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A Decision Support GIS for the Clean Water Act Permit Review Analysis

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Abstract: Section 404 of the Clean Water Act is the primary federal statute of the United States that regulates the discharge of dredged or fill materials into lakes, rivers, and wetlands. The Section 404 permit review process involves comprehensive assessments of physical, biological, ecological, and socioeconomic impacts of potential human alterations on aquatic ecosystems across spatial scales. Such assessments require the integration of management decision-making with innovative data handling techniques and assessment methodology. The Section 404-permit process is often hindered by the lack of well-developed scientific information and the technical tools for efficient data analysis. The individual permit review frequently becomes an intensive, time consuming evaluation process. To address the needs of supporting technical methods for the permit review, a pilot decision-support GIS for permit review is under development. The system is able to implement geospatial information analyses that integrate landscape features and identify the relationships among the essential environmental, ecological, and socioeconomic elements. Decision models for evaluating the vulnerability of waters under potential human impacts were conceptually designed. The large volumes of geospatial data were compiled from the existing state and federal monitoring and assessment programs. Remote sensing images were used to delineate riparian land use and land cover types of the pilot assessment area. The system is under development based on the commercial ArcGIS platform of which the customized user interface facilitates the information query, data management and visualization, and decision model implementation. The permit decision support GIS can be a useful analytical tool that allows efficient and scientifically sound decision-making for the conservation of important aquatic ecosystems.

***Keywords*:** Decision support GIS; Decision models; Aquatic ecosystems; Potential human impact; Environmental permit review.

1. INTRODUCTION

Section 404 of the Clean Water Act regulates the discharge of dredged and fill material into the waters of the United States, including lakes, rivers, and wetlands [General Accounting Office of the United States, 1988]. Regulated activities under this program could include filling or excavating in a wetland for development, water resources projects such as construction of dams or bridges, stream channelization and diversion, infrastructure development and wetland conversion for farming and forestry [U.S. EPA]. Section 404 establishes a permit program to ensure that such activities comply with environmental requirements. Related governmental agencies are responsible for implementing permit reviews to regulate those activities.

The permit review assesses the potential impacts of individual or cumulative human activities on the aquatic ecosystems and determines environmental and socioeconomic interests. To reach these objectives, the permit review requires adequate scientific knowledge on major aquatic ecosystem's functions. This demands an integrated analysis to derive information from the relevant physical (e.g. hydrology and topography), chemical (e.g. water quality), biological (e.g. threatened and endangered species, and habitat) data, and socioeconomic (e.g. recreation, aesthetics, historic and cultural values, and economics) information [Paulson, 1985]. Therefore, it is critical in the Section 404-permit review to be able to effectively and efficiently visualize and analyze the large volumes of data and

information in varied spatial contexts and temporal scales.

The Section 404-permit process is often hindered by the lack of scientifically sound evaluation criteria and the technical tools for analyzing the data and information effectively and efficiently. As a result, the Section 404-permit review frequently becomes an intensive time consuming evaluation process and the permit review results may even be controversial. Therefore, innovative approaches and technical tools are critically needed to facilitate this process. In the past decade, geographic information systems (GIS) have been increasingly customized to develop decision-making tools in environmental and natural resource assessment and management, resulting in the development of decision support GIS (e.g. [Ji and Jeske, 2000], [Ji and Mitchell, 1995], [Ji and Johnston, 1995]). There have been GIS-based methods for environmental permitting applications (e.g. [Ji and Johnston, 1994], [The South Florida Water Management District], [The U.S. Bureau of Land Management]). These approaches provide innovative technical tools for synthesizing, visualizing, and analyzing the spatial data and information in assessing the potential impacts of human activities.

To address needs in new decision support methods for environmental assessment, we are developing a decision support GIS for assessing the potential impact in relation to the activities regulated by Section 404. This research effort mainly includes the synthesis of various geospatial data, the development of decision models used for the permit analysis, and the customization of the GIS for specific analytical functions. This paper mainly describes the conceptual design of the system functions. It also introduces the preliminary developments and the potential applications of the system.

