THE DEVELOPMENT OF A 97,000 cfs FLOW LINE

WITHIN THE GRAND CANYON

USING GEOGRAPHIC INFORMATION SYSTEM TECHNOLOGY

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Technical Service Center
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Denver, CO

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As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering wise use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. Administration.

The Remote Sensing and Geographic Information Group, organized in 1975, provides assistance and advice regarding the application of remote sensing and geographic information systems (GIS) technologies to meet the spatial information needs of the Bureau of Reclamation and other governmental clients.

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INTRODUCTION

At the request of the Upper Colorado Region, the Bureau of Reclamation=s Remote Sensing and Geographic Information Group (RSGIG) has developed map products available for environmental analysis of the Colorado River downstream of the Glen Canyon Dam. The study area runs from Lees Ferry downstream to Diamond Creek a distance of approximately 226 river miles.

The essential data set that was created in this effort was a geo-referenced, geographic information system (GIS) compatible flow line representing a 97,000 cfs stage release by the Glen Canyon Dam. The 97,000 cfs flow line was then used in conjunction with existing geo-referenced data, (riparian vegetation, and archeological sites) to analyze areas of inundation quantitatively. As a byproduct of the effort, other geo-referenced data was created representing inundated riparian vegetation and archeological sites.

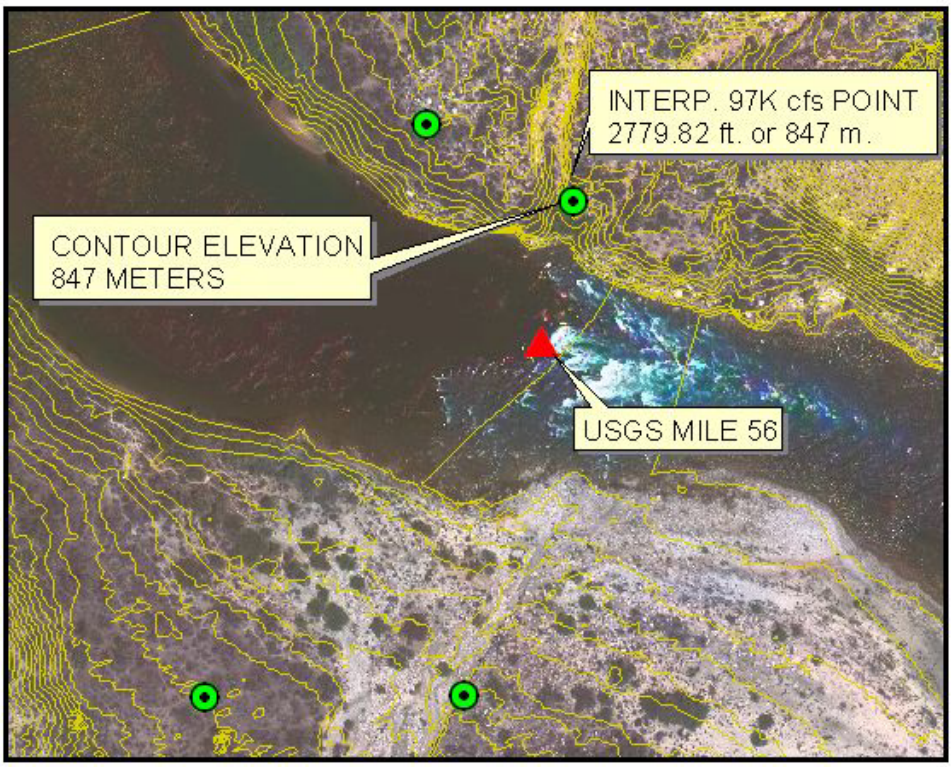
This technical memorandum will briefly discuss the methodology used in the creation of the 97,000 cfs stage release, the existing riparian vegetation and archeological data, the inundation analysis conducted, and the user friendly interface developed to interact with the data sets.

DATA DEVELOPMENT

The estimated flow was produced using a combination of results from the Sediment Transport and River Simulation (STARS) hydrologic model, existing 1 meter LIDAR generated contour data, existing orthophoto data, and interpolation methods.

