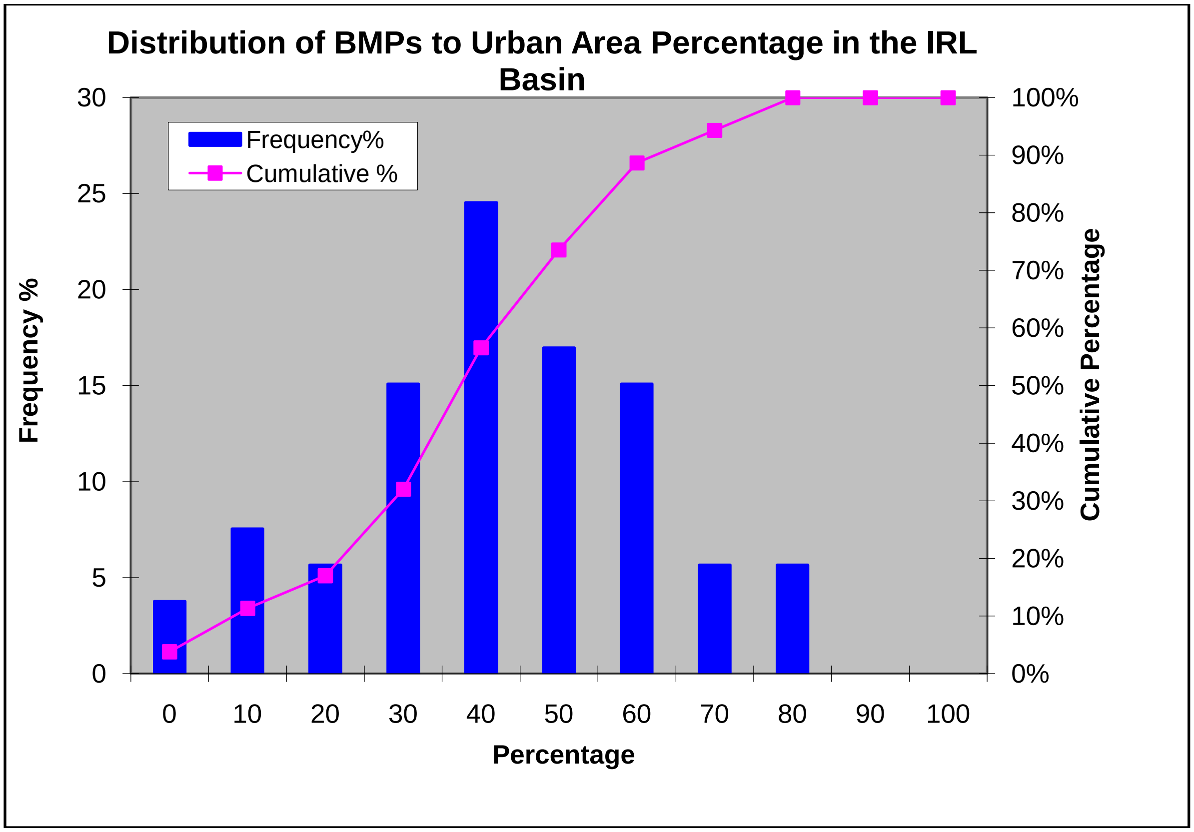
Percentage	*Frequency*	*Frequency%*	*Cumulative %*
0	6	8.22	8.22%
10	38	52.05	60.27%
20	13	17.81	78.08%
30	10	13.70	91.78%
40	5	6.85	98.63%
50	1	1.37	100.00%
60	0	0.00	100.00%
70	0	0.00	100.00%
80	0	0.00	100.00%
90	0	0.00	100.00%
100	0	0.00	100.00%
total sub-watershed	73		

Figure 29. Indian River Lagoon (IRL) Basin: urbanization rate (%).



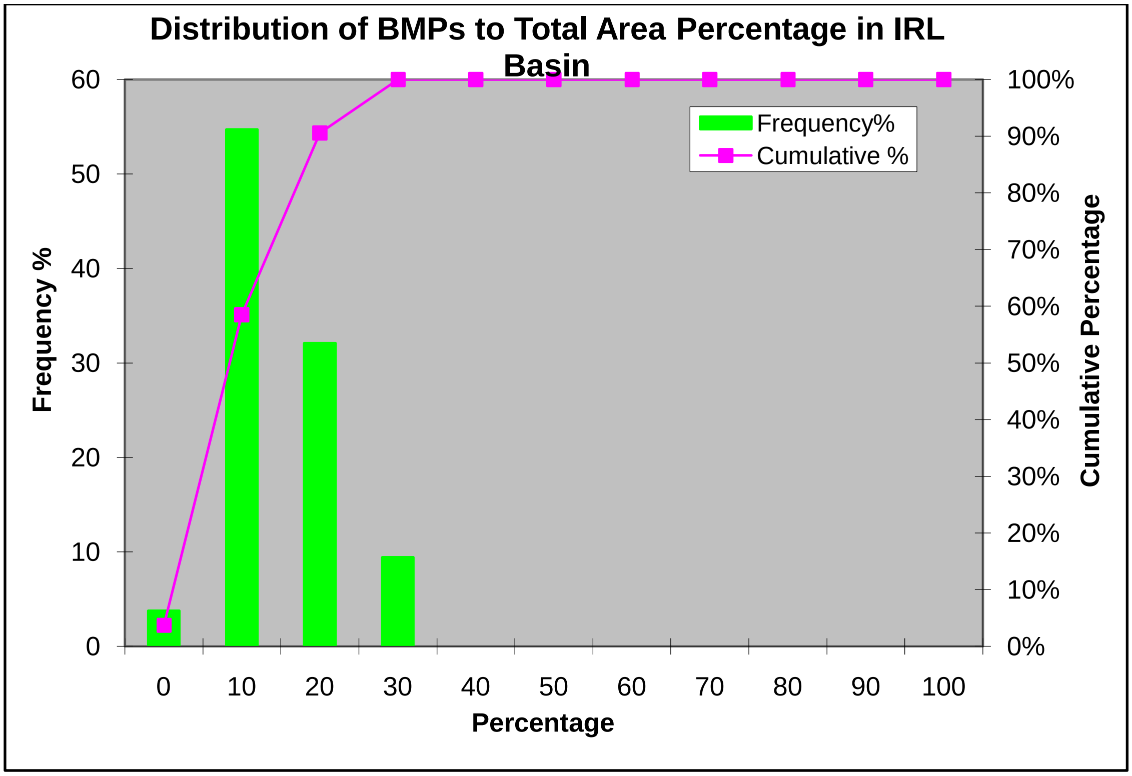
percentage	*Frequency*	*Frequency%*	*Cumulative %*
0	2	3.77	3.77%
10	15	28.30	32.08%
20	10	18.87	50.94%
30	8	15.09	66.04%
40	8	15.09	81.13%
50	5	9.43	90.57%
60	2	3.77	94.34%
70	2	3.77	98.11%
80	1	1.89	100.00%
90	0	0.00	100.00%
100	0	0.00	100.00%
total sub-watershed	53		

Figure 30. Indian River Lagoon Basin: BMPs-treated area to urban area (%).



Percentage	*Frequency*	*Frequency%*	*Cumulative %*
0	2	3.77	3.77%
10	4	7.55	11.32%
20	3	5.66	16.98%
30	8	15.09	32.08%
40	13	24.53	56.60%
50	9	16.98	73.58%
60	8	15.09	88.68%
70	3	5.66	94.34%
80	3	5.66	100.00%
90	0	0.00	100.00%
100	0	0.00	100.00%
total sub-watershed	53		

Figure 31. Indian River Lagoon Basin: BMPs-treated rate (%).



Percentage	*Frequency*	*Frequency%*	*Cumulative %*
0	2	3.77	3.77%
10	29	54.72	58.49%
20	17	32.08	90.57%
30	5	9.43	100.00%
40	0	0.00	100.00%
50	0	0.00	100.00%
60	0	0.00	100.00%
70	0	0.00	100.00%
80	0	0.00	100.00%
90	0	0.00	100.00%
100	0	0.00	100.00%
total sub-watershed	53		

References

Butler, D. and J. W. Davies. 2004. *Urban Drainage*, 2nd edition. Spon Press. London and New York.

Camp Dresser & McKee Inc (CDM). 1985. *An Assessment of Stormwater Management Programs.* Prepared for Florida Department of Environmental Regulation, Tallahassee, Florida.

Camp Dresser & McKee Inc (CDM). 2002. *Literature Review of Stormwater Best Management Practices for the St. Johns River Water Management District*. Technical Memorandum submitted to SJRWMD

Gao, X. 2005. *TMDL Report: Nutrient and Unionized Ammonia TMDLs for Lake Jesup, WBIDs 2981 and 2981A.* Florida Department of Environmental Protection, Tallahassee, Florida, USA

NRCS-USDA. 1986. *Urban Hydrology for Small Watersheds*. Technical Release 55 from Conservation Engineering Division, Natural Resources Conservation Service, U. S. Department of Agriculture. Washington, D.C., USA

SJRWMD. 2005. *Applicant's Handbook: Regulation of Stormwater Management Systems*. St. Johns River Water Management District, Palatka, Florida

SJRWMD. 2006. *Neighborhood Guide to Stormwater Systems*. St. Johns River Water Management District, Palatka, Florida

US Census Bureau. 2006. http://quickfacts.census.gov/qfd/states/12000.html

Appendix I. GIS Mapping Procedures

GIS Mapping Procedures

This procedure involves GIS operations on multiple layers of land cover/land use, regulatory permits, soil and groundwater table data, which may contain large amounts of data. It is in your best interest for you to clip the layers to your project area. Otherwise, it will require hours of computer calculations and occasionally may result in hang-ups or even crashes of your computer. In this procedure, the spatial distribution of BMPs was estimated across the whole St. Johns Water Management District, so all the layers were not clipped and remain in their original size. It is strongly recommended that you use the same names as in this procedure, occasionally if you have to save files to different names, put underscore and your project name behind the original names. Otherwise, you may not get the exact results as in the following screenshots.

This procedure requires the following softwares or associated tools: ESRI ArcMap, Spatial Analyst, XTools Pro and SJR Custom Extension: 9.2.

This procedure is intended for internal District use. Many datasets are located on the SJRWMD local GIS server or internal network drives. If you are outside the SJRWMD and have interest in using this procedure, please contact:

Department of Information Resources,
The St Johns River Water Management District,
4049 Reid Street,
Palatka, Florida 32178-1429

Step 1. Add the following layers to ArcMap, and clip them to the project area:

- ERP boundaries data (polygons) and ERP stormwater data (points);
- 2004 land cover/land use data and 1990 land use data;
- Soil hydrologic group data;
- Groundwater table depth data (Grid format).

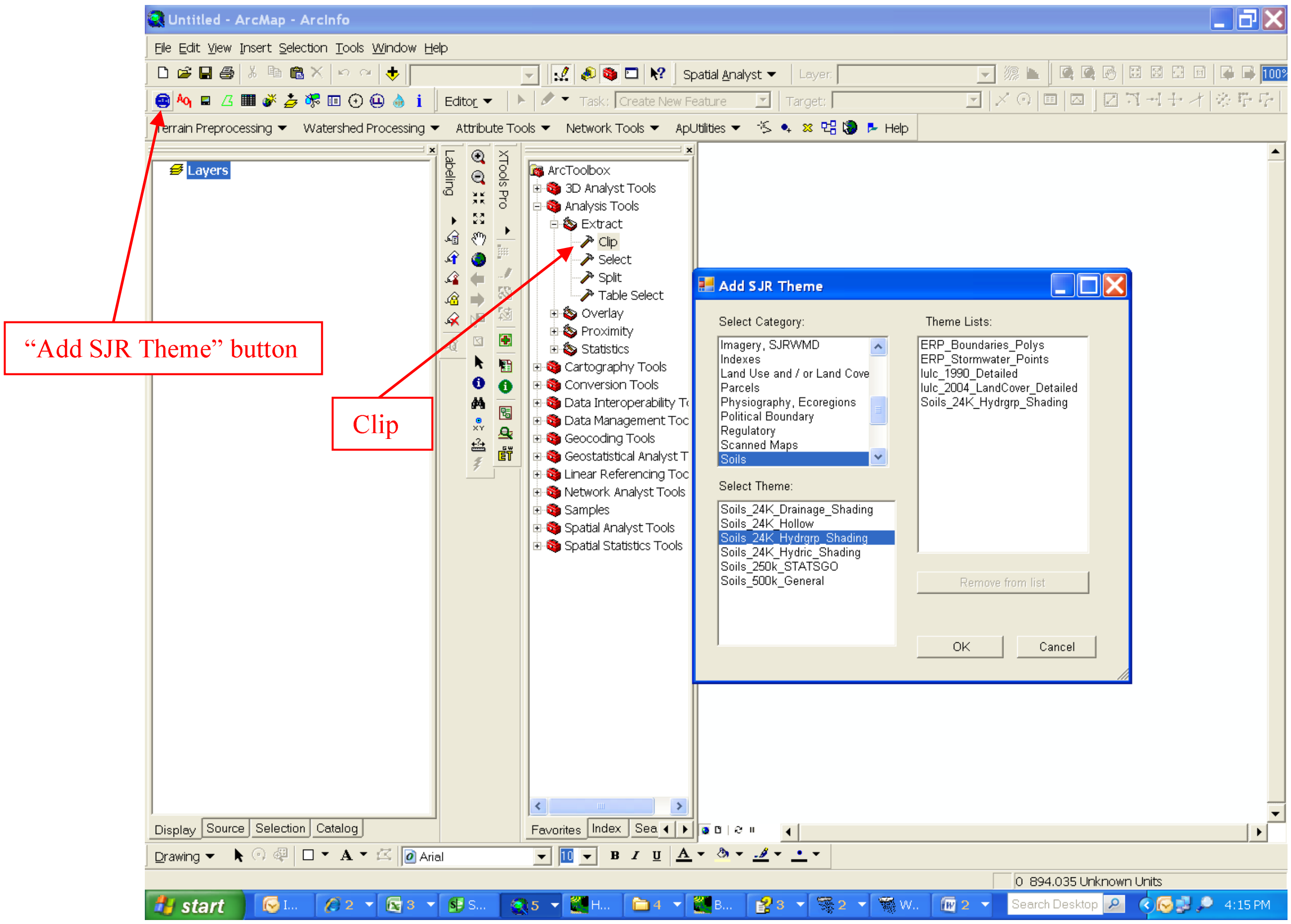


Figure Step 1a. Clicking on “Add SJR Theme” button and add layers “ERP_Boundaries_Polys” and “ERP_Stormwater_Points” from category “Regulatory”, layers “lulc_2004_LandCover_Detailed” and “lulc_1990_Detailed” from category “Land Use and / or Land Cover” and layer “Soils_24k_hydrgrp_Shading” from category “Soils” to ArcMap. Add the boundary layer of the project area (not shown in this procedure). Clip all the layers to the project area by using *ArcToolbox >Analysis Tools >Extract >Clip*. Clip “Land Use 1990” and “Land Cover” to new layers named “LC90” and “LC04”, respectively.

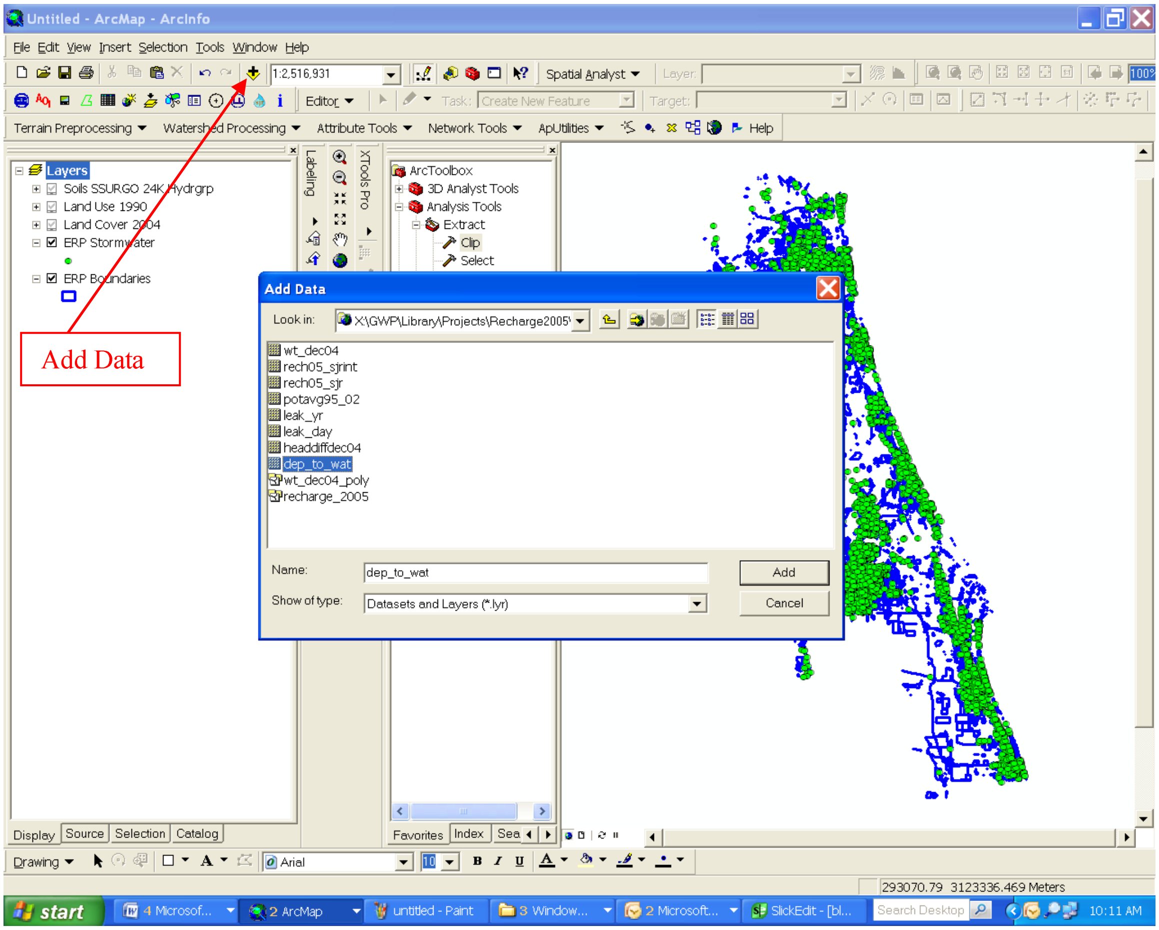


Figure Step 1b. Add layer “dep_to_wat” (groundwater table depth) from network folder “X:\GWP\Library\Projects\Recharge2005\data\”.

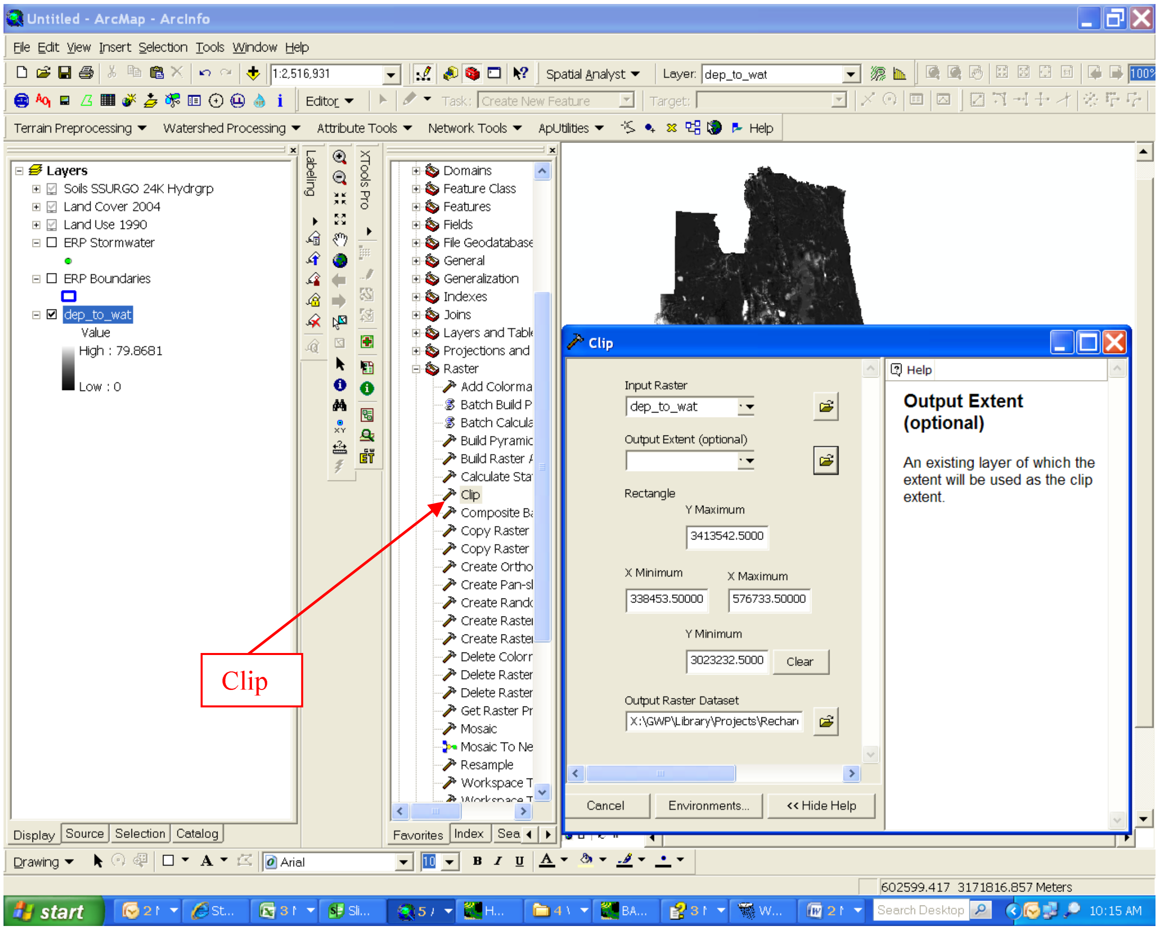


Figure Step 1c. Because layer "dep_to_wat" is in grid format, so the clip tool from Step 1a will not work. Instead click on *ArcToolbox >Data Management Tools >Raster >Clip*, and input a rectangle that is slightly larger than your project area, and name the output raster dataset as "dep_to_wat_your_project_name". In this procedure, this layer is not clipped because the project area is the whole District.

