A GCES GIS Data Base for Long Term Monitoring of Portions of the Grand Canyon River Environment Created by Modern Mapping Techniques

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ABSTRACT

Environmental concerns for natural and cultural resources along the Colorado River in the Grand Canyon required the development of a digital data base to be used in long term monitoring. Fluctuating flows from Glen Canyon Dam have degraded some of the river environment. Interim reduced flows have been established to minimize impacts while the monitoring program commences. The base for the digital data is 1:2,400 large scale topographic maps for thirteen monitoring sites, encompassing 63 river miles, from Lake Powell to Lake Mead. Horizontal and vertical control for the topographic maps was established using a combination of Global Positioning System (GPS) receivers and conventional surveying techniques. Control at the rim of the canyon was extended to the bottom using survey grade GPS receivers. The monitoring sites were photographed with 1:7,200 scale black and white and 1:4,800 scale color infrared film. Analytical stereo plotters then used the control points to produce topographic map sheets with a 0.5 meter contour interval. Approximately 25 natural and cultural resource categories at a pilot monitoring site are being transferred to the map sheets, scanned digitized, and then entered into ARC/INFO format. Point, line, and area information such as river mile, trails, beach areas, vegetation, endangered fish habitat and cultural resource information, can then be rapidly updated, displayed and analyzed for change through time using the geographic information system. Critical resources and areas of interest can be examined at different flow rates to determine the changes due to flow inundation. This paper will report on the initial results of the pilot study.

INTRODUCTION

Public concerns about the Colorado River environment in the Grand Canyon resulted in a Department of Interior decision to develop a data base for long term monitoring of the impacts of variable flow rates from the Glen Canyon Dam. The purpose of this paper is to explain how the Glen Canyon Environmental Studies (GCES) GIS (Geographic Information System) data base was developed for a pilot monitoring site in the Grand Canyon and how it can be used in long term

monitoring. The objective of this program is to utilize an integrated data base and geographic approach to develop an integrated environmental monitoring program.

This paper will describe and discuss the following:

- The production of the base maps.
- The design of the GCES data base
- How information was loaded into a geographic information system or data entry
- How the GIS can be used in long term monitoring.

The GCES studies were initiated in 1982 by the Department of the Interior to study the environmental effects of rewinding the generators at Glen Canyon Dam. Rewinding the generators provided for an increase in the electrical power output for Western (known as Western Area Power Administration) customers. To provide more power for peak demand periods, Reclamation proposed to increase the amount of water released from Glen Canyon Dam. The amount of water that can be released through the powerplant varies from 1,000 to 33,200 cubic feet per second (cfs). A high flow of 90,000 cfs occurred during the flood year of 1983.

Increasing public concern about the impacts of the abrupt and highly variable, fluctuating flows on the Colorado River environment resulted in the initiation of the GCES and the need to develop a data base to evaluate and monitor the impacts. GCES requested the technical expertise of the Remote Sensing and Geographic Information Section, in Denver, to provide the lead in developing the data base so it could be updated, analyzed, and displayed through a GIS and available to other resource agencies.

OBJECTIVES

The GCES GIS data base is being developed for long term monitoring, special studies, and archiving information concerning the Grand Canyon. Long term monitoring is here defined as "measuring the change over time in vegetation, beach areas, cultural resource areas, and habitat for rare and endangered species every 3 to 5 years". Special studies would include the nesting sites of bald eagles near Nankoweap Creek, the habitat for the humpback chub, and other studies. Archiving would consist of storing information such as points, lines, and area information by geographic coordinates and/or river mile. This would include all historic papers or reports that have been written for the GCES. The primary objective of this report is to discuss the progress to date on one of the special monitoring sites in the Grand Canyon.

This paper is laid out to discuss the following key areas and GIS development process: Study Area, Production of the Large Scale Topographic Base Map, GIS Data Base, Long Term Monitoring Using the GIS Data Base, Discussion, Future Plans and Schedules, Recommendations, and Summary.

