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# Advancement of Geospatial Capability by NRiSD and GLAHF in Enhancing Aquatic Ecosystem Research and Management

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**Abstract**

Identifying, measuring, and understanding how landscape factors influence the characteristics of aquatic systems has increasingly become a central theme of research and management of rivers and lakes. Although linkages among landscapes and associated physicochemical and biological characteristics of aquatic systems have long been recognized, the development of conceptual frameworks and tools for measuring and synthesizing such linkages is relatively recent. This article summarizes the major advancements of these spatial frameworks and datasets by NRiDS and GLAHF, illustrates their uses in improving aquatic system research and management, and identifies improvements for future work.

**Keywords**

Geospatial capability; Aquatic ecosystem; Landscape information; Geographic information

## Introduction

Identifying, measuring, and understanding how landscape factors influence the characteristics of aquatic systems has increasingly become a central theme of research and management of rivers and lakes. Although linkages among landscapes and associated physicochemical and biological characteristics of aquatic systems have long been recognized, the development of conceptual frameworks and tools for measuring and synthesizing such linkages is relatively recent [1]. Advancements in identifying and measuring key landscape factors and their linkages with aquatic systems has been largely driven by the emergence of concepts from the disciplines of landscape and river ecology, greater availability of regional databases, and rapid development of geographic information and database management technologies [1,2].

The recent development and public availability of the National River Spatial Dataset (NRiSD) is a milestone for linking landscape information with the inland rivers in the conterminous United States [2] for research and management. This dataset makes it possible for conducting health condition assessment for all streams and rivers of the conterminous United States [3]. The recently developed Great Lakes Aquatic Habitat Framework (GLAHF) Dataset is the first database of its kind that makes it possible to link catchments, lake zones, lake subbasins, and the entire five Great Lakes for the world's largest freshwater system [4].

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The aforementioned two datasets represent unique contributions to the advancement of geospatial capabilities. Both identify and synthesize basic hydrologically and ecologically meaningful spatial units and attribute those units with a rich set of information important for understanding their influences on aquatic systems. Further, units and the information they characterize can be easily aggregated into larger spatial units where research results, management practices, and policy operation can be implemented. This article summarizes the major advancements of these spatial frameworks and datasets, illustrates their uses in improving aquatic system research and management, and identifies improvements for future work.

## Major Advancements in Geospatial Framework and Databases

To analyze and interpret the linkages between landscapes and their associated aquatic systems, it is essential to dissect large lakes or river networks into meaningful spatial units for data attribution and for evaluation against their landscape information. Traditionally, such linkages have been evaluated using sampling sites where biota or habitat data have been collected as the starting point to delineate catchment boundaries and capture catchment information upstream of sampling points [5]. Although such an approach provides relatively reliable linkages between in-waterbody measures and catchment information, it requires the familiarity with geographic information system (GIS) technology and the process is very time consuming to delineate catchment for each sampling location. Additionally, this approach does not provide information for extrapolating a single site-scale result to unsampled areas [6], which has important implication since we will never have enough resources to directly sample every river or lake section across a state or nation. Further, creation of catchments on a site-by-site basis usually does not generate readily comparable information or results across different projects where site locations may differ.

The recent advances in geospatial framework development of the NRiSD and GLAHF datasets provide the capability of linking waterbody spatial units with river catchments, lake zones, lake subbasins, and political boundaries. These spatial frameworks and datasets fill the gaps in linking basic spatial units of water bodies with their catchments for all rivers and lakes of the conterminous United States and for the entire North American Great Lakes Basin of both United States and Canada [2,4].

### National River Spatial Dataset (NRiSD)

The NRiSD spatial framework uses interconfluence river reaches and their associated catchments as fundamental spatial river units and a series of ecological and political spatial descriptors as hierarchy structures to allow users to extract or analyze information at spatial scales that they define. This framework and database provide users with the capability of adding data, conducting analyses, developing management and regulation scenarios, and tracking management progress at a variety of spatial scales.

This geospatial dataset uses river networks and associated catchments of National Hydrography Database Plus (NHDPlus) as

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the backbone for building the spatial framework and database of NRiSD. The NRiSD is a 1:100,000-scale stream-line GIS database that includes all streams, rivers, and impoundments captured at this resolution. Stream lines in the NRiSD are divided into fundamental reaches (smallest spatial units; hereafter referred to as "river reaches") that are defined from the origin of a stream to a confluence at the downstream end, from a confluence to a confluence, from a confluence to the upstream end of an impoundment or lake, from the downstream end of an impoundment or lake to a confluence, or from a confluence to a pour point with the sea or lakes with no outlet [2]. These rivers reaches or impoundments are the finest spatial units in the NRiSD.

