2004 Lower Colorado Region Vegetation Type Mapping, Backwaters Delineation, Orthophotography, and GIS Development

Prepared for:
U.S Bureau of Reclamation
Boulder City, Nevada

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Executive Summary

In July 2004, as part of an ongoing effort to protect endangered species and native habitat, the Bureau of Reclamation, Boulder City Office, contracted with BIO-WEST, Inc. (BIO-WEST), of Logan, Utah to: (1) provide an update to the riparian and marsh vegetation classification within the Lower Colorado Region, which was last mapped in 1997, (2) delineate and type map previously unmapped riparian corridors, (3) update the delineation of backwaters last mapped in 2000, and (4) delineate backwaters previously un-delineated. This project included Phase I: Generation of New Digital Orthophotography, and Phase II: Classification of Riparian and Marsh Vegetation, Delineation of Backwaters and GIS Development.

BIO-WEST subcontracted the orthophotography and geographic information system (GIS) portion of the project to GEO/Graphics, Inc. (GEO/Graphics), of Logan, Utah. GEO/Graphics worked in conjunction with 3001, Inc., of New Orleans, Louisiana, and Bohannan Huston, Inc. of Albuquerque, New Mexico to develop new orthophotography for the Lower Colorado Region. Final products include high-quality, 1-foot resolution color infrared (CIR) and natural color (RGB) orthophoto mosaics tiled to map sheets (465 per image format) and clipped to the project area boundary for the entire project area of 1,790 square miles.

BIO-WEST classified riparian and marsh vegetation from July 2005 through March 2006 using the newly developed 2004 CIR orthophotography as the base layer. The Anderson-Ohmart method of classification (Anderson and Ohmart, 1976) was used to classify vegetation along the lower Colorado, Virgin, Bill Williams, and Gila Rivers. Based on previous mapping efforts (CH2MHill 1999) and current project requirements, additional classes were added to capture non-riparian features. These included Agriculture (AG), Open Water (OW), Structured Open Water (SOW), Backwater (BW), Undeveloped Bare Ground (UD), and No Classification (NC). Phase II also involved delineation of backwaters and the development of modern GIS layers, as well as field verification of the 2004 Cottonwood-Willow (CW) classification and adjacent polygons.

The vegetation community boundaries of the 2004 classification proved to be much more detailed and precise than the 1997 classification. The accuracy assessment indicates a community level overall accuracy of 72 percent. Lumping structure types into groups (i.e., I and II, III and IV, V and VI) across the communities types reveals an overall accuracy of 68 percent at the combined structural types. At the community and structural type-level the overall accuracy is 51 percent. The initial accuracy assessment of the CW communities indicates a community classification accuracy of 60 percent and a type classification accuracy of 37 percent. Systematic errors at the CW type level were identified and a correction factor was applied. The corrected type-level accuracy for the CW community is 61 percent. At the CW community level, differences between the 1997 and current mapping represent an increase of 197 acres of CW when considering identical mapping extent. The most significant differences between the two data sets can be found at the type level (types III, IV, V). Total reported acreage for area delineated as BW is 4,476 acres.

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Background and Purpose

In July 2004, BIO-WEST, Inc. (BIO-WEST), began a project to update vegetation type maps within the riparian zone of the lower Colorado River and designated sections of its tributaries. Specifically, the project included updating the 1997 classification of marsh and riparian vegetation and habitat types, delineation of backwaters, and the expansion of the mapping effort into areas previously unmapped within Lower Colorado Region. Riparian and marsh vegetation were characterized using the classification scheme first devised by Anderson and Ohmart (1976). Periodic updates using this classification system have been conducted along the lower Colorado River to help monitor changes in this important riparian ecosystem (Anderson and Ohmart 1984a, Yonker and Andersen 1986, USBR 1996, CH2MHill 1999). Since implementation of the lower Colorado River MSCP began in 2005, this 2004 update is necessary to document baseline conditions at the beginning of the MSCP.

In the mid-1980s, BIO-WEST conducted a study for Reclamation of the backwaters along the Colorado River between Davis Dam and the Southerly International Boundary (SIB) with Mexico. BIO-WEST mapped existing backwaters and developed a model to classify general wildlife and fish habitat values for these backwaters (Holden et. al. 1986). These backwater maps were updated in 2000. The mapping and classification system developed during these studies have allowed Reclamation to determine the extent of backwaters, assess existing backwaters for habitat value, and determine factors necessary for constructing backwaters for wildlife and fish. The 2004 delineation effort updates the backwaters maps and identifies additional backwaters in previously unmapped areas.

Under the auspices of the MSCP, Reclamation must restore over 8,000 acres of riparian, marsh, and backwater habitats to provide habitat for 26 covered species. To design habitats for these species, habitat requirements for each species must be determined. Once habitat requirements are determined, criteria will be developed to rate backwater habitat values for MSCP covered species. The newly generated high-resolution orthophotography and updated vegetation mapping will help Reclamation achieve the above mentioned requirements as established under the MSCP.

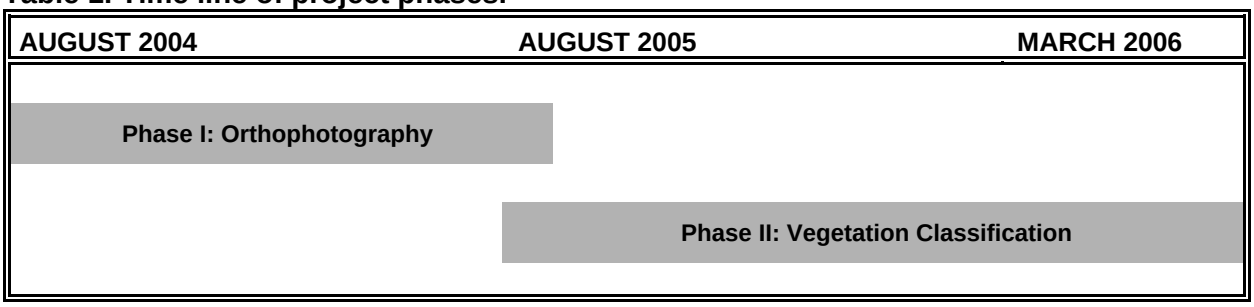
Introduction

This project exceeds the scope of previous classifications of the riparian and marsh vegetation along the lower Colorado River (Anderson and Ohmart 1984a, Yonker and Andersen 1986, USBR 1996, CH2MHill 1999) by developing orthophotography specifically for the project. This project also classifies riparian and marsh vegetation previously unmapped in the Lower Colorado Region. Unlike previous studies, this project combines the delineation of backwaters including areas that have not been previously delineated.

Because of the major effort involved in the generation of 1-foot pixel resolution orthophotography, this project was logically divided into two phases. Phase I consists of the

generation of new orthophotography. Phase II consists of the classification of riparian and marsh vegetation, delineation of backwaters, and geographic information system (GIS) development. Each phase is described separately in this document. The orthophotography phase is described in the next section, followed by the delineation and classification phase. Because the orthophotography provided the base for the delineation and classification it was necessary to complete Phase I before beginning Phase II (Table 1).

Table 1. Time line of project phases.



Phase I: Orthophotography Generation

Introduction: Orthophotography Generation

The first major component of the 2004 effort was the generation of the new orthophotography that would be used as the base layer for vegetation mapping and backwater delineation. The generation of orthophotography is a complex process that involves many steps, which are illustrated in Figure 1. Only with the right training and technology is it possible to create highly accurate orthophotography in a cost- and time-effective manner. The process used by GEO/Graphics, Inc. (GEO/Graphics), applied the best and latest technologies available to provide the highest quality products.

Project Area

The project area consists of an approximately 600-mile-long riparian corridor that includes the lower Colorado River from the Southerly International Boarder (SIB) with Mexico north to Separation Rapid in the Grand Canyon, including the shorelines of Lake Havasu, Lake Mohave, and Lake Mead along with the Virgin River from Lake Mead to Little Field, Arizona; the Bill Williams River from Lake Havasu to Alamo Lake; and approximately 9 miles of the lower Gila River (Figure 2). The total area was 1,790 square miles and required 2,400 photo frames to cover the area with a 1-foot pixel resolution for each data format, for a total of 4,800 photos.

Methods: Orthophotography Generation

Since every orthophotography project is unique and possesses its own set of challenges, the methodology for each project calls for special considerations. The main challenges this project faced were an enormous project area (1,145,841 acres), the need for high-resolution imagery (1-foot pixel resolution), and the need for two image formats (color infrared [CIR] and natural color [RGB]) that required the capture and processing of a daunting 4,800 images.

Given these challenges, the following issues were addressed: 1) how to conduct a cost- and time-effective ground control survey across an extremely large and remote environment, and 2) how to manage the copious amounts of data associated with this project. To address the first issue it was decided that the direct georeferencing method of orthorectification would be used. Available now for almost a decade, this technique is fast becoming the industry standard. Among its many advantages, direct georeferencing significantly reduces the amount of ground control needed for orthorectification (Artes and Hutton 2005). In light of the second concern, a considerable amount of time and effort was invested in the data management aspects of the project. During the height of processing there were approximately 10 terabytes of data on our system solely associated with this project. The data were stored on two servers specifically purchased and exclusively used for the project. One server mirrored the data contained on the other server, providing an effective means of backing up the data. All data transferred between

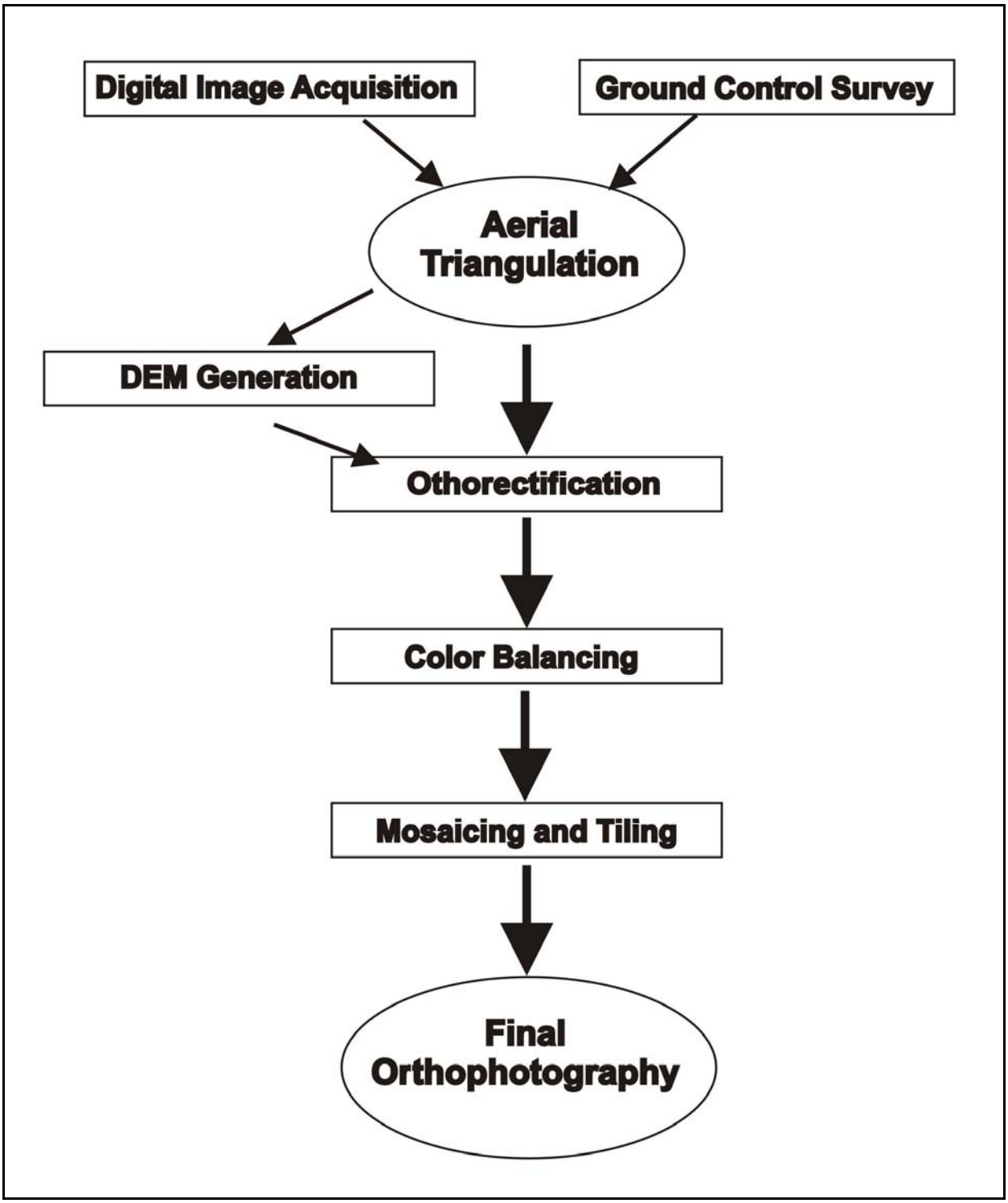


Figure 1. Schematic of the orhtophotography workflow.

