

## ***Appendix 3-C***

# **INFORMATION TOOLS FOR LOCAL STORMWATER MANAGEMENT**

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### 3-C.1.0. INTRODUCTION

Stormwater management is becoming increasingly complex. The simple notion of collecting runoff and sending it efficiently to the nearest stream is being replaced with considerations of stormwater quantity and quality control, infrastructure management, master planning and modeling, financing, complaint and maintenance tracking, and more. Information needs are critical to a successful local program. Virginia communities need to both invest in and be aware of new and emerging technologies that can provide the ability to collect, organize, maintain and effectively use vast amounts of data and information for their community's stormwater management activities.

This Appendix covers the following information tools that can be used by a community to assist in their stormwater management program:

- Stormwater management system inventories
- Geographic Information Systems (GIS) and Databases
- Global Positioning Systems (GPS)
- Remote Sensing
- Computer Models

### 3-C.2.0. STORMWATER MANAGEMENT SYSTEM INVENTORIES

The development of an inventory of the stormwater system is the first step in developing a comprehensive stormwater management program. Like any other public infrastructure (water, wastewater, streets, etc.), having a knowledge of the stormwater infrastructure is important in its proper and efficient management.

Relevant information includes location and classification of storm drains; drainage networks; structural stormwater control facilities; streams, ponds and wetlands; industrial discharges and combined sewer outfalls; watershed boundaries; floodplains; existing and proposed land use and zoning; and known water quality problem areas. This information can be collected and stored on paper maps or, ideally, in an integrated municipal GIS system. For localities with MS4 permits, the inventory should distinguish between components of the system that are part of the MS4 and those that are not (public vs. private; man-made vs. natural, etc.).

Perhaps it is easiest to understand the advantages of an inventory by stating what can be accomplished when a local city or county has effective inventory information. The uses of stormwater infrastructure inventory information include:

- ***Complaint Response.*** The ability to quickly and effectively respond to a customer complaint by having on-line current information linked to addresses, past history of the address, a site map when arriving on the scene, and other information.
- ***Inspection and Maintenance Management.*** This includes a wide array of functions as illustrated below in **Table 3-C.1** and other routine maintenance activities (e.g., mosquito larvae surveillance, inlet cleaning, BMP inspections and repairs, MS4 outfall inspections, complaint responses, etc.).

**Table 3-C.1. Stormwater Infrastructure Inventory Information & Uses**

	Basic Information					Geometry			Condition						Admin./Mgmt. Info.					
	element number	element type	location	elevation	connectivity	size	geometry information	digital picture	material type	age	structural condition	maintenance condition	environmental condition	upstream land use	adjacent flooding potenti	ownership	complaints	utility credits	easement	past activity
initial complaint response	X	X	X						X		X	X		X	X	X	X		X	X
maintenance management	X	X	X		X	X	X	X	X	X	X	X	X			X	X		X	X
remedial construction	X	X	X	X		X	X	X	X		X	X		X		X	X		X	X
capital construction	X	X	X	X		X	X	X	X	X	X	X		X	X	X	X		X	X
inventory control	X	X				X	X		X	X										
master planning	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X		X	X
financial tracking	X		X													X	X	X	X	X
material testing	X	X	X			X		X	X	X	X	X				X	X			X
legal support information	X	X	X										X			X	X	X	X	X
regulatory control	X	X	X			X		X					X	X	X	X	X		X	X

- **Remedial Construction.** Quick turn-around construction on minor systems or minor repairs to larger systems which require little design time and would be handled with unit cost open-ended contracts.
- **Capital Construction.** Programmed construction of larger items handled with pay as you go or bonded capital funds.
- **Inventory Control.** Handling of drainage structures and spare parts in storage locations and warehouses.
- **Master Planning.** System-wide analysis and planning of capital construction for problem areas and for areas facing new development.
- **Financial Tracking.** Tracking of costs, efficiencies, crediting information, assessments, etc.
- **Materials Testing.** Tracking of the age and relative life-cycle costs of different materials.
- **Legal Support Information.** Tracking of easements, ownership, complaints, and other legal information.
- **Regulatory Control.** Including NPDES/VPDES/TMDL monitoring reports, easements, permitting, negotiating requirements for new developments, flood insurance program, floodplain management, erosion control, permits issued, and other regulatory issues.

For each of these applications, information from an inventory serves as the basis for the program function. For example, knowing pipe sizes and general condition allows for long term budgeting and capital planning. Without this information, the city or county is left to simply respond on a reactive case-by-case basis to needs and complaints as they occur.

### 3-C.2.1. Organizing Information

Organizing an inventory can become a complex undertaking. Considerations should include (1) types of structures inventoried; (2) type of information needed; and (3) program/purpose for collecting the information.

The following are stormwater infrastructure components that can be included in a system-wide inventory:

- Streams and rivers
- Ditches
- Pipes
- Culverts
- Manholes
- Outfalls
- Inlets
- Bank or stream protection
- Stream enhancement
- Greenways, corridors
- Junctions
- Stormwater controls
- Detention ponds
- Dams
- Other structures
- Easements
- Floodplains
- Floodways
- Adjacent structures
- Waters of the state
- Drainage area to regulated outfalls
- Other

The type of information collected about stormwater infrastructure falls into several categories including the following:

- Structure type (e.g., channel, BMP)
- Purpose (e.g., water quantity or quality)
- Size
- Drainage area served/treated by BMP
- Material type
- Maintenance condition
- Structural condition
- Elevation
- Connectivity
- Age
- Complaints
- Utility credits
- Geometry information
- Location

Integrating the information collected for each component with the uses of the information is the next step in an infrastructure inventory. **Table 3-C.1** above depicts an example chart that lists of functional uses of inventory information and the types of information necessary to support those uses.

