MD-16-SHA/MSU/4-3

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STATE HIGHWAY ADMINISTRATION

RESEARCH REPORT

HIGHWAY RUNOFF STORMWATER MANAGEMENT POTENTIAL (HRSMP) SITE CHARACTERIZATION USING NASA PUBLIC DOMAIN IMAGERY

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The focus of this research project was the development of geospatial technology (GST) methodology to characterize and evaluate highway runoff stormwater management potential (HRSMP) sites in order to reduce their impact on properties, save lives and cut operational costs. Reduction of Total Maximum Daily Load (TMDL), an important initiative of the SHA, could undoubtedly be achieved through the development and use of GST (remote sensing, geographic information system (GIS), and differential global positioning system (DGPS)). Field activities and groundtruthing were conducted at selected BMP sites to better understand their conditions and the land use/land cover (LULC) types currently present at these sites. Landsat images were assessed for quality-related issues including cloud cover and downloaded from USGS. Based on the outcome of the image assessment, 5 Landsat TM and 1 Landsat OLI_TIRS images which span from 1990 to 2015 were processed and analyzed using the Environment for Visualizing Images (ENVI) software. LULC and the normalized difference vegetation index (NDVI) images were created. Both LULC and NDVI values for the selected BMP sites, which were ranked by the SHA from I (Good) to IV (Failed), were extracted and analyzed to determine their relationship with the performances. The results from the LULC analyses suggested that vegetation was a major factor affecting the performance of the BMP facilities; poor and failed sites showed the excessive overgrowth of vegetation. Analysis of NDVI did not show definitive results, which might have been due to the relatively low spatial resolution of the TM images. Use of higher spatial resolution such as IKONOS multispectral images in the future could help resolve these inconsistencies.

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LIST OF ACRONYMS

BMP	Best Management Practice
DCR	Virginia Department of Conservation and Recreation
DEM	Digital elevation model
DEQ	Department of Environmental Quality
DGPS	Differential Global Positioning System
DOT	US Department of Transportation
ENVI	Environment for Visualizing Images
EPA	US Environmental Protection Agency
ESF	ENVI Standard File
ETM+	Landsat Enhanced Thematic Mapper Plus
GIS	Geographic Information System
GST	Geospatial Technologies
HP	Hewlett-Packard
ICREST	Interdisciplinary Center for Research in Earth Science Technology
ISA	Impervious Surface Area
LDCM	Landsat Data Continuity Mission
LULC	Land-user/land-cover
MDE	Maryland Department of the Environment
MS4s	Municipal Separate Storm Sewer System
MSS	Multispectral Scanner
MSU	Morgan State University
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetative Index
NIR	Near Infrared
NPDES	National Pollutant Discharge Elimination System
NRCS	National Resource Conservation Services
QA	Quality Assurance
RS	Remote Sensing
SHA	Maryland State Highway Administration
SWM	Stormwater Management

TM	Landsat Thematic Mapper
UAV	Unmanned Aerial Vehicle
USGS	United States Geological Survey
WWM	Wastewater Management

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EXECUTIVE SUMMARY

Geospatial technologies (GSTs), especially remote sensing (RS), have been widely accepted as an effective tool, available to engineers and resource managers to accomplish not just tasks but also comply with stringent rules and regulations of the United States Environmental Protection Agency (EPA)/Department of Environmental Quality (DEQ), in a timely manner. GST methodologies, because of their extraordinary capabilities including versatility, speed, and accuracy can provide a cost-effective alternative and enhance operations. Images from the NASA Public Domain databases, which are now available at no cost, were acquired through the United State Geological Survey (USGS), processed and analyzed using ENVI. The image analyses were done on HP workstations, and Trimble's Handheld Differential Global Positioning System (DGPS) were used for field verification activities (groundtruthing) and other related *in situ* activities. After careful assessment and evaluation of the available image dataset, it was decided to use Landsat Thematic Mapper (TM), and Landsat 8 (OLI_IRS)in this research. Landsat TM has a special resolution of 30 meters and spectral resolution of 7 bands. Although Landsat 8 has a spectral resolution of 11 bands and one panchromatic band with a 15-meter spatial resolution, its special resolution is still 30 meters.

Four Maryland State Highway Administration (SHA) ranked Stormwater Management(SWM) Best Management Practices (BMPs) were investigated in this research. SWM ranked I meant they were performing as planned (Good); those ranked II were performing fairly (Fair); those ranked III were satisfactory in their performance; and those ranked IV were not performing as planned (Failed). Field activities were conducted at several of these SWM facility sites in order to get a better understanding of the environment, examine the facilities, and acquire field data including elevation, land-use/land-cover (LULC), and photographs.

Based on image availability and quality (cloud cover and stripping), 6 Landsat images were selected and analyzed for this research. Included in the analyses were LULC classification and normalized difference vegetation index (NDVI). As was evident during the field activities, the major geospatial feature that appeared to have changed substantially was vegetation; given the fact that the BMPs initially performed as intended minimized the need for soil and elevation analyses. Therefore, it was decided to focus on LULC and NDVI since they could help in determining the performance of these BMPs.

The results obtained from the LULC analyses suggested that vegetation was a major factor affecting the performance of the BMP facilities. Most of the poor and failed sites showed excessive overgrowth of vegetation such as high brush and trees, ultimately making them inaccessible. Some that performed as originally intended had less vegetation cover (mostly low-cut grass) and were located in close proximity to streams. Analysis of the NDVI, however, did not show definitive trend as it relates to both temporal and spatial patterns. For example, some BMPs that were ranked Failed showed increase in NDVI values, while others that performed well (Good) also showed increase in NDVI values. The ambiguity in getting definitive results from the NDVI values must have been due to the relatively low spatial resolution of the TMimages (30 m by 30 m). Using higher spatial resolution such as IKONOS multispectral images with a 4-meter spatial resolution could resolve these inconsistencies, an objective that may be included in future SWM research.

1.0. INTRODUCTION

The Project focused on carrying out comprehensive reviews of literature dealing with conventional stormwater management (SWM) and geospatial SWM technology methodologies. An important outcome of this effort was to develop a comprehensive understanding of stormwater best management practices (BMPs) that will help in site characterization using geospatial technology (GST) methodologies. Several BMP manuals were acquired and reviewed, including some from surrounding states, such as Pennsylvania and Virginia. The review revealed three major focus areas: 1) research utilizing geospatial technologies including geographic information system (GIS) and to some extent remote sensing; 2) research into the determination of geospatial features deemed important in wastewater management; 3) the development of stormwater best management practices (BMPs) to effect desired goals such as improving the water quality of our nation’s water bodies, reducing flooding, and enforcing regulations. With regard to No. 2, for example, the majority of the materials reviewed agreed that impervious surface area affects stormwater management. However, there are different approaches as to the tools being used to achieve accurate impervious surface area.

From the time rain water hits the ground to when it enters receiving water bodies, it collects various pollutants from different contaminant sources. The impact of urban runoff pollutants on the water quality of a receiving water body may vary significantly depending upon its existing water quality and the rates at which these pollutants are introduced into the system. Pollutants such as suspended solids, heavy metals, and hydrocarbons are commonly found in stormwater runoff. The suspended solid concentration includes contributions from street dust and eroded sediment. These solids could then deposit at the bottom of a stream, disturbing aquatic habitat. Heavy metals are found in the environment from motor vehicles, industrial land uses, and commercial land uses. Oils, grease, and other hydrocarbons are also frequently found in highway runoff. (Tsihrintzis, 1997) Older basins can be redesigned and retrofitted to reduce or stop the pollutants that are entering receiving waters. However, an important consideration in retrofitting a detention basin is to ensure that the original flood control function is still maintained. Under space and budget restrictions, a trade-off between flood control and water quality improvement may be necessary. (Guo, 2005)

Although there are many studies on conventional stormwater management (SWM), very few exist on the use of GST methodologies, with remote sensing (RS) for SWM. Though some literature on GST methodologies did talk about geographic information system (GIS) applications on SWM, utilizing remotely sensed data including Landsat Thematic Mapper (TM) appears to be at the embryonic stages. This research, in contrast, used National Aeronautics and Space Administration (NASA) Public Domain imagery such as Landsat 7 and Landsat 8. Because of its relatively coarse spatial resolution (pixel size of 30 meters by 30 meters), ancillary multispectral images including IKONOS have been used to enhance and sharpen the selected Landsat bands in order to use them at local scale. The Environment for Visualizing Images (ENVI) formed the main remote sensing software for this project. ENVI is able to process multispectral images, and can also process hyperspectral and other active remotely sensed datasets including Light Detection and Ranging/LIDAR (EXELES, 2014).

2.0. LITERATURE REVIEW

A comprehensive review of the different types of methodologies utilized in stormwater management was conducted. Special attention was placed on GST methodologies since this project used these technologies to characterize SWM sites in selected areas of Maryland (Drury, 1990; Banks/USDOT, 2006). Relevant geospatial features and attributes affecting SWM were identified based on important information from Best Management Practices (BMPs) materials from several states including Maryland. Evaluation of these materials helped avoid unnecessary mistakes and made use of the lessons learned to develop optimum SWM site characterizations (Sigh, 2000 and Dematte, 2004).

A comprehensive search on literature dealing with GST and NASA Public Domain Imagery for SWM revealed limited information on the subject. Most materials were dealing with GIS applications of selected sections of the environment, stormwater, nonpoint-source pollution, or watershed studies. This research study came up several times during the search, and appeared to be the only one of its kind, in which NASA public domain imagery was utilized in SWM. However, it is very important to get insight into the available GIS and remote sensing application resources used in managing stormwater. For example, Sample *et al* (Sample, 2001) demonstrated the use of GIS in stormwater modeling at a neighborhood scale. Virginia Tech's Center for Geospatial Information Technology (CGIT) assisted Blacksburg, Va., in utilizing basic GIS methodologies to control pollutants entering its municipal stormwater sewer system; this nationwide initiative is now known as the National Pollution Discharge Elimination System (NPDES) (Constantinescu, 2006).

One of the major reasons for implementing SWM practices is to control and minimize flooding, especially from runoffs in urbanized areas (Golrang, 2013 and Meierdiercks, 2010). Unlike on-site design and implementation of SWM facilities, this project seeks to provide the SHA with adequate, effective, and timely knowledge and information on the best site locations for the construction of SWM infrastructures during the planning phase of projects. This will therefore enable SHA to meet its obligations in a more cost-effective manner within a shorter period of time.

SWM has initially focused on controlling floods, especially flash floods resulting from intense precipitation, such as heavy rain, snow/ice/sleet melt. Runoff, the substantial portion of liquid precipitation which did not seep into the ground or infiltrates, flows downhill into surface water bodies such as streams, rivers, and lakes and could change the landscape through erosion. In urbanized areas, runoff can be problematic, since it carries contamination and pollution including oil, sediments, debris, nutrients from fertilizers, bacteria from animal and human waste, pesticides from lawn and garden chemicals, heavy metals from rooftops and roads, and petroleum by-products from vehicles (USGS, 2015). By regulating the amount of stormwater entering and leaving SWM, flood water quantity and pollution from stormwater water quality can be controlled efficiently (Davis, 2009). However, in order to get the most effective performance from these SWM facilities, it is very important to know ahead of time where the best site locations are for installing SWM infrastructures including flood control detention basins (Emerson, 2008). Some studies have addressed the use of different construction materials, like pervious concrete in SWM infiltration basins, to determine their effectiveness (Kwiatkowski, 2007 and Allen, 2009). This study, however, makes use of stormwater BMPs from Maryland, and from surrounding states such as Delaware, Pennsylvania, Virginia, and the District of

Columbia (DC). Research projects that have looked into the efficacy of SWM infrastructure designs and construction materials include Liu (Liu, 2008).

2.1. Utilization of GST in Stormwater Management

The use of GIS, coupled with other geospatial methods, has been enumerated by several studies over the past several decades including Aslan *et al*, 2014 and Jennings, 2012. For example, Edward Barnes and Kevin White examined the use of remote sensing to map out soil properties and various geospatial features (Barnes, 2003 and White, 1998). Other researchers, such as Matthew Becker (Becker, 2005) reported on remote sensing applications that were used in predicting hydrologic behavior. Xiaohui Zhang researched the impact of remote sensing resolution on hydrologic parameterization, and impervious areas were extracted from Landsat and SPOT – a French remote sensing satellite system (Zhang, 2000). Rogers' research focused on using satellite technology to calculate impervious surface area in watershed scale. The benefits of remote sensing were described and examples of the extensive applications given, including direct water quality assessment, evapotranspiration research, urban growth and sprawl studies, and land-use-change analysis. The advantages of IKONOS satellite imagery over Landsat is its high spatial resolution. However, its high cost presents a challenge to most resource management dealing with accurate impervious area extraction research. Nevertheless, as the price of commercial satellite imagery such as IKONOS decreases, and image processing costs fall, the possibility of using satellite remote sensing by smaller communities and municipalities will become a reality (Rogers, 2004).

Matt Deane examined the applications of both GIS and remote sensing in SWM (Deane, 2012). Deane described the roles of municipalities and state government as it relates to SWM through the imposition of the US Environmental Protection Agency (EPA) NPDES Phase I and II regulations. The cause-consequence relationships of geospatial features such as impervious surface due to increased urbanization and pollutants, and other impairments to the quality of natural water bodies and the natural system, were reviewed. Deane also touched on the use of BMPs to combat deleterious effects of stormwater. For example, whether the BMP happens to be structural or not, the goals remain the same, to reduce peak flow through infiltration, retention, or detention of the runoff, decrease the amount of nutrient entering the natural water bodies, reduce soil erosion, and minimize the amount of sedimentation.

According to Deane, some of the uses of GIS and remote sensing in stormwater management had to do with the planning and implementation of BMP. Digital elevation model (DEM), land-cover/land-use (LCLU), and impervious surface area (ISA) were very high on his list as very important geospatial datasets for addressing SWM. He provided some sources where these dataset can be obtained, including the soils from the National Resource Conservation Services (NRCS) and DEM from the US Geological Survey (USGS). Trauth discusses the role of remote sensing in assisting with site specific, watershed-based planning and ongoing management. The research was conducted under the auspices of the Interdisciplinary Center for Research in Earth Science Technology (ICREST). Effort was made to develop tools, methodologies, and information by different technical disciplines that meet customer requirements. (Trauth, 2004)

It should be noted, however, that very few studies have reported on the use of NASA Public Domain Imagery for SWM practices. Because of the high quality standard required by the SHA, this research focused on using imageries from the Landsat Data Continuity Mission (LDCM), including Landsat Thematic Mapper (TM), Landsat Enhanced Thematic Mapper Plus (ETM+), and Landsat 8 (Irons, 2012). An important condition of the Landsat Data Continuity Mission (LDCM) regarding the properties of deployed sensors is not just their spatial resolution but their spectral resolution as well (see Table 1).