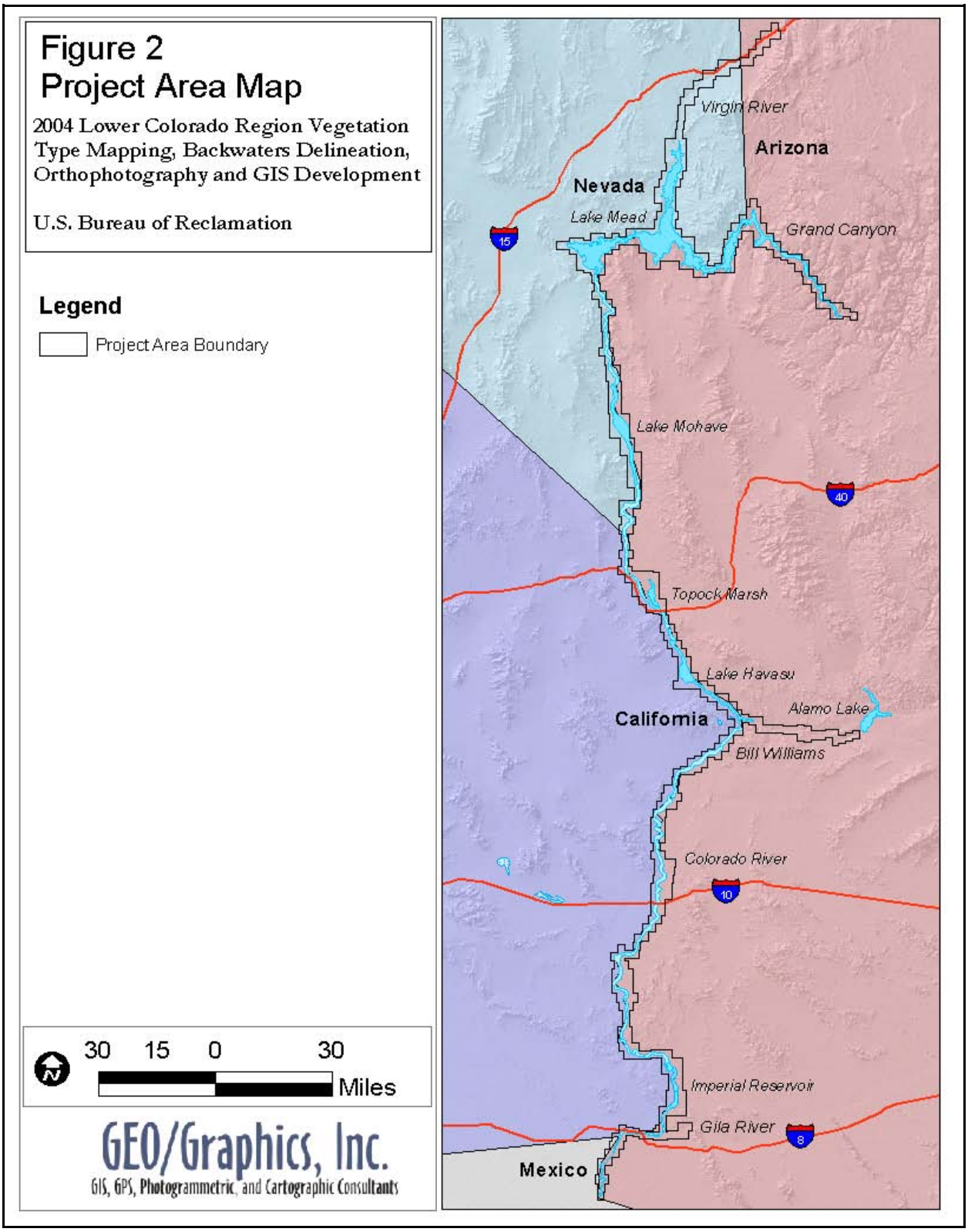


Figure 2. Project area map.

subcontractors was done with either 500 gigabytes or 250 gigabytes external drives. Data management workflows were developed to ensure efficient data processing and data integrity. To make data more accessible, image mosaicing and tiling were utilized.

The following steps were followed to create the 2004 orthophotography: digital image acquisition; ground control survey; aerial triangulation; digital elevation model (DEM) generation; orhtorectification; and color balancing, mosaicing, and tiling. Each of steps is described in detail below.

Digital Image Acquisition

Aerial image acquisition occurred August 2-28, 2004, and was captured by 3001, Inc. A total of 4800 images were collected (2,400 CIR and 2,400 RGB). Imagery was collected during optimum daylight conditions when the sun angle was more than 30 degrees above the horizon. Flight operations were postponed during cloudy, hazy, or dusty conditions, or when conditions presented a risk to the flight crew.

3001, Inc., used the most cutting-edge technology available for image acquisition. Digital aerial imagery was captured using an Intergraph Z/I Imaging Digital Mapping Camera (DMC). The DMC is the most innovative and precise digital camera system on the market (Intergraph Earth Imaging and Photogrammetry 2006).

On-board GPS and IMU Technologies

An on-board Inertial Measurement Unit (IMU) recorded camera orientation (kappa, phi, and omega) and Airborne Global Positioning System (ABGPS) receiver recorded x, y, and z coordinates at the mid-shutter pulse. Prior to and during all aerial imagery acquisition, a global positioning system (GPS) ground station was monitored at an existing first-order (horizontal and vertical) control point (Figure 3). This point supplied correctional GPS information used in the post processing of the final ABGPS data. The aerial mission was conducted using the custom-designed TFlight on-board flight navigation system. This system allowed the pilot to monitor the track of the aircraft over the established flight lines and automatically fired the camera at established image centers.

Following aerial acquisition operations, all ground station GPS, ABGPS and IMU data were downloaded for rigorous, least squares post processing and final adjustment. The project manager at 3001, Inc., reviewed the captured imagery for complete coverage of the project area and data integrity.

Figure 3. Survey-grade GPS set-up on aerial survey panel.

Direct Georeferencing

The Position and Orientation System – Airborne Vehicles (POSAV) system, a hardware and software system specifically designed for direct georeferencing of camera data, was used during the aerial acquisition. By integrating precision GPS with inertial technology, POSAV enables the direct measurement of camera position and orientation without the need for large numbers of ground control points (GCPs) over the project area (Figure 4). This system also streamlines the aerotriangulation process by directly calculating the exterior orientation parameters (Applanix Inertial Geospatial Solutions 2006).

Ground Control Survey

ABGPS and IMU technologies greatly reduced but did not eliminate the need to collect ground control points. Therefore, GEO/Graphics conducted the ground control survey immediately prior to the aerial acquisition. Aerial survey panels were placed at key locations such as the start and end of flightlines throughout the project area. Each panel location was occupied with a survey grade GPS unit for a minimum of 2 hours.

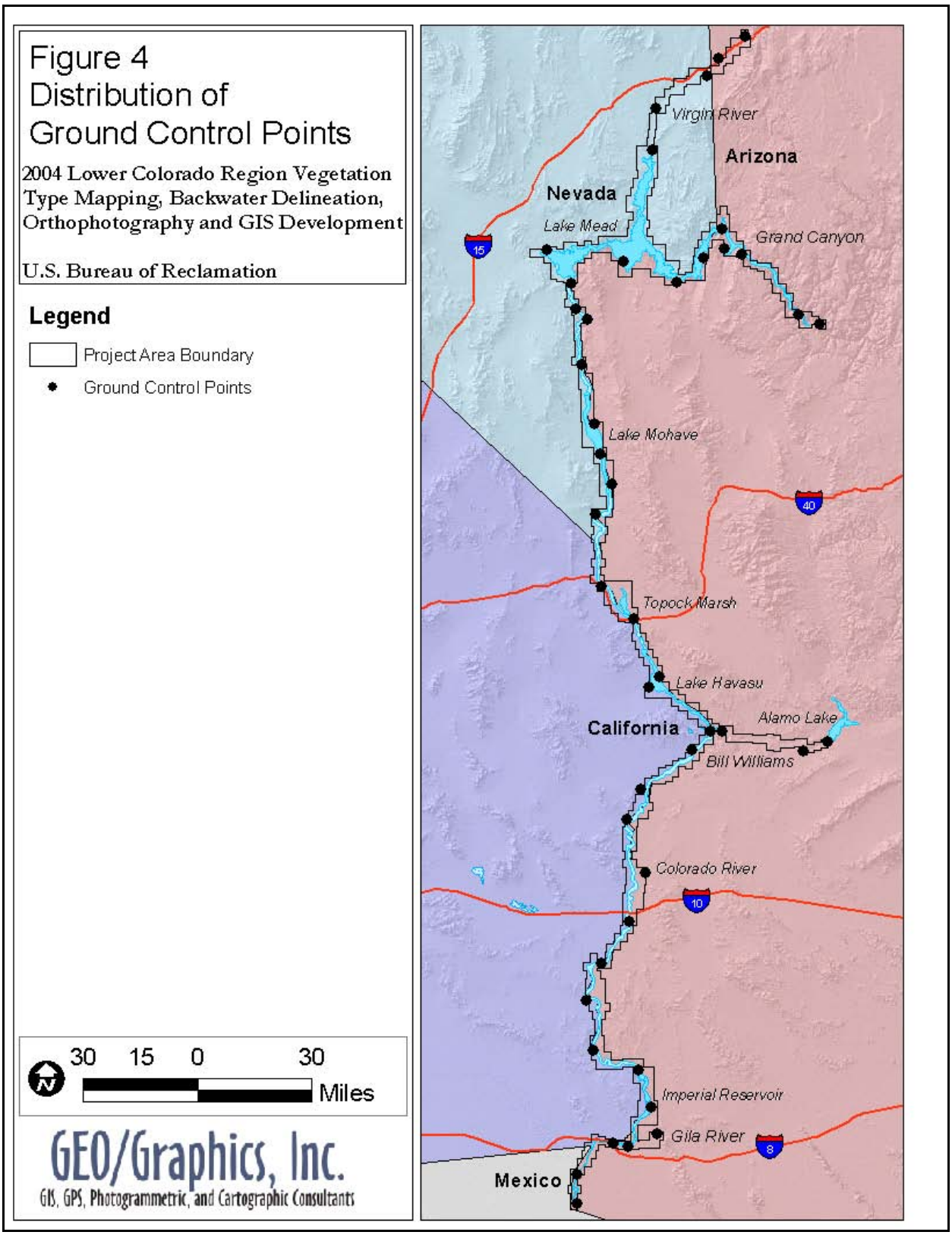


Figure 4. Distribution of ground control points (GPCs).

The positional data collected by the GPS unit were sent to the National Geodetic Survey for post-processing. The accuracy of the GPS collections was calculated at an overall root mean square (RMS) error of 0.03 meter. The GPS control data were then ready for input into the aerial triangulation process, as described in the next section. A total of 45 GCPs were distributed across the project area (Figure 4), far fewer than the approximately 800 GCPs that would have been required without the use of direct georeferencing provided by the use of ABGPS and IMU technologies. Collection of 800 GCPs in this environment would have taken several months of field work and in some cases would not have been practical or possible because of the remote and rugged nature of portions of the project area.

Aerial Triangulation

Even though exterior orientation parameters were calculated with ABGPS and IMU technology, these calculations are not sufficient on their own to reliably convert image coordinates to ground coordinates. By using GCPs collected in the field, reverse calculations were made to verify and support the parameters collected with ABGPS and IMU technologies.

Bohannan Huston, Inc., used Fully Automated Aerial Triangulation (FAAT) software for the block adjustment of the imagery (Intergraph ISAT v4.3). The processed ABGPS and IMU information for each image were imported and preliminary camera station locations were generated. Once the preliminary solution was generated, the GCPs were densified between each model and between adjacent flight lines. Measurement residuals were recorded and a report generated for review by a senior photogrammetrist and the project manager. Discrepancies were investigated and corrected, and a final FAAT solution was generated. Bohannan Huston delivered raw digital imagery and final exterior orientation parameters (x, y, z, kappa, phi, omega) to GEO/Graphics for digital elevation model (DEM) generation and the development of digital orthophotography.

Digital Elevation Model (DEM) Generation

To improve the relative horizontal accuracy of the orthophotography, new DEMs were created based on the newly acquired imagery instead of using existing United States Geological Survey (USGS) DEMs that are based on another aerial flight. Deserts, such as those of the lower Colorado River environment, pose challenging problems for creation of DEMs because of their combination of high terrain relief and low color contrast. These issues were resolved by applying proper extraction strategies in ERDAS IMAGINE OrthoBASE Pro. Ten-meter DEMs were automatically extracted as mass points using a custom strategy. The resulting spatially accurate DEMs were input into the orthorectification process.

Orthorectification

All aerial photography is subject to distortions resulting from the orientation of the aircraft, the shape of the lens, and the Earth's relief. Orthorectification is the process of removing the geometric errors inherent in the aerial photography. The main variables contributing to

geometric errors are camera orientation and topographic relief displacement. The effects of camera orientation are reduced using direct georeferencing and during the aerial triangulation process. The effects of topographic relief displacement are accounted for by using a DEM during the orthorectification process (ERDAS 2001). Digital orthophotography was derived using the aerial triangulation solution and the newly derived DEMs.

Color Balancing, Mosaicing, and Tiling

Color-balancing attempts were made to correct variations within each individual images to achieve a more seamless appearance in the finished mosaic. This process was the most time consuming of all steps in the orthophotography generation process. On the recommendation of Bohnnan Huston, Inc., we selected Inpho's OrthoVista 4.0 as our color balancing tool. OrthoVista utilizes advanced image processing techniques to automatically adjust and combine individual images into a single, seamless, color-balanced mosaic, and automatically compensates for a wide range of image intensity and color variations originating from the imaging process (Inpho Photogrammetry and Digital Surface Modeling 2006).

It was determined that map sheet tiles would be developed for the final output with a 2 x 1.75-mile dimension for a total of 465 map sheets per data set. Each of the datasets, CIR and RBG, were merged into a seamless image, tiled to map sheets, and clipped to the project area boundary. The map sheet orthophoto mosaics became the base layer from which the riparian and marsh vegetation was classified and the backwaters were delineated.

Results: Orthophotography Generation

High-quality CIR and RGB imagery with 1-foot pixel resolution orthophotography were developed for the entire project area. Figures 5 and 6 show an example map sheet mosaic for each dataset and represent the final products of Phase I. The final orthophotography yielded an approximate 1" = 400' horizontal accuracy (RMSE = 1.5 meter), exceeding the accuracy recommended for mapping at the scale of 1:6,000 (1" = 500') and far exceeding the accuracy of the 1997 data, which was calculated at +/- 16 meters. The radiometric quality of the imagery is such that there are virtually no visible seams in the mosaics. Direct georeferencing made the ground control portion of the project feasible and cost effective (Figures 5 and 6).

Discussion: Orthophotography Generation

At the outset of this project, there was considerable discussion and debate over the merits of digital vs. film-based cameras. It is now clear that digital cameras offer clear advantages over film-based cameras.