### 3-C.2.2. Conducting the Inventory

The following items should be considered before undertaking a stormwater system inventory:

1. ***Determine who will use the inventory information and what specific types of information and accuracy are required.*** For example, if the information on street location simply needs a general location of streets then a street centerline file would suffice. But if the actual edges of

pavement are required, a much greater level of complexity is involved including aerial photography and ground surveys. It is critically important to bring all stakeholders into the discussion of data needs, both for cost sharing and to make sure the data is sufficiently accurate for its most stringent use.

2. ***Determine the types of data and the methods of data collection.*** It is important to insure accuracy in the collection, storage, and maintenance of the information. In many instances new technology is available for some data and information. Data may already be available from a government agency (such as land use information from other aerial flights or satellite imagery). There is always a tradeoff between the use of new technology and the opportunity for it to either fail or for unknown errors to be introduced due to lack of familiarity with the technology. Inefficient use of GPS has been an example of this, where some inventories have ended up being more expensive than conventional surveying when the extra time needed to restore lost satellite lock and for training is factored in.
3. ***Determine the technology and organizational responsibilities that will be used to store and maintain the data.*** What types of hardware and software are necessary to collect and manipulate the information? Who will have access to the information and for what purposes? How will it be maintained and by whom? How will the costs be allocated?
4. ***Collect the data and information.*** Quality assurance is paramount. A single simple error repeated consistently over and over can render the whole data effort fruitless. Checks should be made for random errors, systematic errors, blunders, and system assumption errors.
  - ***Random errors occur due to both human error and the inability of equipment to accurately read information.*** They tend to vary around the correct value both high and low. These can be taken into account in planning for the use of the data, and minimized through repeated readings.
  - ***Systematic errors are consistent ways to doing something, but doing it wrong.*** Systematic errors always render a reading high or low, and can be very dangerous. Close supervision at the beginning of the inventory should smoke out most of these types of errors.
  - ***Blunders occur when a reading is simply wrong, and wrong to the point that the information is way off the mark.*** Blunders can usually be caught by error checking software during the input process (i.e. automated out of bounds checking) or during graphical plotting of information to check for outliers.
  - ***System assumption errors are those errors introduced during the planning of the inventory, when the planner simply makes a mistake on specifying how equipment is to be used or data read.*** A simple example of this might be the assumption that a certain datum is correct when it is in error.
5. ***Store and test the data.*** Make sure it is accessible. Develop the data access software and programming. Concentrate on the procedures for data handling and access. Collect and manipulate trial data first, when possible, to make sure the system works as planned.

6. ***Maintain the data.*** Make sure that responsibilities for data updates have been assigned and budgeted. Procedures which are triggered by changes in the specific data (such as subdivision approval or use and occupancy permit issuance) should be set up and worked out.
7. ***Develop and foster applications of the data.*** Data is only as good as the use that is made of it. Therefore it is vitally important that applications are developed for easy use of the inventory data and that a pool of potential users is trained in their use. Those applications envisioned early in the process should be quickly brought on line. The greater amount of time that passes after the inventory, the less chance there is that full use of the information is ever made. One key application will be to use the system to “mine” and organize data needed for required reports to state and federal regulators, as well as to local officials.

### 3-C.3.0. GEOGRAPHIC INFORMATION SYSTEMS

A Geographic Information System (GIS) is a collection of components designed to collect, process, store, analyze, and display geographic data. GIS software stores information about a given area as a collection of thematic layers that can be linked together by geography or geo-referencing. This simple but extremely powerful and versatile concept has proven invaluable for solving many real-world stormwater problems, from tracking complaints to master planning applications and infrastructure management.

#### 3-C.3.1. GIS Components

A functional GIS integrates four key components: hardware, software, data, and trained users:

- ***Hardware.*** Desktop computers and data servers are the primary hardware components of a typical local GIS system.
- ***Software.*** GIS software provides the functionality and tools needed to capture, store, analyze, display, and output geographic information. It links the spatial view of data with the database table entries.
- ***Data.*** Generally the most costly part of a GIS is data development. Some geographic data and related tabular data can be collected in-house or purchased from commercial data providers. A GIS can also integrate tabular data, such as computer aided design (CAD) data and digital imagery, to build information into the GIS database.
- ***Users.*** GIS technology is of limited value without trained operators who understand the data, system, organization and how to apply the resources to achieve the desired results. This technology tends to change and improve rapidly, so periodic training updates should be factored into system administration and use.

#### 3-C.3.2. GIS Functions

General purpose geographic information systems essentially perform the following six processes or tasks.

### 3-C.3.2.1. Data Input

Before geographic data can be used in a GIS, the data must be converted into a suitable digital format. The process of converting data from paper maps or non-coordinate-controlled images into computer files is called digitizing. Modern GIS technology can sometimes automate this process using scanning technology; but most jobs may require some form of manual digitizing to capture clean data. Today many types of geographic data already exist in GIS-compatible formats. These data can be obtained from a number of different sources including local and regional government agencies, the federal government, and state agencies such as the Virginia Geographic Information Network (VGIN) ( <http://gisdata.virginia.gov/Portal/> ).

