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PNL-SA-23511

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April 1994

Presented at the
Mapping and Surveying the Earth's Environment
for a Balanced Future Conference
April 25-28, 1994
Reno, Nevada

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

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Walla Walla, Washington

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ABSTRACT

Although Geographic Information Systems (GISs) have traditionally been used to analyze terrestrial animal habitats, identify migration patterns, and monitor ecosystems, they have rarely been used to understand aquatic species. The U.S. Army Corps of Engineers is working with the Pacific Northwest Laboratory and other government agencies to exploit GIS technology for improving the survival of threatened and endangered salmon in the Snake River in the states of Washington, Oregon, and Idaho. The customized GIS will be used to map the physical environment of the river, to map the current biological environment, and to analyze potential impacts to both of these environments from several mitigation options. Data in both digital and textual formats have been obtained from scientists across the Pacific Northwest who are analyzing the habitats, limnology, and hydrology of the Snake River. The mitigation options focus on studying the effects of lowering the reservoirs of the Snake River in an effort to speed juvenile salmon towards the ocean. The hypothesis being examined is that faster juvenile salmon travel to the ocean may result in higher juvenile survival and greater smolt-to-adult return ratios. Lowering the Snake River reservoirs is expected to have a variety of impacts to the physical environment, including changes to water velocity, temperature, dissolved gasses, and turbidity. Each of these potential changes is being examined to assess their effects on the surrounding terrestrial wildlife and on both the anadromous and resident fish of the Snake River.

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*Pacific Northwest Laboratory is operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76 RLO 1830.

INTRODUCTION

The U. S. Army Corps of Engineers (Corps), in conjunction with the Pacific Northwest Laboratory (PNL) and researchers across the Pacific Northwest, has been investigating aquatic species in the Columbia River Basin with special focus on the threatened and endangered salmon stocks of the Snake River. Before reaching the Pacific Ocean, most juvenile salmon (smolts) originating from the Snake River Basin must navigate through eight dam and reservoir projects located in the Snake and Columbia rivers (Figure 1). To enhance the survival of the salmon, the Corps has been using a number of different mitigation plans. Primary actions include bypassing smolts past the turbines, collecting juvenile salmon above the dams and transporting them by truck and barge to the ocean, increasing water releases from upstream storage reservoirs during smolt migration, diverting water around the dams during migration, and providing fish ladders to assist adult salmon upstream migration (Corps 1993).