2. THE PILOT ASSESSMENT AREA

A pilot area was selected for the system development and related assessment efforts. The area is located in the Lower Missouri-Crooked watershed basin, which extends over ten counties throughout the states of Missouri and Kansas, U.S.A. The focus area covers the portion of the watershed that falls within Jackson County of Missouri (Figure 1). The basin topography consists of rolling to hilly plains. Land cover is mostly rural and dominated by cropland and grassland in addition to scattered forestland. Several perennial and intermittent rivers and streams, private and public lakes, and farm ponds fall within the boundaries of the watershed. The area is prone to

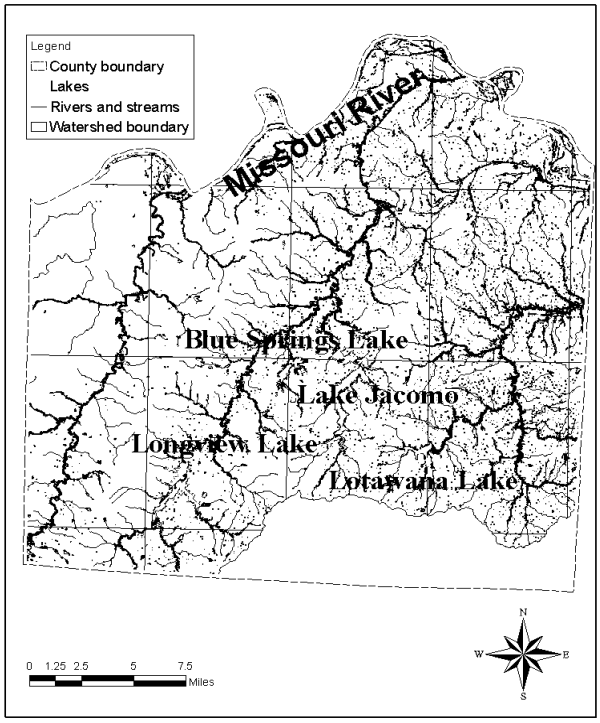

Figure 1. The Pilot Assessment Area in Jackson County, Missouri, U.S.A.

accelerated impacts of human activities due to its current land use pattern and trend. The basin's water resources are potentially subject to water quality problems caused by current and potential point and non-point source pollution. Deeply incised stream channels caused by the downcutting of past channelization activities would become particularly vulnerable to any future hydrological modification projects. The population in the basin is growing as metropolitan Kansas City suburbs are expanding eastward within the watershed. This indicates that extensive development pressure and urban encroachment will constitute a major threat to the existing waters, which will challenge the Section 404 regulations (Kathy Mulder and Jason Daniels of U.S. EPA, personal communications, 2001.)

3. THE TEST GEOSPATIAL DATA SETS

The Section 404 permitting decisions involve the integration and analysis of disparate and pertinent geospatial data with professional judgment. Thus, the

availability of adequate geospatial data is the key to the permit review using the decision support GIS. To develop a prototype GIS database of the pilot area, we fully utilized web-based GIS data sources. The resulting data sets were allocated into major categories. Some examples are described as follows:

Jurisdictional and watershed boundary data
The jurisdictional data category mainly describes county boundaries, Native American reservations boundaries, city boundaries, and county public land survey system. The watershed boundary information was mainly derived from Digital Line Graph, Hypsography, and Digital Raster Graphics of the U.S Geological Survey.

Physical geographical data
This category mainly includes the related geospatial data for soil types and locations, land cover types and distributions, potential runoff contributing areas, digital elevation model, and related geological features.

Water resources and hydrological data
This cluster of data covers the data sets of national wetland inventory, aquifers, flood data, hydrologic unit boundaries, riparian inventories, county primary hydrology, lakes, rivers and streams, and other feature boundaries of water bodies.

Watershed monitoring data
The monitoring data mainly include water quality of lakes, streams and ground waters over time. This category of data also depicts the sites for surface water pollutant discharge, treatment storage disposal locations, identified remedial locations, and landfills.

Biological and environmental data
Data included in this category cover the locations and attributes of designated critical habitats, common plant and animal species occurrences, threatened and endangered species occurrences, and stream evaluation information.

Socioeconomic and cultural data
The data and related information were mainly obtained from the files of the U.S. Census Bureau. Examples include jurisdictional boundaries, cultural and historical sites of significance, recreation and parks, socioeconomic activities, and land ownership designated places, key geographic locations, landmarks, and urban areas.

