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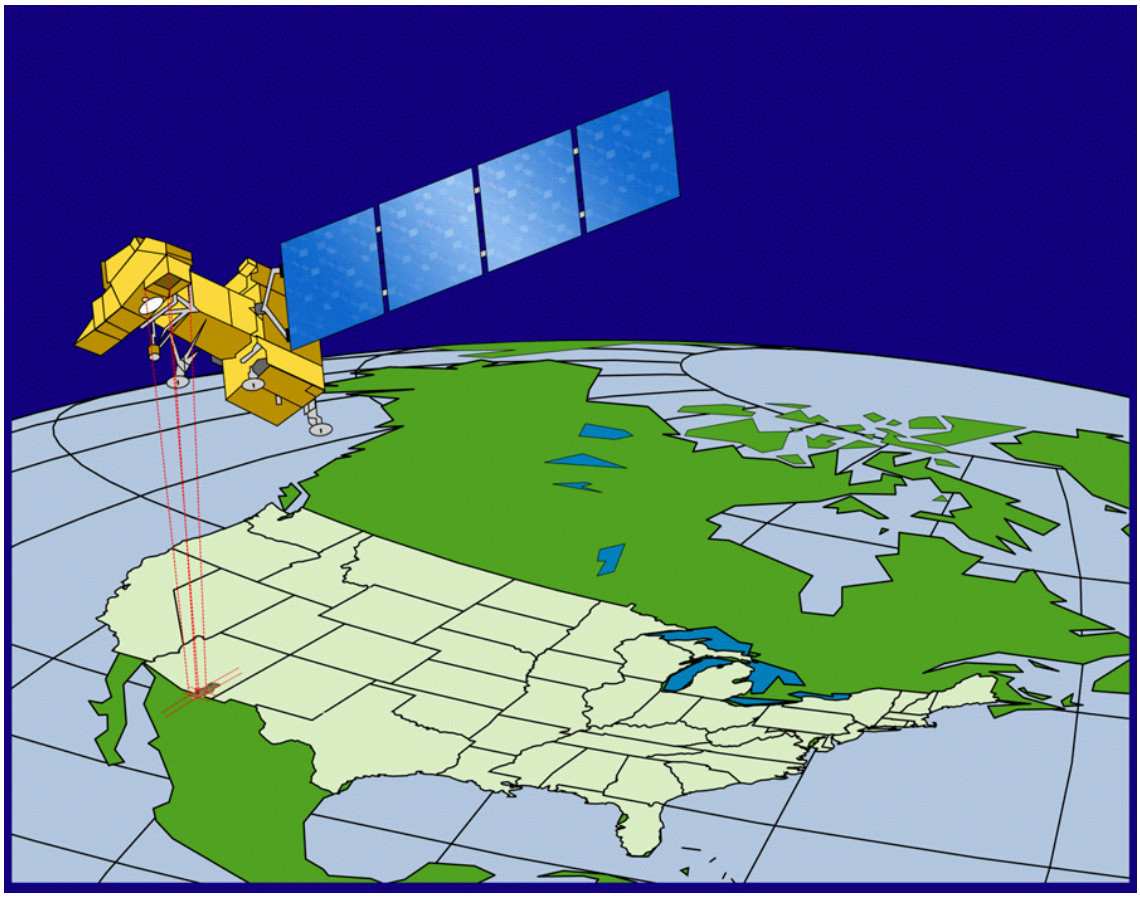
An Accuracy Assessment of 1997 Landsat Thematic Mapper Derived Land Cover for the Upper San Pedro Watershed (U.S./Mexico)



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Susan M. Skirvin
Samuel E. Drake
John K. Maingi
Stuart E. Marsh
Arizona Remote Sensing Center
Office of Arid Lands Studies
University of Arizona
Tucson, Arizona

William G. Kepner
U.S. Environmental Protection Agency
Office of Research and Development
National Exposure Research Laboratory
Las Vegas, Nevada

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Notice

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Executive Summary

High-resolution airborne color video data were used to evaluate the accuracy of a land cover map of the upper San Pedro River watershed, derived from June 1997 Landsat Thematic Mapper data. The land cover map was interpreted and generated by Instituto del Medio Ambiente y el Desarrollo Sustentable del Estado de Sonora (IMADES), Hermosillo, Sonora and supplied to the Arizona Remote Sensing Center at the University of Arizona for evaluation. Map pixel size had been increased from 30 to 60 meters to match the 1973, 1986, and 1992 North American Landscape Characterization (NALC) land cover maps produced from Landsat MSS data.

The airborne color video data included six flight lines acquired 2-5 May 1997 over the San Pedro watershed in the U.S. GPS time and coordinate information encoded on the video tapes were used to generate GIS point coverages of video frames covering the upper San Pedro. A total of 527 video sample points were drawn randomly from a subset of 4567 frames falling on areas of uniform cover classes at least 180 meters square. Sample points were stratified by cover class area, with a minimum sample of 24 points for classes of small areal extent. The Water class was extremely rare (covering less than 0.1% of the study area) and was excluded from video data analysis for lack of data. Video sample points were reviewed by an experienced interpreter who assigned land cover class labels based on available descriptions. Map and video labels were compared to generate a classification error matrix, which produced an overall map accuracy of about 72%.

Chapter 1

Introduction

There is keen interest among Federal agencies, States, and the public to evaluate environmental conditions at community, watershed, regional, and national scales. Advances in computer technology, geographic information systems (GIS) and the use of remotely sensed imagery have provided the first opportunity to assess ecological resource conditions at a number of scales and to determine cross-scale relationships between landscape composition and pattern, fundamental ecological processes, and ecological goods and services. Providing quantifiable information on the thematic and spatial accuracy of land use and land cover data derived from remotely sensed sources is a fundamental step in achieving goals related to performing large spatial assessments using space-based technologies.