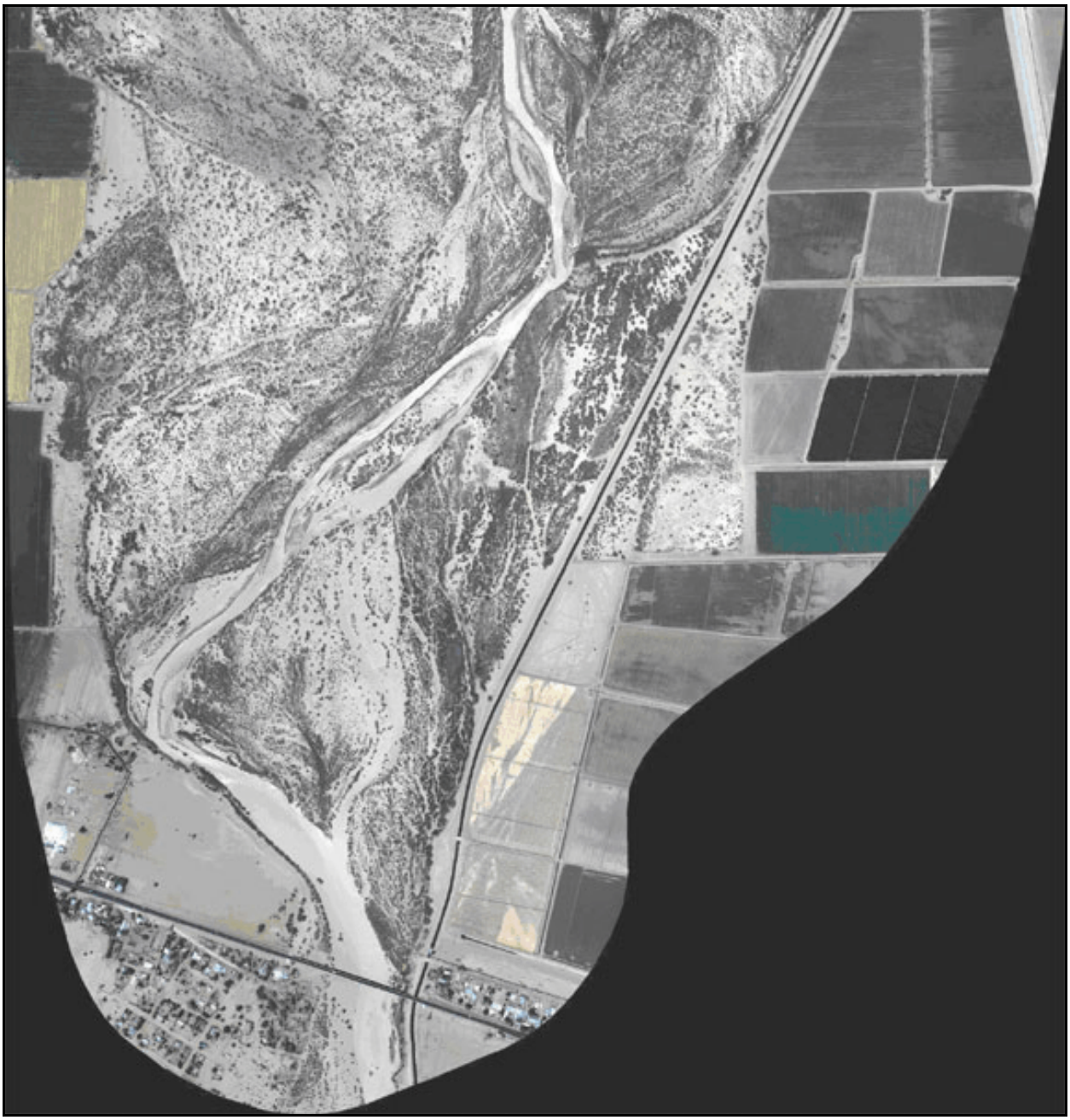


Figure 5. Natural color (RBG) map sheet mosaic clipped to the project area boundary.

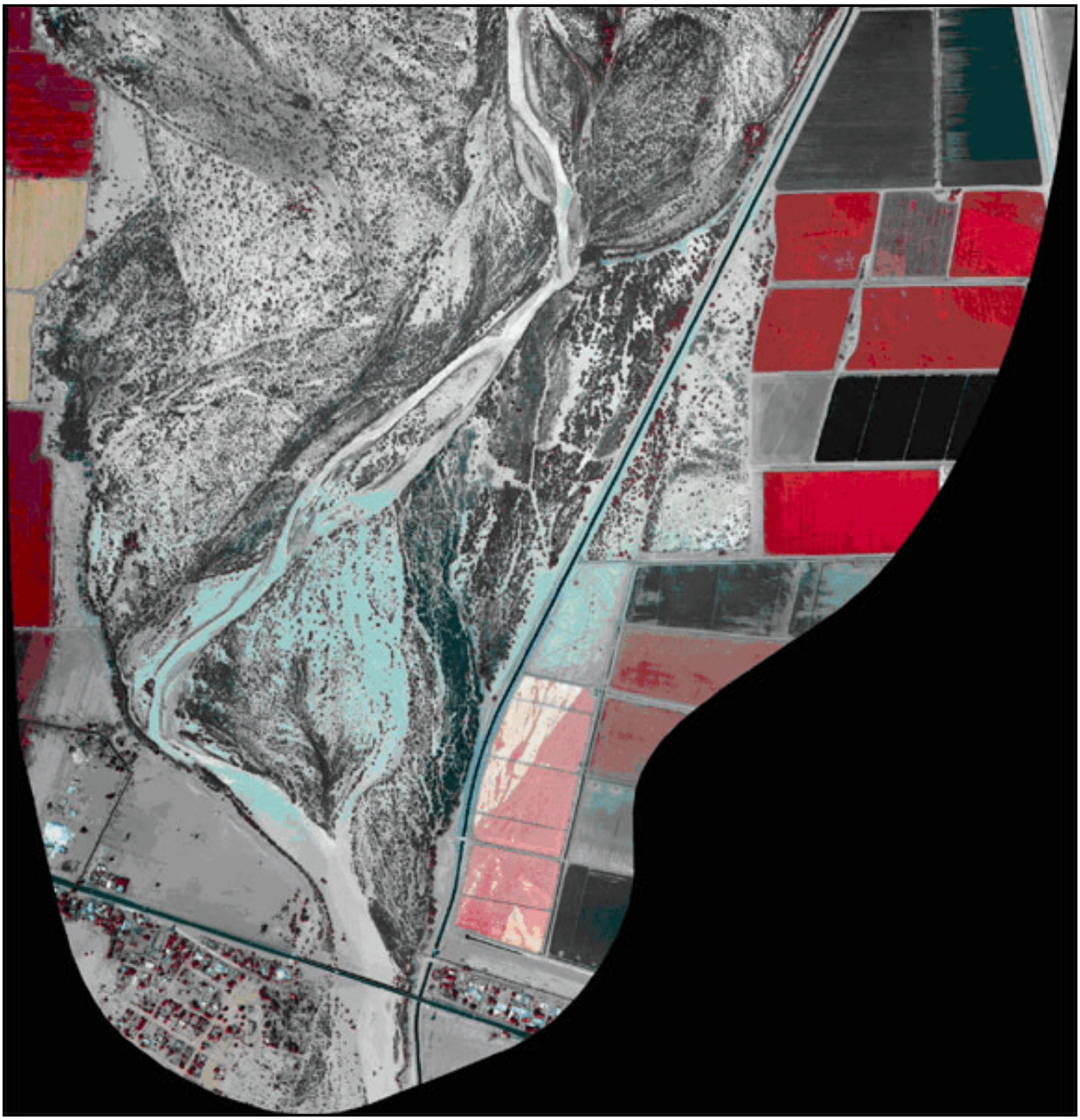


Figure 6. Color infrared (CIR) map sheet mosaic clipped to the project area boundary.

The most significant of these advantages (EarthData 2006) include the following:

- First-generation product, rather than the second-generation products from scanned film
- Superior radiometric resolution
- Increased accuracy of photogrammetric measurements
- Reduction of materials and labor costs to produce digital imagery
- Faster turn-around time from flight to image data
- Multispectral image acquisition during one flight
- Completely digital workflow throughout GIS and remote sensing projects

The only apparent disadvantage of digital photography is that there are no hard-copy contact prints as part of the deliverable and, therefore, viewing the imagery with conventional stereo lenses is not possible unless contact prints are independently developed from the raw imagery.

During the planning stages of the project, there was also much discussion regarding the resolution at which imagery should be captured. Results from the project indicate that although 1-foot pixel resolution is not necessary for the delineation and classification of vegetation polygons, it does greatly facilitate the delineation of backwaters that are much smaller than 1 acre in total size. Thus, the additional processing time required to produce 1-foot pixel resolution images seems justified.

Phase II: Classification of Riparian and Marsh Vegetation, Delineation of Backwaters and GIS Development

Introduction: Classification

The primary purpose of the vegetation mapping portion of the project was to update the vegetation map prepared by CH2MHill in 1999. However, inconsistencies between the 1997 data and the 2004 orthophotography required that polygon boundaries be redefined. Likewise, because of inconsistencies in the 1997 data (thought to have resulted from the use of more than one photo interpreter) it was determined that one photo interpreter should be used to maintain consistency throughout the project area.

In an attempt to find the best possible vegetation and backwater delineation technique, the following three methods were evaluated during the early stages of the project: (1) computerized delineation using Ecognition software, (2) mylar mapping, and (3) on-screen digitizing. Ecognition, a software system that produces unsupervised classifications of imagery, was determined to be inappropriate for vegetation mapping and was only used for backwaters on map sheets 1-47 (SIB to Imperial Dam), open water delineation of Lake Havasu and Lake Mohave, and a small portion of Lake Mead. Map sheets 1-47 were mapped directly on clear mylar, which is the traditional method for this type of mapping. However, this method was discontinued for the remainder of the project because it was found to be too labor-intensive and less accurate. On-screen digitizing, the new standard for photo-interpretation, was determined to be the most appropriate method and was used for the vast majority of the project (sheets 48-465).

The use of stereopairs as part of the photo-interpretive process was also considered during the development of methodology. However, because of the large size of the project area (which would require a total of 2,400 individual stereopairs), the amount of time required to complete the project would have been unacceptable. Additionally, since the photography was collected digitally, the use of stereopairs would have required expensive hardware and software capable of rendering imagery in three dimensions. Therefore, given the current budget and time constraints, it was decided that the use of stereopairs in the project methodology was not feasible.

Methods: Classification

Vegetation Type Mapping

Vegetation type mapping occurred between July 2005 and March 2006 and was based on the Anderson-Ohmart (1976) method of classification (Tables 2, 3, and 4). Based on previous mapping efforts (CH2MHill 1999) and current project requirements, additional classes were added. These included Agriculture (AG), Open Water (OW), Structured Open Water (SOW),

Table 2. Vegetation communities and criteria used in the classification of the lower Colorado River in 2005.

COMMUNITY	CRITERIA
Cottonwood-Willow (CW)	*Salix gooddingii* and *Populus fremontii* (the later in extremely low densities) constituting at least 10% of total trees.
Salt cedar (SC)	*Tamerix chinensis* constituting 80-100% of total trees.
Salt cedar-Honey mesquite (SH)	*Prosopis glandulosa* constituting at least 10% of total trees; rarely found to constitute greater than 40% of total trees.
Salt cedar-Screwbean mesquite (SM)	*Prosopis pubescens* constituting at least 20% of the total trees.
Honey mesquite (HM)	*Prosopis glandulosa* constituting 90-100% of total vegetation in area.
Arrowweed (AW)	*Tessaria sericea* constituting 90-100% of total vegetation in area.
Atriplex (ATX)	*Atriplex lentiformes, A. canescens* and/or *A. polycarpa* constituting 90-100% of total vegetation in area.
Marsh (MA)	Predominately cattail/bulrush (*Typha/Scirpus*) and Carrizo (*Phragmites*).
Creosote (CR)	*Larrea tridentata* constituting 90-100% of total vegetation in area.

Source: Yonker and Anderson (1986).

Table 3. Structural type categories used in classification.

STRUCTURAL TYPE	DESCRIPTION
I	Mature stand with distinctive overstory greater than 15 feet high, intermediate class from 2 to 15 feet tall, and understory from 0 to 2 feet tall.
II	Stand where the overstory (greater than 15 feet tall) constitutes greater than 50% of trees with little or no intermediate class present.
III	Stand where largest proportion of trees are 10-20 feet high with few trees greater than 20 feet tall or less than 5 feet tall.
IV	Few trees >15 feet present; 50% of vegetation is 5-15 feet tall with the other 50% between 0 and 2 feet tall.
V	60-70% of vegetation present between 0 and 2 feet tall with the remainder in the 5-15 feet class.
VI	75-100% of vegetation from 0 to 2 feet tall.

Source: Anderson and Ohmart (1994a).

Table 4. Marsh types and criteria used in classification.

TYPE	CRITERIA
1	Nearly 100% cattail/bulrush; small amounts of *Phragmites* and open water.
2	Nearly 75% cattail/bulrush; many trees and grasses interspersed.
3	About 25-50% cattail/bulrush, some *Phragmites*, open water. Some trees and grass.
4	About 35-50% cattail/bulrush; many trees and grasses interspersed.
5	About 50 to 75% cattail/bulrush; few trees and grasses interspersed.
6	Nearly 100% *Phragmites*; little open water.
7	Open marsh (75% water), adjacent to sparse marsh vegetation; includes sandbars and mudflats when the Colorado River is low.

Source: Anderson and Ohmart (1984a).

Backwater (BW), Undeveloped Bare Ground (UD), and No Classification (NC). These additional classifications were intended to capture non-riparian features that would otherwise have been unmapped and resulted in numerous areas without data. The newly developed CIR orthophotography was used as the base layer for the classification.

The vegetation of the project area was classified into nine major community types (Table 2). Of the nine community types, five describe tree species that were further subdivided into structural types (Table 3), based on the distribution of foliage at various heights (Figures 7 and 8; Anderson and Ohmart 1984b). Additionally, marsh communities were typed as described in Table 4 to reflect the amount of open water, *Phragmites*, and trees present within each of the marsh communities (Anderson and Ohmart 1984a).

As previously mentioned, six additional classification categories were added to capture other features not defined in the Anderson-Ohmart classification system. Of those six categories, four were based on categories developed in previous mapping efforts (CH2MHill 1999) and include AG, OW, SOW, and UD. The BW class is a project-specific category used to capture backwater features along the lower Colorado River and the NC classification was used to capture features that did not fit into any other category and represents features such as golf courses, residential communities, industrial areas, etc.

Technique 1: Ecognition

Ecognition is a remote sensing application that takes advantage of image segmentation and object classification when utilizing standard photo-interpretive attributes including shape, texture, area, scale and context (Definiens The Image Intelligence Company 2006). During the early phases of methodology development, polygon delineation using Ecognition was tested and found to be inappropriate for use with the 1:6,000 scale photo interpretation process given the time constraints of the project. Specifically, software tests indicated that the initial number of polygons the software generates is tremendous and each associated polygon has a very large number of vertices, resulting in an inability to efficiently manually edit the polygons (Figure 9). Because of these constraints and limitations, it was determined that north of sheet 47 (north of Imperial Reservoir) the Ecognition approach would only be used to delineate the OW class of major reservoirs.

