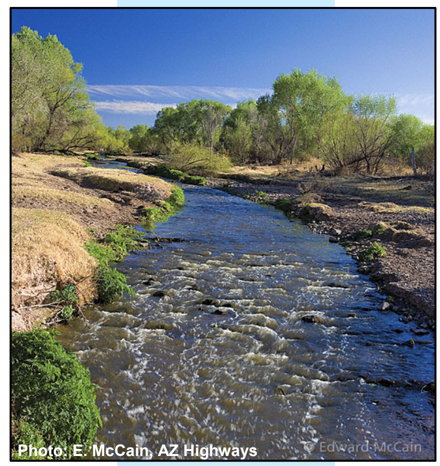
NEMO Watershed-Based Plan
Santa Cruz Watershed



Water Resources Research Center

ADEQ Arizona Department of Environmental Quality

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Arizona Cooperative Extension

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The NEMO website is www.arizonanemo.org

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Section 1: Introduction

Background: Nonpoint Source Pollution and NEMO

The Southwestern United States, including the state of Arizona, is the fastest growing region in the country. Because the region is undergoing rapid development, there is a need to address health and quality of life issues that result from degradation of our water resources.

Water quality problems may originate from both "point" and "nonpoint" sources. The Clean Water Act (CWA) defines "point source" pollution as "any discernable, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft from which pollutants are or may be discharged" (33 U.S.C. § 1362(14)). Point source discharge is regulated through provisions in the CWA.

Although nonpoint source pollution is not defined under the CWA, it is widely understood to be the type of pollution that arises from many dispersed activities over large areas, and is not traceable to any single discrete source. Nonpoint source pollution may originate from many different sources, usually associated with rainfall runoff moving over and through the ground, carrying natural and manmade pollutants into lakes, rivers, streams, wetlands and ground water. In contrast to point source pollution, nonpoint source pollution is addressed primarily through non-regulatory means under the CWA. Nonpoint source pollution is the leading cause of water quality degradation across the United States, and is the water quality issue that NEMO, the Nonpoint Education for Municipal Officials program, and this watershed based plan, will address.

Nationally, NEMO has been very successful in helping to mitigate nonpoint source pollution. The goal of NEMO is to educate land-use decision makers to take proactive voluntary actions that will mitigate nonpoint source pollution and protect natural resources. In the eastern United States (where the NEMO concept originated), land use authority is concentrated in municipal (village, town and city) government. In Arizona, where nearly 80% of the land is managed by state, tribal and federal entities, land use authorities include county, state and federal agencies, in addition to municipal officials and private citizens.

In partnership with the Arizona Department of Environmental Quality (ADEQ) and the University of Arizona (U of A) Water Resources Research Center, the Arizona Cooperative Extension at the U of A has initiated the Arizona NEMO program. Arizona NEMO attempts to adapt the original NEMO program to the conditions in the semiarid, western United States, where water supply is limited and many natural resource problems are related to the lack of water, as well as water quality.

Working within a watershed template, Arizona NEMO includes:

comprehensive and integrated watershed planning support, identification and publication of Best Management Practices (BMP), and education on water conservation and riparian water quality restoration. Arizona NEMO maintains a website, http://www.ArizonaNEMO.org that contains these watershed based plans, Best Management Practices fact sheets, and other educational materials.

Watershed-Based Plans

Watershed-based plans are holistic documents designed to protect and restore a watershed. These plans provide a careful analysis of the sources of water quality problems, their relative contributions to the problems, and alternatives to solve those problems. Furthermore, watershed-based plans present proactive measures that can be applied to protect water bodies.

In watersheds with developed or drafted Total Maximum Daily Load (TMDL) studies for specific waterbodies, the watershed-based plan must be designed to achieve the load reductions identified in the TMDL. The CWA requires each state to perform a TMDL on waterbodies that are identified as impaired due to exceedances of state surface water quality standards. As point sources and nonpoint sources of pollution are determined through TMDL analysis, subsequent load reductions are assigned to each source as necessary for the purposes of improving water quality to meet state standards.

In collaboration with the local watershed partnerships and ADEQ, NEMO will help improve water quality by developing a realistic watershed-based plan to achieve water quality standards and protection goals. This plan will identify:

- Areas that are susceptible to water quality problems and pollution;
- Sources that need to be controlled; and
- Management measures that should be implemented to protect or improve water quality.

The first component of the planning process is to characterize the watershed by summarizing all readily available natural resource information and other relevant data for that watershed. As seen in Sections 2 though 5 of this document, these data are at a broad-based, large watershed scale and include information on water quality, land use and cover, natural resources and wildlife habitat.

The second component of the watershed planning process is to identify nonpoint source pollutants that need to be managed. This is done by ranking and prioritizing areas within the watershed based on water quality concerns and other physical attributes. Hydrologic modeling supports the ranking of the subwatershed areas, as seen in Section 6. Finally, example watershed management practices addressing water pollution due to metals, sediment, organics, and selenium are discussed in Section 7. Example project planning, budgeting, and scheduling, as well as the EPA guidelines for water quality improvement grant applications to implement watershed management projects, are presented in Sections 8 and 9.

It is anticipated that stakeholder-groups will develop their own detailed planning documents. That document may cover a subwatershed area within the NEMO Watershed-based Plan, or include the entire watershed area. In addition, local watershed-based plans generated by stakeholder-groups will incorporate local knowledge and concerns gleaned from stakeholder involvement and will include:

- A description of the stakeholder / partnership process;

- A well-stated, overarching goal aimed at protecting, preserving, and restoring habitat and water quality, and encouragement of land stewardship;

- A plan to coordinate natural resource protection and planning efforts;

- A detailed and prioritized description of natural resource management objectives; and,

- A detailed and prioritized discussion of best management practices, strategies and projects to be implemented by the partnership.

Based on the EPA's *2003 Guidelines for the Award of Section 319 Nonpoint Source Grants*, a watershed-based plan should include all nine of the elements listed below. This NEMO watershed-based plan addresses each of these elements (except for Element 2: Expected Load Reductions for each individual project specific to a 319 grant application); however, the watershed group must determine the final watershed plan and actions for each of these projects.

- Element 1: *Causes and Sources* - Clearly define the causes and sources of impairment (physical, chemical, and biological).

- Element 2: *Expected Load Reductions* - An estimate of the load reductions expected for each of the management measures or best management practices to be implemented (recognizing the natural variability and the difficulty in precisely predicting the performance of management measures over time).

- Element 3: *Management Measures* - A description of the management measures or best management practices and associated costs that will need to be implemented to achieve the load reductions estimated in this plan and an identification (using a map or a description) of the critical areas where those measures are needed.

- Element 4: *Technical and Financial Assistance* - An estimate of the amounts of technical and financial assistance needed, associated costs, and/or the sources and authorities that will be relied upon to implement this plan.

- Element 5: *Information / Education Component* - An information/education component that will be used to enhance public understanding of the project and encourage their early and continued participation in selecting, designing, and implementing management measures.

- Element 6: *Schedule* - A schedule for implementing management measures identified in the plan that is reasonably expeditious.

- Element 7: *Measurable Milestones* - A schedule of interim, measurable milestones for determining whether the management measures, Best Management Practices (BMPs), or other control actions are being implemented.

- Element 8: *Evaluation of Progress* - A set of criteria that can be used to determine whether load reductions are being achieved over time and substantial progress is being made towards attaining water quality standards and, if not, the criteria for determining whether the plan needs to be revised or, if a Total Maximum Daily Load (TMDL) has been established, whether the TMDL needs to be revised.

- Element 9: *Effectiveness Monitoring* - A monitoring component to evaluate the effectiveness of the implementation efforts over time, measured against the criteria established in the Evaluation of Progress element.

These nine elements help provide reasonable assurance that the nonpoint source of pollution will be managed to improve and protect water quality and to assure that public funds to address impaired waters are used effectively.

Purpose and Scope

This watershed-based plan includes a watershed characterization (Sections 2 through 5) and a watershed classification (Sections 6 through 8) for the Santa Cruz Watershed.

ADEQ has combined three watersheds into this Santa Cruz Watershed Based Plan, two of which are primarily located in Mexico. All three watersheds straddle the U.S.-Mexico border. These additional watersheds are included under the Santa Cruz for data administration only; they are not hydrologically connected to the Santa Cruz Watershed. The parts of these two watersheds that lie principally in Mexico will not be covered extensively in this report because of a general lack of available data for these areas.

These three watersheds are the Santa Cruz Watershed; the Rio Asuncion/Concepcion; and the Rio Sonoyta Watershed (Figure 1-1)

About 8,200 square miles (95%) of the Santa Cruz Watershed is in the U.S. and 400 square miles (5%) is within the boundaries of Mexico (Figure 1-1). The portion of the Santa Cruz Watershed that lies in Mexico will be included in this Watershed Based Plan, to the extent that data are available. The Santa Cruz River has its headwaters in Arizona's San Rafael Valley. The river flows south and makes a 25-mile loop through Mexico before returning to U.S. soil about 5 miles east of Nogales, Arizona. The river then flows north from the U.S.-Mexican border up to its confluence with the Gila River, just southwest of Phoenix. The Gila joins the Colorado River near the Arizona-California state line. The Colorado River then crosses into Mexico near Yuma, and in wet years, the river can flow all the way to the Gulf of California. The portion of the watershed within Arizona will be classified most extensively in this plan.

Only 130 square miles (1%) of the Rio Asuncion/Concepcion Watershed is in the U.S., while 10,000 square miles (99%) is in Mexico (Figure 1-2). The U.S. portion of the Rio Asuncion Watershed is located in the southwest portion of the Santa Cruz Watershed, on the U.S. - Mexican border. The Rio Asuncion/Concepcion flows south and discharges into the Gulf of California. We will only model the upland portion of the watershed that lies within the U.S.

In addition to the Santa Cruz and Rio Asuncion/Concepcion Watersheds, we include the Rio Sonoyta Watershed, 3,100 square miles (30%) of which is located in Arizona and 7,300 square miles (70%) in Mexico. The U.S. portion of the Rio Sonoyta Watershed is located to the west/southwest of the Santa Cruz Watershed and includes the communities of Sells and Lukeville. Because little data are available from Mexico, we will characterize and model the U.S. portion and address the Mexican portion as data is available. The Rio Sonoyta also flows southward and eventually into the Gulf of California.

The watershed characterization in Sections 2 through 5 includes physical, biological, and social/economic data in a geographic information system (GIS) database format, as both mapped and tabulated data, that has been collected from available existing and published data sources. No new field data were collected for this plan. This characterization represents an inventory of natural resources and environmental conditions that affect primarily surface water quality. It provides educational outreach material to stakeholders and watershed partnerships.

The watershed classification identifies water quality problems by incorporating water quality data reported in *The Status of Water Quality in Arizona – 2006: Arizona's Integrated 305(b) Assessment and 303(d) Listing Report* (ADEQ, 2006), ADEQ's biennial report consolidating water quality reporting requirements under the federal Clean Water Act. The ADEQ water quality data, TMDL definitions, and further information for each stream reach and the surface water sampling sites across the state can be found at: www.adeq.state.az.us/environ/water/assessment/assess.html.

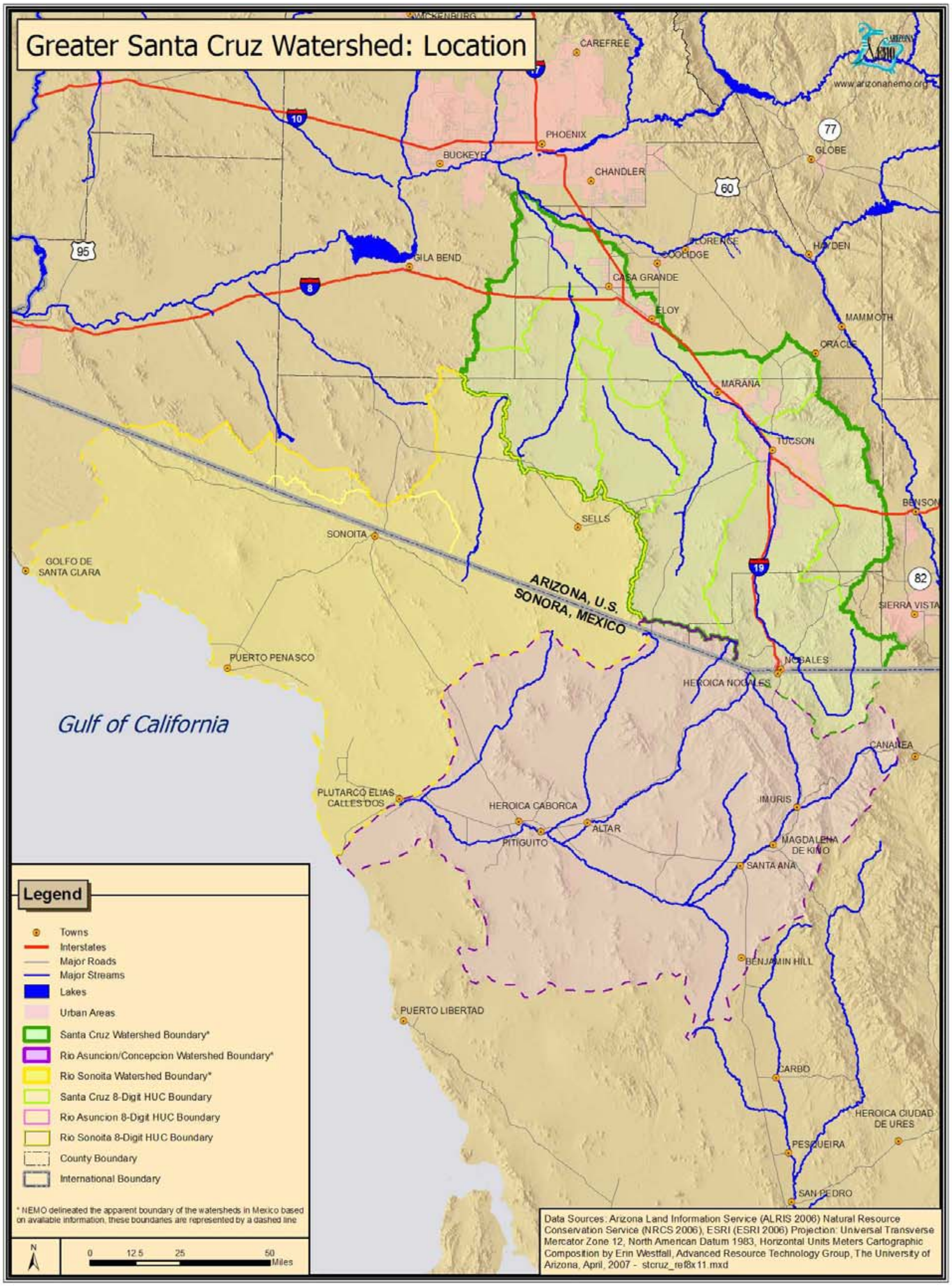

Figure 1-1: Santa Cruz Watershed Location

The watershed classification includes identifying and mapping important resources, and ranking 10-digit HUC (hydrologic unit codes) subwatersheds (discussed later in this section) based on the likelihood of nonpoint source pollutant contribution to stream water quality degradation.