Table 1. Comparison of the Spectral Resolution of Landsat 7 and Landsat 8 (credit: Landsat Science, http://landsat.gsfc.nasa.gov/?page_id=7195).

Landsat-7 ETM+ Bands (μm)			Landsat-8 OLI and *TIRS* Bands (μm)		
			30 m Coastal/Aerosol	0.435 - 0.451	Band 1
Band 1	30 m Blue	0.441 - 0.514	30 m Blue	0.452 - 0.512	Band 2
Band 2	30 m Green	0.519 - 0.601	30 m Green	0.533 - 0.590	Band 3
Band 3	30 m Red	0.631 - 0.692	30 m Red	0.636 - 0.673	Band 4
Band 4	30 m NIR	0.772 - 0.898	30 m NIR	0.851 - 0.879	Band 5
Band 5	30 m SWIR-1	1.547 - 1.749	30 m SWIR-1	1.566 - 1.651	Band 6
Band 6	60 m TIR	10.31 - 12.36	*100 m TIR-1*	*10.60 – 11.19*	Band 10
			100 m TIR-2	*11.50 – 12.51*	Band 11
Band 7	30 m SWIR-2	2.064 - 2.345	30 m SWIR-2	2.107 - 2.294	Band 7
Band 8	15 m Pan	0.515 - 0.896	15 m Pan	0.503 - 0.676	Band 8
			30 m Cirrus	1.363 - 1.384	Band 9

Table 1 makes it easier to choose the right bands for the task, regardless of the sensor. Apart from the Band number, each band also has its wavelength range, and its spatial resolution. Band 8, which has a spatial resolution of 15 meter by 15 meter (a panchromatic band), can be used for sharpening the other bands.

Khan and Singh (Khan, 2000) used the IRS-LISS-II to characterize and map soils in an arid section of Western Rajasthan. IRS-LISS-II is the Indian Remote Sensing Satellite sensor, which has a spatial resolution of 36 meters, and a spectral resolution of 4 Bands (1/Blue, 0.45-0.52 micron; 2/Green, 0.52-0.59 micron; 3/Red, 0.62-0.68 micron; and 4/near Infra Red, 0.77-0.86 micron). Visual analysis and interpretation were used to process the remotely sensed images (Bands 2, 3, and 4), which were then enhanced with groundtruth and soils data to generate physiographic and soil maps of the area. It should be said here that the results might have been improved if digital processing of the images had been employed. Nonetheless, Khan and Singh were able to use remote sensing to map a relatively large area quickly, which is one of the benefits of GST. Spatial resolution has been identified by many studies to be a major factor in determining the classification accuracy of remote sensing imagery (Narayanan, 2010). The spatial resolution of IRS-LISS-II sensor is 36 meters, which happens to be relatively high, though not as high as Landsat TM, which is 30 meters and is being used in this project.

On the potential use of remote sensing for groundwater studies, some studies suggests combining remote sensing data with ancillary data like numerical modeling, geographic GIS, and ground-based information. For example, since remote sensing has been proven to be very useful in surface hydrology studies, then the possibilities exist for using it to monitor expressions of groundwater (Becker, 2005).

Some research has reported on the use of hyperspectral remote sensing for characterizing soil features (Damatte, 2006), while others have reported on the shortcomings of the Landsat Thematic Mapper (TM), which although being a multispectral sensor, lacks the spatial resolution needed for the acquisition of the necessary details for urban land-use/land-cover planning (Thomas, 2003). It must be noted, that in order to address this challenge posed by Landsat TM, this research used Band Sharpening Procedures (specialized remote sensing technique) provided by the Environment for Visualizing Images (ENVI) to enhance the Landsat TM bands (NASA, 2015).

2.2. Determination of geospatial features deemed important in wastewater management

Impervious surfaces have been cited by some research as an important environmental factor affecting SWM, especially in urbanized developments. These surfaces include rooftops, sidewalks, streets, and parking lots which prevent precipitation from infiltrating into the soil and replenishing the groundwater. Thus, impervious surfaces increase the volume of stormwater reaching surface waterbodies, especially streams. The resulting high volume of stormwater runoffs adversely impacts the water quality and the physical landscape through erosion and increased nutrients. (Guo, 2014; USGS, 2013). Sarah Williams reported on the use of remote sensing to manage stormwater runoff, which through federal mandates from the 1987 Water Quality Act or the NPDES affects medium municipalities that still struggle to get a handle on the impact of urban growth affecting their local waterways. Such medium communities have what is termed Municipal Separate Storm Sewer System (MS4s). The main challenge posed by this research, however, is the financial cost to small communities, due to the acquisition of the high-resolution images in the study, which are mostly provided by commercial businesses. (Williams, 2005).

Booth also reported on the impact of impervious surfaces on the runoff processes in urban watersheds, and attributed loss of the water-retaining function of the soil as the major problem in urban landscapes. The unsuccessful use of traditional solutions for SWM in such urban watershed settings, necessitated the proposal of using permeable pavements, which might reduce the downstream consequences of urban development. Results obtained from experiments with permeable pavement materials compared with traditional asphalt were encouraging (Booth, 1999). Another study on impervious surfaces stressed the importance of treating this land-cover as a quantifiable indicator that closely correlates with water-quality impacts. Arnold Chester advocates understanding of the role and distribution of impervious coverage in order to develop better strategies to combat water resource problems and effect better community planning, site-level planning and design (Chester, 1996). Virginia Tech's CGIT under partnership agreement with Blacksburg provided GST assistance in stormwater management. For example, through this partnership, illicit discharges can be detected and eliminated and construction sites can be better supervised (Virginia Tech, 2006).

In the quest to understand the various factors that affect stormwater management, some studies examined the relationships between water quality and different land use, in order to use the results to develop practical guidance in planning future urban development. The research suggested moving beyond customary structural measurements. Examples included using wetlands to deal with stormwater quality, using gross pollutant traps, which may be effective in removing litter but not other pollutants, and the ‘first flush’ which is questionable in terms of urban water quality management (Goonetilleke, 2005).

Meeting new and stringent requirements for stormwater quality, many agencies have resorted to retrofitting existing SWM infrastructures such as detention basins. However, despite the comparatively low cost there are still many other such infrastructures that have not yet been retrofitted to meet the required standards or satisfy current guidelines (Center for Watershed Protection, 2007). Many papers have reported on the nature of pollutants entering streams, rivers, and receiving water bodies, and also the effect of urban runoff pollution together with shorelands planning (Department of Conservation and Recreation, Division of Chesapeake Bay Local Assistance, 2004).

2.3. Stormwater Best Management Practices (BMPs)

Knowledge and understanding of BMPs as it relates to SWM is very important not only for this research, but for appreciating the development and evolution of communities trying to address the challenges of water quality, erosion, pollution, and floods in our nation’s watersheds and landscape. Having regulations to combat water resource degradation is fine, but being able to involve the community and customers in the decision process puts BMPs on a different level. Once people understand the need for regulation and permitting, the entire process moves smoothly. The following are some BMPs for Maryland and surrounding states. Although they all have variations, the common goal remains the same: improving the quality of our nation’s water resources and landscape.

Maryland continues to improve on its BMPs in order to achieve its goals in terms of managing stormwater runoff so that stream channel erosion, pollution, siltation, and sedimentation can be reduced. Without BMP, water and land resources of the state would be impaired and flooding could become a major challenge in the state. The Maryland Stormwater Design Manual serves as a document that integrates the significant experiences gained over the many years of implementing BMPs across the state. Three areas are emphasized in the manual: protecting the state waters from adverse impacts from stormwater runoff, providing effective design guidance for both structural and non-structural BMPs, and improving the quality of BMPs in the state. The Maryland Department of the Environment (MDE) also encourages wise and environmentally sensitive site designs, which reduce pollution from runoff, and implementation of policies like “Smart Growth” (MDE, 2009).

Just as Maryland is constantly seeking innovative ways of achieving its SWM goals, other states are also complementing their BMPs with other approaches and procedures. For example, Pennsylvania has incorporated pervious materials including pervious concrete, asphalt, and paver blocks in certain areas such as parking lots, walkways, playgrounds, and alley ways to increase water infiltration and reduce stormwater runoff (Pennsylvania, 2006).

Delaware maintains stormwater BMPs that also seek to improve the water quality and quantity of its water resources. Apart from the three general BMPs (Wet Ponds, Infiltration Basins, and Dry Ponds), attention is now being directed at a fourth BMP, which is known as Green Technology and Low-Impact Development. This BMP mimics natural processes and requires less maintenance; it is incorporated into the landscape which makes it almost invisible to the ordinary person (Delaware, 2004).

In an effort to provide the necessary information including Virginia's regulations that address water quality and nonpoint source pollution, basic components of stormwater management as found in their BMPs, a comprehensive handbook was developed by the Virginia Department of Conservation and Recreation (DCR, 1999). Virginia, for example, selected phosphorus as a "keystone pollutant" in combating water quality challenges, since phosphorous among other things has a well-defined adverse effect on the Chesapeake Bay and its tributaries and exits in an almost equal split between particulate and soluble phases (TARP, 1999). The purpose for the TARP Protocol is to provide a uniform method for demonstrating stormwater technologies and implement the necessary test for quality assurance (QA) plans for certification or verification of performance plan. This document was endorsed by California, Massachusetts, Maryland, New Jersey, Pennsylvania, and Virginia.

3.0. METHODOLOGY

This research utilizes GSTs, namely RS, to determine its feasibility in assessing the performance of SWM in selected sections of Maryland. RS is a technology that uses sensors such as Landsat TM which are mounted on platforms such as satellites to acquire, process, and analyze data without being in touch with the object or geospatial feature.

Landsat TM and Landsat 8/Operational Land Imager (OLI)_Thermal Infrared Sensor (TIRS) images were acquired from the USGS for this research project. The images were from the time period covered from 1990 to 2015, with a time interval of five years. All the remotely sensed data were evaluated to ensure that the amount of cloud cover was not more than 3%; since lower levels of cloud cover tend to minimize the cloud effects on the remotely sensed data. Cloud cover, among other things, can obscure the geospatial features in the study area and thereby reduce the utility of the image.

ENVI software was used to process and analyze the Landsat images. ENVI offers a wide array of multispectral image processing and analyses tools and procedures, including classification and post classification. LULC classification and normalized difference vegetative index (NDVI were conducted using Landsat TM and Landsat 8 images for the SHA identified BMP sites. These

BMP sites were rated as follows: I (working properly/Good), II (working satisfactorily/Fair), III (working poorly /Poor), and IV (not performing/Bad).

The main challenge posed by the Landsat TM multispectral sensor was its spatial resolution, usually termed its pixel size. The pixel size of Landsat TM is 30 m by 30 m, meaning features/objects less than 30 m by 30 m cannot appear alone in the image. Although pan-sharpening procedures were carried out, using the Panchromatic Band (band 8) of Landsat Enhanced Thematic Mapper (ETM+) and Landsat 8(OLI_TIRS) which had a spatial resolution of 15 m by 15 m, it was still not high enough to be able to meet the very high spatial resolution required for analyzing the BMP sites.

3.1. Baltimore County SWM BMP Rated Sites

The BMPs were rated by the SHA according to their performances. The 4 (four) ratings were I, II, III, and IV, where I/Good was for BMPs performing as intended, II/Fair was for BMPs performing satisfactorily, III/Poor was BMPs performing poorly, and IV/Failed was for BMPs that were not working as originally intended. These BMPs were color coded (see Figure 1).

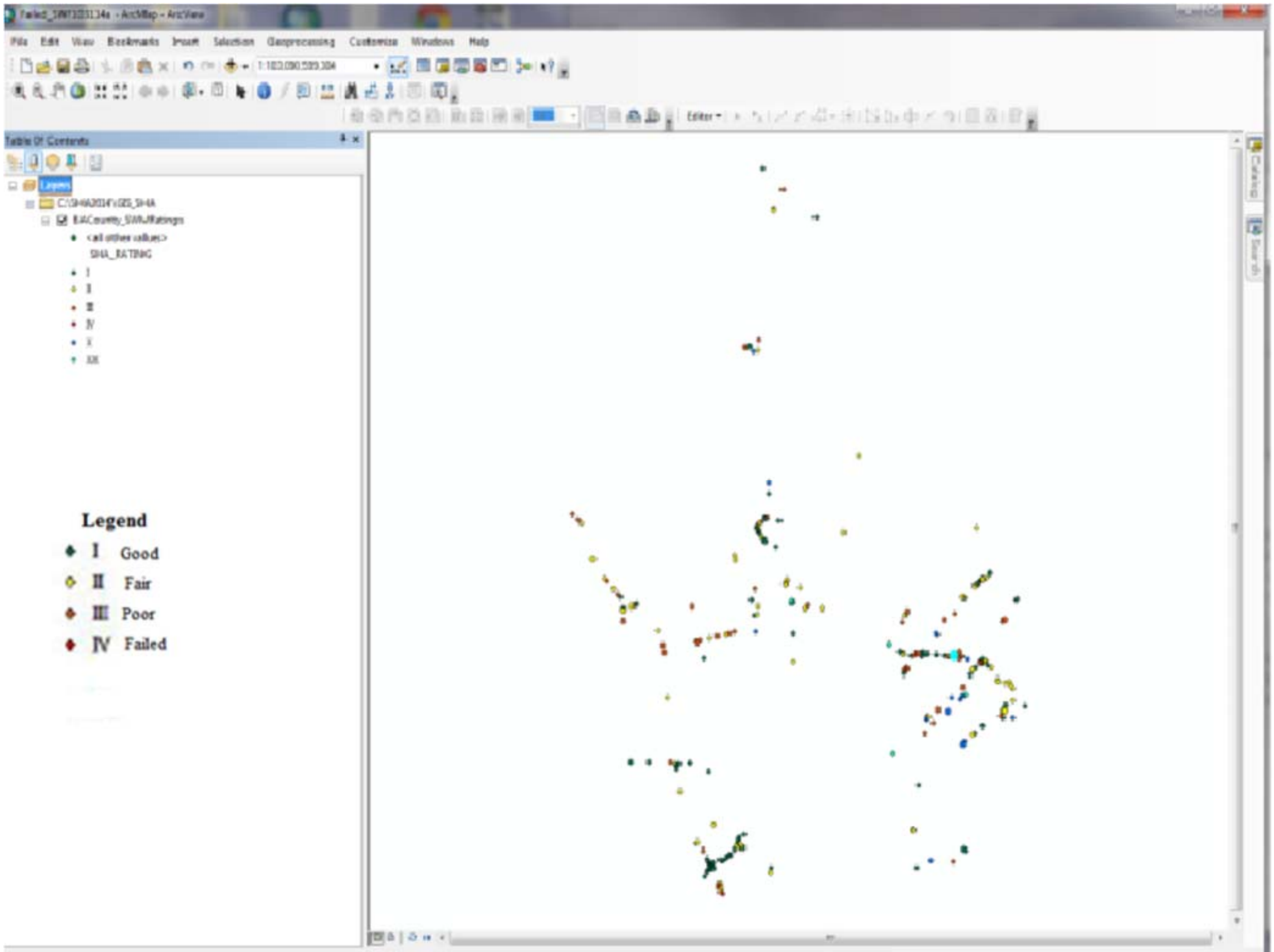

Figure 1. Baltimore County SWM Ratings - SHA Ratings (*ESRI's ArcGIS*.)