Technique 2: Mylar Mapping

Color infrared map sheet mosaics in hard copy format were generated at a 1:6,000 scale by GEO/Graphics. This orthophotography was overlayed with mylar and delivered to BIO-WEST. BIO-WEST mapped and attributed riparian and marsh vegetation directly onto the mylar sheets at a 1:6,000 scale, with a minimum mapping unit of 1 acre. A digital version of the imagery was also used to aid in the delineation of current vegetation communities. Backwaters were delineated for map sheets 1-47 using Ecognition; no minimum map unit was applied to the

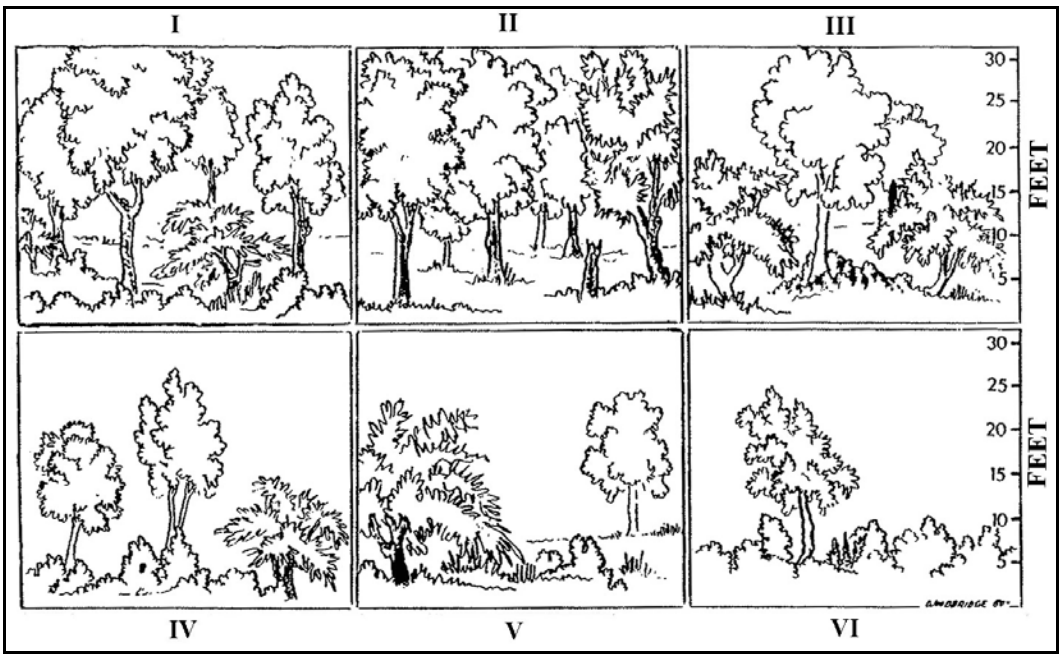


Figure 7. **Vegetation structural types as described by Anderson and Ohmart (1984b).**

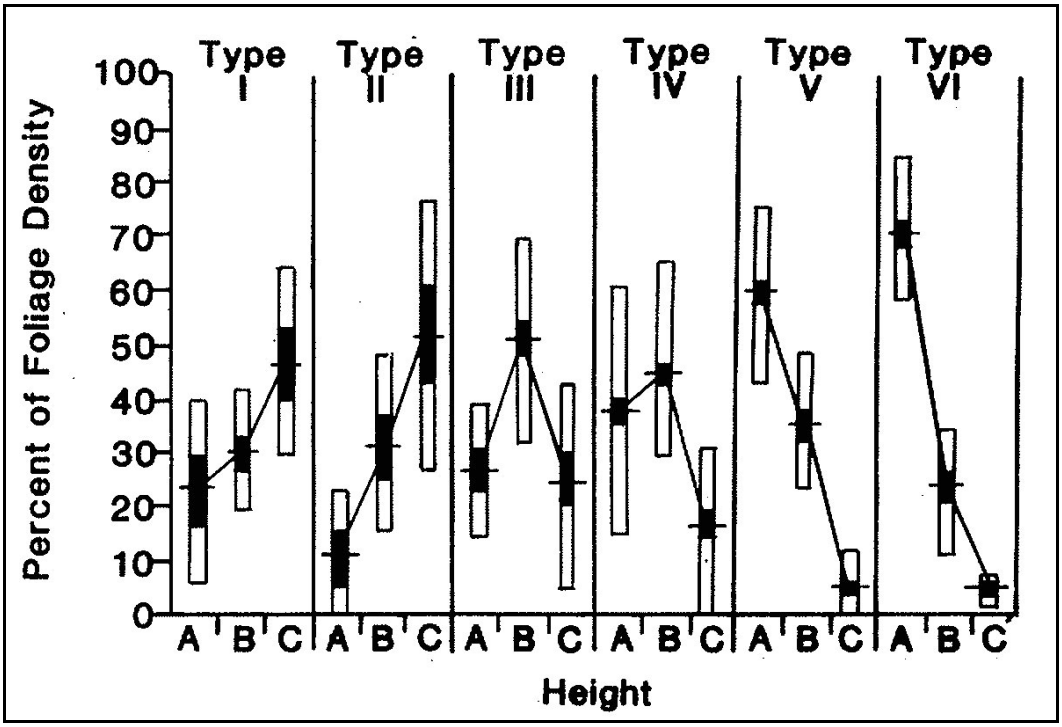


Figure 8. **Distribution of foliage density by vegetation structural type as described by Anderson and Ohmart (1984b).**

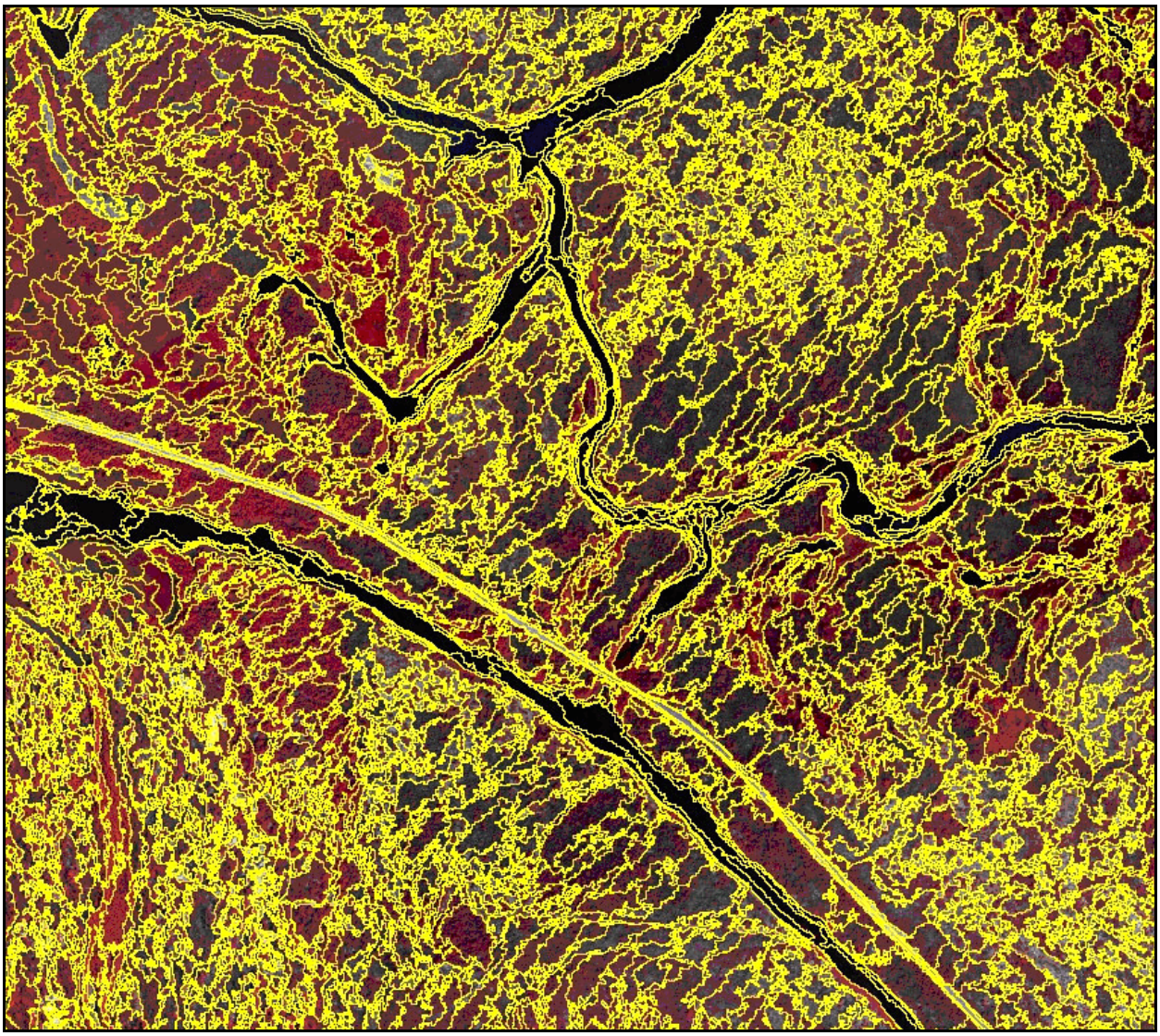


Figure 9. Ecognition processed polygons at the finest scale.

backwaters. After classification was complete, the mylar sheets were returned to GEO/Graphics, where they were tablet digitized and incorporated into the GIS.

This method was discontinued after sheet 47 for the following reasons:

1. The method required the polygons to be delineated and attributed twice, once on the mylar and again with the digitizing tablet, and therefore was inefficient and labor intensive.

2. The workflow went through many different hands and it was observed that unintentional and undesirable changes to the data were potentially occurring.

3. The resulting line work of the polygon delineation was less accurate and detailed than desired.

Technique 3: On-screen Digitizing

Beyond map sheets 1-47, on-screen digitizing replaced the mylar method, a switch that virtually eliminated the issues related to inefficiency and inaccuracy that were encountered using the mylar method. This method of geocoding is commonly called "heads-up" digitizing because the attention of the user is focused up on the screen, and not on a digitizing tablet. The on-screen digitizing method was used for the vast majority of the project (sheets 48-465).

GEO/Graphics prepared empty geodatabase point and polyline feature class templates for each map sheet, applied attribute domains for the label points, and inserted linework of the mapping extent for the polylines. Reservoir boundaries generated by Reclamation using a combination of Ecognition and on-screen digitizing were inserted into empty polyline feature class templates and delivered to BIO-WEST. These geodatabase feature classes provided the starting point for BIO-WEST to digitize vegetative boundaries on screen and assign attributes using the Anderson-Ohmart classification with the 2004 CIR orthophotography as the base layer in ArcMap 9.1.

Once BIO-WEST completed on-screen mapping and label-point attributing for each map sheet, the complete geodatabases were sent back to GEO/Graphics, where feature classes were imported into an ArcInfo 9.1 geodatabase. GEO/Graphics staff validated and fixed line topology for the polyline feature classes, converted the polylines to polygons, and applied attributes from the point feature classes supplied by BIO-WEST.

After dissolving the polygons based on vegetation community and type, GEO/Graphics flagged attributing and linework errors through a series of query- and visual-based quality controls, and a shapefile was sent to BIO-WEST for corrections. BIO-WEST performed all necessary edits and returned the shapefile to GEO/Graphics for final processing.

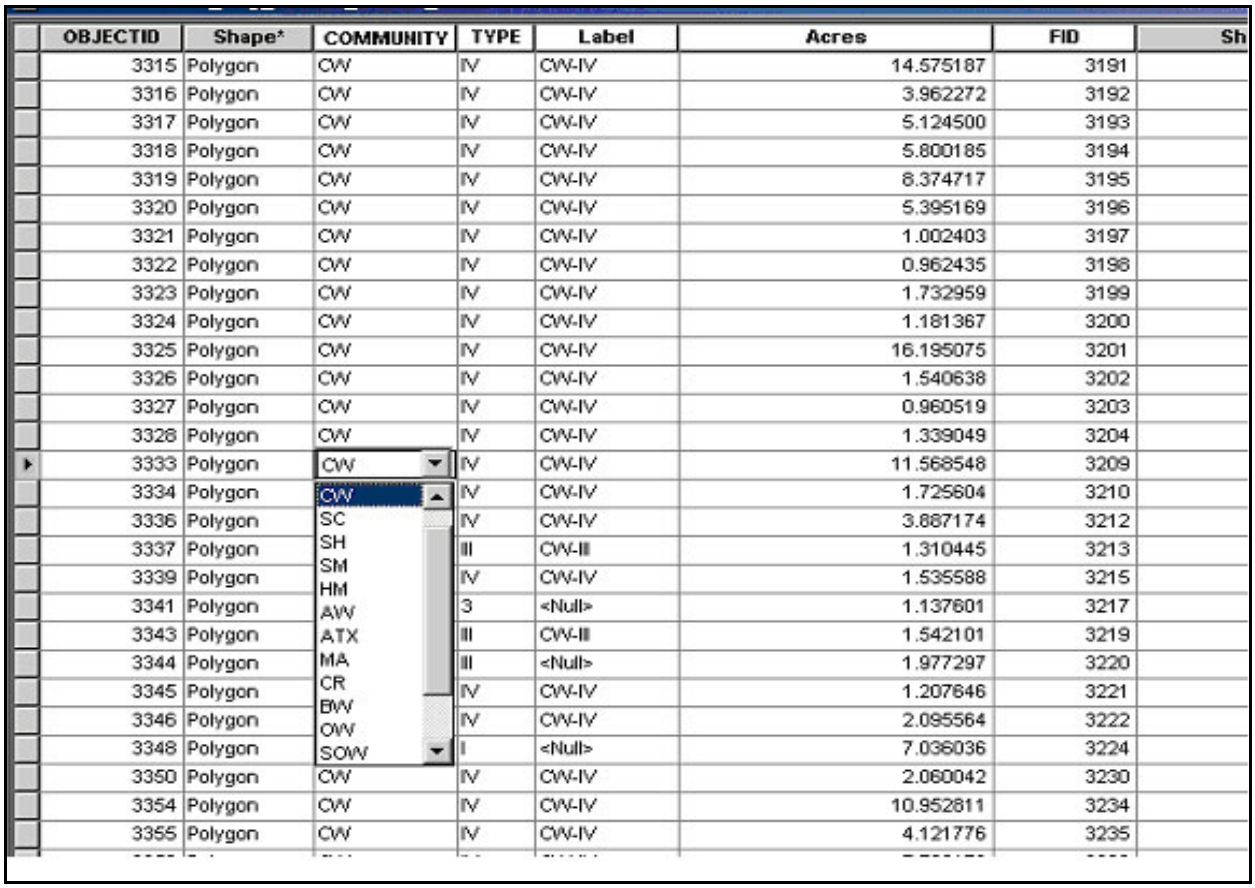
GEO/Graphics calculated acreage and enforced the minimum mapping unit of 1-acre except BW and OW categories. All polygons less than 0.25 acre (excluding BW, OW, and SOW) were automatically merged; remaining polygons less than 0.95 acre and not equal to BW, OW, or SOW were manually merged into the most appropriate adjacent polygon. Polygon topology was then validated and applied to remove overlaps and gaps between polygons. A final dissolve based on community and type was performed, and acreage and labels were recalculated. The feature class was then converted to a shapefile for final delivery.