### 3-C.3.2.2. Data Conversion

It is likely that some needed data may not be in the correct format or proper map projection to use with your system. Most GIS software has the ability to do this conversion. If yours cannot, then try requesting the data in a format you can use rather than hope it will be compatible. In some cases you may need the services of a contractor who specializes in GIS. Be careful with third party data; it is imperative that you understand the source, quality, age, accuracy and limitations of a dataset. This and other information about a dataset is often provided in the metadata that accompanies the dataset. While most data providers automatically make the metadata available, that is not always the case. Therefore, it is wise to request the accompanying metadata when you request any dataset.

### 3-C.3.2.3. Query and Analysis

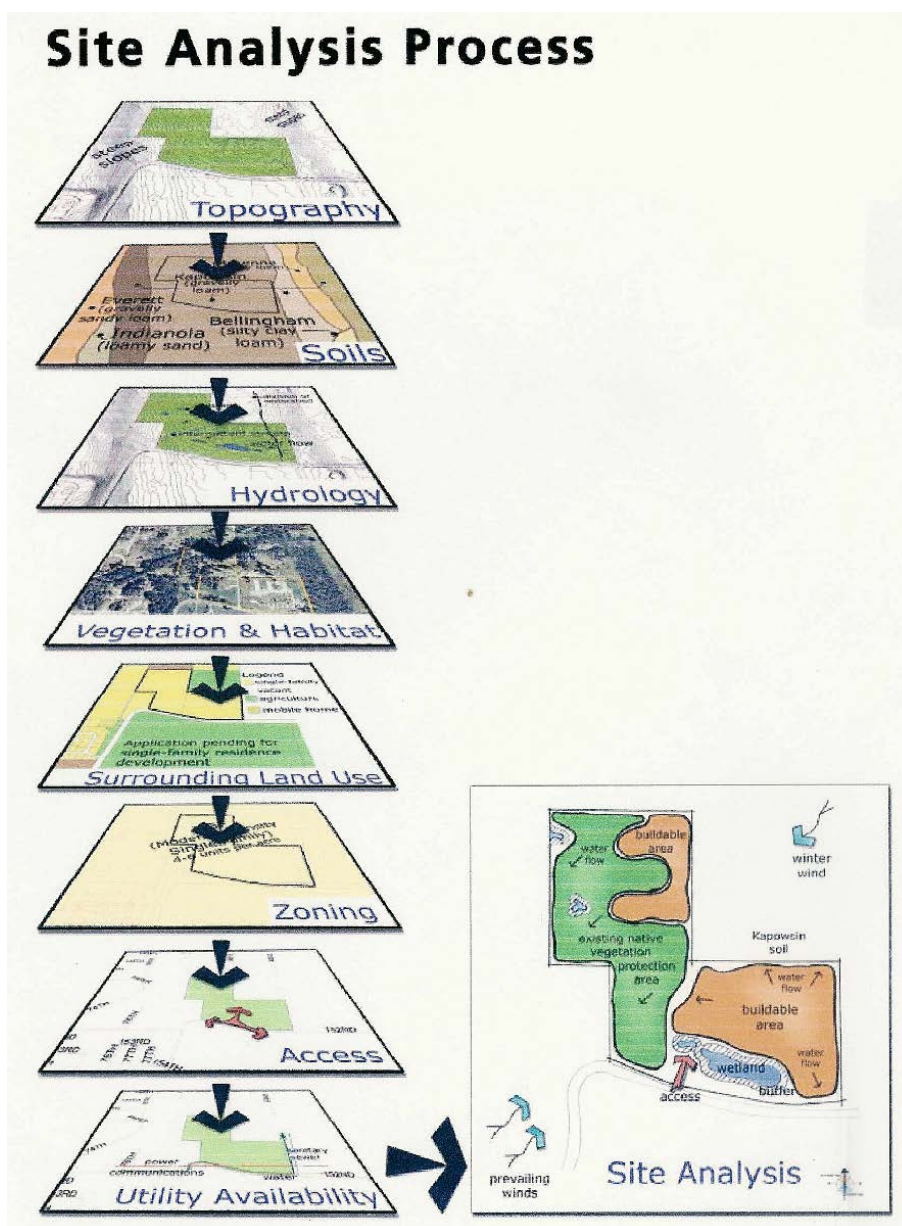
Once there is a functioning GIS containing geographic information, and assuming that you have collected the necessary information and data, the system can be used to answer questions such as the following:

- Who owns the land parcel being flooded?
- What is the distance between two stream locations?
- Which homes are located in the updated floodplain?
- How will the new development impact downstream properties?
- What types of infrastructure give us the most complaints and where are they located?
- When was a particular BMP last inspected/maintained?
- What is the nearest access point to a section of broken/clogged pipe?

GIS provides both simple point-and-click query capabilities and sophisticated spatial analysis tools to provide timely information to stormwater managers and analysts alike. GIS technology can also be used to analyze geographic data to look for patterns and trends and to undertake "what if" scenarios. Most modern GISs have many powerful analytical tools including:

- **Measurement Capabilities.** Allows the measurement of areas and distances not specifically recorded in the databases (e.g., what is the distance between two culverts?)
- **Proximity Analysis.** Determines relationships between objects and areas (e.g., who is located within 100 feet of the streambank?)

- **Overlay Analysis.** Performs integration of different data layers (e.g. what is the NRCS curve number for this sub-watershed, considering soils, and land use?) **Figure 3-C.1** below illustrates the overlay concept.
- **Network Analysis.** Analyzes the connectivity of linear features and establishes routes or direction of flow (e.g. which pipes feed into this junction box?)
- **Raster Analysis.** Uses a raster model to address a number of hydrologic issues (e.g. what does the 3-D model of this watershed look like? Where does the water flow?)