3.2. Field Activities of BMP Sites

Representative BMP sites of the different SHA ratings (I, II, III, and IV) were selected, and field activities were conducted at these sites in order to get a better understanding of the prevailing conditions and LULC data at these sites (for example, see Figure 2 below). Knowledge gained during the field activities will also help characterize the facilities better. Some of the parameters measured included location or coordinate, and elevation; LULC types, proximity to streams or tributaries, and physical conditions of BMPs were photographed and logged. A copy of the Field Activities Log can be found in Appendix A.

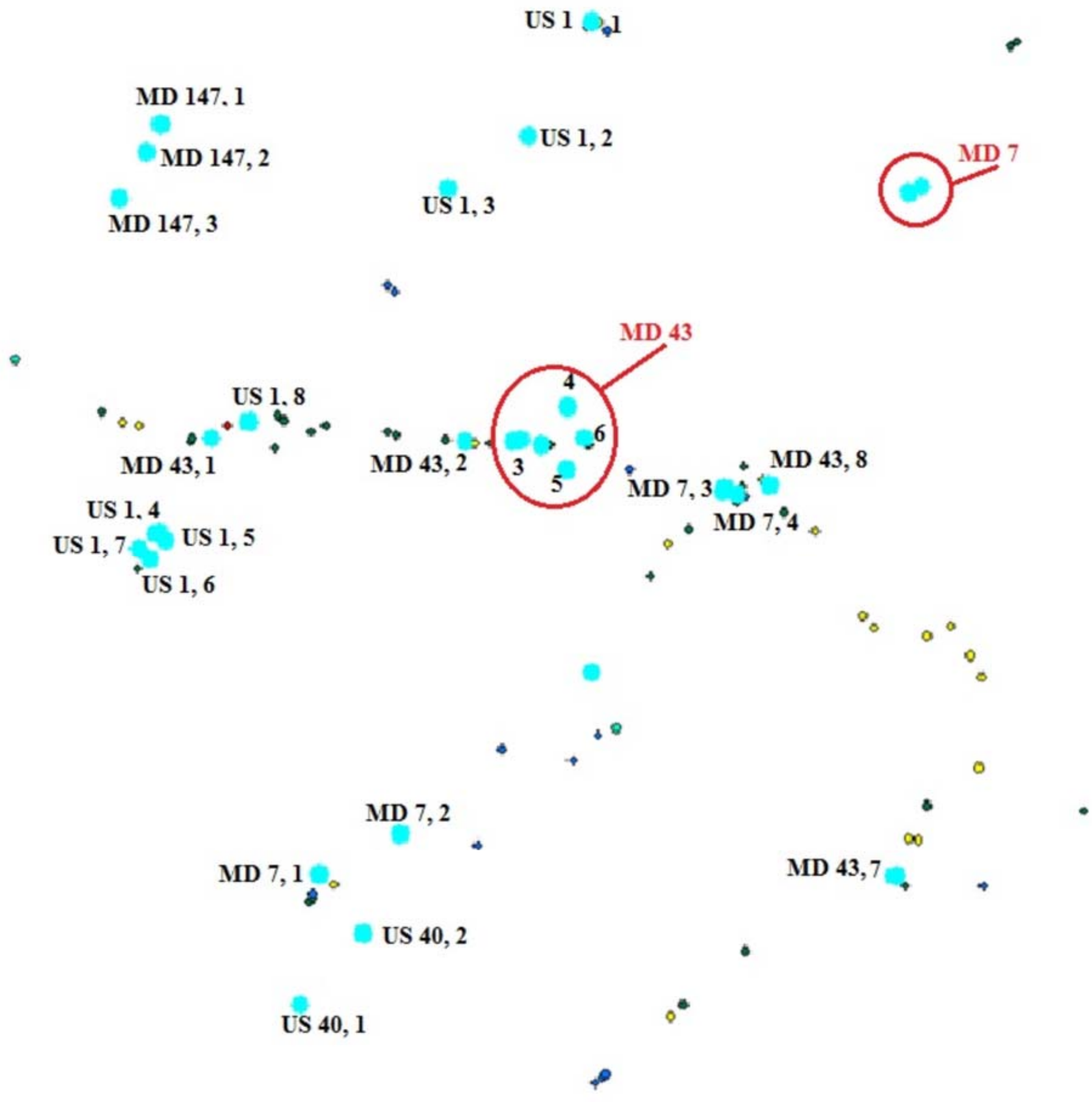

Figure 2. Baltimore County Stormwater Management Facilities with SHA Ratings of III/Poor (Cyan), Prepared for Groundtruthing and Field Activities (C*reated using ArcGIS*). The major roads in close proximity to these BMP sites were identified.

Field observations of SWM sites rated IV/Failed revealed intense vegetative covers including trees, Phragmites, and large amount of grass and leaves. Huge trees were observed to be growing along the conduit of some of the SWM systems (see Figure 3). It was observed that BMPs that were rated I/Good were within close proximity of streams or tributaries and despite the existence of grassy surface covers, there was no standing water, nor trees growing along their conduits (see Figure 4).

Figure 3. BMP Site # 030189 (US 1), SHA rated IV/Failed. Note: Trees growing along the conduit of the system with intense vegetative cover (all included photographs were taken: Fall/December 28, 2014).

Figure 4. BMP Site # 030104 (York Rd by Frankel Mazda), SHA rated I. Note: Was near a streamlet and very limited vegetative cover (Phragmites absent).

3.3. An Overview of Landsat

Landsat, the flagship of the US remote sensing program, is the longest-running satellite imagery acquisition system available to the public for free. The first Landsat - Landsat Multispectral Scanner (MSS) was launched in 1972, with a spatial resolution of 80 m by 80 m, and a spectral resolution of 4 Bands (3 Visible and 1 infrared Bands). In 1982 Landsat TM was launched, with a spatial resolution of 30 m by 30 m, and a spectral resolution of 7 Bands (4 visible, 2 infrared, and 1 thermal Bands). The significant improvements in its spatial and spectral resolutions resulted in an increase in the applications of Landsat satellite remote sensing. The Landsat Enhances Thematic Mapper (ETM) was launched in 1999, with a panchromatic band (Band 8). Today, Landsat 8 (launched in 2013) provides a spectral resolution of 11 Bands (3 Visible, 1 Red, 1 Near-Infrared, 2 Shortwave Infrared, 1 Panchromatic (Pan), 1 Cirrus, and 2 Thermal Infrared Bands). The National Aeronautics and Space Administration (NASA) together with the United States Geological Surveys (USGS), in a consolidated effort, have promised continuity in the Landsat Program by forming LDCM. LDCM ensures consistency in all aspects of the Program with NASA responsible for building and launching the sensors, and USGS being responsible for the archiving and distribution of the Landsat data.

3.4. Landsat Data Acquisition

A USGS Account was created in order to download several Level 1 Landsat datasets, which had the complete spectral set of data. In the case of Landsat TM, the complete spectral set is 7 Bands, 8 Bands for Landsat ETM+, and 11 Bands for Landsat 8. The USGS's EarthExplorer (EE) Tool was launched and the images were selected, evaluated for cloud cover, and then downloaded (see Figure 5).

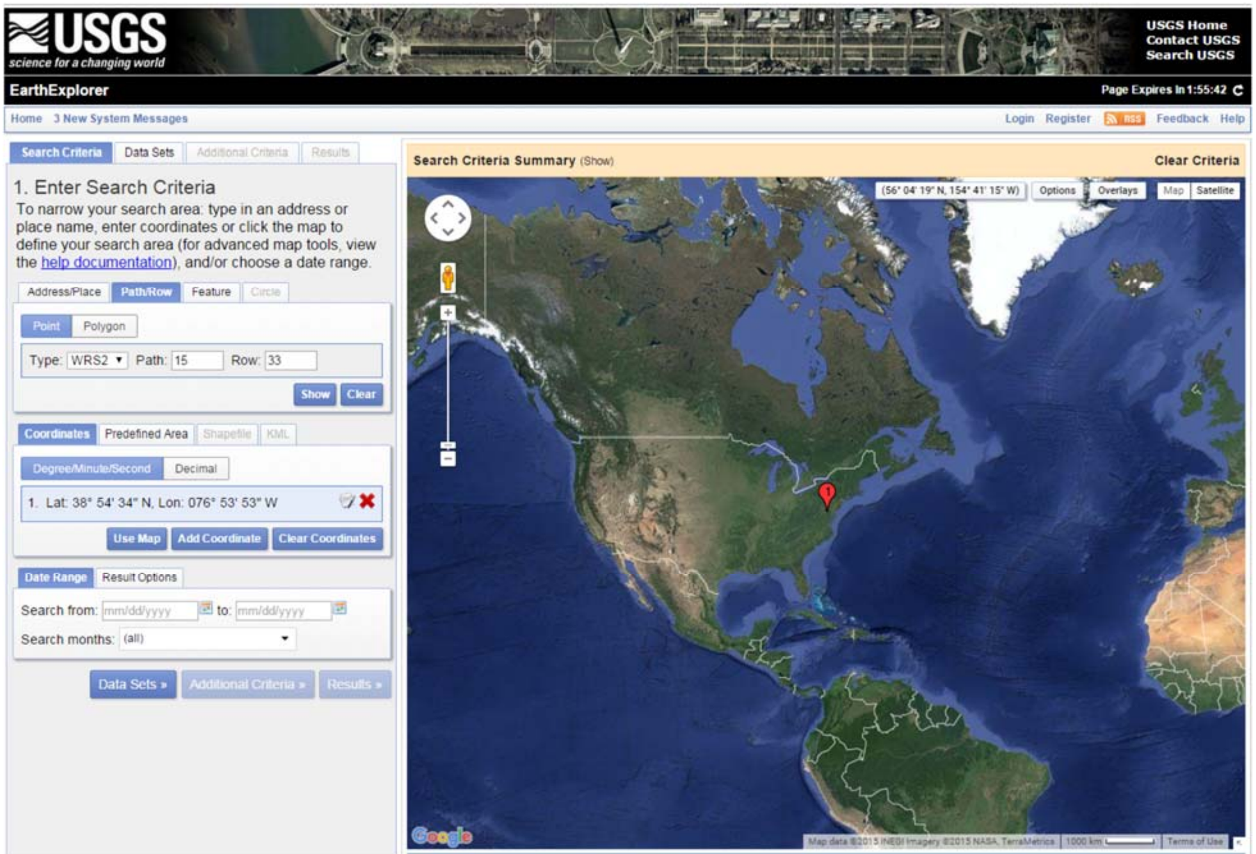

Figure 5. USGS EE Tool for Downloading Landsat Imagery (http://earthexplorer.usgs.gov/).

The Landsat images are usually provided in scenes (sections), and each scene has its specific Path and Row Number which are based on the study area or area of interest. For example, the scene that covers most of Baltimore and surrounding areas in Maryland has a Path Number of 15 and Row Number of 33. In order to be able cover the entire State of Maryland, it would require about four Landsat TM scenes (see Figure 6 and 7). Instead it was decided to select only the Landsat scene which covered Baltimore and most of the SHA-rated BMP sites. All the Landsat TM images acquired for this project were Level 1products which provided among other things the complete spectral resolutions of the sensors. All seven Bands were acquired, making it possible to perform detailed processing and analyses with the multispectral images.