STUDY AREA

Limited funds and time constraints precluded developing a GIS data base for the entire Colorado River from Glen Canyon Dam to Lake Mead. The GCES/GIS work group, which includes federal agencies, a state agency, Native Americans, and other groups, was formed to identify and select special monitoring sites and provide input into the data base development.

The development of the GIS is the responsibility of Reclamation as the lead agency with the GCES Office in Flagstaff, Arizona providing coordination, verification and integration and the Denver Office (the Remote Sensing and Geographic Information Section) responsible for technical development. The other participants will provide natural and cultural information. They include the National Park Service, U.S. Geological Survey, Western Area Power Administration, Native American groups, U.S. Fish and Wildlife Service, Arizona Fish and Game, and contractors.

The GCES/GIS work group selected monitoring sites to represent the ecological diversity in the Grand Canyon and to include areas where special studies or critical resources were located. The work group selected thirteen sites along the area of concern comprising a total river mile distance of 63 miles (Figure 1). The average size of a monitoring site is 5 river miles. In the future, if funds are available, areas between the monitoring sites will be added to the data base. In the interim U.S. Geological Survey 7.5-minute digital elevation models will be used.

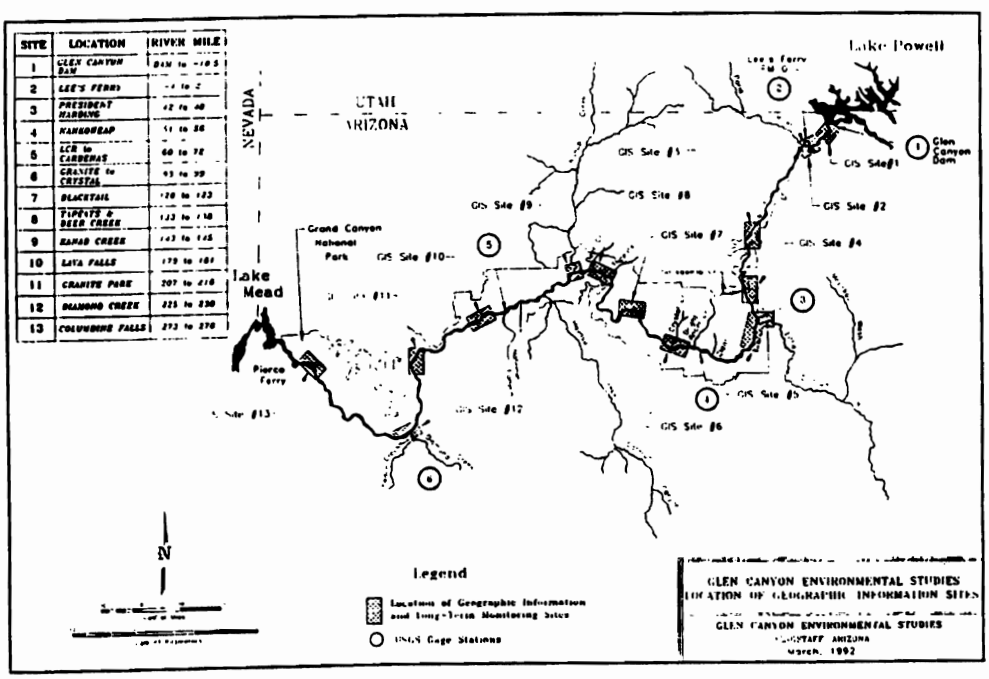

Figure 1. A map showing the location of the 13 GCES monitoring sites along the Colorado River in Glen and Grand Canyon National Parks.

It was determined that a "pilot" survey should be initiated prior to committing the resources to all the thirteen sites. This report focuses on our efforts in developing the data base for the pilot Grand Canyon monitoring site. The Nankoweap Canyon area, site 4, was selected for the pilot because there was considerable historic information available, it was a critical area, and it would provide a good test of the integration needs. The Nankoweap site begins at river mile 51 (according to the U.S. Geological Survey) from Lee's Ferry and ends at river mile 56. The procedures developed and studied for the pilot site will be used on the other twelve sites.

