A MULTI-TEMPORAL, MULTI-ACCURACY FISHERIES GIS DATABASE FOR THE COLORADO RIVER IN GRAND CANYON, ARIZONA.

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ABSTRACT

Fisheries information available for the Colorado River in Grand Canyon ranges from historic accounts by early canyon pioneers to detailed movement and habitat use of individual fish with radiotelemetry technology. Glen Canyon Environmental Studies is assimilating a centralized database with access to all fisheries geographic and tabular information to aid report integration and operation of Glen Canyon Dam. Large volumes of information have been and are being collected on fishery resources of the Colorado River and its tributaries in Grand Canyon that vary both in time and geographic precision. Developing a database that can accommodate the range of spatial and temporal variation inherent in existing data requires special techniques and data handling procedures. Database design is presented along with implementation considerations encountered in developing a multi-temporal, multi-accuracy-level GIS database for fishery resources in Grand Canyon.

INTRODUCTION

The Colorado River in Grand Canyon supports one of the most unique riparian and aquatic ecosystems in the world. Several threatened and endangered species inhabit these ecosystems, including two endangered fish species--humpback chub (Gila cypha) and razorback sucker (Xyrauchen texanus)--and native flannelmouth sucker (Catostomus latipinnis), bluehead sucker (Catostomus discobolus), and speckled dace (Rhinichthys osculus). The endangered Colorado squawfish (Ptychocheilus lucius) and bonytail chub (Gila elegans) have been extirpated from Grand Canyon. Complete and accurate life history information is vital to continued protection of the remaining native fishes of the Colorado River basin.

Construction of Glen Canyon Dam in 1963, and subsequent operation, have significantly affected flow of the Colorado River in Grand Canyon and the associated ecosystems. Concern by the public and governmental agencies over this effect prompted Department of Interior (DOI), in December 1982, to conduct a study of short- and long-term effects of dam operations on vegetation, wildlife, fisheries, recreation, beaches, and other environmental resources. Glen Canyon Environmental Studies (GCES) was formed by DOI to coordinate a multi-agency study to identify adverse effects of dam operations and ways to protect or enhance the environment and recreational resources.

GCES issued a Phase I Report in 1988 (Department of Interior 1988) which identified negative effects, significant enough to warrant initiation of an Environmental Impact Statement (EIS) on dam operations. The Final EIS is

due to be issued in October 1994. The primary objectives of GCES has been to coordinate and centralize data collection, analyze, review, and disseminate scientific and technical information for assessing environmental impacts of Glen Canyon Dam operations. This multi-agency effort has resulted in a large volume of varied information, and a need to efficiently and accurately store and retrieve this information. Information is being assimilated on cultural values, archaeological resources, terrestrial resources, avian communities, riparian communities, physical system elements, hydrology, recreation values, and aquatic resources, including fisheries.

This paper describes development of a multi-temporal, multi-accuracy-level database template for fisheries resources of the Colorado River in Grand Canyon. We discuss problems associated with entry into a Geographical Information System (GIS) of past and ongoing collections of fisheries information collected by numerous investigators from the Colorado River and its tributaries in Grand Canyon. Techniques are discussed for dealing with fisheries data collected with a variety of methods, lacking precise geographic reference and GIS entry format.

PURPOSE AND OBJECTIVES

The purpose for developing a GIS computerized database for fisheries in Grand Canyon is to provide an integration of geographic-based information to biologists, resource managers, and administrators to aid in operation of Glen Canyon Dam. This GIS system will link geographic information with empirical data stored in other database management systems.

Historically, data collected by individual fishery researchers in Grand Canyon have been largely unavailable to other investigators because of a lack of common data format and centralization. Fisheries investigations in this region of the Colorado River basin have been conducted for a variety of reasons to evaluate endangered species, native fishes, and a popular trout fishery. Information collected have included data on individual fish (e.g., length, weight, tag number), habitat (e.g., depth, velocity, substrate), and water chemistry. Sample collection sites have been imprecisely located, using numerous geographic references (e.g., river miles, distance from dam, meters from shore, tributary mouth, etc). In order to integrate these databases, accurate physical locations of measurements, with respect to geographic position in the landscape, become as important as the specific parameters measured.

The objectives of the GCES-GIS fisheries database development project are to:

1. Develop a consolidated, centralized fisheries database template for researchers, managers and decision makers.

2. Provide an archive of endangered fish information, including individual attributes, meristics, photographs, tag numbers, habitat, etc.

3. Provide background information for a long-term monitoring program, including past collection sites for historic distribution and abundance, past and recent population demographics, and current research needs and data gaps.