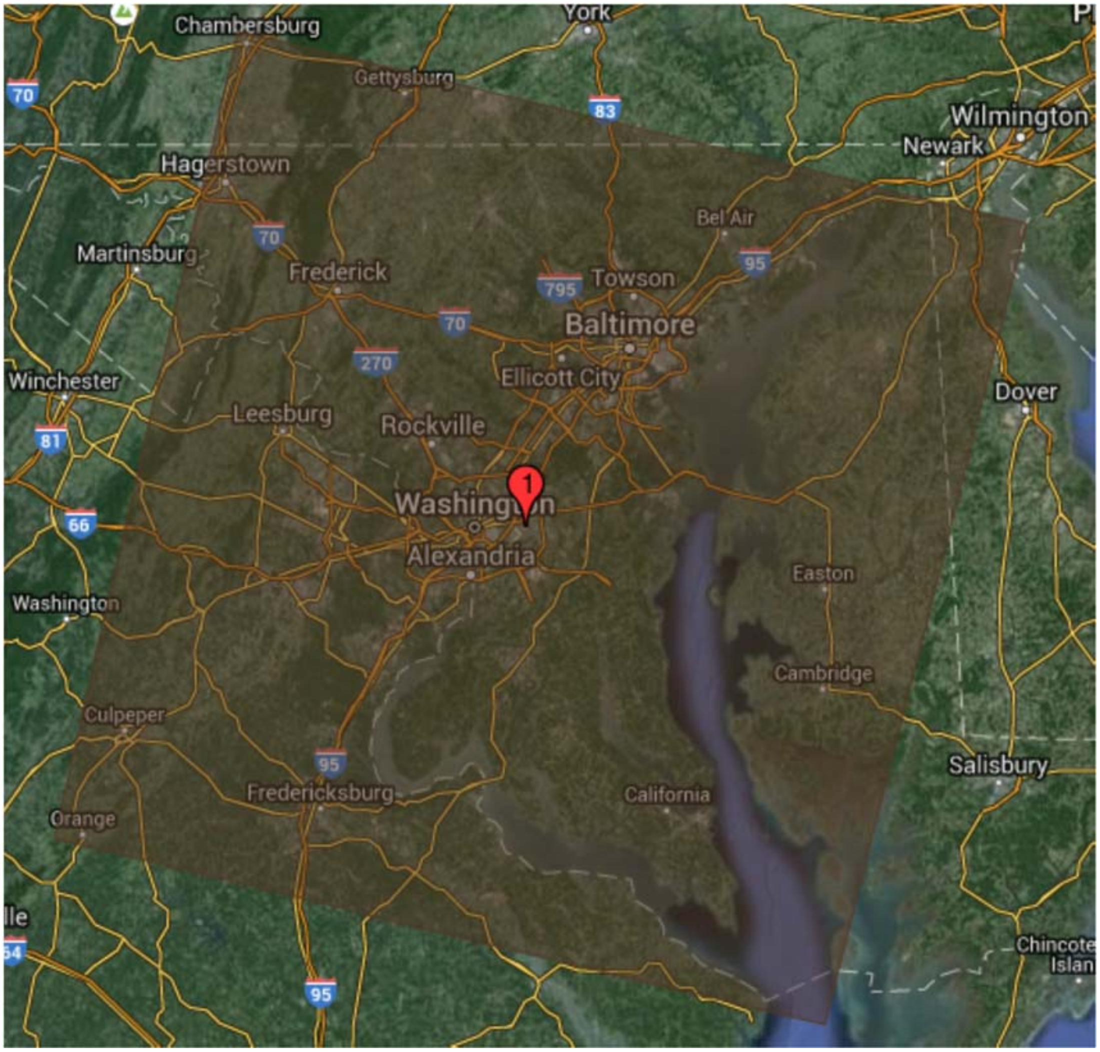

Figure 6. Landsat Image Footprint Superimposed on the State of Maryland.

Although several dozens of Landsat images (Path 15/Row 33) were initially acquired, only a few were selected for further processing and analyses after they had been very carefully evaluated and assessed for quality control (including stripping and cloud cover over the study area). Another factor also considered in the selection of the images was the date of acquisition. Although it would have been best to select all the images on or around the same time period, it was not possible due to availability and cloud cover. As such only six Landsat images – five Landsat TM and one Landsat 8 (OLI_TIRS) – were utilized in this project; four of the six images, were acquired in the month of May (see Table 2). As is evident from the acquisition dates, the research covered 25 years, 1990 to 2015. This enabled the uncovering of LULC and NDVI change patterns which can be linked to the performance of the SWMs.

Table 2. Landsat Data Utilized in this Study

#	Landsat Scene ID	Acquisition Data	Spacecraft ID	Sensor ID	No. of Bands
1	LT50150331990128XXX04	08-May-90	Landsat 5	TM	7
2	LT50150331995142AAA02	22-May-95	Landsat 5	TM	7
3	LT50150332000124XXX04	03-May-00	Landsat 5	TM	7
4	LT50150332005121GNC01	01-May-05	Landsat 5	TM	7
5	LT50150332010263EDC00	20-Sep-10	Landsat 5	TM	7
6	LC80150332015229LGN00	17-Aug-15	Landsat 8	OLI_TIRS	11

NB: For details on Landsat 5 and 8, see http://landsat.gsfc.nasa.gov/?page_id=2290 and http://landsat.gsfc.nasa.gov/?p=3186 respectively.

The TM images were stored on the workstation's hard drives and external secure media including DVDs and CDs. The spatial resolution of the TM 5 is 30 m by 30 m for Bands 1 – 5 and 7, and 60 m by 60 m for Band 6 (Thermal Band); its spectral resolution is 7 Bands. Landsat 8 on the other hand has a spectral resolution of 11 Bands, but maintains the spatial resolution of 30 m by 30 m for Bands 1 – 7; Band 8 (the Panchromatic Band) has a 15 m by 15 m spatial resolution, which can be used for band sharpening of the 30 m by 30 m bands. Band sharpening improves spatial resolution of the lower resolution bands. For example, a 30 m by 30 m band can appear to look like a 15 m by 15 m band. This procedure improves the quality of the images and allows for smaller features to be seen.

Landsat images were acquired in scenes as can be seen in Figure 7 below, where it was overlaid on a vector GIS coverage called County (colored white on a black background). The TM scene is displayed in Natural Color composite display; the red box is situated over Baltimore, Md. It is evident from Figure 7 that at least four TM scenes would be required to cover the whole of Maryland. This same challenge is associated with remote sensing. For example, to cover that little part of Harford County and Cecil County would require the acquisition of a whole TM scene.

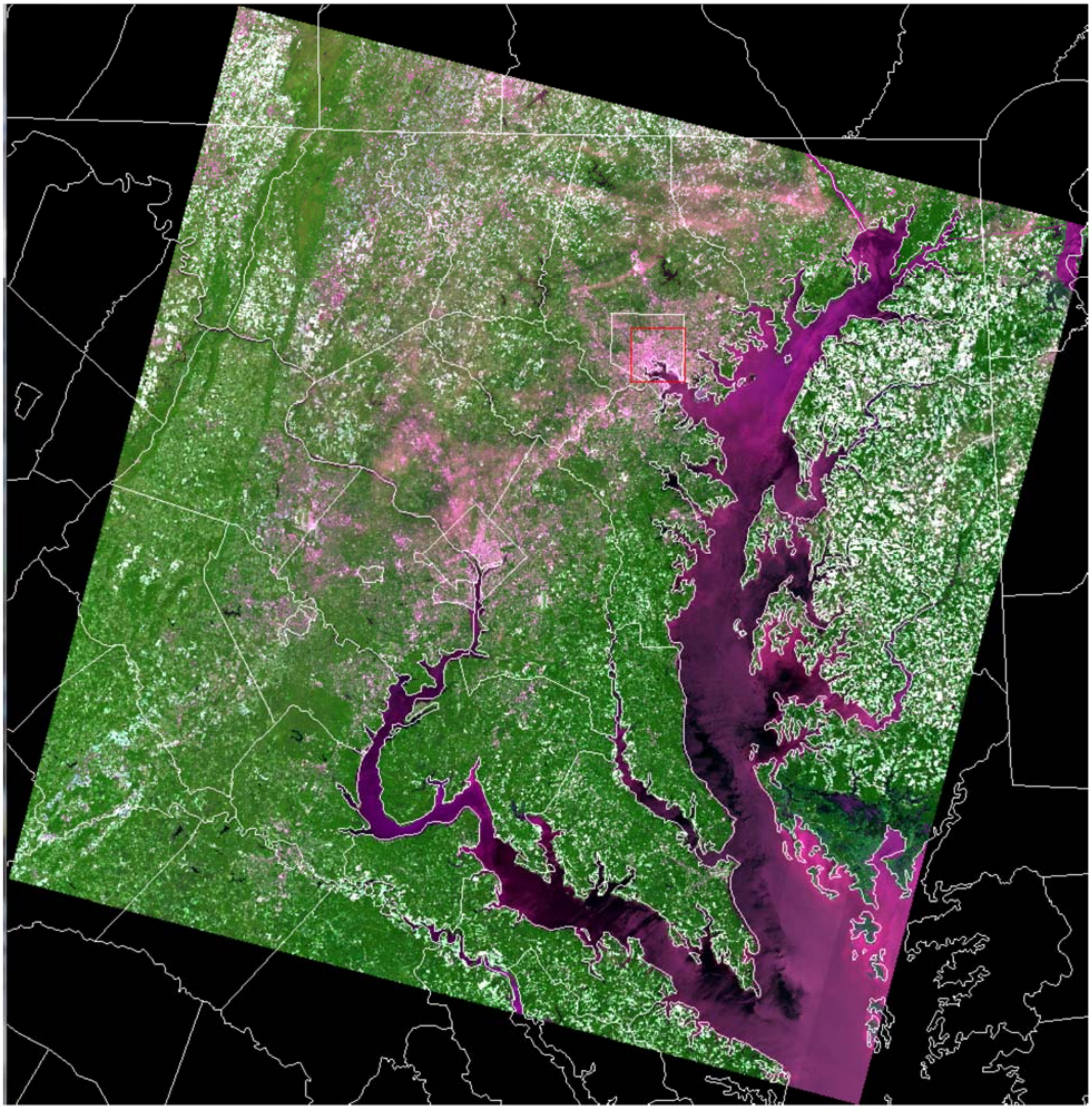

Figure 7. Vector-Image Overlay (US County Map and Landsat 8 Image). Example of a Landsat TM scene with low % cloud cover (acquired 08/07/15; composite display, B364).

4.0. ANALYSIS OF DATA AND PROCEDURES

The analysis and data procedures employed in the research are presented in the subsequent section of this report.

4.1. ENVI Standard Data Files

Once all the bands of the Landsat images were acquired, ENVI Standard Files (ESF) were created. ESFs provided a unique way of saving all the image bands having the same spatial resolution together in one file. For example, working with Landsat TM which has 7 bands means that seven separate files must be loaded individually in order to be able to conduct any analysis, including displaying Landsat TM images in different color composite displays. ESF stores all the six individual bands (Bands 1, 2, 3, 4, 5, and 7) in one file. Band 6 has a different spatial resolution (120 m by 120 m) and cannot be included in the same file with the other bands. Once Band 6 had been sharpened (re-sampled) to 30 m by 30 m, it can be included in the ESF with the others. Working with the ESFs makes the process of analyzing the images much easier, and faster.

4.2. Sub-setting the Images

Remotely sensed data, especially images usually produce large files, and the higher the spatial resolution which equates to smaller image pixel size, the larger the file size. In order to optimize storage space and expedite the processing of the image, the Landsat scenes were sub-setted (resized) to the SHA identified research using ENVI’s Spatial Subset Procedures. The coordinates used were Upper Left (UL): 39° 32’ 54” N, 76° 51’ 17” W and Lower Right (LR): 39° 9’ 20” N, 76° 20’ 0.0” W; an Image Subset Procedure was used (see Figure 8).

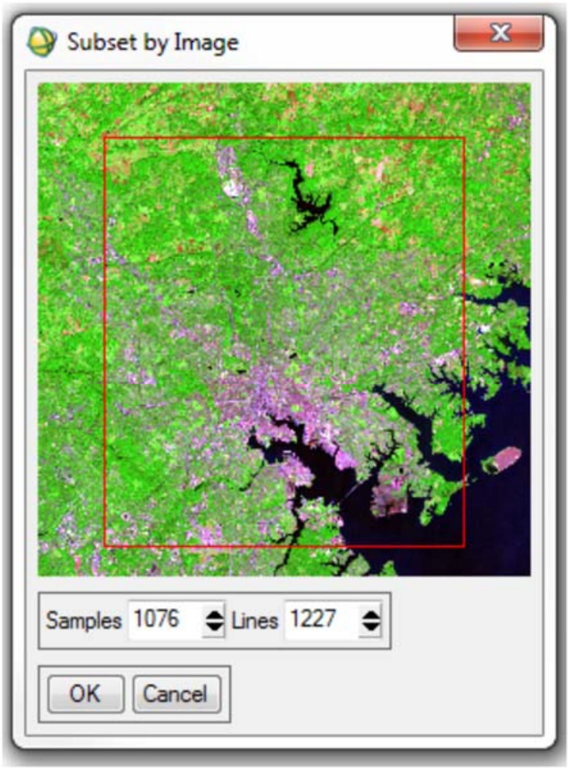

Figure 8. ENVI's Subset by Image Window.

The image subset procedure allowed for the selection of an area of interest by placing the red box over the selected area. The coordinates of the Upper Left corner (UL) and the Lower Right corner (LR) were extracted in either decimal degrees (DD) or degrees minutes and seconds (DMS). It also provided the size of the selected area in "Number of Sample" and "Number of Lines." In the case of the SHA identified research area, the UL is 39°32' 54" N, 76°51' 17" W and LR is 39°9' 20" N, 76°20' 0.00" W.

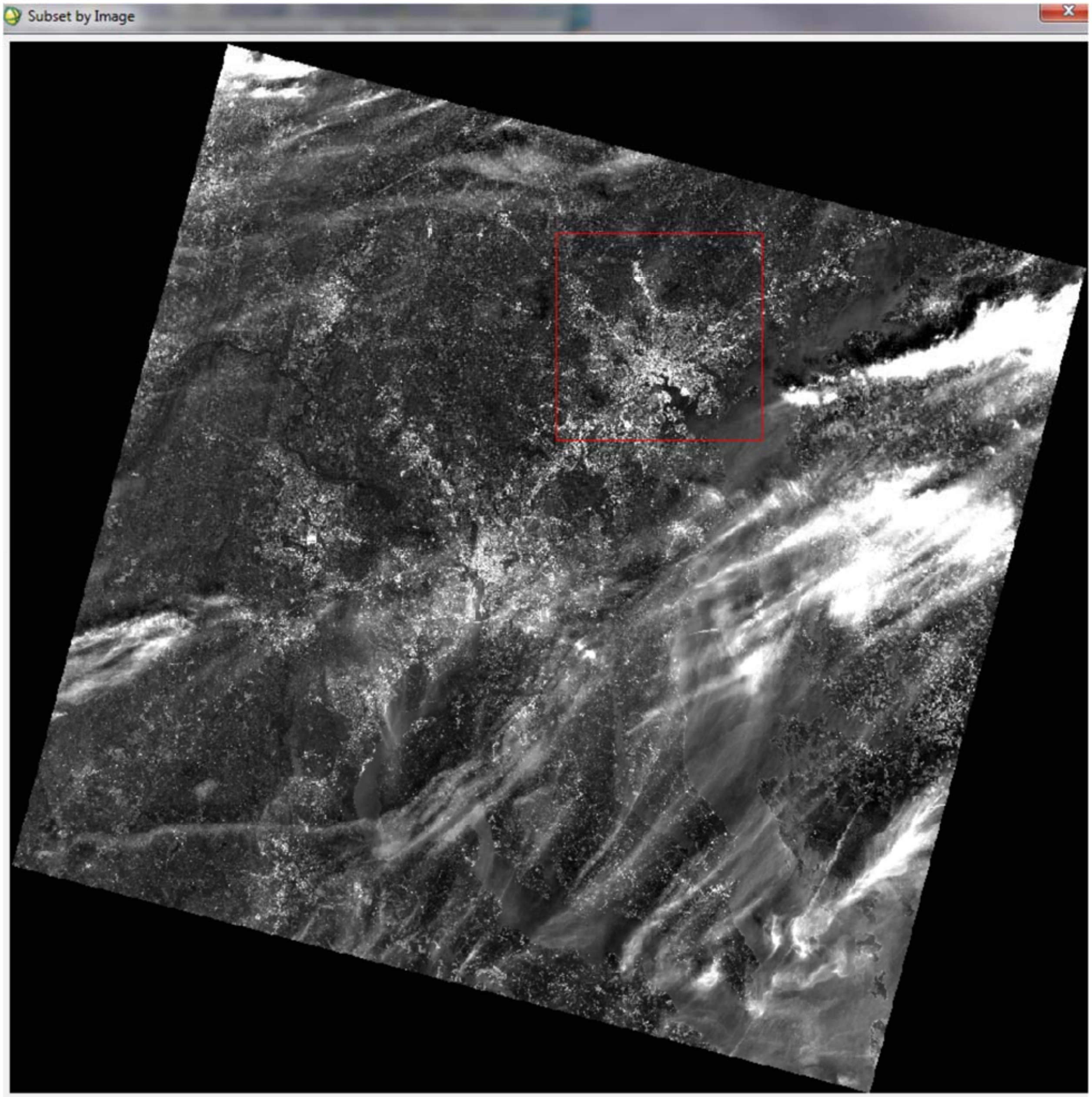

Figure 9. Landsat TM Scene and the Study Area (red box, with Baltimore in the center).

