THE TENNESSEE VALLEY AUTHORITY'S WATERSHED-BASED APPROACH TO INTEGRATED POLLUTANT SOURCE INVENTORY

John B. Holcombe III
Don Malone, Remote Sensing Team Leader
Geographic Information and Engineering
Tennessee Valley Authority
1101 Market Street
Chattanooga, Tennessee 37402

ABSTRACT

Remote sensing and GIS techniques are undoubtedly two of the most powerful tools that can be utilized to facilitate water quality improvement in watersheds. During the past twenty years, the Tennessee Valley Authority has been extensively involved in the identification and abatement of land-based nonpoint source (NPS) environmental problems in the Tennessee River watershed. From our experience, land use and land activity GIS databases, derived from 1:24,000-scale color-infrared aerial photographs, are a cost-effective tool that watershed planners can utilize for developing and implementing NPS pollution corrective actions. The databases aid in:

- documenting the source, location, and magnitude of all nonpoint pollution problems in the watershed,
- providing the impetus for getting agencies, industries, interest groups, and landowners together to work toward a common goal, and
- cost effectively implementing abatement measures through targeting priority watersheds, pollutants, and sites.

The comprehensive data—details such as eroding road and stream banks, livestock sites, illegal dumps, and suspect septic systems—extracted from the stereo photographs provides the first step in determining the cause of a pollution problem in the watershed. Data analysis transforms a dispersed, area-wide concern into a defined, site-specific problem by identifying sub-watersheds that are the greatest contributors to the pollution problem, then determining in each priority sub-watershed the specific sites that contribute the greatest pollutant loads. This basic form of geographical targeting is the most efficient and cost-effective approach to watershed improvement. The generated information provides a foundation for fostering environmental awareness, targeting priority impacted watersheds, and identifying abatement measures.

INTRODUCTION

The Tennessee Valley Authority (TVA) is a U.S. Federal corporation created in 1933 to manage the Tennessee River system, the fifth largest river system in the continental United States for power production, flood control, navigation, recreation, and economic development. TVA is the nation's largest public power producer operating hydro power plants as well as nuclear and fossil fuel plants throughout the Tennessee River basin. The agency owns 420,000 acres (170,000 hectares) along the Tennessee River and manages its holdings for the benefit of the citizens of the region.

Since its inception in 1933, TVA has been tasked with the stewardship of environmental resources. First and foremost of these is the quality of water in the Tennessee River and its tributaries. One important aspect of this stewardship program is the identification and inventory of pollution sources within watersheds. For the past twenty years, TVA has been involved in a watershed approach to maintaining and improving the water quality of the Tennessee River basin. During the 1980s, TVA developed an Integrated Pollution Source Identification (IPSI) inventory approach to the identification and quantification of nonpoint pollution sources (NPS) in watersheds. To date, TVA has completed over 100 IPSI projects for TVA, states, the Environmental Protection Agency (EPA), the U.S. Army Corps of Engineers, other Federal agencies, local governments, and private groups. The IPSI inventory is very detailed, which allows for a more accurate means of watershed and site specific prioritization of pollution sources. Agencies provided with this information have an effective tool to help maintain environmental resources. This paper outlines TVA's IPSI process to construct a Geographic Information System (GIS) and associated analysis capabilities that allow the user to efficiently and effectively manage and restore the water quality of a watershed.

DEVELOPMENT OF NONPOINT SOURCE INVENTORY

The process generates a unique database for the study area and provides a means to screen areas by land activities and conditions that can affect stream quality. In the absence of stream water quality data, the inventory data can be used as surrogate indicators for potential stream impacts associated with Nonpoint Pollution Sources (NPS) activities. By coupling the remotely sensed data with a GIS, the data can be analyzed for selected areas and incorporated into decision-making and problem-solving processes.