Water elevation control points representing a stage release of 97,0000 cfs were plotted to a digital base map of the study area by referencing the United States Geological Survey (USGS) river mileage and stage elevation information provided in the STARS tabular output to the existing geo-referenced river mileage and 1 meter topography (figure 1).

FIGURE 1



STARS OUTPUT

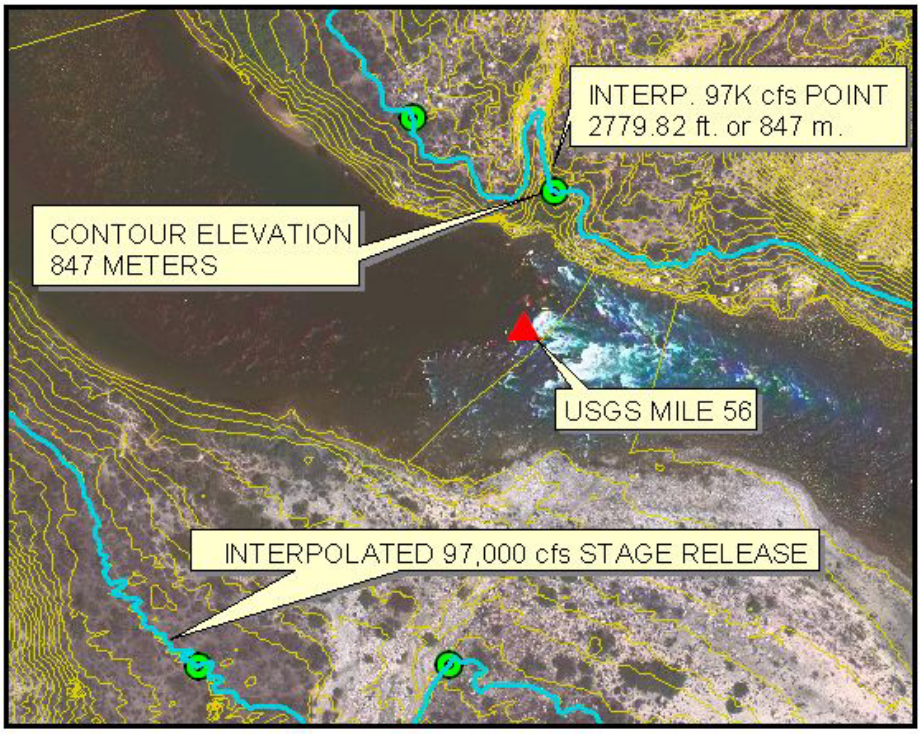
SURFACE ELEV	DISCHARGE	USGS MILEAGE
2776.96	97000	INTERPOLATED AT MILE 56.76
2779.71	97000	INTERPOLATED AT MILE 56.19
2779.82	97000	INTERPOLATED AT MILE 55.99
2788.27	97000	INTERPOLATED AT MILE 55.98
2788.44	97000	INTERPOLATED AT MILE 55.96
2790.02	97000	S-56 AT MILE 54.86

The 97,000 cfs water elevation control point data were digitized wherever the STARS output indicated an elevation change approximately 1 meter or greater. This tended to occur in one river mile intervals with the exception of rapid areas.

It is important to note, in a field comparison of high water marks left by the 1983 Peak Discharge representing flows from 95,000 cfs. to 96,200 cfs. and the STARS computed discharge (Randel & Pemberton 1987), 4 out of the 21 observations were greater than ± 4 feet of the computed discharge, 2 out of the 21 observations were greater than ± 3 feet of the computed discharge, 2 out of the 21 observations were greater than ± 2 feet of the computed discharge, and 13 out of the 21 observations were less than or equal to ± 2 feet of the computed discharge.

Next, using the contour data, the orthophoto background, and the 97,000 cfs elevation points, the 97,000 cfs waterline was digitized (figure 2).

FIGURE 2



STARS OUTPUT

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2790.02	97000	S-56 AT MILE 54.86

A combination of regular vertice-by-vertice line digitizing and stream digitizing was used to create the 97,000 flow line. The waterline started at a particular elevation control point and followed and crossed the contours where geographically appropriate to reach the next 97k water elevation control point. The flow line emulated the curvilinear nature of the contour data as closely as possible.