Field Verifications

In preparation for the field verification portion of the project digital orthophotography and vegetation polygons (geodatabases with applied attribute domains) were loaded onto laptop computers for use in ArcGIS 9.1. The GPS units (Garmin Rhino model 310) were connected to

laptops via a USB-serial bridge. All imagery and polygons were loaded into ArcMap 9.1. The GPS units were configured to use National Marine Electronics Association (NMEA) 0183 protocols, which broadcasts continuous data sentencing to software for real time application of GPS data in a variety of software including ArcMap. The process of interfacing the GPS units with a laptop computer served to simplify navigation to specific polygons.

Geodatabases with applied attribute domains loaded into ArcMap served as datasheets in the field while verifying photo-interpreted polygons (Figure 10). Attribute domains were applied to the Community and Type fields such that when attribute tables were edited, all community and structural type codes were available to choose from via drop-down lists.



OBJECTID	Shape*	COMMUNITY	TYPE	Label	Acres	FID	Sh
3315	Polygon	CW	IV	CW-IV	14.575187	3191	
3316	Polygon	CW	IV	CW-IV	3.962272	3192	
3317	Polygon	CW	IV	CW-IV	5.124500	3193	
3318	Polygon	CW	IV	CW-IV	5.800185	3194	
3319	Polygon	CW	IV	CW-IV	8.374717	3195	
3320	Polygon	CW	IV	CW-IV	5.395169	3196	
3321	Polygon	CW	IV	CW-IV	1.002403	3197	
3322	Polygon	CW	IV	CW-IV	0.962435	3198	
3323	Polygon	CW	IV	CW-IV	1.732959	3199	
3324	Polygon	CW	IV	CW-IV	1.181367	3200	
3325	Polygon	CW	IV	CW-IV	16.195075	3201	
3326	Polygon	CW	IV	CW-IV	1.540638	3202	
3327	Polygon	CW	IV	CW-IV	0.960519	3203	
3328	Polygon	CW	IV	CW-IV	1.339049	3204	
3333	Polygon	CW	IV	CW-IV	11.568548	3209	
3334	Polygon	CW	IV	CW-IV	1.725604	3210	
3336	Polygon		IV	CW-IV	3.887174	3212	
3337	Polygon		III	CW-III	1.310445	3213	
3339	Polygon		IV	CW-IV	1.535588	3215	
3341	Polygon		3	<Null>	1.137601	3217	
3343	Polygon		III	CW-III	1.542101	3219	
3344	Polygon		III	<Null>	1.977297	3220	
3345	Polygon		IV	CW-IV	1.207646	3221	
3346	Polygon		IV	CW-IV	2.095564	3222	
3348	Polygon		I	<Null>	7.036036	3224	
3350	Polygon	CW	IV	CW-IV	2.060042	3230	
3354	Polygon	CW	IV	CW-IV	10.952811	3234	
3355	Polygon	CW	IV	CW-IV	4.121776	3235	

Figure 10. Example of attribute domains applied to GeoDatabases used during field verification.

Any additional notes and photologs (Appendix A) were recorded in Sokkia waterproof field notebooks. Polygons were tracked in field notebooks by feature identification (FID) number, which is unique to each polygon and automatically generated by ArcMap.

The classification accuracy was tested with field checks at 329 selected points within CW polygons chosen at random and from surrounding communities during three ground assessments. A total of 87 CW polygons were randomly selected for field classification, of which 69 were field verified as CW polygons by the staff at BIO-WEST. The remaining 18 (87-69) CW polygons, which were randomly selected as CW but were field verified as another community, became part of the sample size for that given community. Based on the accuracy assessment sample design (i.e., sampling the polygons surrounding the randomly sampled CW polygons) and the homogeneity of vegetation within the project area, a total of 260 polygons adjacent to randomly selected CW polygons were sampled in the field.

GEO/Graphics provided BIO-WEST with a sampling design for their field verification visits for the following time periods: September 19-25, 2005; February 20 through March 4, 2006; and March 7-13, 2006. The first field effort in September concentrated on map sheets 1-27, from the SIB to Imperial Dam. BIO-WEST staff was accompanied by Reclamation biologists during this effort. This first field visit was based on the following:

1. A power analysis was conducted to determine how large a sample was needed to enable statistical judgments that were accurate and reliable. Once the appropriate number of samples was determined, this number was randomly sampled from the polygons of each sheet. An additional 25 percent of sheets 1-27 were randomly selected to be field verified.

2. Two constraints were applied to the sampling, a location constraint (all sample polygons will be within 0.25 mile of a road to facilitate easy access by field crew) and a CW constraint (at least 50 percent of the samples for each sheet will be in the CW category).

The second and third field verifications concentrated on the remaining project area (sheets 28-465), which was the entire project area north of Imperial Dam. These field verifications used the same sampling scheme as the first field verification except for the following:

1. Sampling was limited to the CW category and adjacent communities.

2. Unlike the first field exercise, the field personnel did not have access to polygon classifications while in the field. This “blindness” helped ensure that the field verification process was as unbiased as possible.

The final field verification also served as a means by which to assess the accuracy of CW interpreted polygons. Based on the results of an initial power analysis, it was estimated that a total of 72 CW polygons would have to be sampled to obtain a power of 0.60 and an alpha level of 0.05. The initial power analysis accounted for all six structural types within the CW class. In reality, however, only five CW structural types were mapped (no CW-VI polygons were delineated during photo-interpretation) and only 69 polygons were actually field verified because of access issues. A subsequent power analysis revealed that the actual power of the final sample size (69 polygons) was 0.93 at an alpha level of 0.05, which indicates that the sample size is in fact statistically viable.

Randomly selected polygons were unattributed to satisfy the "blindness" requirements of an accuracy assessment. Biologists edited the appropriate geodatabases using the attribute domains consistent with the classification system previously described. All other polygons were fully attributed in the field versions of the database and were corrected in the field as necessary.

All remote sensing accuracy assessments rely on field verification as being 100 percent accurate. Given the subjectivity of the classification system being used and variability in observations made by more than one biologist, efforts were made to minimize the amount of observational bias in the field data. This was achieved by: 1) using botanists who were experienced in the use of the classification system, and 2) building consensus among the botanists before entering the field regarding particularly difficult "judgment calls" within the classification system. Although these measures were applied to help reduce the amount of observational bias, there remains a level of bias that cannot be accounted for and can be explained, in large part, by the subjectivity inherent to the classification system. This revealed that determining the exact characteristics of a community and the accuracy of a classification can be somewhat arbitrary.

Systematic Error Identification and Correction Factor

Based on the results of the accuracy assessment of 69 CW polygons distributed throughout the project area (excluding the Grand Canyon, Lake Mead, Black Canyon, and Bill Williams River), the overall accuracy of CW polygon classification was 60 percent, which is considered very good for classification at the community level (Landis and Koch 1977). The accuracy of CW polygons at the structural type level was 37 percent. Although somewhat unexpected, such low accuracy is frequently encountered in projects where community structure type is being assessed, as evidenced by previous mapping efforts on the lower Colorado River. For example, the type level accuracy of the initial photo interpretation associated with the 1997 vegetation map prepared for the lower Colorado River was calculated at 40 percent (CH2MHill 1999). Subjectivity inherent to the classification system, subjectivity of field observations, and changes in the vegetation since 2004 no doubt contributed to these mapping results. Nevertheless, because of the assumption that the ground condition as reported by the field biologist is the "truth," the only explanation for GIS and field data not corresponding is incorrect photo-interpretation.

Given the accuracy of this project's initial photo-interpretive effort at the structural type level, field-verified data were compared to all photo-interpreted CW polygons to examine classification error in the database (CH2MHill 1999). A total of 19 potential systematic errors were identified and assigned ERROR_ID numbers (1 through 19); of these 19 potential systematic errors, the photo interpreter and the field biologists determined that ERROR_ID 2, 6, 16, 17, and 18 were actually systematic (Table 5).

Systematic errors are defined as a reproducible discrepancy between the result and "true" value that occurs consistently in the same direction (Baird 1995, Fluke 1994), or as a reproducible inaccuracy introduced by faulty equipment, calibration, or technique (Bevington et al. 1992). Moreover, these errors are difficult to detect and cannot be analyzed statistically (Taylor 1997).

Table 5. Summary of systematic error resulting from field verification.

ERROR_ID	SYSTEMATIC ERROR	OCCURRENCE OF ERROR
2	SC-I interpreted as CW-I	5
6	CW-I interpreted as CW-III	108
16-18	NC interpreted as CW	11

Systematic errors in the classification were determined as follows:

- Systematic error 2: SC-I was consistently mistaken for CW-I. Because of structural similarities that were perceived in the imagery, the interpreter consistently attributed large mature SC stands as CW.

- Systematic error 6: CW polygons classified as structural type I in the field were consistently classified as type III during the photo-interpretive efforts. This was attributed to the similarities in characteristics exhibited between structural types in the orthophotography. The photo interpreter consistently attributed CW polygons that fit within both categories as type III and only selected type I when overstory height was interpreted to be significantly greater than the midstory.

- Systematic errors 16, 17, and 18: These last systematic errors were attributed to the photo interpreter's bias to map every perceived CW stand meeting the 10 percent threshold. Therefore, the interpreter mapped large trees perceived as CW near and within residential and commercial areas that would likely have little biological significance for the target species in question. Consequently, field biologists determined that these attributed CW polygons should be merged with surrounding NC polygons. However, CWs that were near or connected by a natural corridor to the nearest body of water (i.e., river and/or backwater) were not merged.

These identified systematic errors and their frequencies are summarized below (Table 5). The frequency of occurrence represents the total number of polygons found to have been affected by each systematic error.

Systematic error is sometimes called "bias" and, fortunately, can be reduced by applying a "correction factor" to compensate for an effect recognized when calibrating against the "true" value (University of North Carolina 2006). One seemingly problematic assumption under this method is that all systematic error corrections are 100 percent accurate. Because of this, systematic errors were only corrected when the photo-interpreter detected them with a high degree of confidence, thereby reducing the chance of overstating the corrected accuracy of the final database.

Once identified, the systematic errors listed above were corrected for in the GIS. This was done by isolating those polygons with systematic errors using a definition query based on ERROR_ID, which was added as a field to the GIS during the error identification process. Once isolated according to their ERROR_ID, the relevant polygons' community and type attributes

were updated appropriately in the GIS (e.g., all polygons that carried a ERROR_ID of 2 were selected using the ERROR_ID field and changed from CW-I to SC-I using the ArcMap attribute table).

ERROR_ID 6 occurred at the CW structure type-level; therefore, its frequency was used to generate a CW type-level correction factor; based on the 113 systematic type-level errors and the total number of photo-interpreted CW polygons in the database (556 out of the total 610 CW polygons, or the number of CW polygons in the final corrected GIS database not including those that were field verified), a correction factor of 20 percent (113/556) was calculated for 91 percent (556/610) of the database. From the ground truthing and accuracy assessment efforts of September 2005 and March 2006, a type level correction factor of 100 percent was estimated for the remaining 9 percent of the database (54/610, or those CW polygons in the final corrected GIS database that were assessed in the field). A final corrected type-level accuracy was calculated with the following equation:

$$[\, nfv(cf + ia) + fv(1) \,] \times 100 = fc$$

Where:

n*f*v	=	percentage of database non-field verified
c*f*	=	correction factor of non-field verified database
ia	=	initial accuracy
*f*v	=	percentage of database field verified
*f*c	=	final corrected type-level accuracy

This equation was used in order to give proportional weight to each CW data subset (those CW polygons that were photo interpreted and those polygons that were field verified). The actual final corrected type-level accuracy is reported in the Results section. Polygons with non-systematic errors remained unchanged in the GIS and were not considered when calculating the correction factor.

Results: Classification

The 2004 mapping effort resulted in the delineation of 574,845 total acres of potential habitat in the lower Colorado Region, of which 163,678 acres were delineated as riparian or marsh and 4,476 acres were delineated as backwaters (Table 6). Of the riparian and marsh communities, there were a total of 10,343 acres of CW, 866 acres of HM, 9,860 acres of MA, 114,769 acres of SC, 22,160 acres of SH and, 5,680 acres of SM.

Although the application of a correction factor as described above did change the total reported acreage for the CW community, the nature of systematic error identified in Table 5 would indicate that the majority of changes occurred at the type level rather than at the community level. As presented in Table 7, the largest changes were the result of consistently mis-typing CW-I polygons as CW-III (ERROR_ID 6) resulting in a 616.90 acre increase in CW-I and a

Table 6. Acreage calculations for 2004.

COMMUNITY, STRUCTURAL TYPE, AND BACKWATERS	ACREAGE
AG	45895.59
ATX	122.76
AW	15012.45
BW	4475.89
CR	3688.62
CW-I	1703.50
CW-II	102.60
CW-III	1118.67
CW-IV	4577.11
CW-V	2230.85
CW-VI	610.06
HM-III	20.83
HM-IV	100.79
HM-V	572.37
HM-VI	172.10
MA-1	1888.71
MA-2	870.31
MA-3	419.70
MA-4	899.34
MA-5	5010.69
MA-6	708.94
MA-7	61.77
NC	20865.53
OW	164819.38
SC-I	210.85
SC-II	782.65
SC-III	15270.84
SC-IV	48539.05
SC-V	22673.68
SC-VI	27292.36
SH-I	11.11
SH-III	695.67
SH-IV	5539.60
SH-V	8697.85
SH-VI	7215.34
SM-III	600.59
SM-IV	2091.83
SM-V	2651.52
SM-VI	335.89
SOW	908.49
UD	155379.53
TOTAL ACREAGE	**574845.39**

Table 7. Acreages before and after application of the correction factor

BEFORE APPLICATION OF CORRECTION FACTOR			AFTER APPLICATION OF CORRECTION FACTOR		TOTAL CHANGE IN ACREAGE	PERCENT CHANGE
COMMUNITY TYPE	ACREAGE	ERROR_ID	COMMUNITY TYPE	ACREAGE		
CW-I	1750.41	2	CW-I	1703.5027.34	46.91	2.68%
SC-I	187.78		SC-I	210.85		10.94%
CW-I[a]	1086.60	6	CW-I[a]	1703.5	616.90	36.21%
CW-III[a]	1759.41		CW-III[a]	1118.67		36.42%
CW-II and CW-IV	4672.57	16, 17, 18	CW-II and CW-IV	4679.71	7.14	0.15%
NC	20545.95		NC	20865.53		1.02%

[a] Although the change in acreages between CW-I and CW-III are relatively large, they are found only at the structural type level.

decrease of 616.90 acres for CW-III. ERROR_IDs 2, 16, 17, and 18, which represent changes at the community level, account for very small changes in total acreage. Application of the correction factor resulted in a total change of 46.91 acres for ERROR_ID 2 and 7.14 acres for ERROR_IDs 16, 17, and 18 combined. The correction factor was not applied to those communities adjacent to the CW polygons that were sampled during field verification. Therefore, acreages reported in Table 6 for all classes except the CW community are uncorrected.