Step 2. Remove permits or permit applications that were received after December 31, 2003. The reason why only those received before December 31, 2003 are considered is that the SJRWMD's Permit Data Service is constantly updating the two GIS layers, ERP Stormwater and ERP Boundaries, to the current date, so it is important that you select appropriate permit data for your project. In this procedure, 2004 land cover/land use layer was delineated from aerial images flown in November/December 2003. So setting December 31, 2003 as the cutoff date is appropriate.

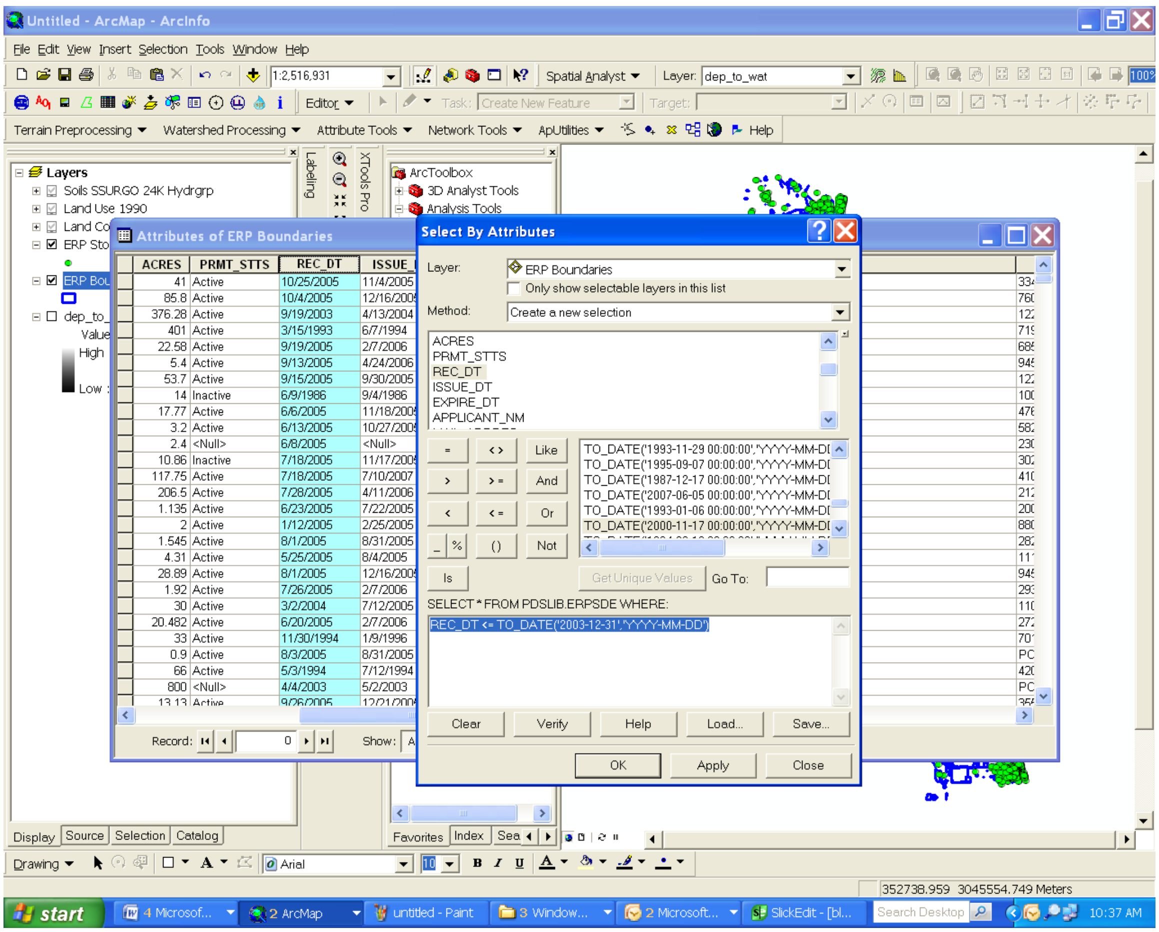


Figure Step 2a. Select permits or permit applications from layer "ERP Boundaries" that were received before December 31, 2003 by clicking on menu *Selection >Select by Attributes* with a criteria "REC_DT <= TO_DATE('2003-12-31','YYYY-MM-DD')" (on your computer TO_DATE('2003-12-31','YYYY-MM-DD')" might become "Date '2003-12-31'").

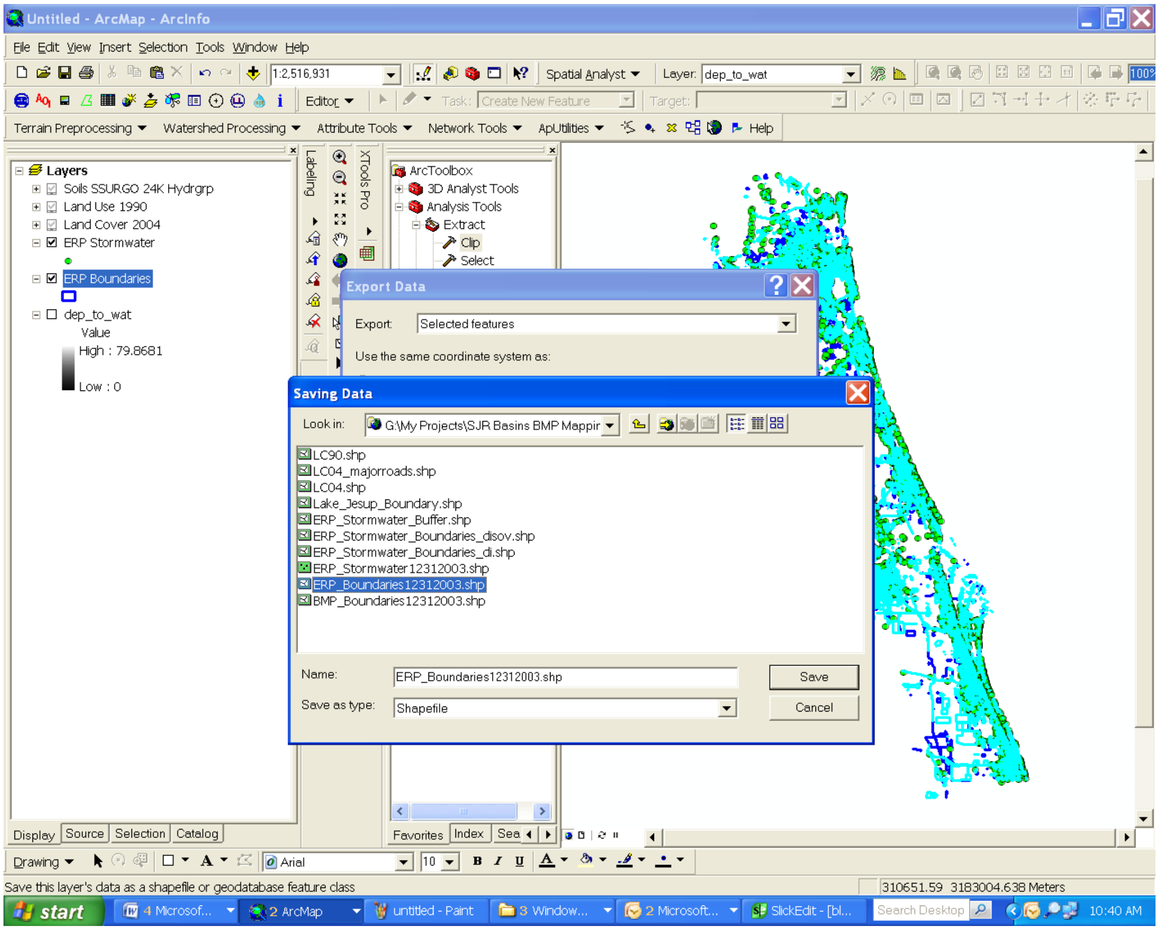


Figure Step 2b. Right click on the layer *Data >Export Data*, and export all the selected features to a shapefile named "ERP_Boundaries12312003". Add this newly created file to ArcMap as a layer.

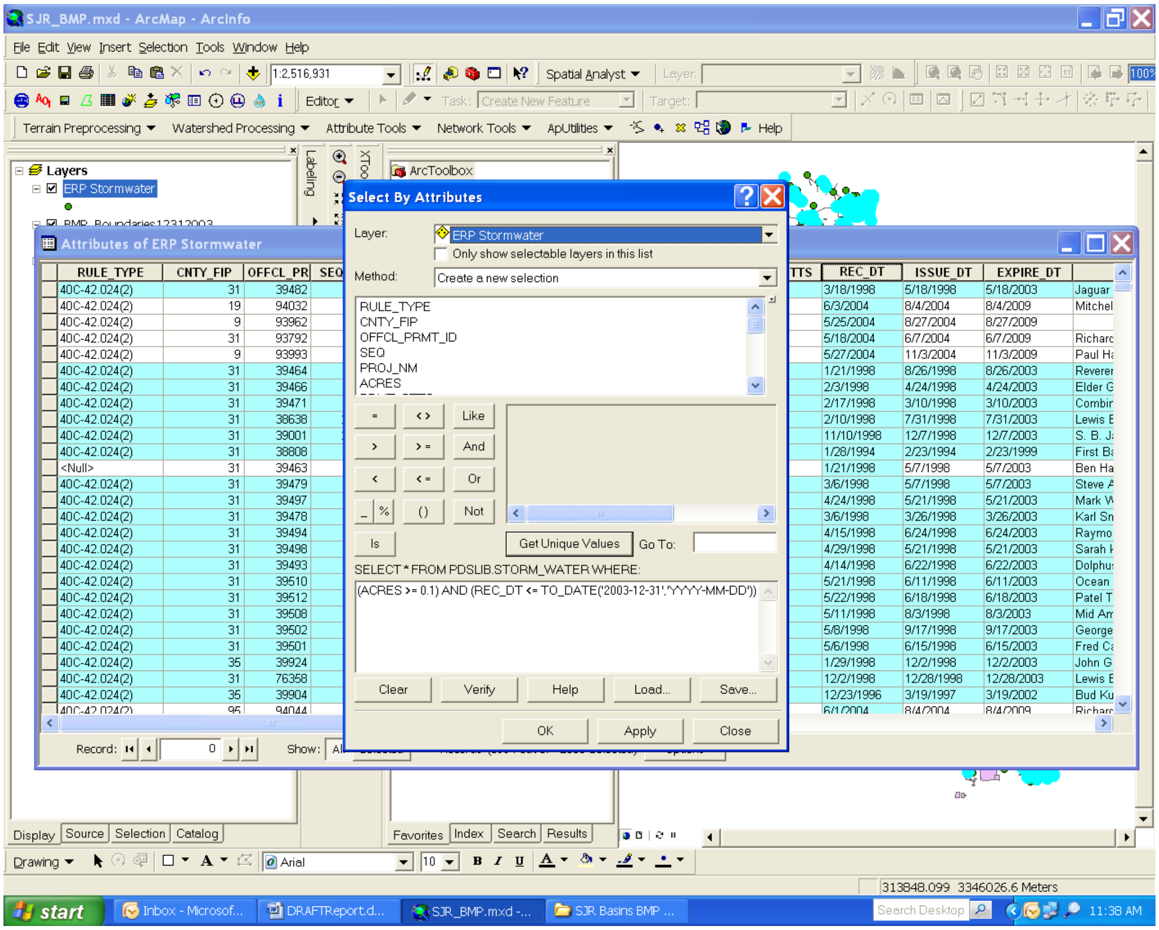


Figure Step 2c. As in Step 2b, select and export all the permits or permit applications received before December 31, 2003 from layer "ERP Stormwater" with a project area greater than 0.1 acres. Export the selected features to a shapefile entitled "ERP_Stormwater12312003" and then add it to ArcMap.

Step 3. Since layer “ERP_Stormwater12312003” is a point feature. It has to be converted to polygon features before it can be utilized for ArcMap operations with other polygon themes. It is converted to polygon features based on the assumption that each project in the permit or permit application is represented as a circle with the point as its center; the area of the circle is the same as the project area (attribute “Acres”). The “radius” (unit: meters) of each circle is calculated as the square root of (4046.86 * each project area /3.14). The project area in “ERP_Stormwater12312003” is in acre unit, and multiplying it by 4046.86 will convert it to square meters; and dividing it by π (3.14), and then square rooting it will get the “radius” of the circle in meter unit.

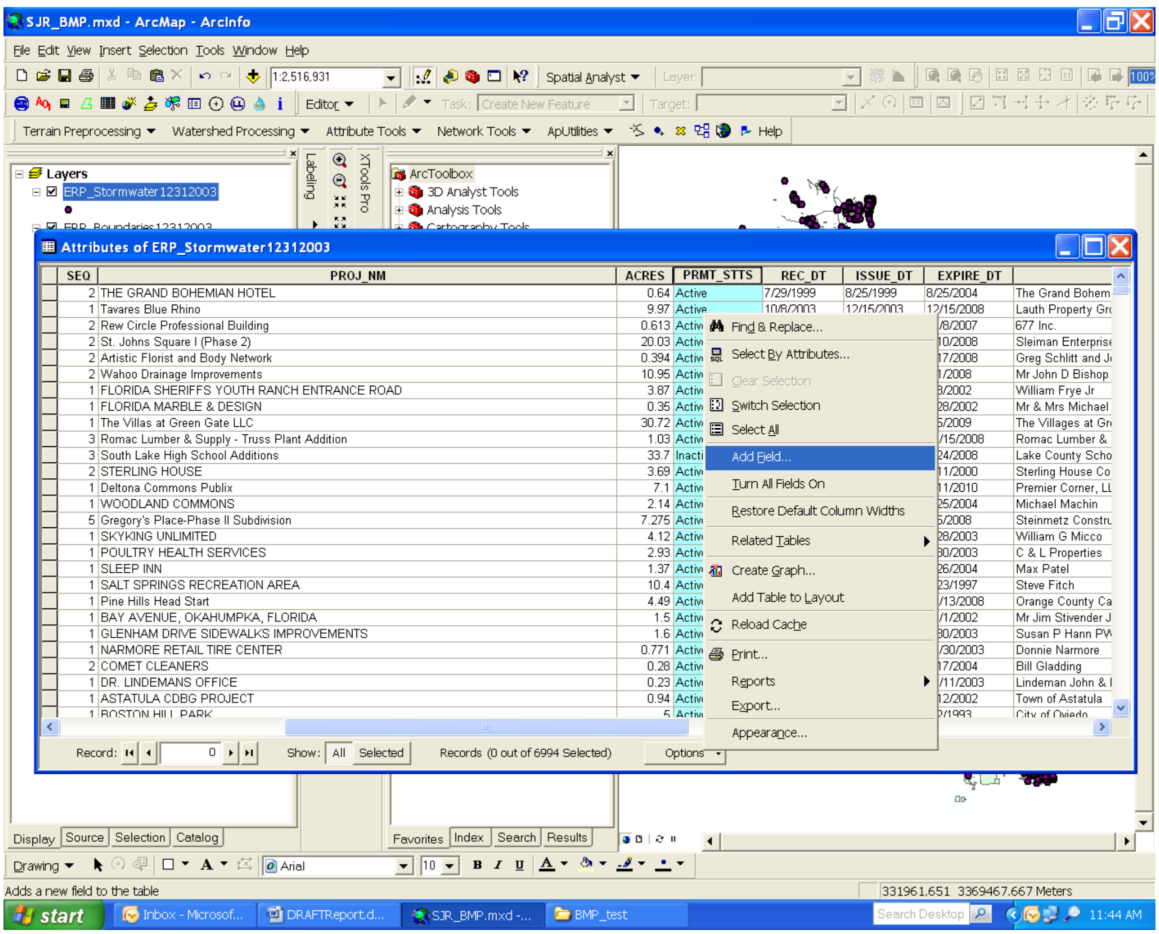


Figure Step 3a. Open the attribute table of “ERP_Stormwater12312003”, and click on Options at the bottom of the attribute table to add a new attribute or field named “radius”, with the data type “float” (Precision =8 and Scale=2).

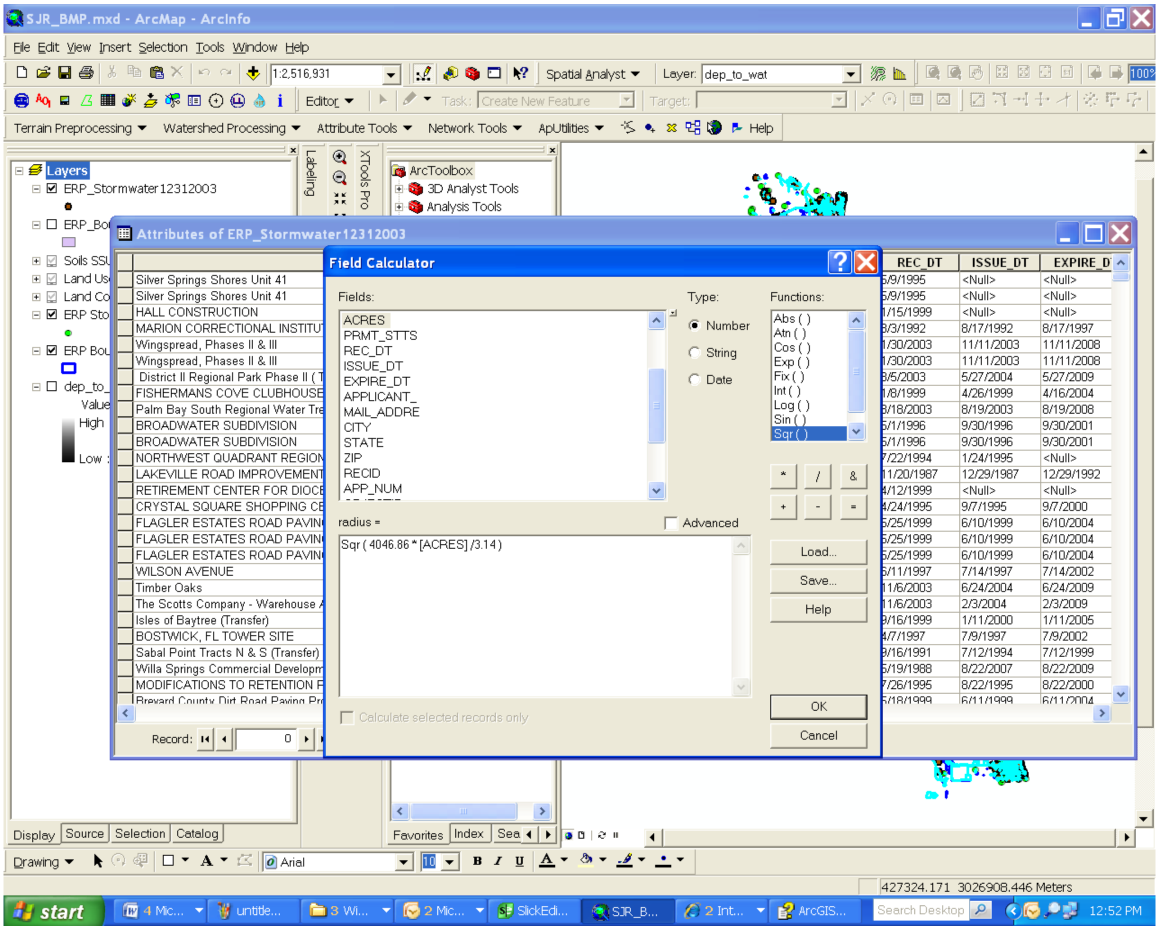


Figure Step 3b. Right click on “radius” column head, select “Field Calculator” and calculate the value of “radius” as “Sqr (4046.86 * [ACRES] /3.14)”. (Make sure that either none or all the records are selected in the table, otherwise the process will only be conducted for selected records).

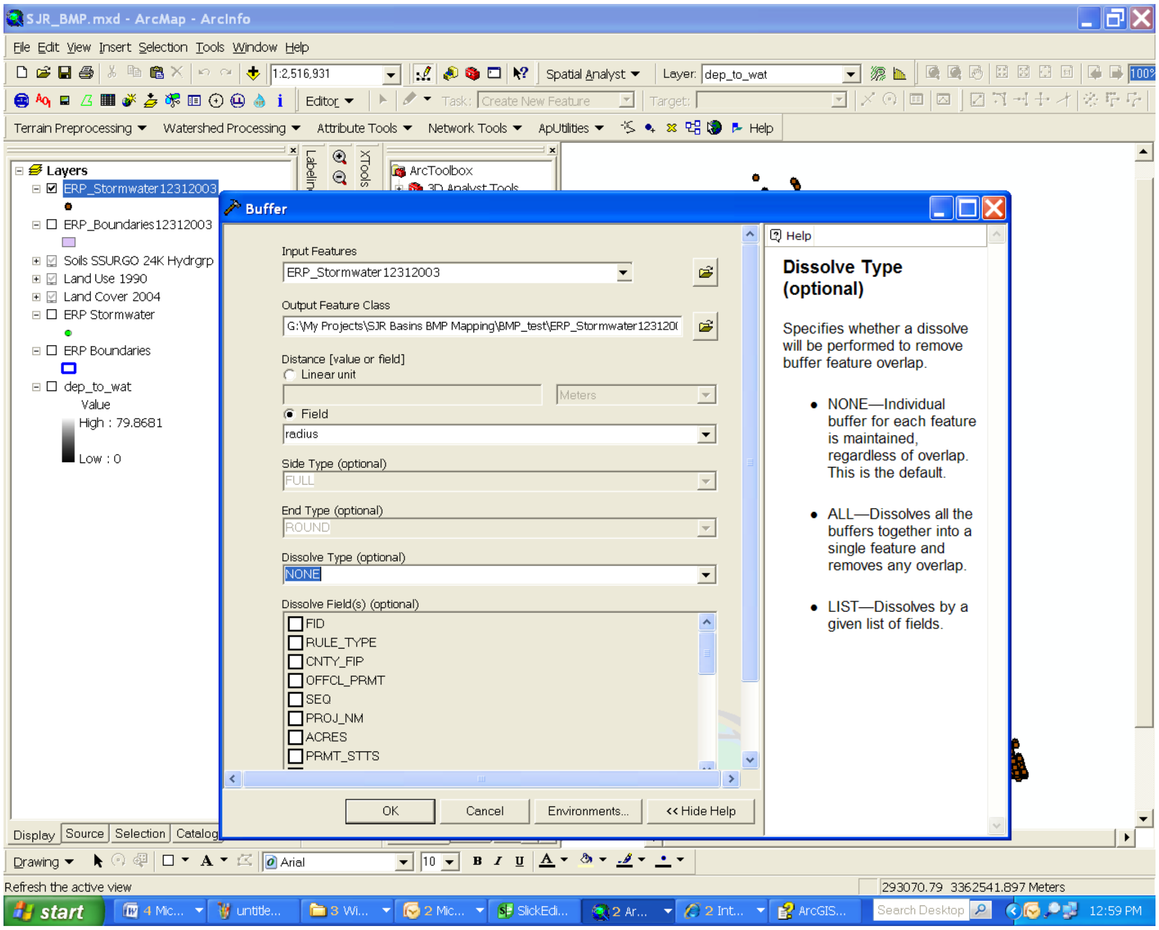


Figure Step 3c. Use Buffer from *ArcToolBox >Analysis Tools >Proximity >Buffer* with "ERP_Stormwater12312003" as input features, "ERP_Stormwater_Buffer.shp" as Output Feature Class and "radius" as Distance field to create a buffer at each point in the "ERP_Stormwater12312003".