As with most projects, the generation of the flow line data did not proceed as smoothly as hoped. In the process of developing the flow line, data gaps in available topography were encountered between river miles 134 through 136, 198 through 201, and 206 through 211. By using the photogrammetrically derived ½ meter contour data developed in the early 1990's, the 97,000 cfs flow line data was generated for river miles 134 through 136 and 206 through 211, but a three mile stretch (river miles 198 through 201) within the study area remains incomplete.

An additional two miles of the 97,000 cfs flow line was generated from Lees Ferry up river, to include in the analysis at least some of the sites above river mile 0. Note, the STARS data did not go above river mile 0 and the two miles of flow line above Lees Ferry is only interpolated from the last known water elevation control point, thus this portion of the data set should be used with caution.

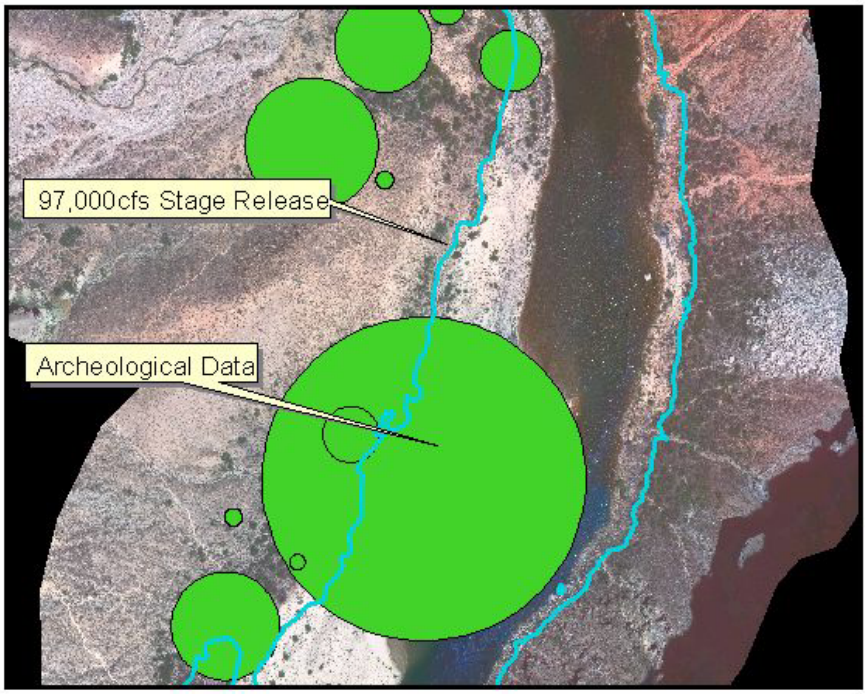
DATA ANALYSIS

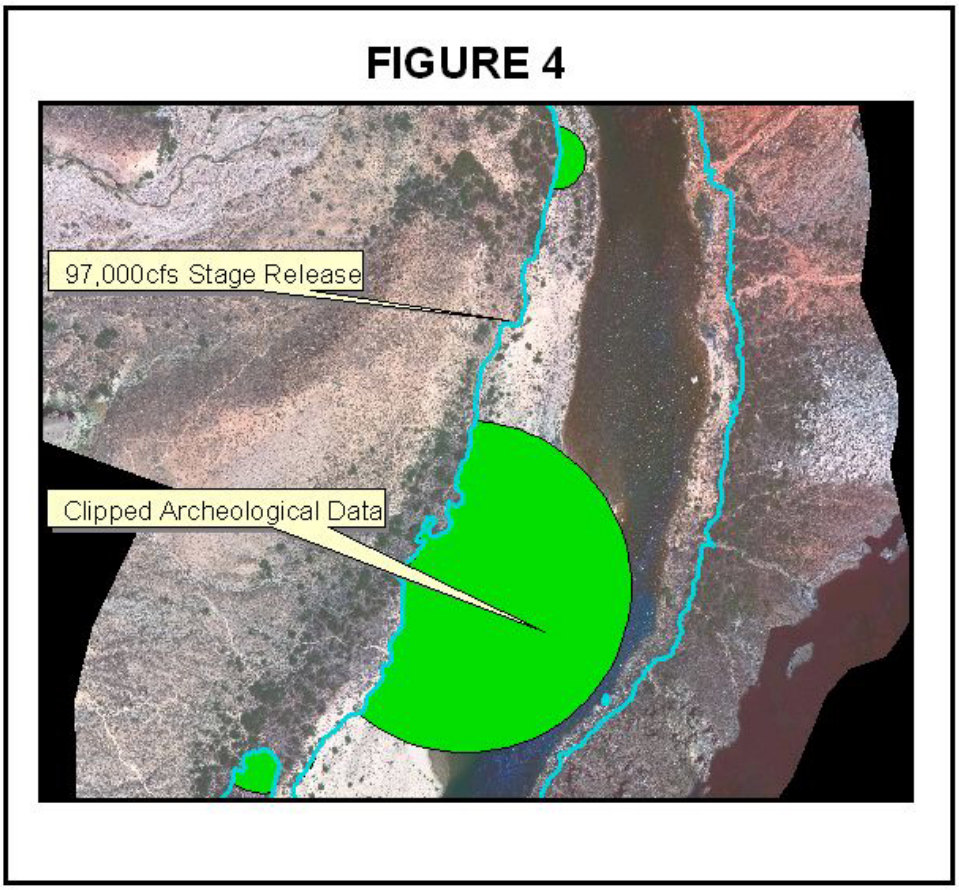
3.1 GIS Functionality

The accepted proposal for this project defined that inundation of riparian vegetation, jurisdictional boundaries, sensitive species and archeological data would be studied. In pursuing the acquisition of these data, it was discovered that the archeological and riparian vegetation data sets were the only comprehensive geo-referenced data currently available. This section will discuss the analysis completed on both of these data sets.