The U.S. Environmental Protection Agency has established a priority research area for the development and implementation of methods to document the accuracy of classified land cover and land characteristics databases (Jones *et al*., 2000). The research provided in this report assesses the accuracy of a classification product, derived from a Landsat satellite platform, for a watershed in southeast Arizona and northeast Sonora, Mexico. Secondly, it provides a methodology using georeferenced high-resolution airborne videography as a substitute for actual ground sampling for contemporary imagery.

A land cover map for the Upper San Pedro Watershed (Figure 1) was provided to the Arizona Remote Sensing Center, University of Arizona, by the Instituto del Medio Ambiente y el Desarrollo Sustentable del Estado de Sonora (IMADES) for classification accuracy assessment. The map (Figure 2) was based on a digital classification of a Landsat Thematic Mapper (TM) image acquired on 8 June 1997. The same 10-class classification scheme used for 1973, 1986 and 1992 North American Landscape Characterization (NALC) land cover maps was used in the preparation of the 1997 map (Table 1). The selected cover classes represent very broad biome-level categories of biological organization and are similar to the ecological formation levels as provided in the classification system for biotic communities of North America (Brown *et al*., 1979). The ten classes included Forest, Oak Woodland, Mesquite Woodland, Grassland, Desertscrub, Riparian, Agriculture, Urban, Water, and Barren. The classes were selected prior to digitally classifying the imagery, after direct consultation with the major land managers and stakeholder groups within the San Pedro watershed in Arizona and Mexico. The resolution of the 1997 land cover map had been degraded from 30 meter to 60 meter pixel size for consistency with NALC land cover maps derived from Landsat MSS data for the project area under a previous accuracy assessment study (see Maingi *et al*., 1999).

Accuracy assessment of the 1997 land cover map was performed using airborne color video data encoded with GPS time and latitude and longitude coordinates. The video data were acquired between 2 and 5 May 1997 and were therefore nearly coincident with the June Landsat TM scene. There were 11 hours of continuously recorded videography of the San Pedro Watershed for the area north of the US-Mexico border. The video was acquired at a flying height of 600 m above ground level (agl). The camera used a motorized 15X-zoom lens that was computer controlled to cycle every 12 seconds during acquisition, with a full-zoom view held for three seconds. The swath width at wide angle was about 750 m, and

approximately 50 m at full zoom. At full zoom, the ground pixel size was about 7 cm, and the scale of a frame, when displayed on a 13 inch monitor, was about 1:200. The video footage was acquired by flying north-south transects spaced 5 km apart and the total flight coverage encompassed a distance of nearly 2000 km (Figure 3).

A similar video data set was acquired over the same transects between 17 and 19 November 1995. This video was available for comparison with the interpretation of the 1997 video. For another research project (McClaran *et al*., 1999), over 550 full zoom video frames from the 1995 video were selected and interpreted and estimates of canopy cover and plant density of species or species groups determined. Identification of species was accomplished by using cues such as size, shape, color, texture, shadow and context, along with ancillary knowledge derived from fieldwork. However, resolution of the video data did not permit species identification of grasses and forbs or small shrubs under 1 meter tall. Although the nominal accuracy of the encoded GPS coordinates acquired using a Trimble Basic Receiver was only 100 m, ground sampling revealed the positional accuracy was closer to 40 m.