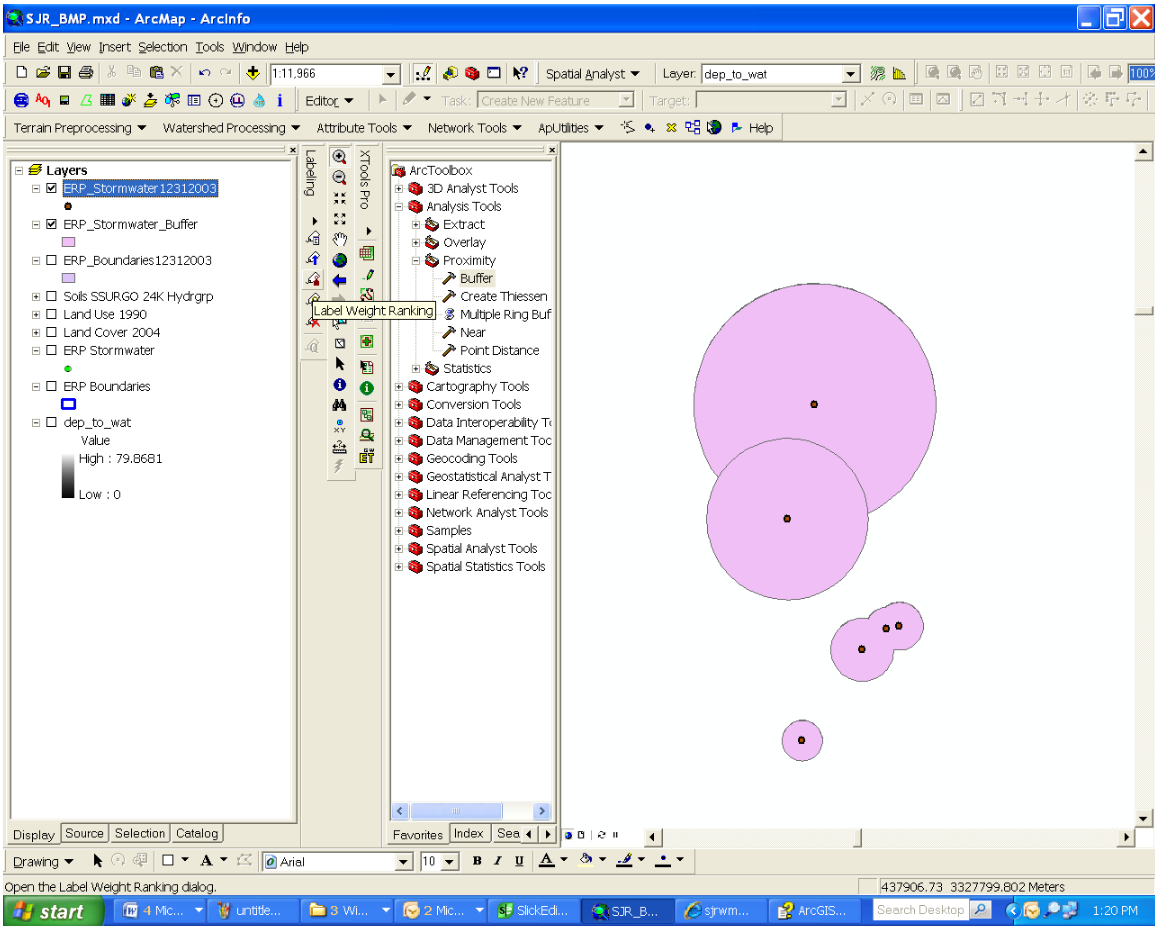


Figure Step 3d. A closer look at the new "polygon" theme, "ERP_Stormwater_Buffer", created at Step 3c. Layer "ERP_Stormwater12312003" can be removed from the project now. It is no longer used.

Step 4. Union layer “ERP_Boundaries12312003” with layer “ERP_Stormwater_buffer”. This will create a new theme that is the base map for BMPs covered areas based on regulatory data.

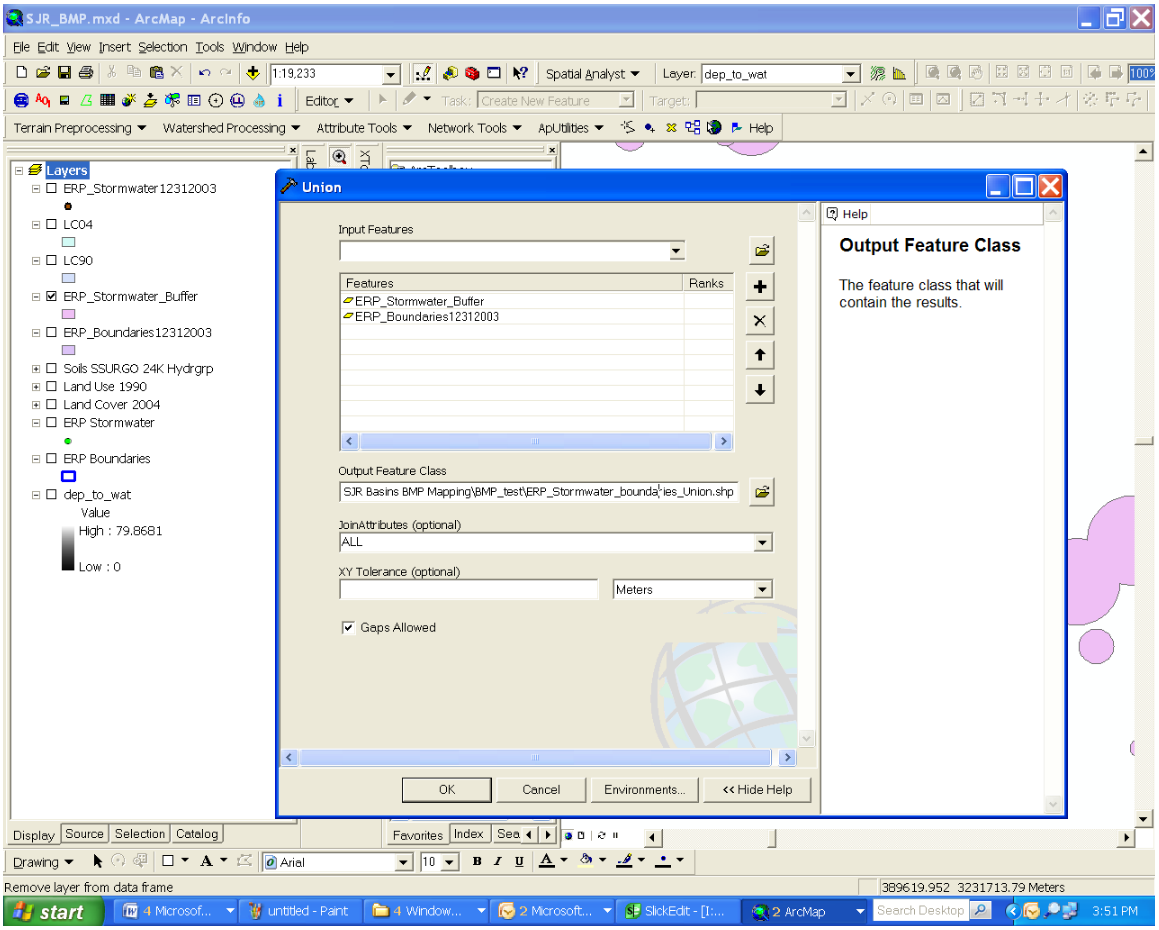


Figure Step 4a. Union “ERP_Boundaries12312003” with “ERP_Stormwater_buffer” (use *ArcToolBox > Analysis Tools > Overlay > Union*), creating a new layer named “ERP_Stormwater_Boundaries_Union”.

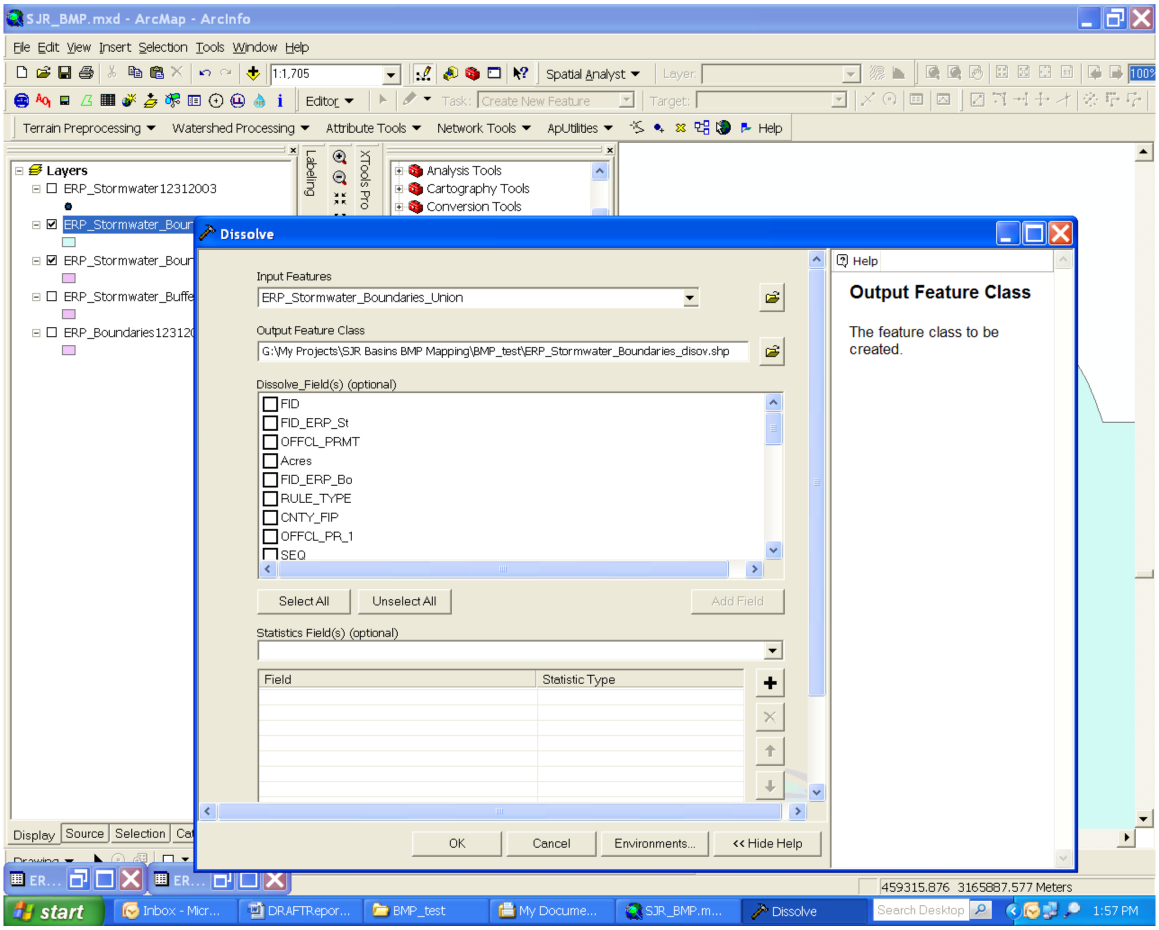


Figure Step 4b. Dissolve (*ArcToolbox >Data Management Tools > Generalization >Dissolve*) the new layer from Step 4a to remove any overlapping features, and then output the “dissolved” result to a new layer named “ERP_Stormwater_Boundaries_disov”.

Step 5. In Step 4, a base map layer of BMPs covered areas based on regulatory data was created ("ERP_Stormwater_Boundaries_disov.shp"). In Step 5, an additional map of BMPs covered areas will be created from "urban or industrial/commercial land use changes" from 1990 to 2004 by comparing 1990 land cover/land use (LC/LU) with 2004 LC/LU data. The "urban or industrial & commercial land use changes" are defined here as any land cover changes from rural to urban or industrial & commercial, or from low density residential to higher density (refer to Appendix II for details). Since stormwater programs were adopted by Florida in early 1980s, it is a reasonable assumption that any land use changes from rural to urban/industrial & commercial or from low density residential to higher density will be treated with some type of post-development BMPs.

Theoretically, all this urban development should be reflected in regulatory permit datasets, and hence should be already included in the map produced in Step 4. Although the SJRWMD's Permit Data Service has tried very hard to digitize all the permits or permit applications, due to the large number of permit applications, some older permits still have not been digitized. The undigitized permits are not included in the two GIS layers, "ERP Stormwater" or "ERP Boundaries". Therefore, the purpose of Step 5 is to create a new map of BMPs covered areas based on LC/LU changes to supplement the base BMPs layer from Step 4. Typically, the land use change area is only a small fraction of the permitted area.

To facilitate the comparison of land use changes between 1990 and 2004, all the different land uses are to be grouped or classed into 13 types of land uses, i.e., Low Density Residential, Medium Density Residential, High Density Residential, Industrial and Commercial, Mining, Open Land and Barren Land, Animal Production, Agricultural General, Agricultural Tree Crop, Rangeland, Forest, Water, and Wetlands based on their assigned FLUCs Codes. Two DBF files, LU_MODEL_HSPF04.dbf and LU_MODEL_HSPF90.dbf, are used to summarize 2004 LC/LU and 1990 LC/LU, respectively. Both are located in network folder X:\Eng\MultiBasin\gis\BMP_Mapping\DBF. Both files are very similar. Both have two columns, one is detailed land use codes, named "LUCODE", and the other is summarized land use types, which is named "HSPFLU90" or "HSPFLU04". Their values vary from 1 (Low Density Residential) to 13 (Wetland) (see Appendix II for details).

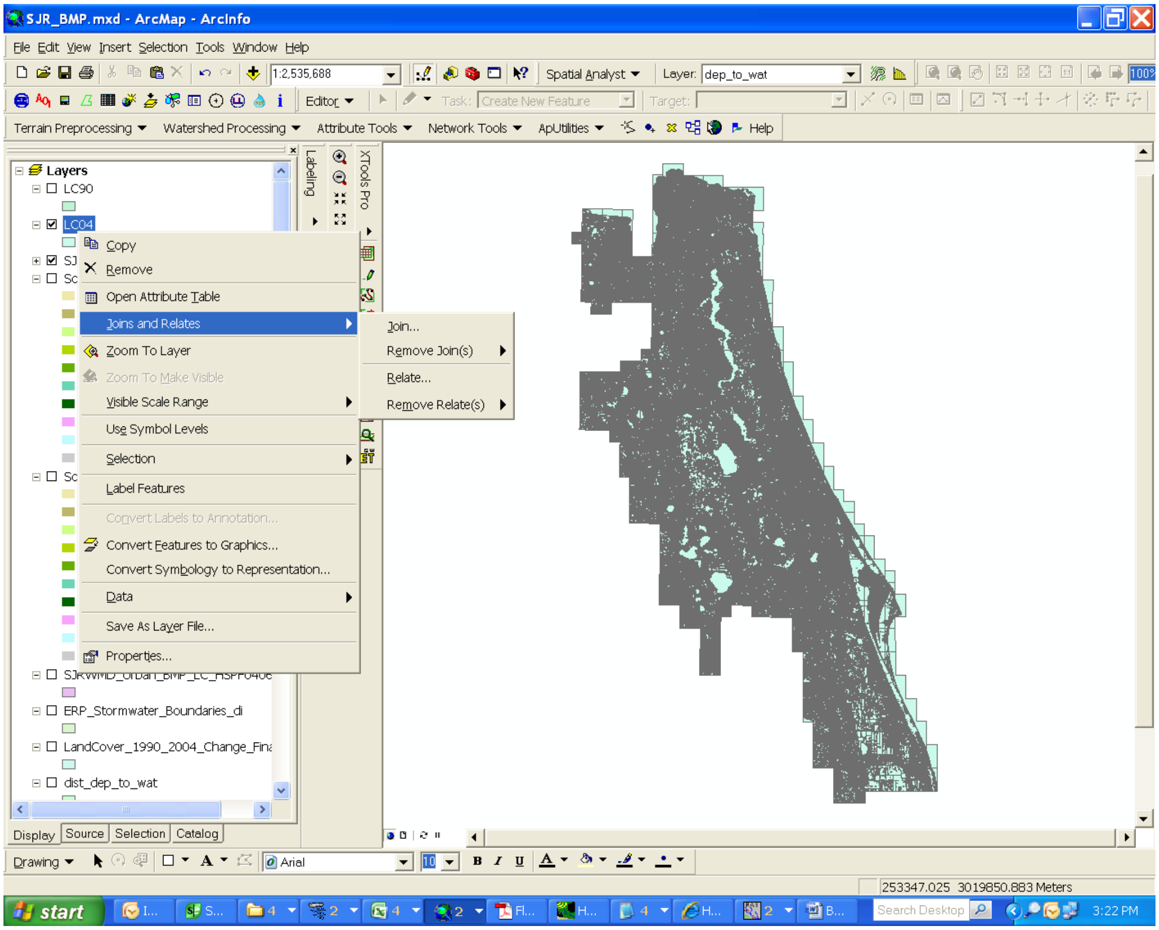


Figure Step 5a. Right click “LC04” and select *Joins and Relates >Join*.