**Figure 3-C.1. Example of a GIS Overlay Analysis**  
Source: Puget Sound LID Technical Manual (2005)

### 3-C.3.2.4. Data Display, Output and Visualization

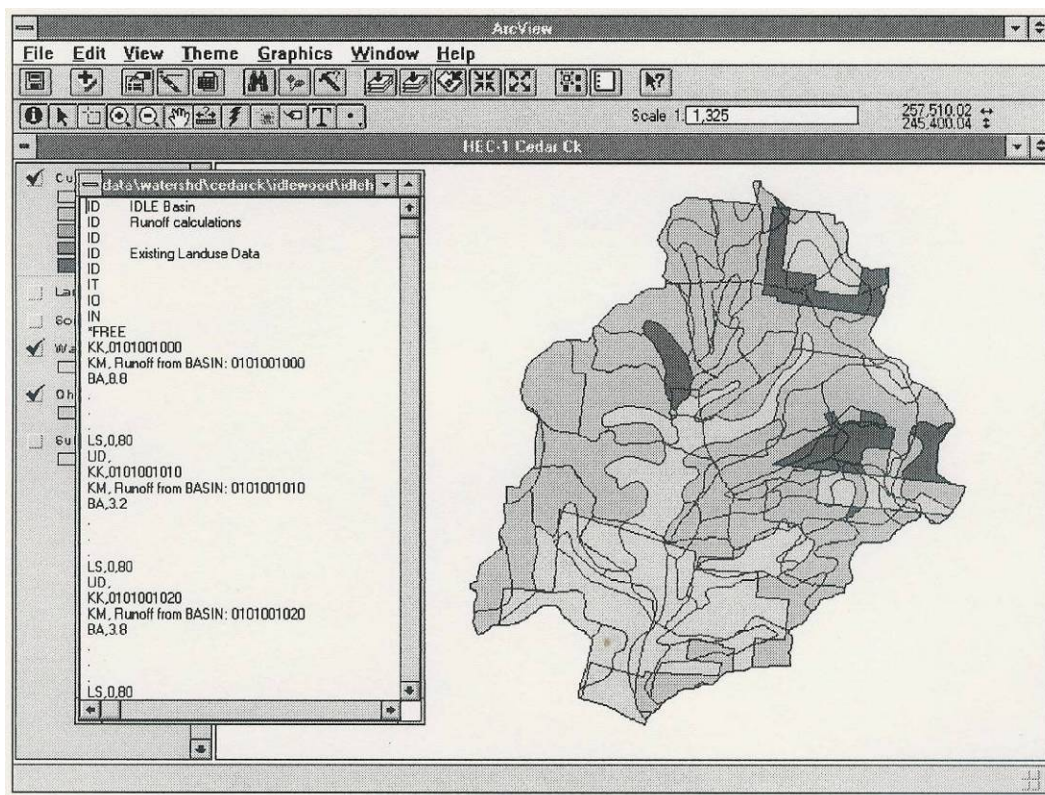
Geographic information systems excel at being able to create rich and detailed maps, graphs and other types of output which allow local staff, elected officials and the general public to be able to visualize and understand complex problems and large amounts of information. These maps and charts can be integrated with reports, three-dimensional views, photographic images, and multimedia presentations.

### 3-C.3.3. Use of GIS in Stormwater Management

#### 3-C.3.3.1. Types of Uses

GIS can be useful to a community in a wide variety of stormwater-related applications:

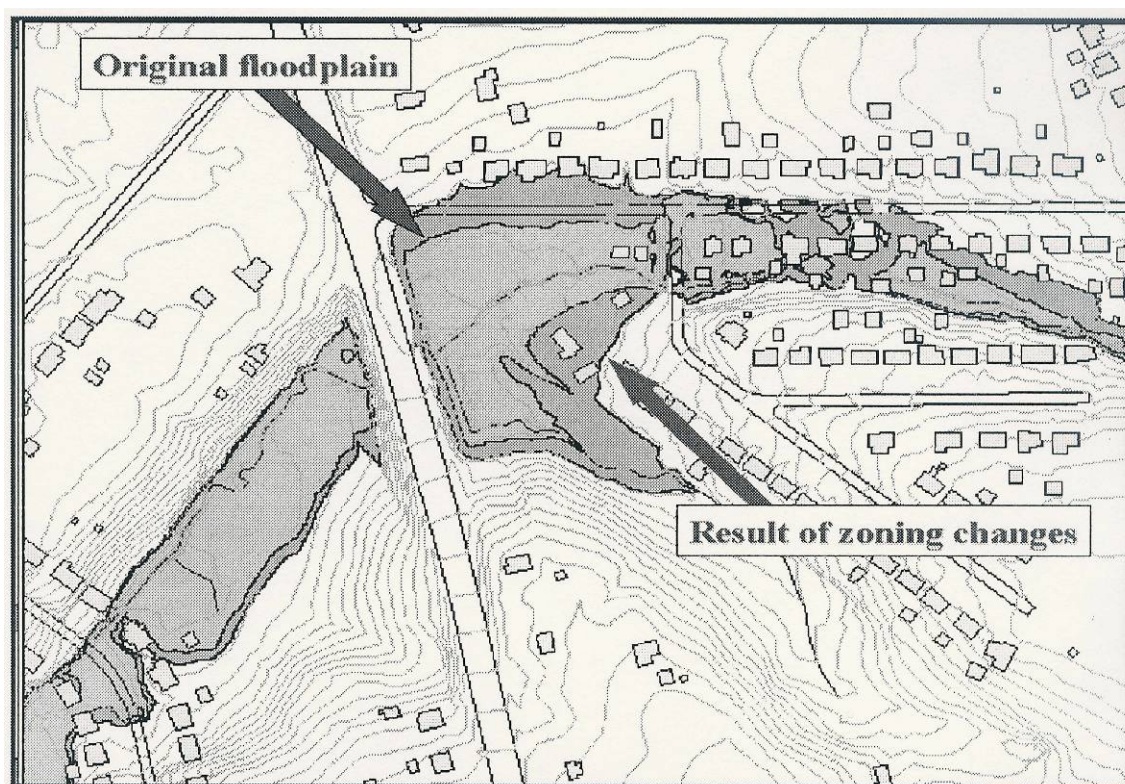
- GIS can be used for the mapping of surface features, land uses, soils, rainfall amounts, watershed boundaries, slopes, land cover, etc.
- A GIS can manage a stormwater system inventory and information about facility conditions, storm sewer networks, maintenance scheduling, and problem areas.
- GIS can be used to automate certain tasks such as measuring the areas of subwatersheds, plotting floodplain boundaries, or assessing stormwater utility fees. **Figure 3-C.2** shows an example of automated hydrologic mapping.