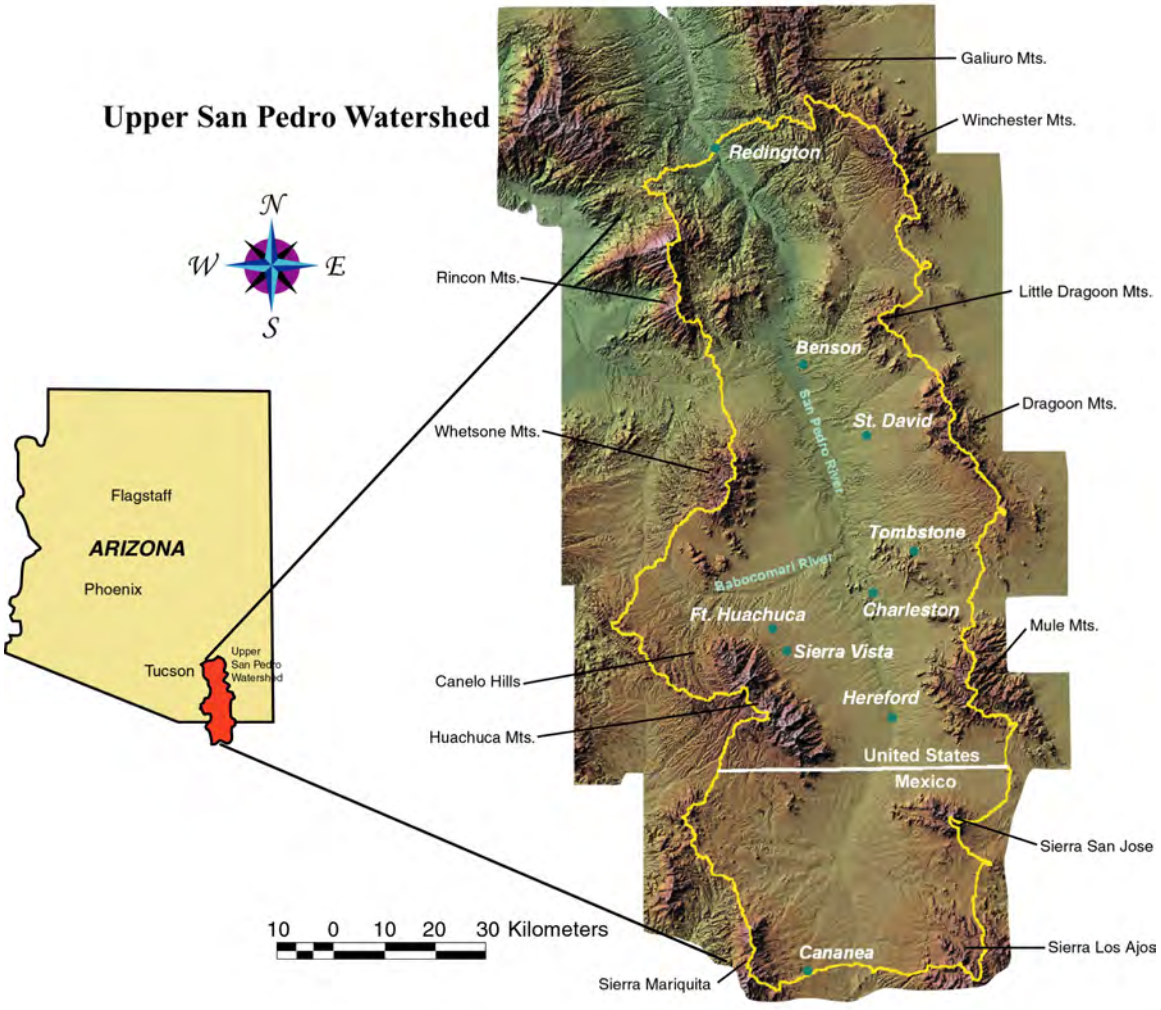

Figure 1. Location of the Upper San Pedro River basin, Arizona/Sonora.

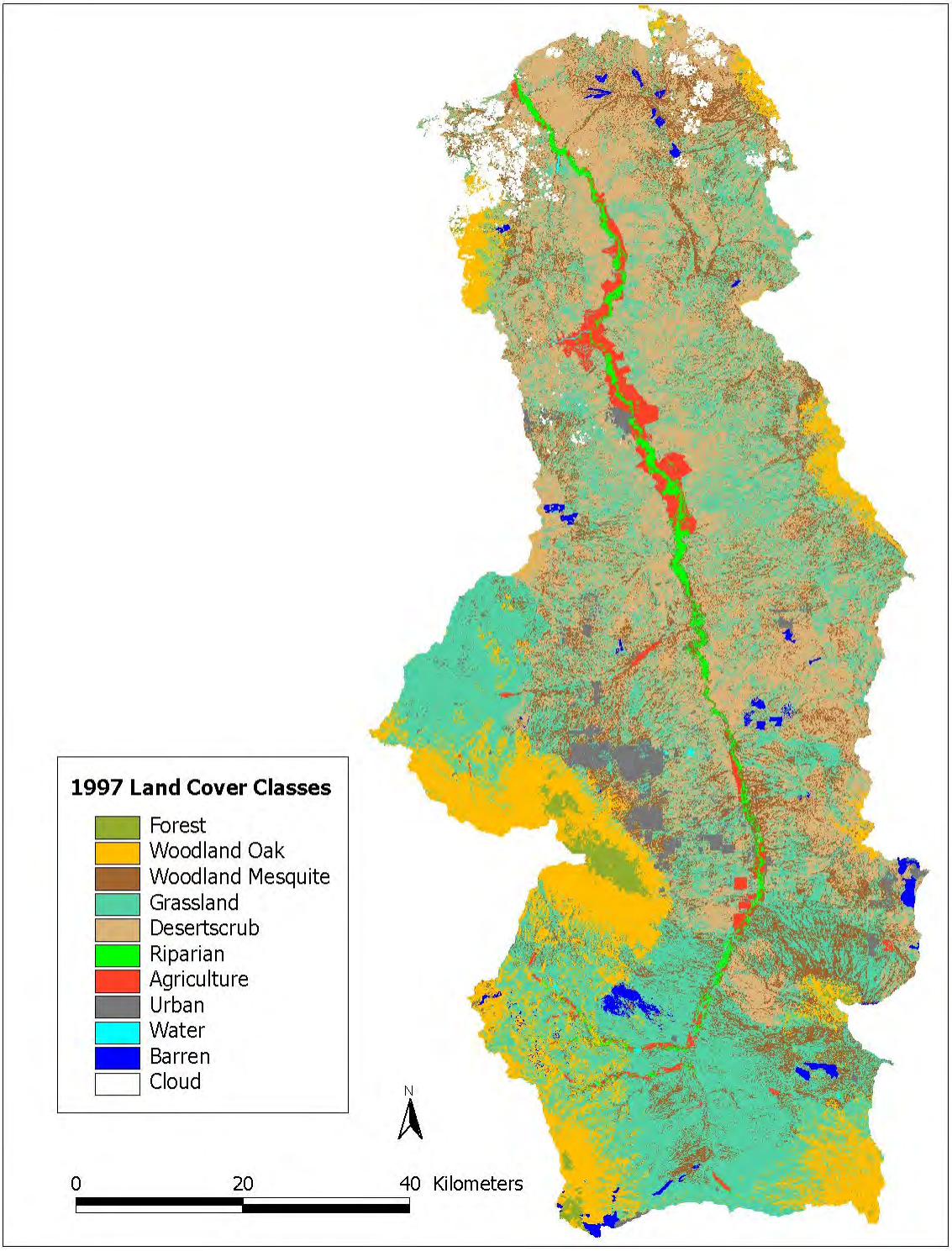

Figure 2. Map of 1997 land cover for the Upper San Pedro watershed.

Table 1. Land cover class descriptions for the Upper San Pedro Watershed (Maingi *et al*., 1999).