PRODUCTION OF THE LARGE SCALE TOPOGRAPHIC BASE MAPS

Horizontal and vertical control points, which are required to produce accurate base maps, were established using a combination of GPS (Global Positioning System) and conventional surveying techniques. There were very few reliable control points in the bottom of the Grand Canyon. Existing control on the rim was transferred down to the river using GPS technology. Limited time and money and terrain excluded running standard survey level lines down existing trails.

The river bottom is accessible only by floating on the river or by helicopter. It wasn't logistically or administratively possible to move all the control survey party throughout the canyon by helicopter. The targeting and traversing were accomplished by 2 crews each on a large support raft, with a small powered Zodiac boat to run up and down river from each raft location. A Jet Ranger helicopter was used to transport the GPS crew between 46 existing NGS (National Geodetic Survey) control points in the rim area and to the bottom to place 2 monuments on each of the 13 monitoring sites. As the survey crews carried their traverse downstream, they were able to tie the GPS points established for each monitoring site.

The Department of Defense developed GPS to determine the geographical position, anywhere in the world, of military ships, planes, and personnel. Possible civilian use of the technology has been recognized and today surveyors, scientists, city planners, transportation planners, and many others are using GPS on a daily basis to accurately locate important geographic features. Geographical locations are determined by measuring radio signals transmitted from satellites that are 11,000 miles above the earth. The radio signals are received from a minimum of 3 satellites and are measured in terms of how long it takes for the signals to reach a ground receiver. The classical D(distance) = R(rate) X T(time) is calculated by ground receivers. With the position of each satellite known, the latitude and longitude of the ground point can be determined by triangulation. The elevation of a point can be calculated if the radio signals from at least 4 satellites are received. Currently, radio signals from 3 satellites are received during certain times of the day

depending on the world position and the topography. When the full constellation of 21 satellites are in orbit, signal reception will be possible 24 hours a day.

GPS receivers were positioned over existing known Grand Canyon control points on the canyon rim and control was extended to two points per monitoring site in the bottom of the canyon. GPS control points were established at the beginning and end of each monitoring site. GPS receivers have been used for surveying in other areas of the country but this is the first time that GPS technology has been used in environments such as the Grand Canyon where elevation differences between the top and the bottom can be as great as 5,000 feet and the availability of satellite acquisition is limited. Theodolites and electronic distance measuring instruments were used to do traverses between the GPS control points. This process added intermediate control points that were used in producing the base maps.

AERIAL PHOTOGRAPHY

Aerial photography of the GIS sites were collected for the mapping efforts. Flight operations required an unusual amount of coordination and briefing by the NPS (National Park Service). Because of the high density of air traffic over the Canyon due to scheduled air tours and other aerial sightseers, the Federal Aviation Administration has the area designated as a controlled air space. The photo pilots were briefed on operations by the NPS coordinator at Grand Canyon National Park. Radio communication between river crews, flight crews, and anybody else are not possible because of the Canyon effect on radio transmission.

Prior to photography, control panels were placed on both sides of the river at specific sites used as reference points for mapping. The 5X5-foot panels were designed to be recognizable on aerial photographs taken from 3,600 feet above the ground. The monitoring sites were photographed with 1:7,200 and 1:14,400 (orthophotos) scale black and white aerial photographs during June and July, 1990, during a constant flow release of 5,000 cfs. In addition, the entire river corridor of 291 miles was photographed with 1:4,800 scale color infrared to map natural resources. The 1:7,200 scale black and white film was used to produce glass diapositives for use in an analytical stereo plotter. The coordinates of the horizontal and vertical control points were used to scale and level the stereo models. Contour lines, accurate to 1.0 meter, and other features up to the old high water line on both sides of the Colorado River were digitized and plotted as 1:2,400 scale base maps (Figure 2.). The products produced in this process include digital data files and mylar map sheets.