**Figure 3-C.2. Automated Hydrologic Modeling**

Source: ARC (2001)

- A GIS can be used to evaluate water quality impacts and answer cause and effect questions, such as the relationship between various land uses and in-stream pollution monitoring results.
- “What if” analyses can be undertaken with GIS. For example, various land use scenarios and their impacts on pollution or flooding can be tried in various combinations to determine the best management solutions or to determine the outcome of current decisions. When tied to hydrology, hydraulics and/or water quality models, this type of analysis becomes a powerful tool to assess the impacts of new development on downstream properties. For example, **Figure 3-C.3** shows the flooding impacts on a small tributary for a proposed new development approved during a rezoning.



**Figure 3-C.3. Use of a GIS to Map Current and Potential Floodplains & Flood-Prone Homes**

Source: ARC (2001)

**Figure 3-C.4** below is an image from a commercial GIS application displaying, in this case, an inventory of storm sewer system maintenance.

- GIS databases can provide staff, elected officials, and citizens with immediate answers and ready information. For example, inventory, complaints and other information about stormwater infrastructure (including pictures) can be placed in a database tied to geographic location. Henrico County is an excellent example of a locality that has developed this kind of GIS capability.
- Complex problems or changes over time, such as water quality improvements, can be easily visualized in maps and graphs generated by GIS systems.

- GIS maps can be used to educate or persuade citizens and political leadership concerning a course of action or a project's viability.



**Figure 3-C.4. Commercial GIS Application Showing Storm Sewer Maintenance**

Source: Storm Water Solutions (Mar-Apr 2010)

### 3-C.3.3.2. Implementation Issues

Communities often make the mistake of making enormous expenditures on data, hardware and software and databases but little on planning, staff familiarization, training and graphical user interface (GUI) and applications development. The end result is often an unusable system accessible by only a few who have the resources both to learn the system, hire competent staff, and develop applications. It is often better to target the GIS implementation to certain needs and quickly roll out applications that work for these needs, even prior to the complete development of the database and overall system.

Proper implementation of GIS applications for stormwater management involves planning for both stormwater-only applications and to integrate these applications with other potential users within the municipality.

### 3-C.3.4. Other Related Technologies

GIS is closely related to several other types of information systems, and can be used with these other information tools, including the following.

### 3-C.3.4.1. CAD

Computer-Assisted Design (CAD) systems evolved to create designs and plans of buildings and infrastructure. The systems are designed to do very detailed drafting and drawing but have only limited capability to attach data fields to the electronic drawing. As a result these systems do not have the capability to perform spatial analysis. Fortunately these drawings can be input to a GIS, saving significant digitizing efforts. Once in a GIS, attribute data can then be added to the graphic features.

### 3-C.3.4.2. Database Management Systems (DBMS)

Database Management Systems specialize in the storage and management of all types of data including geographic data. DBMSs are optimized to store and retrieve data, and many GISs rely on them for this purpose. They do not typically have the analytic and visualization tools common to GIS.

### 3-C.3.4.3. SCADA

SCADA stands for Supervisory Control and Data Acquisition System. These systems combine the ability to monitor information (e.g. rainfall, stream flow, flood level, etc.) remotely through telemetry. SCADA systems can also execute commands to do such things as open gates or close valves from a distance. Examples of the use of SCADA include automating stormwater pump station operation, automated alarms for flood warning, automated triggering of flow and water quality monitoring devices, and automated lowering of traffic control barrier arms during high water periods. SCADA systems can be combined with GIS to create comprehensive tracking systems.

### 3-C.4.0. GLOBAL POSITIONING SYSTEMS

The Global Positioning System (GPS) is a space satellite-based radio positioning system for obtaining accurate positional information for mapping or navigational purposes. GPS is made up of three distinct parts:

- **Satellites.** A constellation of 24 satellites orbiting the earth continuously emit a timing signal, provided by an on-board atomic clock, which is used to calculate the distance from each satellite to the receiver.
- **Receiver.** A GPS receiver located on the ground converts satellite signals into position, velocity, and time estimates.
- **Ground Control.** The U.S. Department of Defense (DOD) developed and currently manages the maintenance of the satellite system. The DOD uses tracking antennas to constantly monitor the precise position of the NAVSTAR satellites. These positions can be used to correct for errors in the calculated positions of the roving receivers.