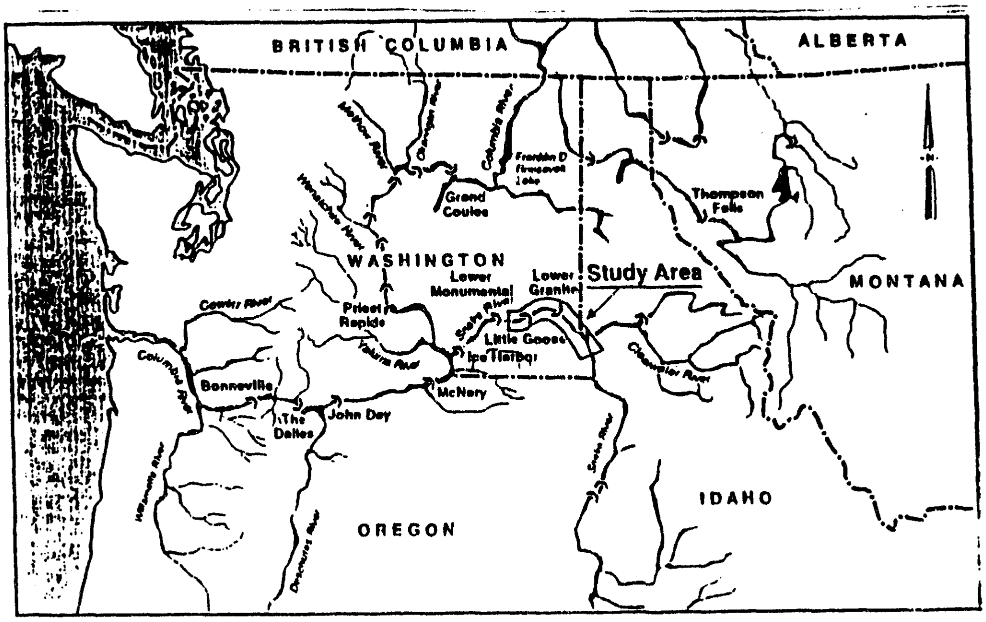

Figure 1. Study Area in the Columbia River Basin

Another operational strategy being investigated is to lower the primary reservoir operating pool elevations (drawdown) during spring and fall migration. Theoretically, this option would increase river velocities, which in turn would improve the downstream migration travel times of the smolts. Because implementation of this option would impact aquatic and terrestrial wildlife, power generation, river navigation, irrigation, and recreational use of the river, and would also require modifications to the dam and surrounding facilities, effects of the various drawdown options are being modeled using computer technology.

PNL is currently providing input to three Corps investigations: the Biological Plan for the lower Columbia and Snake Rivers drawdowns; dam tailrace spawning activity; and the Lower Granite sedimentation study. The spatial extent of the biological plan and sedimentation study is the Lower Granite Reservoir, which runs from the Lower Granite Dam to the confluence of the Clearwater River at Lewiston, Idaho (Figure 1). The dam tailrace spawning study focuses on areas below each of the four dams of the lower Snake River in Washington State. Data to be analyzed include biological information (fish sampling station data and terrestrial wildlife habitat) and physical information (river properties such as bathymetry, velocity, turbidity, substrate, and temperature).

DATA SOURCES AND MODEL GENERATION

Much of the biological data in the system was obtained by fisheries biologists who have been working with the Corps studying the Snake River reservoirs. Dr. David Bennett, University of Idaho, provided fish sampling information that included average monthly catch per effort, fish species, age, and physical properties of the sampling point. Dr. Bennett's data span 6 years of sampling efforts. Point samples have been collected for such physical properties as substrate sieve analysis, temperature, dissolved oxygen level, benthic community abundance, velocities, shoreline gradient, and macrophyte distribution.

Bathymetric data was crucial for the analyses. Although the Corps had the most accurate data, there was no recent bathymetry that encompassed the whole Lower Granite Reservoir. PNL merged the most current bathymetric surveys to create a composite bathymetry surface model. To ensure the linearity of the bathymetry, a center line with bottom elevations of the reservoir was digitized. Bathymetric contours were produced and reviewed by the Corps for accuracy.

The bathymetric surface model was used to create slope layers at 5-degree intervals and depth surface models. Although time consuming to produce, the depth surface models were critical. Many of the aquatic habitat models were based on water depths, and changes in the reservoir volumes were determined from the depth layers. The Corps' water surface profile model, HEC-2, was used to generate water surface elevations at a variety of river miles for each of the elevation/flow scenarios. These water surface elevations were used to create a river surface model for each drawdown scenario. Each river surface model was subtracted from the bathymetric layer to create the depth layers.

ANALYSES

Geographic Information System (GIS) techniques were the primary analysis tool in this investigation; a variety of PNL-developed computer programs supported the analysis, and a relational database was utilized for data storage. An Intergraph GIS (Intergraph Corporation, Huntsville, AL) and an Oracle database (Oracle Corporation, Belmont, CA) were selected to perform the analyses. These systems were chosen to ensure compatibility with the Corps' existing computer systems and because of the sophisticated surface generation and analyses capabilities of the Intergraph system.

Biological Plan

Four drawdown elevations were chosen for analyses (623', 681', 700', and 733' above mean sea level) along with three flow rates (30,000 cfs, 60,000 cfs, and 140,000 cfs). Each pair of elevations and flow rates constitutes a drawdown scenario for which analyses were performed. A number of analyses were performed using the GIS and PNL-developed software. One important calculation was total bottom surface of areas for different drawdown elevations and flow rates for both lotic (free-flowing) and lentic (reservoir) environs. This analysis was performed by creating surface models for each drawdown scenario and using Intergraph's surface modeling software to compute the surface areas. Reservoir volumes were also calculated for different drawdown elevations and flow rates.