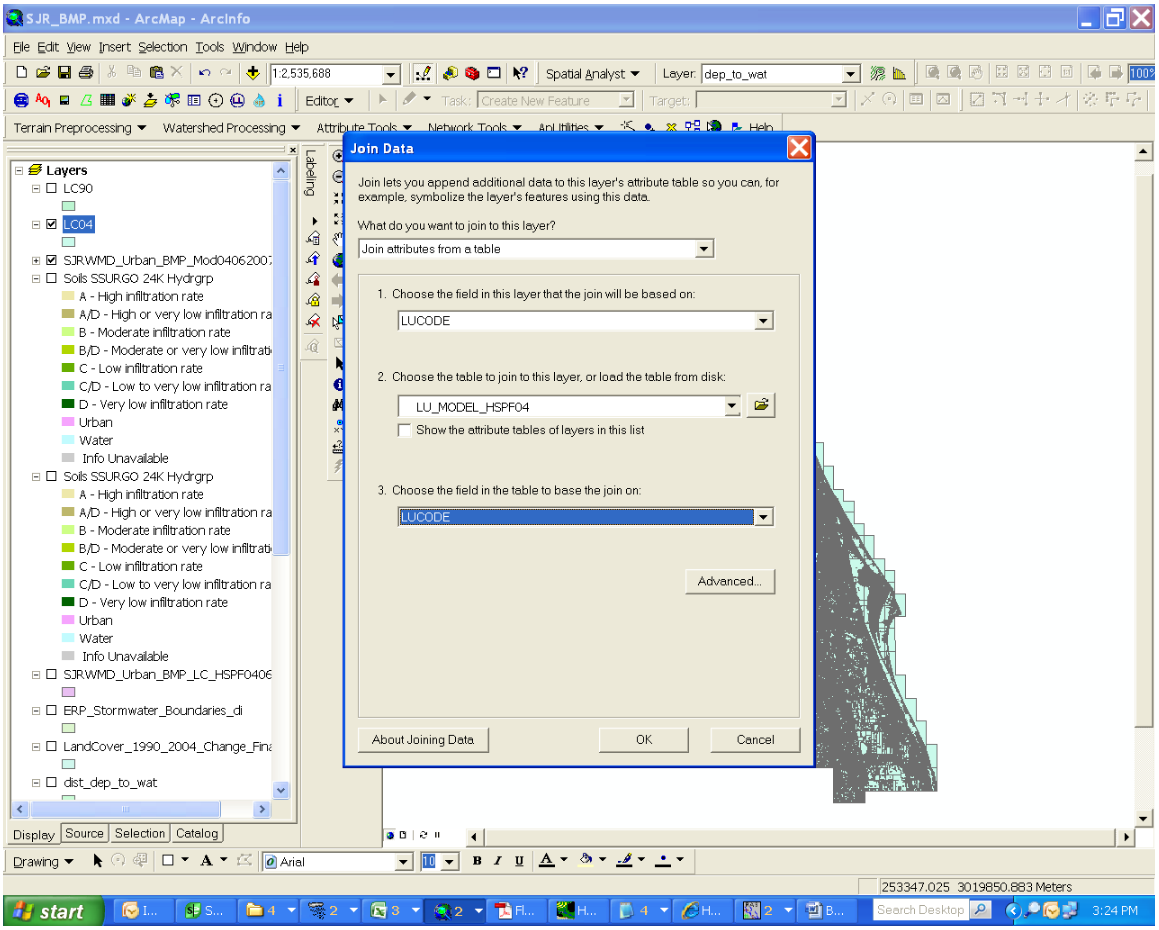


Figure Step 5b. Join "LC04" with table "LU_MODEL_HSPF04". Choose "LUCODE" as the field that the join will be based on (1); choose "LU_MODEL_HSPF04" as the table to join this layer (2); and choose "LUCODE" as the field in the table to base the join on (3)

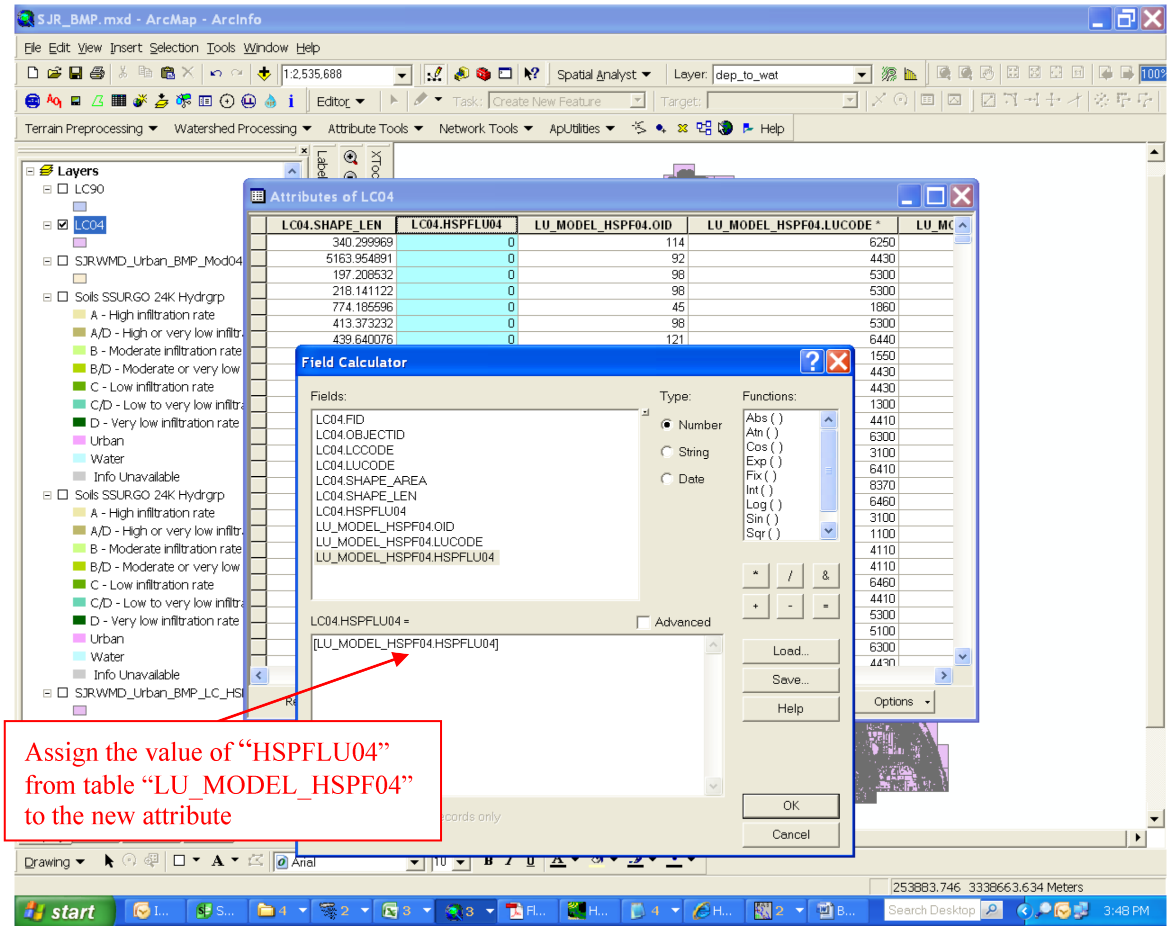


Figure Step 5c. After joining, create a new attribute, named "HSPFLU04" (data type = "short integer" and precision = "4") in the attribute table of "LC04" which was just joined with "HSPFLU04" and assign the value of "HSPFLU04" from joined table "LU_MODEL_HSPF04" to it. Similarly, join layer "LC90" with table "LU_MODEL_HSPF90", create a new attribute "HSPFLU90" in its attribute table and assign to it the value of column "HSPFLU90" from the joined table "LU_MODEL_HSPF90". After that, remove all the joins from both layers by right clicking on the layers and select *Joins and Relates >Remove Join(s) >Remove All Joins*.

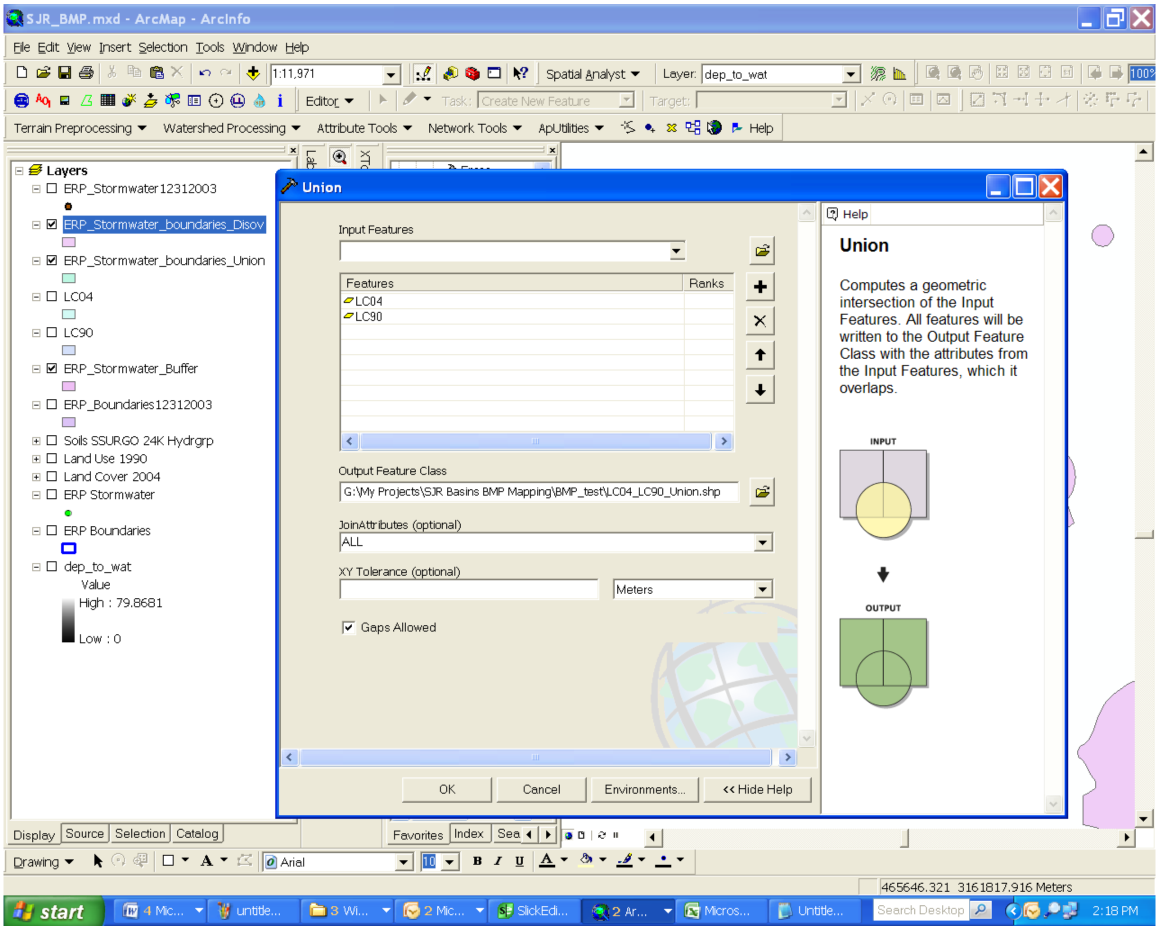


Figure Step 5d. Union (*ArcToolbox >Analysis Tools >Overlay >Union*) “LC04” with “LC90” to create a new layer “LC04_LC90_Union”.

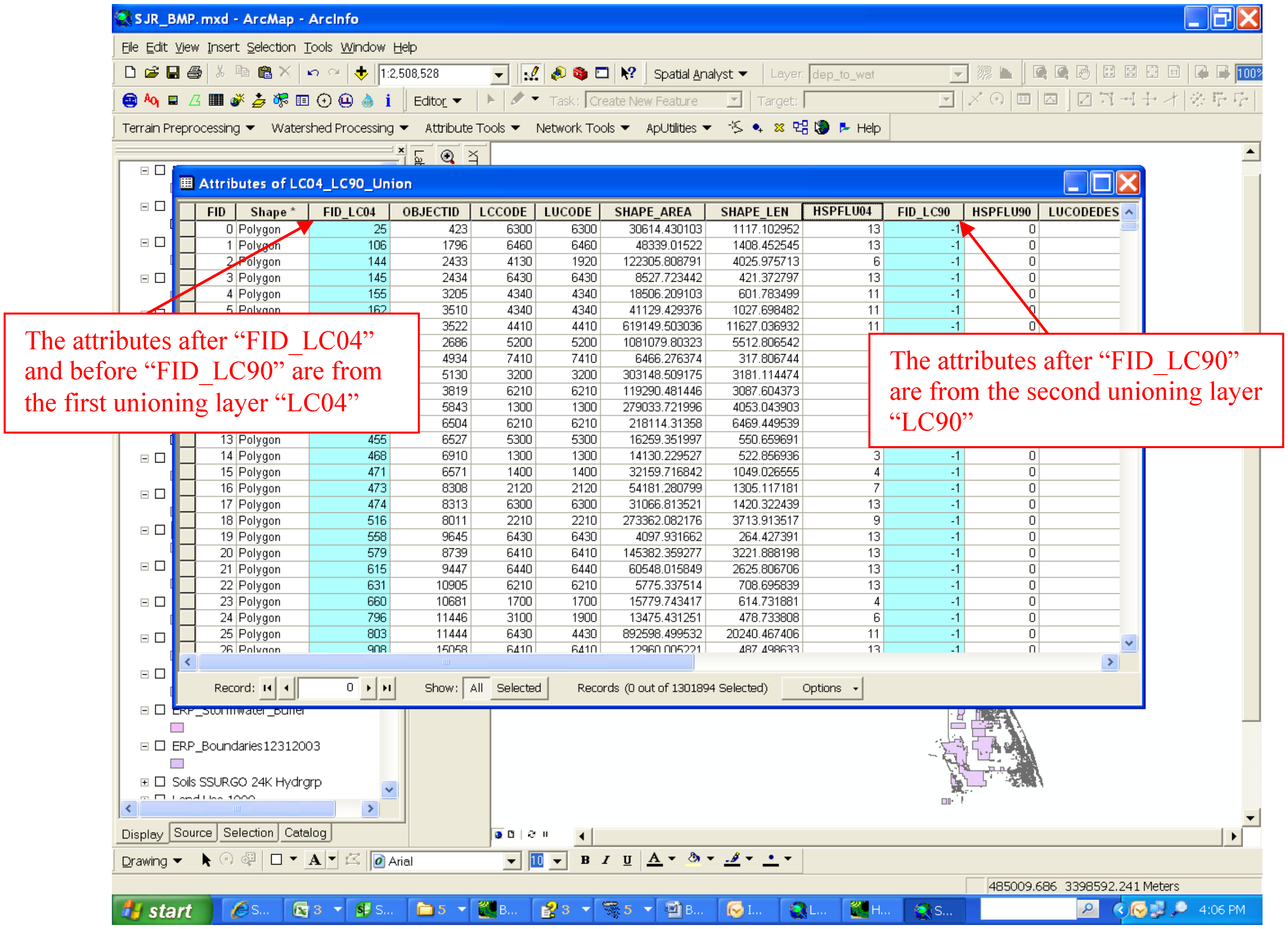


Figure Step 5e. In the attribute table of union output layer “LC04_LC90_Union”, there are two attributes starting with “FID_” and followed by unioning layer names (if their names are too long, they will be truncated to the first six letters), i.e., “FID_LC04” and “FID_LC90”. This is very import concept as in later steps we need to use this information to identify the sources of the attributes. Clicking Selection >Select by Attributes to select features from this new layer such that both values of “HSPFLU90” and “HSPFLU04”are greater than zero. Export the selected features to a new layer, named “LandCover_1990_2004_Change_final”.

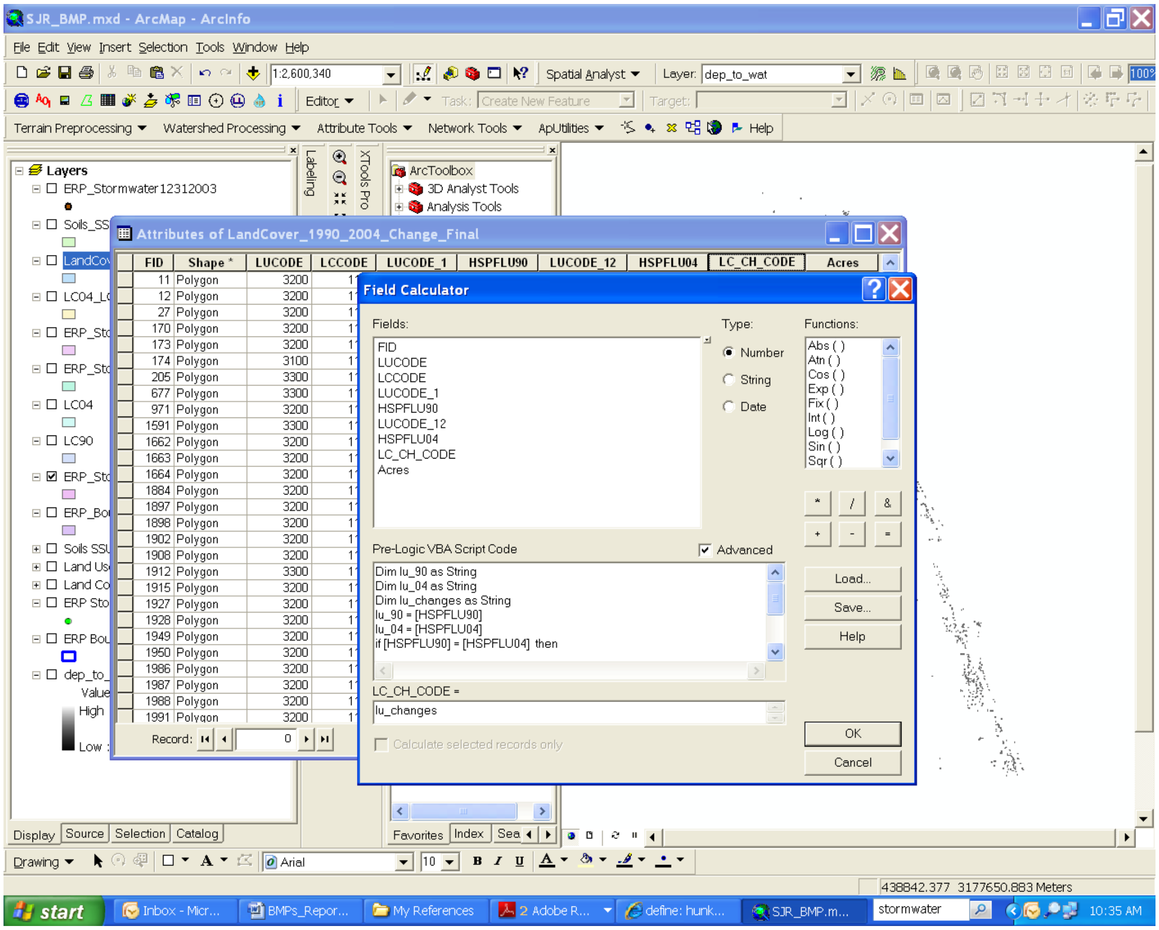


Figure Step 5f. Create a new attribute (data type= "text" and length = "10"), entitled "LC_CH_CODE" in the attribute table of "LandCover_1990_2004_Change_final". Right click on the "LC_CH_CODE" column head and select "Field Calculator". Check "Advanced Code" and put the following VBA code in "Pre-Logic VBA Code" window and write "lu_changes" in the bottom window:

```
Dim lu_90 as String
Dim lu_04 as String
Dim lu_changes as String
lu_90 = [HSPFLU90]
lu_04 = [HSPFLU04]

if [HSPFLU90] = [HSPFLU04]  then
   lu_changes = "no changes"
else
   lu_changes = lu_90 + "to" +lu_04
endif
```

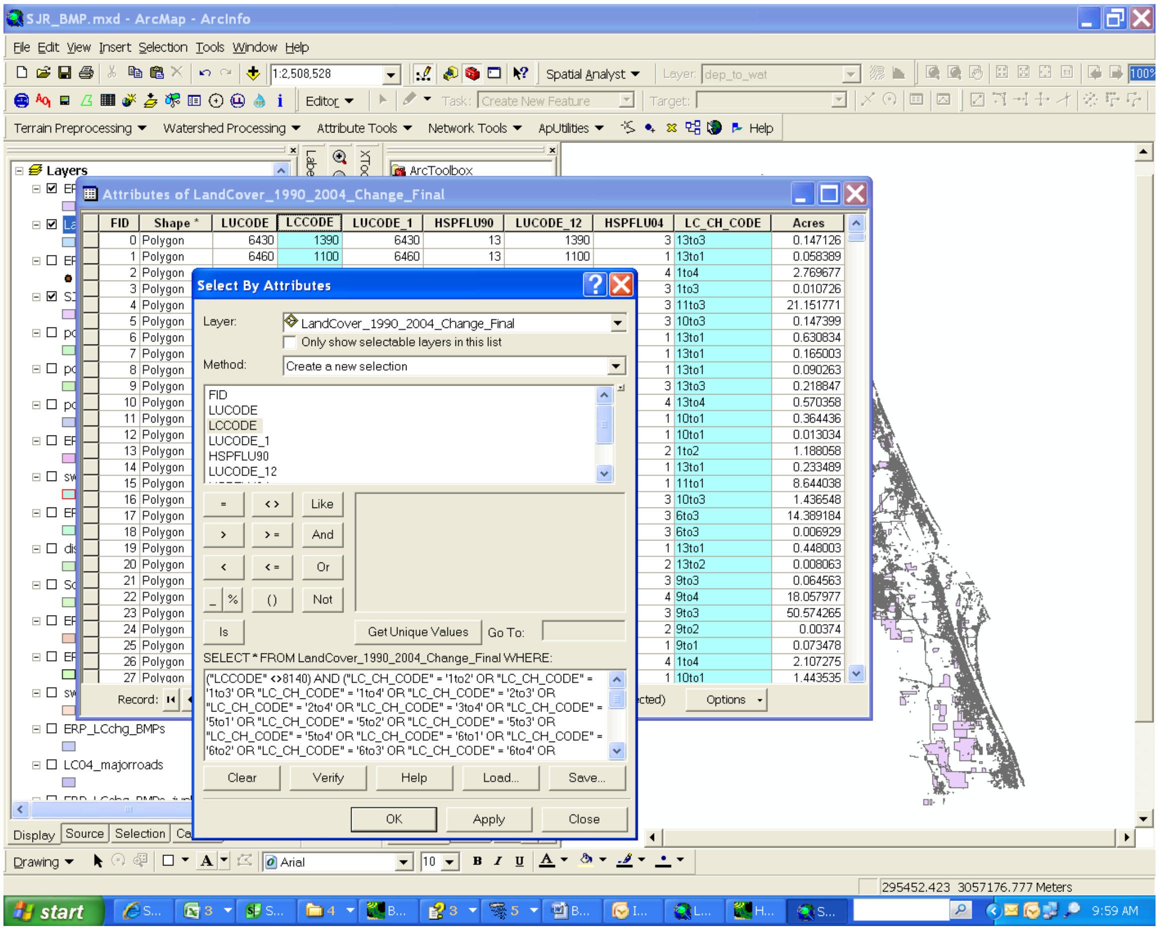


Figure Step 5g. In this step, we need to select all the features that had been subjected to urban land changes from 1990 to 2004. Since swale is estimated from only regulatory data source, we need not to select the road features that were constructed during 1990 to 2004. Click *Selection >Select by Attributes* from layer "LandCover_1990_2004_Change_final" and type the following criteria into the bottom window:

"LCCODE" <>8140 AND ("LC_CH_CODE" = '1to2' OR "LC_CH_CODE" = '1to3' OR "LC_CH_CODE" = '1to4' OR "LC_CH_CODE" = '2to3' OR "LC_CH_CODE" = '2to4' OR "LC_CH_CODE" = '3to4' OR "LC_CH_CODE" = '5to1' OR "LC_CH_CODE" = '5to2' OR "LC_CH_CODE" = '5to3' OR "LC_CH_CODE" = '5to4' OR "LC_CH_CODE" = '6to1' OR "LC_CH_CODE" = '6to2' OR "LC_CH_CODE" = '6to3' OR "LC_CH_CODE" = '6to4' OR "LC_CH_CODE" = '7to1' OR "LC_CH_CODE" = '7to2' OR "LC_CH_CODE" = '7to3' OR "LC_CH_CODE" = '7to4' OR "LC_CH_CODE" = '8to1' OR "LC_CH_CODE" = '8to2' OR "LC_CH_CODE" = '8to3' OR "LC_CH_CODE" = '8to4' OR "LC_CH_CODE" = '9to1' OR "LC_CH_CODE" = '9to2' OR "LC_CH_CODE" = '9to3' OR "LC_CH_CODE" = '9to4' OR "LC_CH_CODE" = '10to1' OR "LC_CH_CODE" = '10to2' OR "LC_CH_CODE" = '10to3' OR "LC_CH_CODE" = '10to4' OR "LC_CH_CODE" = '11to1' OR "LC_CH_CODE" = '11to2' OR "LC_CH_CODE" = '11to3' OR "LC_CH_CODE" = '11to4' OR "LC_CH_CODE" = '13to1' OR "LC_CH_CODE" = '13to2' OR "LC_CH_CODE" = '13to3' OR "LC_CH_CODE" = '13to4')

This should select all the features that had been subjected to urban land use changes from 1990 to 2004 except the road features ("LCCODE" <>8140).