Within the NRiSD, the local catchment boundaries of a river reach (the land area where surface runoff flows directly into a river reach) are delineated (Figure 1). The network catchment of a river reach (the entire catchment area upstream of the downstream end of the reach) boundaries are also defined (Figure 1). This database covers the entire conterminous United States and has a topological structure (e.g., flow direction and neighbor river or impoundment unit descriptor) that makes it feasible to calculate multiple spatial unit connectivity and network position variables using GIS tools.

The NRiSD contains two types of variables that are attributed to the spatial units (i.e., river reach). The first type of variable captures the values of natural variation in climate, elevation, geology, soil, land cover, groundwater contribution, and river connectivity that can serve as surrogates of river reach-level natural variation in physicochemical and biological characteristics. Some of these descriptors of natural variation such as network catchment size, Strahler order, reach length; reach mean elevation, reach gradient, and mean annual air temperature and precipitation were from the NHDPlus database. The other natural variables, such as soil permeability, types of surficial geology, and groundwater contribution were calculated based on readily available data sources using GIS tools. The second type of variables measures variation in human activities in the river channels, riparian and floodplain, and catchments. River reach human disturbance descriptors, representing land uses, population density, transportation, nutrient enrichment, agricultural pollutants, dams, and point source pollution, were gathered from various data sources [2,7] and their known influences on river health [5]. The natural and human activity variables in the local catchment are attributed to each river reach first. Then the network catchment data are obtained by aggregating data attributed to each through summarizing each variable from all local catchments upstream of each reach [2,8]. The NRiSD data are available as part of the National Fish Habitat Partnership Data System [9].

Although the catchment boundaries of impoundments or lakes are not consistently defined nationally in the current version of NRiDS, they have been delineated for all lakes that are 2 ha or larger in the State of Michigan [10,11]. Similar to the river catchments delineation of NRiDS, the local catchment of an impoundment or lake is defined as land areas where surface runoff flows directly into a water body; and the tributary catchment of an impoundment or lake is defined as the network catchments of all tributaries that inflow into the waterbody (Figure 2). The local and tributary catchments of impoundments or lakes are also delineated based on the 1:100,000-scale NHDPlus dataset using GIS tools. The available lake morphology and the other physicochemical, biological, and landscape variables described for river reaches are also attributed to each impoundment or lake.

## Great Lakes Aquatic Habitat Framework (GLAHF)

The GLAHF dataset is a GIS spatial framework and database with a hierarchical structure of zones that have similar environmental characteristics based on dominant processes that shape the physicochemical and biological characteristics in the Great Lakes. The largest three levels of GLAHF spatial hierarchy structure are the entire Great Lakes Basin, individual Great Lakes, and lake subbasins within a lake (Figure 3). These three spatial scales also include their corresponding catchments and connecting channels. For each lake subbasin, the GLAHF dataset incorporates five types of spatial zones, including tributaries and their catchments, coastal terrestrial, coastal margin, near shore, and offshore regions.

The spatial units of tributaries and their catchments are delineated the same way as described for the NRiSD mentioned above. An important component of GLAHF is the incorporation of influences from terrestrial catchments to the coastal and offshore regions of the Great Lakes. Such catchment influences on the lakes are quantified at lake-river connection pour points or lake-coastline segments and further transferred into the coastal and offshore lake regions.

A river pour point is the downstream end of the downstream-most reach of a river network at the coastal region of the lakes, which has an accumulative area of a river catchment greater than or equal to an 8-digit Hydrologic Unit Code. A lake-coastline segment is identified as a shoreline segment bordered by interfluve catchments with drainage areas that are between catchments of two river pour points along the Great Lakes coastline. In the GLAHF dataset, all catchment data described in the NRiSD dataset are attributed to the river pour points or lake-coastline segments.

The coastal terrestrial zone begins at the lake shoreline and extends landward for 5 km (Figure 3). The lake shoreline is defined as the ordinary high watermark elevation, or the terrestrial edge of hydrologically connected coastal wetlands. The coastal margin zone is defined as lake areas with water depth between 0 and 3 m for all lakes, and the near shore zone was defined as lake areas with water depth between 3 and 15 m for Lake Erie and 3 and 30 m for Lakes Superior, Michigan, Huron, and Ontario. The offshore zone is defined as lake areas with water depths greater than 15 m for Lake Erie and greater than 30 m for the other four lakes.