In addition to the above data sets, we are also compiling the following data and information of the pilot area that may be useful for the permit review analysis. (1) Site information, such as historical Section 404 permit sites, wetland mitigation sites, advanced identification of disposal sites, and resource conservation sites. (2) Biological and ecological data, such as in-stream biological inventory, potential riparian plant species richness, various habitats and wildlife data, and predicted distribution of species. (3) Infrastructure data such as rail lines, roads, highways, traffic analysis zones, and public water supply sites.

4. SYSTEM FUNCTIONS

The functional design of the permit decision support GIS has been completed, and the system is under development. Figure 2 outlines the system functionality which primarily includes GIS-based capabilities in permit-related geospatial data management, analytical query in permit review, permit analysis and decision-making, and permit review results output. The decision models constitute the important part of the system functions. The system development began with the test data compilation and the GIS customization for specific capabilities. The system functions and preliminary developments are described as follows.

4.1 Geospatial data management

An essential component of the permit decision support GIS is to integrate, manage, and manipulate various permit-related geospatial data and attribute information for specific permit review tasks. To achieve efficient data manipulations, this function addresses the following capabilities: (1) Categorize related data layers based on major review concerns to facilitate quick data retrieval. Major categories of the data are listed in Figure 2. (2) Incorporate all the data layers through customized user interface to facilitate permit review addressing multiple evaluation criteria. (3) Allow dynamic updating and documenting the database for new permit review tasks. Web-based data search techniques as well as the metadata will be part of this capability. In addition, remotely sensed data was processed to delineate the boundaries of waters and riparian land covers to link the permit review to the analysis across spatial scales.

4.2 Analytical query

The permit review for a proposed activity using the decision support GIS starts from the search and display of the proposed activity site. With the system's capability of analytical query, the spatial