In addition to the watershed characterization and classification, this plan includes general discussions of recommended nonpoint source Best Management Practices (BMP) that may be implemented to achieve pollutant load reductions and other watershed goals. It provides methods and tools to identify problem sources and locations for implementation of BMPs to mitigate nonpoint source pollution.

These watershed management activities are proposed with the understanding that the land-use decision makers and stakeholders within the watershed can select the BMPs they feel are most appropriate and revise management activities as conditions within the watershed change. Although these chapters are written based on current information, the tools developed can be used to update this plan and reevaluate water quality concerns as new information becomes available.

<u>Methods</u>

The methods used to develop this watershed-based plan include GIS analysis and hydrologic modeling to classify and characterize the subwatersheds, and *fuzzy logic* to rank them.

GIS and Hydrologic Modeling

GIS and hydrologic modeling were the major tools used to develop this watershed-based plan. In a GIS, two types of information represent geographic features: locational and descriptive data. Locational (spatial) data are stored using a vector (line) or a raster (grid) data structure. Vector data are object based data models which show spatial features as points, lines, and/or polygons. Raster data models represent geographical space by dividing it into a series of units or cells, each of which is limited and defined by an equal amount of the earth's surface. These cells may be triangular or hexagonal, although the square is the most common. Corresponding descriptive (attribute) data for each geographic feature are stored in a set of tables. The spatial and descriptive data are linked in the GIS so that both sets of information are always available.

Planning and assessment in land and water resource management requires spatial modeling tools to incorporate complex watershed-scale attributes into the assessment process. Modeling tools applied to the Santa Cruz Watershed include AGWA, SEDMOD, SWAT, and RUSLE, as described below.

The Automated Geospatial Watershed Assessment Tool (AGWA) is a GIS-based hydrologic modeling tool designed to evaluate the effects of land use change (Burns et al., 2004). AGWA provides the functionality to conduct all phases of a watershed assessment. It facilitates the use of the Soil and Water Assessment Tool

(SWAT), a hydrologic model, by preparing the inputs, running the model, and presenting the results visually in the GIS. AGWA has been used to illustrate the impacts of urbanization and other landscape changes on runoff and sediment load in a watershed.

AGWA was developed under a joint project between the Environmental Protection Agency (EPA), Agricultural Research Service (ARS), and the University of Arizona. SWAT was developed by the ARS, and is able to predict the impacts of land management practices on water, sediment, and chemical yields in complex watersheds with varying soils, land use and management conditions (Arnold et al., 1994).

The SEDMOD model (Van Remortel et al., 2004), which uses the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997), was applied in this plan to estimate soil erosion and sediment delivery from different land use types. Hydrologic modeling can only be performed in hydraulically connected watersheds. The modeling involves a series of automated Arc Macro Language (AML) scripts and two supported programs that run an ESRI ArcGIS 9.x Workstation platform. ERSI is a corporation that provides GIS modeling and mapping software & technology.

The watershed classification within this plan incorporates GIS-based hydrologic modeling results and other data to describe watershed conditions upstream from an impaired stream reach identified within Arizona's Integrated 305(b) Assessment and 303(d) Listing Report (ADEQ, 2006). In addition, impacts due to mine sites (erosion and metals pollution) and grazing (erosion and pollutant nutrients) are simulated.

The Santa Cruz Watershed is defined and mapped by the U.S. Geological Survey using the six-digit Hydrologic Unit Code (HUC). The United States is divided and sub-divided into successively smaller hydrologic units of surface water drainage features, which are classified into four levels, each identified by a unique hydrologic unit code consisting of two to eight digits: regions (2 digit); sub-regions (4 digit); accounting units (6 digit); and cataloging units (8 digit) (Seaber et al., 1987).

The Rio Sonoyta and the Rio Asuncion/Concepcion are also six-digit HUC watersheds. Within the Arizona portions of the Santa Cruz, Rio Sonoyta, and the Rio Ascension/Concepcion, smaller subwatershed areas are delineated using the eight-digit cataloging HUC. These eight-digit HUCs were used for the characterizations so as to refine the watershed, classifications and GIS modeling. We report the rankings, based on the smaller, ten digit HUC as discussed in Section 6.

The following ten, eight-digit HUC units and subwatershed names are used to clarify locations in this plan.

Santa Cruz Watershed

15050301 Upper Santa Cruz River
1505030101-San Rafael
1505030102-Sonoita

1505030103-Potrero Creek
1505030104-Sopari Wash
1505030105-Josephine Canyon
1505030106-Demetrie Wash
1505030107-Box Canyon Wash
1505030108-Canada del Oro
1505030109-Julian Wash

15050302 Pantano Wash-Rillito River
1505030201-Cienega Creek
1505030202-Agua Verde Creek
1505030203-Tanque Verde Creek

15050303 Lower Santa Cruz River
1505030301-Guild Wash
1505030302-Agua Verde Creek
1505030303-Greene Wash
1505030304-Upper Vekol Wash
1505030305-Lower Vekol Wash
1505030306-Lower Santa Cruz Wash

15050304 Brawley Wash Los Robles Wash
1505030401-Arivaca Creek
1505030402-Puertocito Wash
1505030403-Altar Wash
1505030404-Upper Brawley Wash
1505030405-Lower Brawley Wash

15050305 Aguirre Wash Tat Momoli Wash
1505030501-Viopuli Wash
1505030502-Upper Aguirre Wash
1505030503-Lower Aguirre Wash
1505030504-Tat Momoli Wash

15050306 – Santa Rosa Wash
1505030601-Upper Santa Rosa Wash
1505030602-Kohatk Wash
1505030603-Middle Santa Rosa Wash
1505030604-Lower Santa Rosa Wash

Although not delineated in the map, in Mexico, this area is known as La Cuenca del Rio Santa Cruz

Rio Asuncion /Concepcion Watershed

15080200 – Rio Asuncion
1508020001-Rio Alta Headwaters
1508020002-Rio El Sasabe Headwaters
The Mexico portion not mapped to the 8-digit HUC detail.

Rio Sonoyta Watershed

15080101 – San Simon Wash
1508010101-Hickiwan Wash
1508010102-Upper San Simon Wash
1508010103-Upper Vamori Wash
1508010104-Sells Wash
1508010105-Lower Vamori Wash
1508010106-Middle San Simon Wash
1508010107-Chukut Kuk Wash
1508010108-Rio San Francisquito
1508010109-Lower San Simon Wash

15080102 – Rio Sonoyta
1508010201-Pai Oik Wash-Menagers Lake
1508010202-Sonoyra Valley Area
1508010203-Davidson Canyon
1508010204-Aguajita Wash

15080103 – Tule Desert
1508010301-Pnacate Valley-Las Playas
1508010302-Puente Cuates
1508010303-La Jolla Wash
The Mexico portion is not mapped to the 8-digit HUC detail.

Fuzzy Logic

To rank the 10-digit HUC subwatershed areas that are susceptible to water quality problems and pollution, and to identify sources that need to be controlled, a *fuzzy logic* knowledge-based methodology was applied to integrate the various spatial and non-spatial data types (Guertin et al., 2000; Miller et al., 2002; Reynolds et al., 2001). This methodology has been selected as the basis by which subwatershed areas and stream reaches are prioritized for the implementation of BMPs to assure nonpoint source pollution is managed.

Fuzzy logic is an approach to set theory that handles vagueness or uncertainty, and has been described as a method by which to quantify common sense. In classical set theory, an object is either a member of the set or excluded from the set. Fuzzy logic allows for an object to be a partial member of a set.

For example, classical set theory might place a man into either the tall or short class, with the class of tall men being those over the height of 6'0". Using this method, a man who is 5' 11" tall would not be placed in the tall class, although he would not be considered 'not-tall'. This is unacceptable, for example, for describing or quantifying an object that may be a partial member of a set. In fuzzy logic, membership in a set is described as a value between 0 (non-membership in the set) and 1 (full membership in the set). For instance, the individual who is 5' 11" is not classified as short or tall, but is classified as tall to a degree of 0.8. Likewise, an individual of height 5' 10" would be tall to a degree of 0.6.

In *fuzzy logic*, the range in values between different data factors are converted to the same scale (0-1) using fuzzy membership functions. Fuzzy membership functions can be discrete or continuous depending on the characteristics of the input. In the illustration above, the degree of tallness was iteratively added in intervals of 0.2, creating a discrete data set. A continuous data set would graph the heights of all individuals and correlate a continuous fuzzy member value to that graph. A user defines their membership functions to describe the relationship between an individual factor and the achievement of the stated goal.

A benefit of using a fuzzy membership function is that it can be based on published data, expert opinions, stakeholder values or institutional policy, and can be created in a data-poor environment. Another benefit is that it provides for the use of different methods for combining individual factors to create the final classification, and the goal set. Fuzzy membership functions and weighting schemes can also be changed based on watershed concerns and conditions.

The general approach used in this plan was to integrate watershed characteristics, water quality measurements, and modeling results within a multi-parameter ranking system based on the *fuzzy logic* knowledge-based approach, as shown schematically in Figure 1-4.

This approach requires that a goal be defined according to the desired outcome, and that the classification be defined as a function of the goal and is therefore reflective of the management objective. For this watershed classification, the goal is to identify critical subwatersheds in which BMPs should be implemented to reduce nonpoint source pollution.

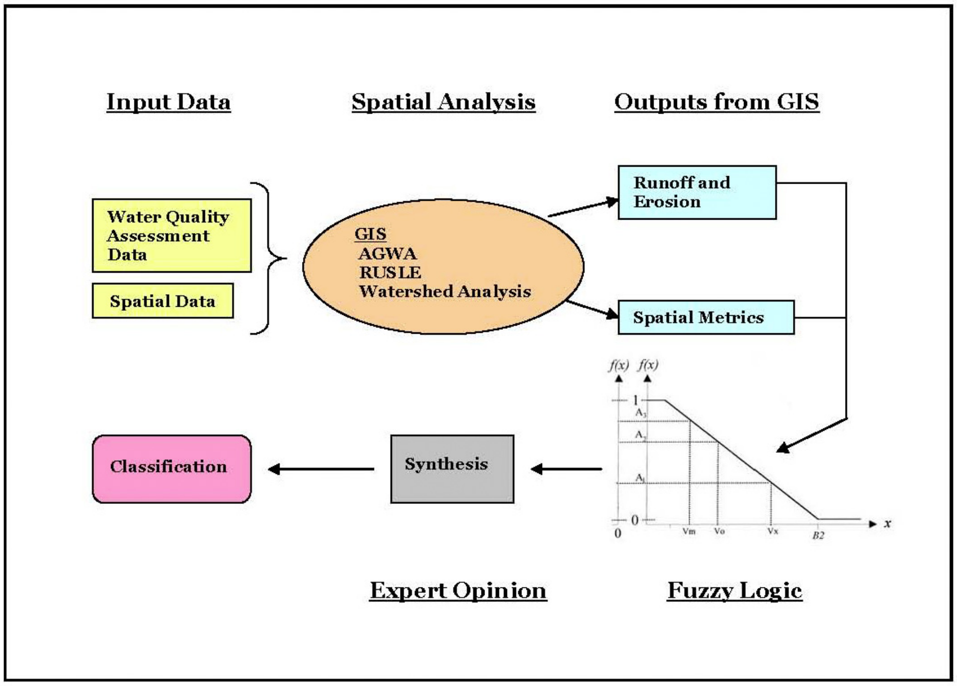

Figure 1-2: Transformation of Input Data via a GIS, Fuzzy Logic Approach, and Synthesis of Results into a Watershed Classification.

The classification process was implemented within a GIS interface to create the subwatershed classifications using five primary steps:

1. Define the goal of this watershed classification: For example, classify water quality impairment due to dissolved total metals from mining activity;

2. Assemble GIS data and other observational data;

3. Define watershed characteristics through:

    a. Water quality data provided in Arizona's Integrated 305(b) Assessment and 303(d) Listing Report (ADEQ, 2006);

    b. GIS mapping analysis; and,

    c. Modeling and simulation of erosion vulnerability and potential for stream impairment (i.e. from soils at mine sites and proximity to abandoned mine sites).

4. Use fuzzy membership functions to transform the vulnerability and impairment metrics into fuzzy membership values; and,

5. Determine a composite fuzzy score representing the ranking of the combined attributes for each subwatershed, and interpret the results.

Arizona's Integrated 305(b) Assessment and 303(d) Listing Report (ADEQ, 2006), was used to classify each monitored stream reach based on its relative risk of impairment for each of the chemical constituent groups. The constituent groups include metals, organics, nutrients, and turbidity/sediment.

Two final levels of risk were defined: high and low. For example, if elevated concentrations of metals, such as copper and mercury, are found above standards, the water body would be classified as 'high' risk if ADEQ has currently assessed it as being "impaired" for that constituent group. Conversely, a water body is classified as 'low' risk if there are no exceedances in a constituent group and there are sufficient data to make a classification.

Classifications were conducted at the 10-digit HUC subwatershed scale for just the Arizona portion of the Santa Cruz Watershed, resulting in the ranking of the 31 Santa Cruz, two Rio Ascuncion, and the 16 Rio Sonoyta Watershed 10-digit HUCs/ subwatershed areas.
Because the Rio Asuncion/Concepcion and the Rio Sonoyta flowed into Mexico (where we had insufficient data) and are not hydraulically connected, these watersheds could not be modeled and were not classified.

Structure of this Watershed-Based Plan

Watershed characterizations, including physical, biological, and social characteristics, are discussed in Sections 2 through 4. Important environmental resources are discussed in Section 5. These sections will focus on the Santa Cruz Watershed, but include sections of two other watersheds that lie primarily in Mexico, but also have sections that overlap into Arizona.

The subwatershed classifications based on water quality attributes including concentrations of metals, sediment/turbidity, organics, and nutrients are found in Section 6. Watershed management strategies and BMPs are provided in Section 7, the Watershed Plan is presented in Section 8, and a summary of EPA's 9 Key Elements is provided in Section 9. These sections will address primarily the Santa Cruz Watershed (thirty-one 10-digit HUCs).

The full tabulation of the ADEQ water quality data and assessment status is provided in Appendix A. Suggested technical references of studies completed across the Santa Cruz Watershed are included in Appendix B, a description of RUSLE is in

Appendix C, and a description of AGWA is in Appendix D.

References:

Arizona Department of Environmental Quality, ADEQ. 2006. The Status of Water Quality in Arizona – 2006: Arizona's Integrated 305(b) Assessment and 303(d) Listing Report, 1110 West Washington Ave., Phoenix, Arizona, 85007, from http://www.azdeq.gov/environ/water/assessment/2006.html.

Arnold, J.G., J. R. Williams, R. Srinivasan, K.W. King, and R. H. Griggs. 1994. SWAT - Soil & Water Assessment Tool. USDA, Agricultural Research Service, Grassland, Soil and Water Research Laboratory, Temple, Texas.