The SHA-identified research area encompassed most of the SWM facilities selected for this research study (see Figure 9). All the multispectral image bands were sub-setted (resized), in order to be able to perform spectral analyses including LULC and NDVI for this research.

4.3. Land Use/Land Cover (LULC) Analyses

Land-use refers to the functions performed by the geospatial features covering the surface of the earth including its management and modifications. Land-cover refers to the geospatial feature covering the surface of the earth, including man-made materials such as asphalt, concrete, and natural materials including grass, water bodies, and rocks. Because of the spatial resolution of the Landsat multispectral images (30 m by 30 m), Level I LULC classification was carried out for the study area (Anderson, *et al* 1976 Classification Scheme).

Level I Classification of LULC analysis was carried out using ENVI's Unsupervised Classification Procedure, ISOData. Unsupervised Classification requires minimal input, such as the number of Classes, the number of Iterations, the Threshold Value, and the number and types of Bands. In order to select the optimum bands for the general classification, spectral profiles of different geospatial features were constructed using ENVI's procedure. By studying the spectrum of each feature and their position as it relates to the other features spectra, optimum bands can be identified. For example, selecting bands where the geospatial features have wider separations can minimize errors in the general classification process. For example, Bands 4 and 5 show wider separations of all the four geospatial feature types as compared to Band 6, where all the four feature types appear to converge (see Figure 10).

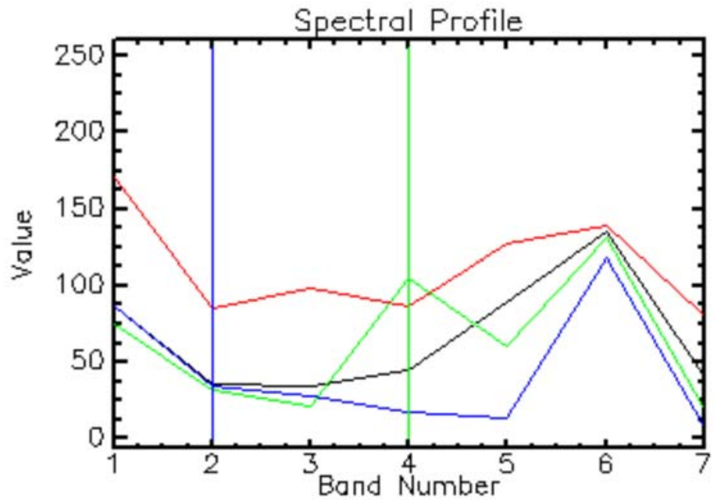

Figure 10. Spectral Profile of Landsat TM of geospatial features in SHA identified research area (Urban/Built-Up Areas – Red, Vegetation – Green, Marsh – Black, and Water Bodies – Blue).

4.4. Image Classification

An Unsupervised Isodata Classification Procedure was carried out for all six Landsat multispectral images, which were acquired during the period 1990 to 2015 at five-year intervals. The IsoData parameters were set at Number of Classes: Minimum 5 and Maximum 10; Maximum Iterations = 2; Change Threshold percentage = 65%; and the rest were left at their default values. Based on the spectral profiles of the LULC features, Bands 4, 5, and 2 were selected and used as the spectral subset for the Level I general classification of the SHS identified research area. The Level I Classification from Anderson Classification Scheme (Anderson, 1976) was used in this study. The class types observed in this research were Urban Built-Up Areas, Vegetation Areas, Marsh, and Water Bodies. The Unsupervised K-Means procedure was also conducted and the results compared with those of IsoData. However, the comparison showed no difference in the results for either the IsoData or K-Mean; therefore the IsoData classification procedure was selected over K-Mean.

After the images had been classified, the class types were identified by dynamically linking the raw image, which was displayed in Natural Color Composite, with the Classified Image, which was randomly color coded. Utilizing ENVI’s Pixel Locator and Values in the zoom window, each feature class type was systematically identified and colored to reflect their natural colors. For example, Urban/Built-Up were colored Orchid; Vegetation colored Green; Marsh colored Thistle; and Water Bodies were colored Blue (see Figures 11).

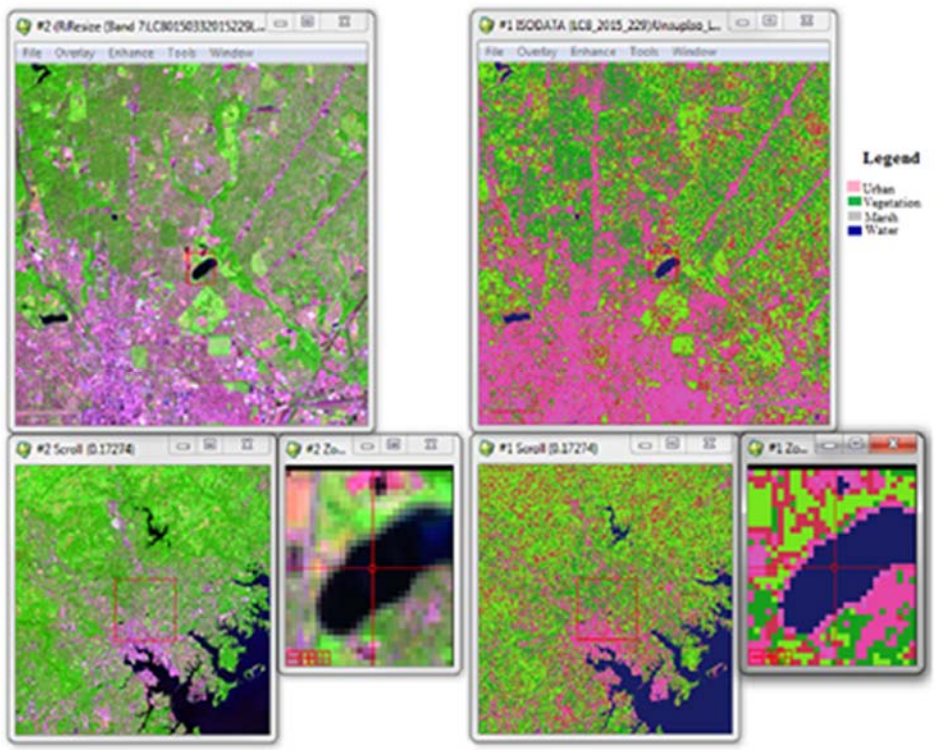

Figure 11. Landsat 8 Classified Image Class Type Identification Process using Pixel Locator (Zoom Window), showing Water Bodies (left 3 Image Windows – Raw Image and right 3 Image Windows are the Classified Image).

Note that the crosshairs in both of the zoom windows are resting exactly on Lake Montebello, which represented Water Bodies in the Classified Image. The green patch south of Lake Montebello in the image window (top right window) represents Clifton Park which is mostly vegetation, and the linear feature (colored Orchid) running NE from Lake Montebello is Harford Road (which is an urban/built-up area). This procedure was repeated until all the feature class types were identified. Color coding the Classified Image was done using ENVI’s Color Palettes. All vegetative features were colored green (the change in the tone of green reflected the variations in the vegetation types), all urban/built-up Areas were colored orchid, and all water Bodies were colored dark blue (see Figure 12).

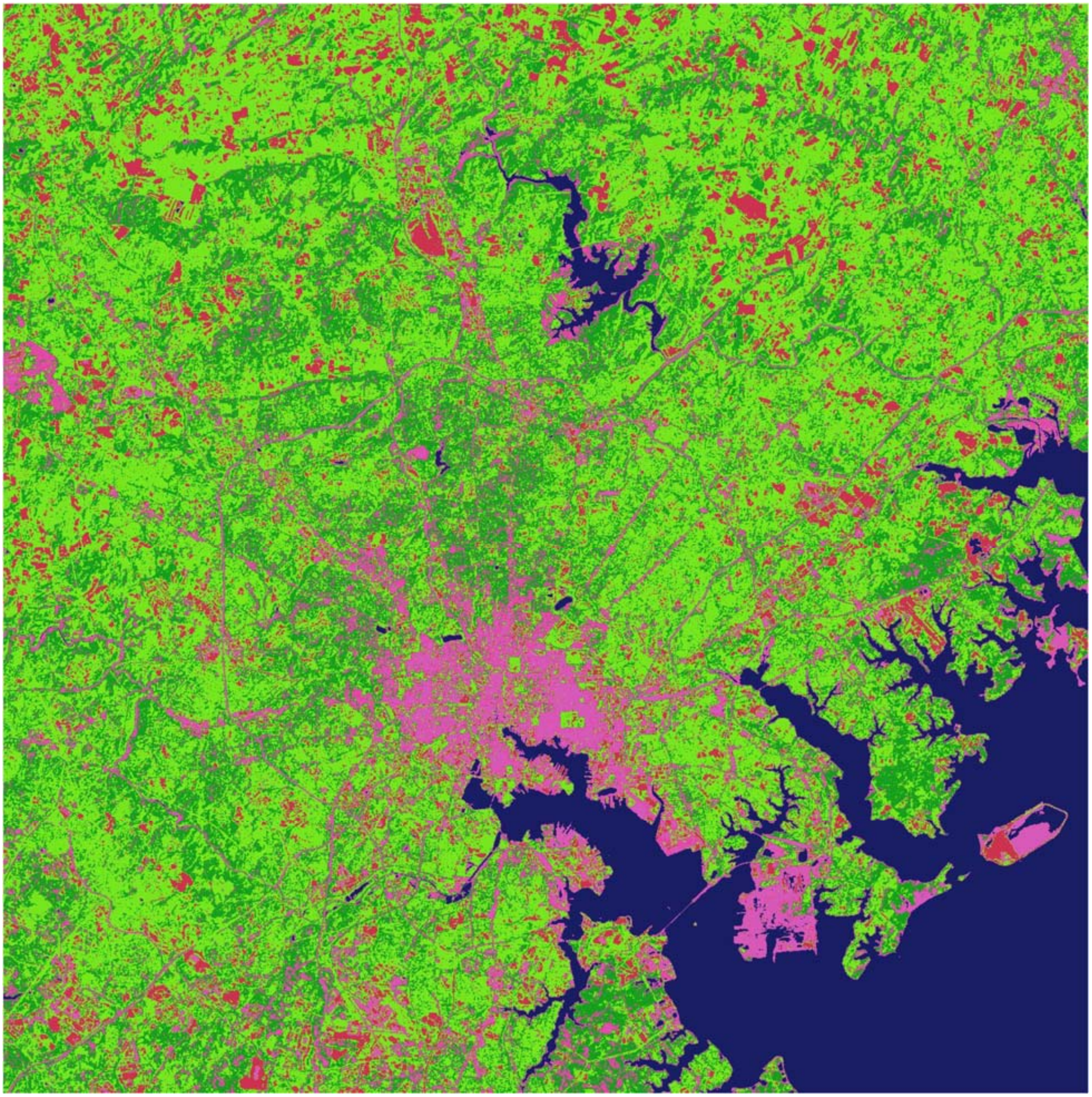

Figure 12. Landsat TM (2000) Unsupervised Classification of Study Area (Urban – Orchid, Vegetation – Green, Marsh – Thistle, and Water – Blue).

4.5. Groundtruthing

Groundtruthing, which refers to the collection of field data for verifying the accuracy of previously classified remotely sensed images, was carried out in order to determine the accuracy of the classification. It also provided the opportunities to observe and document current LULC on the sites. The field sites were randomly selected for each Class Type in the lab and their locations were logged. These sites were then verified in the field to determine their correct Class

Types; Google Earth was also used for some sites that were inaccessible. An Error Metrics Table was developed using the groundtruth and lab data (see Table 3).

Table 3. Error Metrics Computation for Classified Images: Lab – Predicted Classes and Field – Real/Correct Classes

Error Metrics of Unsupervised Classification						
		Field				∑
		U	V	M	W	
Lab	U	**16**	4	0	0	20
	V	0	**15**	0	0	15
	M	0	0	**0**	0	0
	W	0	0	0	**5**	5
∑		16	19	0	5	40

Accuracy:

1. Urban – U = 80%
2. Vegetation – V = 100%
3. Marsh – M = N/A
4. Water Bodies – W =100%
5. Average accuracy = 93.3%
6. Alternate overall accuracy = (16 +15+5)/40 = 90%

4.6. Normalized Difference Vegetation Index

Normalized difference vegetative index (NDVI), which is considered the foundation for remote sensing phenology due to the interactions of sunlight (the electromagnetic spectrum) and pigments in plant leaves, provided important indications about the conditions of vegetative cover/growth at the BMP sites. NDVI was computed using the equation:
NDVI = NIR - Red / NIR + Red,
where, NIR is the Near Infrared Band and Red is the Red Band.