High temperatures, winds and fluctuating water flow all made a difficult project even harder and added risk. For instance, a survey instrument left out overnight on what seemed to be high ground - was swamped with rising river water. The instrument had to be packed out and a

replacement shipped in overnight. On some days the helicopter couldn't operate due to high temperature and drafty wind conditions in the Canyon. At least, the GPS crew could shower and live in air conditioned motel comfort at night, while they computed their observations.

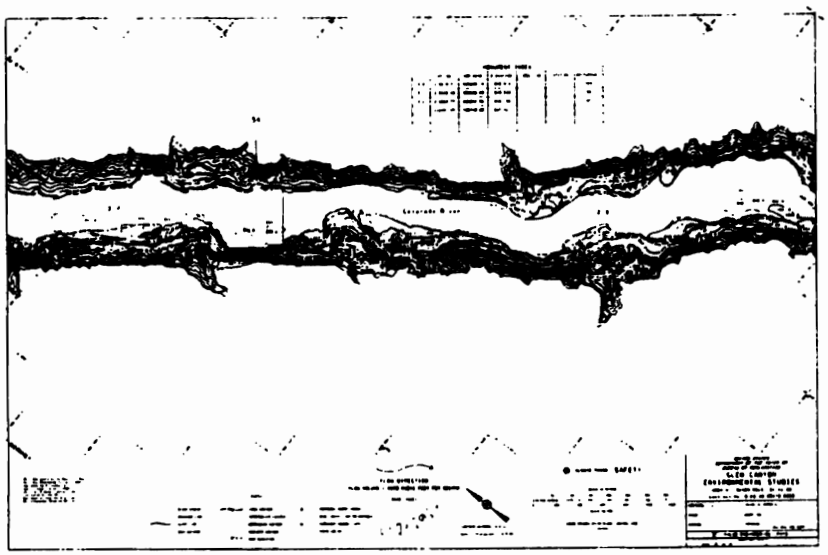

Figure 2. An example of an 1:2,400 map sheet produced for the Nankoweap pilot site.

GIS DATA BASE

A geographic information system is a computer-based system that stores and analyzes information that is georeferenced or has an identified spatial location. The location can be latitude and longitude coordinates of points, lines, or areas. In a GIS the information can be stored, retrieved, manipulated, analyzed, and displayed. Output products can be both tabular and graphic. The GIS software used for the GCES data base is *ARC/INFO. This software is being used by the other resource agencies.

The design of the GCES GIS data base was developed by representatives of the U.S. Geological Survey, National Park Service, and the Remote Sensing and Geographic Information Section. The data base design consists of two components; structure and content. Structure includes the layout of computer directories and the grouping of data. Content includes a listing of the data themes to be included (geology, hydrology, etc.) and the specific classifications of data to be included for each theme (formation, flow velocity etc.).

All ARC/INFO coverages or data layers are to be integrated into a computer directory tree structure under one master directory, called GCES. Two types of sub-directories will be found under directory GCES. They are: 1) a directory

* ARC/INFO is the geographic information system software produced by ESRI, Inc. Mention of this or any other commercial product or vendor is not to be construed as an endorsement by the U.S. Government.

containing basin-wide coverages (sampling sites, climatic monitoring stations, etc), and 2) 14 directories dividing the data base by geomorphic reach. The reaches extend continuously from Glen Canyon Dam to Lake Mead. Under each geomorphic reach will be a subdirectory of monitoring sites encompassed by the reach. Within each of the monitoring site directories will be located subdirectories divided by theme. Within each theme will be the appropriate ARC coverages.