Burns, I.S., S. Scott, L. Levick, M. Hernandez, D.C. Goodrich, S.N. Miller, D.J. Semmens, and W.G. Kepner. 2004. Automated Geospatial Watershed Assessment (AGWA) - A GIS-Based Hydrologic Modeling Tool: Documentation and User Manual *Version 1.4,* from http://www.tucson.ars.ag.gov/agwa/

Guertin, D.P., Fiedler, R.H., S.N. Miller, and D.C. Goodrich. 2000. Fuzzy logic for watershed assessment. Proceedings of the ASCE Conference on Science and Technology for the New Millennium: Watershed Management 2000, Fort Collins, CO, June 21-24, 2000.

Miller, S.N., W.G. Kepner, M.H. Mehaffrey, M. Hernandez, R.C. Miller, D.C. Goodrich, K.K. Devonald, D.T. Heggem, and W.P. Miller. 2002. Integrating Landscape Assessment and Hydrologic Modeling for Land Cover Change Analysis, in Journal of the American Water Resources Association, Vol. 38, No. 4, August. P. 915- 929.

Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, and D.C. Yoder. 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE), U. S. Department of Agriculture, Agriculture Handbook No. 703. 404 pp.

Reynolds, K.M. 2001. Fuzzy logic knowledge bases in integrated landscape assessment: Examples and possibilities. General Technical Report PNW-GTR-521. USDA Forest Service Pacific Northwest Research Station. 24 pp.

Seaber, P.R., F.P. Kapinos, and G.L. Knapp. 1987. Hydrologic Unit Maps: U.S. Geological Survey Water-Supply Paper 2294. 63p.

Van Remortel, R., D. Heggem, and A. Pitchford. 2004. SEDMOD, Version 1.1 of Soil & Landform Metrics: Programs and U.S. Geodatasets (CD). U.S. Environmental Protection Agency, Environmental Sciences Division, Landscape Ecology Branch, Las Vegas, NV.

Section 2: Physical Features

The Santa Cruz Watershed is defined as the area drained by the Santa Cruz River to the confluence with the Gila River southwest of the Phoenix metropolitan area near Chandler. The watershed is located in the south central part of the state, originating in Arizona and then extending south through northern Mexico, then flowing north to southwest of Phoenix, as shown in Figure 1-1.

Most of the population in the Santa Cruz Watershed is found in the city of Tucson (population 530,000) (City of Tucson, 2007), the state's second largest city. There is also a population of 370,000 located on the U.S.-Mexico border in the sister border cities of Nogales, Sonora, Mexico and Nogales, Arizona. Grazing and irrigated crop production are principal land uses. Much of the agricultural land has been converted to urban use or retired. Mining is scattered across the watershed. The watershed includes eight designated wilderness areas, along with National Forests and National Parks with restricted land uses (ADEQ, 2006).

Watershed Size

The Santa Cruz Watershed covers approximately 8,000 square miles, representing about 10% of the state of Arizona. The watershed has a maximum width of 102 miles east-west, and a maximum length of 175 miles north-south, including the section in Mexico. The U.S.-only section of the watershed is 155 miles.

The Asuncion/Concepcion Watershed is located in Mexico, southwest of the Santa Cruz Watershed. The watershed measures about 29 miles wide and 6 miles long in the U.S. section, and about 135 miles wide and 116 miles long in the combined U.S. and Mexico section. The watershed is called the Rio Asuncion in the United States and is called the Concepcion in the Mexico.

The Sonoyta Watershed is located to the east and southeast of the Santa Cruz Watershed. The watershed is located in both Mexico and the U.S. It measures about 155 miles wide and 48 miles long in the U.S., and 162 miles wide and 137 miles long in the combined U.S. and Mexican sections. Both the Rio Asuncion/Concepcion and the Sonoyta watershed drain south, discharging to the Gulf of California.

All watersheds in the U.S. were originally delineated by the U.S. Geological Survey into 6-digit HUC cataloging units, and were later subdivided into 8 or 10-digit HUC subwatersheds by the NRCS (http://water.usgs.gov/GIS/huc.html). Each drainage area has a unique hydrologic unit code number, or HUC, and a name based on the primary surface water feature within the HUC. The Santa Cruz is an 6-digit HUC, and the subwatershed areas for this watershed-based plan were delineated on the basis of the 8-digit HUC. The classifications and GIS modeling were conducted on the ten-digit HUC subwatershed areas.

The subwatersheds for the Santa Cruz, Asuncion, and Sonoyta Watersheds are listed in Tables 2-1.1 and 2-1.2. The largest subwatershed in the Santa Cruz

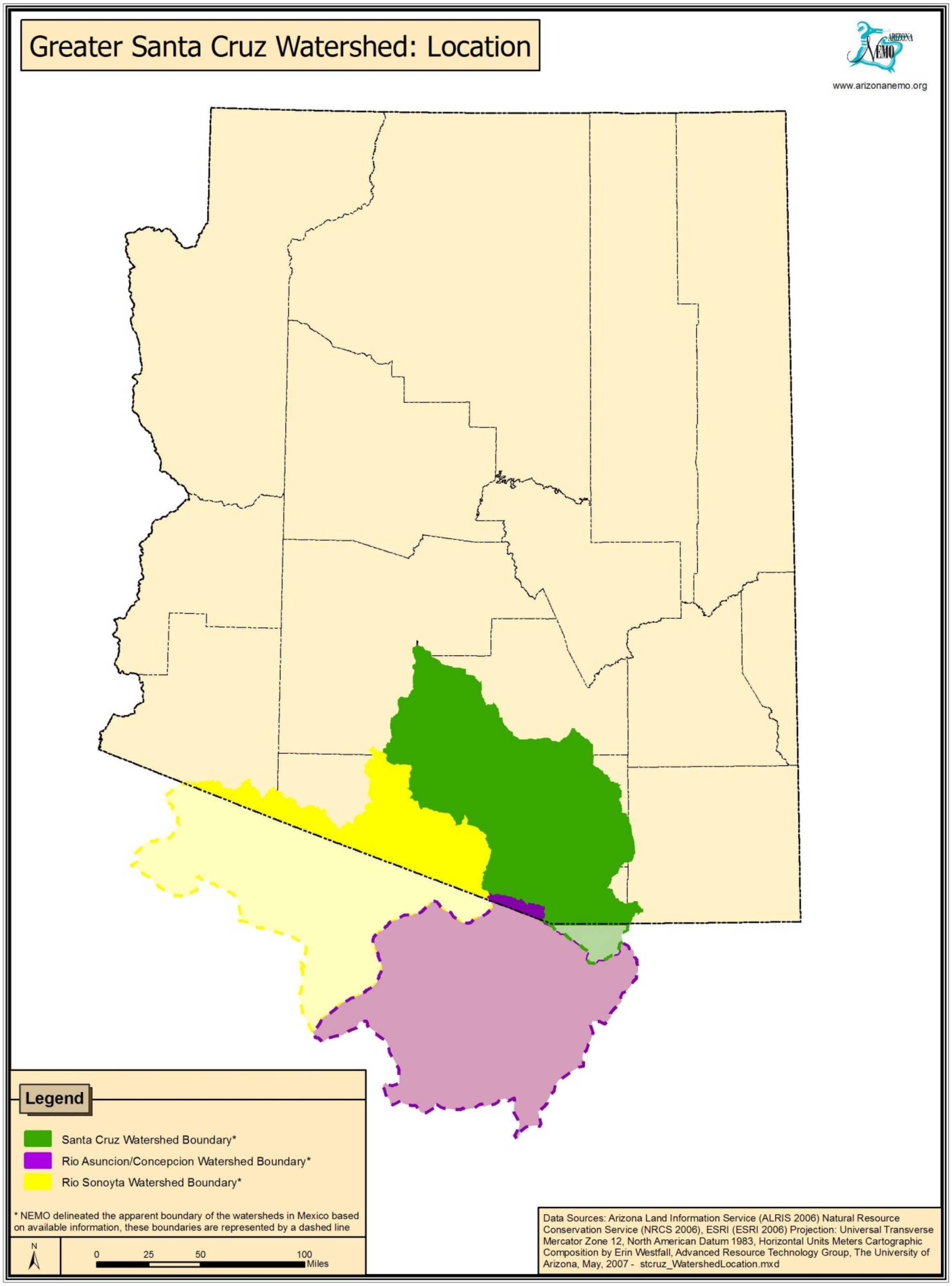

Figure 2-1: Watershed Location

Watershed is the Upper Santa Cruz River with an area of 2,227 square miles. The only subwatershed in the Rio Asuncion has an area of 128 square miles, while the largest subwatershed in the Rio Sonoyta Watershed is the San Simon Wash with an area of 2,154 square miles. The subwatershed areas are delineated in Figure 2-2.1 and Figure 2-2.2.

Table 2-1.1: Santa Cruz Watershed 8-digit HUCs and Subwatershed Areas.*

Subwatershed Name and HUC Designation	**Area (square miles)**
Aguirre Wash Tat Momoli Wash H15050305	733
Brawley Wash – Los Robles Wash H15050304	1,408
Lower Santa Cruz River H15050303	1,682
Pantano Wash – Rillito River H15050302	920
Santa Rosa Wash H15050306	1,208
Upper Santa Cruz River H15050301	2,227
Santa Cruz Watershed	*8,178*
Rio Asuncion H15080200	128
Rio Asuncion Watershed	*128*

*Data pertains to the U.S. portion of the watershed only.

Table 2-1.2: Rio Sonoyta Watershed *8-digit HUCs and Subwatershed Areas*.*

Subwatershed Name and HUC Designation	**Area (square miles)**
Rio Sonoyta H15080102	424
San Simon Wash H15080101	2,154
Tule Desert Area H15080103	497
Rio Sonoyta Watershed	*3,075*

*Data pertains to the U.S. portion of the watershed only.

The Santa Cruz Active Management Area (AMA) is located in the southern portion of the watershed. AMAs are managed by the State to provide long-term management and conservation of ground water resources. The Santa Cruz AMA covers 716 square miles, and is primarily concentrated around a 45-mile reach of the Santa Cruz River from the international border to the Santa Cruz/ Pima County line. The mission of this AMA is to maintain safe yield and prevent long-term declines in the local water table (ADWR 1999).

The Tucson AMA is located in the central part of the watershed. The Tucson AMA covers 3,866 square miles in southeastern Arizona and includes the Avra Valley Ground Water Subbasin and the northern part of the Upper Santa Cruz Valley Ground Water Subbasin. The mission of the Tucson AMA is the attainment of safe yield, or to maintain a long-term balance between the amount of ground water removed and recharged is in balance.