NDVI values range from -1.0 to +1.0 where, for example, rocks and sand display very low NDVI values and areas of thick vegetation correspond to higher NDVI values (Figure 13). It was hypothesized, that since the SWM were functioning properly as intended when they were constructed only the changes in the vegetative cover may have been responsible for the change. This hypothesis was confirmed during field observations conducted at these SWM facility sites; therefore NDVI was used to determine the vegetativeness at these SWM facilities site to assist in determining the level of performance over time.

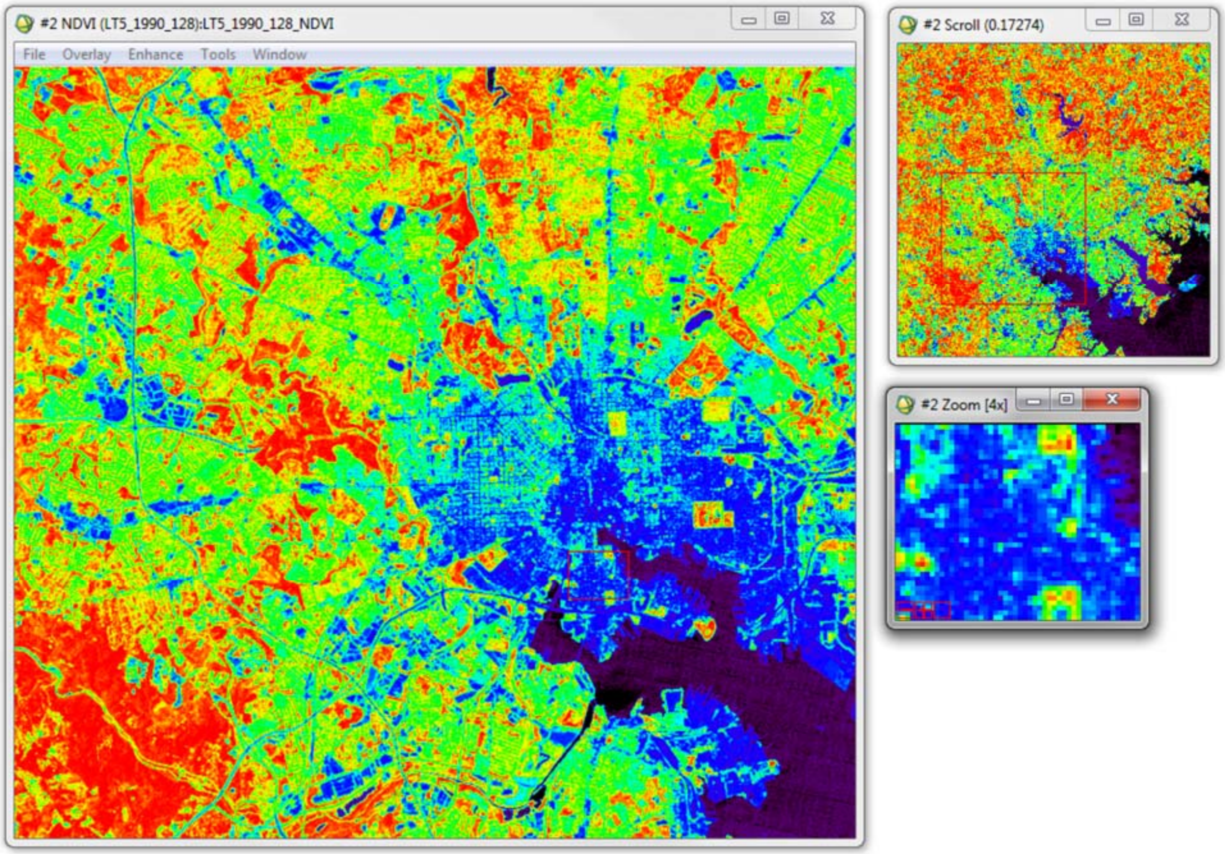

Figure 13. NDVI Landsat TM Image of Study Area (red – highly vegetated area, blue less vegetated areas).

After the NDVIs were computed for all the images, the Classified Images and NDVI Images were dynamically linked. The SWM facilities coordinates were then entered into the ENVI's Pixel Locator Window (in Decimal Degrees) and Cursor Location/Value Tool was used to extract the LULC and NDVI values at the selected SWM facility coordinate points (see Figure 14).

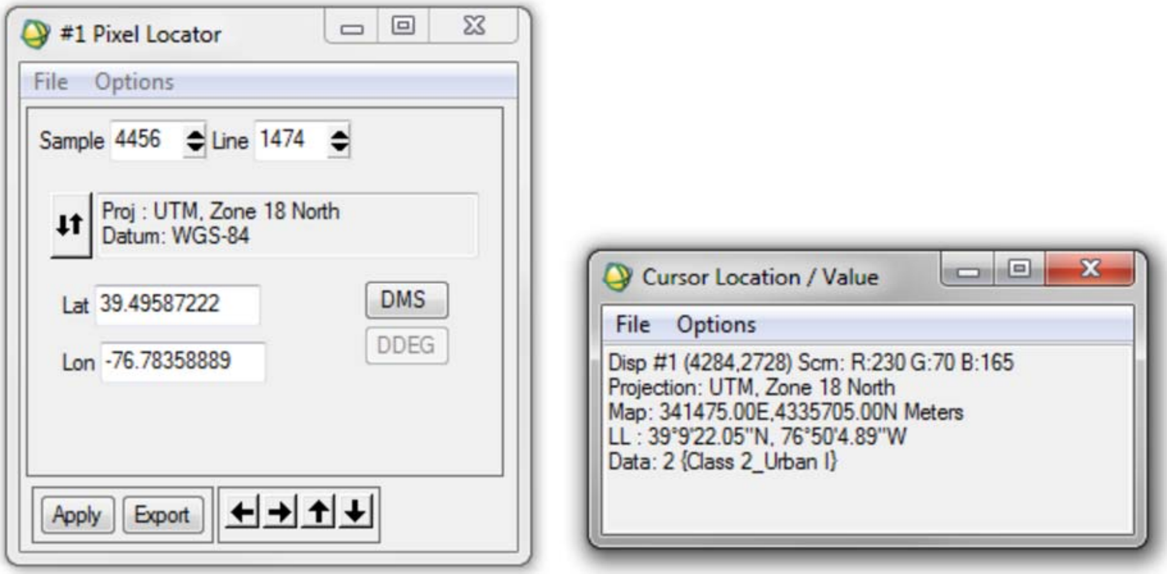

Figure 14. Locator Window (left) and Cursor Location/Value Window (right).

Because of these ENVI capabilities, several NDVIs and LULC classifications displays were linked together and multiple year values extracted (Figure 15). Once the NDVI and LULC values for all the SWM facilities have been extracted, they are tabulated using Microsoft Excel (Excel) further analyses.

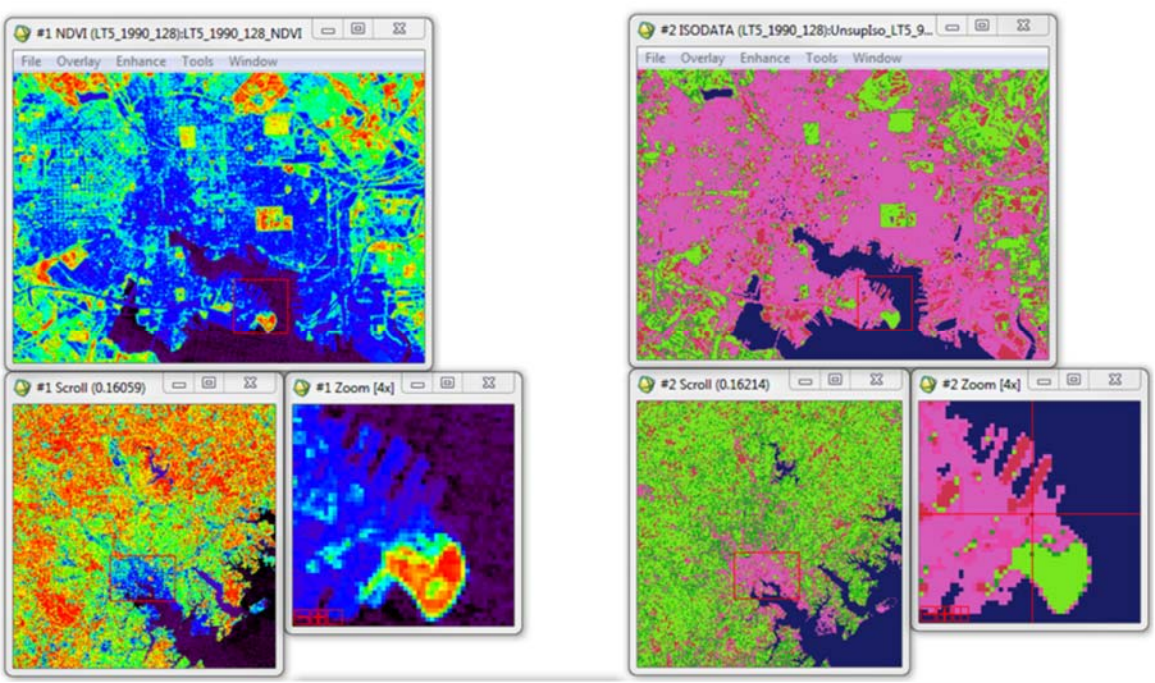

Figure 15. Extracting NDVI and LULC Values of Selected BMP Sites (NDVI Image – top left and LULC Image – top right image). The crosshair in the LULC Zoom Window makes the extraction process more reliable and very accurate, since each SWM facility location (site) can be accurately entered and easily observed.

The NDVI values were extracted for all of the selected SWM sites, using the latitudes and longitudes obtained from the SHA GIS Database. Since the cloud cover affects the quality of the images, only those with cloud cover less than 3 percent were selected. This criterion made it very difficult to obtain images with the same Acquisition Dates and Sensor Type/ID (see Table 2).

Table 4. NDVI Values for Selected BMP Sites, where lower values indicate low vegetation and higher values indicate high vegetation.

#	BMP	Lat	Lon	BMP	1990	1995	2000	2005	2010	2015
1	ID	DD	DD	Rated	NDVI	NDVI	NDVI	NDVI	NDVI	NDVI
2	30104	39.47318	-76.6407	I	0.090	0.2	0.138	0.069	**0.140**	**0.169**
3	30266	39.42043	-76.7997	I	0.452	0.483	0.409	0.419	0.510	0.429
4	30178	39.36645	-76.4501	I	0.023	**-0.043**	0.275	0.260	0.467	0.448
5	30125	39.25099	-76.7244	I	0.524	0.428	0.397	0.452	0.407	0.330
6	30268	39.51806	-76.5606	II	0.493	0.611	0.528	**0.626**	0.514	0.475
7	30162	39.46847	-76.6632	II	**0.618**	0.630	0.324	0.323	0.381	0.398
8	30200	39.43058	-76.4402	II	0.558	0.609	0.458	0.459	0.558	0.410
9	30014	39.36069	-76.4146	II	0.486	0.527	0.437	0.113	0.522	0.412
10	30135	39.23036	-76.6502	II	0.196	0.333	0.321	0.327	0.186	0.289
11	30113	39.47856	-76.8483	III	0.578	**0.671**	0.431	0.484	0.65	0.465
12	30286	39.21642	-76.6991	III	**0.018**	0.145	**0.111**	0.138	0.188	0.198
13	30187	39.40325	-76.4167	III	0.428	0.597	0.390	0.430	0.448	0.470
14	30334	39.41442	-76.6108	III	0.483	0.615	0.469	**0.062**	0.363	0.363
15	30124	39.30666	-76.7508	III	0.328	0.260	0.301	0.204	0.209	0.210
16	30214	39.428	-76.4431	IV	0.45	0.146	0.128	0.183	0.184	0.211
17	30189	39.43254	-76.4372	IV	0.607	0.509	0.451	0.464	0.548	0.388
18	Min				0.567	0.640	**0.555**	0.569	**0.663**	**0.493**
19	Max				0.018	**-0.043**	0.111	0.064	0.140	0.169

4.7. Analyses of NDVI and LULC Values

The NDVI and LULC values were tabulated and used to conduct temporal analyses with respect to the selected SWM sites. The following fields were used in this analysis (see Table 4– NDVI & LULC):

- Record Number,
- BMP Rated Value (I – IV),
- Year (1990 – 2015),
- NDVI Values (-0.04348 to 0.671053), and
- LULC Values (U – Urban, V – Vegetation, M – Marsh, and W – Water).

The LULC results were weighted based on SWM performance suitability:

- Urban/Built-Up areas (including asphalt and concrete) were assigned the lowest weight value of 1 (one) meaning unsuitable (symbol US),

- Vegetation – Less Suitable (LS), assigned a weighted value of 2 (two); Marsh – Moderately Suitable (MS), assigned a weighted value of 3 (three), and
- Water Bodies – Highly Suitable (HS), assigned a weighted value of 4 (four).

Urban/built-up areas and highly impervious surfaces prevent water from infiltrating the soil. Water bodies including streams and rivers act as very good conduits for stormwater. Vegetation on the other hand can enhance stormwater infiltration to a certain degree. However, excessive vegetation growth can ultimately inhibit the proper performance of SWM facilities. The spatial resolution of the Landsat TM images did not allow for Level II classification of the SWM facility which would have enabled a more detailed and accurate classification/breakdown of the vegetation types at these SWM sites (see Table 5). For example, IKONOS multispectral and panchromatic images with 4 m by 4 m and 1 m by 1 m spatial resolution respectively would have allowed for the Level II and higher classification of the SWM sites. Unfortunately, IKONOS is a commercial business entity, and the acquisition cost was prohibitive for the scope of this research.

Table 5. LULC Weighted Values for Selected BMP Sites, where U-Urban, Wt = 1, Unsuitable; V-Vegetation, Wt = 2, Less Suitable; M-Marsh, Wt = 3, Moderately Suitable; and W-Water, Wt = 4, Highly Suitable. No Marsh and Water classes were found in the Study Area.