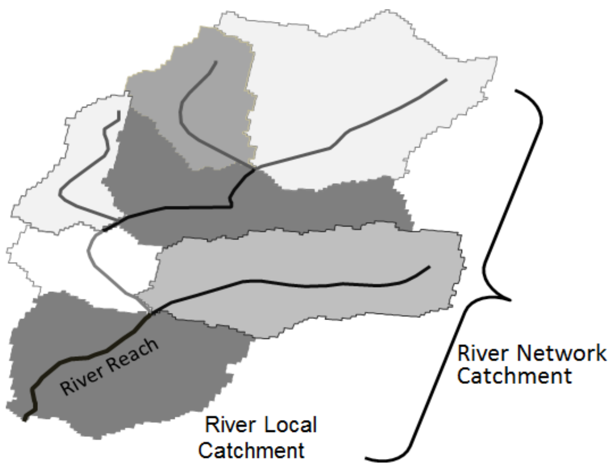


**Figure 1:** River reach and the local and network catchments of the river reach.

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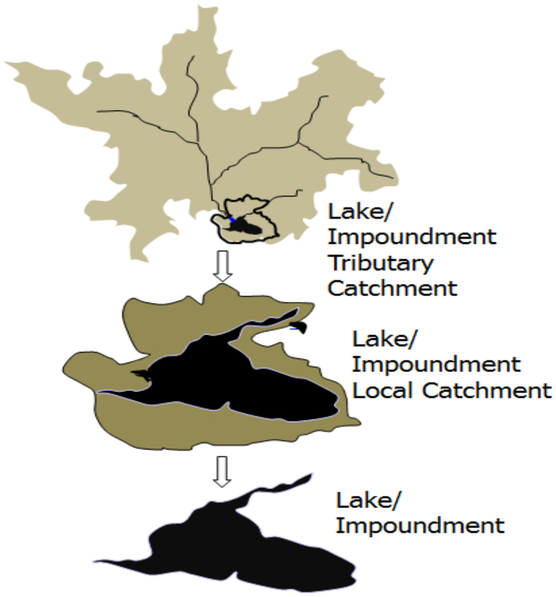


**Figure 2:** Lake or impoundment and its associated local and tributary catchments.

The spatial structure of GLAHF consists of 30 × 30 m grid cells in the coastal terrestrial, coastal margin, and near shore zones (depth < 30 m), and 1.8 × 1.8 km grid cells in the offshore (depth > 30 m) region (Figure 3). Each river pour point and lake-coastline also consists of multiple 30 × 30 m cells. All the 30-m and 1.8-km grid cells are attributed with over 300 landscapes, climate, physicochemical, and biological variables from many sources [4].

Each 30-m or 1.8-km cell has a unique spatial identifier that locates the cell within each zone, Lake Sub basin, lake, and management or political boundary units. The data attributed to each 30-m or 1.8-km cell are linked to the unique cell identifier in the GLAHF relational database structure. This spatial structure provides the mechanism for the data attributed to each cell to be aggregated, synthesized, analyzed, scaled up or down, and reported at various spatial scales depending on research and management needs. The GLAHF database is available publicly [12].

## Major Advancements in Providing Information for all Waters at the U.S. National and The Great Lakes Basinwide Scales

The NRiSD and GLAHF datasets described above provide hierarchical geospatial frameworks and databases that assemble all stream and river reaches, inland lakes, and the Great Lakes spatial units and their associated descriptors for network positions, network connectivity, and catchment natural variations and human disturbances for the entire conterminous United States and the Great Lakes Basin. These hierarchical geospatial frameworks and databases have advanced our capabilities in information management, synthesizing, and delivering at different spatial scales; and in extrapolating information from regions and waters where data are rich to areas with limited information.

### Advancement in information management, synthesizing, and delivering at different spatial scales

The NRiSD and GLAHF hierarchical geospatial frameworks help resolve several challenges in data management and delivery. First, they provide the basic spatial units for data attribution that facilitates incorporation of data from multiple sources into a common spatial network, and integrates data across data types, scales, and ecosystem and political boundaries. The features of these frameworks can potentially be used to identify the size of a region that sampling sites can effectively represent, how such data can be synthesized to represent larger spatial units, and how variation within and among spatial units can be properly measured. Second, it provides a mechanism to quantify connectivity among spatial units and their positions within the system. This feature is extremely important because the natural physicochemical and biological habitat characteristics of a spatial unit are largely determined by catchment, water body morphology, landscape geomorphology, and climate conditions at the spatial scales of interest. These habitat characteristics are also strongly influenced by their connectivity with other major system features, such as distance to wetlands, point pollution sources, or protected areas. Last, these hierarchical spatial frameworks and databases provide a mechanism for synthesizing data and information at local, regional, and nation-wide scales, Great Lakes basin-wide scales, or political jurisdictions. They enable managers, policy makers, and researchers to access data summarized for different spatial scales to better understand, protect, and restore aquatic ecosystems.