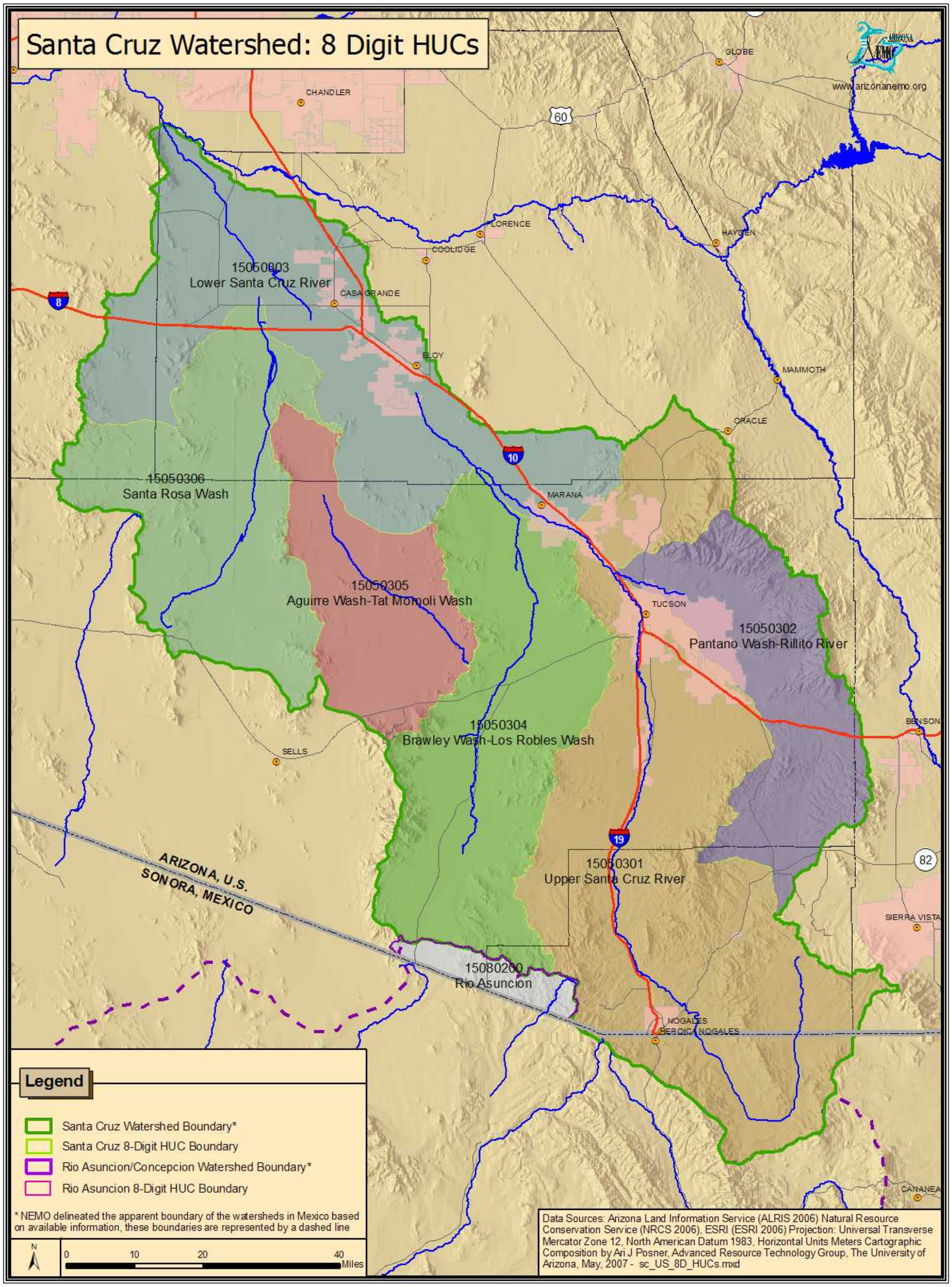

Figure 2-2.1: Santa Cruz Watershed 8 Digit HUCs

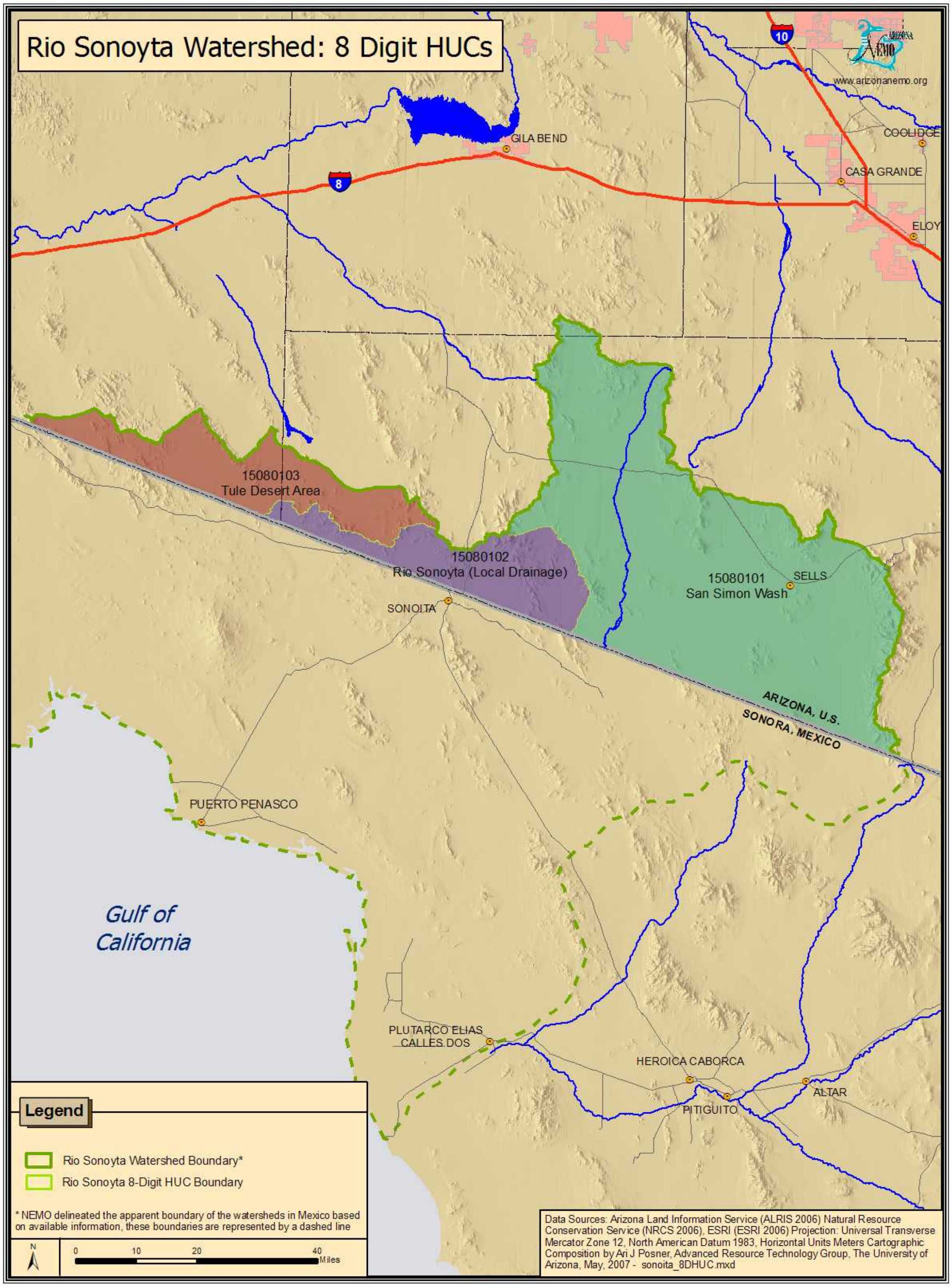

Figure 2-2.2: Rio Sonoyta Watershed 8 Digit HUCs

The Pinal AMA, which is located between the Tucson AMA and the Phoenix AMA, also includes a reach of the intermittent Santa Cruz River. The Pinal AMA covers about 4,000 square miles in central Arizona and contains the site of the confluence of the Santa Cruz and Gila Rivers. The management goal of the AMA is to allow development of non-irrigation uses and to preserve existing agricultural economies in the AMA for as long as feasible (ADWR 2007). The Rio Asuncion Watershed lies within the Santa Cruz AMA, while the Rio Sonoyta Watershed lies outside of AMA boundaries.

Topography

Topography and land slope, as well as soil characteristics, are important when assessing the vulnerability of the subwatershed to erosion, as will be discussed later in this document.

The land surface elevation of the combined Santa Cruz and Rio Asuncion Watersheds ranges between 9,452 feet to 1,037 feet above sea level (Table 2-2.1 and Figure 2-3.1). The Sonoyta Watershed elevation ranges from 7,730 ft. to 682 ft. above sea level (Table 2-2.2 and Figure 2-3.2)

The tallest feature in the combined Santa Cruz and Rio Asuncion Watersheds is Mt. Wrightson at 9,452 feet, located near Green Valley. The lowest point in the watershed at 1,037 feet is the confluence of the Santa Cruz and Gila Rivers, south of the Phoenix metropolitan area and about 20 miles southwest of Chandler. The highest point in the U.S. portion of the Rio Sonoyta Watershed is Baboquivari Peak at 7,730 feet, on the eastern border of the watershed. The lowest point in the Rio Sonoyta Watershed is 682 feet, in the Tule Desert Area Subwatershed near the U.S. – Mexico border.

Mean elevation for the entire Santa Cruz Watershed is 5,042 feet, 4,685 feet for the Rio Asuncion Watershed and 4,206 feet for the Sonoyta Watershed. The Lower Santa Cruz River Subwatershed (HUC 15050303) is the lowest subwatershed in the watershed with a minimum elevation of 1,037 feet. The Tule Desert Area Subwatershed (HUC 15080103) is the lowest subwatershed in the Rio Sonoyta Watershed (located in the U.S.) with a minimum elevation of 682 feet (Table 2-2.2).

Approximately 12.3% of the Santa Cruz Watershed has a slope greater than 15%, while 73% of the watershed has a slope less than 5% (Table 2-3.1 and Figure 2-4.1). The Lower Santa Cruz River subwatershed is flatter than the watershed mean with only 5.0% of its area over 15% slope, and 88.5% less than 5% slope. The Pantano Wash-Rillito River subwatershed has the greatest slope, with 27% of the area greater than 15% slope. The Rio Sonoyta Watershed has 81.8% of land with less than 5% slope and 8.7% of the area greater than 15% slope, while 46.2% of the Rio Asuncion area has a slope of less than 5.0% and 26.5% with a slope of greater than 15% (Table 2-3.2 and Figure 2-4.2).