	BMP	Lat	Lon	BMP	1990	1995	2000	2005	2010	2015
	ID	DD	DD	Rated	LCLU Wt	LULC Wt	LULC Wt	LULC Wt	LULC Wt	LULC Wt
1	30104	39.47318	-76.6407	I	1	2	2	2	2	1
2	30266	39.42043	-76.7997	I	2	2	2	2	1	2
3	30178	39.36645	-76.4501	I	1	1	2	2	2	1
4	30125	39.25099	-76.7244	I	2	2	2	1	2	2
5	30268	39.51806	-76.5606	II	2	2	2	2	2	2
6	30162	39.46847	-76.6632	II	2	2	2	2	1	2
7	30200	39.43058	-76.4402	II	1	2	2	2	1	2
8	30014	39.36069	-76.4146	II	2	2	2	2	1	2
9	30135	39.23036	-76.6502	II	1	1	2	1	2	1
10	30113	39.47856	-76.8483	III	2	2	2	2	1	1
11	30286	39.21642	-76.6991	III	1	1	2	2	1	1
12	30187	39.40325	-76.4167	III	2	2	1	1	2	1
13	30334	39.41442	-76.6108	III	2	2	2	1	2	2
14	30124	39.30666	-76.7508	III	2	1	2	1	1	1
15	30214	39.428	-76.4431	IV	2	1	1	1	1	1
16	30189	39.43254	-76.4372	IV	2	2	2	2	2	2

Analysis of the LULC values for the SWM sites revealed only Urban/Built-Up and Vegetation Areas; no Marsh or Water Bodies were observed at the selected SWM sites. Although there was no clear trend in the LULC change over the period 1990 to 2010 as it related to the SHA rankings, it must be noted that vegetation cover appeared to have dominated the majority of the SWM sites (64.6%). This dominance of vegetative covers was also confirmed during groundtruthing and field activities at these sites.

5.0. **RESEARCH FINDINGS/DISCUSSION**

In some cases, it was observed that Vegetation (one of the LULC class types) decreased with SHA's BMP rated rankings. For example, BMPs rated I and II had an average Vegetation Weighted value of 1.7, while SWM rated III and IV had 1.5, suggesting that Vegetation does play a role in the performance of the BMPs. However, in order to determine the exact role(s) played by vegetation, multispectral images with higher spatial resolution such as IKONOS with 4 m by 4 m pixel size would be required.

Normalized difference vegetative index (NDVI) – Although it is difficult to establish trends in the NDVI values over the sample time period, the NDVI values for BMP rated I and IV in 2010 and 2015 did show some trend. The NDVI values for the BMP sites rated I were less than those rated IV in both 2010 and 2015 (see Figure 16).

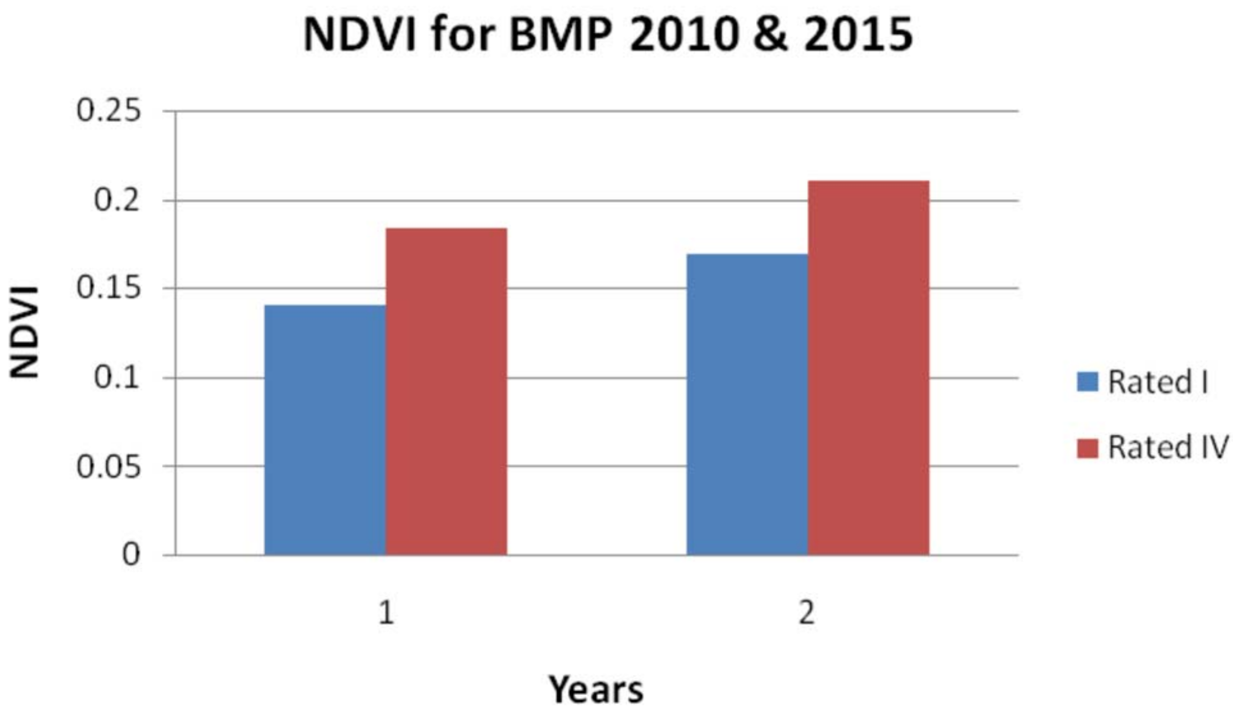

Figure 16. NDVI Values for BMP Rated I & IV in 2010 (graph 1) and 2015 (graph 2).

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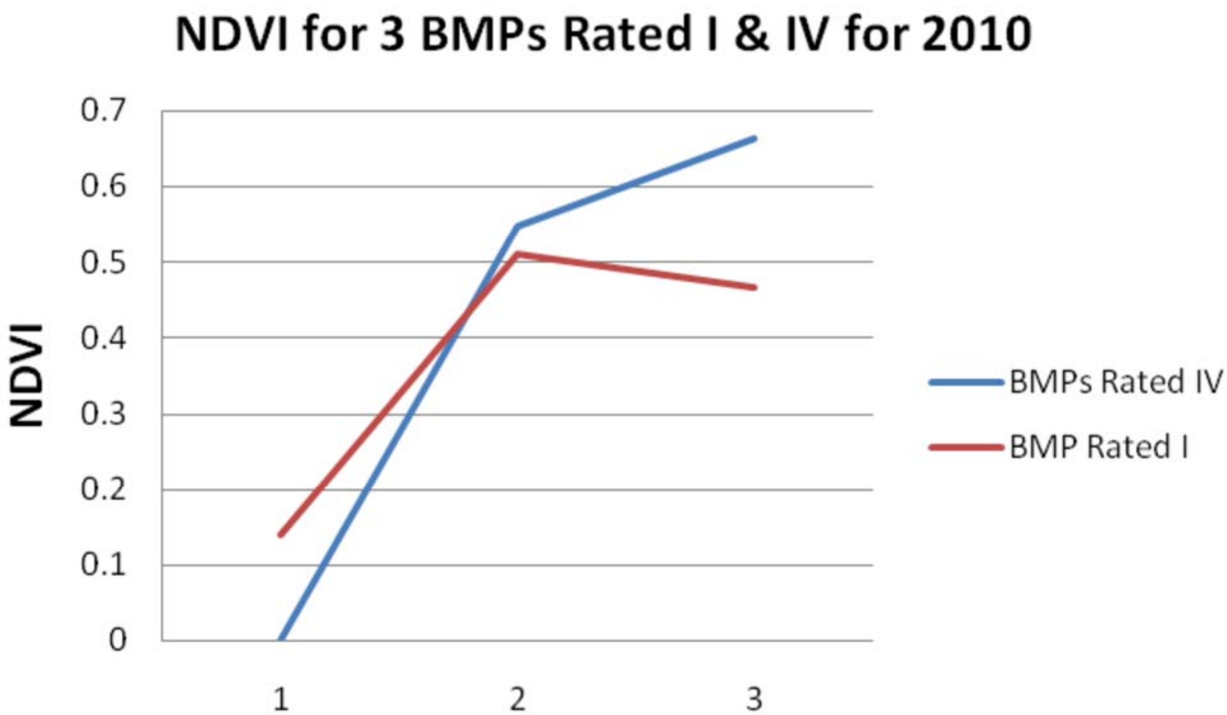

Figure 17. NDVI Values for 3 BMP Rated I (1-ID 30104, 2-ID 30266, 3-ID 30178) and IV (1-ID 30214, 2-ID 30189, 3-ID 30223) in 2010.

Temporal analyses of the NDVI values for all four different types of SWM ratings (I/Good, II/Fair, III/Poor, and IV/Failed) were carried out; however, the results were inconclusive. In some cases, NDVI values increased over the years (1990 to 2015) as with SWM site 3 (Rated I), while it decreased over time for Site 4 (Rated I), (Figures17 and 18). The same analyses were completed for the other SWM ratings (Rated II, III, and IV), (Figures 19, 20, and 21).

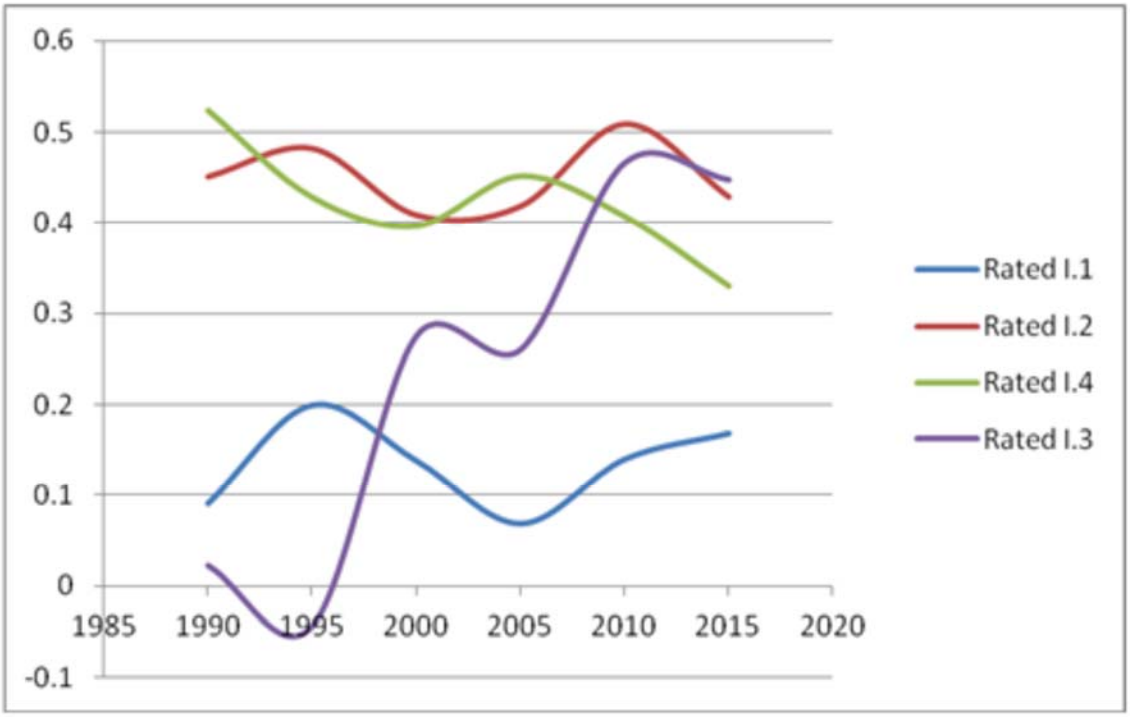

Figure 18. Temporal Distribution of NDVI for BMP Rated I.

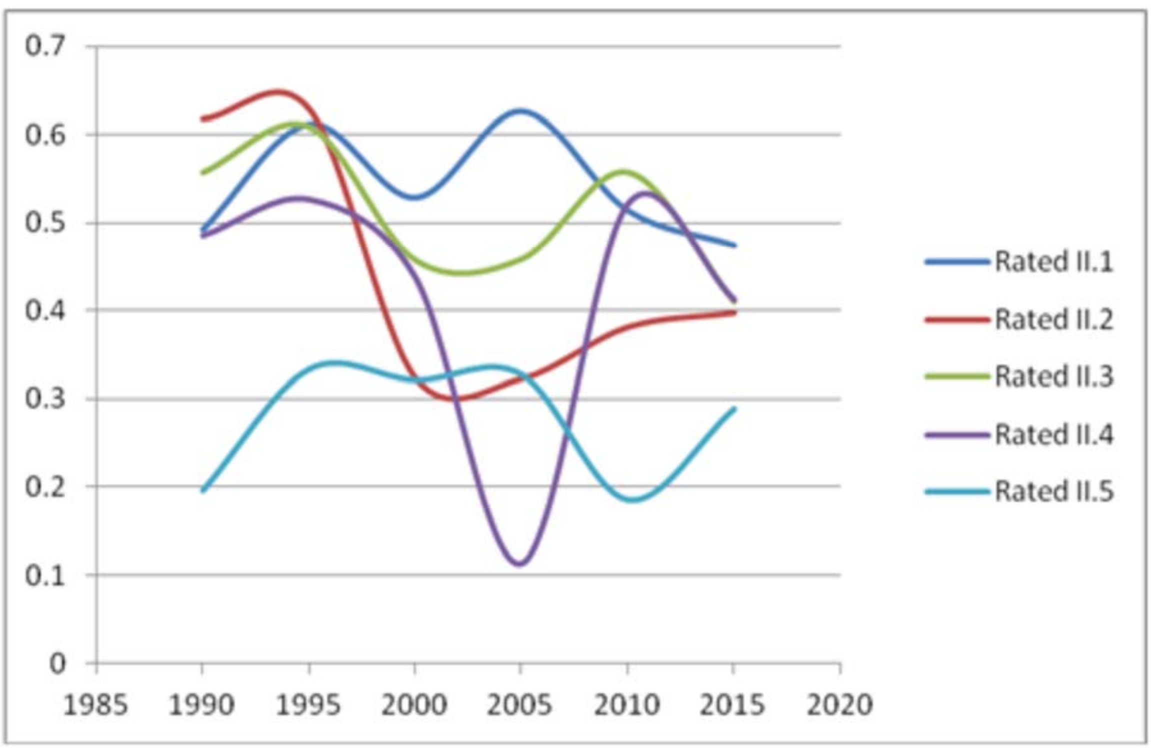

Figure 19. Temporal Distribution of NDVI for BMP Rated II.

