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A High-Resolution Land-Use Map—Nogales, Sonora, Mexico

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Contents

Figures

Tables

A High-Resolution Land-Use Map—Nogales, Sonora, Mexico

By Laura M. Norman[1], Miguel L. Villarreal[1], Cynthia S. A. Wallace[1], Claudia Zulema Gil Anaya[2], Israel Diaz Arcos[2], and Floyd Gray[1]

Abstract

The cities of Nogales, Sonora, and Nogales, Arizona, are located in the Ambos Nogales Watershed, a topographically irregular bowl-shaped area with a northward gradient. Throughout history, residents in both cities have been affected by flooding. Currently, the primary method for regulating this runoff is to build a series of detention basins in Nogales, Sonora. Additionally, the municipality also is considering land-use planning to help mitigate flooding. This paper describes the production of a 10-meter resolution land-use map, derived from 2008 aerial photos of the Nogales, Sonora Watershed for modeling impacts of the detention basin construction and in support of an "Early Warning Hazard System" for the region.

Introduction

The Ambos Nogales Watershed is 93.98 square miles (243 km^2), and is bisected almost evenly by the east-west International Boundary between the United States and Mexico (fig. 1). The Nogales Wash originates 6.72 miles (10.83 km) south of the border and flows north another 8.88 miles (14.29 km) before joining with the Santa Cruz River in Arizona. The main branch of the Nogales Wash has a contributing area in Nogales, Sonora, of 25.79 square miles (66.8 km^2) that discharges into Nogales, Arizona. Actions to control and regulate dangerous flows into the urban areas of Ambos Nogales are being carried-out primarily upstream in Mexico within this subwatershed.

Locations for the installation of gabion-type flood detention features to reduce flood-stage discharges in washes are based on the recommendations of the USACE report (2005). Norman and others (2010) implement the KINEROS2 (K2) model using the Automated Geospatial Watershed Assessment 2.0 geographic information system interface to evaluate the Ambos Nogales Watershed's vulnerability to flooding. The K2 model is used to identify flood-prone areas, to simulate the impact of land-use change, and to evaluate the impact of potential flood-control interventions. A heterogeneous land-cover dataset was developed by Norman and Wallace (2008) for the Ambos Nogales Watershed to support input needed for calculating the hydrological parameters of a small Watershed. The data were derived from imagery acquired on October 7, 1992, and the pixel size for the raster land-use map is 60 m.

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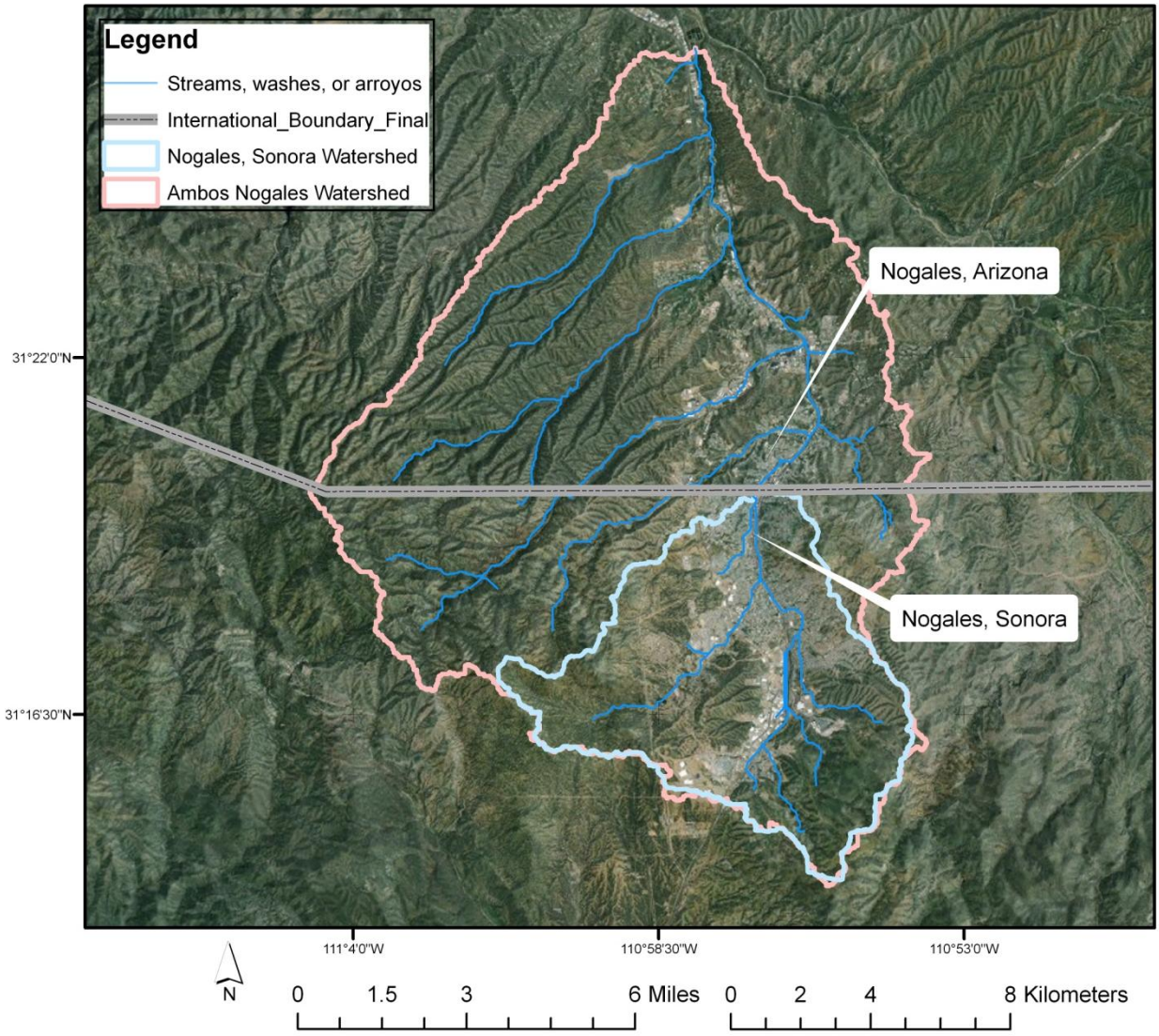