Forest	Vegetative communities comprised principally of trees potentially over 10m in height and frequently characterized by closed or multi-layered canopies. Species in this category are evergreen (with the exception of aspen), largely coniferous (e.g. ponderosa pine, pinyon pine), and restricted to the upper elevations of mountains that arise off the desert floor.
Oak Woodland	Vegetative communities dominated by evergreen trees (*Quercus spp.*) with a mean height usually between 6 and 15m. Tree canopy is usually open or interrupted and singularly layered. This cover type often grades into forests at its upper boundary and into semi-arid grassland below.
Mesquite Woodland	Vegetative communities dominated by leguminous trees whose crowns cover 15% or more of the ground often resulting in dense thickets. Historically maintained maximum development on alluvium of old dissected flood plains; now present without proximity to major watercourses. Winter deciduous and generally found at elevations below 1,200m.
Grassland	Vegetative communities dominated by perennial and annual grasses with occasional herbaceous species present. Generally grass height is under 1m and they occur at elevations between 1,100 and 1,700m; sometimes as high as 1,900m. This is a landscape largely dominated by perennial bunch grasses separated by intervening bare ground or low-growing sod grasses and annual grasses with a less-interrupted canopy. Semi-arid grasslands are mostly positioned in elevation between evergreen woodland above and desertscrub below.
Desertscrub	Vegetative communities comprised of short shrubs with sparse foliage and small cacti that occur between 700 and 1,500m in elevation. Within the San Pedro river basin this community is often dominated by one of at least three species, i.e. creosotebush, tarbush, and whitethorn acacia. Individual plants are often separated by significant areas of barren ground devoid of perennial vegetation. Many desertscrub species are drought-deciduous.
Riparian	Vegetative communities adjacent to perennial and intermittent stream reaches. Trees can potentially exceed an overstory height of 10m and are frequently characterized by closed or multi-layered canopies depending on regeneration. Species within the San Pedro basin are largely dominated by two species, i.e. cottonwood and Goodding willow. Riparian species are largely winter deciduous.
Agriculture	Crops actively cultivated (and irrigated). In the San Pedro River basin these are primarily found along the upper terraces of the riparian corridor and are dominated by hay and alfalfa. They are minimally represented in overall extent (less than 3%) within the basin and are irrigated by ground and pivot-sprinkler systems.
Urban (Low and High Density)	This is a land cover dominated by small ejidos (farming villages or communes), retirement homes, or residential neighborhoods (Sierra Vista). Heavy industry is represented by a single open-pit copper mining district near the headwaters of the San Pedro River near Cananea, Sonora (Mexico).
Water	Sparse free-standing water is available in the watershed. This category would be mostly represented by perennial reaches of the San Pedro and Babocomari rivers with some attached pools or repressos (earthen reservoirs), tailings ponds near Cananea, ponds near recreational sites such as parks and golf courses, and sewage treatment ponds east of the city of Sierra Vista, Arizona.
Barren	A cover class represented by large rock outcropping or active and abandoned mines (including tailings) that are largely absent of above-ground vegetation.