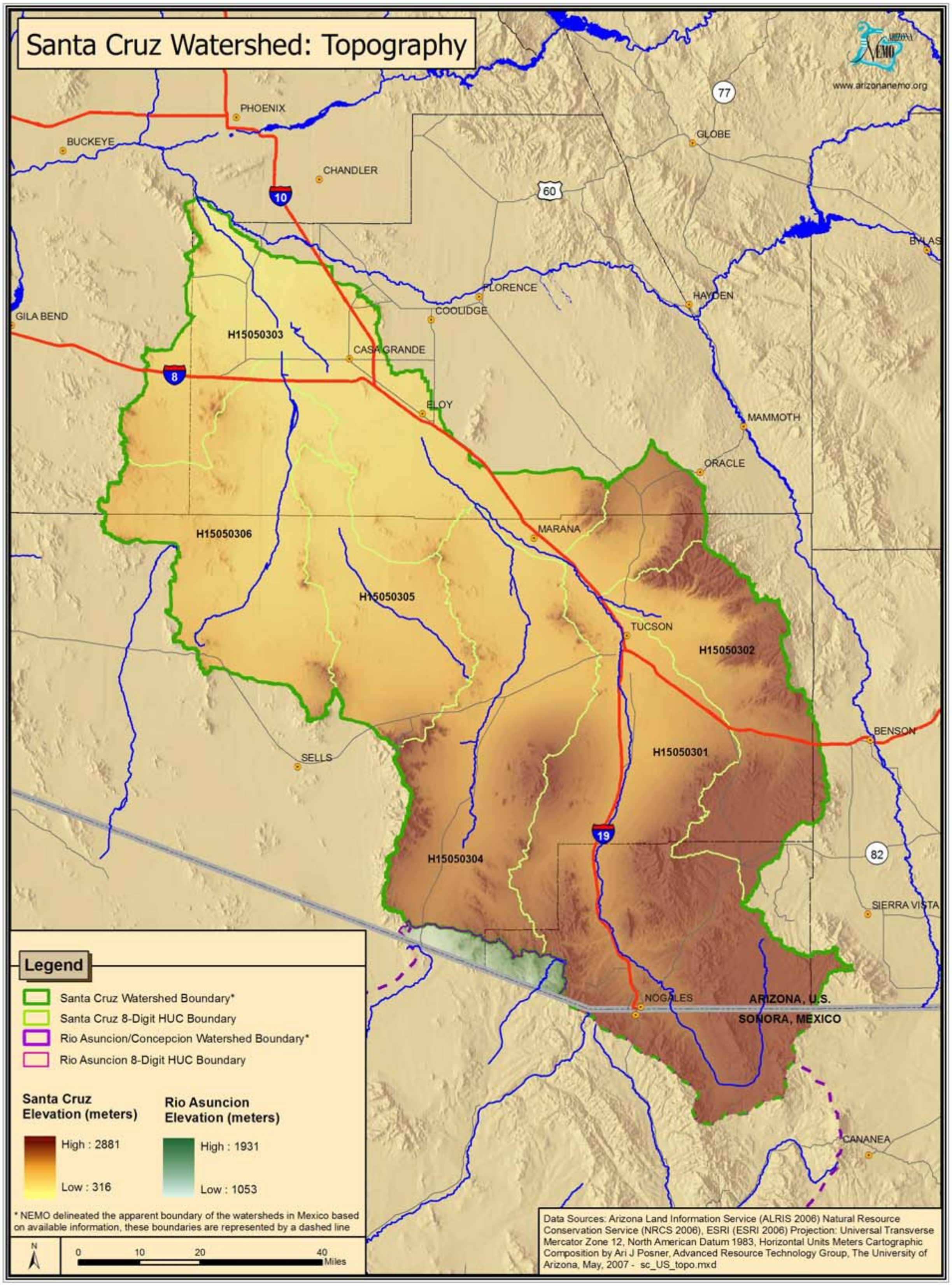

Figure 2-3.1: Santa Cruz Watershed Topography

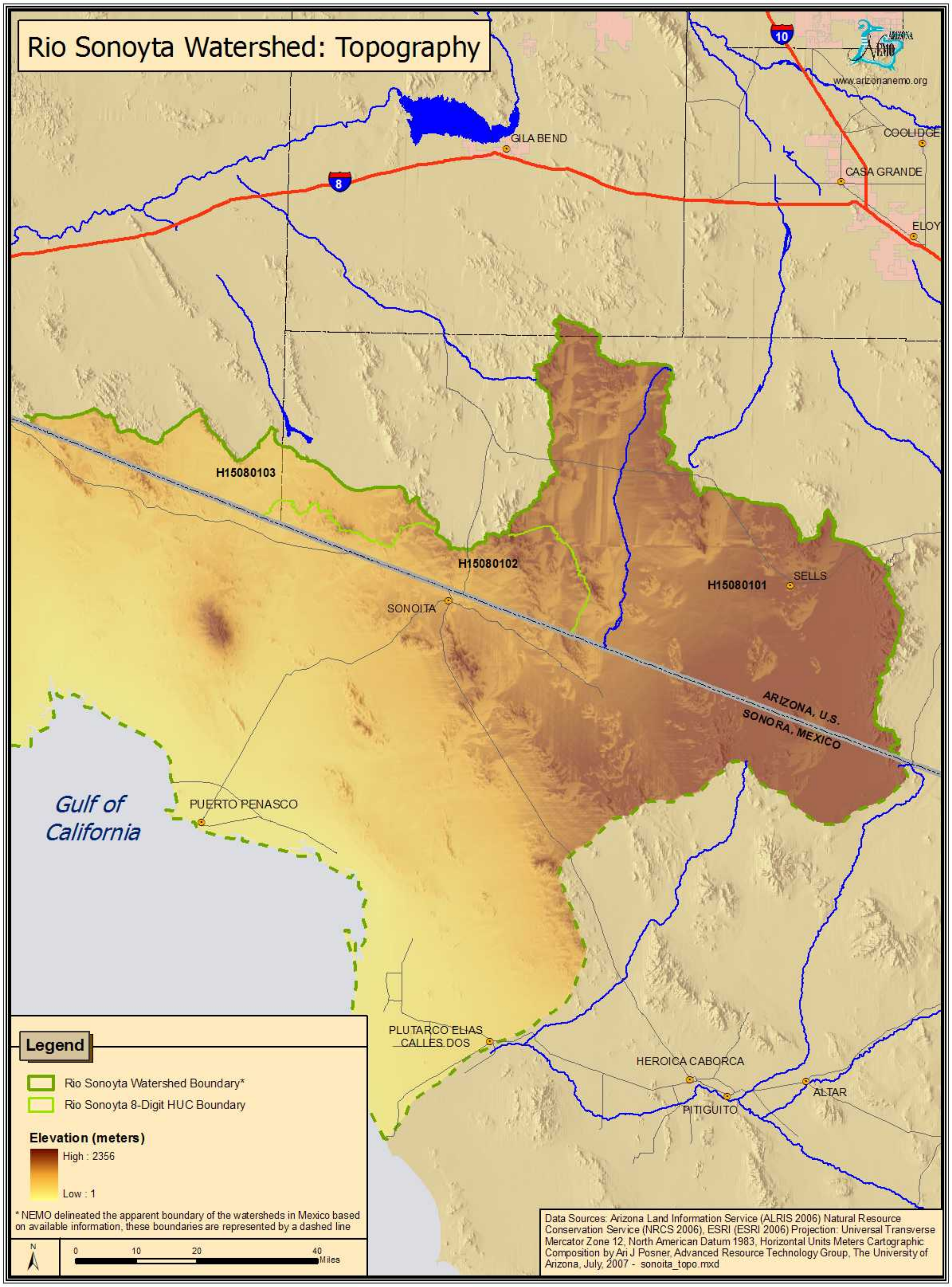

Figure 2-3.2: Rio Sonoyta Watershed Topography

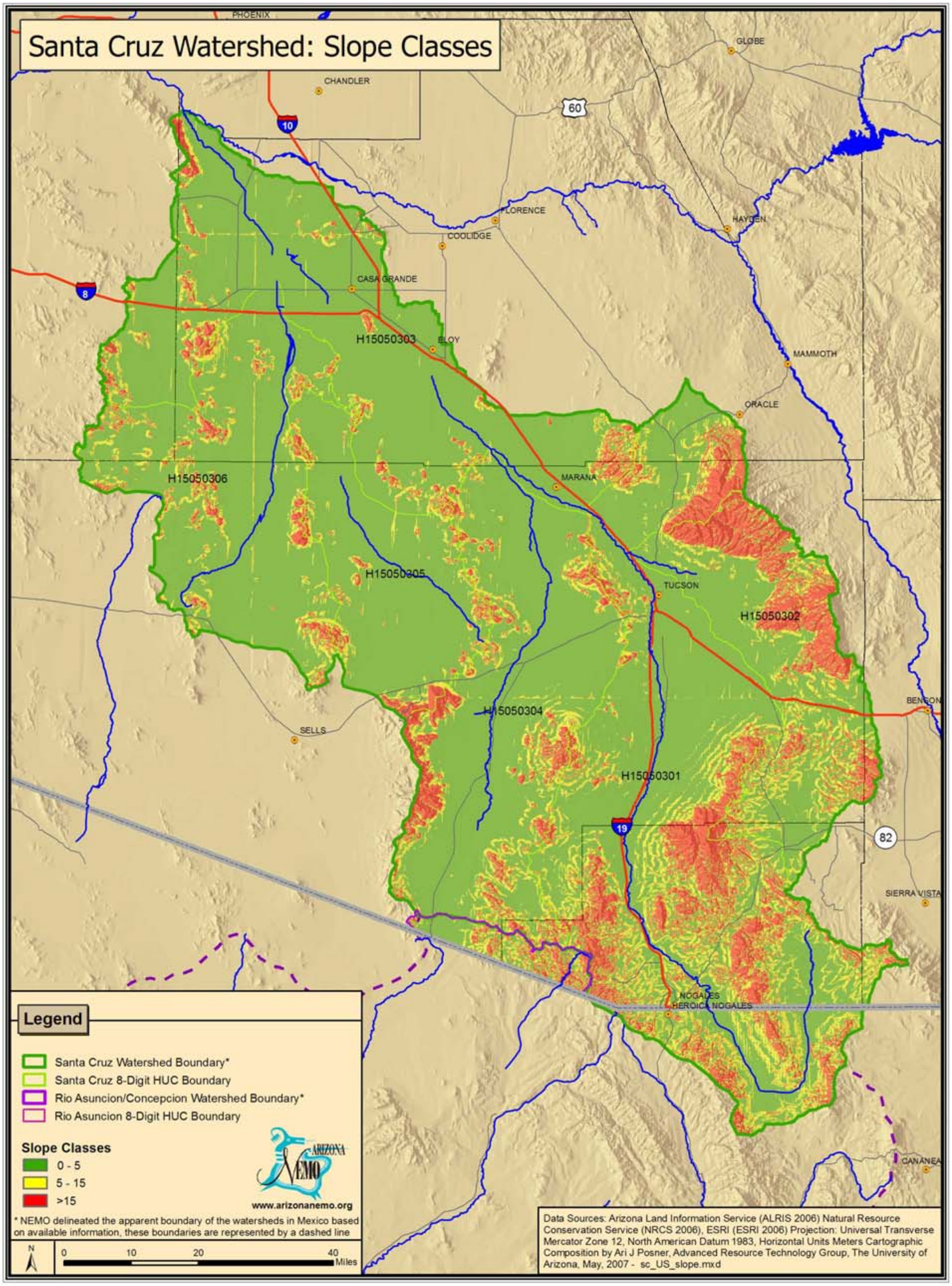

Figure 2-4.1: Santa Cruz Watershed Slope Classes

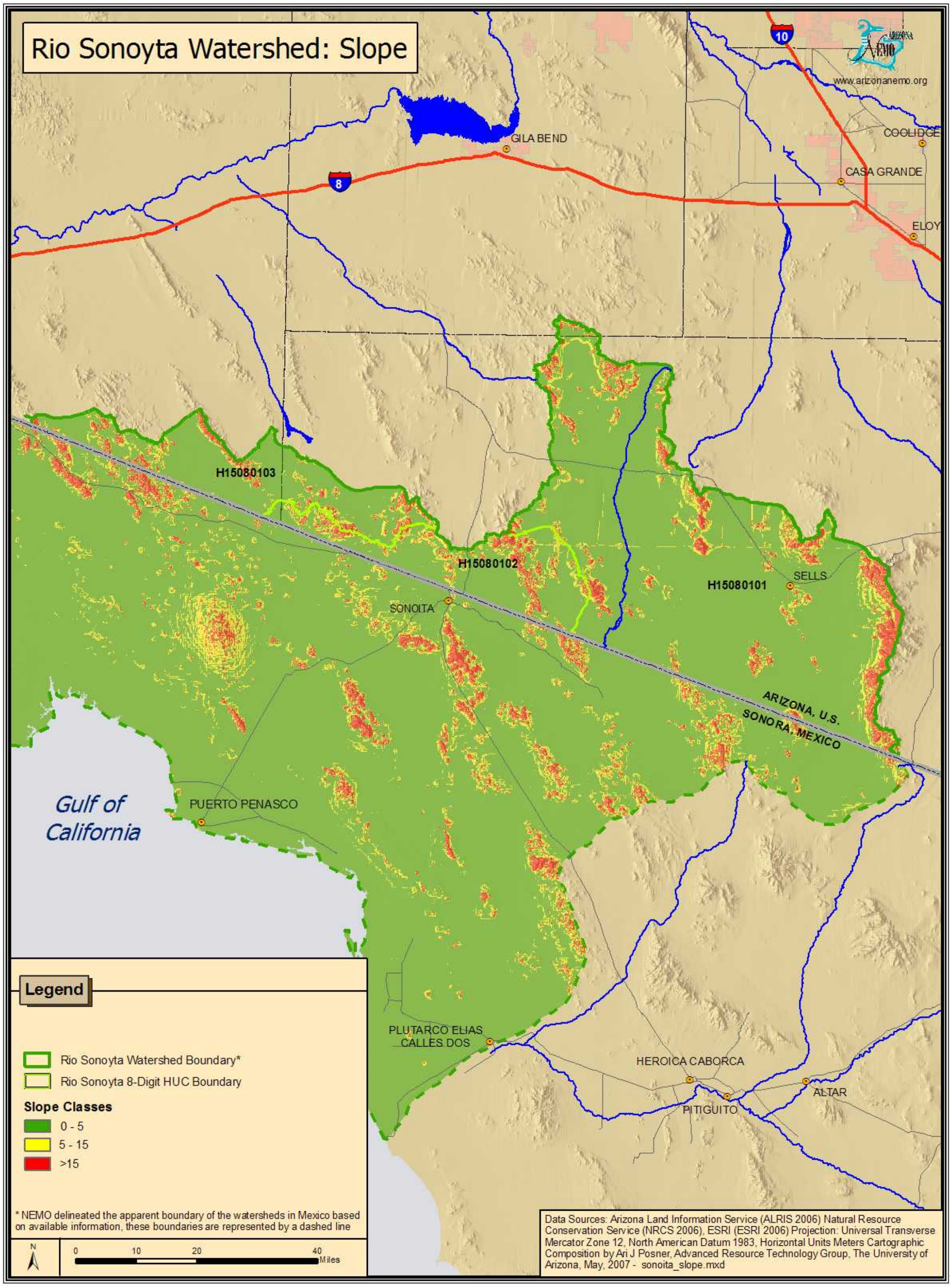

Figure 2-4.2: Rio Sonoyta Watershed Slope Classes

Table 2-2.1: Santa Cruz Watershed Elevation Range*.

Subwatershed Name	Min (feet)	Max (feet)	Mean (feet)
Upper Santa Cruz River H15050301	2156	9452	5564
Pantano Wash-Rillito River H15050302	2198	8999	5532
Lower Santa Cruz River H15050303	1037	4593	2759
Brawley Wash-Los Robles Wash H15050304	1854	6883	4127
Aguirre Wash-Tat Momoli Wash H15050305	1552	6877	3944
Santa Rosa Wash H15050306	1283	4596	2897
Santa Cruz Watershed	*1037*	*9452*	*5042*
Rio Asuncion H15080200	3454	6335	4685
Rio Asuncion Watershed	*3454*	*6335*	*4685*

*Data pertains to the U.S. portion of the watershed only.

Table 2-2.2: Rio Sonoyta Watershed Elevation Range.*

Subwatershed Name	Min (feet)	Max (feet)	Mean (feet)
Rio Sonoyta H15080102	699	4,554	2,474
San Simon Wash H15080101	1,680	7,730	4,167
Tule Desert Area H15080103	682	2,949	1,706
Sonoyta Watershed	682	7,730	4,206

*Data pertains to the U.S. portion of the watershed only.

Table 2-3.1: Santa Cruz Watershed Slope Classes.

Subwatershed Name	Area (sq. mi.)	Percent Slope		
		0-5%	5-15%	>15%
Aguirre Wash Tat Momoli Wash H15050305	733	87.0%	7.2%	5.8%
Brawley Wash – Los Robles Wash H15050304	1,408	78.1%	12.1%	9.8%
Lower Santa Cruz River H15050303	1,682	88.5%	6.6%	5.0%
Pantano Wash – Rillito River H15050302	920	53.1%	19.8%	27.0%
Santa Rosa Wash H15050306	1,208	83.5%	10.9%	5.6%
Upper Santa Cruz River H15050301	2,628	61.0%	21.0%	18.0%
Santa Cruz Watershed	*8,178*	*73.0%*	*14.0%*	*12.3%*
Rio Asuncion H15080200	128	46.2%	27.3%	26.5%
*Rio Asuncion Watershed**	*128*	*46.2%*	*27.3%*	*26.5%*

*Data pertains to the U.S. portion of the watershed only.

Table 2-3.2: Rio Sonoyta Watershed Slope Classes.

Subwatershed Name	Area (sq. mi.)	Percent Slope		
		0-5%	5-15%	>15%
Rio Sonoyta H15080102	424	84.2%	8.2%	7.6%
San Simon Wash H15080101	2,154	72.7%	15.5%	11.8%
Tule Desert Area H15080103	497	79.0%	10.3%	10.7%
Rio Sonoyta Watershed*	3,075	81.8%	9.5%	8.7%

*Data pertains to the U.S. portion of the watershed only.

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Surface Water Resources

There are 25 mapped lakes and other water features in the Santa Cruz Watershed. Tailing Pond #1330 and Tailing Pond #1329 are the largest surface water features with areas of 1,289 acres and 493 acres, respectively. The largest water body that is not a tailing pond is Patagonia Lake which covers 230 acres. Four water features are mapped in the Rio Sonoyta Watershed. The largest water body is Menagers Lake at 266 acres. Tables 2-4.1 and 2-4.2 list the major surface water bodies and their associated areas. Figures 2-5.1 and 2-5.2 show the major lakes and streams

*Table 2-4.1: Santa Cruz Watershed Major Lakes and Reservoirs.**

Lake Name (if known)	Subwatershed	Surface Area (acre)	Elevation (feet above mean sea level)	Dam Name (if known)
Aguirre Lake	Brawley Wash – Los Robles Wash	51	3,450	
Arivaca Lake	Brawley Wash – Los Robles Wash	118	3,800	Arivaca Dam
Bear Grass Tank	Upper Santa Cruz River	12	4,000	
BK Tank	Brawley Wash – Los Robles Wash	33	2,000	
Lakeside Park	Pantano Wash – Rillito River	14	2,700	Lakeside Park Dam
Mormon Lake	Brawley Wash – Los Robles Wash	30	3,400	
Parker Lake	Upper Santa Cruz River	129	5,300	Parker Canyon Dam
Patagonia Lake	Upper Santa Cruz River	230	3,750	
Pena Blanca Lake	Upper Santa Cruz River	51	3,900	
Twin Lakes	Upper Santa Cruz River	13	3,000	
Sewage Pond ID# 1317	Upper Santa Cruz River	16	2,200	
Sewage Pond ID# 1318	Upper Santa Cruz River	16	2,200	
Sewage Pond ID# 1344	Upper Santa Cruz River	19	3,400	
Sewage Pond ID# 1345	Upper Santa Cruz River	41	3,400	