The Remote Sensing and Geographic Information Section has developed a temporary classification scheme to be used until GCES experts can provide their own information for the data base. The GCES is concurrently developing a consolidated Scientific Information Management and Data System. The final information in the data base will be provided by the respective GCES specialist; however, in the interim, the staff of the Remote Sensing and Geographic Information Section will categorize resources to the best of their ability to prevent gaps in the monitoring sites. The purpose of the classification scheme is to identify natural and cultural features that are important to long term monitoring of the river environment. The classification scheme includes such features as new (exotic) and old (native) high water vegetation, cobble bars, riffles, side channels, etc. The 40 categories in the classification scheme are shown in Table 1.

Table 1. Grand Canyon Mapping Classification Scheme

Theme	Type	Classification
Sediment	Travertine ledge	6
	Rock ledge	7
	Alluvial fan	8
	Rock face	9
	Talus slope	10
	Beaches	11
	Camping beaches	11c
	Channel configuration	12
	Surficial geology	13
	Cobble bars	14
	Boulders	15
	Gravel bars	16
	Sand bars	17
	Contours	18
	River miles	19
Terrestrial Vegetation	Other	20
	Native (OHWZ)	21
	Exotic (NHWZ)	22
	Bare soil	23
	Marsh	24
	Endangered species	25

	Seep	26
	Sparsely vegetated slope	27
	Terrace	28
Aquatic Biology	Cladophora	31
	Riffles	32
	Runs	33
	Pools	34
	Backwaters/attribute	35
	Eddys	36
	Open water	37
	Isolated pools	38
	Side channels	39
	Right or Left bank	Right R
		Left L
Recreation	Mooring sites	41
	Lunch spots	42
	Trails	43
	Rapids	44
	Attraction sites	45
	Roads	46
	Indian ruins	47

FIELD VERIFICATION AND TRANSFER

River trips were made during the summers of 1990 and 1991 to map features according to the classification scheme. Emphasis was on mapping the new and old high water vegetation but features such as cobble bars, riffles, and pools were also mapped. The features were delineated on mylar overlays and registered to the 1990 color infrared photographs that were enlarged to 1:2,400 scale. Monitoring sites 1 through 5 were completed in 1990. Sites 6 through 11 were mapped in 1991. Sites 12 and 13 will be mapped in the summer of 1992.

The mapped information was visually transferred to the 1:2,400 scale map sheets on a light table. Natural, cultural, and cartographic information that is in the data base for site 4 include the following: contours, rapids, new high water-old high water (NHWZ-OHWZ) vegetation, camp sites, cliffs, GPS sites, River mile-Stevens, River mile-USGS, cfs-Historical photos, River tributaries, Riffles and pools, Backwaters, Map feature names, Surface flow pattern, Bed material, and Trails. The map sheets were scan digitized for each information category. The resultant digital files were entered into the GCES GIS.

LONG TERM MONITORING USING THE GCES DATA BASE

Once spatial information such as point, line, and areas are encoded and captured into a geographic information system they can be easily stored, retrieved, manipulated, analyzed, and displayed. Land information will be updated when new photography is acquired and interpreted. The

information can be retrieved as either spatial entities or as tabular summaries. For example, all of the beach areas in the monitoring sites could be plotted out or the area of beach area per monitoring site could be provided in tabular form. Inquiries to the data base could be made to locate all campgrounds that occur at a given elevation or find out how beach area has changed comparing one photo date to another. Manipulation processes include but are not limited to the following: changing raster to vector, map projection, and map composition.

One of the more common analysis techniques is overlaying. Multiple data themes or coverages can be overlayed to produce a composite map or a new map. An example of this would be overlaying the amount of beach at 5,000 cfs with the amount of beach area at 35,000 cfs to produce a map depicting the beach area that has been inundated. The amount of exposed beach area and cobble bars at 5,000 cfs vs 35,000 cfs is dramatically different. The amount and change in backwaters, side channels, pools, and riffles resulting in high flow rates are very useful in examining habitat of rare and endangered species such as the humpback chub. Another generated map could show the terrain and vegetation types that are found within a certain radius of an eagle nesting site. Still another use of overlaying would be to superimpose a soils map with vegetation transects to be able to predict where specific vegetation type would occur based on soil type.