Change Detection

Change detection is a technique often used in remote sensing studies to determine changes over time and across a landscape. Therefore, change detection is an important process for monitoring and managing habitat for both aquatic and terrestrial species. Although important, caution should be used in applying such comparisons because the classification system used is only semi-quantitative and cannot be accurately used to calculate total acreage for a given species. Furthermore, the subjectivity inherent to the classification system complicates the process of comparing community changes over time, especially at the structural type level, because subjectivity accounts for a considerable amount of classification error. Additionally, the error in each classification (1997 and 2004, respectively) compounds the difficulty in comparing across time. The final corrected accuracy of the 1997 data is reported at 82 percent and the overall community accuracy of the 2004 data is 78 percent. However, corrections to the 1997 data were applied throughout the database, which is not the case for the 2004 data.

Given the differences in spatial extent mapped when comparing the 1997 and 2004 mapping effort, direct comparisons are not appropriate. Therefore, the 2004 GIS data was clipped to match the 1997 GIS data's spatial extent. As a result, a comparison of acreage across the project area was possible with less than 3 percent difference in total acreage. The total acreage

presented in Table 8 does not account for the following classes: BW, NC, OW, RIV, SOW, and UD. The following are the reasons why these classes were not included in the total acreage:

1. The backwater (BW) class was not mapped in 1997 and therefore a meaningful comparison cannot be made.

2. In 1997 the Colorado River (RIV) was defined as a separate class, while in 2004, the Colorado River and all other open water were delineated as (OW).

3. In 2004 the no classification (NC) class was used to capture those features that did not fit into any Anderson-Ohmart classification, but this class was not used in the 1997 mapping effort.

4. Although defined in both mapping efforts, the UD class represents highly disturbed areas of little or no biological significance and therefore was not compared in the change detection.

Cottonwood/willow, marsh, and backwater communities are of great importance to those aquatic and terrestrial species identified in the MSCP. As such, special attention to those communities was made when attempting to detect change over time. When comparing the total acreage of specific riparian and marsh communities over the time period, differences are small and represent a total change of only 8.7 percent.

The community-level acreage comparisons reveal a 3 percent increase in CW since 1997. Specifically, 7,375 acres were delineated as CW in 1997, while 7,572 acres were delineated in 2004. Acreage differences may be due to changing vegetation community types through disturbance, succession, regeneration, and restoration. Differences may also arise from biases inherent in the project methodology, observer bias, Anderson and Ohmart classification bias, and differences in methodology between mapping efforts.

The current mapping effort shows a 26 percent reduction in total marsh acreage since 1997. Drastic changes in marsh classification and acreage numbers are a byproduct of the Lower Colorado River as it is managed today. Water levels fluctuate daily along reaches of the river. Isolated backwaters grow stagnant and change to more upland vegetation because they do not receive freshening flows.

Table 7 and Figure 11 indicate considerable differences in acreage over time for communities other than cottonwood/willows. These differences might be partially explained by a correction factor that was applied across all communities represented in the 1997 data; given the abbreviated sampling design in 2004, a correction factor was used only with the CW polygons. It is believed that if systematic error was identified and a correction factor was applied to the remaining communities within the current set, differences between the 1997 and 2004 data would likely be significantly reduced.

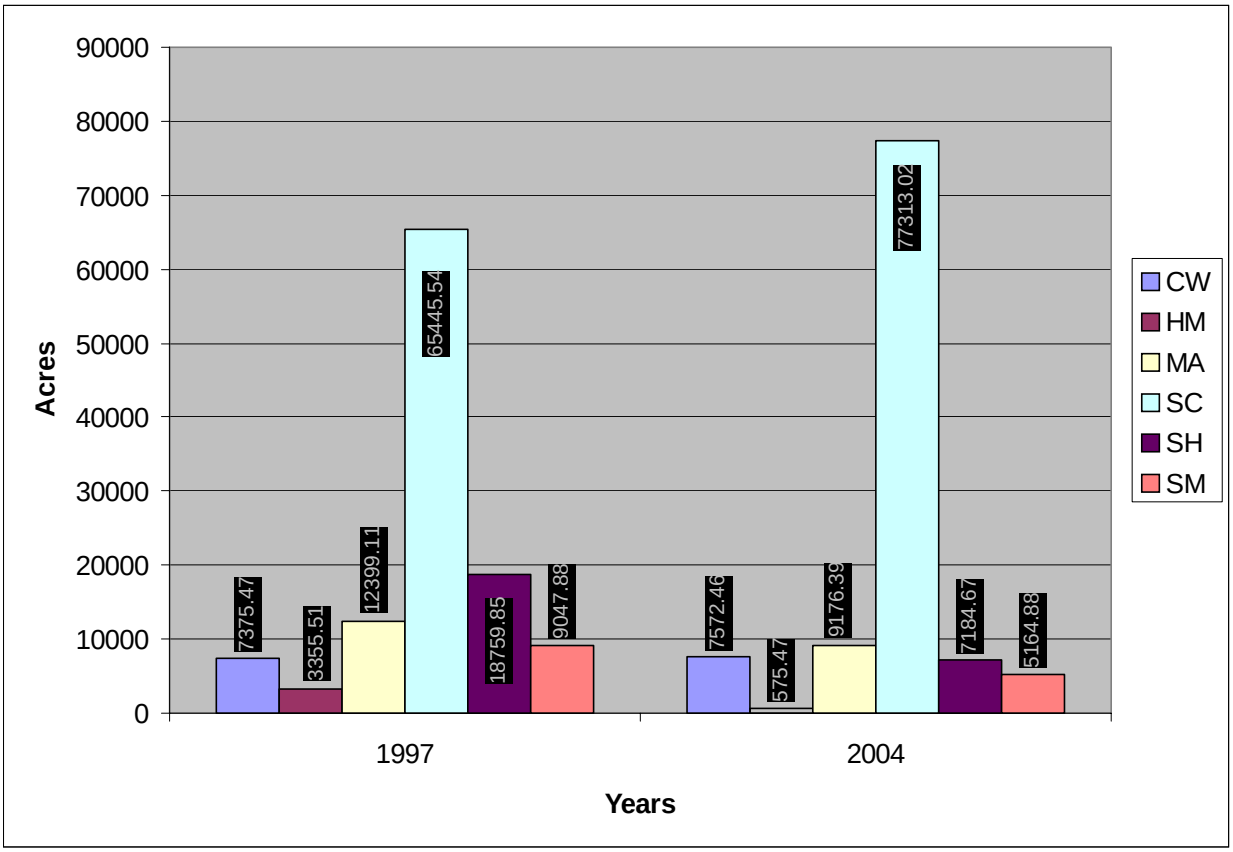


Figure 11. Comparison of riparian and marsh communities across mapping years.

Error Matrix Defined

Examining accuracy statistics can be misleading if one does not understand what they represent. In an effort to avoid misinterpretation of the results the error matrix and how accuracy was determined is described in the following. Note: If not otherwise indicated the definitions of error matrix terms in this section were paraphrased from the Canada Centre for Remote Sensing Glossary of Remote Sensing Terms (Natural Resources Canada 2006).

An error matrix is the standard for reporting remote sensing classification accuracies (Congalton et al. 1998), and does so by showing the degree of misclassification among types. In this case, the columns (horizontal) indicate field-verified data and the rows (vertical) represent the classification generated from the photo interpretation (Table 8). The basic test of accuracy using this method is percent correct, which uses the diagonal elements of the error matrix. For instance, the sum of the diagonal cells in the matrix represents the total number of correctly classified polygons. Therefore, the proportion of the total number of correctly classified polygons to the total number of polygons in the matrix gives the "overall accuracy" for the classification as a percentage.

Table 8. Acreage comparison between 2004 and 1997 mapping efforts at same spatial extents.

2004 COMMUNITY AND STRUCTURAL TYPE	2004 ACREAGE	1997 COMMUNITY AND STRUCTURAL TYPE	1997 ACREAGE
AG	4492.12	AG	2180.39
ATX	33.38	ATX	798.38
AW	13106.80	AW	4240.36
BW	2960.60	BW	
CR	433.27	CR	1486.59
CW-I	1319.86	CW-I	1134.91
CW-II	68.32	CW-II	126.99
CW-III	928.96	CW-III	3543.44
CW-IV	3553.23	CW-IV	1818.45
CW-V	1544.80	CW-V	477.92
CW-VI	157.28	CW-VI	273.44
HM-III	19.44	HM-III	402.08
HM-IV	63.58	HM-IV	2404.06
HM-V	413.67	HM-V	485.39
HM-VI	78.77	HM-VI	63.87
MA-1	1859.34	MA-1	4290.37
MA-2	859.47	MA-2	651.16
MA-3	410.13	MA-3	2916.10
MA-4	890.12	MA-4	2185.46
MA-5	4417.73	MA-5	915.89
MA-6	679.79	MA-6	639.32
MA-7	59.81	MA-7	800.28
NC	3019.49	OW	9458.58
OW	64482.70	RIV	63406.26
SC-I	149.01	SC-I	365.80
SC-II	216.79	SC-II	39.88
SC-III	13738.92	SC-III	4617.18
SC-IV	43329.78	SC-IV	36860.42
SC-V	15364.56	SC-V	16755.67
SC-VI	4513.95	SC-VI	6803.86
SH-I	9.699.70	SH-III	551.94
SH-III	496.45	SH-IV	10983.60
SH-IV	2886.56	SH-V	6213.31
SH-V	2897.86	SH-VI	1010.31
SH-VI	894.10	SM-I	10.48
SM-III	536.30	SM-III	671.66
SM-IV	1848.74	SM-IV	6356.59
SM-V	2561.02	SM-V	1390.28
SM-VI	218.84	SM-VI	618.50
SOW	609.02	SOW	453.45
UD	4798.55	UD	2516.08
Total Acres	125052.47	Total Acres	125084.35

Note: Rows with grey fill represent areas that were not included in the total acreage calculation.

Additionally, for each row in the matrix, the proportion of correctly classified polygons (the number of polygons in the cell on the diagonal) to the total number of polygons in that row expressed as a percentage provides a measure of the classification accuracy for the type represented by the row. This is called the "producer's accuracy" because it provides a measure of how well the technician did when "producing" the photo-interpreted classification.

Similarly, for each column in the matrix, the proportion of correctly classified polygons (the number of polygons in the cell on the diagonal) compared to the total number of polygons in that column expressed as a percentage provides a measure of the classification accuracy for the type represented by the column. This is called the "user's accuracy" because it provides a measure for the map user of the probability that the polygons on the classified map have been correctly attributed during the classification process.

The producer's accuracy for each type is different. This is because some types were more easily distinguished during photo interpretation compared to other types and therefore these types were classified more accurately. The total of the non-diagonal cell values in any one row represents the number of polygons that were incorrectly assigned to classes other than the class that the row represents. By dividing this total by the sum of the row total, the "error of omission" (polygons that were falsely excluded from a type) can be calculated for each type. In a similar manner, the total of the non-diagonal cell values in any one column represents the number of polygons that have been incorrectly included in the type that the column represents. By dividing this total by the sum of the column total, the "error of commission" can be calculated for each type.

Error Matrices Results

The results of the accuracy assessment were recorded in the following three (3) separate error matrices:

1. Community-level error matrix (Table 9)
2. Grouped type-level error matrix (Table 10)
3. Community and structural type-level error matrix (Table 11)

Production of error matrices was an important step in the classification process. It clearly defined the accuracy of the classification, and in examination the community and type-level error matrix (Table 9) an important pattern of error emerged for the CW community. This error is manifest in two locations in the community and type-level error matrix. First, at the bottom of the CW-I column the matrix indicates that only 24.3 percent (9/37) of this type were classified correctly and of the 28 that were misclassified 24 of them were classified as CW-III. This is the producer's accuracy of CW-I. Second, at the right side of this CW-III row the matrix indicates that only 23.4 percent (16/68) of this type were classified correctly and of the 52 that were misclassified 24 of them were misclassified as CW-I. This is user's accuracy of CW-III (column). These errors, illustrated in the error matrix, support the decision to investigate CW-I and CW-III categories for the possibility of systematic error.

Table 9. Community-Level Error Matrix.

USER'S ACCURACY	PRODUCER'S ACCURACY																
	AG	ATX	AW	BW	CR	CW	HM	MA	NC	OW	SC	SH	SM	SOW	UD	TOTAL	PERCENT CORRECT
AG	14					1										15	93.3
ATX																0	0
AW			7					4			1		1			13	53.8
BW				5												5	100
CR					1											1	100
CW			1		1	67			14		24		3		2	112	59.8
HM												1				1	0
MA								19								19	100
NC			1						12		1					14	85.7
OW										6						6	100
SC	2		3				1	1	2		73		5		3	90	81.1
SH		1	1		4							10				16	62.5
SM	1												1			2	50.0
SOW														7		7	100
UD		1							2						25	28	89.3
Total	17	2	13	5	6	68	1	24	30	6	99	11	10	7	30	329	71.7
Percent Correct	82.4	0	53.8	100	16.7	98.5	0	79.2	40.0	100	73.7	90.9	10.0	100	83.3	61.9	

Note: CW and SC are the only community types with large enough sample sizes to provide statistically credible assessments.

Table 10. Grouped Type-Level (I and II, III and IV and V and IV) Error Matrix.