It is necessary to understand the nature of how a GIS can produce analysis on inundation in order to understand the output information. Data being analyzed in a GIS is physical information found on the earth's surface represented digitally by a point, line or polygon. Each of these digital elements is located in space by a common reference grid, defining the term geo-referenced. Because of geo-referencing, the GIS software can overlay multiple data sets and determine their physical relation and proximity to each other. In the inundation analysis being conducted for this project, the GIS was used to calculate the area shared in common between the estimated 97,000 cfs stage release and the archeological and the riparian vegetation data and thus defined inundated areas. For example, the input of flow line data and archeological data was evaluated by the GIS through a clipping function producing a third data set representing only the common area shared by both input data sets (figures 3 and 4).

FIGURE 3





The GIS then calculated the area value for the remaining archeological data and stored this information as tabular attributes for each remaining polygon in the output data set.

All GIS work in this project was either done with the Environmental Systems Research Institute (ESRI) ArcView or ArcMap products. All data sets produced in this project are in ESRI shapefile format in the following cartographic projection:

Projection = Arizona Stateplane
Zone = Central
Datum = NAD83
Units = Meters

3.2 Archeological Sites

Three tabular data sets representing archeology were provided to RSGIS to perform inundation analysis on. Two data sets were provided by the Bureau of Reclamation Upper Colorado Region (UC) that represented point data for the Lees Ferry area and one data set was provided by the Grand Canyon Monitoring and Research Center (GCMRC) representing point data with a numerical area value attributed to most of the sites.