4. Document specific locations of fishery-related data collections to allow repeated site visits, which are essential to long-term monitoring.

5. Provide a visual representation of fishery resources and sample locations in the Colorado River in the Grand Canyon to facilitate impact analyses and resource assessments.

6. Facilitate exportation of data to other scientists and importation of newly collected information into a common database.

7. Provide a consolidated fisheries database for resource managers with the information necessary to assess impacts of Glen Canyon Dam operations on fisheries resources.

EXISTING DATA

Area Of Interest

Data for this fisheries GIS program development were gathered from the Colorado River and its tributaries in Grand Canyon, from Glen Canyon Dam to Pearce Ferry, a distance of nearly 300 miles (482 km) of river. The principal tributaries in this study area include the Paria River, Little Colorado River, Bright Angel Creek, Shinumo Creek, Tapeats Creek, Kanab Creek, and Havasu Creek.

Historic And Recent Fisheries Data

Since the early 1900's individuals, agencies, universities, and private researchers have collected fisheries information from the Colorado River and its tributaries in Grand Canyon. Historic collections have been catalogued by C.O. Minckley, and include McDonald and Dotson (1960), Stone and Queenan (1967), Stone and Rathban (1968), Miller and Smith (1973), Holden and Stalnaker (1975), R.R. Miller (1955, 1946), Minckley and Blinn (1976), Sutkus et al. (1976), C.O. Minckley (1978), Carothers and Minckley (1981), Kaeding and Zimmerman (1983), Maddux et al. (1987), and Kubley (1990).

More recent fishery information have been collected by Valdez et al. (1982), Valdez and Hugentobler (1993), Angradi et al. (1992), Arizona Game and Fish (1993), Arizona Game and Fish (1994), Gorman (1994), Otis (1994), Allen (1993), and Weiss (1993).

The historic databases were not computerized, except for more recent efforts by Arizona Game and Fish Department to assimilate information collected by their efforts. The more recent fishery information are being entered in computer databases soon after collection.

Existing GCES/GIS Database

The Remote Sensing and Geographic Information Section in the Bureau of Reclamation's Denver office is responsible for the technical development of a GCES/GIS database (Werth et al., 1994). The GCES/GIS database is being developed as an integrative tool for long-term monitoring, special studies (e.g., hydrology, geomorphology, cultural resources) and archiving information for 13 long-term monitoring sites and two special study sites in Grand Canyon. This database is structured with three levels of spatial accuracy. The first consists of data referenced to 1:24,000 quadrangle maps and will obtain the National Map Accuracy Standard of 40 feet in the horizontal and half a contour interval in the vertical. The second level consists of data photo-referenced and transferred to the 1:2,400 scale orthophoto grid base maps developed for the GCES projects. These map products have 2.0 m accuracy in the horizontal and 1.0 m in the vertical. The third level of accuracy is survey-referenced data with sub-centimeter accuracy. It is important to note that these accuracies are best-case scenarios, and that accuracy of data input from additional researchers is dependent on methodology and field mapping accuracy used in collection of the original data. (Werth et al., 1994).

METHODS

Developing a template for incorporating fisheries information into a GIS database is a step-wise process, according to the following:

1. Define needs and objectives of the database.
2. Identify sources and access to information.
3. Describe methods used for data collection and storage.
4. Develop a template that is both geographic and tabular for integrating the information from the different sources into one readily accessible database.
5. Define linkages of fisheries information into a GIS working environment.

Assimilation Of Fisheries Information

Three principal types of data have been identified, including historic, qualitative information; historic and recent quantitative information, and ongoing quantitative information. Historic qualitative information will be assimilated from reports, photographs, and diaries of travelers and visitors through Grand Canyon. Quantitative information will be assimilated from reports and computerized in a field-format database to facilitate retrieval and enhance archival value. Much of the recent information is already computerized and will be accessed through permission and agreements with cooperating agencies and individuals. Development of this GIS database will provide input to ongoing

investigations and modify data collection protocols, if necessary, to facilitate future data integration.

Types Of Information Available

Qualitative historic data consists primarily of general locations, approximate numbers, sampling techniques, and possible species of fish captured or observed. Quantitative historic information may contain more specific locations, numbers and species of fish, and some information on habitat, water quality, etc. The more recent and ongoing data can be categorized as (1) fish captures, (2) fish habitat, (3) radiotelemetry, (4) drift samples, and (5) water quality (Table 1).

Table 1. Categories and types of fisheries data assimilated for the Grand Canyon GIS database.