### Advancement in extrapolating information from sampled waters to areas with limited data

The NRiSD and GLAHF hierarchical geospatial frameworks include two types of data. One type of data (here referred to as landscape data) consists of GIS or remote sensing generated measures such as spatial unit descriptors, natural landscape settings, climate characteristics, and anthropogenic factors, which are readily available for all the spatial units in the databases. The other type of data consists of physicochemical and biological data that are collected by field surveys, which are available only for some the spatial units in the databases.

Because physicochemical and biological conditions at local spatial units are largely controlled by characteristics and processes operating over larger spatial scales, many physicochemical and biological characteristics of water bodies can be predicted from landscape data. The major advantage of such an approach is that landscape data can be obtained from readily available databases and are available for all spatial units throughout large regions; hence, landscape-based model predictions that provide information for many sites can be much less expensive than field sampling those same sites, although some field data are required for initial model development, calibration, and validation. Additionally, this approach not only uses model outputs to fill data gaps where the physicochemical and biological data are not available, but also utilizes models for hind casting historical or predevelopment conditions or for predicting consequences of alternative future management or climate change scenarios.

An example of such uses is that a common approach for measuring human disturbance on streams is using multimetric biological, physical, or chemical indicators. Using such an approach, river health can only be assessed for areas where those data are available, which may comprise only a fraction of total river reaches within a region. The NRiSD dataset provides essential data for establishing relationship between human disturbances and biological conditions for some river reaches and for applying relationships to all river reaches where human disturbance levels can be quantified without requiring field sampling at a regional or national scale [3].

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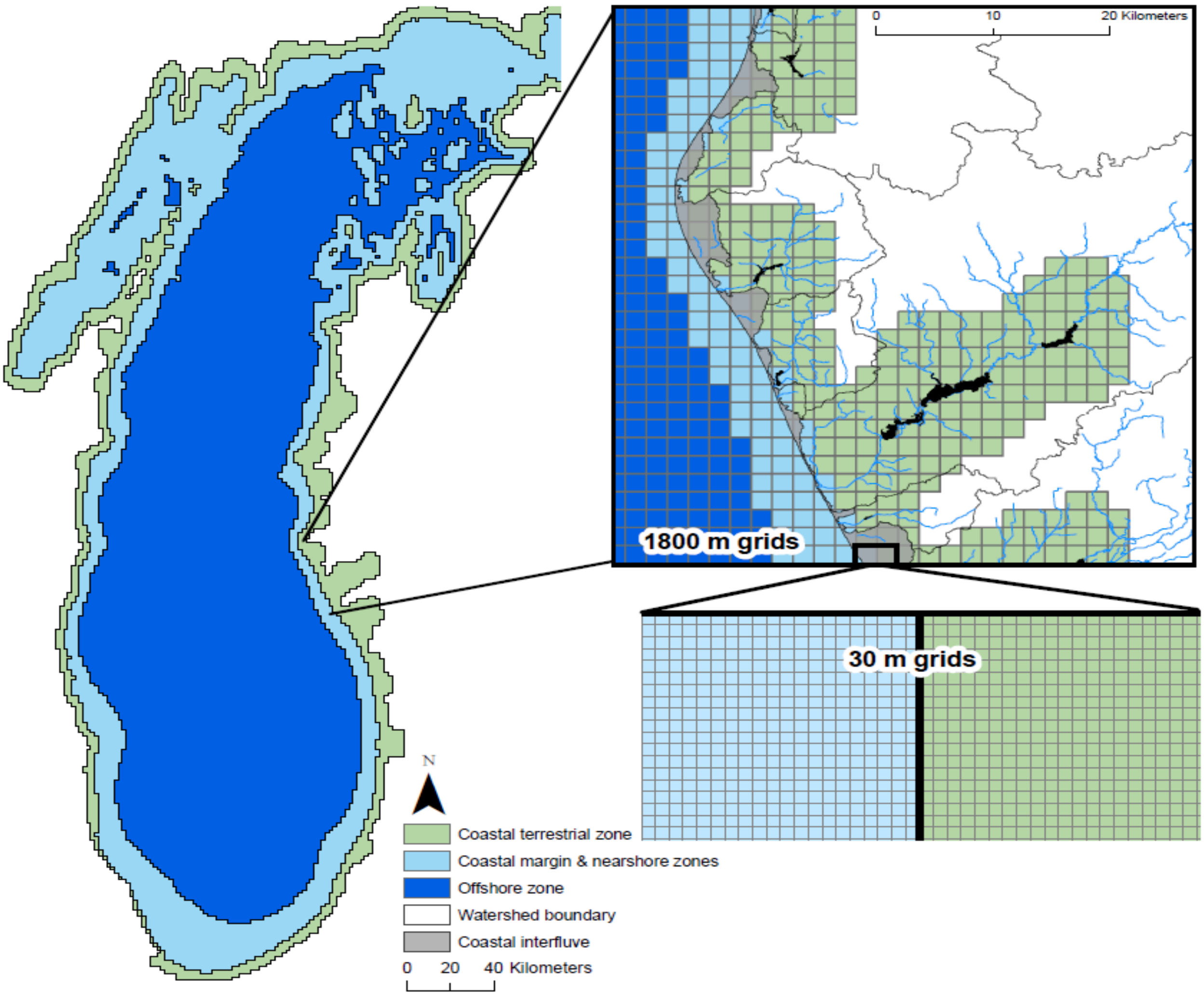