Figure 1. Locality map depicting streams, washes, and arroyos, the cities of Nogales, Arizona, and Nogales, Sonora; the Ambos Nogales Watershed boundary and the Nogales, Sonora Watershed boundary.

The demonstration of this model's utility to simultate these impacts prompted the International Boundary and Water Commission (IBWC) to implement a higher-resolution study on the impacts of the detention basins that have been constructed in Nogales, Sonora, to provide a more accurate understanding of the volume of water being detained by these features and the magnitude of discharge for all the return periods studied, 10-YR, 25-YR, 50-YR, using the KINEROS2 (K2) model .

Nogales, Sonora, offers employment opportunities for people in Mexico. The city is growing without much regard to slope, location of washes, or infrastructure capacity. Within Nogales, Sonora the 2000 census recorded a population of 159,787, with an annual growth rate of 4.9 percent. In 2009, unofficial estimates suggest the population is closer to 300,000. Based on urban growth scenarios predicted by Norman and others (2009) the SLEUTH model predicted

that Nogales, Sonora, urban area would grow to almost 3.5 times its 2002 size by 2030. In order to characterize the impacts of increasing impervious surfaces on modeling results, an updated higher-resolution land-use map is warranted.

The following sections describe the procedure employed to develop and test the accuracy of a 10-meter resolution land-use map, using recent orthophotos of the Nogales, Sonora Watershed. The product will assist in modeling impacts of the detention basin construction for the IBWC and also as a part of a larger project to develop an "Early Warning Hazard System" for the region in cooperation with the U.S. Department of Defense's Northern Command (NORTHCOM).

Procedures

High-resolution orthoimagery was acquired October 13, 2008, by the National Geospatial-Intelligence Agency (NGA). The orthoimages were produced at 0.3-meter pixel resolution (approximately 1-foot) in three color bands represented by the red, green, and blue (RGB) portions of the spectrum. Pixel values range from 0 to 255. Seventy-two images comprised the study area (fig. 2).

The National Land Cover Dataset (USGS Land Cover Institute, 1992) classification schema (fig. 3; table 1) was employed to classify the imagery because that type of dataset was used previously in modeling the Watershed runoff (Norman and Wallace, 2008; Norman and others, 2010).

Vegetation can be identified using aerial photography; in the shorter, visible wavelengths, the reflectance of vegetation demonstrates a peak at the green region and is low in both the blue and red regions of the electromagnetic spectrum (Jensen, 2007). A level-slice classifier was applied to the data layers after evaluating the relationship between image histogram distributions and observed land cover. Each TIFF was reclassified in ESRI ArcMap 9.3 based on the longest visible red wavelength. The histogram of these red band data were boxed into three classes: those with values 0-50, were classified as 43: Mixed Forest, 50-100, were classified as 51: Shrubland, 100-255, were classified as 31: Bare Rock/Sand/Clay (fig. 4).

These raster datasets were mosaicked into a new raster dataset and resampled to a 10-meter resolution using the nearest neighbor assignment (fig. 5*A*). The transportation vector data layer of the Municipal Institute of Research and Planning was merged with linear transportation data (roads, streets, highways, and railroad) from the Mexican National Institute of Statistics and Geography (Instituto Nacional de Estadística y Geografía; INEGI) to develop a raster grid represention with the class value of 23: Commercial/Industrial/Transportation, which was overlain onto the land-use map (fig. 5*B*). Land-use vector data developed by Municipal Institute of Research and Planning (Instituto Municipal de Investigación y Planeación; IMIP) in 2009 was then substituted in the urban area (fig. 5*C*). Specifically, the population density and services, trade, and industrial locations as specified by 31: Bare Rock/Sand/Clay were substituted with either 21: Low Intensity Residential, 22: High Intensity residential, or 23: Commercial/Industrial/Transportation, according to the corresponding polygonal reference data (fig. 5*D*).