Category	Data Types	Spatial Accuracy
Fish Captures	Gill/Trammel Nets	100 meters
	Electrofishing	0.20 river miles
	Seines	0.20 river miles
	Minnow Traps/Hoop Nets	0.20 river miles
	Angling	0.20 river miles
Fish Habitat	Surficial Habitat Maps	10 meters
	Current Pattern Maps	10 meters
	Shoreline Habitat Measures	10 meters
	Bathymetric Maps	10 centimeters
Radiotelemetry	Surveillance	0.20 river mile
	Monitoring	5 meters
	Remote Stations	100 meters
Drift Samples	Shoreline Drift Sets	0.20 river miles
Water Quality	Hydrolab Datasonde	0.20 river miles
	Hydrolab Surveyor II, III	0.20 river miles
	TempMentors	0.20 river miles

Spatial Accuracy Levels For Fisheries Data

Fisheries data identified for entry into GIS are not entirely compatible with the broad three-level structure developed by the Bureau of Reclamation for the GCES/GIS database. To allow for integration, a six-level structure has been developed for the fisheries information, ranging from level one, as the most geographically accurate, to level six, as the least geographically accurate.

Level One: Surveyed Information. Level one is survey information with sub-centimeter accuracy. Survey information is collected primarily by GCES contract surveyors working with the fisheries biologists. These data include bathymetric maps developed from total survey station techniques and superhydro technology. These maps were developed for specific tributary inflows and eddy complexes in Grand Canyon. Information such as critical spawning habitat were also surveyed to allow analysis of the impact of fluctuating flow releases from Glen Canyon Dam.

Level Two: 1:2,400-Scale Mapping. Level two is primarily for information referenced to or mapped onto 1:2,400-scale orthophotos developed for the GCES projects. Individual fish that were tagged with transmitters for tracking using radiotelemetry provide the highest locational accuracy for actual fish location information. Radiotelemetry monitoring data are precise to the nearest 5 m, based on locations of radio-tagged humpback chub and subsequent monitoring of movements over periods of up to 72 hours. At specified time intervals, the location of each fish is plotted on mylar overlaying aerial photographs. Each of the locations is then transferred to the 1:2,400 orthophotos and digitized into the database. Fish identification information for each fish is then stored in the database, allowing movement and habits of individual fish to be tracked over time. Overlaying these locations with available habitat allows for quantification of habitat use by individual fish.

Gill and trammel nets and remote stations are located to the nearest 10 m on uncorrected 1:1,200 aerial photographs. Records of each individual net set and remote station are recorded on mylar overlaying the aerial photographs when in the field. Each location is transferred to 1:2,400 orthophotos and then digitized into the database. Each net set and remote station location is assigned an identification number because each location may be fished multiple times.

Level Three: 1:1,200-Scale Mapping From Uncorrected Aerial Photography. Surficial habitat maps, current pattern maps, and shoreline habitat measurements are located within 10 m, and provide assessment of habitat conditions at different flow stages. This information is recorded on mylar field maps overlaying aerial photography flown at 1:2,400 scale and enlarged and printed at 1:1,200 scale. Each photograph is ground referenced by identifying features on both the photographs and orthophotos to be used as ground control points (GCP). For each segment of river mapped, 10 or more GCPs are identified. Residual means squares (RMS) errors are calculated for each set of GCPs and each point that contributes the greatest amount to the RMS error are eliminated until the RMS can be brought below 0.01. GCPs are then transferred to each mylar field map. Each field map is then digitized into the database to be attributed with the habitat types identified by biologists.

Level Four: 1:24,000-Scale Mapping. Many of the fisheries data collection efforts are conducted throughout the entire Grand Canyon corridor. Detailed maps, such as the 1:2,400-scale orthophotos, are available for only 15 special study areas. To have a mapping base throughout Grand Canyon, the Colorado River shoreline and river centerline are to be entered from 1:24,000-scale USGS quadrangle maps. Fisheries information collected outside the special

study areas and referenced to specific ground features are recorded within this level.

Level Five: River Mile Referencing. The least spatially accurate of fishery data are to the nearest 0.20 river miles. These data generally reflect fish sample efforts, drift samples, and water quality data, and are identified in empirical databases to the nearest 0.20 river miles, as recorded from 7.5-minute topographic maps or commercially available river guides. Data referenced to river miles comprise the majority (>70%) of fisheries information for the Colorado River in Grand Canyon. River mileage is not a coordinate mapping system and was never intended to be a precise locating system. It is intended to provide a system for referencing a position along the river corridor. However, there are several different river mile referencing systems in use on the Colorado River in Grand Canyon, including Belknap's River Guide, Stevens River Guide, and the USGS mile markers. Researchers from different agencies have not been using the same river mile referencing system. Consequently, for the same reach of river there may be three or more river mileage designations. Rather than converting all researchers' data to one river mile referencing system, a method is being developed that allows each database to be referenced to location according to the river mile system used in collection. It is within this accuracy level that geographic referencing of fisheries-related data into a GIS requires specialized techniques.

