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DETECTING CHANGES IN WETLAND MORPHOLOGY USING A GEOGRAPHIC INFORMATION SYSTEM: HISTORICAL DATABASE APPLICATION AT THE SAVANNAH RIVER SITE

Lynne M. Christel-Rose
The U.S. Department of Energy Remote Sensing Laboratory
operated by EG&G Energy Measurements, Inc.
Multispectral Remote Sensing Department
Las Vegas, Nevada 89191

Halkard E. Mackey, Jr., Ph.D.
Westinghouse Savannah River Company
Environmental Sciences Section
Aiken, South Carolina 29808

ABSTRACT

New policies regarding the "no net loss" of wetlands has presented resource managers and GIS analysts with a challenging ecological application. Historical aerial photography provides a temporal record of conditions over time. Access to temporal data sources is beneficial when appraising wetland gain and loss because man-made disturbances can have both short and long term effects on wetland communities. This is particularly true when trying to assess the existing communities for the specific purpose of restoration and reclamation of the ecologic structure and function of the community prior to a disturbance. Remediation efforts can be optimized when definitive documentation exists of the original communities. The Geographic Information System (GIS) is a powerful tool for integrating these data sets and performing spatial and temporal analyses in support of ecological applications.

The Savannah River Site (SRS) is owned by the U.S. Department of Energy and operated by Westinghouse Savannah River Company. The land was privately owned prior to the start-up of SRS nuclear facilities in 1952. Temporal analysis of multispectral scanner data has shown where wetlands were impacted by reactor operation, such as thermal discharge into creeks and swamps, and where wetlands have been completely removed due to the construction of facilities. The GIS database was used to determine how the distribution and composition of wetland classes have changed over time.

Black and white aerial photography of the site was acquired prior to any operations at the SRS. Recent 1989 color infrared aerial photography also exists and was used to develop a more current landcover database. Six wetland classes were photointerpreted from the early photographs and included in the GIS. The same six wetland classes were derived from the 1989 landcover data. The historical data layer was then used in spatial analyses to aid in deriving potential viable and cost-effective management technique alternatives for remediation of wetlands influenced by past reactor operations. This layer has also provided accurate acreage estimates of lost wetlands. These acreage values have been used by management to estimate the potential costs of wetland remediation at the SRS. This application of temporal analysis using a GIS demonstrates not only the utility of documenting prior conditions before remediation actually commences, but also how to maximize the cost-effectiveness of remediation efforts.

INTRODUCTION

The Savannah River Site (SRS) is owned by the United States Department of Energy. It was operated under the auspices of E.I. du Pont de Nemours and Company until 1989 when operations were taken over by Westinghouse Savannah River Company. SRS is comprised of approximately 80,500 hectares which was privately owned prior to the start-up of SRS nuclear facilities in 1952. Roughly 25% of the landcover is wetland community. Recent federal policies regarding the "no net loss" of wetlands have presented resource managers at the SRS with the challenging ecological applications of remediation and restoration.

When assessing wetland gain and loss, access to temporal data sources is beneficial because man-made disturbances can have both short and long term affects on diverse wetland communities. This is particularly true when trying to assess existing communities for the specific purpose of restoration and reclamation of the ecologic structure and function of the community prior to a disturbance. Several dates of black and white aerial photography were acquired by the Department of Agriculture and U.S. Army Corps of Engineers prior to any operations at SRS. These photographs provided the sitewide baseline information to which recent information can be compared.

Wetland data were interpreted from several dates of aerial photography using stereoscopic photo interpretation techniques. Multiple dates were necessary to get complete sitewide coverage. Figure 1 illustrates the specific dates of the photography used for each location at SRS. The classification scheme is comprised of six forested and nonforested wetland classes based upon a scheme developed by the U.S. Fish and Wildlife Service (Cowardin et al., 1979). Refer to Appendix A for the description of these classes.

The information was entered into a digital geographic information system (GIS) to support timely analyses based on spatial and thematic attributes. Initially, the data were used to estimate the area each wetland class represented historically and for mapping purposes. The availability of an existing postactivity landcover data layer that was developed in the same manner as the historical data layer facilitated further analyses that included estimating net gain and loss in specific wetland classes since the establishment of the SRS.

The discussions that follow include a brief description of the site prior to and after operations of the SRS nuclear production facility, the methodology used to incorporate the data into the GIS, and a synopsis of early results derived from the initial analyses. The final section provides discussion and insight regarding possible future applications of the historical data and recommendations based upon this experience.