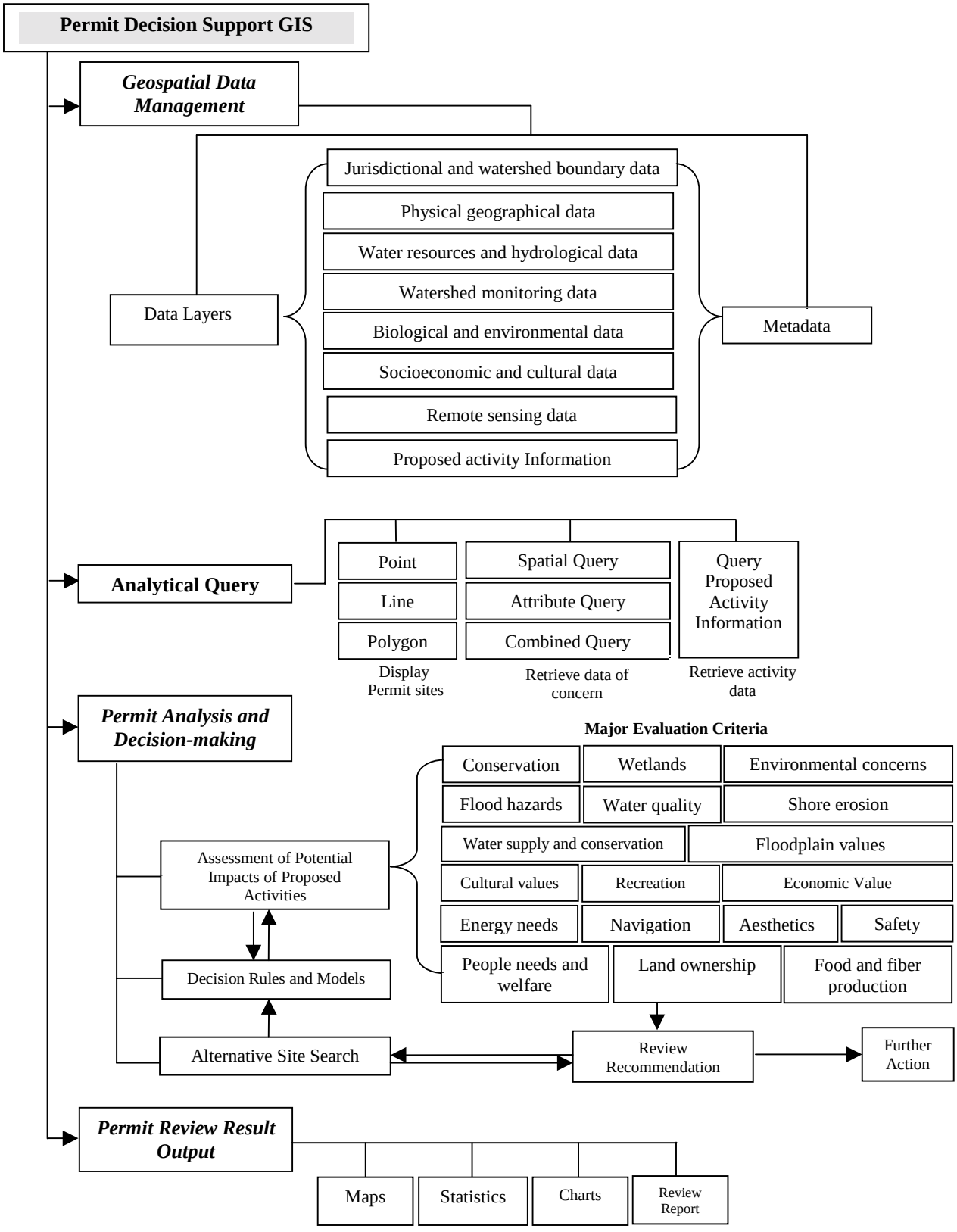

Figure 2. The functionality of the permit decision support GIS

location of the activity site can be identified based on the spatial features (point, line, or polygon) of the potentially affected portion of the water ("display activity sites".) The next step is to query and visualize the spatial occurrence and attribute information of the data of concern to answer the questions, such as "are there any endangered species or important wetlands around the proposed activity site?" This can be done by specifying spatial domains, temporal variables, related attribute information, or a combination of search criteria to "retrieve the data of concern." Specially designed graphical user interface will facilitate implementing this function.

4.3 Permit analysis and decision-making

This is a core function of the system that aims at assisting the reviewer to visualize and analyze the data and information queried through "Analytical Query" for evaluating the potential impacts of a proposed activity. This process will address "major evaluation criteria" listed in Figure 2. For example, assessments will be made to see if the proposed activity would potentially affect the conservation of valuable biological resources such as endangered species, impair an important wetland, or impact the water's recreation value. Such assessments will be mainly based on visualizing the occurrence of the concerned entities (such as an endangered species or a wetland) and analyzing the degree of their spatial overlap with the proposed activity site. Under some circumstances, quantitative rules may be adopted. For example, the decision-maker would examine the buffer distance from the proposed activity site to a specific endangered species. The buffer distance will be determined according to the available ecological information on the habitat requirement of the species.

Decision rules are under development to assess the impacts on some major functions of aquatic ecosystems. Some rules are based on specific environmental regulations, such as the required hydrological threshold to preserve a wetland. Other rules will be formulated according to biological or environmental justifications. For example, we may develop “distance rules” to answer the question “how far the activity site from an important wetland is tolerable.” Some rules are simply for checking whether the proposed activity is adjacent to valued or protected lands or facilities such as a recreation area. The decision rules can be formed as "If-Then" type decision-making list and stored as a searchable knowledge base in the permit decision support GIS. In addition to being used to assess the potential impact on specific functions of waters, the individual rules will be also combined to help assess the general vulnerability of the waters under overall potential impacts. This prior assessment result on a particular water will be stored in the permit decision support GIS and can be retrieved by the permit reviewer for reference when making a permit decision. As a pilot study, we are assessing the waters in the study area (Figure 1). We are developing index-based decision models for this effort. This type of models can rank (score) the potential impacts on each of major functions of the water under assessment, based on the analysis of available data and pertinent decision rules. The ranking scores will be weighted according to the level of potential impacts or the importance of the function of the water. For example, the occurrence of endangered species will be weighted higher than that of threatened species in the determination of the vulnerability of its biological protection function of the water under potential activities regulated by the Section 404 of the Clean Water Act. The ranking scores for individual functions will be combined to generate "vulnerability index" for the water. This index will be used to indicate how “vulnerable” the assessed water could be when it is subject to potential human-induced alternations.