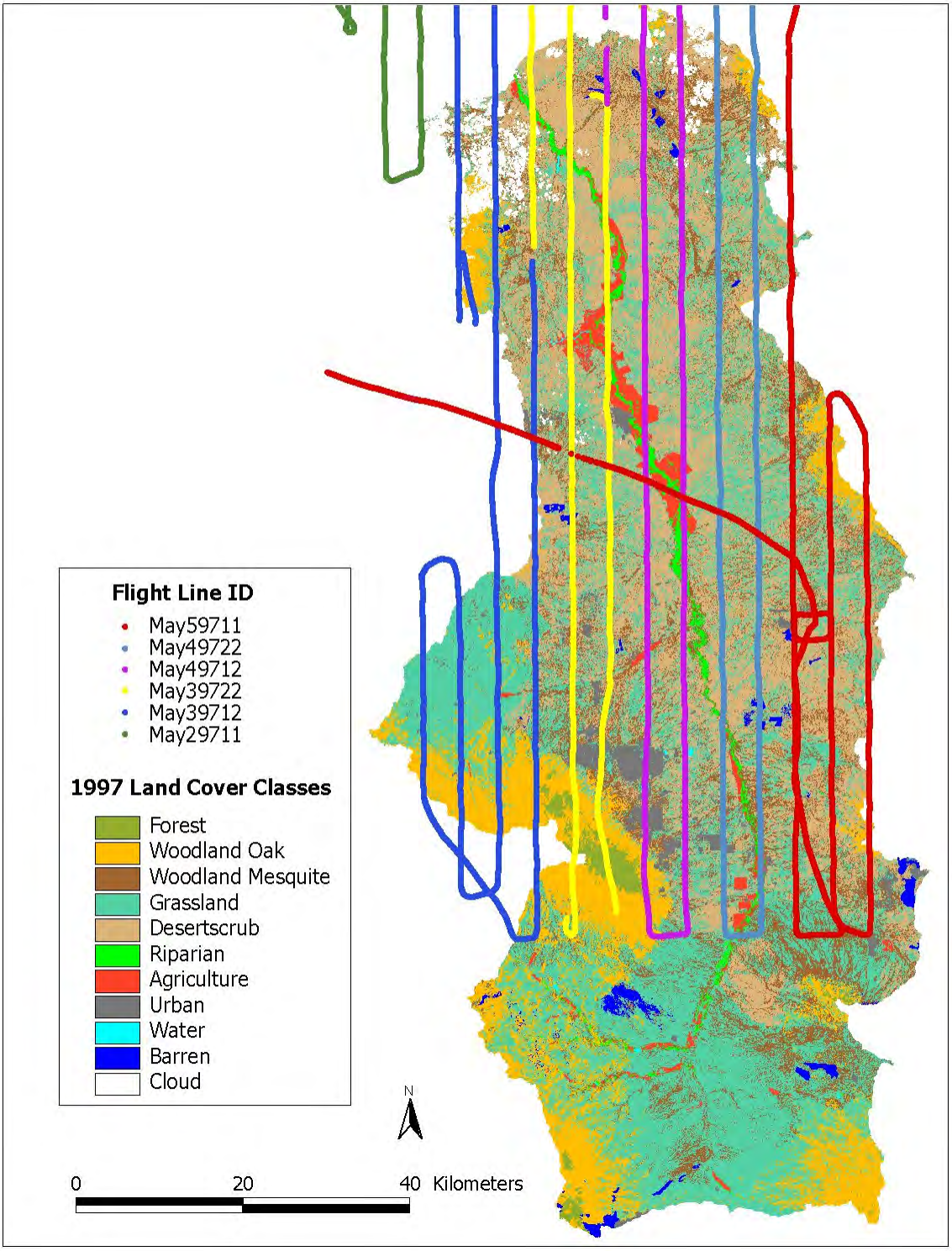

Figure 3. Video acquisition flight lines overlaid on the 1997 San Pedro land cover map. Flight line colors represent the different acquisition dates during 1997.

Chapter 2

Methodology

2.1 Video and GIS Data Preparation

Information for the 1997 land cover map indicated a projection in UTM Zone 12, based on the Clarke 1866 spheroid and NAD27 datum. The map was clipped to the revised upper San Pedro watershed boundary (Maingi *et al*., 1999) which encompassed the 1973, 1986, and 1992 NALC land cover maps using the same projection. The encoded airborne video GPS time and geographic coordinate data were extracted from the video into a spreadsheet for each flight line. Coordinate data were exported from each spreadsheet as a text file in Arc "generate" format (ESRI, 1998), then transformed into an Arc/Info point coverage of the video flight line. Flight line coverages were reprojected from geographic to UTM coordinates with the same projection as the 1997 land cover map (Figure 3).

Individual frames of the video data were identified during viewing by a time display showing hours:minutes:seconds, in addition to a counter which numbered the 30 frames recorded per second. Encoded time data (available only as hh:mm:ss), along with flight line tape number, were exported from the spreadsheets as delimited text, then imported into ArcView 3.1 (ESRI, 1998) and re-exported as a dBase table which was joined to the point attribute table of the flight line coverage. This roundabout procedure was necessary to preserve the time information as character data in the desired format and to link times and tape numbers with the flight line points, each of which represented the first of 30 frames per second. The coverages were inspected for erroneous coordinate or time data, indicated by points which fell off the flight lines or which were out of time sequence; such points were deleted.

2.2 Video Sample Point Selection

2.2.1 Initial Homogeneity Screening

To minimize the likelihood of video sample points falling on boundaries between land cover classes, selection of random sample points along the video flight lines was restricted to relatively homogeneous areas within classes. This was accomplished by applying a 3 × 3 diversity filter to the 1997 map (ERDAS, 1998). The diversity filter replaced the center pixel in a moving window by the number of different data file values (land cover classes) present among the pixels in the window. Pixels assigned the value of one therefore represented centers of 180-meter square homogeneous areas on the map. Background areas (class = 0) were excluded from the process, while the diversity function was not applied at clouds or cloud-shadowed pixels (class = 11). These restrictions prevented the selection of pixels that fell at the edge of the map or within openings in clouds and cloud-shadowed areas, where the adjacent land cover classes were not known.

The diversity-filtered image was converted to an Arc/Info grid and cells with value = 1 were selected to create a homogeneity mask, with other cell values set to NODATA. The 1997 land cover map was also

converted to an Arc/Info grid and the homogeneity mask was applied in order to select only land cover cells falling in homogeneous areas (Figure 4). The masked homogeneous land cover grid was then converted to a polygon coverage.