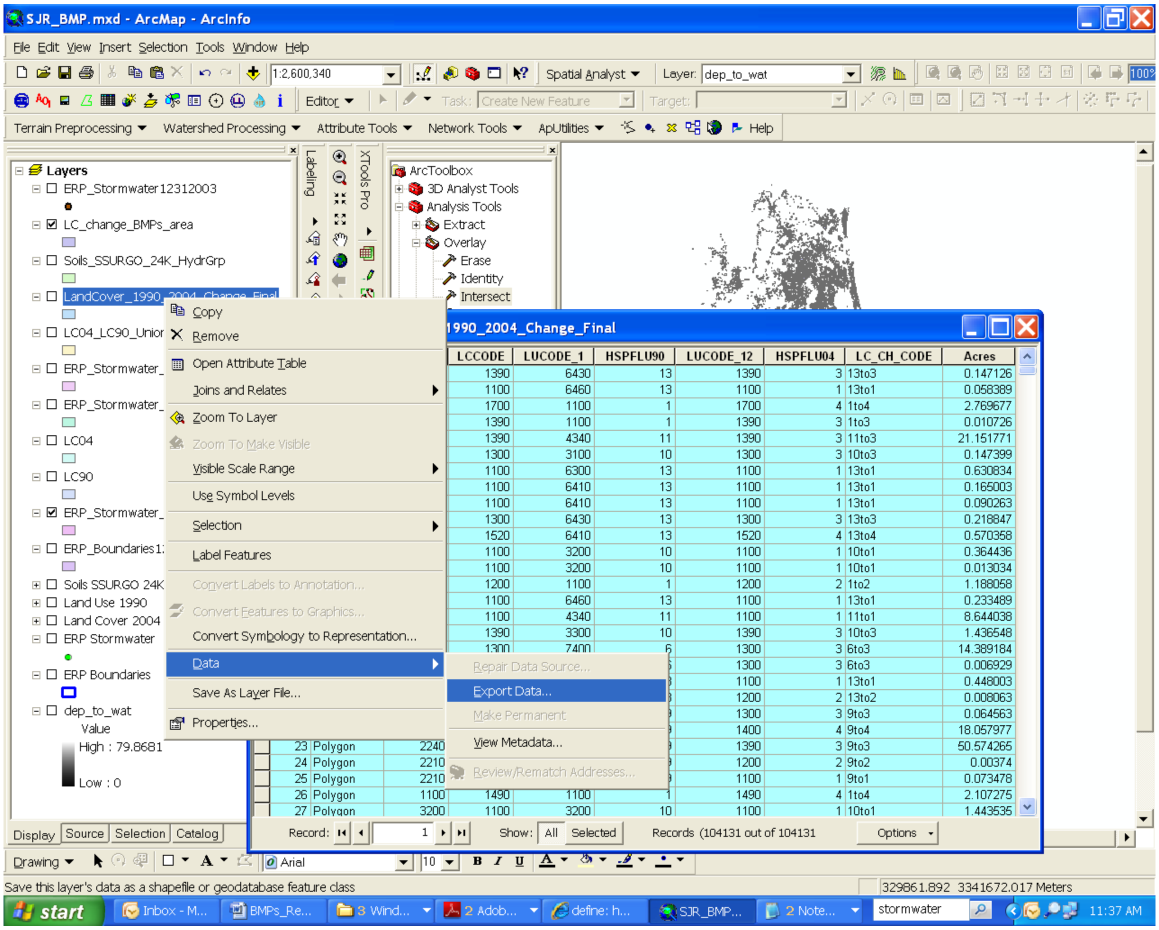


Figure Step 5h. Right click on layer “LandCover_1990_2004_Change_final”, *Data >Export Data* the selected records from it to a new layer named “LC_change_BMPs_area”. This should include all the BMPs covered areas due to urban development. This layer is used later to complement the ERP-based BMPs-covered areas.

Step 6. In this step, layer "ERP_Stormwater_Boundaries_disov" from Step 4b will be first limited to urban or industrial & commercial areas. This limitation is necessary because some of the properties in the permits applications data sets have not been developed yet and therefore no BMPs have been installed on those properties. Later it will be unioned with layer "LC_change_BMPs_area" from Step 5h to create a new layer, which represents the total BMPs-covered area.

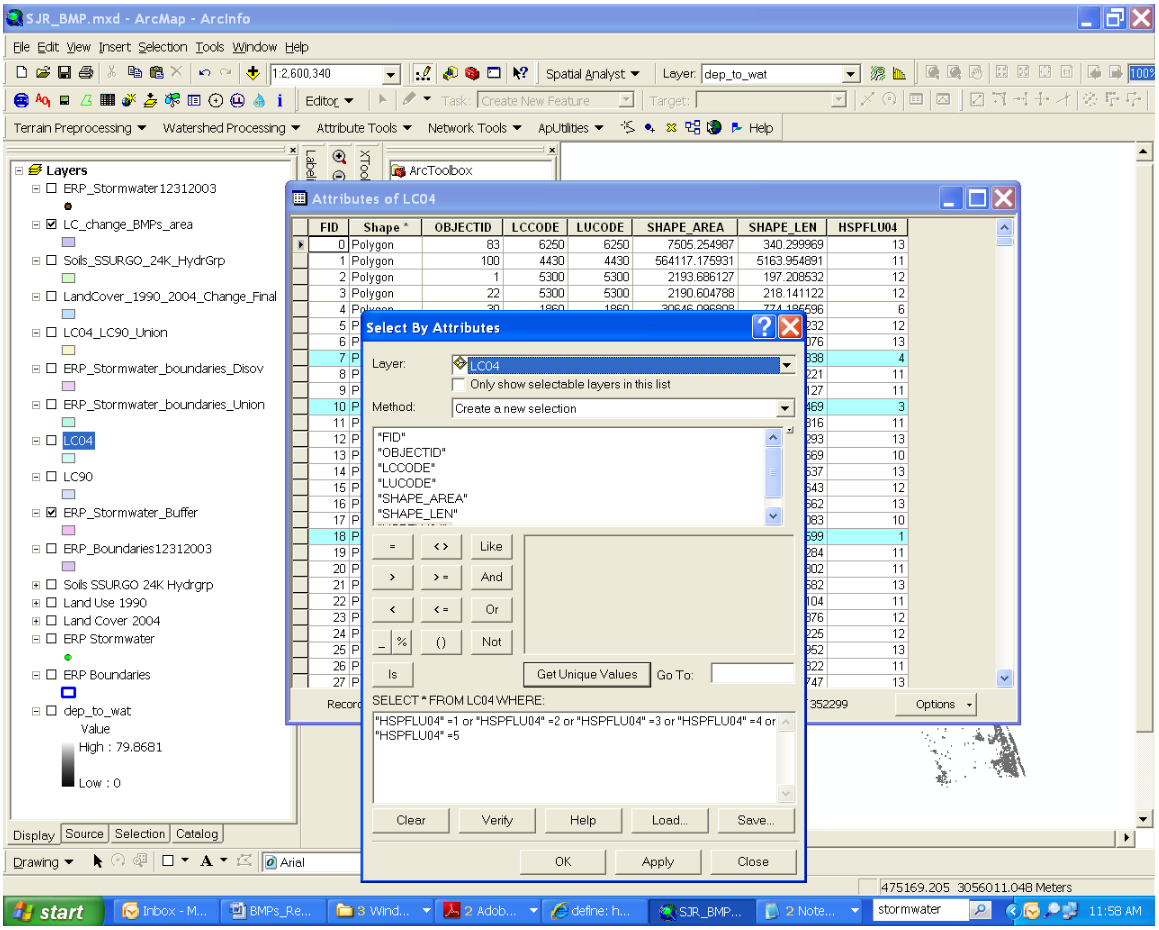


Figure Step 6a. Select all the urban or mining features from layer "LC04" by clicking *Selection >Select by Attributes* and typing ""HSPFLU04" =1 or "HSPFLU04" =2 or "HSPFLU04" =3 or "HSPFLU04" =4 or "HSPFLU04" =5" into the bottom window. Export all the selected features to a new layer entitled "urban_mining_areas".

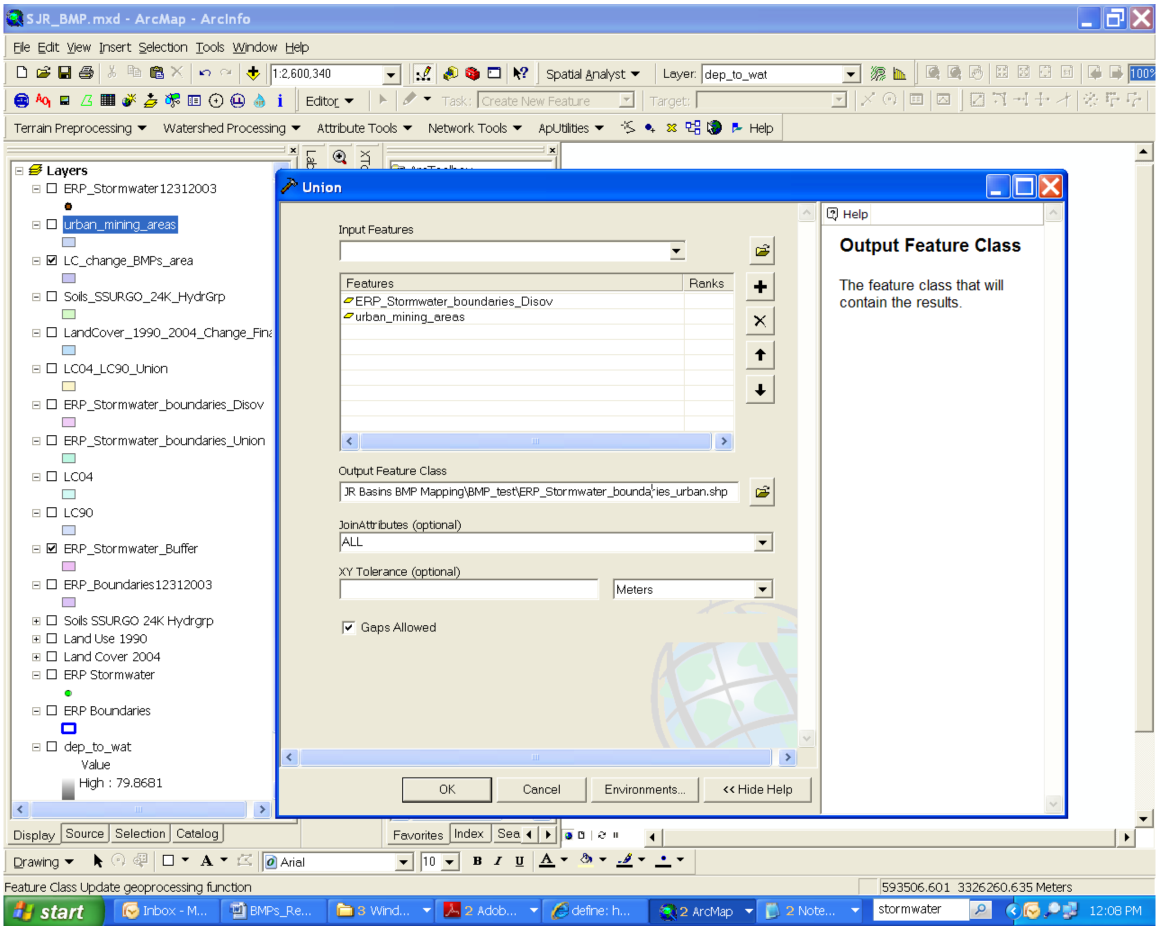


Figure Step 6b. Union (*ArcToolbox->Analysis Tools >Overlay->Union*) layer "ERP_Stormwater_boundaries_Disov" with layer "urban_ming_areas" to create new layer "ERP_Stormwater_boundaries_urban". Select all the features from layer "ERP_Stormwater_boundaries_urban" by clicking *Selection >Select by Attributes* and typing "("FID_ERP_St" >-1) AND ("HSPFLU04" >0)" into the bottom window. Export all the selected features to a new layer entitled "ERP_Stormwater_Boundaries_Urban_BMPs". This new layer will include all the urban areas that had permits filed on them.

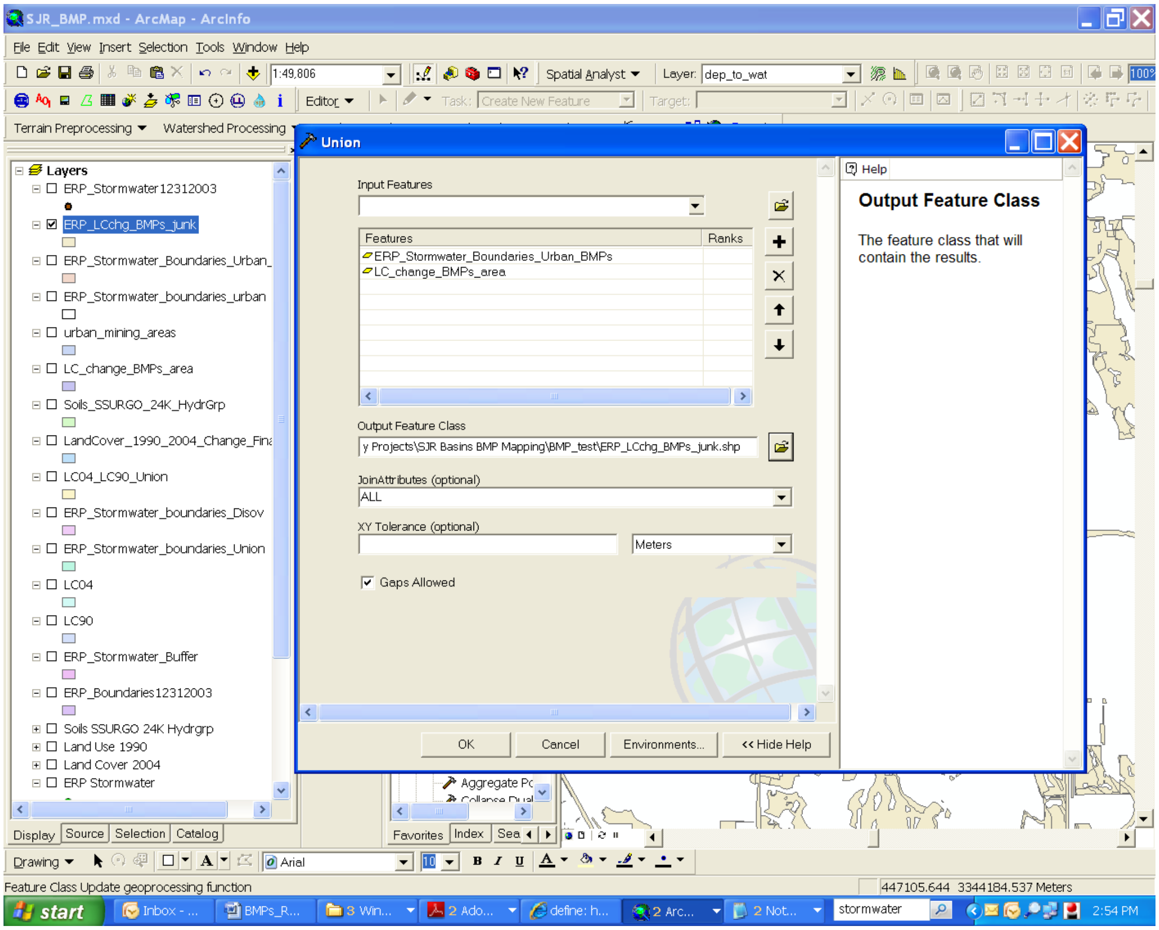


Figure Step 6c. Union (*ArcToolbox >Analysis Tools >Overlay >Union*) layer "ERP_Stormwater_Boundaries_Urban_BMPs" from Step 6b with layer "LC_change_BMPs_area" from Step 5h to create a new layer entitled "ERP_LCchg_BMPs_junk".

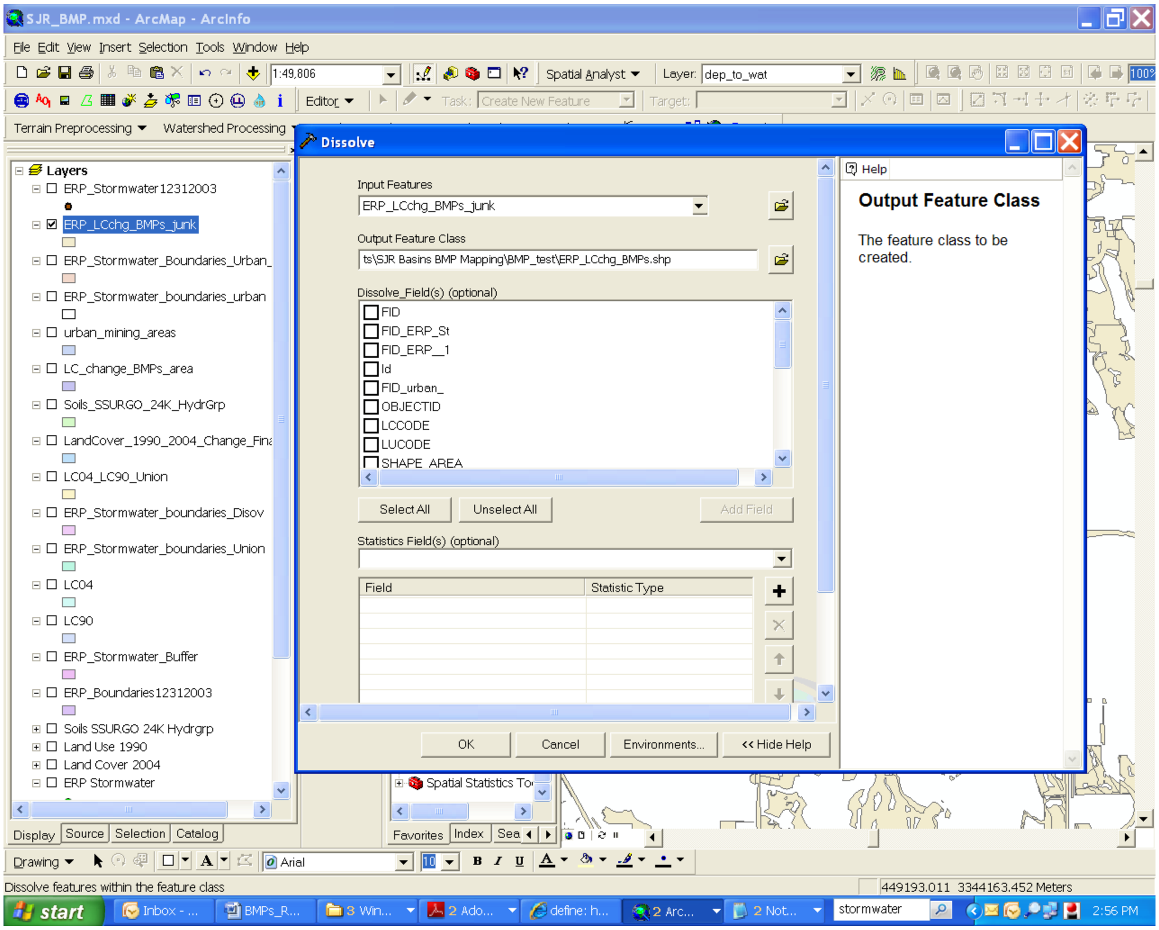


Figure Step 6d. Dissolve (*ArcToolbox >Data Management Tools > Generalization->Dissolve*) all the features in layer “ERP_LCchg_BMPs_junk” to a new layer “ERP_LCchg_BMPs” (do not check any fields in Dissolve_Field(s) window).

Step 7. Convert groundwater table depth from grid format to feature format (shape file).

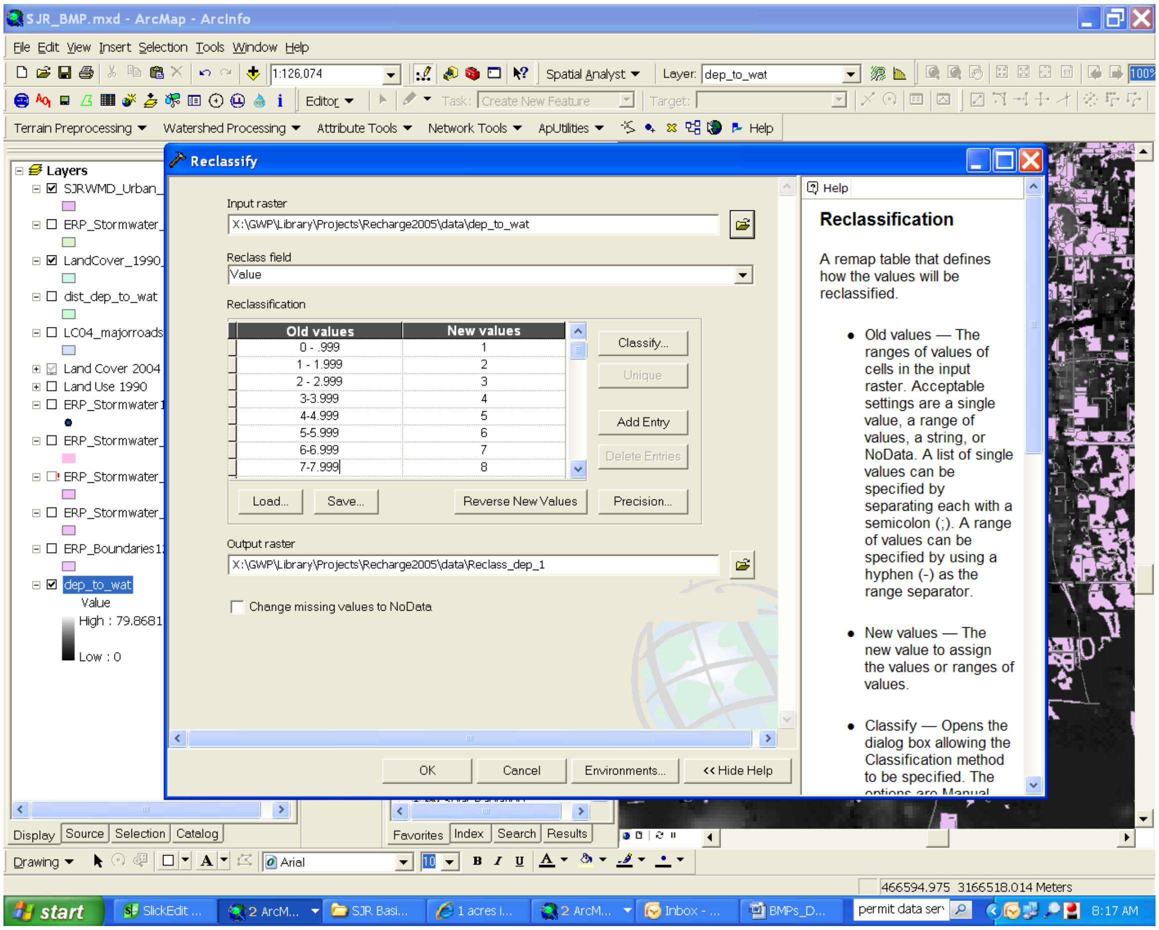


Figure Step 7a. Reclassify grid “dep_to_wat” with “Spatial Analyst Tool”. This extension needs to be turned on by clicking on *Tools >Extension* and checking “Spatial Analyst”. Reclass (*ArcToolbox >Spatial Analyst Tool >Reclass >Reclassify*) the values (groundwater table depth) from “float” data type to “integer” data type using one foot interval reclassification table:

Old values	New values
0 - 0.999	1
1 - 1.999	2
2 - 2.999	3
3 - 3.999	4
4 - 4.999	5
etc.	etc.