The GPS was built and is maintained by the U.S. government. The satellites orbit at an altitude of approximately 12,000 miles in a 12-hour pattern that provides coverage to the entire earth. The system is capable of serving an unlimited number of users free of charge.

A GPS receiver uses information from at least 4 of the 24 satellites to precisely triangulate its position on the earth. Depending on the quality of GPS receiver being deployed, captured coordinate location accuracy can be from within 10 meters to within just centimeters of true ground location. If a receiver cannot "see" four satellites, it can calculate a less-accurate estimate based on three satellites. Virtually all GPS receivers display basic positional information including latitude, longitude, elevation and speed (if moving). Most receivers also display time, heading, the number of satellites in view, where those satellites are positioned in the sky, and signal quality. GPS receivers for data collection can collect both the location (coordinates) and the attribute data of a given geographical feature.

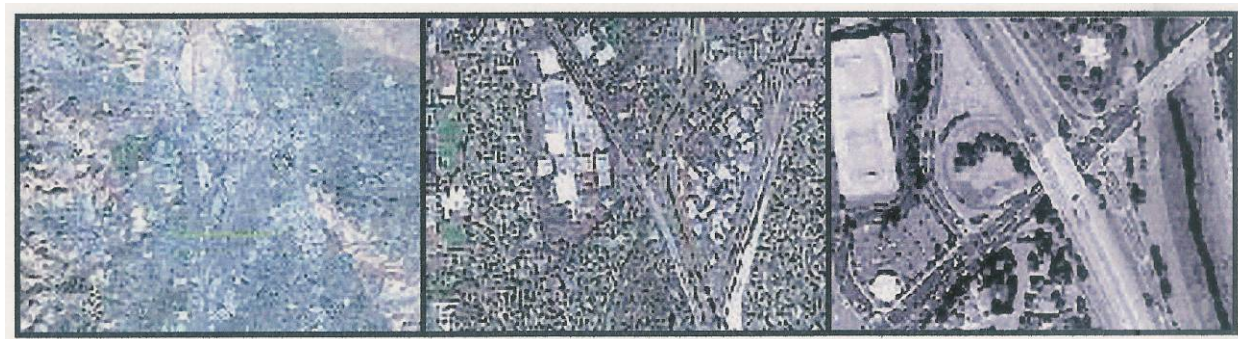
### 3-C.4.1. GPS Application to Stormwater Management

Stormwater infrastructure inventories can be conducted more easily and in far less time using GPS. In the past, traditional geodetic surveying was used to locate and map stormwater system components. A transit survey requires traversing between a known point to the point of interest, which may take half to one day per point. GPS surveying is much more efficient, possibly taking as little as a few seconds to map each point. Using bicycle or car-mounted equipment, a community may be able to survey up to 500 points per day.

GPS inventory work can be integrated with GIS application software. For example, a GIS layer of structural control locations can be created using GPS data and linked to a maintenance database. GPS data can also be used in computer modeling activities for stormwater management. For instance, GPS data can be used to create a ground surface for automated stream floodplain modeling and mapping.

### 3-C.5.0. REMOTE SENSING

Remote Sensing is a technique for collecting observations of the earth using airborne platforms (airplanes and satellites) that have on-board instruments, or sensors. These sensors record physical images based on light, temperature or other reflected electromagnetic energy. This sensor data may be recorded as either analog data, such as photos or digital image data. **Figure 3-C.5** gives an example of low- (25-meter), medium- (5-meter) and high- (1-meter) resolution satellite imagery.



**Figure 3-C.5. Low-, Medium- and High-Resolution Satellite Imagery**

Source: Space Imaging, Inc. and ARC (2001)

Ground reference data is then applied to aid in the analysis and interpretation of the sensor data, to calibrate the sensor, and to verify the information extracted from the sensor data. Remotely sensed images have a number of advantages to on-the-ground observation, including the following:

- Remote sensing can provide a regional view.
- Remote sensing can provide repetitive looks at the same area over time.
- Remote sensors "see" over a broader portion of the electromagnetic spectrum than the human eye.
- Sensors can focus on specific bandwidths in an image and can also look at a number of bandwidths simultaneously.
- Remote sensors often record signals electronically and provide geographically referenced data in digital format.
- Remote sensors operate in all seasons, at night, and in bad weather.

The airborne platforms that carry remote sensing instruments can be any kind of aircraft or satellite observing the Earth at altitudes anywhere from a few thousand feet to orbits of hundreds of miles. Satellites may employ a variety of sensors for numerous of applications. Currently, no single sensor is sensitive to all wavelengths. All sensors have fixed limits of spectral sensitivity and spatial sensitivity, the limit on how small an object on the earth's surface can be seen. The common type of sensors aboard satellites include the following:

- ***Multispectral Scanner (MSS) Sensors.*** Data are sensed in six spectral bands simultaneously: visible (green and red), UV, near-infrared (IR), mid-IR and thermal.
- ***Thematic Mapper (TM) Sensors.*** Data are sensed in seven spectral bands simultaneously: visible (blue, green, red), near-IR, and two in mid-IR. The seventh band detects only the thermal portion of the spectrum.
- ***Radio Detection and Ranging (RADAR).*** Examples are Doppler radar systems used in weather and cloud cover predictions.
- ***Light Detection and Ranging (LIDAR).*** Lasers are beamed to the ground and the return time is measured to capture detailed terrain images.