SAVANNAH RIVER SITE DESCRIPTION

Early black and white photographs show a predominantly agricultural landuse rich with bottomland hardwood trees commonly associated with riparian communities. Carolina Bays, wetland features unique to this geographic location, dotted the landscape. Many were ditched by landowners hoping to increase cropland acreage. Several small communities existed within what is now the SRS but the area was best described as rural.

Since the inception of SRS, the landscape has evolved to include a dense transportation network. The small communities were moved off site and five nuclear production reactors and other support structures were erected. Most recently, facilities to accommodate storage and restoration practices have been added. Much of the site remains somewhat rural and Carolina Bays are still numerous, but there is noticeable change along the stream channel floodplains and the Savannah River Swamp primarily attributed to thermal effluent of the production reactors (Tinney et al., 1986; and Gladden et al., 1985). Several large cooling ponds were developed along the Steel Creek and Lower Three Runs Creek to reduce effects of the discharge. They have had a significant impact on the appearance of the landscape and have increased the acreage of open water.

Place Figure 1 here.

Figure 1: Photography acquired by the U.S. Department of Agriculture in 1943 and the U.S. Army Corps of Engineers in 1951 are sources of the historical wetlands database.

METHODOLOGY

Techniques used to quantify production impact on the environment at the SRS include gamma detection surveys, multispectral scanner surveys, aerial photography missions, and the time intensive ground truthing procedures that accompany them. While all contribute to the effort aimed at measuring environmental changes at SRS and are potential elements for a sitewide GIS, it was determined that stereoscopic photo interpretation of the earliest available aerial photography would be the most suitable foundation for wetlands change detection analyses because it was the oldest and most thorough documentation available to illustrate pre-SRS activity. The classification scheme presented in Appendix A was previously used for the sitewide landcover classification from which the recent wetlands data layer information was extracted. Because both data layer are components of the Comprehensive Integrated Remote Sensing program, the scheme was used again in the historical wetlands interpretation to promote compatibility among the existing data layers.

Stereoscopic Photo Interpretation

Black and white aerial photographs were acquired in March, April and May of 1943 at scale 1:10000 and in January and May of 1951 at scale 1:20000. While studies have shown that acquisition of both Spring and Fall color infrared photography yields optimum results for delineating specific wetland species (Shima et al., 1976; Best et al., 1981; and Howland, 1987), success in mapping wetland communities using black and white film has been documented (Steffensen et al., 1976).

Approximately 110 aerial photographs were analyzed with a Bausch and Lomb stereoscope mounted on a Richards light table using standard photo interpretation techniques (Avery, 1968; Paine, 1981). Wetland information was manually traced onto removable transparent mylar. Interpretation was limited to the center of the photographs to minimize the effect of distortion that increases towards the edge of a photograph. The relief of the terrain aided in identifying lowland areas or upland depressions where wetlands are most likely to occur. Tonal and textural differences helped differentiate stands of Bottomland Hardwoods from Swamp Forest.

Geographic Information System Processing

After the photo interpretation task was completed, a hydrographic map at scale 1:20000 was generated from the current landuse data layer. The mylars were removed and placed under the hydrographic map and the wetland class information in the form of polygons were manually transferred onto the map sheet. The 1943 data were reduced to scale 1:20000 to facilitate data transfer. Each polygon was digitized and labeled with its wetlands class code using ARC/INFO VAX version 5.1 software interfaced with a CalComp Series 9100 digitizing tablet. RMS errors did not exceed 2 meters. The data layer was systematically reviewed, edited and replotted, and checked once again against the photographs. Polygons from each class were randomly selected and compared to the classification scheme to assure consistent class labeling.

Several versions of color-coded and black and white maps were generated. Sitewide and 7.5 minute quadrangle area statistics were calculated to compare with those derived from the recent wetlands data layer. The Pen Branch Delta was also mapped to illustrate the changes that have occurred in the Bottomland Hardwood class representation. Examples of several map products are presented in the following section.

TABLE I

Wetland Class	Pre-Activity	Post-Activity	Change
Bottomland Hardwood	15077 (287)	13825 (869)	-1252
Bottomland Scrub-shrub	1548 (186)	843 (359)	-705
Swamp Forest	2341 (41)	2331 (83)	-10
Emergent Wetland	408 (216)	519 (102)	+111
Aquatic Bed	320 (134)	85 (43)	-235
Open Water	438 (37)	2215 (139)	+1777

TABLE II

Wetland Class	1951 Area		1989 Area	
	Min.	Max.	Min.	Max.
Bottomland Hardwood	**.036**	**4374.956**	.002	1054.745
Bottomland Scrub-shrub	**.274**	**187.906**	.138	69.143
Swamp Forest	**.158**	**1905.260**	.006	1687.035
Emergent Wetland	.066	15.657	**.139**	**110.021**
Aquatic Bed	.150	20.824	**.212**	9.330
Open Water	**.127**	348.504	.119	**878.475**

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RESULTS

Although unrectified photographs were used as the base data, the photo interpretation process resulted in a historical wetlands data layer that can be used with existing data layers. When looking at specific elements in the landscape, good agreement exists between the historical wetlands landcover classification and the current wetlands landcover classification. There is also good agreement between the historical wetlands classes and the hydric soils class in the existing soils data layer.