The river environment viewed in 3-Dimension can serve as a powerful tool to analyze changes caused by variable flow rates and to get a different perspective of the river environment. The 3-D view is a good way to look at slope, aspect, and measure the surface area of cliffs. The 3-D perspective can be a very effective way to show agencies and individuals what is being monitored and protected in the Grand Canyon.

DISCUSSION

The generated map work for the prototype site 4 has been completed. The maps have index and intermediate contours, creek, map sheet borders, hydrologic features, alluvial fan, talus slope, cobble bars, and sand bars. Overlays show new and old high water vegetation, 1984 bed material, trails, tics, river mileage, and campgrounds.

An initial analysis was completed by overlay analysis to examine the effects of inundation. This includes sand bars, inundated sand bar, beach, inundated beach, cobble bar, inundated cobble bar, 5,000 cfs water line, 35,000 cfs water line, index contours, and creek. Overlay analysis was used to measure areas of features such as sand bar, cobble bar, and beach.

The data base for site 4 has been reviewed by GCES researchers in June, 1991. Representatives from GCES, National Park Service, Navajo Natural Heritage, U.S. Bureau of Reclamation (Salt Lake City), and Arizona Fish and Game were given a demonstration of what was in the data base and

examples of how the GIS could be used to generate new maps by overlay analysis. This will allow for a determination of the effects of variable flow rates on beach areas. The participants gave their approval of the pilot data base. At that time the Remote Sensing Staff was instructed to begin work on the remaining monitoring sites.

A concern on the quality of the initial base surveying was identified during the fall of 1991. A National Park Service geodist notified GCES that the maps in site 5 may not meet National Map Accuracy Standards due to a horizontal and vertical error found in some of the control points used to produce the maps. In order to assess the level of concern the maps for site 1 and 2 were checked to see if they met National Map Accuracy Standards. In November 1991, the easting (x) and northing (y) accuracy of points used to produce the base maps were checked by GPS and conventional surveying. A team from the Arizona Projects Office (APO) resurveyed the control points on the rim and the points down on the canyon bottom. APO ran an open traverse from GPS points at the beginning and end of each monitoring site. They also completed a vertical profile from some of the control points to rivers edge. The accuracy of the control points was well within the tolerance to compile topographic maps with a 1 meter contour accuracy. Upon completion of the analysis it was determined that the maps were found to be within National Map Accuracy Standards.

The map accuracy of site 5 (river mile 60 to 72 which includes the confluence of the Little Colorado with the Colorado River) was checked in February and March of 1992 using the same procedures as site 1 and 2. Again the control points were within the limits to compile topographic maps with a 1 meter contour interval. Analysis of the vertical profiles and map points confirmed this.

FUTURE PLANS AND SCHEDULES

The order of priority for data base development will be sites 1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 12, and 13. Based on the experience gained from prototype site 4 it took approximately 100 person hours to do 1 river mile. This includes all the activities from data preparation to entering the information into the ARC/INFO data base. The activities are as follows:

1. Reviewing hard copy and digital base maps
2. Photo interpretation of native and exotic vegetation and other categories by monitoring site
3. Edit photo interpreted information
4. Transferring interpreted photo information to base maps
5. Digitize base maps by individual category
6. Attributing information
7. Plotting and distributing information to contributors
8. Preparing information received by contributors
9. Transferring information to base maps
10. Scan or manually digitize base maps by category

11. Entering digitized information into the GCES data base
12. Attributing contributed information
13. Disseminating data base to designated users

The tentative plan is to complete sites 1-5 by December 30, 1992 and the other sites by October 15, 1993. This estimate is based on two people working full time on the project and all base maps and data from contributors are delivered on time.