**Figure 3:** The hierarchical geospatial structure of GLAHF dataset that consists of catchments, 30-m grid cells in coastal terrestrial and coastal aquatic zones, and 1.8-km grid cells in offshore zones [4].

## Major Challenges in the Use of Geospatial Framework and Databases

The NRiSD and GLAHF datasets are not without weaknesses. Data spatial resolution and availability of nationwide or Great Lakes basin-wide data are the two major challenges related to database development. For example, although the NRiSD database enables us to map all river reaches and calculate their positions and connectivity based on 1:100,000 NHDPlus, their accuracy could be improved substantially when the 1:24,000 NHDPlus becomes available nationally. Some of the data attributed to each river reach, such as reach position, connectivity, and land use/cover are suitable for uses at all scales, while others, such as nutrient yield and water-use data are suitable only for analyses and reporting at larger spatial scales (i.e., counties). The database does not include some important local or regional scale data, such as bank erosion, farm animal grazing and trampling data that require field measurement and other local point and nonpoint source disturbance data that can be obtained from local agencies. Such data do exist for many regions of the Nation and can be incorporated into the database by regional or local users. Additionally, the human disturbances in the database describe only a temporal snapshot of the health conditions of the river, which do not take into account legacy effects and future human activities [2].

For the GLAHF dataset, the database does not include all data collected from the Great Lakes. The goal of developing the database has been to integrate available basin-wide data to address needs for data rectified to a common spatial framework. The outcome is a spatial dataset of consistent data available throughout the Great Lakes Basin scale and minimally at a lake system scale. For example, no efforts are made to assemble and harmonize data that were collected for specific objectives at a local scale. For local users, the database provides only a data spatial hierarchical framework to link localized data with the readily available broad scale data to meet their own needs. Because the spatial resolution, type, and availability of lake system-wide data could vary depending on data source, the data attribution process has simplified some of the data that were inconsistent across the scales into common descriptors or common spatial units. Hence, some of the data in the GLAHF may have lost their fine detail or resolution.

Some of the data currently in the database are incomplete and can be improved in the near future. Nearshore areas of the Great Lakes have only recently been sampled and studied basin-wide and these data need to be incorporated into GLAHF when they become available. The coastline typology for the United States is much newer and more detailed than that available for the Canada. This will require updating when newer data become available. Given the fast development of information technology and increasing availability of regional data, the database will require periodic and regular updates and improvements.

Overall, NRiSD and GLAHF datasets provide essential data for meeting needs of many management and research programs. The utility of the database can be improved by incorporating additional detailed localized data that are not available at nationwide or Great Lakes basin-wide scales. Presently, many additional data layers and higher resolution data layers are available only at a regional or local scale. Adding such data to these databases by regional agencies or partnerships will improve the utility of these datasets for local users by providing information that otherwise could not be supplied by the nationwide or region-wide databases and by placing that data within a lake- or basin-wide framework. These databases can also be improved by incorporating updated or new data layers, newly designed systematic collected information, and modeled physicochemical and biological parameters under projected climate changes.

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