Photic (0-15' depths) and non-photic zones (greater than 15') were derived from the depth surface models. These zones represent the amount of area available for primary photosynthetic production. Surface areas for photic and non-photic zones were computed for the whole reservoir. Changes in the photic zones for different drawdown scenarios were depicted graphically for areas near Silcott Island (Figure 2), which is located in the upper Lower Granite Reservoir near Lewiston, Idaho. The relationship between bathymetric slope and fish habitat or spawning locations is being studied by PNL researchers. Maps depicting changes in the photic zone located in areas where the bathymetric slope ranged from 0 to 5 degrees were created for areas near Silcott Island (Figure 3).

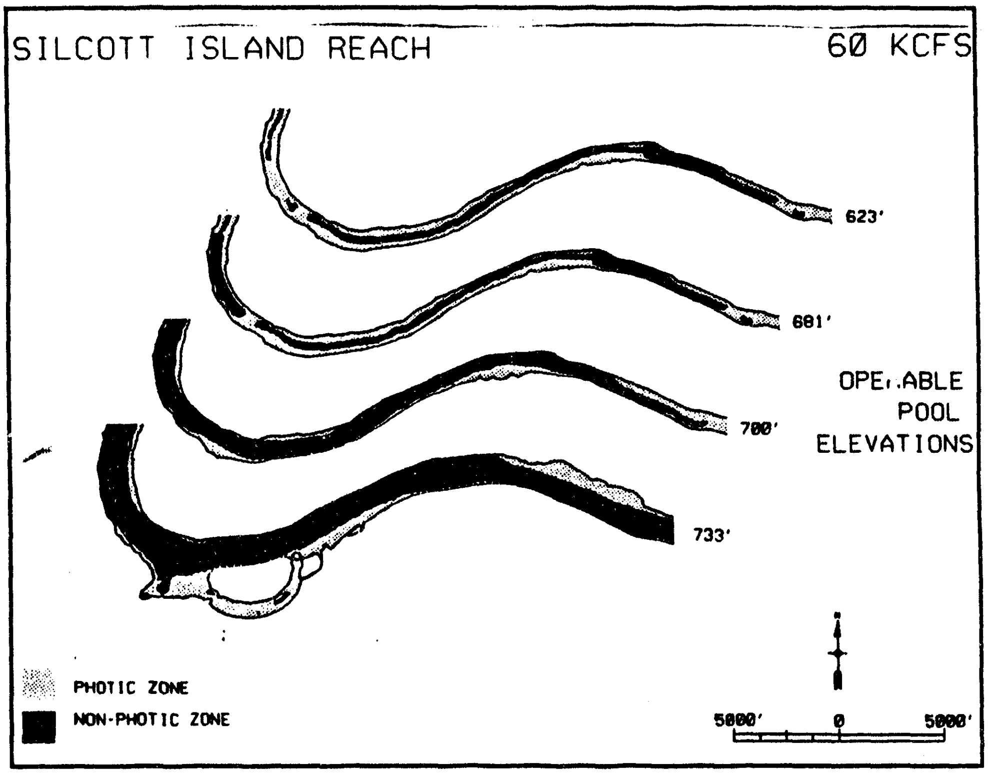

Figure 2. Photic Zone Map of Silcott Island Reach

Velocity/bathymetry profiles were created for three sample cross sections of the river using output from a velocity calculation program developed by PNL. This program is based on the HEC-2 flow model but computes velocities continuously across the cross section, not just one average velocity for the whole cross section. This analysis illustrates how the velocities change in response to changes in the bathymetry for each drawdown scenario. In Figure 4, the top graphs represent the computed water velocities for three operable pool elevations (623', 700', and 733' above mean sea level) at the river miles noted on the top of the figure. The bottom graphs represent the geometrical relationship between bathymetry at the river miles and the surface of the water for the operable pool elevations.