Table I shows the overall net gain or loss of six wetland classes since the inception of SRS. Estimates indicate that approximately 314 hectares of wetlands have been lost. The largest losses appear to be in the Bottomland Hardwood and Bottomland Scrub-Shrub classes. Combined, the losses are of the same magnitude as the gain in Open Water. Comparison of Figures 1 and 2 indicates that this relationship has been verified through the photointerpretation process. Loss of the Aquatic Bed community may be attributable to a shift in classification to Emergent Wetland class which have increased with site activity. This may be due to the reestablishment of some of the Carolina Bays after they were drained. The Swamp Forest community area estimates are within 10 hectares and exhibit the least amount of change with site activity.

TABLE I. Area estimates in hectares and frequency of occurrence (in parenthesis) for six pre- and post-SRS wetland classes.
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If one considers the frequency of occurrence for each class when looking at the total area for each class, the numbers suggest that the landscape has become fragmented since 1951. For example, Swamp Forest has remained at roughly 2300 hectares. In 1951, this acreage was comprised of 41 separate stands. In 1989, the area representing Swamp Forest was comprised of 83 separate stands. Bottomland Hardwood and Bottomland Scrub-Shrub communities have lost acreage since 1951 but the number of separate stands have increased substantially. As Table II shows, minimum and maximum area values for these three classes were notably larger in 1951 when compared to recent values, indicating again that the stands were expansive and that there were fewer of them prior to site activity. Causes of this perceived fragmentation could include natural invasion of a species, man-made disturbances, or improvement to the quality of photographic methods used in the recent aerial surveys. The more recent surveys were acquired seasonally over the last few years and included color infrared photography. However, the tonal quality of the older photography was very good and at a scale that was very easy to interpret. Given the development of the road network to support SRS activities, man-made disturbances may play some role in the apparent decrease in the average minimum and maximum areas for several of the classes as well as the increases in their frequency of occurrence. Increased fragmentation of the landscape can affect the the distribution of natural species and must be considered in reclamation and restoration planning.

TABLE II. Minimum and maximum areas of pre- and post-SRS wetlands classes in hectares.

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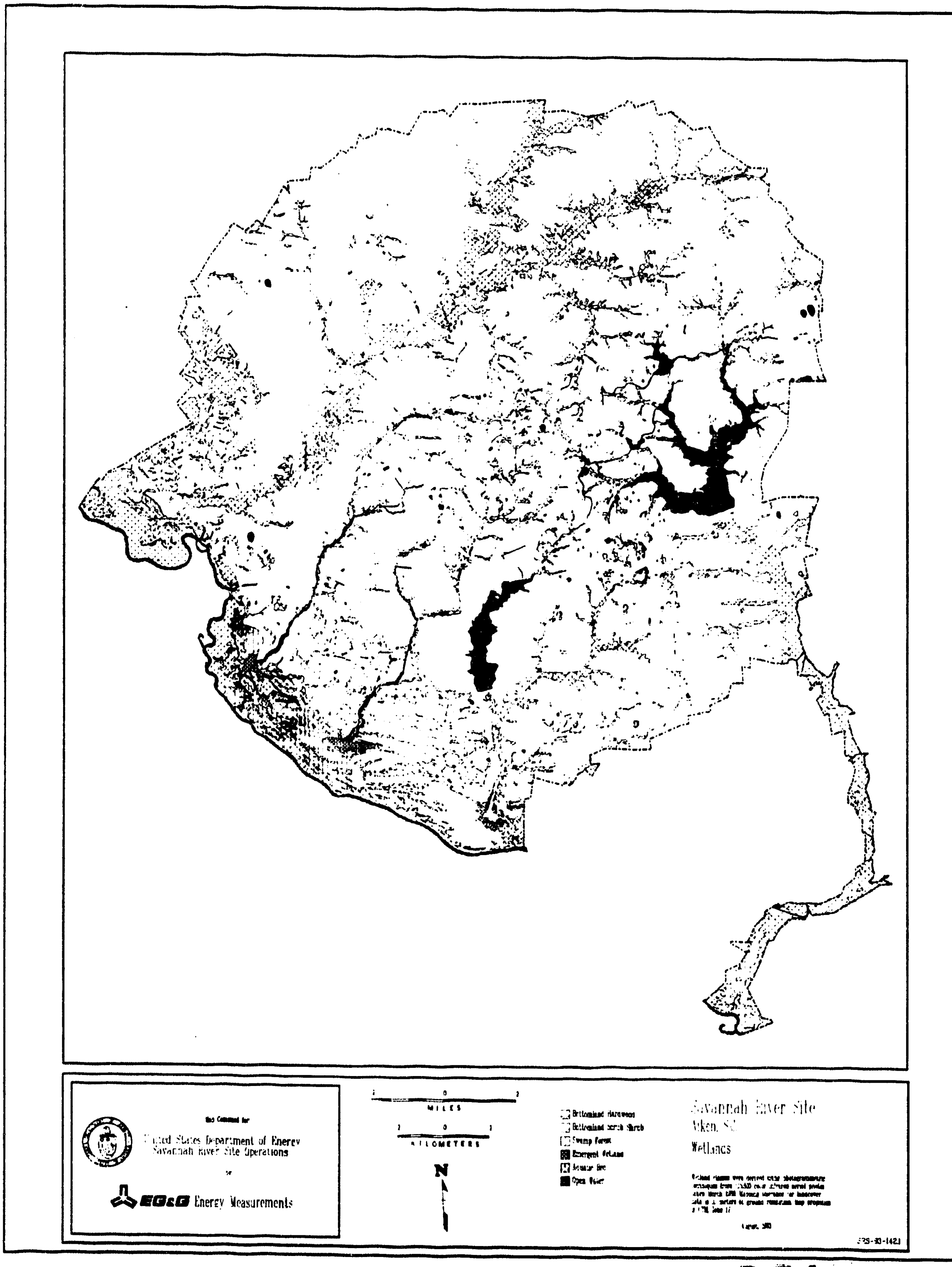
Figure 2. Historical wetland map depicting six landcover classes.