The data base will be delivered as each site is completed. The deliverables will include digital tapes, mylar map sheets for each monitoring site, color infrared aerial photographs, and a final report. The final report will include how the data base was developed and how to use the data base for long term monitoring, special studies, and archival. The data base will be reviewed by GCES and integrated with the GCES Scientific Information Management Data Base.

RECOMMENDATIONS

The pilot site # 4 served as a useful tool in learning how and how not to develop a GIS data base for long term monitoring. Recommendations for developing a GIS data base will be separated into QA/QC (Quality Assurance/Quality Control) of contractors data, data acquisition standards, and GIS data base development.

Products produced by the contractor that include map sheets and digital tapes need to be reviewed both by staff of the Remote Sensing and Geographic Information Section and GCES. The Remote Sensing and Geographic Information Section can find technical photogrammetry and geographic information system errors but the survey and river people of GCES can find location and feature mistakes that only knowledgeable local people could detect.

The first digital files produced by the contractor had some coverages that could be merged into one coverage. For example, the topographic coverage of index and intermediate contours could be merged into one coverage segregated by a unique attribute value. Coverage names between sites should remain consistent for each site. Coverage name for site 4 should be identical for the same coverage in site # 8 and so on.

Data from contributors for site 4 arrived in many different formats and stages of completion. It became readily apparent that standards would have to be set for tape and data format, cartographic representation, interpretation, and map transfer. Standards have since been drafted and will be used when requesting information from contributors. Because of the problems encountered with some of the data that was not photo referenced, all future data must be referenced to aerial photographs or orthophotos that will be provided.

Data base development of site 4 provided a good testing ground for increasing the efficiency and quality of the other 12 sites. Some of the points that were learned or reaffirmed include the following:

1. The data base at this point is site specific and will be expanded to include basin wide development.

2. The GCES GIS data base will be structured to be multi-leveled to include information that is general to very specific.

3. Temporary work spaces set up in the data base structure were found to be very useful in terms of editing.

4. Sensitive data protection methodology needs to be investigated and developed.

5. It is important to know how the data was collected, accuracy standards used, and who to contact if there are any questions in building the data base.

6. The photo interpretation for all sites must be consistent.

7. The data base needs to be user friendly.

8. Scanning is the most efficient method of data entry compared to manual digitizing.

9. All data entry must be checked by an outside party to verify the structure, coverage names, etc.

10. The data base needs to be created in such a way to promote flexibility.

SUMMARY

The data base for the GCES - Geographical Information System (GIS) is being developed for long term monitoring of the Colorado River corridor in the Glen and Grand Canyons. Thirteen (13) sites have been established which are considered selectively representative of the Colorado River. The Nankoweap site was selected as the prototype for developing a concise methodology and streamlining a process for developing the other designated sites. Due to the success of the prototype we consider that the GIS is an effective system to be used in long term monitoring of the riverine ecosystem and with some adjustments in data collection and procedures the systematic approach developed will be used for the remaining 12 sites.

The GCES - GIS data base will be integrated with the GCES Scientific Information Management/Data System being developed from previous and present research in the Colorado River. This approach will serve as the foundation for long term monitoring of the ecosystem in the Glen and Grand Canyons. Information collected by GCES scientists and independent researchers will be entered and analyzed

for use by cooperative agencies and concerned parties. Periodic updates and analysis in the future will be applied to long-term monitoring as part of the Adaptive Management of the Colorado River.

ACKNOWLEDEMENTS

We would like to acknowledge Horizons, Inc.; Banner Associates, Inc.; and David Evans & Associates. Horizons, Inc. was brought on board for mapping the GCES Project in April 1990. Banner Associates, Inc of Grand Junction, Colorado was the survey for establishing control between the GPS points. David Evans & Associates of Portland, Oregon was contracted as a subconsultant to perform GPS surveys which extended the available NGS control from the Canyon rim to 26 selected locations on the Canyon floor.

We would also like to thank Jay R. Carlson and Kathleen Baker of the Remote Sensing and Geographic Information Section for critical reviews of this paper and paper layout, respectively.