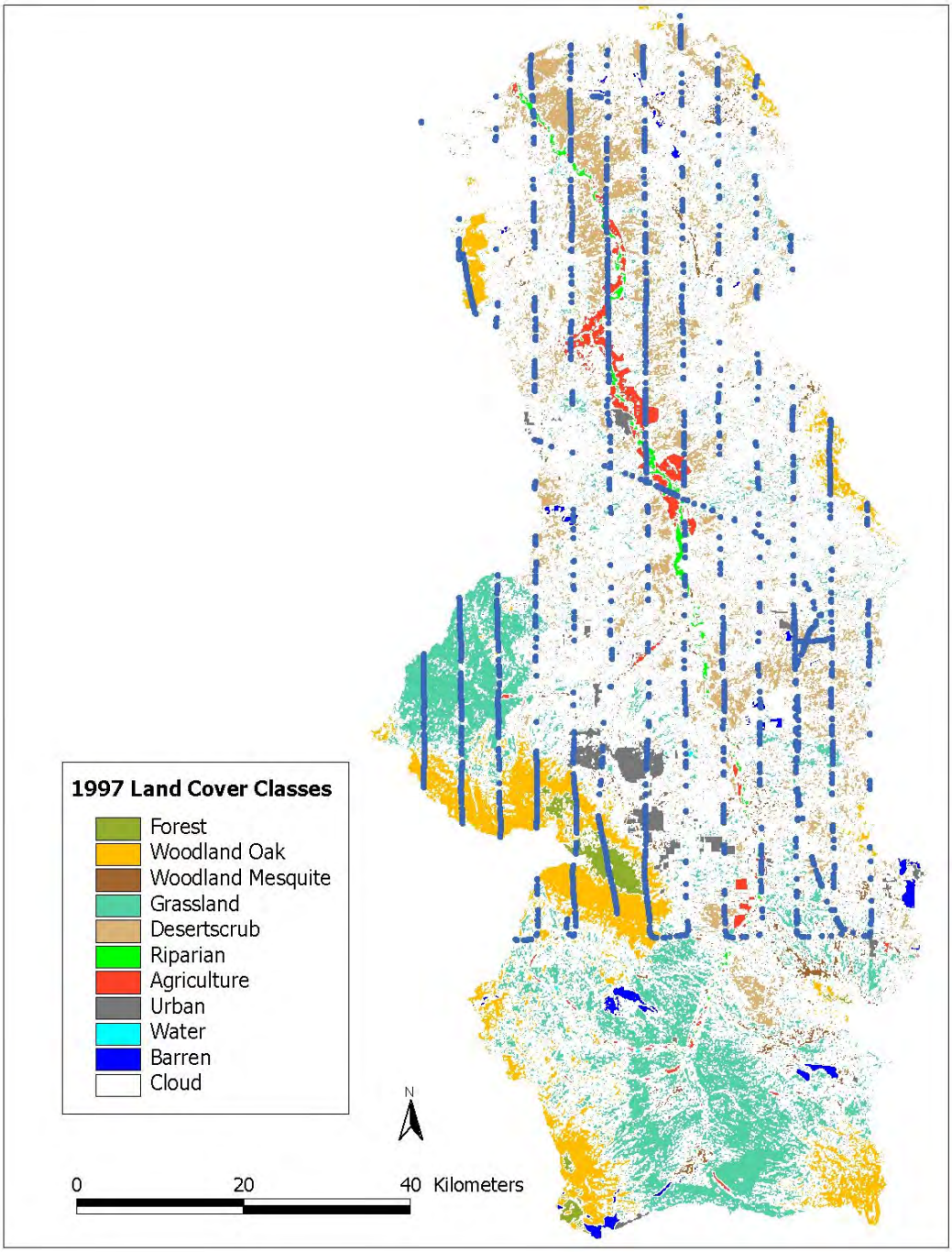

Figure 4. Video sample points overlaid on homogeneous areas on the 1997 land cover map. The homogeneous areas were determined by using a diversity filter.

In order to determine which points along the video flight lines fell within homogeneous areas, video point coverages were intersected with the homogeneous land cover polygon coverage in Arc/Info (Figure 4). The resulting intersected coverages were merged into a single point coverage, representing the total number of sample points that were available from the video for classification accuracy assessment (N = 4567). The range of 1997 land cover classes represented in the video sample points is shown in Table 2, as well as classes for all flight line points falling within the upper San Pedro watershed (N = 18,104). Land cover class information was added to the video sample point coverage by summarizing classes of the land cover grid on zones of the sample point coverage in ArcView, then exporting the resulting .dbf table to Info and joining to the sample point attribute table in Arc/Info.

Table 2. Availability of video sample points by land cover class in the 1997 map.

1997 Land Cover Class	Total Video Points	Video Points in Homogeneous Areas
Forest	177	122
Woodland Oak	1721	1109
Woodland Mesquite	2312	123
Grassland	5245	968
Desertscrub	6876	1576
Riparian	327	148
Agriculture	399	228
Urban	459	243
Water	6	1
Barren	75	51

2.2.2 Statistical Requirements

An equation based on binomial probability theory, relating classification accuracy assessment sample size to overall classification accuracy and allowable error, can be used to calculate the allowable error on the accuracy of a land cover map (van Genderen and Lock, 1977; Fitzpatrick-Lins, 1981, Marsh *et al.*, 1994). The equation is:

$$N = \frac{Z^2 pq}{E^2}$$

where:

N = number of samples required
Z = Standard normal deviate for the 95% two-tail confidence level (1.96)
p = expected or calculated accuracy (in percentage)
q = 100-p
E = Allowable error

We assumed a ± 5% allowable error and an overall map accuracy of at least 60%. Using the formula shown above, we needed a total of 369 sample points for the accuracy assessment. Apportionment of sample points to the different land cover classes was stratified according to area. However, because the area covered by some of the smaller land cover classes was negligible compared to the rest of the classes, these classes were not apportioned a sufficient number of sample points. If sample size within a stratum is too small, chances are that no classification errors would be sampled even if the classification is poor (Miguel-Ayanz and Biging, 1997). In such situations, van Genderen and Lock (1977) suggested that the smallest sample in this class should be 20 or 30 for maps in which the admissible percentage errors are 15% and 10%, respectively. For this reason, the minimum number of sample points for any class was 20, which increased the minimum total number of sample points from 371 to 464 (Table 3).

Table 3. Number of sample points per land cover class stratified by area.

Land cover	Area (Ha)	Proportion of area (%)	Calculated samples	Minimum number of samples	Final number of samples
Forest	7193	1.0	4	20	24
Woodland Oak	90540	12.2	46	46	55
Woodland Mesquite	101559	13.7	51	51	56
Grassland	263475	35.6	132	132	159
Desertscrub	229571	31.0	115	115	137
Riparian	9217	1.3	5	20	24
Agriculture	14530	2.0	7	20	24
Urban	16562	2.2	8	20	24
Water	417	< 0.1	0	20	0
Barren	6814	0.9	3	20	24
Total	739878	100.00	371	464	527

2.2.3 Random Frame Selection and Evaluation

From the set of 4567 candidate frames, a random sample of 527 was chosen for analysis, stratified by map class as shown in Table 3. Class 9, Water, was excluded from analysis for lack of data (only 6 possible frames; Table 2) and does not appear in the final error matrix. Within each remaining map class, frames were assigned a simple, unique sequential identification number, and random selection of these numbers was performed with Microsoft Excel 97's RANDBETWEEN function. A surplus of about 15% over the calculated minimum number of frames needed in each class was selected, giving the set of 527 frames instead of the minimum 464.