Prepared for
United States Department of Energy
Savannah River Site Operations
by
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Bottomland Hardwood
Bottomland Scrub Shrub
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Emergent Wetland
Open Water
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Figure 3. Wetland map illustrating class data derived from current landcover data.

DISCUSSION AND RECOMMENDATIONS

This analysis has demonstrated the utility of GIS technology in environmental assessment. With the addition of historical data and other ancillary data that can be tied to the database by geographic coordinates, resource analysts can extract and investigate specific regions and themes of interest in a timely manner. The GIS becomes increasingly comprehensive and useful as more information becomes available and is incorporated into the database.

In this study, the net gains or losses to specific wetland class areas were estimated using a combination of standard photo interpretation techniques and leading edge technology. Simple statistics were generated to determine how wetland class distributions may have changed since the start-up of SRS. Further analyses with recent data in the GIS will include wetland class net gain and loss as it relates to the 7.5 minute United States Geological Survey quadrangles that comprise SRS. Changes in the Carolina Bay community will also be addressed. Finally, where the changes occurred over time for each class will also be determined. The results from these investigations can then be used to aid resource managers in defining their questions regarding restoration needs and procedures.

An important factor in database development is an understanding of the overall quality of the data sources. Sources take on many forms and they are not always of the integrity a manager would like but are unique pieces of information that could add considerably to the usefulness of GIS analyses. While incorporation into the database may not seem ideal, adequately maintained quality assurance records would permit prospective GIS users to weigh the advantages of incorporating such a data layer into their analyses against eliminating it altogether. One common example of this is the use of unrectified aerial photography. Depending on the extent of the area of study, the photorectification process can be costly and deemed as an unnecessary expenditure for a specific task. Skilled interpreters can decrease the effects of distortion by restricting interpretation to the center of the photo, as was done in this study. Comparison to other related data layers, such as soil type or transportation, can give a fair estimate as to the spatial integrity of data obtained in this manner. When accuracy becomes a critical issue, it becomes necessary to ensure that data are of the best quality available. Temporal analysis of digital orthophotographs derived from color infrared film is recommended if highly accurate wetland classifications are desired. Happily, industry has recognized the need for cost-effective methods of photorectification and the technology is becoming more affordable as time passes.

Finally, while automation of old methods is almost always expensive due to capital equipment expenditures and the investment in man hours needed to convert data, the flexibility and speed afforded by the technology outweighs the costs in most environmental applications of the magnitude required for SRS. Centralization of extensive data layers tied together by geographic location can be used for unlimited analytical and spatial investigations. Furthermore, it can be easily updated and appended, and the potential applications are restricted only by the limitations of one's imagination and budget.

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