Output the reclassification to a temporary raster “reclass_dep_1”.

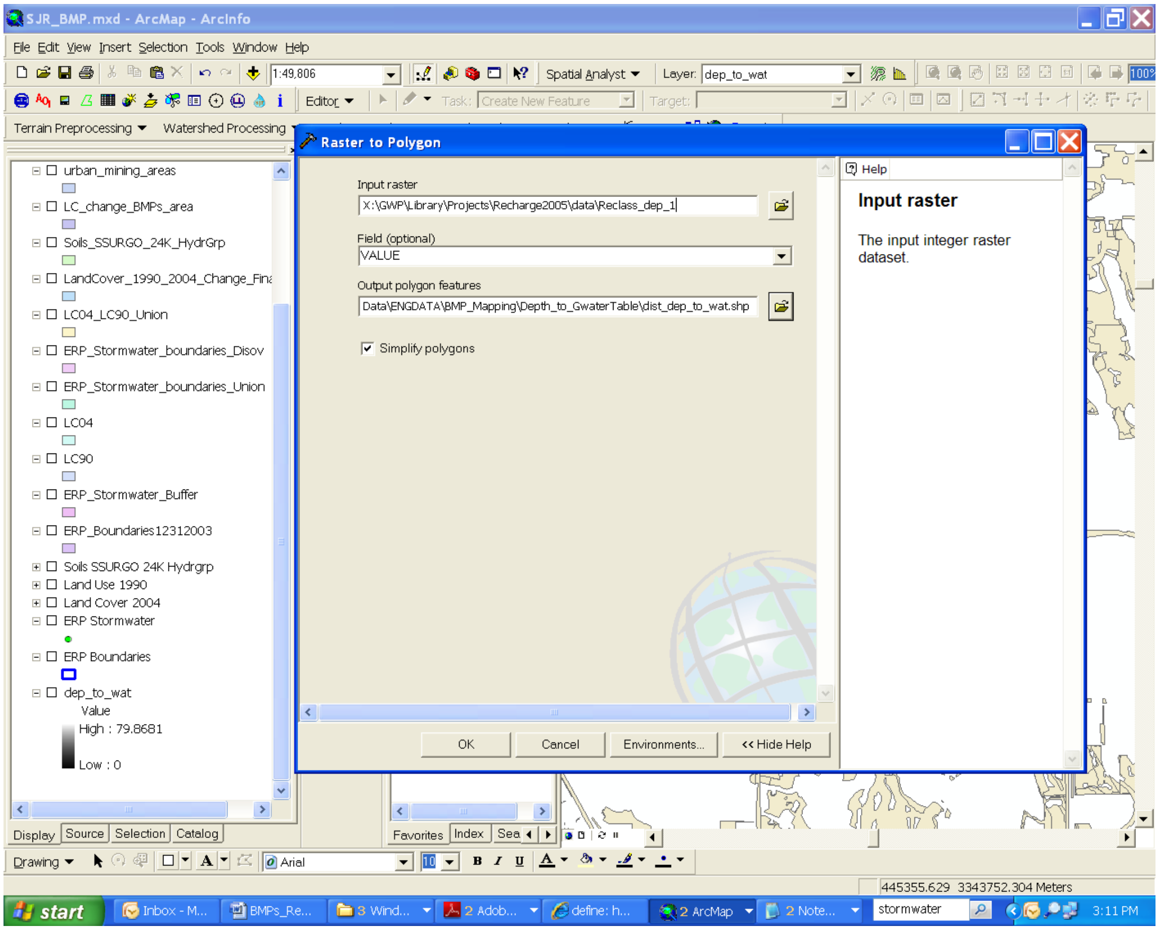


Figure Step 7b. Convert the temporary raster “reclass_dep_1” from grid format to shapefile format by clicking on *ArcToolbox >Conversion Tools >From Raster >Raster to Polygon*, and name the output polygon features as “dist_dep_to_wat”.

Step 8. Create a new layer for one of the BMPs types, “swales”, and then remove “swales” feature from layer “ERP_lCchg_BMPs”. This step is based on the assumption that all the major roads (four lanes with divide) will be covered with swales for stormwater treatment.

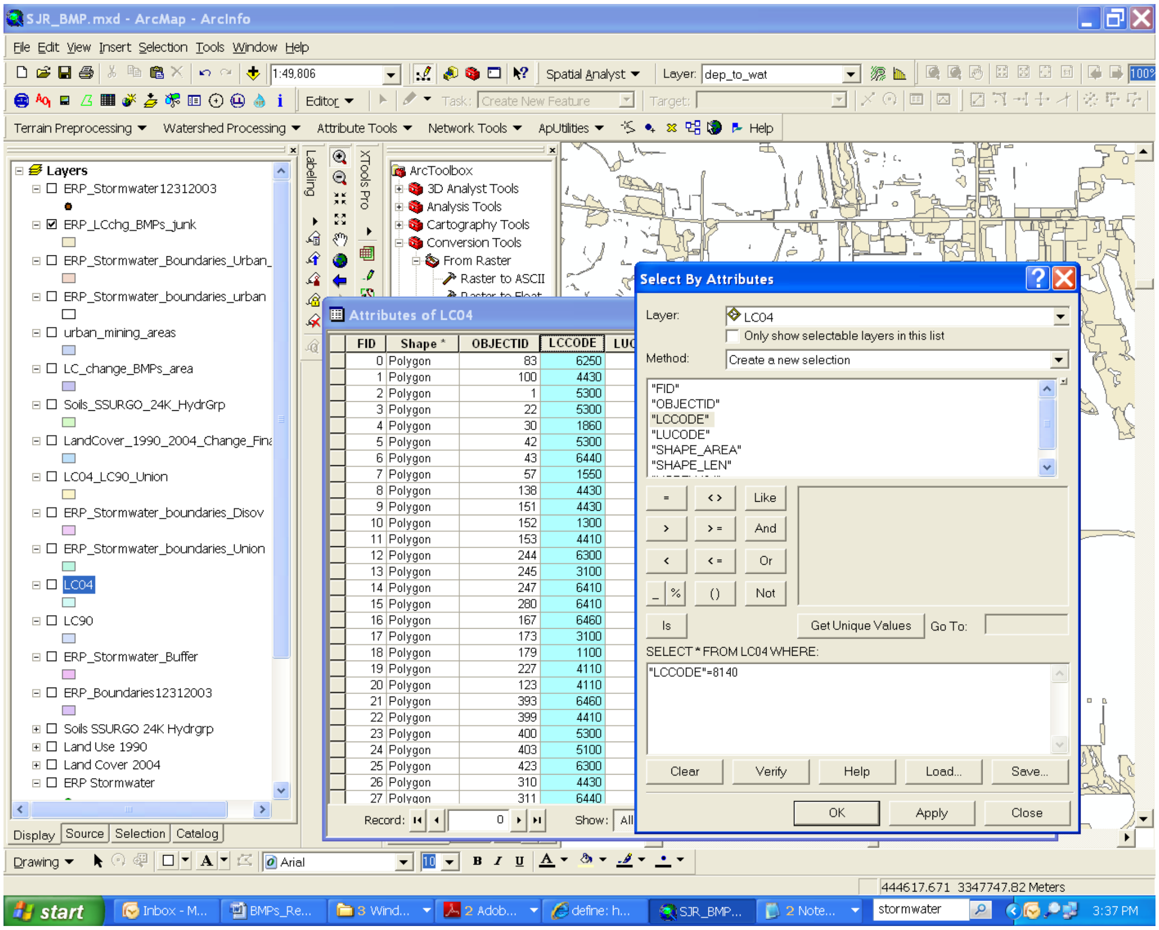


Figure 8a. Select (click on menu *Selection >Select by Attributes*) all the major roads features from layer “LC04” by inputting criteria “"LCCODE"=8140” in the bottom window and export all the selected features to a new layer named “LC04_majorroads”.

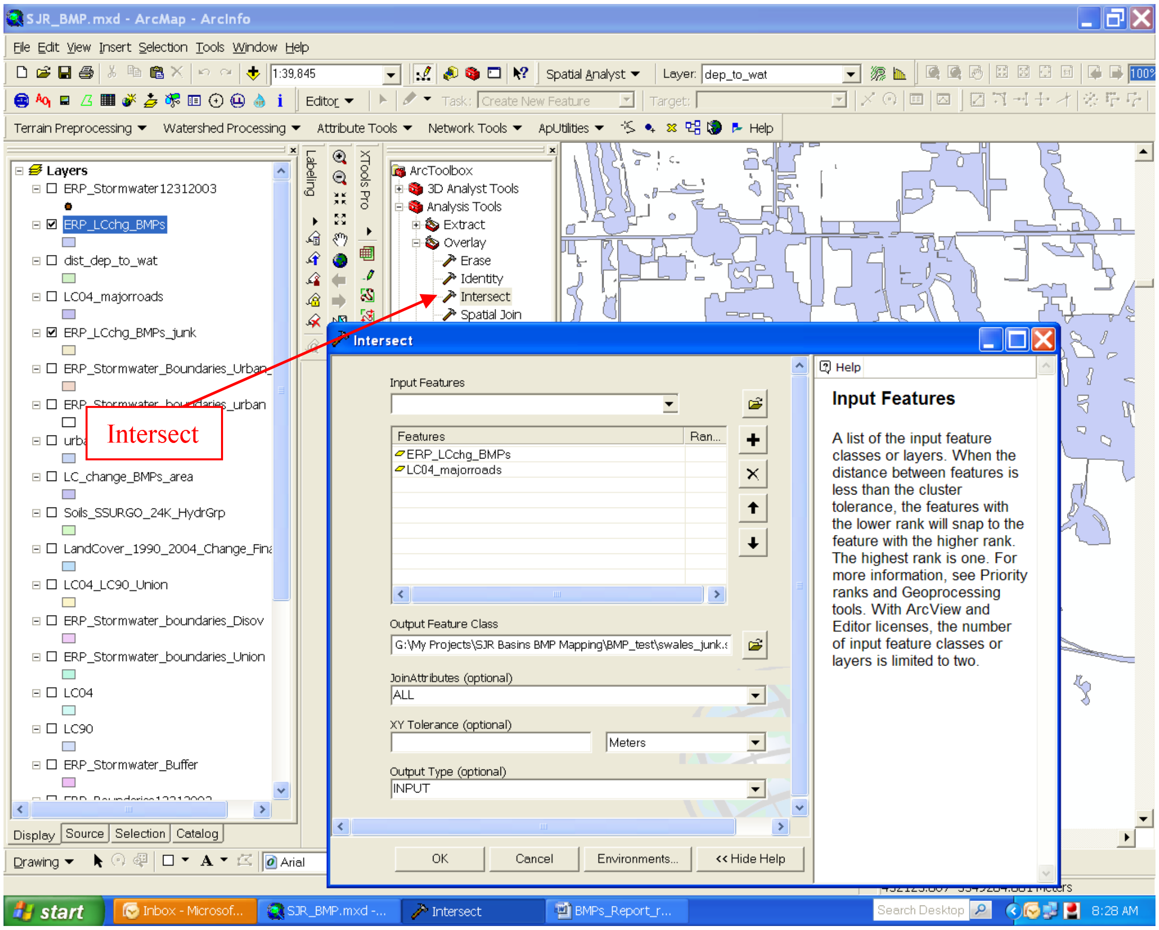


Figure Step 8b. Intersect (*ArcToolbox >Analysis Tools >Overlay > Intersect*) layer "LC04_majorroads" with layer "ERP_lCchg_BMPs" to output a new layer entitled "swales_junk".

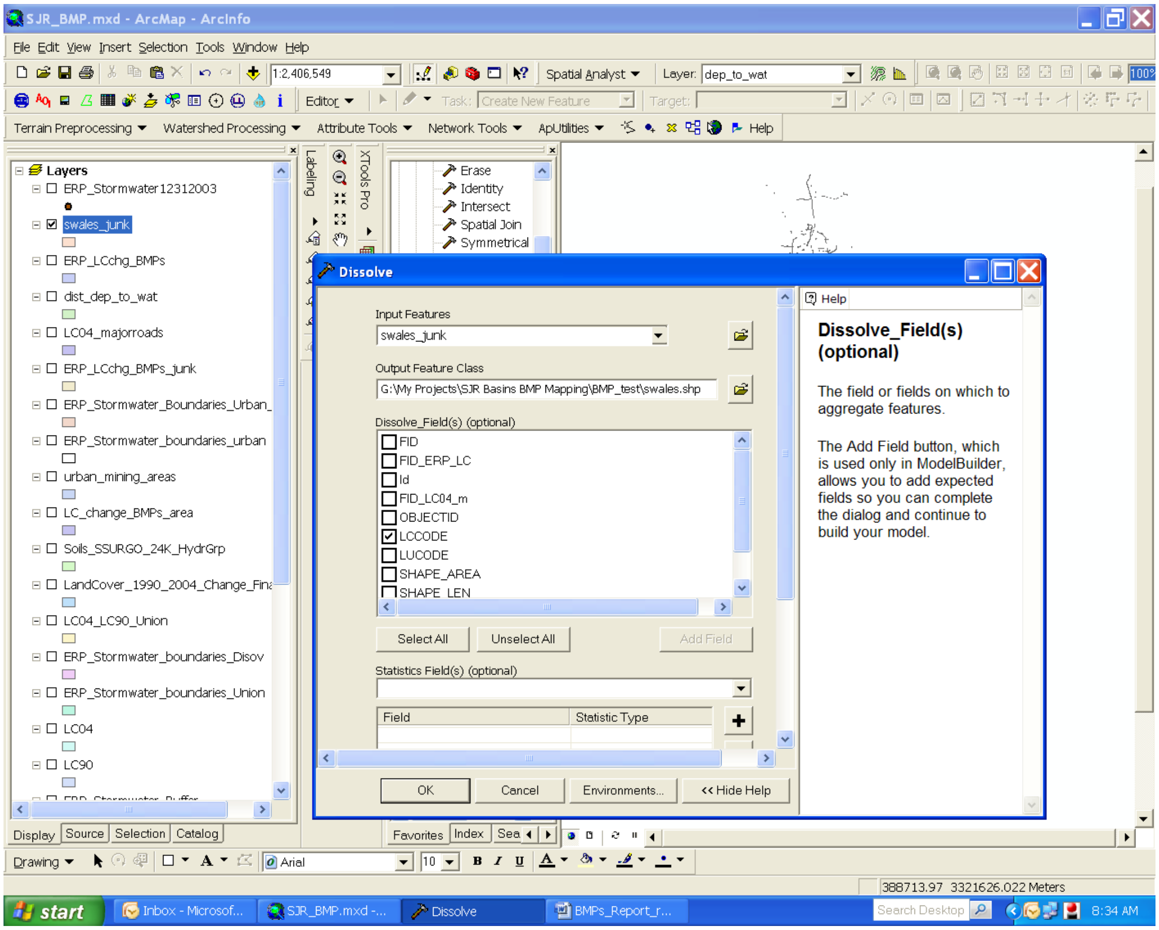


Figure Step 8c. Dissolve (*ArcToolbox->Data Management Tools-> Generalization->Dissolve*) layer “swales_junk” based on “LCCODE” to output a new layer “Swales”. Add a new attribute “BMP” (data type = “short integer” and precision = “4”) to its attribute table and assign value “1” to attribute “BMP” (“1” = Swales) with field calculator (right click column “BMP” and select field calculator) and then delete “LCCODE” from its attribute table.

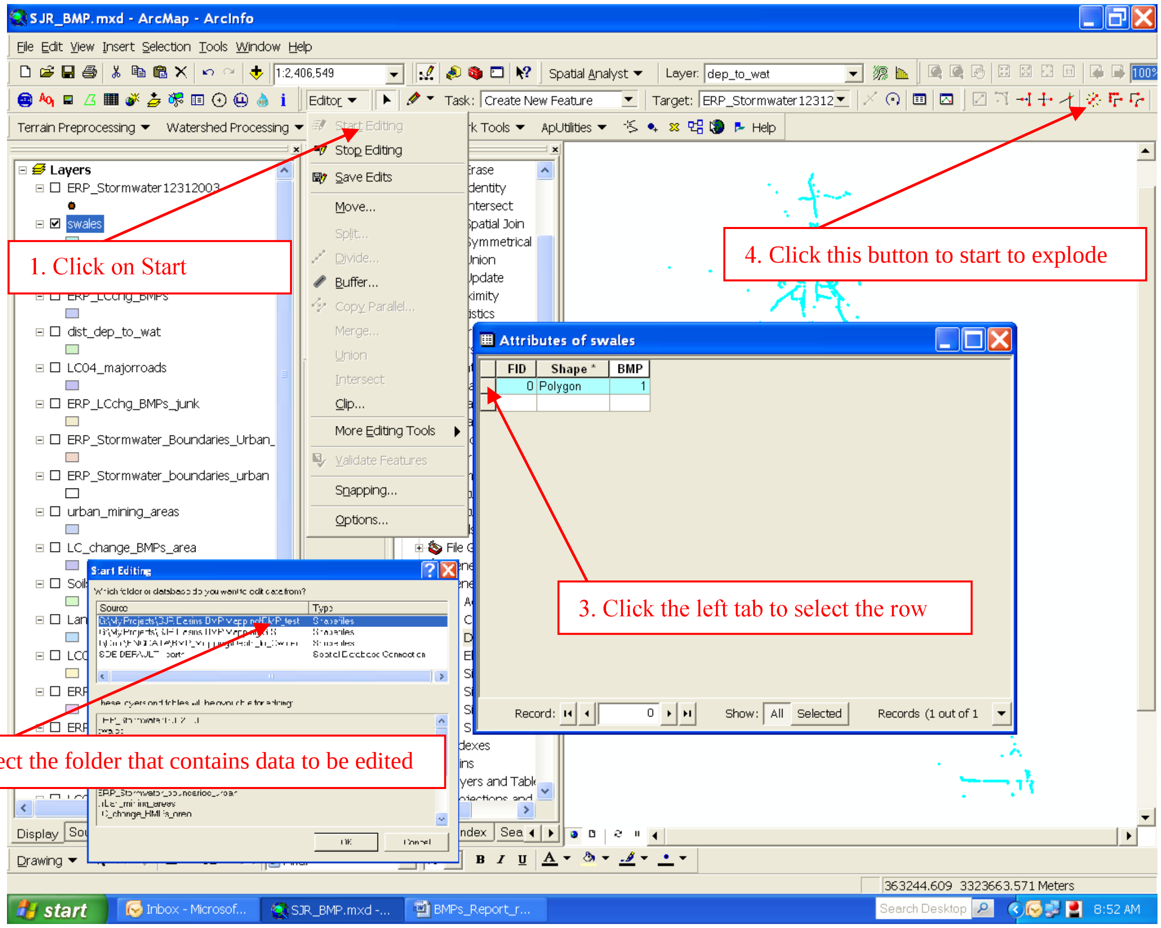


Figure Step 8d. Explode layer “Swales” from multi-part feature to multiple features. To do that, you need to:
1) Click on toolbar *Editor >Start Editing*;
2) Select the folder that contains data to be edited;
3) Select the row that has data by clicking on the left tab;
4) Click on the button named “Explode Multi-part Feature” on the top right corner of the window.

After exploding, click on *Editor >Save Edits* to save the changes and then clicking on *Editor >Stop Editing* to end the editing session.