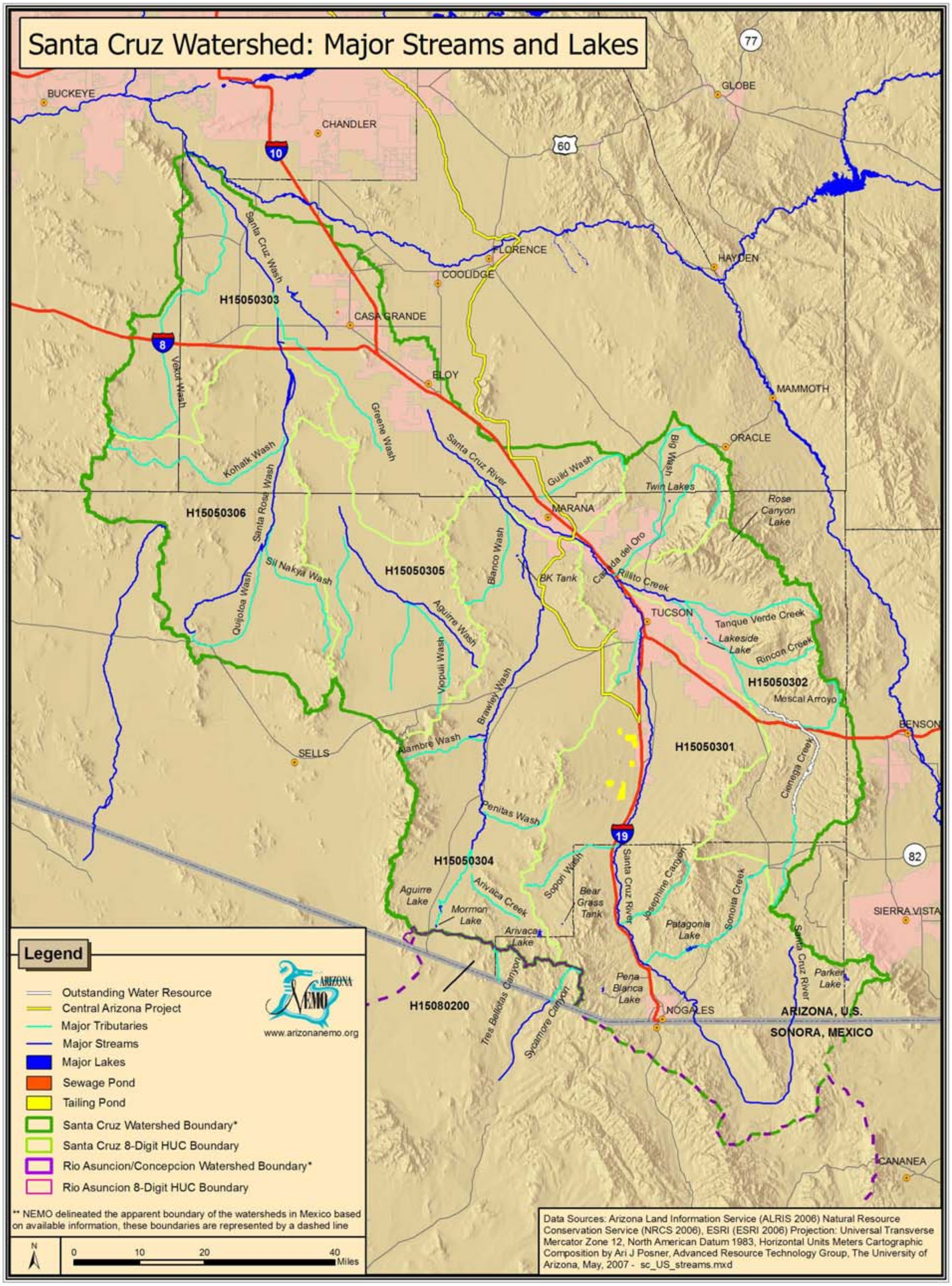

Figure 2-5.1: Santa Cruz Watershed Major Streams and Lakes

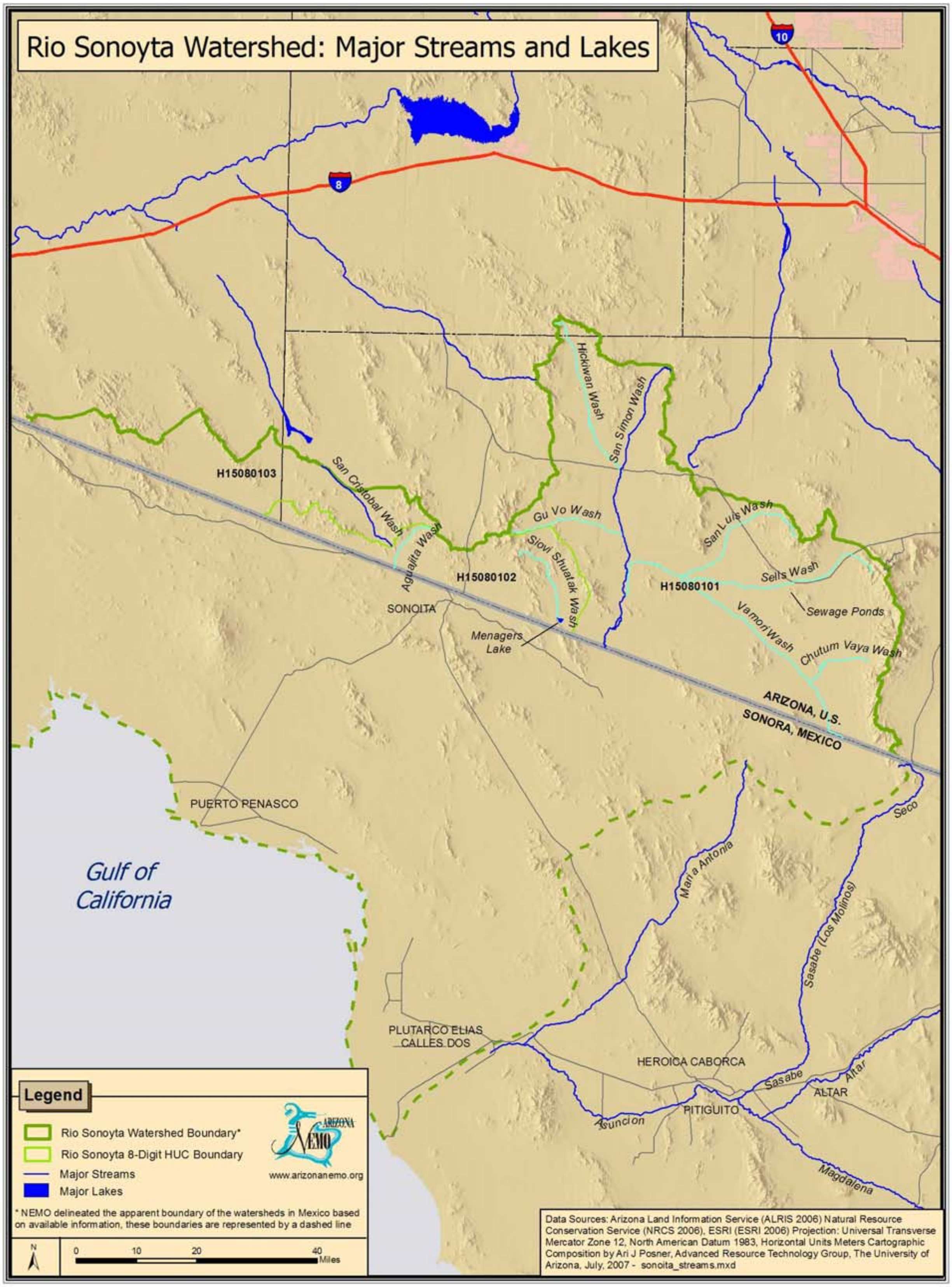

Figure 2-5.2: Rio Sonoyta Watershed Major Streams and Lakes

Lake Name (if known)	Subwatershed	Surface Area (acre)	Elevation (feet above mean sea level)	Dam Name (if known)
Sewage Pond ID# 1346	Upper Santa Cruz River	12	3,400	
Sewage Pond ID# 2419	Lower Santa Cruz River	31	1,300	
Tailing Pond ID# 1323	Upper Santa Cruz River	98	3,150	
Tailing Pond ID# 1324	Upper Santa Cruz River	131	3,100	
Tailing Pond ID#1325	Upper Santa Cruz River	493	3,100	
Tailing Pond ID# 1326	Upper Santa Cruz River	319	3,000	
Tailing Pond ID# 1329	Upper Santa Cruz River	496	3,030	
Tailing Pond ID# 1330	Upper Santa Cruz River	1,289	3,150	
Tailing Pond ID# 1339	Upper Santa Cruz River	351	3,000	
Tailing Pond ID# 1340	Upper Santa Cruz River	439	3,000	
Tailing Pond ID# 2575	Upper Santa Cruz River	13	3,500	

*Data pertains to the U.S. portion of the watershed only.
Note: The ID numbers for Sewage Ponds and Trailing Ponds were derived from the ALRIS lakes dataset and refer to the LAKES_ID column.

*Table 2-4.2: Rio Sonoyta Watershed Major Lakes and Reservoirs.**

Lake Name (if known)	Subwatershed	Surface Area (acre)	Elevation (feet above mean sea level)	Dam Name (if known)
Menagers Lake	Rio Sonoyta	266	1,750	
Sewage Pond ID# 1357	San Simon Wash	4	2,300	
Sewage Pond ID# 1358	San Simon Wash	3	2,300	
Sewage Pond ID# 1359	San Simon Wash	2.5	2,300	

*Data pertains to the U.S. portion of the watershed only.
Note: The ID numbers for Sewage Ponds were derived from the ALRIS lakes dataset and refers to the LAKES_ID column.

Outstanding Arizona Waters

The Arizona Department of Environmental Quality (ADEQ) recognizes state resource waters of unique value as Outstanding Arizona Waters (OAW), a designation which affords such waters a Tier 3 level of antidegradation protection, meaning no degradation of current water quality can be tolerated. As stated in Antidegredation Implementation Procedures (ADEQ 2007), a body of water is eligible to be considered for OAW classification if the following criteria are met:

- The surface water is a perennial water and is in a free-flowing condition;
- The surface water has good water quality. For the purpose of this regulation, "good water quality" means that the surface water has water quality that meets or is better than applicable water quality standards; and
- The surface water meets one or both of the following conditions: (a) is of exceptional recreational or ecological significance because of its unique attributes; (b) threatened or endangered species are known to be associated with the surface water and maintenance of existing water quality is essential to maintenance or propagation of said species or the surface water provides critical habitat for a threatened or endangered species.

Site-specific water quality standards may be implemented to maintain and protect existing water quality conditions for an OAW. ADEQ may consider the following factors when evaluating waters nominated for OAW classification:

- Whether there is the ability to manage the OAW and its watershed to maintain and protect existing water quality;
- The social and economic impact of Tier 3 antidegradation protection;
- Public comments in support of or opposition to the OAW classification;
- The timing of the OAW nomination relative to the triennial review of surface water quality standards;
- The consistency of an OAW classification with applicable water quality management plans; and
- Whether the nominated surface water is located within a national or state park, national monument, national recreation area, wilderness area, riparian conservation area, area of critical environmental concern, or has another special use designation (for example, Wild and Scenic River designation).

ADEQ currently recognizes 20 reaches of various water bodies throughout the state as Outstanding Arizona Waters, and is reviewing two additional streams for possible OAW classification. Within the Santa Cruz Watershed, portions of two areas are currently protected as Outstanding Arizona Waters: Cienega Creek and Davidson Canyon. Table 2-5.3 shows that 28.3 miles of Cienega Creek is currently recognized as an OAW, while 17 miles of stream in Davidson Canyon, from its headwaters to Cienega Creek, is currently under consideration for OAW classification (OAW candidate waters are afforded protection during the course of the approval process) (ADEQ 2007)

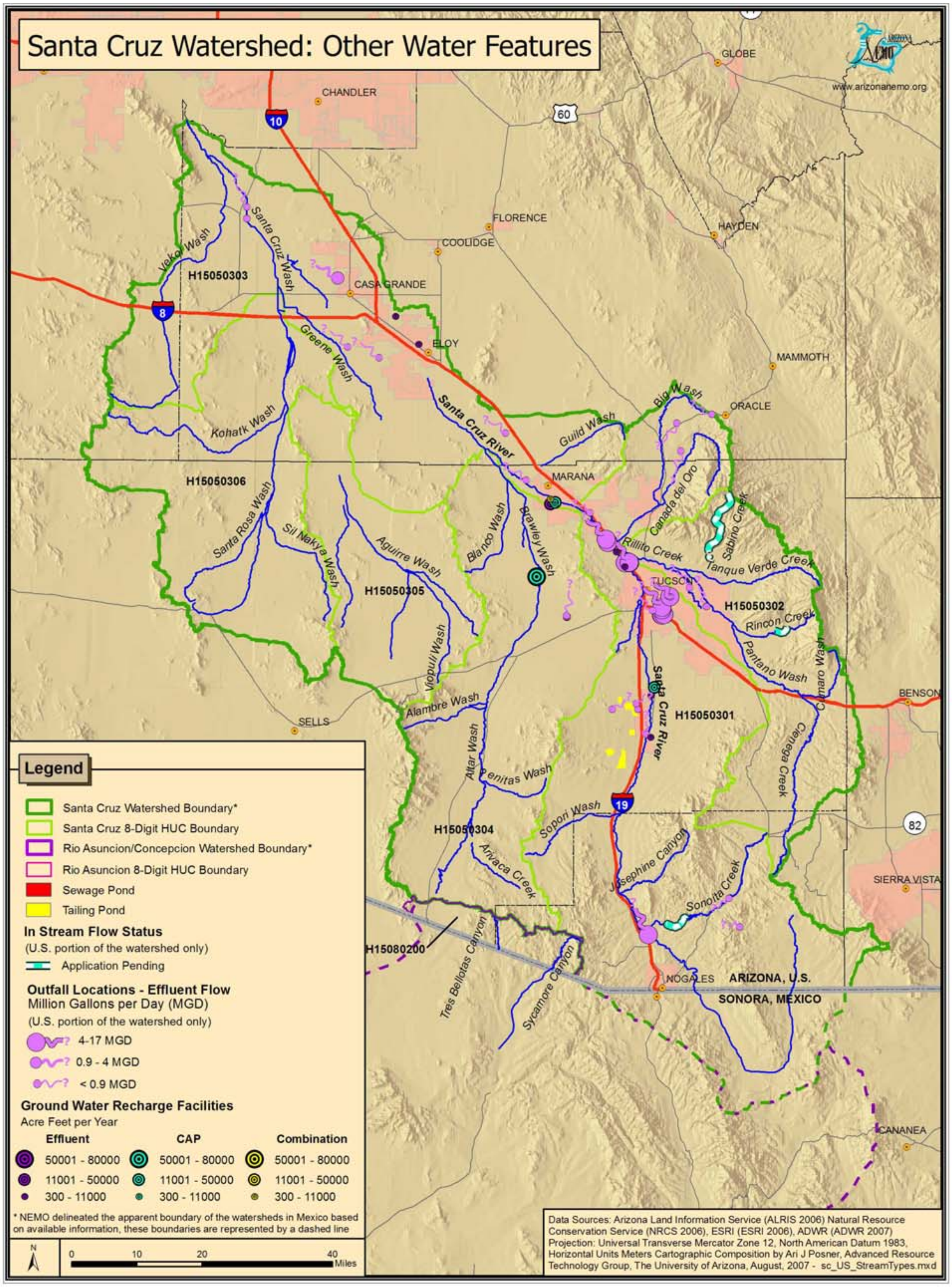

Figure 2-5.3: Santa Cruz Watershed, Other Water Features

Table 2-5.3: Santa Cruz Watershed Outstanding Water Resource.

Stream Name	Subwatershed	Stream Length (miles)
Cienega Creek	Pantano Wash-Rillito River	28

*Data pertains to the U.S. Only

Instream Flow Status

Six streams have applications pending for in-stream flow status in the Santa Cruz Watershed. Instream flow is the maintenance flow necessary to preserve instream values such as aquatic and riparian habitats, fish and wildlife and riparian-based recreation related to a particular stream or stream segment(s) (ADWR 1997). The lengths of the instream flow range from 12.9 miles on Sabino Creek (ID 14175) to 0.1 miles on also on Sabino Creek (ID 6389) (Table 2-6.1 and Figure 2-5.3)

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Table 2-6.1: Santa Cruz Watershed Instream Flow Status and Length

Stream Name	In Stream Flow Status	Permit Holder(s)	Instream Flow Length (miles)
Rincon Creek (ID 87535)	Application Pending	Saguaro National Park	2.2
Sabino Creek (ID 6389)	Application Pending	Joseph and Lynette Marco	0.1
Sabino Creek (ID 14175)	Application Pending	Sierra Club	12.9
Sabino Creek (ID 78531)	Application Pending	Hidden Valley HOA	0.4
Sonoita Creek (ID 86164)	Application Pending	Arizona State Parks Board,	2.7
Sonoita Creek (ID 14412)	Application Pending	Arizona State Land Department	1.7

*Data pertains to the U.S. Only

Stream Types

The Santa Cruz Watershed contains a total of 1,043 miles of streams (Table 2-7.1). The longest stream is the Santa Cruz River with a length of 142 miles. Effluent discharges from the Nogales International Wastewater Treatment Plant create a 12-mile perennial flow downstream of the plant (ADWR Santa Cruz AMA 1999). The longest stream in the Rio Asuncion Watershed is Sycamore Canyon at 10 miles in length, and the longest stream for the Rio Sonoyta Watershed is San Simon Wash with a length of 60 miles (Table 2-7.2).

There are four different stream types in the watershed: perennial, intermittent, ephemeral, and effluent dependent.

- Perennial streams have surface water that flows continuously throughout the year.

- Intermittent streams are streams or reaches that flow continuously only at certain times of the year, as when it receives water from a seasonal spring or from another source, such as melting spring snow.

- Ephemeral streams are at all times above the elevation of the ground water table, have no base flow, and flow only in direct response to precipitation.

- Effluent dependent streams consist of 100% effluent discharged under permit issued by ADEQ under the AzNPDES program. An effluent dependent stream would cease to flow if anthropogenic sources were to stop discharging. Effluent dominated streams contain more effluent than receiving water (>50% effluent).