USER'S ACCURACY	PRODUCER'S ACCURACY														
	AG	ATX	AW	BW	CR	I & II	III & IV	V & VI	MA	NC	OW	SOW	UD	TOTAL	PERCENT CORRECT
AG	**14**					**1**								**15**	**93.3**
ATX														**0**	**0**
AW			**7**				**2**		**4**					**13**	**53.8**
BW				**5**										**5**	**100**
CR					**1**									**1**	**100**
I & II						**18**				**6**				**24**	**75.0**
II & IV	**3**		**1**		**2**	**31**	**112**		**1**	**8**			**3**	**161**	**69.6**
V & VI		**1**	**4**		**3**		**3**	**21**		**2**			**2**	**36**	**58.3**
MA									**19**					**19**	**100**
NC			**1**				**1**			**12**				**14**	**85.7**
OW											**6**			**6**	**100**
SOW												**7**		**7**	**100**
UD		**1**								**2**			**25**	**28**	**89.3**
Total	**17**	**2**	**13**	**5**	**6**	**50**	**118**	**21**	**24**	**30**	**6**	**7**	**30**	**329**	**78.9**
Percent Correct	**82.4**	**0**	**53.8**	**100**	**16.7**	**36.0**	**94.9**	**100**	**79.2**	**40.0**	**100**	**100**	**83.3**	**68.2**	**Overall Grouped 67.6**

Note: Grouped type-level III and IV is the only group with a large enough sample size to provide a statistically credible assessment.

Table 11. Community and Structural-level Error Matrix.

USER'S ACCURACY	PRODUCER'S ACCURACY																																	
	AG	ATX	AW	BW	CR	CW-I	CW-II	CW-III	CW-IV	CW-V	HM-III	HM-V	MA-1	MA-3	MA-4	MA-5	MA-6	MA-7	NC	OW	SC-I	SC-II	SC-III	SC-IV	SC-V	SC-VI	SH-IV	SH-V	SH-VI	SM-III	SM-IV	SOW	UD	Total	Percent Correct
AG	14					1																												15	93
ATX																																		0	0
AW			7										4										1								1			13	53.8
BW				5																														5	100
CR					1																													1	100
CW-I						9															5													14	64.3
CW-II							3												6		1													10	30.0
CW-III					1	24	2	16											5		1	1	11	4						3				68	23.5
CW-IV						3		6	3										3				1										2	18	16.7
CW-V			1							1																								2	50.0
HM-III																																		0	0
HM-V																											1							1	0
MA-1																																		0	0
MA-3															1																			1	0
MA-4													2																					2	0
MA-5													4			4	1																	9	44.4
MA-6																	6																	6	100
MA-7																		1																1	100
NC			1																12				1											14	85.7
OW																				6														6	100.0
SC-I																																		0	0
SC-II																																		0	0
SC-III	2												1										14											17	82.4
SC-IV			1								1												11	34						5			1	53	64.2
SC-V			1																2					2	11								1	17	64.7
SC-VI			1																							1							1	3	33.3
SH-IV					1																						2							3	66.7
SH-V					1																							3						4	75.0
SH-VI		1	1		2																								5					9	55.6
SM-III																														1				1	100
SM-IV	1																																	1	0
SOW																																7		7	100
UD		1																	2														25	28	89.3
Total	17	2	13	5	6	7	5	22	3	1	1	0	11	0	1	4	7	1	30	6	7	1	39	40	11	1	3	3	5	9	1	7	30	329	48.5
Percent Correct	82.4	0	53.8	100	16.7	24.3	60.0	72.7	100	100	0	0	0	0	0	100	85.7	100	40.0	100	0	0	35.9	85.0	100	100	66.7	100	100	11.1	0	100	83.3	55.1	

Note: CW-III and SC-IV are the only community types with large enough sample sizes to provide statistically credible assessments.

Correction Factor and Corrected Type-Level Accuracy

The process of determining and calculating systematic error is described in the Methods section. An important systematic error was identified in this process – CW polygons classified as structure type I in the field consistently classified as type III in the photointerpretive efforts. Once this systematic error was identified and corrected for, a final corrected type-level accuracy was calculated as follows:

$$[\ .91(.37+.20) + .09(1)\ ] \times 100 = 61\ \%$$

Therefore, the corrected type-level accuracy of the 2004 CW community is estimated at 60 percent, which represents an improvement of 23 percent over the initial, pre-field verification database.

Comparison of 1997 and 2004 Line Work

It is not surprising that the 2004 line work is superior in terms of accuracy and detail compared to the 1997 line work done by CH2MHill. The 2004 line work is based on high-quality, CIR, 1-foot pixel imagery, whereas the 1997 line work is based on lower quality black and white digital orthophoto quads. Figure 12 shows a comparison between these two data sets. From this example one can see that the level of detail resulting from the use of 1-foot pixel imagery (right side of Figure 12) is much greater than the level of detail generated during the 1997 mapping effort (right side of Figure 12). The use of higher quality imagery results in the delineation of greater number of polygons and represents a more accurate model of ground conditions. When comparing the total number of polygons generated between 1997 and the current mapping effort (at the same spatial extent), the 1997 mapping effort delineated a total 6,900 polygons, whereas the current mapping effort delineated 10,063 polygons, representing an increase of 31.4 percent (3,163 polygons) in the total number of polygons delineated.

Discussion: Classification

Limitations of Our Method

There are several notable limitations to our methodology, each of which reduces the ability to accurately type-map vegetation communities. Each limitation has a compounding effect on each others. The first limitation, realized early on in the project, was that it is difficult to map vegetation structural types using our photo interpretation method, even when using the best imagery available. Structural type mapping is a three dimensional issue, whereas our photo interpretation method is limited to two dimensions.

Another important limitation, noticed during the course of the field verification visits, was that significant vegetation changes have occurred on the ground since the imagery was captured in

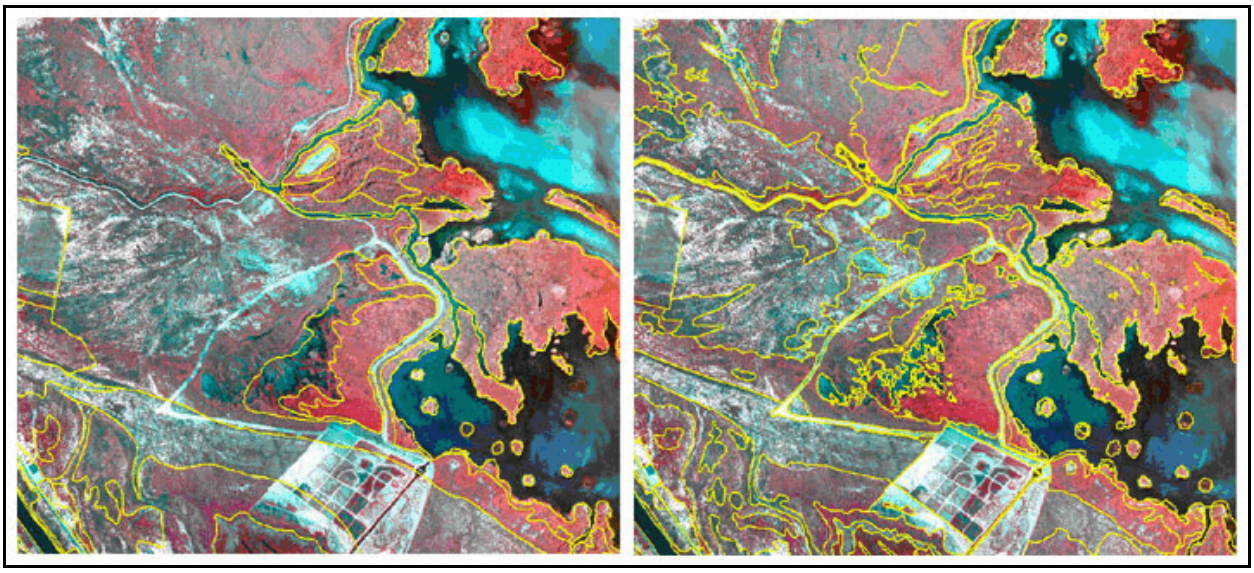


Figure 12. Differences in level of detail generated between 1997 (left) and 2004 (right) vegetation maps.

August 2004. Flooding on the Virgin River during the winter of 2005 scoured and removed vegetation that was present on the 2004 imagery. The refuge manager at Bill Williams River National Wildlife Refuge also indicated that a large flood release in late 2004 from Alamo Dam resulted in scouring of vegetation and noticeable changes to vegetation communities. In fact, the changes are significant enough that the 2004 vegetation mapping is now being used as baseline data prior to the flood, instead of a current vegetation classification (R.A. Gilbert, pers. comm.).

Limitations directly associated with the Anderson Ohmart Classification System were also identified. While differences in image characteristics can be rather conspicuous for certain structural types or communities, many of the judgments are subjective and interpretation of image signature can be less definitive for other structural or species types (CH2MHill 1999). For example, in many cases types III and IV are so similar that it is difficult to decide between types, as shown in Proportional Distribution of Vegetation Layers (Figure 8). Figures 13 and 14 provide examples of the subjectivity inherent to the photo-interpretive process when using the Anderson-Ohmart method of vegetation classification. In these two examples, CW structural types III and IV, as seen in the CIR orthophotography, appear very similar based on color, texture, tone, etc., but on the ground, as seen in the inset photos, these communities appear quite different.

The Anderson-Ohmart method of classifying vegetation was originally designed to provide resource managers with quantified baseline information on riparian vegetation and wildlife along the lower Colorado River (Anderson and Ohmart, 1976) and is based on a series of studies that describe community structure. Although the method has served as the basis for vegetation classification along the lower Colorado River since its inception in the 1970s, repeated use of the method has identified a number of limitations that should be considered when applying the results of current mapping effort.

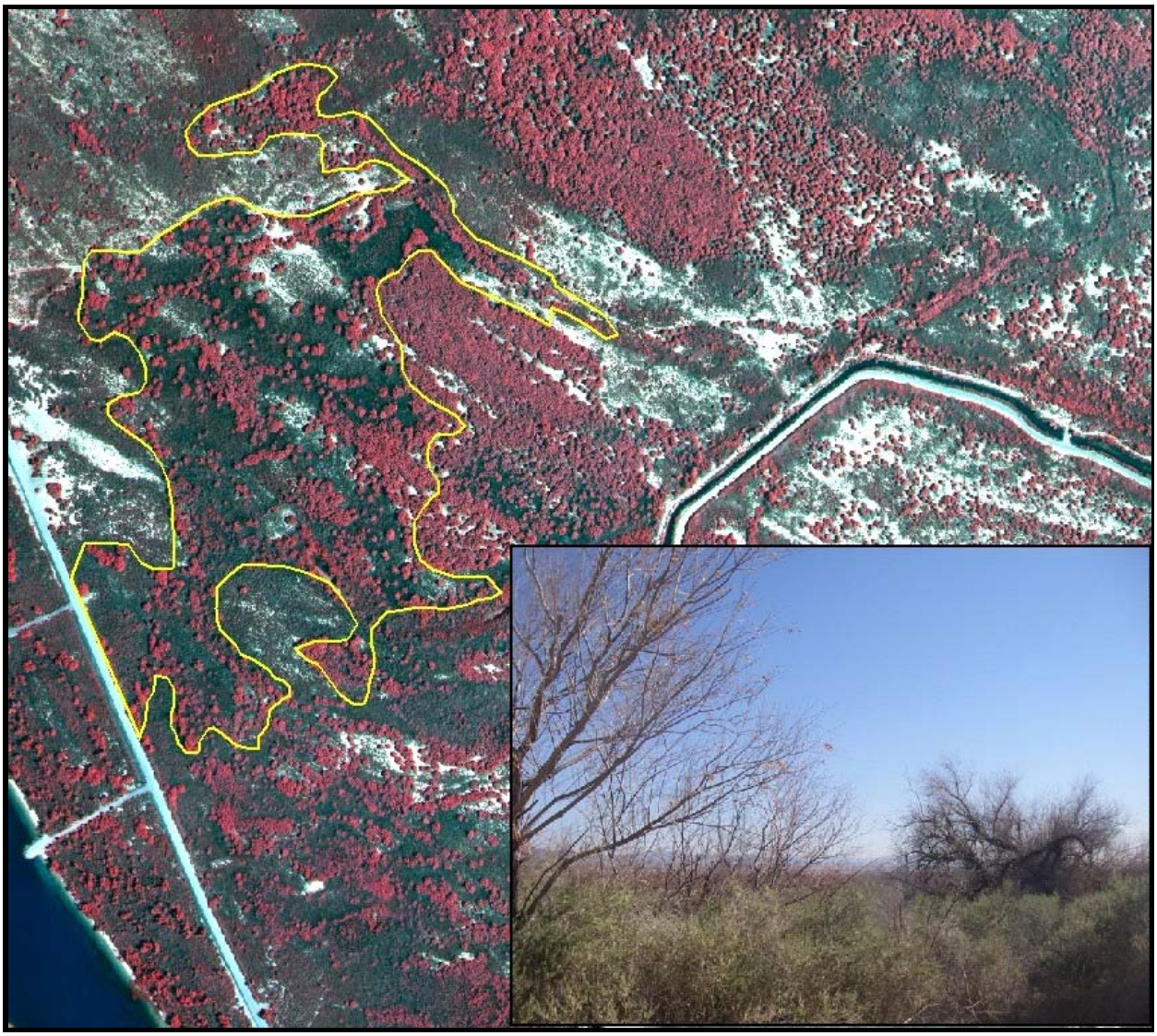


Figure 13. Example of a photo-interpreted CW-III polygon and actual conditions.