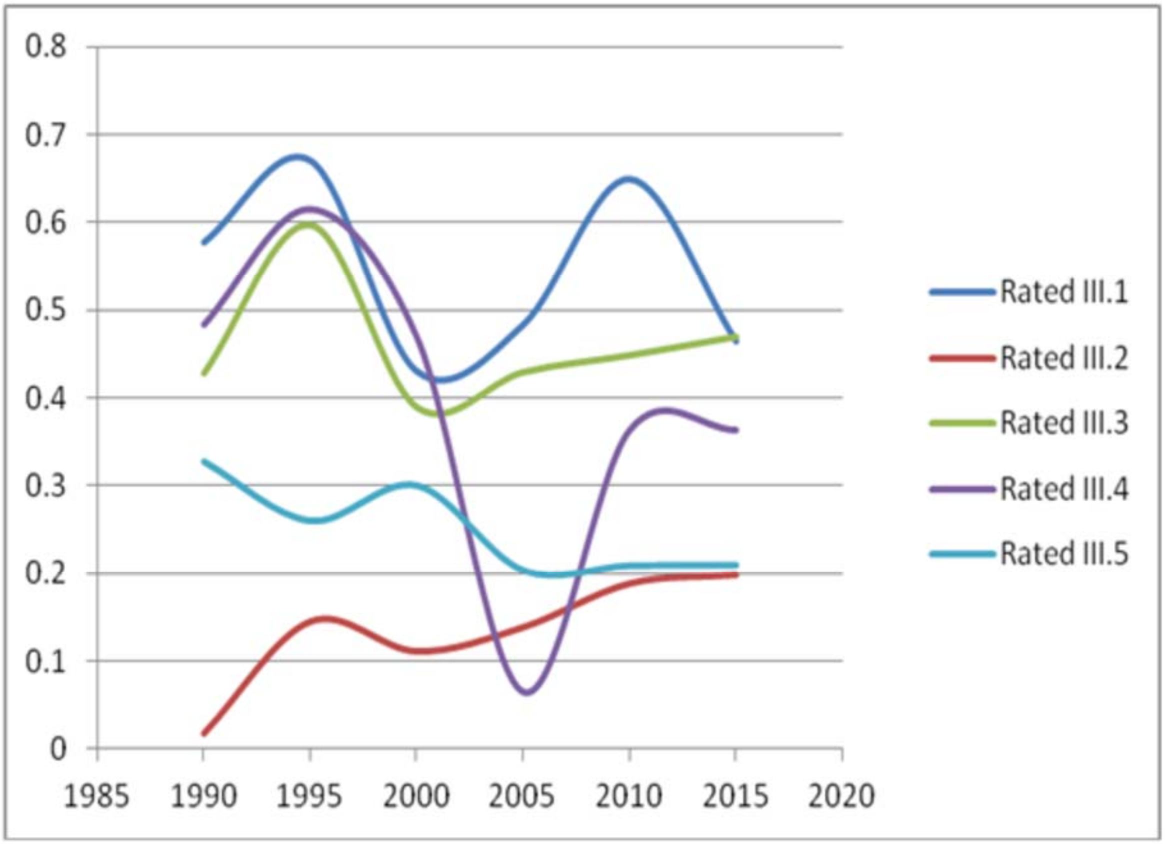

Figure 20. Temporal Distribution of NDVI for BMP Rated III.

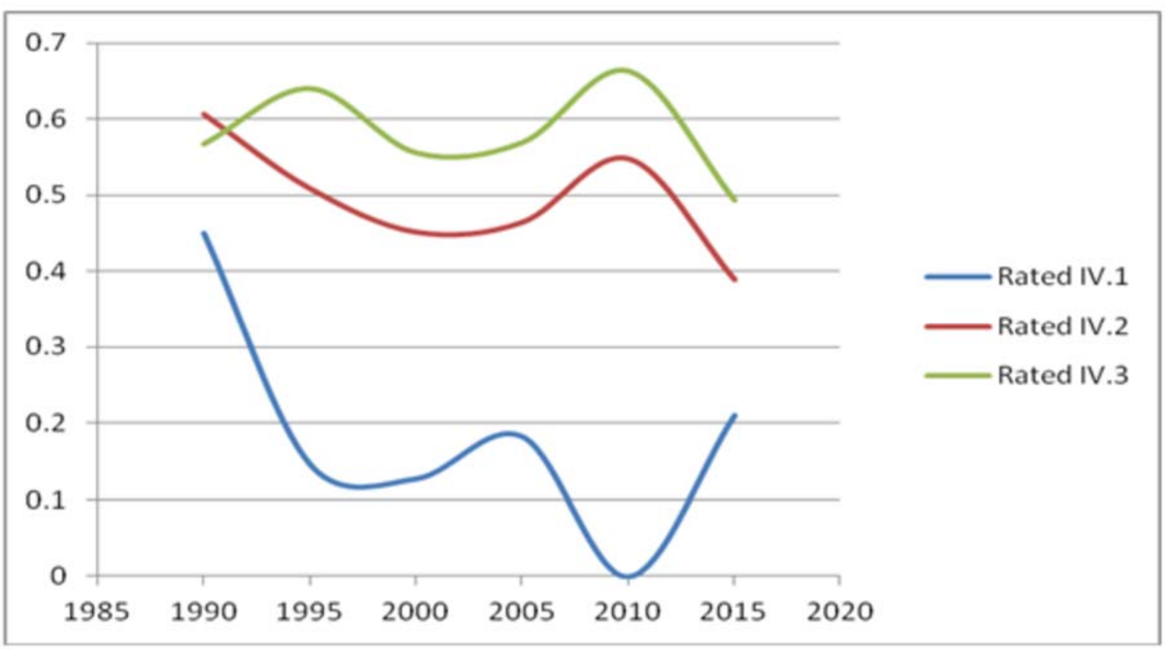

Figure 21. Temporal Distribution of NDVI for BMP Rated IV.

Several SWM sites with different ratings (4 rated I/Good, 5 rated II/Fair, 5 rated III/Poor, and 3 rated IV/Failed) were also analyzed but the results obtained did not show consistency in trend or pattern corresponding to their rated performances. In general, fluctuations were observed within the different ratings. It was difficult to establish patterns based on the ratings (see Figure 22).

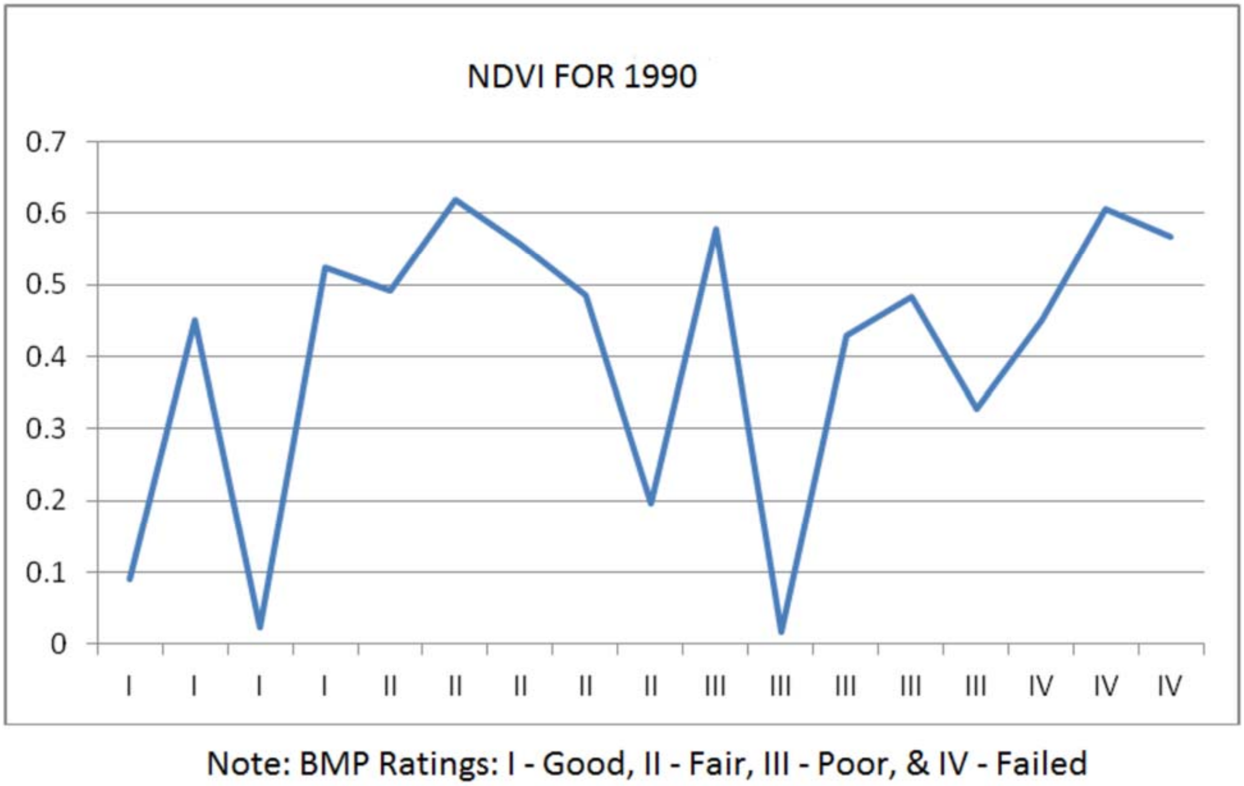

Figure 22. Spatial Distribution of NDVI for BMP Rated I, II, III, and IV.

6.0. CONCLUSIONS AND RECOMMENDATIONS FOR IMPLEMENTATION

The use of Landsat images in determining the functionality of the SHA's SWM facilities posed several challenges in identifying features due to the special resolution of the images. The spatial resolution of the Landsat images (30-meter resolution) did not allow for individual SWM site analyses, since most of the SWM site/facilities are smaller than the pixel size of the image. It is therefore recommended that higher spatial resolution images such as IKONOS with a 1- and 4-meter spatial resolutions be used in the future. The IKONOS panchromatic band (1-meter band) could be used to sharpen the multispectral bands (4-meter bands) to enhance their spatial resolution and thus reduce errors during processing, analyses, and synthesis of the results.

The cost of IKONOS images depend on the size of the study area and the type of image being acquired, panchromatic, multispactral, or a combination of both. However, based on previous procurement of IKONOS panchromatic and multispectral images (combined), the cost was $2,981.48 per scene/168.37 km square area. Because of the rapid growth and acceptance of unmanned aerial vehicles (UAVs) applications, it might be possible to use UAVs to acquire even higher spatial resolution images at a considerably lower cost, which in turn could serve vital roles in SWM studies in the future.

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APPENDICES

APPENDIX A

SHA Stormwater Project Field Activities Form

Selected SWM will be observed to determine the Structural Integrity, Working Conditions, LULC features, and Others (proximity to highways, general feature type, presence of wetland plants/hydric soil)

I. Structural Integrity: Please circle one answer (“Yes”, “No”, “N/A”) below.

1. Does the facility show signs of settling, cracking, bulging, misalignment, or other structural deterioration?
   Yes No N/A
2. Do embankments, emergency spillways, side slopes, or inlet/outlet structures show signs of excessive erosion or slumping?
   Yes No N/A
3. Is the outlet pipe damaged or otherwise not functioning properly?
   Yes No N/A
4. Do impoundment and inlet areas show erosion, low spots, or lack of stabilization?
   Yes No N/A
5. Are trees or saplings present on the embankment?
   Yes No N/A
6. Are animal burrows present?
   Yes No N/A
7. Are contributing areas unstabilized with evidence of erosion?
   Yes No N/A
8. Do grassed areas require mowing and/or are clippings building up?
   Yes No N/A

II. Working Conditions: Please circle one answer (“Yes”, “No”, “N/A”) below.

1. Does the depth of sediment or other factors suggest a loss of storage volume?
   Yes No N/A
2. Is there standing water in inappropriate areas, such as on filters or cartridges after a dry period?
   Yes No N/A
3. Is there an accumulation of floating debris and/or trash?
   Yes No N/A

III. Other Observation Items: Please circle one answer (“Yes”, “No”, “N/A”) below.

1. Is there evidence of encroachments or improper use of impounded areas?
   Yes No N/A
2. Are there signs of vandalism?
   Yes No N/A
3. Do the fence, gate, lock, or other safety devices need repair?
   Yes No N/A
4. Is there excessive algae growth, or has one type of vegetation taken over the facility?
   Yes No N/A
5. Is there evidence of oil, grease, or other automotive fluids entering and clogging the facility?
   Yes No N/A

Remote Sensing Procedure

1. BMP Coordinate (DD): Lat____________ Long_____________
2. Elevation (ft): ______________________

Spatial Resolution

1	2	3
4	5	6
7	8	9

Pixels around BMP
Please identify the LCLU type in each pixel and it approximate percentage

3. LCLU Type & Symbols:

F- Forest/Trees, **G**- Grass, **O**- Outcrop/Rocks, **S**- Soils, **U**- Urban, **W**- Water

Comments:
____
____
____

APPENDIX B

U.S. Geological Survey Land Use/Land Cover Classification System for Use with Remote Sensors Data (source: Anderson et al. 1972)

Level I	Level II
1 Urban or Built-up land	11 Residential
	12 Commercial and services
	13 Industrial
	14 Transportation, communications, and services
	15 Industrial and commercial complexes
	16 Mixed urban or built-up land
	17 Other urban or built-up land
2 Agricultural land	21 Cropland and pasture
	22 Orchards, groves, vineyards, nurseries, and ornamental horticultural areas
3 Rangeland	31 Herbaceous range;and
	32 Shrub and brush rangeland
	33 Mixed rangeland
4 Forest land	41 Deciduous forest land
	42 Evergreen forest land
	43 Mixed forest land
5 Water	51 Streams and canals
	52 Lakes
	53 Reservoirs
	54 Bays and estuaries
6 Wetland	61 Forested wetland
	62 Nonforested wetland
7 Barren land	71 Dry salt flats
	72 Beaches
	73 Sandy areas other than beaches
	74 Bare exposed rocks
	75 Strip mines, quarries, and gravel pits
	76 Transitional areas
	77 Mixed barren land
8 Tundra	81 Shrub and brush tundra
	82 Herbaceous tundra
	83 Bare ground
	84 Mixed tundra
9 Perennial snow and ice	91 Perennial snowfields
	92 Glaciers