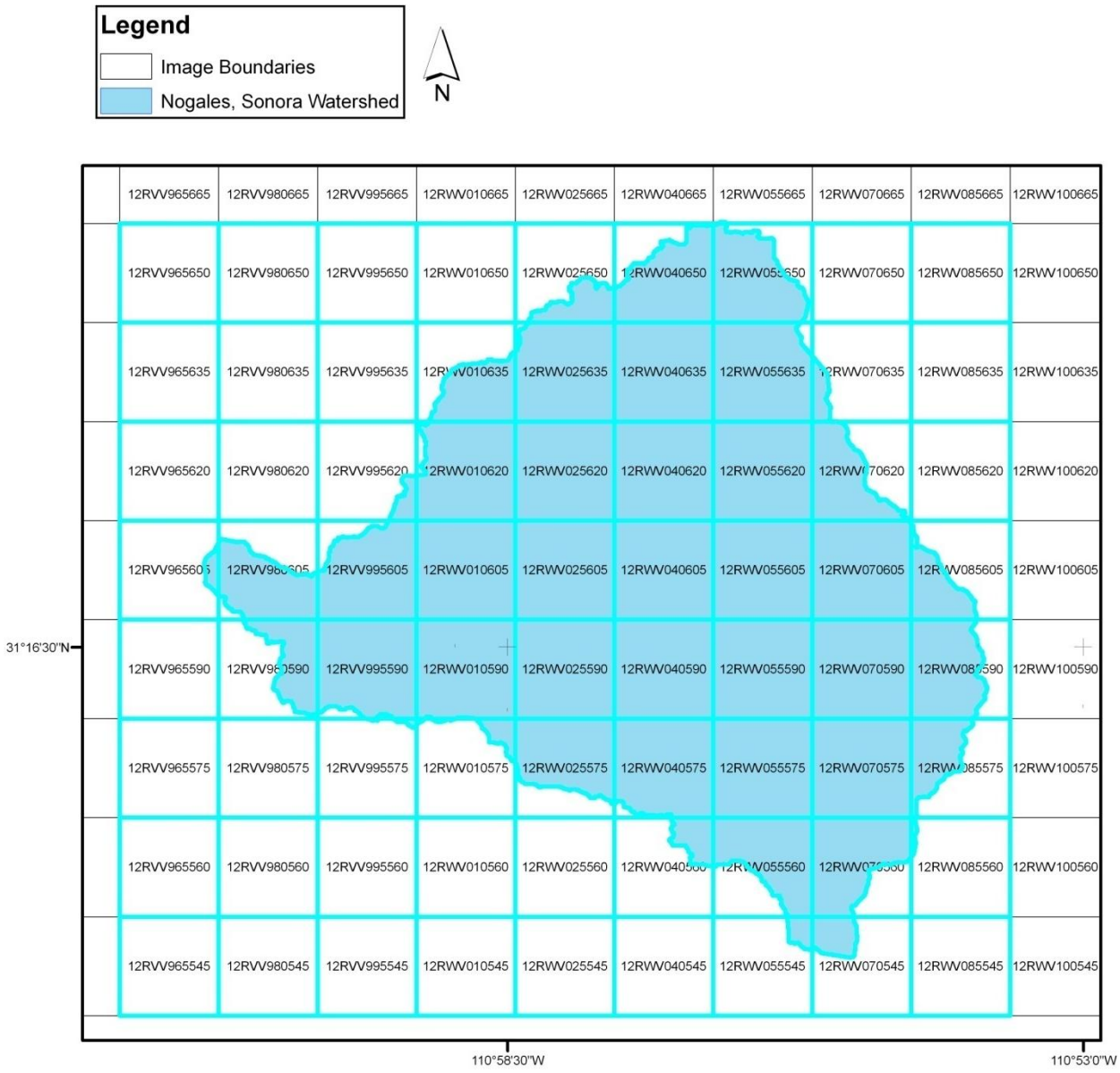

Figure 2. National Geospatial-Intelligence Agency (NGA) high-resolution orthoimagery boundaries for the Nogales, Sonora Watershed.

Figure 3. National Land Cover Dataset (NLCD) 1992 Land-Cover Color Classification Legend.

Table 1: Description of the National Land Cover Dataset 1992 classification system for classes used in Nogales, Sonora, subwatershed (*http://landcover.usgs.gov/classes.php*).

Land-Cover Classification	**Description**
11. Open Water	All areas of open water, generally with less than 25 percent cover of vegetation/land cover.
21. Low Intensity Residential	Includes areas with a mixture of constructed materials and vegetation. Constructed materials account for 30-80 percent of the cover. Vegetation may account for 20-70 percent of the cover. These areas most commonly include single-family housing units. Population densities will be lower than in high-intensity residential areas.
22. High Intensity Residential	Includes highly developed areas where people reside in high numbers. Examples include apartment complexes and row houses. Vegetation accounts for less than 20 percent of the cover. Constructed materials account for 80 to100 percent of the cover.
23. Commercial/ Industrial/ Transportation	Includes infrastructure (for example, roads and railroads) and all highly developed areas not classified as High Intensity Residential.
31. Bare Rock/ Sand/ Clay	Perennially barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, beaches, and other accumulations of earthen material.
43. Mixed Forest	Areas dominated by trees where neither deciduous nor evergreen species represent more than 75 percent of the cover present.
51. Shrubland	Areas dominated by shrubs; shrub canopy accounts for 25-100 percent of the cover. Shrub cover generally is greater than 25 percent when tree cover is less than 25 percent. Shrub cover may be less than 25 percent in cases when the cover of other life forms (for example, herbaceous or tree) is less than 25 percent and shrub cover exceeds the cover of the other life forms.