A river centerline for the entire length of Grand Canyon is being developed to be used for a base map. This file will be copied for each river mile referencing system (e.g., USGS, Belknap, Stevens). The river centerline will then be split at each river mile marker according to the appropriate referencing system. Each segment of the river centerline will then be attributed with the appropriate beginning and ending river mile values for that segment.

Using the capabilities of ESRI's ARC/INFO Dynamic Segmentation software module, the location of each fisheries data collection point, recorded with any river mile referencing system, can be located along the river corridor. By specifying which river mile system is used prior to assigning coordinates to each data collection point or reach, fisheries information referenced to different river miles can be viewed and analyzed concurrently.

Level Six: Historical Information. The historical information is geographically referenced using whatever means are necessary. Because of the wide variety of accuracies for spatially referencing historic fisheries data and because much of the location identification is done on a "best guess" basis, level seven has no specific spatial requirements.

Photographic Record

An additional application of GIS technology to fisheries research which is not classified into the above six level accuracy structure is using georeferencing capabilities to rectify photographs of individual fish. A plexiglas sheet with a one-centimeter grid is used as a background for photographing each fish. Each photograph (in slide form) is then scanned to create a digital file. By using the one-centimeter background grid, each photograph is georeferenced and

rectified to remove distortion. With the photograph scaled and referenced, morphometric measurements of fish can be made. These corrected photographs are then stored as attributes for each fish record. Morphometric measurements can then be made and stored for each photograph to be used in principal components analysis.

DISCUSSION

Using GIS for fisheries information integration is a relatively new application of GIS technology. Traditional fisheries biology has not focused on relating fish locations to mapped information of large river resources. For many fisheries studies the effort required to map actual river resources is not justifiable or has not been planned for. However, the increasing importance of the endangered and native fish requires decision makers to make better use of the information collected. In addition to query and viewing of archived fisheries information, fisheries biologists can make use of the analysis capabilities offered by GIS.

Fisheries information in a GIS database provides an inventory of endangered and native fish handled by biologists and all associated information, including scanned photographs (to be used for morphometric measurements and archival purposes), tag numbers, meristics, etc. These data can be used as important historic information for developing long-term monitoring to identify past collection sites for historic distribution and abundance, past and recent population demographics, and current research needs and data gaps. Also, specific locations of fishery-related data collections are documented to allow revisiting previous collection sites.

An additional benefit of a GIS database is the visual representation of fishery resources and sample locations. This facilitates evaluation of relationships between fisheries and other resources and enhances analysis capabilities for impact analyses and resource assessments.

The greatest long-term benefit of a GIS database is the capability to share and exchange information that is complete both historically and spatially. To more fully understand the relationships between the various resources under study and Glen Canyon Dam operations, individual researchers need to be able to access and use other databases.

The GCES/GIS fisheries database will provide a structure for a consolidated, centralized fisheries database that will be accessible to managers and decision makers. With a formalized structure, data from current and future research can easily be incorporated into the database to provide an ongoing information and retrieval system. This database is unique in that it is geographically referenced, multi-temporal, multi-accuracy, and multi-media. It is currently being developed for the portion of the Colorado River in Grand Canyon and will serve as a template for the integration of the rest of Colorado River system. There is a great need for a standard fisheries database structure for the entire Colorado River basin. This database development can serve as a prototype to be expanded and improved as a valuable information source for many researchers for years to come.

ACKNOWLEDGEMENTS

This project is being funded by the Bureau of Reclamation, Salt Lake City, Utah. We thank D. Wegner, A. Haden, and M. Yard of the Glen Canyon Environmental Studies, P. Wright of the Bureau of Reclamation, Denver, Colorado Office for early drafts of the GIS database for Grand Canyon report, and M. Hugentobler for her editorial assistance.