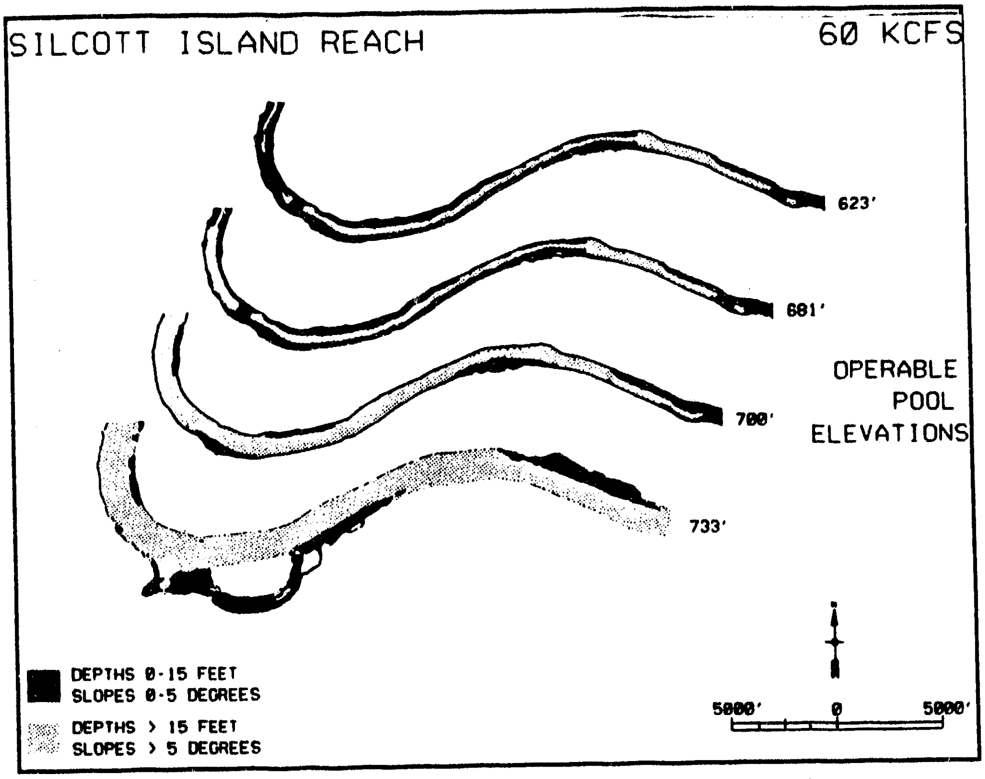

Figure 3. Depth/Slope Map of Silcott Island Reach

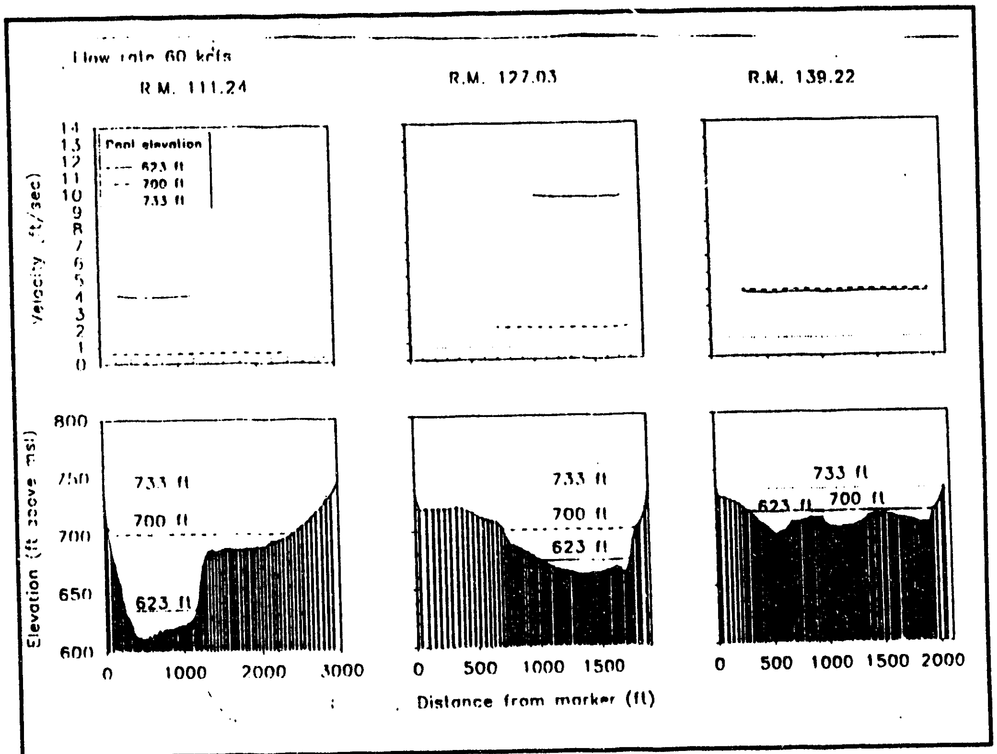

Figure 4. Velocity and Bathymetry Profiles

Tailrace Spawning

Another task employing GIS technology was directed at predicting potential spawning habitat at the tailraces of the dams on the Snake River based on its physical characteristics. Usually, fisheries biologists scuba dive to inspect the river bottom and locate spawning areas, but the danger of diving in the tail-race waters precluded using this means for identifying spawning sites. Instead, the PNL biologists had to remotely film the bottom of the river with a