IPSI projects use a watershed-based approach to determine the source and needed remedial action to reduce pollutant loads to streams. The components of the process include selection of the watershed, completion of a nonpoint source (NPS) inventory, and analysis of the inventory data to target and prioritize the nonpoint sources within those watersheds.

Selection and Delineation of the Project Watershed

The first step in an IPSI project is to meet with the body requesting an NPS inventory. The scope of the project is outlined, and the project watershed is defined. In most instances, these requesters have identified pollutant problems in their watershed and intend to use the IPSI inventory to support grant proposals or other funding sources to obtain funds to implement remediation steps in the watershed. When funding is obtained, the inventory is used to target the most effective on-ground Best Management Practice (BMP) to meet the needed water quality improvements.

Acquisition of Photography

After delineation of the watershed and identification of the hydrologic unit boundaries for subwatersheds, the next step in the development of an NPS inventory is the acquisition of aerial photography. Color infrared (CIR) aerial photography at a scale of 1:24,000 is acquired of the project area. Key to the photointerpretation process is imagery acquisition prior to spring leaf-out for maximum visibility of small or subtle landscape features without excessive interference from vegetation. Photographs are processed and delivered as CIR transparencies. CIR photography is used for several reasons:

- Near-infrared wavelengths are totally absorbed by clear water, resulting in clear bodies of water appearing black in photographs.
- Healthy vegetation has a high infrared reflectance. Healthy and vigorous vegetation appears as red, while stressed or dormant vegetation appears in shades ranging from pink to blue to green to gray.
- Near-infrared light penetrates atmospheric haze due the sensitivity of the emulsion layers.

The exposed film is checked to verify that it conforms to the Draft Standards for Aerial Photography published by The American Society for Photogrammetry and Remote Sensing. The film is scanned at a project-specific resolution (usually 800 dpi) to create a digital image for use in the GIS database. The images are orthorectified using the United States Geological Survey (USGS) 7.5 Minute Topographic map series and USGS Digital Ortho Quarter Quads (DOQQ) as the X,Y control and USGS 30-meter or 10-meter Digital Elevation Models (DEM) as the elevation control.

Field Verification and Photography Signature

A significant component of an NPS inventory is knowledge of the natural and cultural characteristics of the study area. This knowledge can then be correlated to the "signatures" on the imagery used to identify NPS features. The remote sensing scientist’s primary role is to use a limited amount of field work to verify what to interpret and determine what inferences can reliably be made from the imagery. A site visit accomplishes two things. First, the scientist observes the relationships, terrain, and land uses in the study area. Second, the interpreter correlates the photography signature to the ground features. This correlation enables the interpreter to produce “photo keys" that can be extrapolated to the study area.

Photographic Interpretation and GIS Database Construction for NPS Inventory

After field reconnaissance to develop photointerpretation keys, the aerial photographs are interpreted for:

- Hydrologic unit and subwatershed mapping
- Stream order
- Detailed land use and land cover
- Livestock, dairy, and poultry operations
- Drainage conditions
- Road conditions
- On-site septic conditions

- Riparian zone conditions
- Impervious surface percentages
- Dump sites
- Drainage points
- Geologic features

The photointerpretation is done in stereo using mirror stereoscopes with 3x and 8x magnification. The level of detail extracted in the photointerpretation process enables TVA's IPSI process to be highly successful. When the database is completed, the information provided includes such features as locations where cattle are entering streams, homes and commercial buildings with potentially stressed on-site septic systems, livestock operations without proper waste management, and the riparian buffer condition of streams. This precise spatial data provides key targets for abatement measures and planning of BMPs.

Hydrologic Unit and Subwatershed Mapping. Hydrologic Unit or Subwatershed is a hydrologically correct area within the project area. The unit defines a topographically correct area contributing to the surface runoff at a defined point on a stream. The point on the stream may be a tributary intersection, sampling site, stream gage, or accessible point for future sampling.