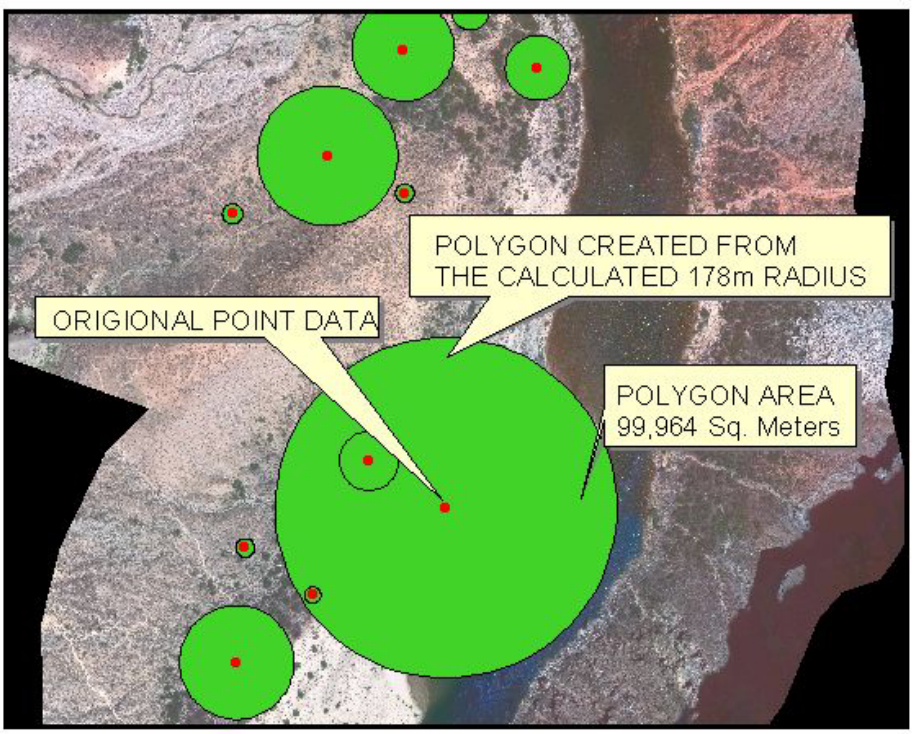
The data contributed by UC were merged and generated into a geo-referenced shapefile by using the coordinate information provided in the tables. The data set provided by GCMRC was also converted into a shapefile in the same way. Sites that did not fall within the designated study area or did fall in the aforementioned gap between river mile 198 and 201 within the stage release data were deleted from both data sets. Two sites within the GCMRC data set had no coordinate values (Sitekey = C:02:109 and C:13:486 unique identifier) and were also deleted.

The archeological data provided by GCMRC contained an area value in square meters for 405 out of the 410 sites within the study area. Consultation with representatives of GCMRC and UC determined that it was accepted practice to convert these points into circular polygon data by buffering the calculated radius and using the output polygonal data for the inundation analysis. The radius for the buffer function was calculated as follows:

$$\mathbf{R} = \sqrt{\frac{\mathbf{A}}{\mathbf{\Pi}}}$$

The buffering operation was used to create a polygonal data set representing the GCMRC contributed sites (figure 5).

FIGURE 5



A separate point data set was created for the remaining five sites that had no area value.

Both the UC contributed point data and the GCMRC point and polygon data were clipped by the 97,000 cfs stage release data as described in section 3.1.

General statistics for the output/inundated archeological data sets:

1) GCMRC contributed polygon data
   405 original polygons = 1,168,860 sq meters in area
   177 polygons inundated = 377,834 sq meters in area
      100 of these polygons inundated completely = 48,463 sq meters in area
      77 of these polygons inundated partially = 329,371 sq meters in area

2) GCMRC contributed point data within study area:
   G:03:08 = inundated
   B:15:138 = not inundated
   B:15:100 = not inundated
   C:13:387 = not inundated
   C:13:386 = inundated

3) UC contributed point data within study area:
   None of the 29 point sites within the study area were inundated

3.3 Riparian vegetation

A limited amount of applicable riparian vegetation data was available for the inundation analysis. In evaluating the existing riparian vegetation data for the study area, it was determined that the most current and comprehensive in terms of the amount of study area covered would be the data set created by Dr. Gwendolyn L. Waring, School of Forestry, Northern Arizona University. These data were created for the riparian vegetation trend analysis report submitted to Glen Canyon Environmental Studies in the report titled "Current and Historical Riparian Vegetation Trends in the Grand Canyon, Using Multitemporal Remote Sensing Analysis of GIS Sites".