video camera to locate spawning areas and wanted a map of potential sites to guide this effort. GIS layers were prepared for a range of velocities, sub-strate, slopes, and depths, then aggregated to identify potential spawning locations (Figure 5). These locations were used as a basis for production of a sampling grid. At two of the three dam tailraces where sampling efforts have been completed, spawning sites were indeed discovered in the areas pre-dicted by this approach. This project has demonstrated the viability of using GIS technology in aquatic ecological studies.

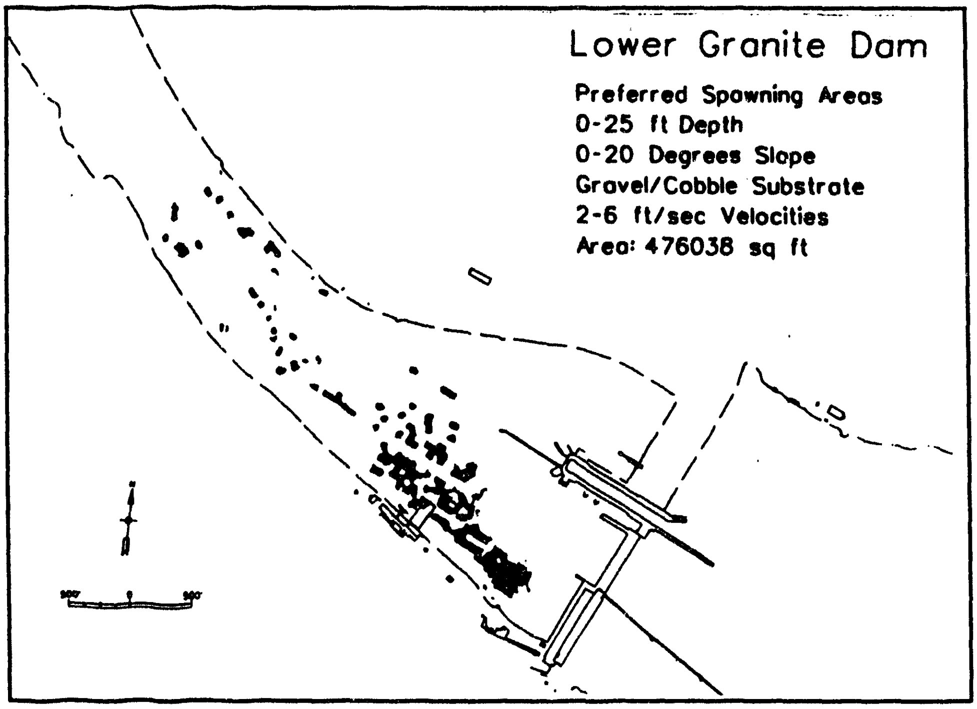

Figure 5. Potential Spawning Locations.