Stream Network and Order. The stream network is based on the blueline streams from USGS/TVA 7 _-Minute Topographic Maps. The streams are entered into the GIS either by loading existing digital data or by digitizing the stream network from the maps. This base level of streams is then enhanced, based on the photointerpretation. Streams are added or alignment modified, as appropriate, to accommodate loading of the photo-interpreted information. The order of streams is based on the blueline stream network on the map base. Stream order is a number representing the streams relationship to the overall stream network of a watershed. Headwater tributaries are first-order streams. The convergence of two first-order streams creates a second-order stream. A third-order stream results when two second-order streams converge; this numbering continues until all the streams of a watershed are ordered.

Land Use and Land Cover. The study area is divided into unique polygons, based on land use and land cover (LU/LC) as interpreted from the aerial photograph. Each polygon is assigned an LU/LC code. Such mapping provides a baseline characterization of the watershed and allows relationships between land use and water quality impairment to be evaluated. The classification scheme used is a hierarchical system based in part on the classification developed by the USGS for use with remotely sensed data (Anderson, et al.). The classification system is tailored to the study area while maintaining the ability to aggregate the land cover to Anderson Level 1 or 2 classes. For example, the LU/LC classification scheme can be modified to further identify lands that contribute sediment to streams. Such land use/land covers include crop fields with different residue cover and conservation tillage practices. A sample land use classification scheme is shown in Table 1.

Livestock Operations. Livestock and poultry operations are mapped by interpretation of facilities and their relationships or associations with the landscape. Examples of the relationships are: soil compaction, soil staining, soil moisture content, size and presence of barns and other structures, presence of hay bales, animal trails, water sources, fencing, and feedlots. These relationships and associated land cover are used to determine the relative size and type of livestock operation. Other potential impacts identified include proximity to streams, whether a site has critical impact factors such as a large concentration of animals, poor or no waste management, presence of waste management ponds or lagoons, and whether the animals are confined. The type of operation is identified by looking at clues such as exercise rings for horse operations, silos, and loafing areas at dairies, large open pastures for cattle operations, and large buildings for confined poultry operations.

Drainage Conditions. Drainage conditions associated with the various land uses and livestock operations are mapped. The drainage conditions mapped are listed in Table 2.

Road Conditions. Base information for road coverage is the road network on the USGS 7.5-Minute Topographic maps. The road network is updated to the date of the project photography. Road conditions interpreted for the NPS inventory are the surface type and the significant erosion features associated with the road. Road surface is either paved (impervious) or unpaved. Unpaved roads are all classes of unpaved surface from well-maintained gravel to off-road vehicle trails. The significant erosion features associated with the road include eroding cuts and fills and eroding ditches along the road.

Table 1. Example Land Use/Land Cover Classification System

1.	Developed (Urban or built-up)
11.	Residential
110.	Single family, high density (more than 6 per acre)
111.	Single family, medium density (2 to 5 per acre)
112.	Single family, low density (few than 2 per acre)
1121.	Subdivision under construction (roads and some house construction)
114.	Multi-family or duplex
115.	Apartment or condominium complex
117.	Mobile home park
118.	Farmstead with accompanying structure
12.	Commercial, service, institutional
1121.	Athletic field
1124.	Commercial, service, or institutional under construction
1234.	Waste disposal area
1235.	Water treatment
1236.	Sewage treatment
1237.	Water tank
1238.	Dumpsites
1253.	Religious
1255.	Cemetery
13.	Industrial
14.	Transportation, communication, utility
142.	Major highway right-of-way
145.	Electric transmission right-of-way
146.	Electric power generating station
2.	Agriculture
21.	Cropland and pasture
210.	Cropland
2101.	Row crop: residue (0 to 10%)
2102.	Row crop: with residue (> 30%)
2103.	Strip cropped: alternating strips of cultivated and n-cultivated
2104.	Row crop: medium residue (10 to 30%)
211.	Pasture
212.	Good pasture: well maintained
213.	Fair pasture: uneven growth and condition, minimal maintenance
214.	Woodland pasture: 10% or greater crown cover
215.	Heavily overgrazed pasture
217.	Feedlot or loafing areas
22.	Orchards, vineyards, or nurseries
23.	Confined feeding operations
231.	Poultry operation
3.	Range land
32.	Shrub and brush: old field with volunteer woody growth
4.	Forest land
45.	Clear cut
47.	Plantation
5.	Water
7.	Barren land
75.	Strip mines, quarries, and borrow areas
751.	Abandoned strip mine (orphan): area with artificial reclamation
752.	Reclaimed strip mine
753.	Flooded strip mine
754.	Active quarry
755.	Abandoned quarry (Wetland Classification)
756.	Flooded quarry
757.	Active borrow area
758.	Abandoned borrow area
759.	Flooded borrow area