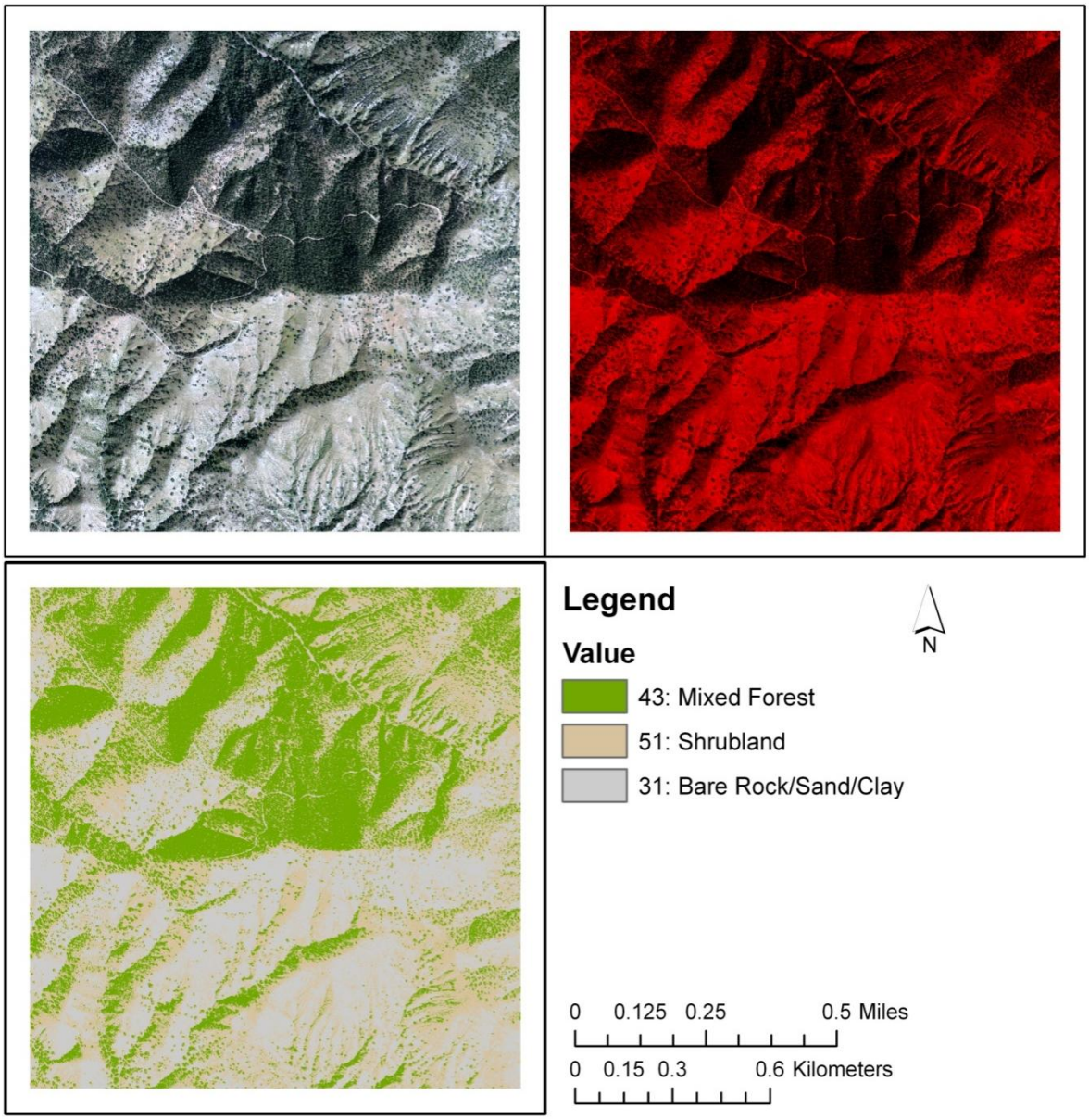

Figure 4. Image 12RVV965605; RGB composite, red band, and reclassification.