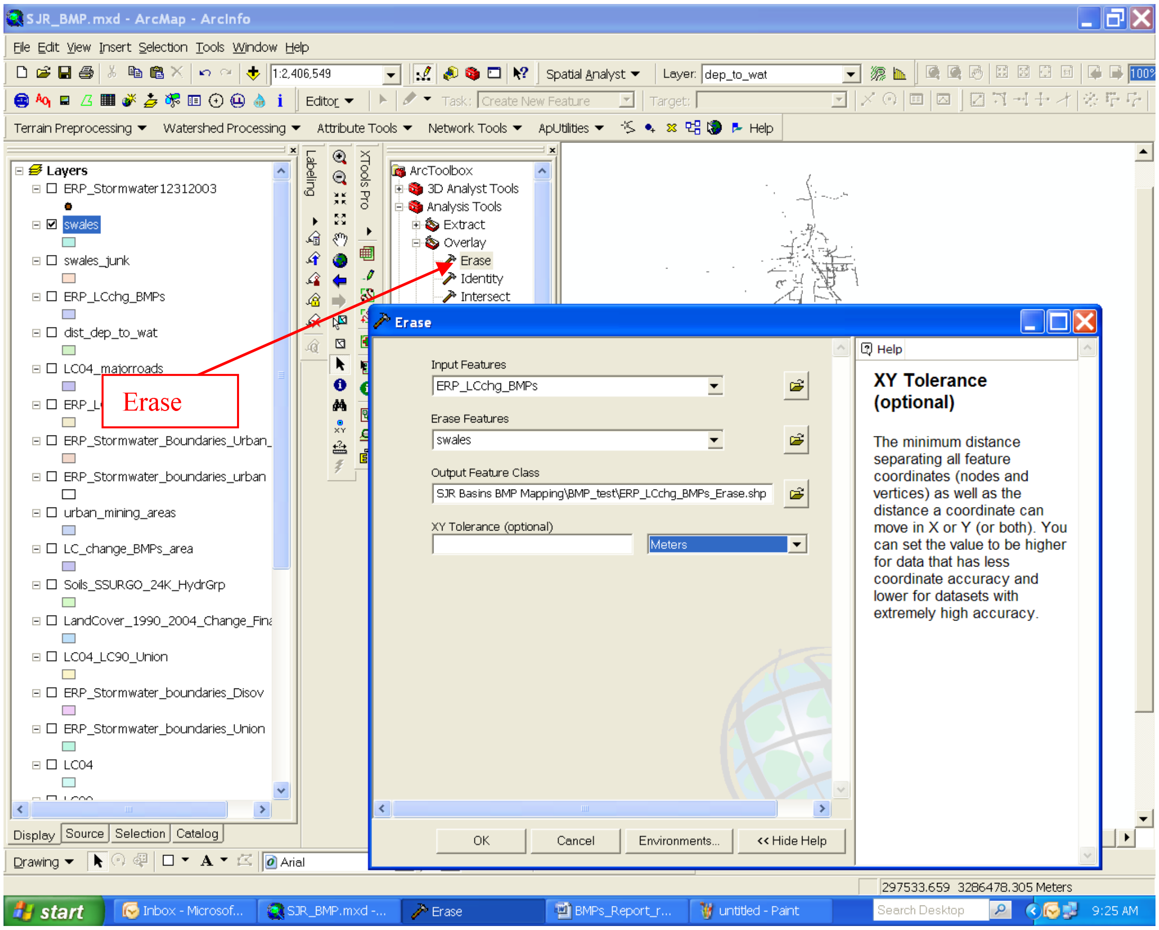


Figure Step 8e. Since “swale” features have already been identified in the layer “Swales”, all the “swale” features need to be erased (*ArcToolbox >Analysis Tools >Overlay >Erase*) from layer “ERP_LCchg_BMPs” and output to a new layer “ERP_LCchg_BMPs_Erase”, which contains only “wet detention pond” or “dry detention pond” features.

Step 9. In this step, soil hydrologic group data and groundwater table depths are utilized to separate “dry detention ponds” from “wet detention ponds”. Groundwater table depth and soil infiltration rate are the most important factors for engineers to consider when designing dry/wet detention ponds. Typically, they will take advantage the local hydrology and soil properties. Ignoring the local conditions will result in failure or incur high costs to maintain the ponds. For example, a dry pond constructed at a site with a shallow groundwater table and/or low infiltration rate will not function as a dry pond, but rather a wet pond. On the other hand, a wet pond constructed in an area with a very deep groundwater table and/or high soil infiltration rate cannot hold a permanent pool, and hence it will function as dry pond instead of its designed usage. Therefore, our separation of dry/wet ponds is based on functional types rather than designed types. Our assumption is:

a. If the groundwater depth is less than 5 feet, it will be a wet pond regardless of the soil hydrologic group data;
b. If the groundwater depth is greater than 10 feet, it will be a dry pond regardless of the soil hydrologic groups;
c. If the groundwater depth is between 5 and 10 feet, then it depends on the soil hydrologic groups: if it is “A” soil (high infiltration rate) then this site most likely will be treated by dry detention pond; otherwise it will be a wet detention pond.

Classification:

BMP=1 → Swales
BMP=5 → Dry Detention Ponds
BMP=11 → Wet Detention Ponds

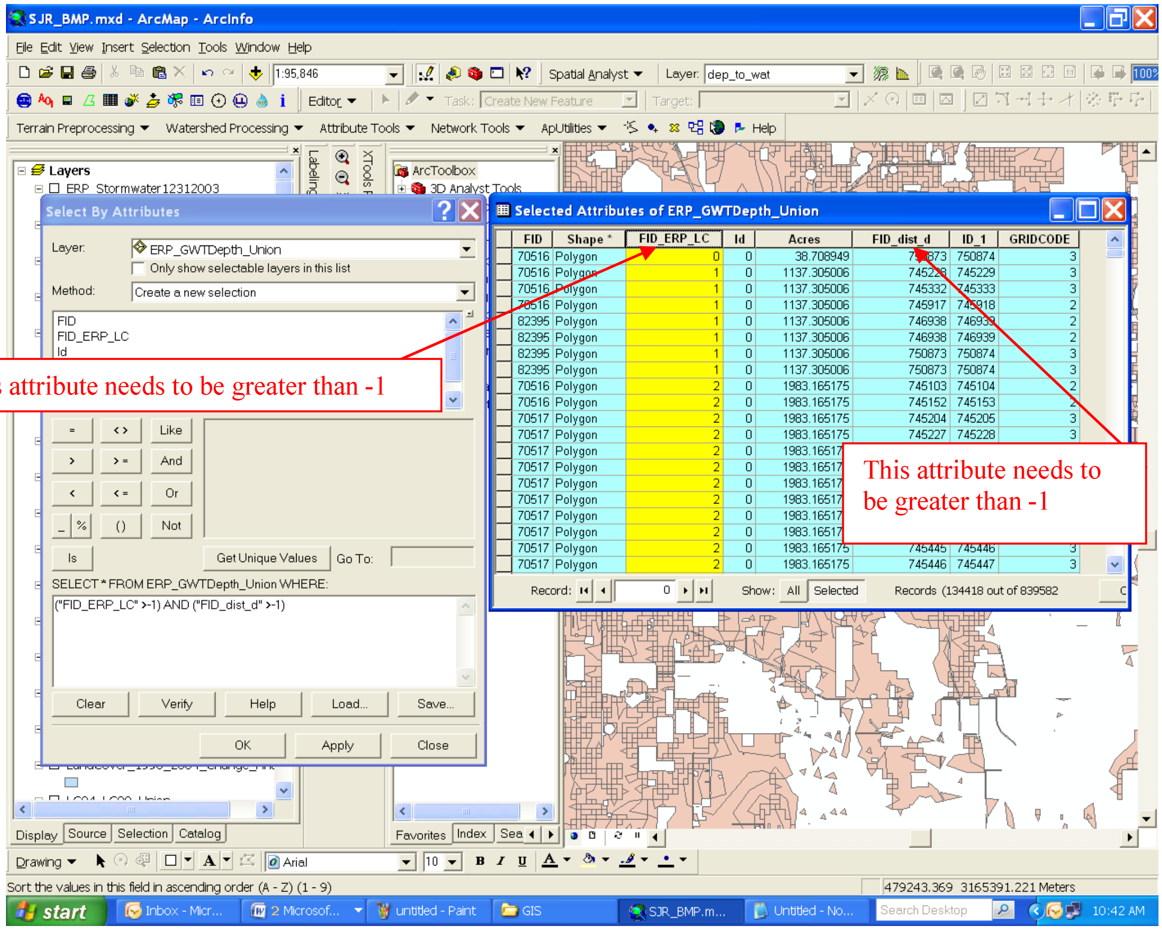


Figure Step 9a. Union layer “ERP_LCchg_BMPs_Erase” from Step 8e with layer “dist_dep_to_wat” to create a new layer “ERP_GWTDepth_Union”. Click on *Selection >Select by Attributes* to select features from layer “ERP_GWTDepth_Union”, and type “("FID_ERP_LC" >-1) AND ("FID_dist_d" >-1)” in the bottom window. Attributes "FID_ERP_LC" and "FID_dist_d" were automatically generated in the attribute table of “ERP_GWTDepth_Union” by ArcMap during the union of two layers. If the value of "FID_ERP_LC" equals -1, this means that the feature doesn’t exist in the layer “ERP_LCchg_BMPs_Erase”. The same is true for "FID_dist_d". A feature with both "FID_ERP_LC" and "FID_dist_d" greater than -1 will ensure that it has both BMPs and groundwater table depth data. The six alphabets after “FID_” refer to the names of layers participated in the union. Therefore, if you have different layer names, you will not have the exact same attribute names in the union output result. In this case, you need to look for the two attributes starting with “FID_” and followed by the first six letters of the names of layers participating in the union. Export all the selections to a new layer named “ERP_GWTDepth_Union_Export” and then union it with layer “Soils_SSURGO_24kK_HydrGrp” to output to a new layer entitled “ERP_GWTDepth_SoilHydroGrp_Union”.

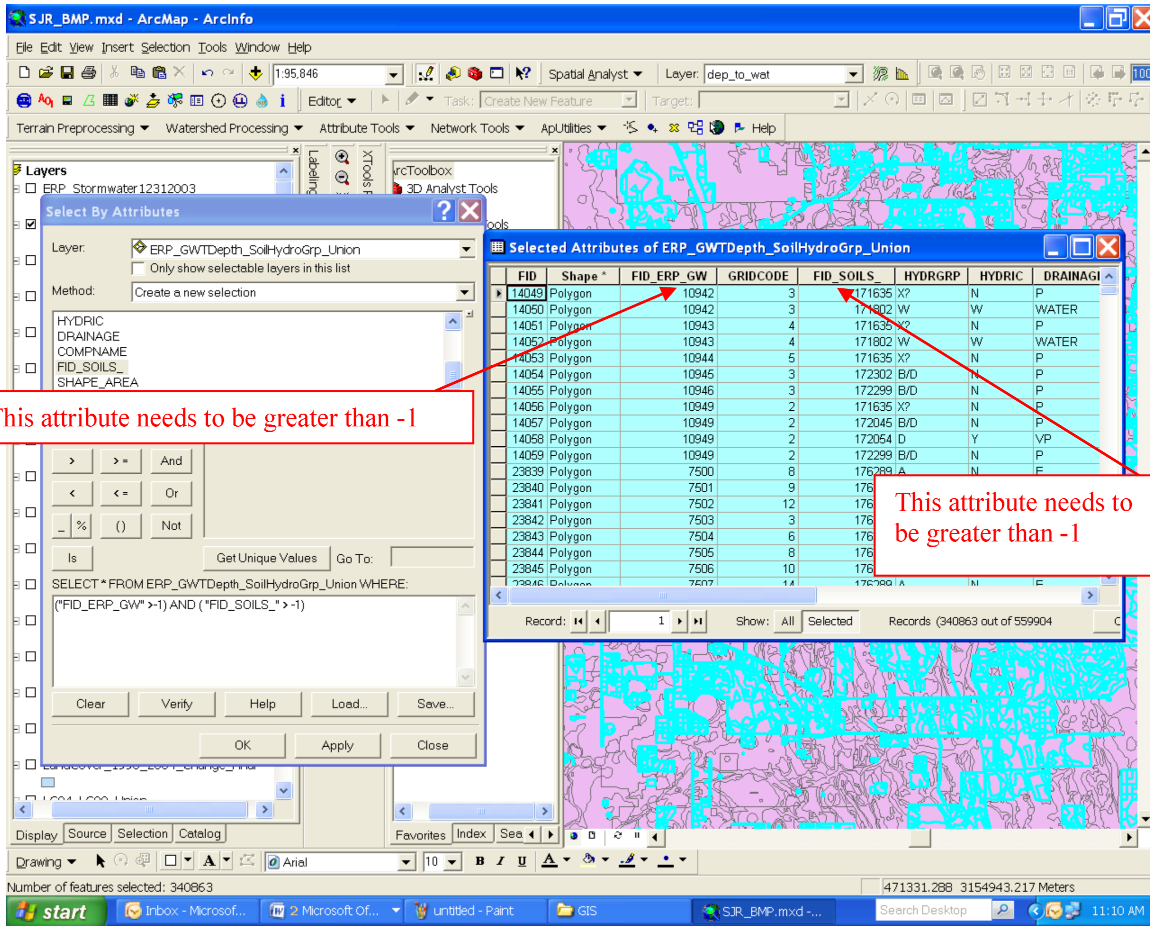


Figure Step 9b. Click on *Selection* >*Select by Attributes* to select features from layer “ERP_GWTDepth_SoilHydroGrp_Union”, and type “("FID_ERP_GW" >-1) AND ("FID_SOILS_" > -1)” in the bottom window (once again, you might have different attribute names if the union layer names are not the same as “ERP_GWTDepth_Union_Export” and “Soils_SSURGO_24kK_HydrGrp”). This will select all the features that have BMPs, groundwater table depths and soil infiltration rate information. Export the selections to a new layer named “ERP_GWTDepth_SoilHydroGrp_Union_Export”.

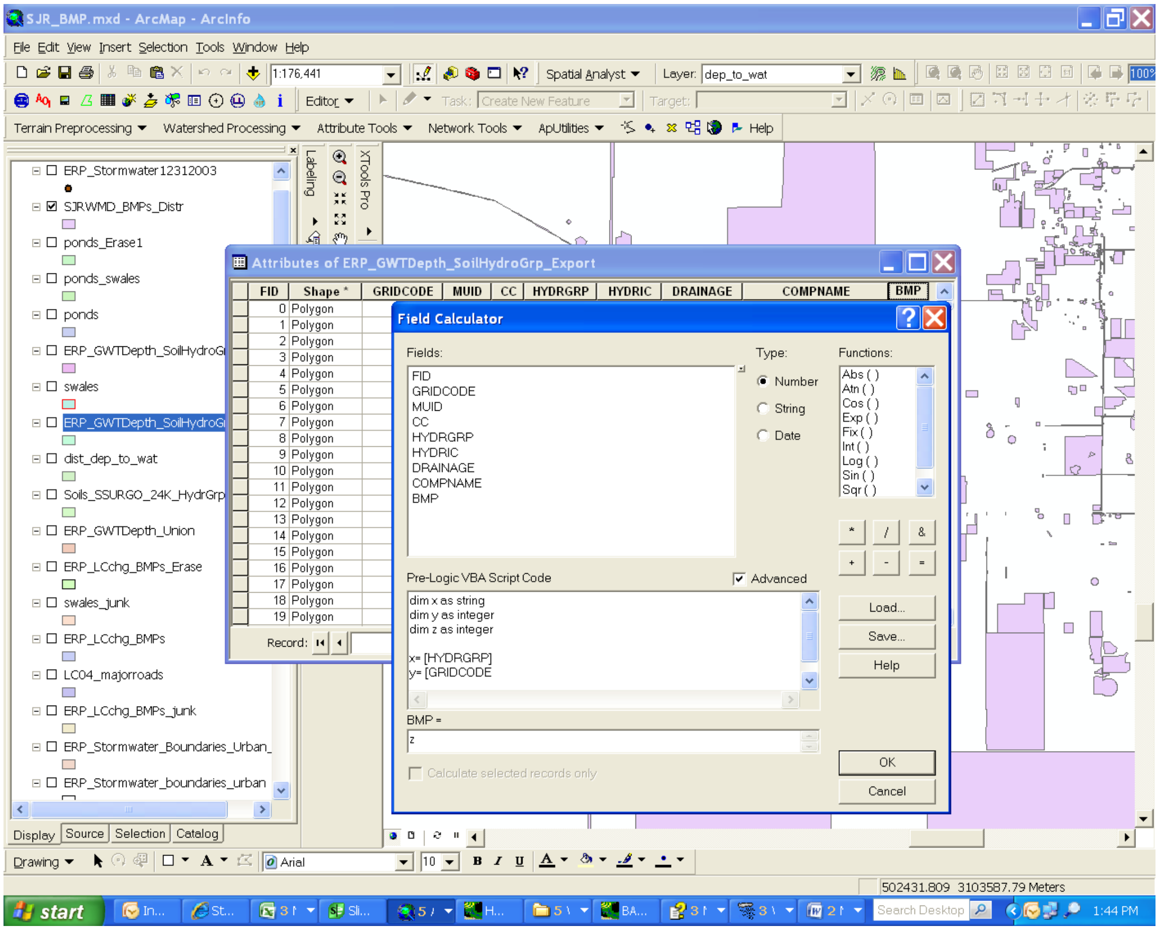


Figure Step 9c. Add a new attribute "BMP" (data type = "short integer" and precision = "4") to the attribute table of "ERP_GWTDepth_SoilHydroGrp_Union_Export" and calculate its values with advanced calculation. To activate advanced calculation, right click on column "BMP" which will pop window "Field Calculator" and then check "Advanced". This will replace the below window with two small windows. Type "z" in the bottom window and the following codes in the "Pre-logic VBA Script Code" window:

```
dim x as string
dim y as integer
dim z as integer

x= [HYDRGRP]
y= [GRIDCODE]

if  (y>=10) or ((y<10) AND (y>=5) AND (StrComp(x, "A")=0))  Then
      z= 5
else
      z= 11
end if
```

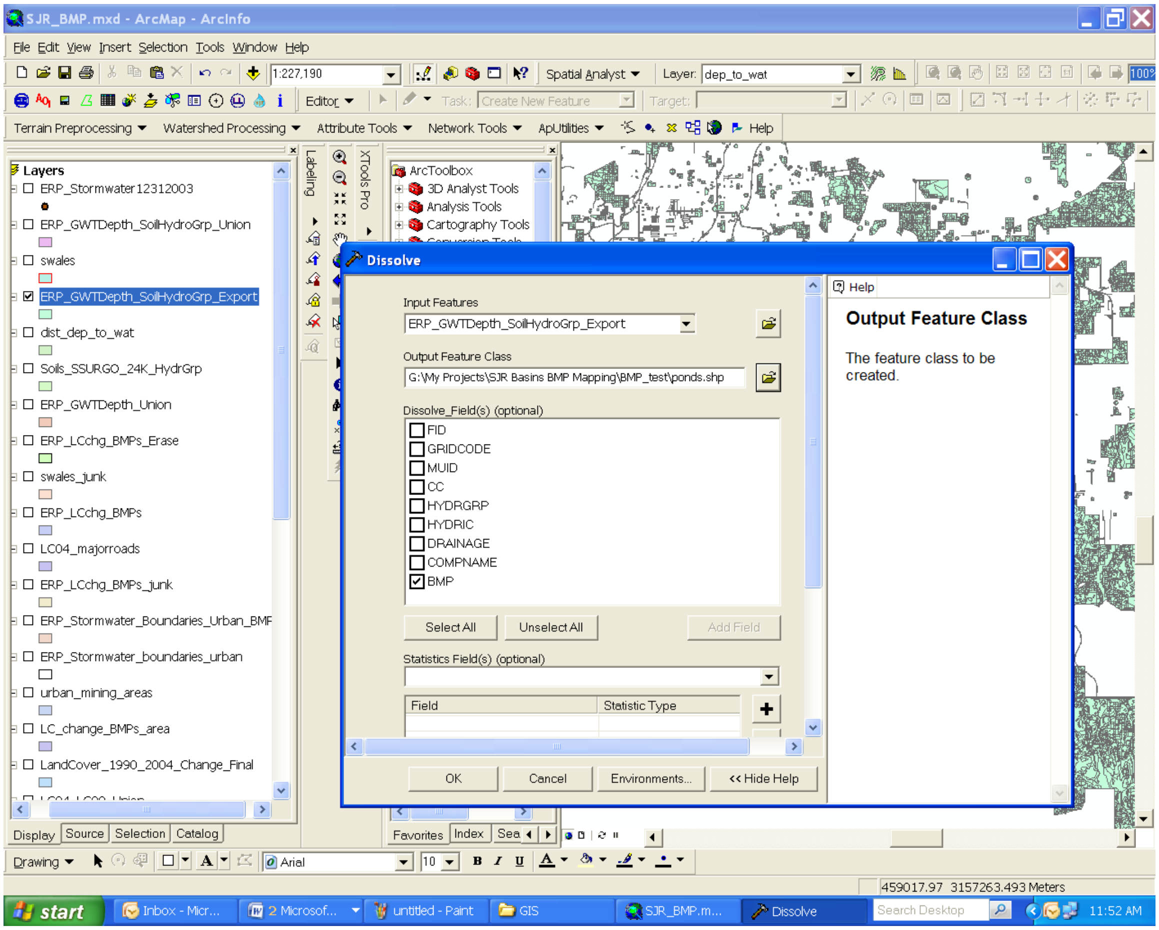


Figure Step 9d. Dissolve (*ArcToolbox >Data Management Tools > Generalization >Dissolve*) layer "ERP_GWTDepth_SoilHydroGrp_Union_Export" based on "BMP" (check "BMP" in "Dissolve_Field(s) (optional)" window) to output a new layer named "ponds".

Step 10. Update layer “ponds” with layer “Swales” to create a new layer that contains all three types of BMPs.