The spreadsheet records for frames selected for analysis were edited and pasted into a new worksheet which contained only information on the frames' latitude, longitude, videotape library identifier, and GPS time for frame location on the tape. This information was supplied to the videography interpreter, along with the 10 map class descriptions shown in Table 1, and the instruction that each video frame in the selected sample be located, visually interpreted and classified into one of the 10 map classes.

Since the videography varied in scale between wide angle and 15X full zoom, and no selection could be made for frames at a particular scale, the operator visually estimated a 60x60m window around each frame center for interpretation. The contents of this window in each case were used to classify a "frame," regardless of the frame's actual scale. The local context for the interpretation of each frame

was provided through analysis of the continuous videography. Although the accuracy of video frame interpretation was not assessed explicitly in this study, it is expected to be very high. Drake (1996) reported that land cover identification of similar airborne videography at the more detailed biotic community level averaged 80% accuracy after only 3 hours of interpreter training. The interpreter for this study had substantial prior experience in both video frame interpretation and ground sampling for videography accuracy assessment in this region.

After interpretation and classification of the sampled 527 video frames, the assigned video classifications were entered into a spreadsheet containing the assigned map classifications for each sample location, and used as reference data to assess the accuracy of the map classifications. The facilities of SYSTAT 9 (SPSS, Inc., 1999) were used to create an error matrix for the data and to generate Cohen's Kappa and Kendall's Tau-b statistics for quantification of overall classification accuracy. Raw percent correct for the matrix, and user's and producer's accuracies for each class were also calculated. These results are summarized in Table 4.

Table 4. Results of video-based accuracy assessment of the 1997 land cover map: classification error matrix, summary, and statistics.

		Reference (Video Frame Data)									
		1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***10***	**Grand Total**
Land Cover Classes 1997	**1**	**20**	4	0	0	0	0	0	0	0	**24**
	2	2	**50**	0	3	0	0	0	0	0	**55**
	3	0	1	**27**	13	12	2	0	1	0	**56**
	4	0	8	16	**113**	21	0	0	1	0	**159**
	5	0	4	4	12	**115**	0	0	2	0	**137**
	6	0	0	0	0	0	**21**	2	1	0	**24**
	7	0	0	1	0	15	2	**5**	1	0	**24**
	8	0	0	0	0	0	0	0	**24**	0	**24**
	10	0	0	2	0	19	0	0	0	**3**	**24**
Grand Total		**22**	**67**	**50**	**141**	**182**	**25**	**7**	**30**	**3**	**527**

Land Cover Class	97 Map Total	Video Total	Number Correct	Producer's Accuracy (%)	User's Accuracy (%)
1. Forest	24	22	20	91	83
2. Woodland Oak	55	67	50	75	91
3. Woodland Mesquite	56	50	27	54	48
4. Grassland	159	141	113	80	71
5. Desertscrub	137	182	115	63	84
6. Riparian	24	25	21	84	88
7. Agriculture	24	7	5	71	21
8. Urban	24	30	24	80	100
9. Water	N/A	N/A	N/A	N/A	N/A
10. Barren	24	3	3	100	13
Total:	**527**	**527**	**378**		

Overall Accuracy (%):	**71.73**

Coefficient	Value	Standard Error
Kendall's Tau-B	0.741	0.024
Cohen's Kappa	0.646	0.024

Chapter 3

Results and Discussion

Examination of the results in Table 4 by map class indicates that there is substantial variability in classification accuracy. Producer's accuracy varies from 100% to 54%, and user's accuracy from 100% to 13%. For most classes the two measures are roughly comparable and fall within the range of 60-90%. The Barren, Agriculture, and Mesquite Woodland classes are those presenting some difficulty. Three general explanations may be offered for discrepancies between map classifications and video classifications, and the resulting low assessed accuracy of a class. First, locational errors or misregistration of sampled points may be to blame; second, vagueness or inconsistency of the class definitions used (leading to some unmeasurable "error" in the reference data) may be responsible; and third, true thematic errors or misclassifications of map polygons may have been detected.

Of the above explanations, there is no evidence that locational error of the sampled video frames contributed significantly to a reduction in the assessed accuracy of any class; such reduction can be attributed to vagueness in class definitions and to true thematic map errors. The selection of candidate frames of 60x60m only from within homogeneous map areas of 180x180m helped ensure that sampled frames fell within the intended class, given the 40m mean locational error of frame center coordinates established in an earlier validation study. Observation of the spatial context of some video frame classifications differing from map classifications did not indicate that a coordinate offset on the order of 100 meters or less in any direction would have brought the two classifications into agreement.

Vagueness and overlap in the class definitions provided to the video interpreter were certainly an issue in this accuracy assessment, and it is likely that doubt and inconsistency between video interpretation criteria and satellite image classification criteria were the cause of some discrepancies between the video reference data and the map data being assessed. All nine non-water classes as originally defined by the satellite image classification group contained a certain degree of vagueness. This forced the interpreter of the video frames to make subjective judgements that may have been contrary to those subjective decisions made by the satellite image classification group. Of particular note are the difficulties in separating Forest from Oak Woodland, and Mesquite Woodland from Grassland from Desertscrub based on the initial idealized descriptions of these classes. In reality, these classes intergrade subtly more often than not, and some viable criteria must be used to separate intermediate cases. No concrete criteria were available at the time of analysis that would be appropriate at both satellite and video scales. Moreover, the criteria of potential tree height (overlapping, in the critical case of Forest and Oak Woodland) and general elevation ranges for classes, provided in the descriptions, could not be used practically during video interpretation.