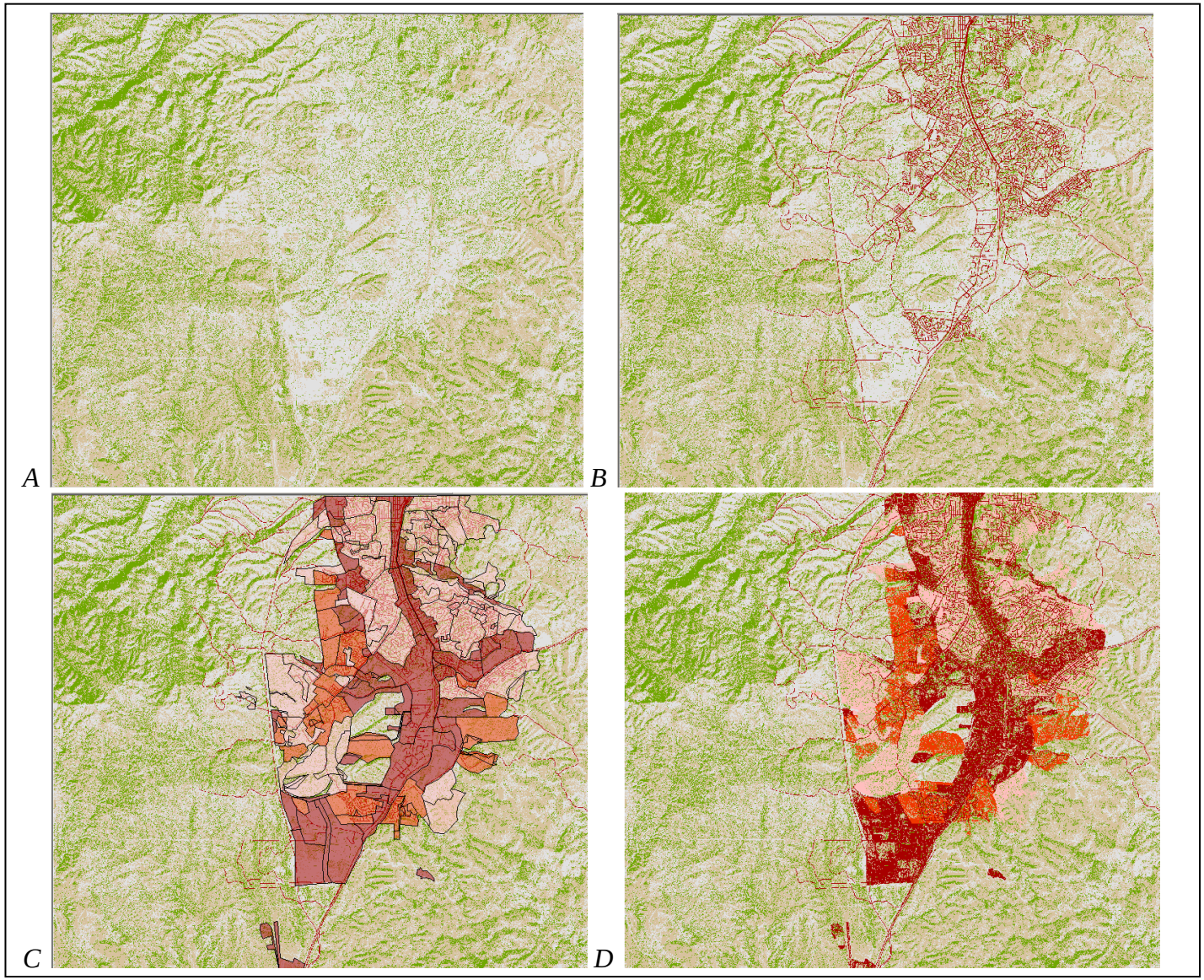

Figure 5. Pictorial evolution of classification process, including: *A*, the supervised classification process on the RGB bands, *B*, transportation layer infusion, *C*, the urban zone information outlined in black, and *D*, the final product of these processes.

Upon visual inspection, we identified some very green looking, turbid pond features that had not been mapped correctly by the classification procedure. These were digitized into a "water" shapefile to represent these locations, converted to a raster dataset, and overlain into the land-use map in the class 11: Open Water (fig. 6).

Figure 6: Pictorial display of transforming the visualized ponds into the land use map, including: *A*, the aerial photo of pond, *B*, the digitized water polygon, and *C*, the final raster depiction at that site.

Classes used in this land-use map are described in table 1. Metadata were developed (appendix), and the final dataset is available as a raster download through this online publication (fig. 7).

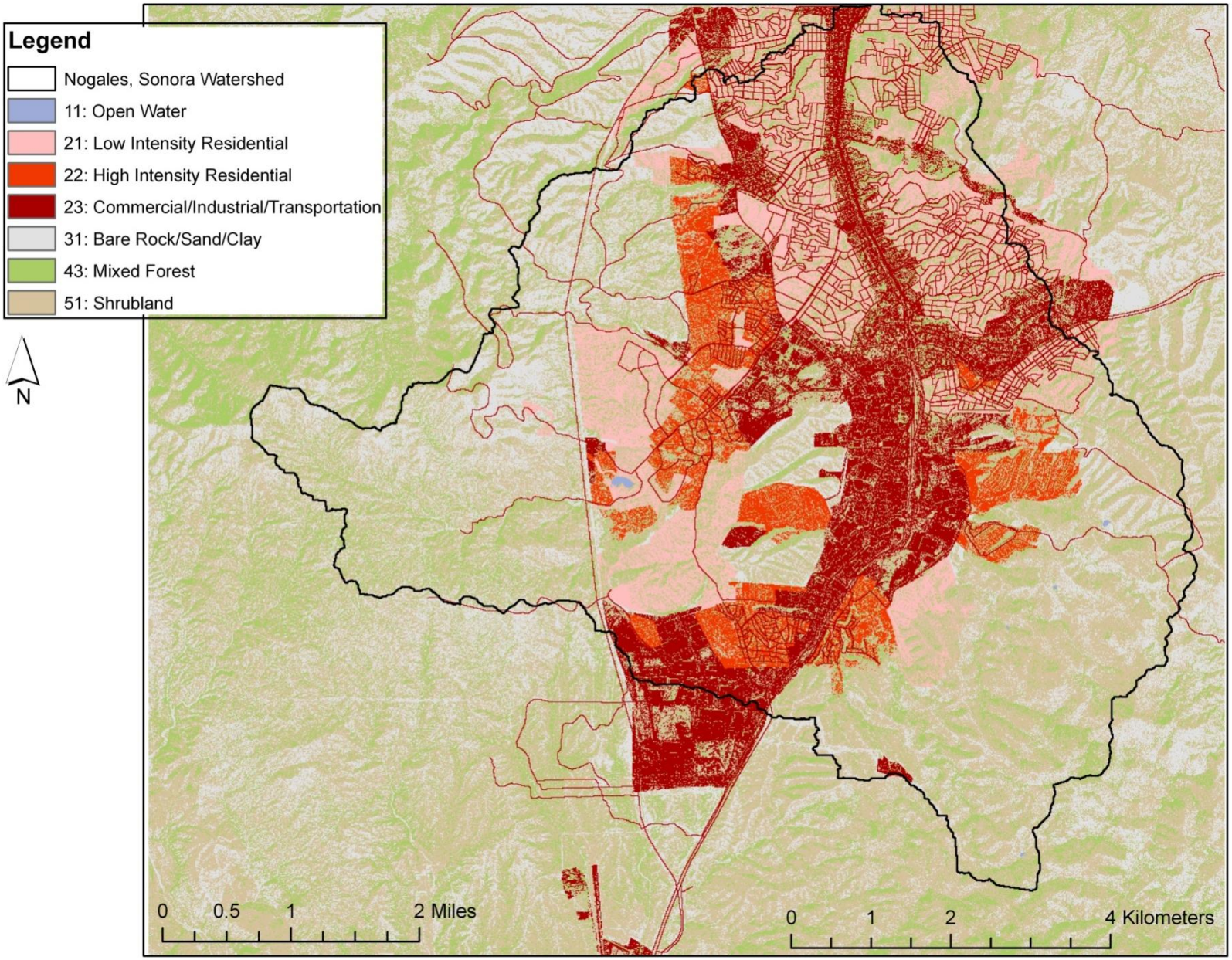

Figure 7. Final land-use map for Nogales, Sonora

Accuracy Assessment

An accuracy assessment was performed on the final product, which revealed an overall classification accuracy of 91.43 percent. An accuracy assessment was completed to determine if the mapped land cover would match the field data for 300 random points; 50 points per class (except water) were stratified across classes. Random points were generated using Leica Geosystems Erdas Imagine 9.1 and assigned to the distribution of thematic layer classes. The orthophotos that comprise the subwatershed boundaries were mosaicked, and 175 of the 300 random points occurred on the mosaicked watershed-boundary image. These points were used for the accuracy assessment (fig. 8).