4.4 Permit review results output

This function will generate appropriate formats of output to facilitate the delivery of the permit review data and information. The customized application interface will be created to facilitate the output automation.

5. SYSTEM DEVELOPMENT

We use ArcGIS (ArcGIS is the product of ESRI, Inc.) as the platform for this permit decision support GIS development. The VBA macros in ArcGIS applications are being written to create the graphical user interface (GUI) and integrate data, information, and decision models in a unified framework for the permit review analysis.

The user interface of the permit decision support GIS is critical to determine the efficiency of the system implementation. The menu tools have been developed to organize and manipulate large volumes of geospatial data based on the theme categories. The interface allows for data and information to be conveyed efficiently to the permit reviewer. The interface tools are under development to facilitate the interactive query and retrieval of the data and

information based on related criteria such as the spatial and temporal domains of the proposed activity, or the impact types of the activity. The user interfaces for different functions of the system will have a common look and will be functionally interrelated. For example, the particular data sets selected through the Geospatial Data Management interface would determine the data manipulated through the Analytical Query interface.

6. DISCUSSIONS

Although the project is an ongoing effort, the preliminary results and the conceptual development of the system functions demonstrate that GIS can provide innovative decision tools for assessing complex human impacts on ecosystems. To reach this goal, adequate geospatial data are needed to address major evaluation criteria, and the development and use of decision rules and models is the key for successful assessment tasks. GIS needs to be customized to integrate all the components into a unified form.

According to the experience gained from the development and application of other environmental decision support GIS (e.g. [Ji and Mitchell, 1995], [Ji and Johnston, 1995]), we are able to envision that the degree of the usefulness of such a system would depend on the following factors: (1) User-friendliness. Simplicity has been emphasized in the system design and development, and the user interface will be easy to comprehend allowing its implementation by the permit review professionals, particularly for those who may have little in-depth knowledge and skills on GIS. (2) Transferability of the system. Considering this factor, the system development has been based on the ESRI GIS product that is widely used in the United States and by the international community. Therefore, the system codes can be easily transferred to a large community of potential users for a variety of applications. (3) System flexibility. The system should be flexible to dynamically update geospatial database for changing application needs. This has been reflected in the system interface design for geospatial data manipulation that is based on multiple criteria such as data category and attributes, or spatial proximity. The effort will also be made to directly link the system to Internet-based data sources.

The permit decision support GIS can be adopted by the decision-makers and resource managers of federal and state agencies that are responsible for the Clean Water Act Section 404 permit review or other environmental permitting programs. It also can be used or adapted as a spatial analysis tool for related ecological assessment research.

7. ACKNOWLEDGEMENT

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8. REFERENCES

General Accounting Office of United States. Wetlands: The Corps of Engineers' administration of the Section 404 program, 1988.

Ji, W. and C. Jeske, Spatial modeling of the geographic distribution of a wildlife population: a case study in the lower Mississippi River region. *Ecological Modeling*, 132, 95-104, 2000.

Ji, W. and J. B. Johnston, A GIS-based decision support system for wetland permit analysis. In Proceedings of GIS/LIS'94, Phoenix, Arizona, 1994.

Ji, W. and J. B. Johnston, Coastal ecosystem decision support GIS: functions and methodology. Marine & Coastal GIS issue (Ronxing Li ed.), *Marine Geodesy*, 18(3), 229-241, 1995.

Ji, W. and L. C. Mitchell, An analytical model-based decision support GIS for Wetland Resource Management. Chapter 4 in *Wetland and Environmental Applications of Geographic Information Systems*, John Lyon & Jack McCarthy eds., Lewis Publishers, Boca Raton, Florida, 1995, 373 pp.

Paulson, G.A., Wetlands and water quality: a citizen's handbook on how to review and comment on Section 404 permits. Lake Michigan Federation, 1985.

U.S. Environmental Protection Agency, Section 404 of the Clean Water Act: An Overview http://www.epa.gov/owow/wetlands/facts/fact10.htm

U.S Bureau of Land Management, a GIS-based tool for environmental assessment permit applications. http://www.sdvc.uwyo.edu/blmtool/

The South Florida Water Management District, wetland rapid assessment procedure. http://www.esri.com/library/userconf/proc00/professional/papers/PAP305/p305.htm