Table 1. Example Land Use/Land Cover Classification System (continued)

PFO	Palustrine (trees and persistent emergents)
PFO/SS	Palustrine (trees, scrub-shrubs, and persistent emergents)
PSS	Palustrine (scrub-shrub)

Table 2. Drainage Conditions Mapped in IPSI Project

Feature	Description
Perennial Stream	Water is present throughout most years. Stream usually has a base flow.
Intermittent Stream	Water is not present at all times. Stream does not have a base flow throughout most years. The stream has a well-defined channel.
Ephemeral Stream	Drainage ways which flow during an individual storm event. There is not a well-defined channel.
Channelized Stream	Perennial or intermittent stream channel altered by straightening or dredging.
Eroded Stream Bank	Stream segments that are eroding with visible collapsed banks.
Grassed Waterway	Stream channel that has been planted in vegetation as an erosion control.
Animal Access	Stream segments where livestock have direct constant access. Animals are not restricted from the stream by natural or artificial constraints, and there is evidence that animals are entering the stream. Such segments may be small sites where the animals drink or longer segments such as streams through confined feedlots.
Probable Animal Access	Stream segments through areas where there is direct evidence of presence of animals and no physical barrier to the stream. Barriers could be fences or high banks. Livestock have access to the entire segment of the stream.
Potential Animal Access	Stream segment through areas that exhibit no direct evidence of current animal activity. An example is a hay field that may be used in pasture rotation. The stream has no physical barrier to livestock.

On-Site Septic Systems. Stressed on-site septic systems can contribute contaminants to the surface water through overland flow, particularly when saturated soil conditions exist. The NPS inventory identifies signatures on the aerial photography which may be associated with on-site systems and may indicate the conditions of a stressed or potentially stressed system. Table 3 details the four conditions identified.

Table 3. Description of On-Site Septic Systems

Condition	Description
Distinctive Moisture Pattern	Effluent plume from visible fieldline pattern.
Suspicious Moisture Pattern	Visible plume pattern but no fieldlines visible; condition may be straight pipe from septic system, gray water disposal, system breakout with no fieldlines showing, roof drainage, or natural seepage/spring.
Distinctive Drainfield Area	Fieldline pattern but no plume visible; may indicate slow leaching of a seasonally or hydraulically stressed system or evapotranspiration characteristic of a functioning system or newly installed system.
Suspect Location	No plume or fieldlines; homesites on very steep slopes, small lots, visible rock outcrops, in close proximity to streams or reservoirs, and/or heavily wooded lots.

Riparian Buffer Condition and Features. The riparian condition in the NPS inventory is a characterization of the land cover buffer adjacent to a stream. As the area of interaction between the land and streams, riparian zones can control both erosion and runoff. The width of the riparian zone, as well as the types and amounts of vegetation, can influence the quantity of pollutants entering a stream. While woody vegetation, such as trees and shrubs, contribute to the control of runoff, the root systems of grasses help to hold the soil in place and prevent erosion. The surface organic layer that has developed from the vegetation litter allows water to infiltrate the soil. As a general rule, the flow of water and the erosion rate increase with the steepness of the slope of the stream bank. Thus, steeper slopes require wider riparian buffers. Riparian zone conditions are interpreted for each stream bank.