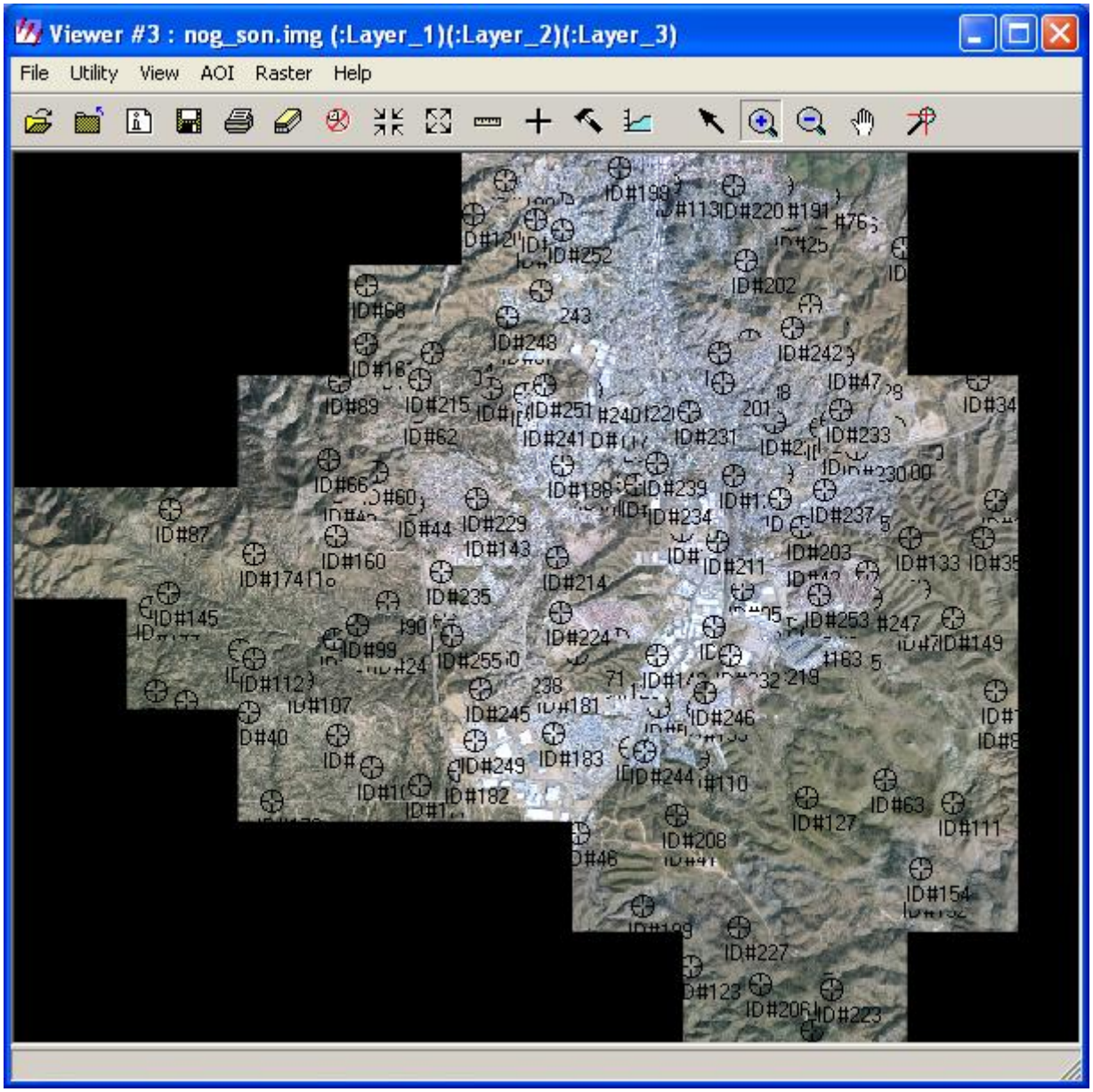

Figure 8. Random-point distribution within the Watershed boundary on orthophotos.

While the overall classification accuracy of this map is 91.43 percent, the overall kappa value is 0.8961, which is characterized by Landis and Koch as almost perfect agreement (1977). Individual class Kappas are reported in table 2. The reference data for accuracy assessment (table 3) and the classification-accuracy totals are reported in table 4.

Table 2. Table of conditional Kappa for each category/class.

Classified name	Category description	Conditional Kappa
Class 21	Low Intensity Residential	0.9615
Class 22	High Intensity Residential	0.9012
Class 23	Commercial/Industrial/ Transportation	0.7871
Class 31	Bare Rock/ Sand/ Clay	0.9550
Class 43	Mixed Forest	0.8408
Class 51	Shrubland	0.9587

Table 3. Reference data for accuracy assessment of each class.