The appropriate band or combination of MSS bands should be selected for each interpretive use. For example bands 4 (green) and 5 (red) are usually best for detecting cultural features such as urban areas, roads, new subdivisions, gravel pits, and quarries. The TM bands are more finely tuned for vegetation discrimination than those of the MSS due in part to the narrower width of the green and red bands.

Examples of remote sensing satellites include the early U.S. Landsat satellites, the Indian Remote Sensing (IRS) satellites, Canada's RADARSAT, and the European Space Agency's Radar Satellite, as well as more recent higher resolution satellites from a number of private companies. Images from these satellites have spatial resolutions ranging from approximately 30 meters to sub-meter, and they may capture different parts of the electromagnetic spectrum. Therefore, the choice of satellite imagery must be made with consideration of the precision needs of the application.

### 3-C.5.1. Digital Orthophoto Quarter Quadrangles

Digital orthophoto quarter quadrangles (DOQQs) combine the image characteristics of a photograph with the geometric qualities of a map. Unlike standard aerial photography, relief displacement in orthophotos has been removed, displaying ground features in their true ground position, thus allowing for direct measurement of distance, area, angles, and positions. They also are placed in a real-world coordinate system, allowing for the collection of coordinates from them in a heads-up digitizing mode (on the computer screen) and to be overlaid with other spatial data in a GIS. **Figure 3-C.6** is a DOQQ of the Virginia State Capitol campus in Richmond.



**Figure 3-C.6. Example of a DOQQ: Virginia State Capitol Campus**  
Source: Virginia Base Mapping Program

All Virginia localities have access to recent high resolution imagery (1-foot to 6-inch pixels) through the Virginia Base Mapping Program. This imagery is now being collected in two-year cycles. More information about this image product and how to acquire it can be found at the following web site: <http://gisdata.virginia.gov/Portal/ptk?command=openchannel^channel=24> .

### **3-C.5.2. Remote Sensing Applications for Stormwater Management**

Satellite imagery offers a diverse set of mapping products for projects ranging from land use/land cover evaluation to urban and regional planning, tax assessment and collection, and growth monitoring. In the case of stormwater runoff, multispectral imagery can be used to measure impervious surfaces, such as rooftops, streets, and parking lots. Pervious surfaces, such as tree and grass-covered areas can also be measured or delineated. Applying runoff coefficients to the area of each surface type can provide the best available estimates for nonpoint source water pollution. By adding parcel boundaries, it is possible to provide estimates of runoff per parcel in order to calculate stormwater user fees. Similarly, designated land use categories can be applied to the area of each surface type and, in combination with known soil type data, can be used to calculate hydrologic curve numbers. Flood boundaries can be measured within a few meters accuracy in areas without tree cover, using sub-meter multispectral fused imagery. Individual buildings and parcel boundaries can also be identified in order to assess flood vulnerability.

### **3-C.6.0. COMPUTER MODELS**

There is a great deal of computer software that has been developed based on intensive research efforts in urban hydrology, hydraulics and stormwater quality. Computer models use the computational power of computers to automate the often tedious and time-consuming manual calculations. Most models also include extensive routines for data management, including input and output procedures, and possibly including graphics and statistical capabilities.

Computer modeling became an integral part of storm drainage planning and design in the mid-1970s. Several agencies undertook major software development projects, and these were soon supplemented by a plethora of proprietary models, many of which were simply variants of the originals. The proliferation of personal computers in the 1990s has made it possible for virtually every engineer to use state-of-the-art analytical technology for purposes ranging from analysis of individual pipes to comprehensive stormwater management plans for entire cities.

In addition to the simulation of hydrologic and hydraulic processes, computer models can have other uses. They can provide a quantitative means to test alternatives and controls before implementation of expensive measures in the field. If a model has been calibrated and verified at a minimum of one site, it may be used to simulate non-monitored conditions and to extrapolate results to similar ungauged sites. Models may be used to extend time series of flows, stages and quality parameters beyond the duration of measurements, from which statistical performance measures then may be derived. They may also be used for design optimization and real-time control.

A local staff or design engineer will typically use one or more of these pieces of software in stormwater facility design and review, according to the design objectives and available resources. However, keep in mind that proper use of computer modeling packages requires a good knowledge of the operations of the software model and any assumptions that the model makes. The engineer should have knowledge of the hydrological, hydraulic and water quality processes simulated and knowledge of the algorithms employed by the model to perform the simulations.

### 3-C.6.1. Types of Models

In urban stormwater management there are typically three types of computer models that are commonly used: *hydrologic*, *hydraulic* and *water quality* models.

- **Hydrologic Models** attempt to simulate the rainfall-runoff process to tell us “how much water, how often.” They use rainfall information or models to provide runoff characteristics including peak flow, flood hydrograph, and flow frequencies.
- **Hydraulic Models** take a known flow amount (typically the output of a hydrologic model) and provide information about flow height, location, velocity, direction and pressure.
- **Water Quality Models** simulate the various processes and interactions of stormwater pollution. Water quality models have been developed with an ability to predict loadings of various types of stormwater pollutants.

There are also a number of other specialty models to simulate any number of ancillary topics (some of which are sub-sets of the three main categories) including sediment transport, scour, lake quality, dissolved oxygen, channel stability, evapotranspiration, etc.