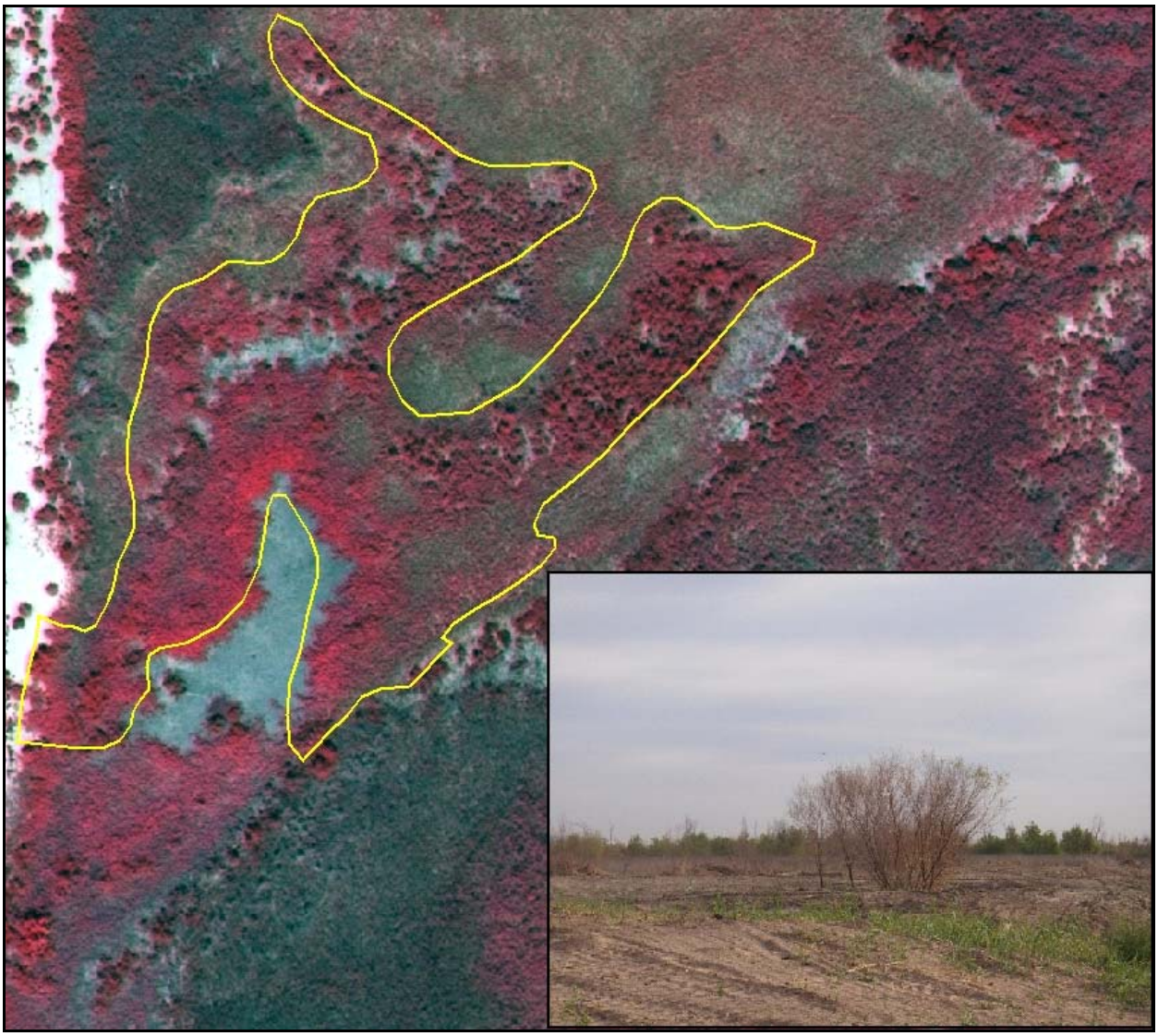


Figure 14. Example of photo-interpreted CW-IV polygon and actual conditions.

The following limitations have been identified in either past or current vegetation mapping efforts:

- The classification system is frequently used to capture the major habitat types with respect to avian communities along the lower Colorado River. However, it is only semi-quantitative and cannot be used to actually calculate how many acres of riparian vegetation exist for a given species, such as cottonwoods and willows.

- Although foliage density as described by MacArthur and MacArthur (1961) is used to describe structural type for the entire stand, it does not account for structural diversity within the stand. For example, a community consisting of 10 percent CW would automatically be labeled a CW community, thus leaving the remainder of the species within that stand undocumented.

- When photo interpreted, similarities between specific structural types (i.e. types III and IV) based on color, texture, reflectance, canopy structure, etc., make it very difficult to accurately distinguish between structural types due to the subjectivity inherent to the classification system. The use of stereo pairs may improve the ability of the photo interpreter to distinguish between the different structural types. However, it is still anticipated that such photo interpreted methods will still face a rather high level of error inherent to the methodology.

- Under the current methodology for photo interpretation, a minimum mapping unit of 1 acre is applied to all polygons except the BW class. Given technological advances and improvements in the resolution of imagery used, the use of a 1-acre minimum mapping unit may no longer be applicable.

- The scale at which the original classification system was developed was much coarser than the scale at which it is being applied today. Differences in scales are a function of advances in available technology and resolution of imagery. These differences may likely be sources of non-systematic error in mapping data that cannot be accounted for.

- Although the use of trained and experienced botanists reduces the overall variability in observations made during field verification, there will always be a level of error that cannot be accounted for. In some cases, observer error (or the way in which an observer perceives a specific structural type) is likely a direct result of the subjectivity inherent to the classification system.

- In most cases, vegetation mapping projects that are intended to update previous mapping efforts attempt to quantify differences in total acreage within each classification type. However, differences in methodology and resolution of imagery between the 1997 and 2004 efforts do not allow for such comparisons to be made. Such comparisons would not provide a realistic accounting of how the landscape is changing over time (i.e. encroachment by *Tamarix* spp. into areas that were previously dominated by *Populus* and *Salix* spp.). Additionally, the 1997 mapping effort consisted of an elaborate sampling

design for field verification that is not consistent with the current methodology. Therefore, a comparison of acreage between the current and 1997 mapping efforts may lead to an inaccurate representation of actual changes on the ground.

Recommendation: Orthophotography

CH2MHill (1999) provided several useful recommendations regarding how future vegetation classifications of the lower Colorado Region could be improved. Some of their recommendations were aimed directly at the orthophotography generation portion of such an effort. Our research followed these recommendations by generating new imagery specifically for the project, using on-board GPS for ground control, and collecting the imagery as closely as possible to the field verification date.

Based on our findings from the current project, we make the following recommendations with respect to photogrammetry for future research: In terms of resolution 2-foot pixel imagery should be considered as a viable alternative to 1-foot data. Two-foot imagery is more than adequate, in terms of resolution, for vegetation typing and backwater delineation and the file size of a 2-foot resolution image is 25 percent of the size of a 1-foot image. Thus, using 2-foot data would reduce data storage and processing by 75 percent. However, the greatest benefit of using coarser data comes in terms of the increased ground area coverage per photo and therefore the reduction in number of total photos required to cover a given project area. Specifically, if 2-foot data were collected instead of 1-foot data, it is estimated that the number of images required to cover the project area would be greatly reduced from the 2,200 images required for 1-foot data, resulting in a proportional reduction in the processing time and cost associated with this phase of the project. As a potential added benefit, stereo mapping would become much more conceivable if there were fewer stereopairs to examine.

We recommend the use of 12-bit imagery in future vegetation classifications in order to better delineate and type vegetation communities. Digital datasets are grayscale images, with each pixel represented by a numeric value beginning at 0, for black. Depending on the “bit depth” of the sensor system, grayscale increments can be represented by 255 values (for an 8-bit system) or 4,096 values (for a 12-bit system like the DMC camera that was used in this project). By dividing digital imagery into smaller value increments, any features in shadows, or the subtle differences across areas with little color variation, are more precisely described. With a greater amount of variation, image analysis is greatly improved (EarthData 2006). Given current software limitations, 12-bit data were converted to 8-bit to be used in existing software for this project. However, future releases of image processing software promise to better facilitate the use of 12-bit imagery. At least one study has already evaluated 12-bit image data for mapping riparian vegetation within the region and indicates the usefulness of 12-bit data (Davis et al. 2002).

Recommendation: Classification

The following represents a list of recommendations that may help address some of the limitations identified above:

- The classification system, as it was originally developed, produced favorable results given the state of technology and resolution of imagery available in the mid-1970s. However, the state of technology and the methods by which data are collected have improved significantly over the years. The classification system, in large part, remains relatively unchanged and, in its current state, may not be the most applicable method to use. Refining the classification system to match current technological advances and improvements in resolution of imagery would likely result in much improved vegetation map with fewer non-systematic errors.

- The current field methodology used to verify the accuracy of vegetation type mapping included the qualitative assessment of foliage height and percentage of species composition. Although such methods are cost effective and less time consuming than more quantitative methods, they contribute significantly to the overall amount of observational bias in the field verification data and is a potentially significant source of non-systematic error. By collecting quantitative vegetation data in the field and applying such data to a refined classification system, one could expect a significant decrease in the overall amount of observational bias in the field verification data and thus, an overall reduction in the amount of non-systematic error.

- As previously mentioned, the existing classification system is unable to account for structural diversity within a stand of riparian vegetation. By either decreasing or completely eliminating the minimum mapping unit requirements, as currently established, the photo interpreter is likely to produce a significantly greater number of polygons per unit area than would be possible using the current 1-acre standard. As such, the likelihood of accounting for structural diversity may be greatly improved.

- The current mapping project has frequently been described as an incredibly large undertaking. The overall size of the project area and complexity of vegetation communities within that area make it very difficult to accurately represent existing conditions. For example, aerial photographic data collected in August 2004 and subsequent photo interpretation do not represent conditions found during field verification activities conducted in March 2006. As such, it may be more appropriate to update vegetation type mapping by smaller geographic regions rather than the entire project area. Additionally, increasing the frequency of mapping updates by region may yield more favorable results. This approach would ensure that photo interpreted updates are more closely related to existing conditions within each region and would make the use of stereo pairs more cost effective and practical.

- To more easily quantify the amount of change that has occurred at the community level between mapping updates, it is recommended that standardized methods be developed for imagery acquisition, photo-interpretation, and field verification. Such methods should standardize the following: (1) resolution at which new digital orthophotography data is collected, (2) scale at which photo-interpretation is conducted, and (3) sampling design for field verification and subsequent accuracy assessment. Standardized methods should be flexible enough to allow for the implementation of new technologies that would improve the quality of photo-interpretive efforts and field verification activities.

REFERENCES

Anderson, B. W., and R. D. Ohmart. 1976. Vegetation type maps of the lower Colorado River from Davis Dam to the southerly international boundary. U.S. Department of the Interior, Bureau of Reclamation, Boulder City, NV.

Anderson, B. W., and R. D. Ohmart. 1984a. Vegetation community type maps, lower Colorado River. U.S. Department of the Interior, Bureau of Reclamation, Boulder City, NV.

Anderson, B. W., and R. D. Ohmart. 1984b. Vegetation management study for the enhancement of wildlife along the lower Colorado River. U.S. Department of the Interior, Bureau of Reclamation, Boulder City, NV.

Applanix Inertial Geospatial Solutions. 3/14/2006. POS AV hardware and software. Located at: http://www.applanix.com/products/index.php#airborne.

Artes, F. and J. Hutton 2005. GPS and Inertial Navigation- Delivering, GEOconnexion International Magazine

Baird, D.C. 1995. Experimentation: An Introduction to Measurement Theory and Experiment Design, 3rd. ed. Prentice Hall: Englewood Cliffs, NJ.

Bevington, Phillip R. and D. Keith Robinson. 1992. Data Reduction and Error Analysis for the Physical Sciences, 2nd. ed. McGraw-Hill: New York, 1992.

CH2MHill. 1999. 1997 vegetation mapping and GIS development. Report prepared for U.S. Department of the Interior, Bureau of Reclamation, Boulder City, Nevada.

Congalton, R.G., Balogh, M., Bell, C., Green, K., Milliken, J.A., and R. Ottman. 1998. Mapping and monitoring agricultural cops and other land cover in the lower Colorado River Basin. Photogrammetric Engineering and Remote Sensing 64(11):1107-1113.

Davis, P.A., Staid, M.L., Plescia, J.B., and J.R., Johnson. 2002. Evaluation of airborne image data for mapping riparian vegetation within the Grand Canyon. Open-file Report 02-470 U.S. Department of the Interior, U.S. Geological Survey, Flagstaff, Arizona.

Definiens The Image Intelligence Company. 3/18/06. Ecognition Professional. Located at: http://www.definiens.com/.

EarthData. 3/18/2006. Digital Imaging and ISTAR. Located at: http://www.earthdata.com/.

ERDAS. 2001. ERDAS IMAGINE OrthoBASE Pro User's Guide, ERDAS, Inc. Atlanta, Georgia.

Fluke. 1994. Calibration: Philosophy and Practice, 2nd. ed. Fluke Corporation: Everett, WA, 1994.

Gilbert, R. A. 2006. Manager, Bill Williams NWR. Personal communication with M. P. Sipos.

Holden, P. B., R. D. Hugie, L. Crist, S. B. Chanson, and W. J. Masslich. 1986. Development of a fish and wildlife classification system for backwaters along the lower Colorado River. Final report submitted to U.S. Bureau of Reclamation, Lower Colorado Region, Boulder City, NV, by BIO-WEST, Inc., Logan, UT. 205 p.

Inpho Photogrammetry and Digital Surface Modeling. 3/14/2006. Orthovista. Located at: http://www.inpho.de/.

Intergraph Earth Imaging and Photogrammetry. 3/14/2006. Intergraph's Z/I Imaging DMC (Digital Mapping Camera). Located at: http://www.intergraph.com/earthimaging/.

Landis, J. and G. G. Koch. 1977. The measurements of observer agreements for categorical data. Biometrics 33:159-174.

Lower Colorado River Multi-Species Conservation Program. 2004. Lower Colorado River Multi-Species Conservation Program, Volume III: Biological Assessment. June 18. (J&S 00-450.) Sacramento, California.

MacArthur, R. H., and J. W. MacArthur. 1961. On bird species diversity. Ecology 42:594-598.

Natural Resources Canada. 3/13/2006. Glossary of remote sensing terms. Located at: http://ccrs.nrcan.gc.ca/glossary/index_e.php?id=3124.

Taylor, J. 1997. An Introduction to Error Analysis, 2nd. ed. University Science Books: Sausalito, CA.

[University of North Carolina] Department of Physics and Astronomy, University of North Carolina at Chapel Hill, Definitions of Measurement Uncertainty Terms. 3/14/2006. Located at: http://www.physics.unc.edu/~deardorf/uncertainty/definitions.html.

[USBR] Bureau of Reclamation. 1996. Riparian vegetation mapping of the lower Colorado River from Davis Dam to the International Border. Technical memorandum no. 8260-96-03. Technical Service Center, Denver, Co. 42 p.

Yonker, G. L., and C. W. Andersen. 1986. Mapping methods and vegetation changes along the lower Colorado River between Davis Dam and the border with Mexico. For U. S. Bureau of Reclamation, Lower Colorado Region, Boulder City, NV. Contract No. 6-CS-30-03800.

APPENDIX A: PHOTO LOG

Polygon FID 2733: SC-I

Polygon FID 2994: SC-II

Polygon FID 5700: SC-III

Polygon FID 5804: SC-IV

Polygon FID 7191: SC-V

Polygon FID 2939: CW-I

Polygon 2922: CW-II

Polygon FID 3220: CW-III

Polygon FID 3161: CW-IV

Polygon FID 4270: MA-1

Polygon FID 6341: MA-3

Polygon FID 3658: MA-4

Polygon FID 3772: MA-5

Polygon FID 4269: MA-6

Polygon FID 3283: AW

Polygon FID 3290: ATX

Polygon FID 2938: CR

Polygon FID 6547: SM-III

Polygon FID 525: SM-IV

Polygon FID 8583: HM-IV