DISCUSSION

Because GIS is a fairly new tool for aquatic environmental studies, the technology must be proven before it will gain wide acceptance. Some special difficulties are encountered when using GIS for aquatic analyses. Hydrologic systems, such as rivers, lakes, and reservoirs, are dynamic systems that can fluctuate radically in short time spans. Water surface elevations downstream from a dam can change dramatically in a matter of hours in response to water releases. Erosion and deposition of substrate are continuous and aquatic species migrate in response to a variety of phenomena not yet understood. Currently GIS technology can represent only static views of an ecosystem. Using a GIS for aquatic studies entails periodic updates of data and analyses based on new samples. The frequency of updates depends on the variability of the hydraulic system.

It is difficult to sample aquatic environments. The most useful types of GIS data are polygonal, continuous data. However, it is hard to obtain continuous samples of many types of physical hydrologic features because they are obscured by water. Positions of fish in the water columns are difficult to determine because of limitations in fish tagging devices and the attenuation of signals through water. The large physical size of most aquatic systems also poses a challenge. When dealing with large terrestrial areas, remote sensing is used to acquire data, but few remote sensing techniques can be applied to aquatic environments. The linear nature of hydrologic data is not conducive to most contouring or analyses packages. Most hydrological analysis programs being used, such as HEC-2, are based on static systems. Hydrologic ecosystems are truly three-dimensional and some properties, like velocity, should optimally be sampled as a continuous three dimensional volume, which might not be practical. Although surface analysis is a feature of many GISs, few currently have the capability to perform volume analysis.

CONCLUSIONS

PNL's research has proven that Geographic Information Systems technology is a viable tool for aquatic studies despite its limitations. GIS technology is a powerful mechanism for linking spatial data with relational databases and provides sophisticated spatial analysis functions. Much of the data needed for aquatic studies, such as slope and depths, can be generated automatically using a GIS. GIS technology is moving toward three-dimensional modeling and analysis, which will significantly enhance GIS capabilities. For example, PNL is currently evaluating a new GIS product that performs three-dimensional modeling and analysis. GIS allows data to be shared easily between researchers. Many of the sampling problems faced by fisheries biologists are being addressed with new technology. Sampling and tracking of fish is being accomplished through the use of new types of sensors. Models of physical systems can also be used to simulate data and alleviate some sampling problems. One of the most important benefits of using a GIS is that results of studies are reproducible.

This project has clearly demonstrated the usefulness of GIS for modeling and analyzing aquatic ecosystems. The Lower Granite GIS Project has successfully aided the Corps and PNL in understanding issues impacting alternate flow strategies for the lower Columbia and Snake rivers and in predicting the location of spawning activity in dam tailraces. More research is being planned to determine the best way to incorporate biological information into traditional GIS analyses and how to utilize GIS more effectively to understand and model temporally varying environments.

ACKNOWLEDGMENTS

Many individuals made this project a success. Members of the Lower Granite GIS team are Karin Hoover, Guy McWethy, Duane Wessels, Brian Moon, Joe Stephan, Karen Steinmaus, and George Wukelic. PNL fisheries biologists who were instrumental in testing the viability of this technology for aquatic ecosystems include Dennis Dauble, Dave Geist, Duane Neitzel, and Tom Carlson. Our thanks go to the many Corps personnel who provided us with quality information and expertise: Sara Wik, Lester Cunningham, Tom Miller, Bob Meyer, Tom Seiner, Blaise Grden, Julie Daven, and Dan Kenney. Data were provided by Tom Curret and Dave Bennett of the University of Idaho and Dennis Rondorf of the National Fishery Research Center.

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