Most streams in desert regions are intermittent or ephemeral. Some channels are dry for years at a time, but are subject to flash flooding during high-intensity storms (Gordon et al., 1992). Effluent discharge into these intermittent or ephemeral streams results in effluent dependent flow at a distance from the permitted discharge point that will be dependent on flow rate and seasonal conditions.

Approximately 89% (926 miles) of the streams in the Santa Cruz Watershed are intermittent or ephemeral. Only 4% (48 miles) of streams are perennial (Table 2-8.1 and Figure 2-6.1). In the Rio Sonoyta Watershed, all 304 miles of streams are intermittent (Table 2-8.2 and Figure 2-6.2) The majority of the effluent from two regional wastewater treatment plants, located along the Santa Cruz River at Roger Road and Ina Road is discharged into the Santa Cruz River Channel where it infiltrates into the aquifer (ADWR Tucson AMA, 1999).

Table 2-7.1: Santa Cruz Watershed Major Streams and Lengths.

Stream Name	Subwatershed	Stream Length (miles)
Aguirre Wash	Aguirre Wash-Tat Momoli Wash	37
Alambre Wash	Brawley Wash-Los Robles Wash	14
Alamo Wash	Pantano Wash-Rillito River	7
Altar Wash	Brawley Wash-Los Robles Wash	23
Arivaca Creek	Brawley Wash-Los Robles Wash	15
Arroyo del Compartidero	Brawley Wash-Los Robles Wash	7
Bailey Wash	Brawley Wash-Los Robles Wash	2
Big Wash	Upper Santa Cruz River	27
Brawley Wash	Brawley Wash-Los Robles Wash	35
Canada del Oro	Upper Santa Cruz River	42

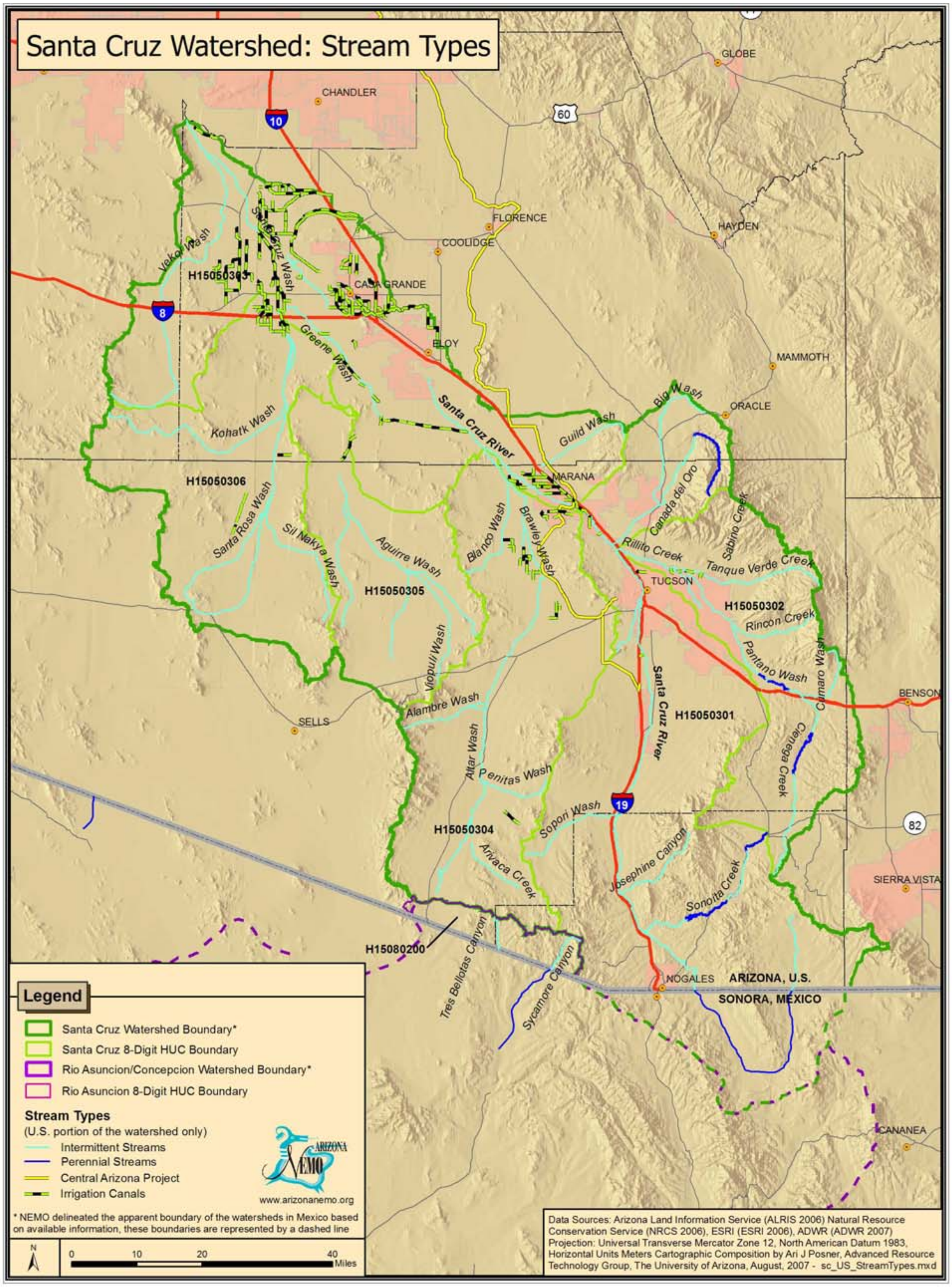

Figure 2-6.1: Santa Cruz Watershed Stream Types

Figure 2-6.2: Rio Sonoyta Watershed Stream Types

Stream Name	Subwatershed	Stream Length (miles)
Central Arizona Project	Brawley Wash-Los Robles Wash, Lower Santa Cruz River, Upper Santa Cruz River	68
Cienega Creek	Pantano Wash-Rillito River	45
Cumaro Wash	Pantano Wash-Rillito River	9
Drainage Way	Pantano Wash-Rillito River	2
Greene Wash	Lower Santa Cruz River	34
Guild Wash	Lower Santa Cruz River	18
Josephine Canyon	Upper Santa Cruz River	19
Kohatk Wash	Santa Rosa Wash	38
Los Robles Wash	Brawley Wash-Los Robles Wash	19
Mescal Arroyo	Pantano Wash-Rillito River	4
Pantano Wash	Pantano Wash-Rillito River	23
Penitas Wash	Brawley Wash-Los Robles Wash	13
Puertocito Wash	Brawley Wash-Los Robles Wash	10
Quijotoa Wash	Santa Rosa Wash	24
Rillito Creek	Pantano Wash-Rillito River	12
Rincon Creek	Pantano Wash-Rillito River	16
Santa Cruz River	Lower Santa Cruz River, Upper Santa Cruz River	142
Santa Cruz Wash	Lower Santa Cruz River	42
Santa Rosa Wash	Santa Rosa Wash	76
Sil Nakya Wash	Santa Rosa Wash	28
Sonoita Creek	Upper Santa Cruz River	37
Sopori Wash	Upper Santa Cruz River	20
Tanque Verde Creek	Pantano Wash-Rillito River	26
Vekol Wash	Lower Santa Cruz River	59
Viopuli Wash	Aguirre Wash-Tat Momoli Wash	22
West Branch Santa Cruz River	Upper Santa Cruz River	10
Sycamore Canyon	Rio Asuncion	10
Tres Bellotas Canyon	Rio Asuncion	6

*Data pertains to the U.S. Only

*Table 2-7.2: Sonoyta Watershed Major Streams and Lengths.**

Stream Name	Subwatershed	Stream Length (miles)
Aguajita Wash	Rio Sonoyta (Local Drainage)	12
Chutum Vaya Wash	San Simon Wash	14
Gu Vo Wash	San Simon Wash	21
Hickiwan Wash	San Simon Wash	33
Menagers Lake	Rio Sonoyta (Local Drainage)	4
San Cristobal Wash	Tule Desert Area	19
San Luis Wash	San Simon Wash	28
San Simon Wash	San Simon Wash	60
Sells Wash	San Simon Wash	38
Siovi Shuatak Wash	Rio Sonoyta (Local Drainage)	17
Vamori Wash	San Simon Wash	59

*Data pertains to the U.S. Only

*Table 2-8.1: Santa Cruz Watershed Stream Types and Length for All Streams.**

Stream Type	Stream Length (miles)	Percent of Total Stream Length
Perennial	48	4%
Intermittent	926	89%
Unknown	1	0.1%
Central Arizona Project	68	7%
Total Length	1,043	100%

*Data pertains to the U.S. Only

*Table 2-8.2: Rio Sonoyta Watershed Stream Types and Length for All Streams.**

Stream Type	Stream Length (miles)	Percent of Total Stream Length
Perennial	-	-
Intermittent	304	100%
Unknown	-	-
Total Length	304	100%

*Data pertains to the U.S. Only

Stream Density

The density of channels in the landscape is a measure of the dissection of the terrain. The stream density is defined as the length of all channels in the watershed divided by the watershed area. Areas with high stream density are associated with high flood peaks and high sediment production, due to increased efficiency in the routing of water from the watershed. Since the ability to detect and map streams is a function of scale, stream densities should only be compared at equivalent scales (Dunne and Leopold, 1978).

Figure 2-7.1 and Figure 2-7.2 show the stream network for the Santa Cruz Watershed, and Table 2-9.1 and Table 2-9.2 gives the stream density for each subwatershed in feet of stream length per acre. The average stream density for the Santa Cruz Watershed is 10.5 feet/acre. The Brawley Wash-Los Robles subwatershed has the highest drainage density at 11.7 feet/acre. The Lower Santa Cruz River subwatershed has the lowest drainage density at 8.0 feet/acre. The Rio Asuncion Watershed (U.S. section only) has a stream density of 13.9 feet/acre.

Stream density in the Rio Sonoyta Watershed ranges between 12.0 feet/acre and 13.7 feet/acre with a watershed average of 13.1 feet/acre.

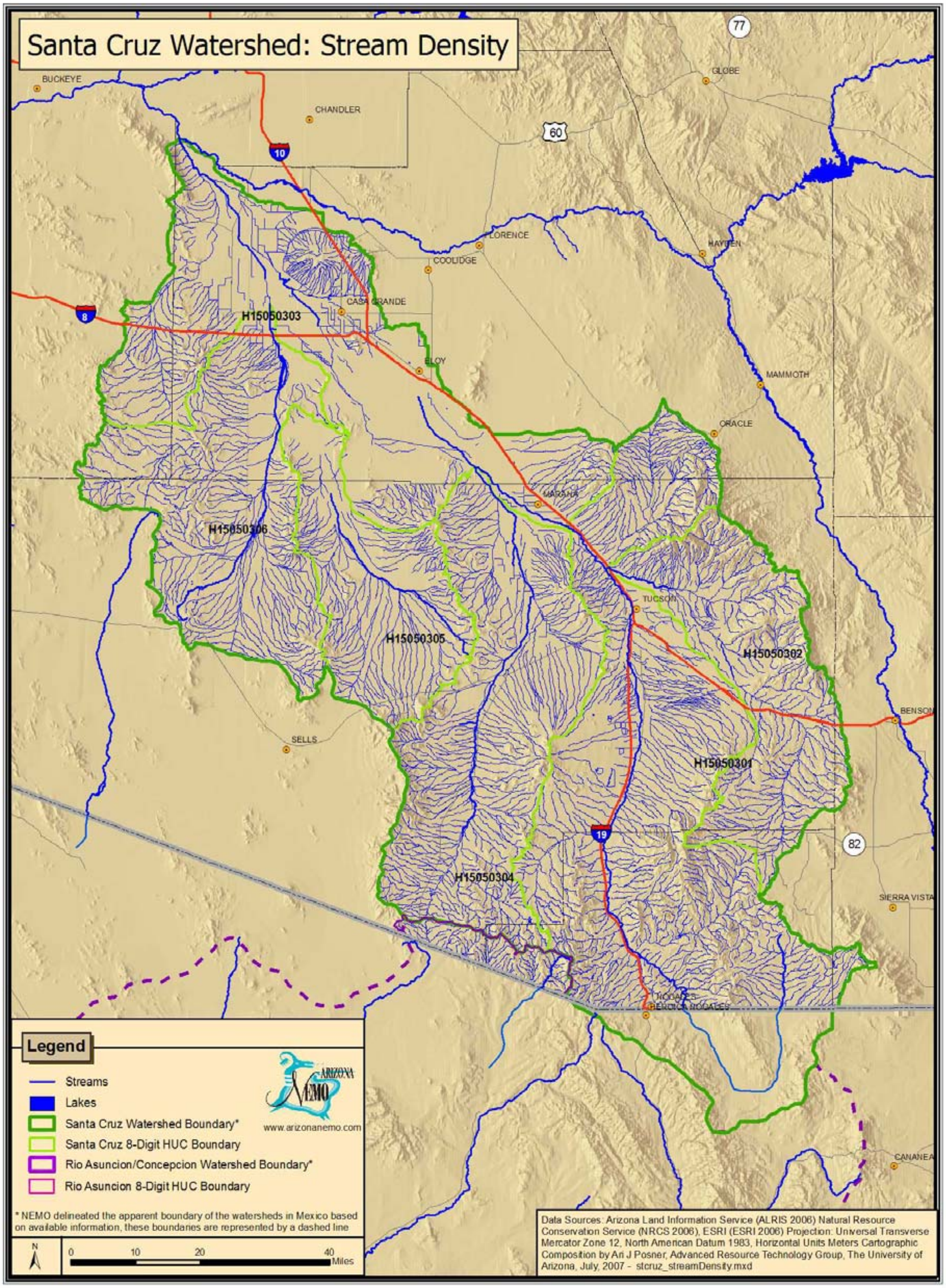

Figure 2-7.1: Santa Cruz Watershed Stream Density

Figure 2-7.2: Rio Sonoyta Watershed Stream Density

Table 2-9.1: Santa Cruz Watershed Stream Density.