The riparian data set represents the existing conditions of New High Water Zone (NHW), the Old High Water Zone (OHW) and Tara vegetation classes that existed in 1992 at a flow regime of 8,000cfs. The NHW zone vegetation follows the banks of the river extending up to the OHW zone at approximately the elevation that represents the 120,000 cfs pre-dam flooding. The NHW zone consists primarily of coyote willow and tamarisk. The OHW zone represents hackberry, Apache plume, honey mesquite and catclaw acacia (figure 6). Tara is defined as tamarisk found in the OHW zone. The 1992 riparian vegetation data set does not cover the complete study area but is available for five of the original GCES long term monitoring (LTM) sites:

1) LTM Site 2 = river miles -2 to 2
2) LTM Site 4 = river miles 51 to 56
3) LTM Site 5 = river miles 60 to 72
4) LTM Site 8 = river miles 133 to 138
5) LTM Site 10 = river miles 179 to 181

FIGURE 6

The vegetation data was merged into a single shapefile and clipped for inundated area by the same process as described in section 3.1.

General statistics for the output/inundated riparian vegetation data sets:

1) Original riparian vegetation data set
   A. All classes a total of 12,461 polygons = 2,339,009 sq meters in area
   B. OHW zone a total of 7,586 polygons = 1,261,029 sq meters in area
   C. NHW zone a total of 4,754 polygons = 1,026,616 sq meters in area
   D. Tara a total of 121 polygons = 51,364 sq meters in area

2) Inundated riparian vegetation data set
   A. All classes a total of 6,798 polygons = 1,132,240 sq meters in area
   B. OHW zone a total of 2,298 polygons = 205,690 sq meters in area
      16% of total OHW zone inundated
   C. NHW zone a total of 4,406 polygons = 892,630 sq meters in area
      87% of total NHW zone inundated
   D. Tara a total of 94 polygons = 33,920 sq meters in area
      66% of the total Tara inundated

USER FRIENDLY INTERFACE

4.1 Interface Logic

Historically the final product in a project similar to this would be a compact disc (CD) containing the base data and a report containing a series of hard copy map plots and tables representing changes pre and post inundation. Given that the archeological data represents over 400 sites distributed linearly along approximately 226 miles of the Colorado River, the number of hard copy maps at a scale that would depict the results properly would most likely exceed 200.

The utility and power of the data produced from this work can be derived through real-time interaction with the digital data. It is for this reason that a user friendly interface to the data set was developed and provided with this report.

The interface was developed to be accessed through the ESRI public domain ArcReader software. ArcReader provides the user many of the simplistic yet powerful tools available in a GIS without the costs involved in training and purchasing a GIS system. It is important to note at this point that if the functionality of ArcReader does not provide the analytical tools needed, the data provided with this report are fully functional within full blown GIS software's.

4.2 Software Installation

The CD provided in this report contains both the data derived from this work as well as the ArcReader software. ArcReader requires Microsoft Window NT 4.0, Microsoft Windows 2000 , or Microsoft Windows XP. It is not for Windows 98SE or Windows Millennium. It is necessary to load the ArcReader software onto your PC hard drive but installation can be accomplished with these few steps:

1) Load CD onto your PC
    a. Click "START" on the Windows taskbar.
    b. Click "RUN"
    c. Click "Browse" and navigate to the CD and open the ESRISOFT folder
    d. Select "ESRI.exe"
    e. Click "Run"
2) Click on "Install ArcReader"
   Feel free to query the "Before You Install" and "Using Arc Reader" windows
3) Click on "Install ArcReader" within this window
   Give the install time to run its course
4) At the "Welcome to the ArcReader Setup Program" window click "Next"
5) Read the license agreement and if you agree click the "I accept the license agreement" button and click "Next"
6) Click the "Complete" installation button and click "Next"
   This will give the option to run through the ArcReader tutorial if you wish.
7) Select the default destination folder or browse for a new one and click "Next".
8) Click "next" to start the installation
9) Click "Finish" to complete the installation

ArcReader can access the stage release interface directly off the CD provided although it runs slowly. If you want the interface to run quickly it is best to copy the 97k folder from the CD to your Hard drive.

4.3 Interface Use

Although ArcReader is somewhat intuitive, at this point it is recommended to complete chapter two in the ArcReader tutorial "Using_ArcReader_and_ArcGIS.pdf" located on the provided CD under ESRISOFT\ArcReader\Documentation. Note, you will need Adobe Acrobat reader capabilities!