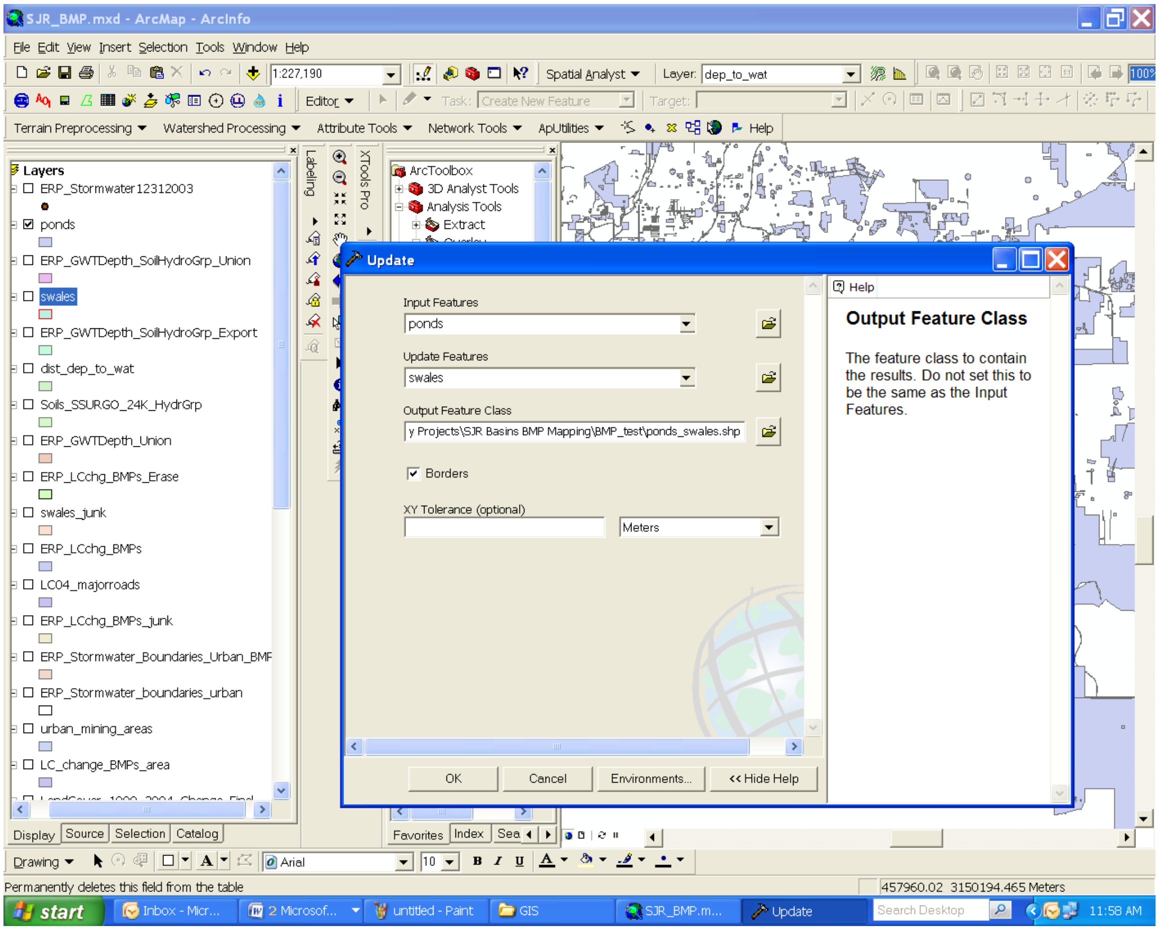


Figure Step 10a. Update (*ArcToolbox >Analysis Tools >Overlay >Update*) layer “ponds” from Step 9d with layer “Swales” from Step 8d to output a new layer that contains all three types of BMPs entitled “ponds_swales”.

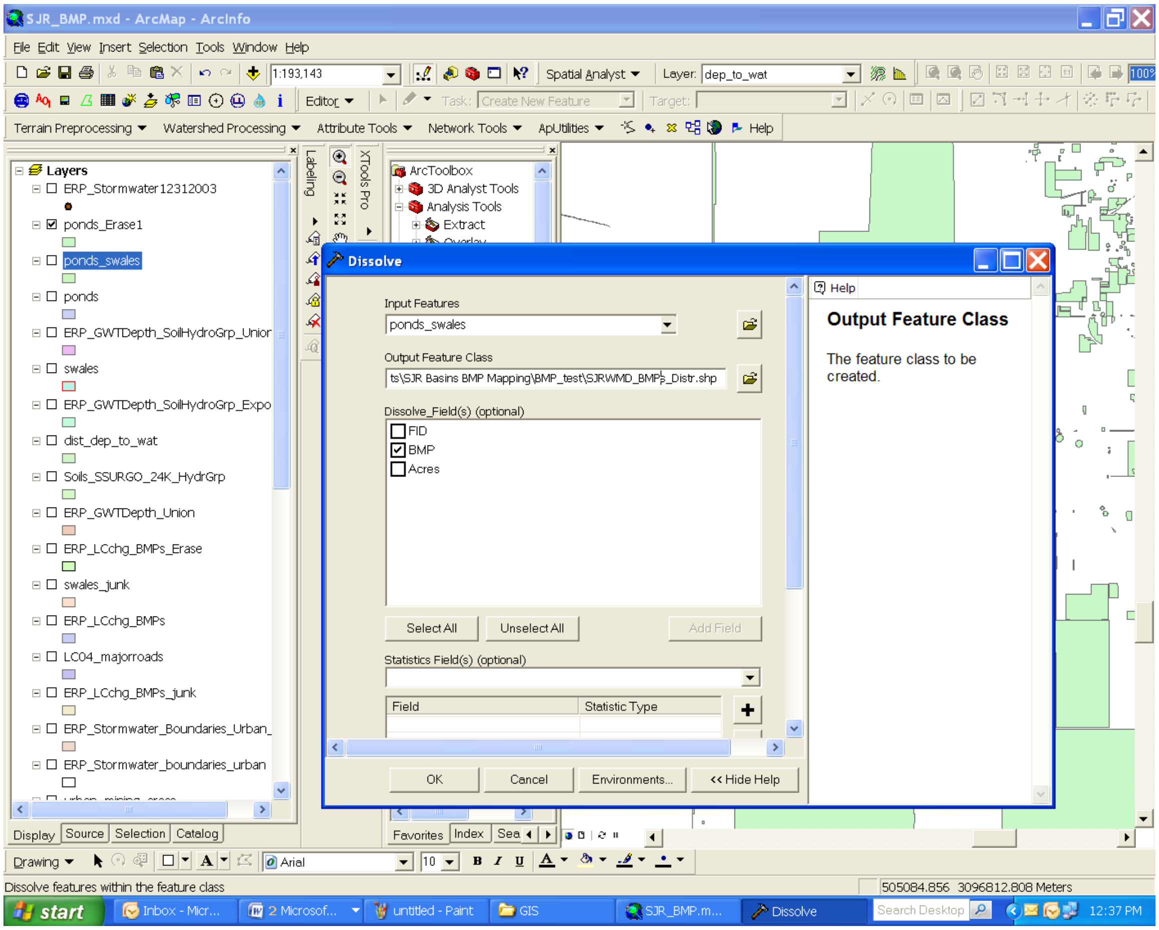


Figure Step 10b. Dissolve layer “ponds_swales” with “BMP” as “Dissolve_Field” to create a new layer “SJRWMD_BMPs_Distr” (or something appropriate for your project area’s BMPs).

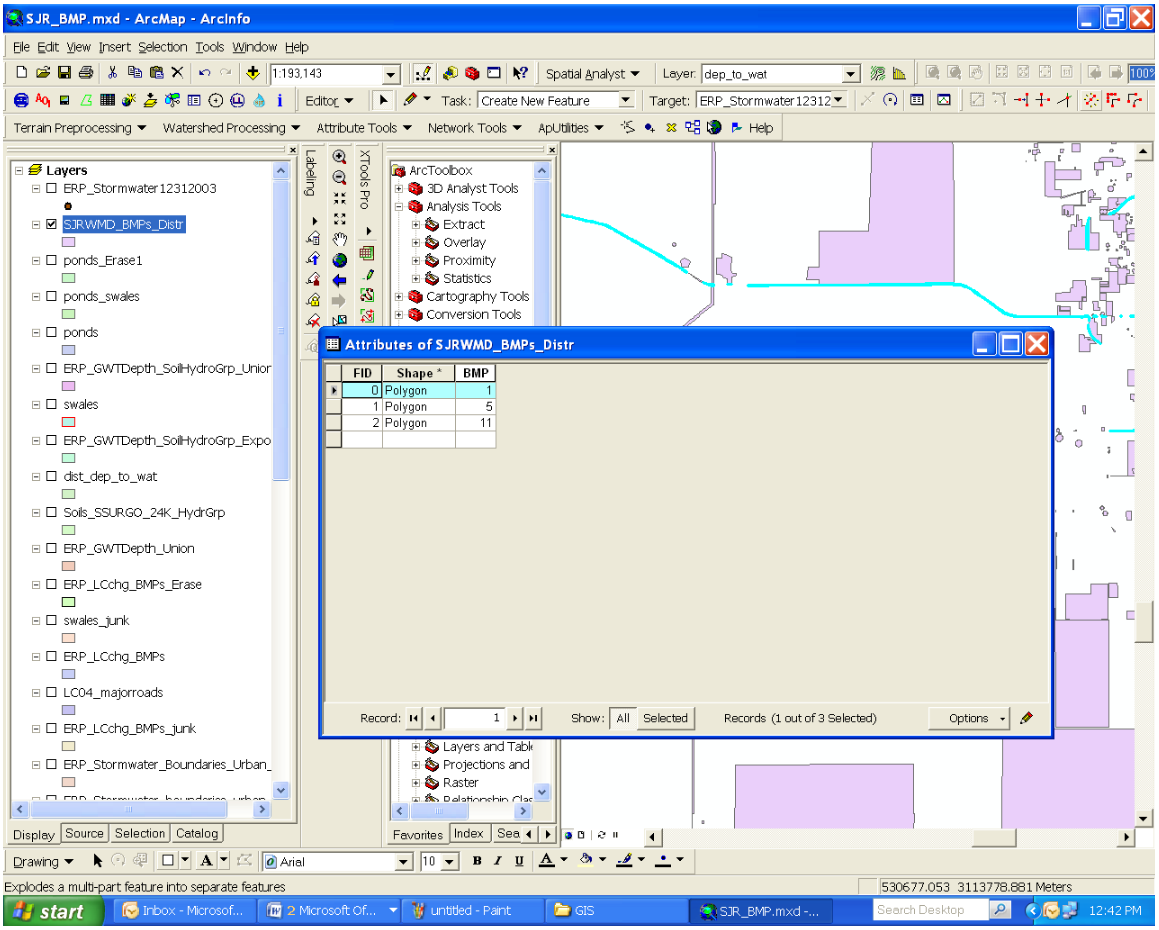


Figure Step 10c. Explode layer "SJRWMD_BMPs_Distr" into multiple features by exploding one type of "BMP" at one time (refer to Step 8d to see how to use tool "explode"). After exploding, click on *Editor >Save Edits* to save the changes and then clicking on *Editor >Stop Editing* to end the editing session.

Step 11. Calculate the areas or acreages of BMPs features

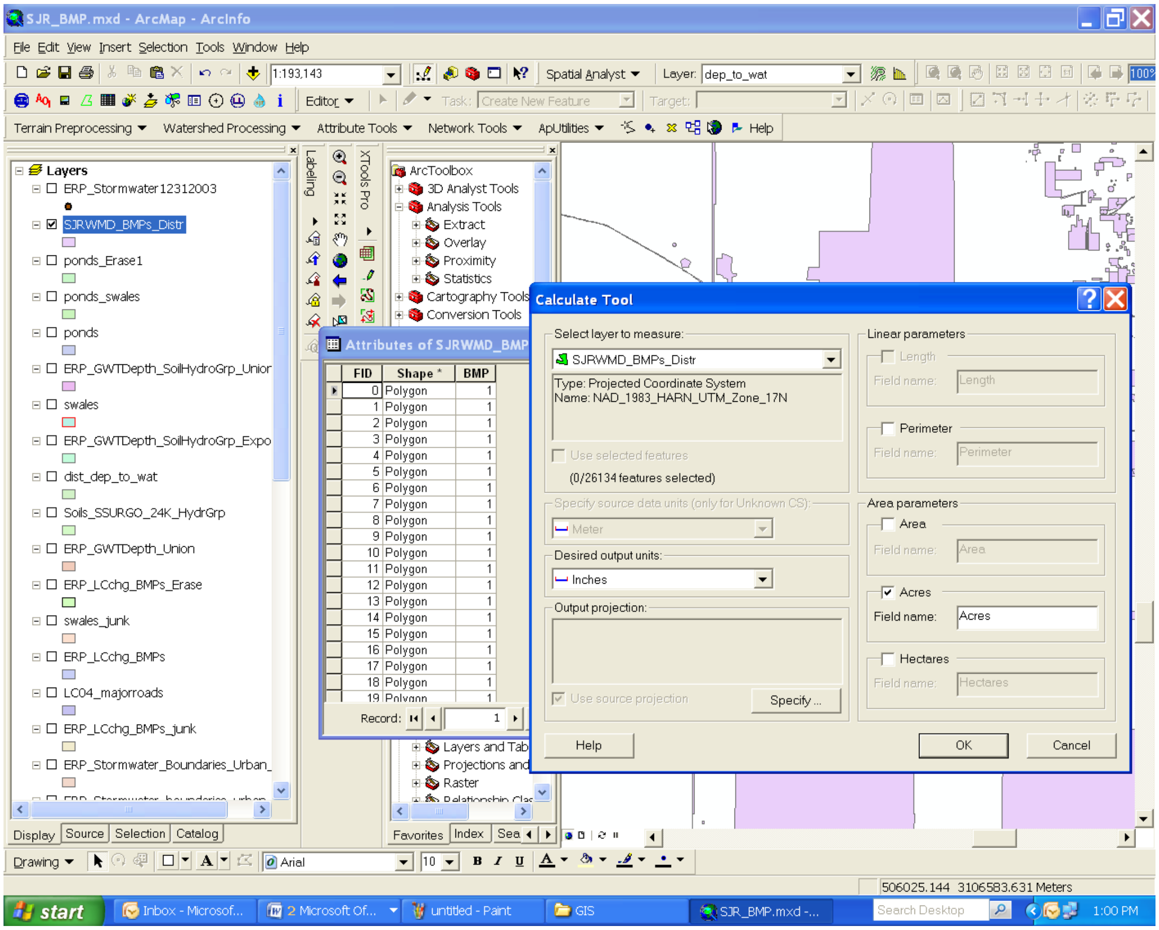


Figure Step 11a. Click on *XTools Pro >Table Operations >Calculate Area, Perimeter, Length, Acres and Hectares*, Select “SJRWMD_BMPs_Distr” as layer to measure and uncheck all the other measurements except “Acres” and then click ok.

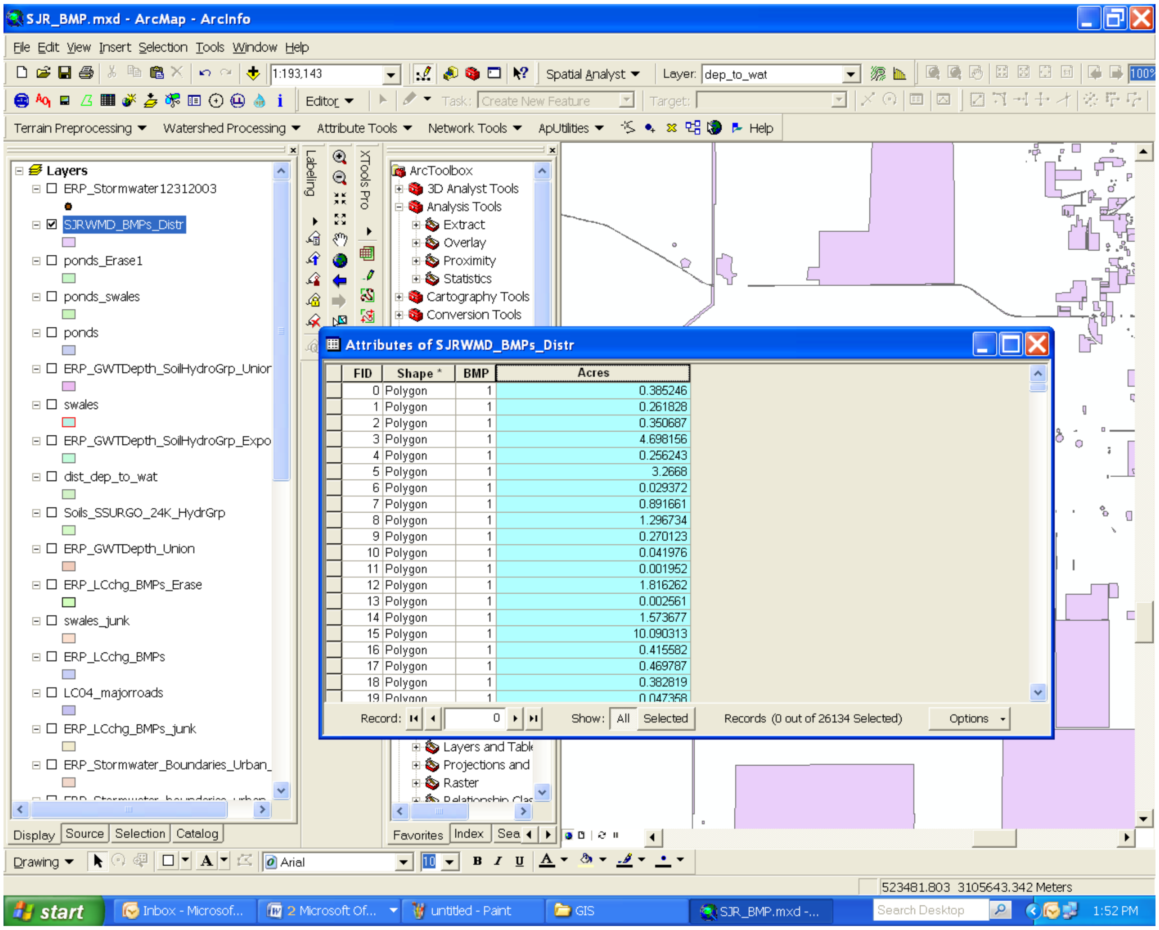


Figure Step 11b. Attribute “Acres” was automatically added to the attribute table of layer “SJRWMD_BMPs_Distr”

Step 12 (final step). Remove all the intermediate layers and adjust the final layer symbology to make it look professional and appropriate for your purpose.

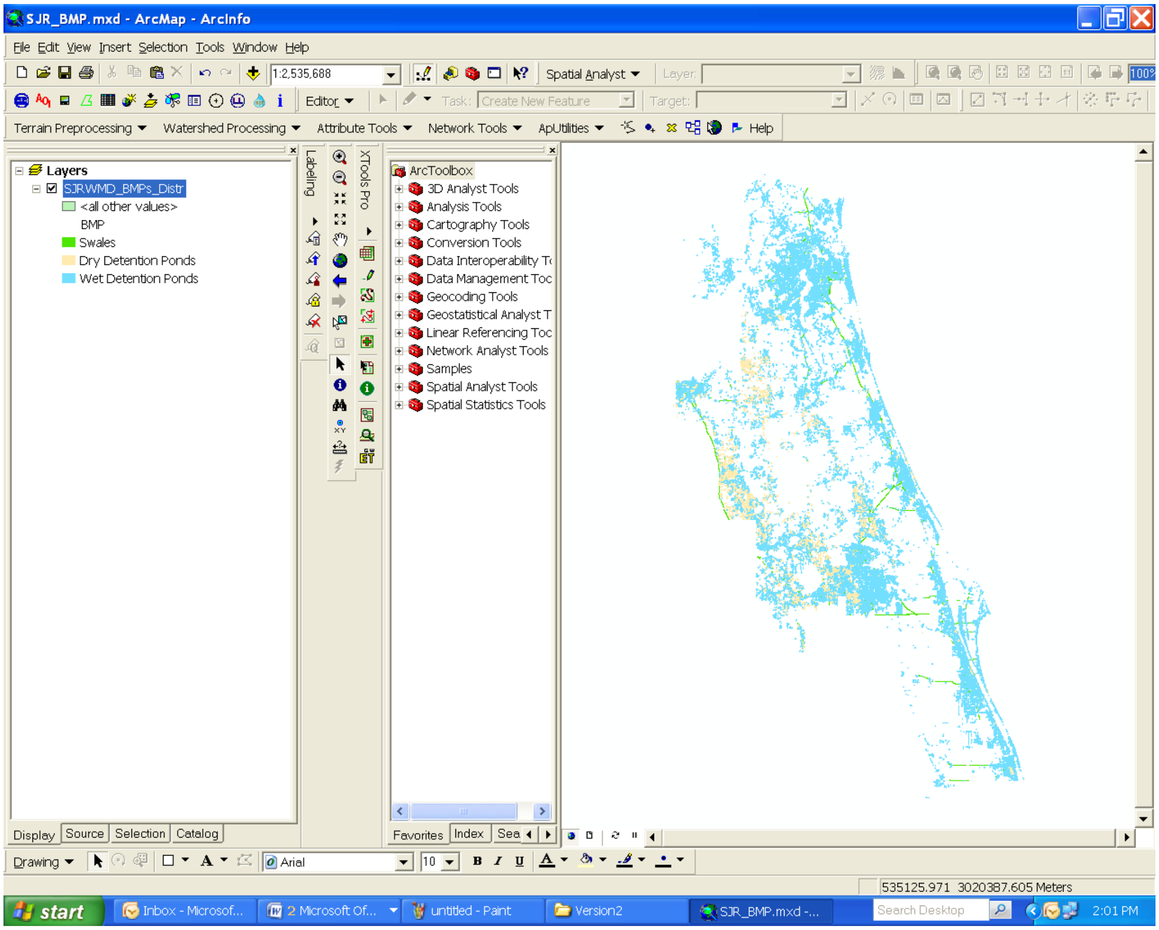


Figure Step 12. Finally, the SJRWMD’s estimated BMPs distribution layer is complete after removing all the intermediate layers and adjusting the symbology (BMP=1, “Swales”; BMP=5, “Dry Detention Ponds”; BMP=11, “Wet Detention Ponds”)

Appendix II. HSPF Land Cover/Land Use Codes

HSPF Land Cover /Use Classification Codes	Description
1	Low Density Residential
2	Medium Density Residential
3	High Density Residential
4	Industrial and Commercial
5	Mining
6	Open Land and Barren Land
7	Animal Production
8	Agricultural General
9	Agricultural Tree Crop
10	Rangeland
11	Forest
12	Water
13	Wetlands

Urban/ Industrial & Commercial: 1, 2, 3, and 4

Mining: 5

Rural: 6, 7, 8, 9, 10, 11, 12, 13