The riparian conditions are mapped in two landscape categories. The first is an open landscape referring to areas lacking appreciable woody vegetation; the stream is adjacent to grass, bare ground, or urban land cover. The second is a closed landscape referring to being dominated by woody vegetation. The following riparian buffer features are mapped for the perennial streams: vegetative type, the percent of coverage of the vegetative type, the quality of the vegetative cover, and width of the vegetation. Vegetative type is identified as either woody, grass, or bare. Percent of coverage is identified as 0 to 33 percent, 34 to 66 percent, or 67 to 100 percent for woody vegetation, and grass cover quality is rated as poor, moderate, or good. The width of vegetation is identified as 0 to 15 feet, 16 to 30, 31 to 50 feet, 51 to 100 feet, or greater than 100 feet.

Impervious Cover. The natural surface runoff characteristics of a watershed can be altered by impervious surfaces. Impervious surfaces include roads, parking lots, sidewalks, rooftops, and other impermeable surfaces of the urban landscape. Imperviousness is defined as the percent of the total area of the mapped unit that is covered by impervious surface. A percent imperviousness, excluding paved roads, is assigned to each land use/land cover polygon based on interpretation of the photography. For example, a low-density residential area might have an imperviousness of 5 percent, based on the estimated coverage of structures, driveways, and sidewalks. The percent of area covered by paved roads is calculated from the roads' coverage layer in the database. The percent imperviousness for each watershed is calculated by summing the percent imperviousness area of each polygon and the roads within the watershed.

Dump Sites. Small undocumented dumping locations can have an adverse effect on the environment and serve as nonpoint sources. Dump sites, usually along roads and often adjacent to streams, are identified from the aerial imagery.

Drainage Points. Points where water emerges or submerges are an important concern to the hydrology of a watershed. Drainage points identified in the NPS inventory include:

- Sinking Points: Points where surface water enters the groundwater system.
- Springs: Points where water surfaces from groundwater.
- Catch Basins: Manmade feature designed to catch and hold or redirect flow of surface water.
- Emerging Points: Points where previously subsurface flow emerges and continues on the surface.

Geologic Features. The term geologic features are better described as geomorphology. The NPS inventory identifies subsidence features. Subsidence features may be a well-defined sinkhole or subtle feature only a few feet or inches in depth. Sinkholes provide additional routes for excess nutrients and other pollutant to enter the groundwater. These subtle features are photo-identifiable due to soil moisture characteristics or vegetation changes.

Construction of IPSI GIS. The database software is Environmental Research Systems Institute's (ESRI's) ARC/INFO, utilizing custom proprietary tool palettes specifically designed for the IPSI process. Photo-interpreted features are digitized into the GIS in a logical sequence. The database components are interrelated and are populated in the database in a defined process. This process also serves as a working edit as each image is utilized to input the features outlined in the previous section. The design of the database is one such that each layer is related and must coincide with others. Typically, the roads and streams are entered into the database first. The land cover layer is then digitized and populated with the attribute information for each polygon. Information source identification is based on where the data originated, either from an existing source or from the project aerial photography. Critically eroding roadbanks identified are confirmed prior to database entry. Dumps are also entered during this stage. Stream attributes are entered followed by livestock sites and attributes. Once this is accomplished, the riparian conditions are input into the database. Septic points are added based on the interpreted data, along with drainage points and sinkhole polygons.

After each subsequent layer has been created in the database, a standard quality control process follows. This ensures that each layer possesses logical relationships to other layers. Standard methods for quality control consist of generating frequency tables and analyzing them for erroneous entries. A particular example would be a riparian condition of urban in the middle of forested lands. Once identified, these errors can be selectively analyzed and corrected accordingly.