### 3-C.6.2. Model Applications

Stormwater computer models can also be categorized by their use or application:

- **Screening level models** are typically equations or spreadsheet models that give a first estimate of the magnitude of urban runoff quality or quantity. At times this is the only level that is necessary to provide answers. This is true either because the answer needs to be only approximate or because there is no data to justify a more refined procedure.
- **Planning level models** are used to perform “what if” analyses comparing in a general way design alternatives or control options. They are used to establish flow frequencies, floodplain boundaries, and general pollution loading values.
- **Design level models** are oriented toward the detailed simulation of a single storm event for the purposes of urban stormwater design. They provide a more complete description of flow or pollution values anywhere in the system of concern and allow for adjustment of various input and output variables in some detail. They can be more exact in the impact of control options, and tend to have a better ability to be calibrated to fit observed data.
- **Operational models** are used to produce actual control decisions during a storm event. They are often linked with SCADA systems described earlier. They are often developed from modified or strongly calibrated design models, or can be developed on a site specific basis to appropriately link with the system of concern and accurately model the important physical phenomena.

### 3-C.6.3. Basic Computer Modeling Principles

The following basic principles apply to all forms of computer modeling:

- All computer models require site-specific information to be supplied by the user. Inputs are the measured or estimated parameters the model needs to make calculations. For example, for basic hydrologic models it might include: area, slope, land use, channel forms and roughness, connectivity, and rainfall. A basic hydraulic model would include: channel slope, discharge, roughness, shape, obstructions or constrictions, and connectivity. Water quality models may add pollution loading or build-up-washoff factors, and fate and transport information. All models, for planning and design, allow the modeler to try different combinations of variables to see what happens (called a “what if” analysis).
- While modeling generally yields more information, simpler methods may provide sufficient information for design or solving management issues. In general, the simplest method that provides the desired analysis should be used. The risk of using a more complex (and presumably “better”) model is that it requires more expertise, data, support, etc. to use and understand, with a consequent higher probability of misapplication.
- If water quality problems are being considered, it still may not be necessary to simulate quality processes, since most control strategies are based on hydrologic or hydraulic considerations. Quality processes are very difficult to simulate accurately. If abatement strategies can be developed without the simulation of water quality parameters, the overall modeling program will be greatly simplified.

Models sometimes may be used to extrapolate beyond the measured data record. It is important to recognize, however, that models do not extend data, but rather generate simulated numbers that should never be assumed to be the same as data collected in the field. Careful consideration should be given when using models to provide input to receiving water quality analyses. The quality response of most receiving waters is relatively insensitive to short-term variations. In many instances, the total storm load will suffice to determine the receiving water response. Simulation of short-time increment changes in concentrations and loads is generally necessary only for analysis of control options, such as storage, or high-rate treatment, for which efficiency may depend on the transient behavior of the quality constituents.

### 3-C.6.4. Selecting the Appropriate Computer Model

Models can be simple, representing only a very few measured or estimated input parameters or can be very complex involving 20 times the number of input parameters. The “right” model is the one that: (1) the user thoroughly understands, (2) gives adequately accurate and clearly displayed answers to the key questions, (3) minimizes time and cost, and (4) uses readily available or collected information. Complex models used to answer simple questions rarely provide an advantage. However, simple models that do not model key necessary physical processes or that involve arguable data inputs are useless.

**Appendix 11-D of Chapter 11** of this Handbook provides additional information and guidance for local governments and engineers on computer models for stormwater management modeling and design.

### 3-C.7.0. REFERENCES

Atlanta Regional Commission (ARC). 2001. *Georgia Stormwater Management Manual*. Prepared by AMEC, the Center for Watershed Protection, Debo and Associates, Jordan Jones and Goulding, and the Atlanta Regional Commission. Atlanta, Georgia.

Center for Watershed Protection (CWP). 1998. *Better Site Design: A Handbook for Changing Development Rules in Your Community*. Ellicott City, MD.

City of Atlanta, 1998. *Metro Atlanta Urban Watershed Initiative Document*.

Houghton, Ryan. March-April 2010. "Tying It All Together." *Storm Water Solutions*. Scranton Gillette Communications, Inc. Arlington Heights, IL.

Marsh, W. 1983. *Landscape Planning: Environmental Applications*. John Wiley & Sons. New York, NY.

Maryland Department of the Environment. 2000. *Maryland Stormwater Design Manual, Volumes I and II*. Prepared by Center for Watershed Protection (CWP). Baltimore, MD.

Massachusetts Department of Environmental Protection and the Massachusetts Office of Coastal Zone Management. 1997. *Stormwater Management -- Volume One: Stormwater Policy Handbook and Volume Two: Stormwater Technical Handbook*. Boston, MA.

North Carolina Department of Environment and Natural Resources. 1998. *Stormwater Management Site Planning*. Raleigh, NC.

Puget Sound Action Team. May 2005. *Low Impact Development Technical Guidance Manual for Puget Sound*. Office of the Governor. Olympia, WA.

Schueler, T. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs*. Metropolitan Washington Council of Governments. Washington, DC.

Schueler T., and Holland, H. 2000. *The Practice of Watershed Protection*. Center for Watershed Protection. Ellicott City, MD.

Texas Natural Resource Conservation Commission. 2000. *Texas Nonpoint Source Book*. Available online at: [www.txnpsbook.org](http://www.txnpsbook.org)

Washington State Department of Ecology. 2000. *Stormwater Management Manual for Western Washington*. Olympia, WA.