Classified Data	Class 21	Class 22	Class 23	Class 31	Class 43	Class 51
Class 21	31	0	0	0	0	1
Class 22	0	21	0	2	0	0
Class 23	0	0	35	7	0	0
Class 31	0	0	1	27	0	0
Class 43	2	0	1	0	18	0
Class 51	0	0	1	0	0	28
Column total	33	21	38	36	18	29

Table 4. Classification accuracy totals.

Class name	Reference totals	Classified totals	Number correct	Producers accuracy, in percent	Users accuracy, in percent
Class 21	33	32	31	93.94	96.88
Class 22	21	23	21	100.00	91.30
Class 23	38	42	35	92.11	83.33
Class 31	36	28	27	75.00	96.43
Class 43	18	21	18	100.00	85.71
Class 51	29	29	28	96.55	96.55
Totals	175	175	160		

Discrepancies are noted in the accuracy assessment. Primarily, Class 31: Bare Rock/Sand/Clay is mislabeled as either Class 22: High Intensity Residential or Class 23: Commercial/Industrial/Transportation. This mislabeling resulted from the constraints of using IMIP data to support the supervised classification since the classes associated with the zoning polygons have a coarser aerial resolution compared to the more discrete spectrally derived classes. In addition, the IMIP data may represent land-use classes that were in planning stages when the imagery was originally flown. Other errors include the shadows inherent in the photos being misclassified or resulting from the resampling from less than 1-meter data to 10-meter data.

Results

A detailed land-use map has been produced to be used as an input into the K2 model, which will be used to support flood control efforts in the Ambos Nogales Watershed. As demonstrated, the majority of Low Intensity Residential; High Intensity Residential; Commercial/Industrial/Transportation; Bare Rock/Sand/ Clay; Mixed Forest; and Shrubland are classified very accurately. The small number of misclassified pixels should not disturb the suitability of the map for use as input to the K2 model. Derived land-use parameters for K2 include the fraction of surface covered by intercepting cover, Manning's roughness coefficient, and percentage covered by impervious materials. Manning's roughness coefficient, *n*, represents the resistance to flood flows in channels and flood plains. Respective runoff values should not be greatly affected by the small number of misclassified pixels. Note in table 5 that the runoff parameters assigned for the classes in this map demonstrate that runoff characteristics of bare rock, soil, and sand are very similar to those of commercial, industrial, and transport classes.

Table 5. Selected classes from the AGWA associated look-up table for K2 modeling derived from Woolhiser, Smith, and Goodrich (1990).

Class	Name	A	B	C	D	Cover	Int	N	Imperv
11	Open Water	100	100	100	100	0	0.00	0.000	0.00
21	Low-Intensity Residential	77	85	90	92	15	0.10	0.150	0.40
22	High-Intensity Residential	81	88	91	93	10	0.08	0.120	0.75
23	Commercial/Industrial/Transport	89	92	94	95	2	0.05	0.010	0.80
31	Bare Rock/Sand/Clay	96	96	96	96	2	0.00	0.010	0.00
43	Mixed Forest	55	55	75	80	50	1.15	0.015	0.00
51	Shrubland	63	77	85	88	25	3.00	0.055	0.00

Conclusions

Remote-sensing data coupled with field-information and geographic information systems have been recognized as an effective methodology in identifying spatial patterns for mapping land use. The hybrid procedure described is not a new approach; however, we were fortunate to be able to recognize a pattern in the natural color imagery from which to classify the vegetation structure from the green band data that was available. Additionally, the input of existing city zoning data and transportation data compliments the output by providing real-world data to describe the current or intended use of the land that can be fitted into the hydrological model and used to develop scenarios; however, using the vegetation classification overlay, allows for the shrubland or mixed forest classification to be identified within. The resulting map will be used by local managers to examine the impacts of constructed flood-detention features and locate priority areas more vulnerable to flooding hazard. It will also be used in combination with cooperative raingage data to stream live precipitation data into the live model to simulate runoff scenarios for a flood warning system that will benefit both communities living in the Ambos Nogales Watershed.

Acknowledgments

The U.S. Section of the International Boundary and Water Commission, El Paso, Texas (IBWC) has funded the implementation of developing more accurate predictions of the detention basins and the updated land-use map to support it. In a cooperative effort, NORTHCOM is implementing the linked emergency flood response system that will ultimately run off of this combined modeling effort. The developed model integration project described in this paper was supported by the USGS Geographic Analysis and Monitoring (GAM) Program to contribute towards an understanding of the land-surface changes occurring and the consequences of these changes.

This project is in collaboration with many integral partners, including La Sección mexicana de la Comisión Internacional de Límites y Aguas, Nogales, Sonora (CILA); the National Water Commission in Mexico (CONAGUA); the Nogales, Sonora Wastewater Utility (OOMAPAS-NS); the Arizona Department of Environmental Quality (ADEQ); the U.S. Department of Agriculture, Tucson, Arizona (USDA-ARS-SWRC); the University of Arizona, Tucson, Arizona (UA); Sonora's Water Commission, Hermosillo, Sonora (CEA); and the City of Nogales, Sonora, Mexico—Department of Emergency Response.

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Norman, Laura M., Huth, Hans, Levick, Lainie, Burns, I. Shea, Guertin, D. Phillip, Lara-Valencia, Francisco, and Semmens, Darius, 2010, Flood Hazard Awareness and Hydrologic Modeling at Ambos Nogales, US-Mexico Border, Journal of Flood Risk Management, Volume 3: Issue 2, 15 p.

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Woolhiser, D.A., Smith, R.E., Goodrich, D.C., 1990. KINEROS, a kinematic runoff and erosion model: Documentation and user manual. U.S. Department of Agriculture, Agricultural Research Service, ARS-77, 130p. SWRC Reference No.: 703.