DATA ANALYSIS

Calculation of Pollutant Loadings and Soil Loss

Pollutant Loading Calculations. The pollutant loadings in the source water are calculated by a desktop computer model that uses Microsoft Excel software to estimate pollutant loadings based on the NPS inventory data. The model estimates pollutant loads to the watershed for total suspended solids, five-day biochemical oxygen demand, total nitrogen, and total phosphorous from the following sources: residential, commercial, industrial, transportation, cropland, pasture, orchards, forest clear cuts, mining, disturbed areas, livestock, and poultry.

Soil-Loss Estimates. Soil loss for selected land use classes and other high-impact erosion features are calculated. The amount of soil loss estimated is the total potential soil movement for the feature. For example, the soil loss for a particular agricultural field is an estimate of the amount of soil movement, in tons per acre per year (T/A/Y), on the field based on the Revised Universal Soil Loss (RUSLE) Equation. The soil loss from unpaved roads and other erosion features—roadside ditches, cuts and fills, and eroding stream banks—are calculated by establishing an average erosion rate for the feature. All soil loss factors used in the equations are acquired from the Natural Resources Conservation Service (NRCS).

Watershed Prioritization

The data are used to prioritize subwatersheds based on severity of pollutant loads. Understanding the pollution problem (using information from the watershed representatives and from the pollutant loading model) is the first step in watershed prioritization. Next, using the land use drivers for the pollution will isolate priority subwatersheds. At this stage, priority sites can be identified. Working in conjunction with the customer, BMPs tailored specifically to identified problems can be developed. This detailed NPS inventory can help city, state, and county governments, non-profit groups, as well as the EPA develop cost-effective targeting of improvement efforts. This in turn can lead to the development of manageable watershed programs.

Other Related Uses

The IPSI database can also offer Total Maximum Daily Load (TMDL) support. By utilizing the land use database, a TMDL "Watershed Characterization" can be developed. The database can also aid in locating where to go to meet TMDL requirements. Source water protection analysis is another benefit of the IPSI database. Both surface and groundwater sources can be analyzed. Knowing land use and activities within buffer zones combined with the identification of potential spill sites are beneficial. When combined with time of travel studies, the data can help planners with regulation information as well as cost analysis. Overall, this leads to the development of long-term surface water protection strategies and programs. This analysis ability is vital to agencies such as state governments, water suppliers, and the EPA.

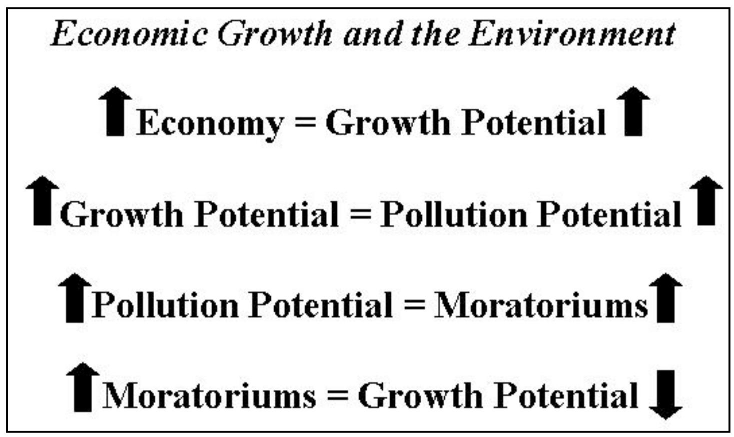

Fig. 1. Economic Growth and Environmental Impacts

The IPSI database can also be used to test changes in economic growth and the environment. As illustrated by Figure 1, a rising economy leads to an increase in growth potential. This also leads to increased pollution potential, which could lead to moratoriums; the final result being a decrease in growth potential. By understanding and analyzing future trends and growth plans, water quality impacts can be assessed.

This can help the study of protection costs and program/regulation implementation. The ability to do this enables planners to determine the best growth alternatives as well as cost-effective protection strategies. State,
city, and county governments as well as utilities and power service providers can all benefit from this information.

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