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International Symposium on the Spatial Accuracy of Natural Resource [illegible]

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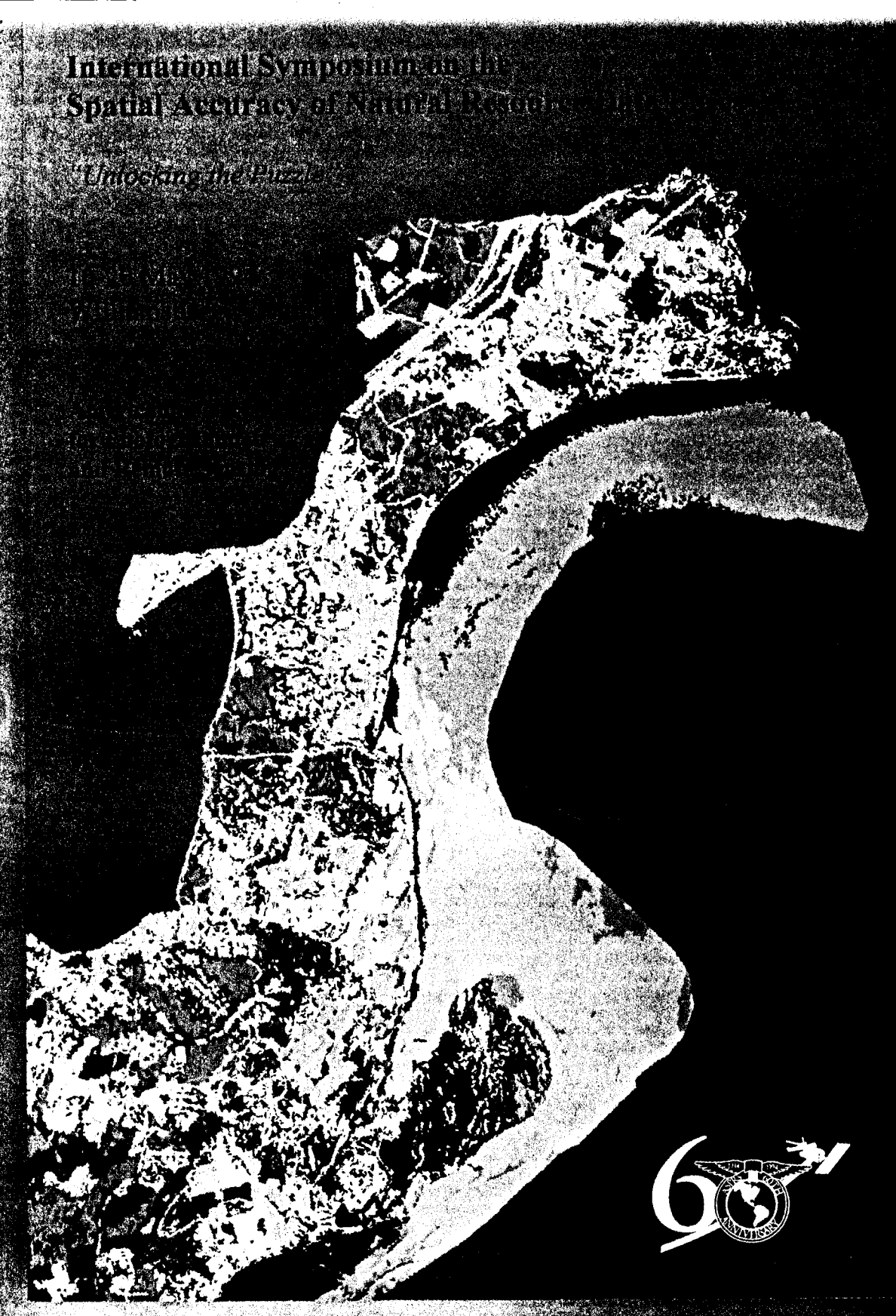

Proceedings:

International Symposium on Spatial Accuracy of Natural Resource Data Bases

Unlocking the Puzzle

16-20 May 1994
Williamsburg, Virginia

Russell G. Congalton, Editor

Sponsored by:

International Union of Forest Research Organizations
Forest Inventory and Monitoring Subject Group (S4.02)
and
American Society for Photogrammetry and Remote Sensing

Endorsed by:

Society of American Foresters, GIS Working Group

ISBN 1-57083-008-8

The cover image was produced by the College of William & Mary, Virginia Remote Sensing Center from June 1989 SPOT satellite data. The image was created for the James City County Real Estate Division, and was commissioned to help the county's zoning and GIS efforts. It is also being marketed as a 2x3 foot poster with proceeds toward a greenway in the county. Posters are available through the Historic Rivers Land Conservancy, P.O. Box 2000, Williamsburg, VA 23187 ($19.85 each or $125.00 framed, including shipping and handling). Image processing and analysis was accomplished using an Intergraph InterPro 6040 with MicroStation Imager.

Published by

American Society for Photogrammetry and Remote Sensing
5410 Grosvenor Lane • Suite 210
Bethesda, Maryland 20814

Printed in the United States of America