Appendix. Metadata

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      Geospatial_Data_Presentation_Form: raster digital data
      Series_Information:
        Series_Name: Open-File Report
      Publication_Information:
        Publisher: USGS
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    Abstract: This is a 10-meter resolution land-use map derived from 2008 aerial photos and vector data for the Nogales, Sonora, Mexico part of the Ambos Nogales Watershed.
    Purpose: The results will be used for modeling impacts of detention basin construction and also as a part of a larger project to develop an "Early Warning Hazard System" for the region. This dataset was created to be used as input to the Automated Geospatial Watershed Assessment (AGWA) Tool, in order to predict runoff in this urbanizing Watershed.
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Point_of_Contact:
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Contact_Person_Primary:
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Contact_Position: Research Scientist
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Address: 520 N. Park Ave., Ste #102K
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State_or_Province: AZ
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Country: USA
Contact_Voice_Telephone: 5206705510
Contact_Electronic_Mail_Address: lnorman@usgs.gov
Native_Data_Set_Environment: Microsoft Windows XP Version 5.1 (Build 2600) Service Pack 3; ESRI ArcCatalog 9.3.0.1770
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Attribute_Accuracy_Report: The Overall Kappa (K^) Statistics was .8961--the classification process is avoiding 89.61 percent of the errors that a completely random classification generates and the overall classification accuracy is 91.43percent . The area is dominated by both mixed forest (trees) and shrubland around bare areas of transportation and urban area, which is represented in our map.
Logical_Consistency_Report: The accuracy of the dataset is based on the software's ability to detect land use signatures and the analysts's interpretation of features on the ground. Additional inaccuracy could occur in the original image it was processed from, because even slight measurement inaccuracies of the ground features selected for ortho control can affect the final accuracy.
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Source_Citation:
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Process_Description: Each TIFF was reclassified based on the RGB composites. Those with values 0 - 50, were classified as "43: Mixed Forest", 50-100, were classified as "51: Shrubland", 100-255, were classified as "31: Bare Rock/Sand/Clay". These raster datasets were mosaiced into a new raster dataset and resampled to a 10-meter resolution using the nearest neighbor assignment
Process_Date: 2010
Process_Step:
Process_Description: The transportation vector data layer of the Municipal Institute of Research and Planning was merged with linear transportation data (roads, streets, highways, and railroad) from INEGI to develop a raster grid represention with the class value of "23: Commercial/Industrial/Transportation" which was overlain onto the land use map
Process_Date: 2010

Process_Step:
Process_Description: Land-use vector data was then substituted in the urban area having been developed by Municipal Institute of Research and Planning for 2009. Specifically, the population density and services, trade, and industrial locations as specified with the class "31: Bare Rock/Sand/Clay" were substituted with either "21: Low Intensity Residential", "22: High Intensity residential", or "23: Commercial/Industrial/Transportation", according to the polygonal reference data it corresponded with.
Process_Date: 2010
Process_Step:
Process_Description: An accuracy assessment was performed on the final product, which revealed an overall classification accuracy of 91.43percent
Process_Date: 2010
Process_Step:
Process_Description: Upon manual inspection, we realized some very green looking pond features that had not been recognized by the classification procedure. These were digitized into a "water" shapefile to represent these locations, converted to a raster dataset, and overlain into the landuse map in the class "11: Open Water".
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Geodetic_Model:
Horizontal_Datum_Name: North American Datum of 1983

Ellipsoid_Name: Geodetic Reference System 80
Semi-major_Axis: 6378137.000000
Denominator_of_Flattening_Ratio: 298.257222
Entity_and_Attribute_Information:
Detailed_Description:
Entity_Type:
Entity_Type_Label: landuse.vat
Attribute:
Attribute_Label: Rowid
Attribute_Definition: Internal feature number.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain: Sequential unique whole numbers that are automatically generated.
Attribute:
Attribute_Label: VALUE
Attribute_Definition: Land Cover Class
Attribute_Definition_Source: The National Land Cover Dataset (NLCD 1992) classification schema was employed to classify the imagery
Attribute_Domain_Values:
Enumerated_Domain:
Enumerated_Domain_Value: NLCD 1992 Classification System
Enumerated_Domain_Value_Definition: Classes used in Nogales, Sonora subWatershed
Enumerated_Domain_Value_Definition_Source: (http://www.epa.gov/mrlc/definitions.html#1992).
Attribute:
Attribute_Label: COUNT
Attribute_Definition: # of times this value occurs
Attribute_Definition_Source: ESRI
Distribution_Information:
Distributor:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: U.S. Geological Survey
Contact_Person: Laura Norman
Contact_Position: Research Physical Scientist
Contact_Voice_Telephone: 5206705510
Hours_of_Service: 8am-5pm, M-F
Resource_Description: Downloadable Data
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Standard_Order_Process:

Digital_Form:
Digital_Transfer_Information:
Format_Name: ERDAS
Format_Version_Number: GRID
File_Decompression_Technique: no compression applied
Transfer_Size: 1.432
Fees: None
Ordering_Instructions: Data are available online at no charge via Internet download.
Acknowledgement of the U.S. Geological Survey would be appreciated in products derived from these data.
Metadata_Reference_Information:
Metadata_Date: 20100513
Metadata_Contact:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: USGS
Contact_Person: Laura M. Norman
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State_or_Province: AZ
Postal_Code: 85719
Country: USA
Contact_Voice_Telephone: 520-670-5510
Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial Metadata
Metadata_Standard_Version: FGDC-STD-001-1998
Metadata_Time_Convention: local time
Metadata_Extensions:
Online_Linkage: http://www.esri.com/metadata/esriprof80.html
Profile_Name: ESRI Metadata Profile