To start ArcReader and invoke the interface:
1) Click "Start" on the Windows taskbar
2) Click "Programs", point to "ArcGIS", and click on ArcReader.
3) Once ArcReader is up, click the "File" pulldown menu and select "Open"
4) Navigate to and open the 97k folder either on the CD or where copied to hard drive
5) Open the "Publish" folder and select 97kflow.pmf

This process should start the interface. Get to know the functionality of the software by moving the cursor over buttons and invoking a popup window with a brief description of its utility. The interface gives the user the ability to ZOOM, PAN, QUERY, PRINT and more. To the left of the main viewing window are the data sets available to the interface:

1) Site Locations are a combination of points representing all of the site data contributed to this project. The significant attribute associated with these data are the location coordinates.
   The symbology for these data are designed to disappear once the user zooms to a scale 1:30,000 or larger.

2) USGS 10R_Mile are the USGS river mile markers at 10 mile increments. The significant attribute associated with these data are the USGS river mileages. The symbology for these data are designed be displayed at a scale of 1:100,000 and to disappear once the user zooms to a scale 1:20,000 or larger.

3) USGS 1R_Mile are the USGS river mile markers at 1 mile increments. The significant attribute associated with these data are the USGS river mileages. The symbology for these data are designed to disappear once the user zooms to a scale 1:200,000 or larger.

4) Glen Canyon Point Sites are the point data representing the archeological sites contributed by UC in the Lees Ferry area. The significant attributes associated with these data are the location coordinates and the unique identifier of "Sitekey".
   The symbology for these data are designed to display once the user zooms to a scale 1:100,000 or larger.

5) Non-Area Point Data are the point data representing archeological sites contributed by GCMRC w/o area values. The significant attributes associated with these data are the location coordinates, the unique identifier of "Sitekey" and inundated (yes or no field indicating inundation).
The symbology for these data are designed to display once the user zooms to a scale 1:100,000 or larger.

6) Inundated Area Sites are the polygons represent the inundated areas of archeological data provided by GCMRC. The significant attributes associated with these data are the preclipare (the area value for the site before inundation analysis) and the postclipar (the area value for the site after inundation analysis).
The symbology for these data are designed to display once the user zooms to a scale 1:100,000 or larger.

7) Area Sites are the polygons representing the buffered areas of archeological data provided by GCMRC. The significant attribute associated with these data is the preclipare (the area value for the site before inundation analysis).
The symbology for these data are designed to display once the user zooms to a scale 1:100,000 or larger.

8) 97,000 cfs Flow Line represents the 97,000 cfs stage release developed by RSGIG. The significant attribute associated with these data is the surface area value associated with the polygons representing the flow.

9) 1992 Vegetation represents the pre-stage release vegetation at 8,000 cfs. The significant attributes associated with these data are vclass, density and area.
The symbology for these data are designed to display once the user zooms to a scale 1:100,000 or larger.

10) 1992 Inundated Vegetation represents the inundated vegetation at 97,000 cfs. The significant attributes associated with these data are vclass, density and area.
The symbology for these data are designed to display once the user zooms to a scale 1:100,000 or larger.

This is a brief summary of the data available in the interface. For a more detailed description refer to the "Data Dictionary" found in Appendix I. Again note, if the functionality of ArcReader does not provide the analytical tools needed, the data provided with this report is fully functional within most full blown GIS software.

SUMMARY

In summary, the essential data set that was created in this effort was a geo-referenced, geographic information system (GIS) compatible flow line representing a 97,000 cfs stage release by the Glen Canyon Dam. The 97,000 cfs flow line was then used in conjunction with existing geo-referenced data, (riparian vegetation and archeological sites) to analyze areas of inundation quantitatively. As a byproduct of this effort, other geo-referenced data was created representing inundated riparian vegetation and archeological sites.

It is important to recognize that the 97,000 cfs stage release data developed in this project is dynamic and can be used now and in the future. The inclusion of 97klinemetadata.txt a Federal Geographic Data Committee compliant document describing the details of the data will ensure this. The provided user interface gives the researcher many of the utilities that are required to access and manipulate the GIS, thereby avoiding the cumbersome aspect of a multitude of hard copy map sheets and associated costs.