While some apparent classification error can be attributed to a lack of clear, applicable class descriptions, it is probably much less than that attributable to true thematic error in the map being assessed. This is certainly true for the low-accuracy classes labeled Barren and Agriculture. Review of the discordant sample locations in these classes clearly showed, for example, characteristic Desertscrub in video frames mapped as Agriculture, and Mesquite Woodland (>15% canopy cover) in frames mapped as Barren (see

examples in Figure 5). While the Barren class had a producer's accuracy of 100%, its user's accuracy was only 12.5% because so many mapped polygons were labeled Barren which the videotape revealed as supporting a substantial vegetative cover of 30-50% or more. While no definite criterion was given in the class description, a video frame was not classified as Barren unless its total cover was less than 10%.

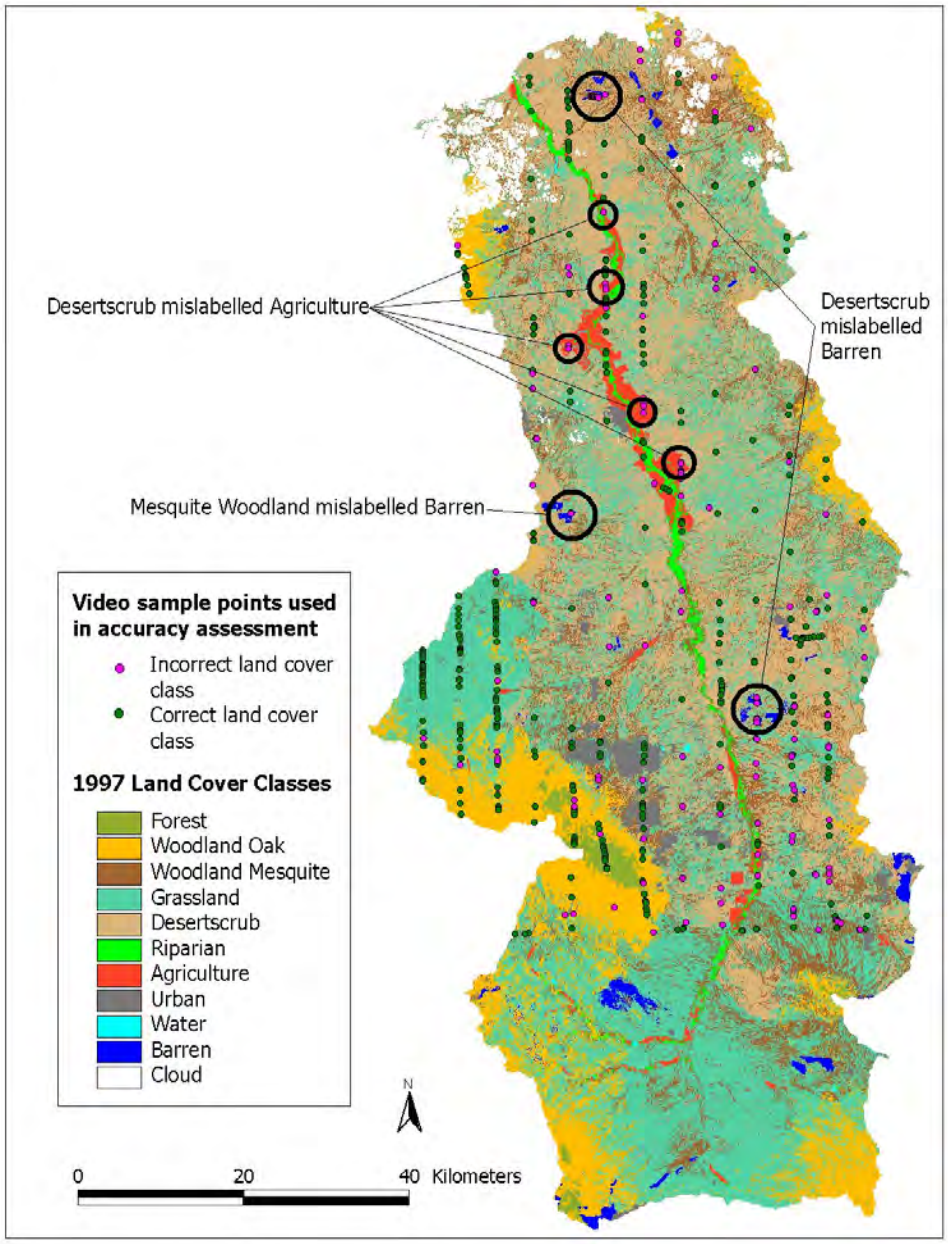

Figure 5. Locations of video sample points and misclassifications on 1997 land cover map. Examples shown for land cover classes with low user's accuracy.

Chapter 4
Conclusions

The results of this accuracy assessment show that six of nine classes were mapped with good to excellent accuracy. Surprisingly, the contrasting classes labeled Barren and Agriculture were mapped least accurately from the user's standpoint. Not surprisingly, the more ill-defined and heterogeneous class Mesquite Woodland had both low producer's accuracy and user's accuracy.

The use of georeferenced high-resolution airborne videography as a proxy for actual ground sampling for satellite image classification accuracy assessment has merit. A statistically meaningful number of sample points can be gathered at practical expense. Coordinate locational error can be controlled and compensated for in the methodology. The choice of scale in videography acquisition can allow for the identification of plant species or communities, and the clear depiction of cultural features and land cover characteristics.

The key to using aerial videography for a meaningful accuracy assessment is providing the video interpreter with applicable classification criteria. Class definitions must be concrete, mutually exclusive, and capable of making the distinctions necessary for classifying the inevitable video frames that seem intermediate between two or more classes. They must also be congruent with those definitions used by the developers of the image-map to be assessed, although exactly how to achieve this congruence may be a larger question. Without the application of clear and appropriate criteria, the measured accuracy of a map is liable to be biased negatively.

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