APPENDIX I

DATA DICTIONARY

1) **Sitelocationstp832.shp =** a combination of points representing all of the site data contributed to this project.

Interface name = Site Locations

Format: Point shapefile

Entity & Attributes Fields:
Sitekey = unique site identifier
X_coord = Stateplane X coordinate
Y_coord = Stateplane Y coordinate

Meta data file: NA
Location: \97K\sitedata

2) **USGS_mile =** the USGS river mile markers at 1 mile increments.

Interface name = USGS 10R_Mile/ USGS 1R_Mile

Format: Point coverage

Entity & Attributes Fields:
Rivermile = river mileage

Meta data file: metadata.xml
Location: \97K

3) **Leeferrystp83.shp =** the point data representing the archeological sites contributed by UC in the Lees Ferry area.

Interface name = Glen Canyon Point Sites

Format: Point shapefile

Entity & Attributes Fields:
- Site = unique site identifier
- Desig1 = ?
- Desig2 = ?
- Desig3 = ?
- Desig4 = ?
- Locality = ?
- Mquad = quad name
- X_coord = Stateplane X coordinate
- Y_coord = Stateplane Y coordinate
- Inundated = yes or no indicator of inundation

Meta data file: none
Location: \97K\sitedata

4) **Gcra83pnt.shp =** the point data representing archeological sites contributed by GCMRC w/o area values.

Interface name = Non-Area Point Data

Format: Point shapefile

Entity & Attributes Fields:
- Sitekey = unique site identifier
- X_coord = Stateplane X coordinate
- Y_coord = Stateplane Y coordinate
- Inundated = yes or no indicator of inundation

Meta data file: none
Location: \97K\sitedata

5) **Polyclip3.shp =** polygons representing the inundated areas of archeological data provided by GCMRC.

Interface name = Inundated Area Sites

Format: Polygon shapefile

Entity & Attributes Fields:
Sitekey = unique site identifier
X_coord = Stateplane X coordinate
Y_coord = Stateplane Y coordinate
Sitearea = original area value assigned to site
Bufferm = calculated buffering distance
Preclipare = area calculated for pre-inundation
Postclipar = area calculated for post-inundation

Meta data file: none
Location: \97K\sitedata

6) **Grca83poly2.shp =** polygons representing the areas of archeological data provided by GCMRC.

Interface name = Area Sites

Format: Polygon shapefile

Entity & Attributes Fields:
Sitekey = unique site identifier
X_coord = Stateplane X coordinate
Y_coord = Stateplane Y coordinate
Sitearea = original area value assigned to site
Bufferm = calculated buffering distance
Preclipare = area calculated for pre-inundation
Meta data file: none
Location: \97K\sitedata

7) **Line97kpolyc.shp =** polygons representing the generated 97,000 cfs stage release

Interface name = 97,000 CFS Flow Line

Format: Polygon shapefile

Entity & Attributes Fields:
Area = area calculated for surface area of polygons
Meta data file: 97klinemetadata.txt
Location: \97K\flowlinedata

8) **Vegetation.shp =** polygons representing pre-stage release vegetation at 8,000 cfs

Interface name =1992 Vegetation

Format: Polygon shapefile

Entity & Attributes Fields:

Area = area calculated for polygons
Perimeter = perimeter of polygons
Density = estimated canopy cover density
1 = 0-20%
2 = 21-40%
3 = 41-60%
4 = 61-80%
5 = 81-100%
Vclass = vegetation class
OHW = old high water zone
NHW = new high water zone
Tara = tamarisk in OHW
O = Open area

Meta data file: None
Location: \97K\vegetation

9) **Innunvegetation.shp =** polygons representing pre-stage release vegetation at 8,000 cfs

Interface name =1992 Inundated Vegetation

Format: Polygon shapefile

Entity & Attributes Fields:

Inunarea = area calculated for remaining polygons after clipping
Perimeter = perimeter of polygons
Density = estimated canopy cover density
1 = 0-20%
2 = 21-40%
3 = 41-60%
4 = 61-80%
5 = 81-100%
Vclass = vegetation class
OHW = old high water zone
NHW = new high water zone
Tara = tamarisk in OHW
O = Open area

Meta data file: None
Location: \97K\vegetation