Subwatershed Name	Area (acres)	Stream Length (feet)	Stream Density (feet / acre)
Upper Santa Cruz River H15050301	1,425,198	16,350,274	11.4
Pantano Wash-Rillito River H15050302	588,880	6,399,468	10.8
Lower Santa Cruz River H15050303	1,076,145	8,627,484	8.0
Brawley Wash-Los Robles Wash H15050304	901,025	10,548,365	11.7
Aguirre Wash-Tat Momoli Wash H15050305	468,924	4,758,406	10.1
Santa Rosa Wash H15050306	773,195	8,485,992	10.9
Santa Cruz River Watershed	*5,233,920*	*55,169,989*	*10.5*
Rio Asuncion H15080200	81,920	1,135,613	13.9
Rio Asuncion Watershed	81,920	1,135,613	*13.9*

*Data pertains to the U.S. Only

*Table 2-9.2: Sonoyta Watershed Stream Density.**

HUC 8 Name	Area (acres)	Stream Length (feet)	Stream Density (feet/acre)
Rio Sonoyta H15080102	271,538	3,124,009	11.5
San Simon Wash H15080101	1,378,856	18,876,109	13.7
Tule Desert Area H15080103	318,247	3,806,122	12.0
Rio Sonoyta Watershed	*1,968,641*	*25,806,241*	*13.1*

*Data pertains to the U.S. Only

Annual Stream Flow

Annual stream flows for six gages were obtained for the Santa Cruz Watershed and four gages for the Rio Sonoyta Watershed. These gages were selected based on their location, length of date record, and representativeness of watershed response. Figures 2-8.1 and 2-8.2 identify the locations of all USGS gages. The locations of the graphed hydrographs are highlighted. The gage at the Santa Cruz River at Cortaro had the highest annual mean stream flow, in the Santa Cruz Watershed, with 60 cubic feet per second (cfs) (Table 2-10.1). For the Rio Sonoyta Watershed, Quitobaquito Spring near Lukeville, Arizona, had the only recorded stream flow at .064 cfs (Table 2-10.2).

Figures 2-9 through 2-16 show hydrographs for four selected U.S. Geological Survey stream gages for mean daily flow and for a five-year moving average mean annual flow. These graphs show the variability in streamflow over time and space in this watershed.

For example, Figure 2-9 shows that at the Santa Cruz River at Nogales there were series of years where there was little or no flow, but the five year moving average (Figure 2-10) shows an increasing trend in stream flow. This gage is located five miles east of Nogales, just north of where the Santa Cruz River crosses the international border into the United States. Figure 2-11 shows that at the Santa Cruz River

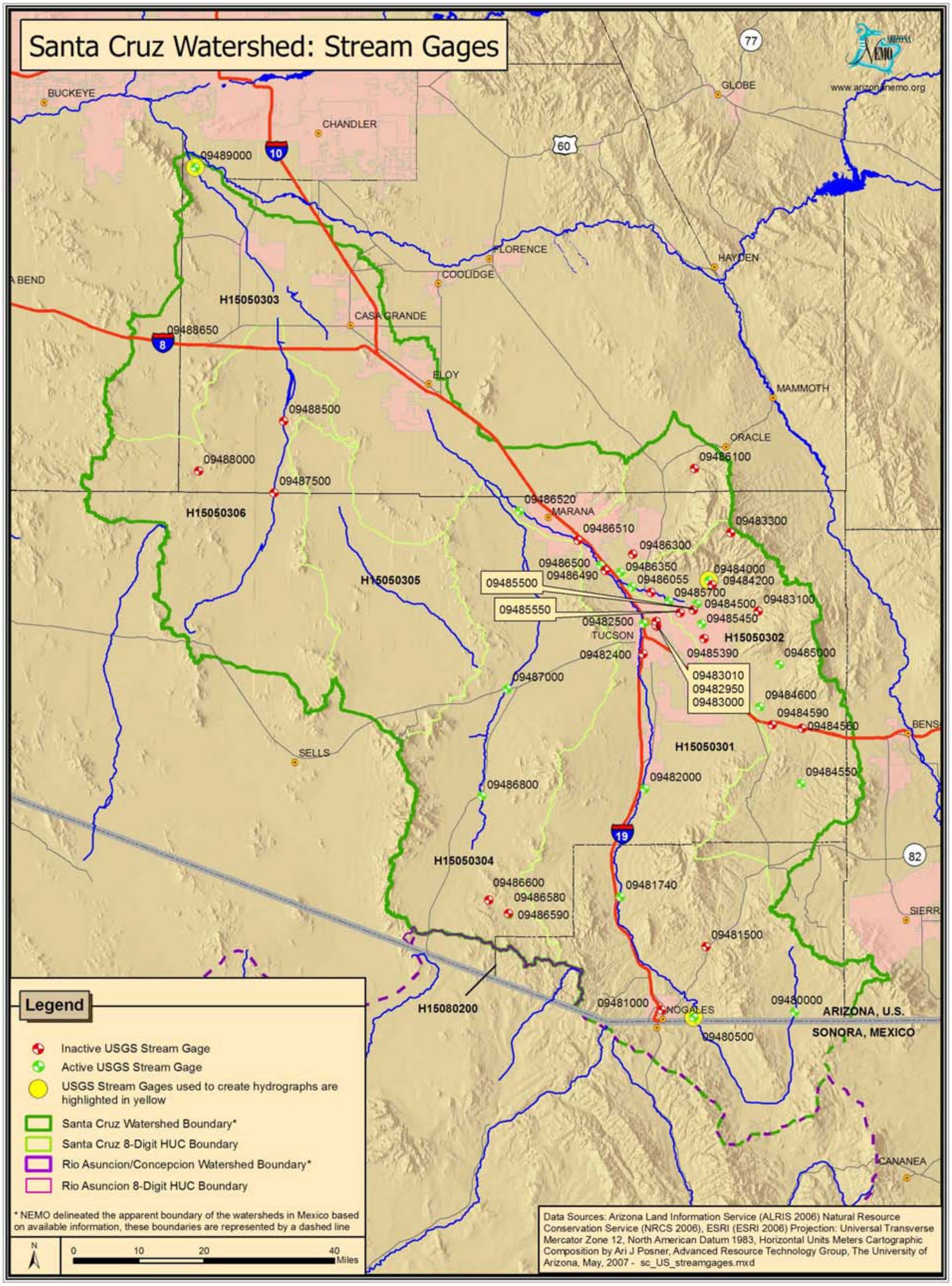

Figure 2-8.1: Santa Cruz Watershed Stream Gages

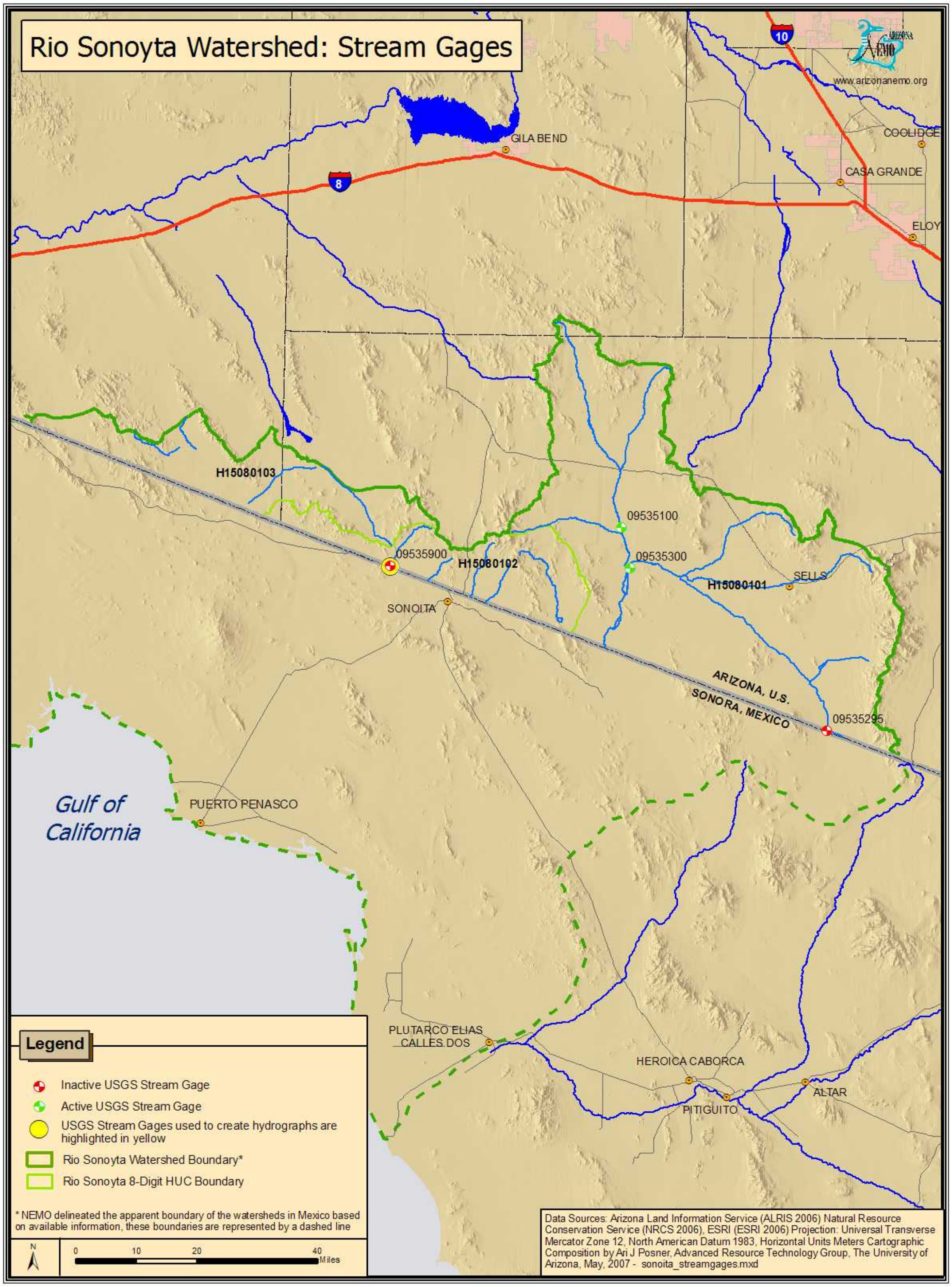

Figure 2-8.2: Rio Sonoyta Watershed Stream Gages

near Laveen there was a similar series of years with little or no flow, but in this case, the five year moving average (Figure 2-12) shows a decreasing trend in steam flow. Laveen is located about 8 miles south of downtown Phoenix, near the northern most part of the watershed.

The Sabino Canyon hydrograph, like other hydrographs in the Santa Cruz Watershed, displays high peaks sandwiched between periods of significantly drier years (Figure 2-13) The 5 year moving average mean stream flow shows a downward trend (Figure 2-14).

The hydrograph in Figure 2-15 documents that Quiobaquito Spring near Lukeville, Arizona, also displays a series of years with little or no stream flow. Like Laveen and Sabino Canyon, the five year moving average shows a decreasing trend in stream flow (Figure 2-16).

Table 2-10.1: Santa Cruz Watershed USGS Stream Gages and Annual Mean Stream Flow.*

USGS Gage ID	**Site Name**	**Begin Date**	**End Date**	**Annual Mean Stream Flow (cfs)**
09480500	SANTA CRUZ RIVER NR. NOGALES **	1914	2006	26
09480000	SANTA CRUZ RIVER NEAR LOCHIEL	1950	2006	4
09481000	NOGALES WASH AT NOGALES	1933	1934	0.5
09481500	SONOITA CREEK NEAR PATAGONIA **	1931	1972	8
09481740	SANTA CRUZ RIVER AT TUBAC	1996	2006	34
09482000	SANTA CRUZ RIVER AT CONTINENTAL **	1941	2006	23
09482400	AIRPORT WASH AT TUCSON	1966	1981	0.4
09482500	SANTA CRUZ RIVER AT TUCSON	1999	2006	15
09482950	RAILROAD WASH AT TUCSON	1976	1983	0.2
09483000	TUCSON ARROYO AT VINE AVE AT TUCSON	1945	1981	1
09483010	HIGH SCHOOL WASH AT TUCSON	1974	1983	0.1
09483100	TANQUE VERDE CREEK NEAR TUCSON	1960	1974	9
09483300	SABINO C NR MT LEMMON	1952	1959	2
09484000	SABINO CREEK NEAR TUCSON	1990	2006	21
09484200	BEAR CREEK NEAR TUCSON	1960	1974	5
09484500	TANQUE VERDE CR AT TUCSON **	1941	2006	25
09484550	CIENEGA CREEK	2002	2006	1
09484560	CIENEGA CREEK NEAR PANTANO	1969	1975	2
09484590	DAVIDSON CANYON WASH NEAR VAIL	1969	1975	1
09484600	PANTANO WASH NEAR VAIL **	1960	2006	6
09485000	RINCON CREEK NEAR TUCSON **	1953	2006	6
09485390	ATTERBURY WASH TRIBUTARY AT TUCSON	1976	1983	0.2
09485450	PANTANO WASH (BROADWAY BLVD) AT TUCSON	1999	2006	4
09485500	PANTANO WASH NEAR TUCSON **	1940	1977	0.1
09485550	ARCADIA WASH AT TUCSON	1976	1983	0.4
09485700	RILLITO CREEK AT DODGE BLVD. AT TUCSON **	1991	2006	29

USGS Gage ID	Site Name	Begin Date	End Date	Annual Mean Stream Flow (cfs)
09485850	RILLITO CREEK NEAR TUCSON **	1914	1975	14
09486055	RILLITO CR AT LA CHOLLA BLVD NR TUCSON	1996	2006	14
09486100	CANADA DEL ORO NR ORACLE JUNCTION	1985	1991	6
09486300	CANADA DEL ORO NEAR TUCSON	1966	1990	2
09486350	CANADA DEL ORO BELOW INA RD NR TUCSON	1996	2006	2
09486490	SANTA CRUZ RIVER AT INA RD. NR. TUCSON	1991	1993	59
09486500	SANTA CRUZ RIVER AT CORTARO **	1940	2006	60
09486510	SANTA CRUZ RIVER NR. RILLITO	1991	1993	37
09486520	SANTA CRUZ RIVER AT TRICO RD. NR MARANA	1990	2006	47
09486580	ARIVACA CR. AT ARIVACA	1996	2001	1
09486590	ARIVACA CREEK AT ARIVACA	2003	2006	0.2
09486600	ARIVACA WASH NR. ARIVACA	1968	1972	3
09486800	ALTAR WASH NR THREE POINTS **	1967	2006	5
09487000	BRAWLEY WASH NEAR THREE POINTS	1993	2006	5
09487500	SANTA ROSA WASH AT GU KOMELIK NR SELLS	1955	1959	14
09488000	KOHATK WASH NEAR CHIAPUK NEAR SELLS	1955	1959	3
09488500	SANTA ROSA WASH NR. VAIVA VO	1955	1980	11
09488650	VEKOL WASH NR STANFIELD	1990	1996	1
09489000	SANTA CRUZ RIVER NEAR LAVEEN	1940	2006	18

*Data pertains to the U.S. Only
** Discontinuous years of data

Table 2-9.2: Rio Sonoyta Watershed USGS Stream Gages and Annual Mean Stream Flow.*

Site ID	Name	Begin Date	End Date	Annual Mean Stream Flow (cfs)
09535900	Quitobaquito Spring Near Lukeville, AZ**	1982	1992	0.064
09535295	Vamori Wash At Intl Boundary NR Sells, AZ	1995	2000	-
09535300	Vamori Wash at Kom Vo, AZ	1972	2006	9.1
09535100	San Simon Wash Near Pisinimo, AZ	1972	2006	-

*Data pertains to the U.S. Only
**Discontinuous years of data

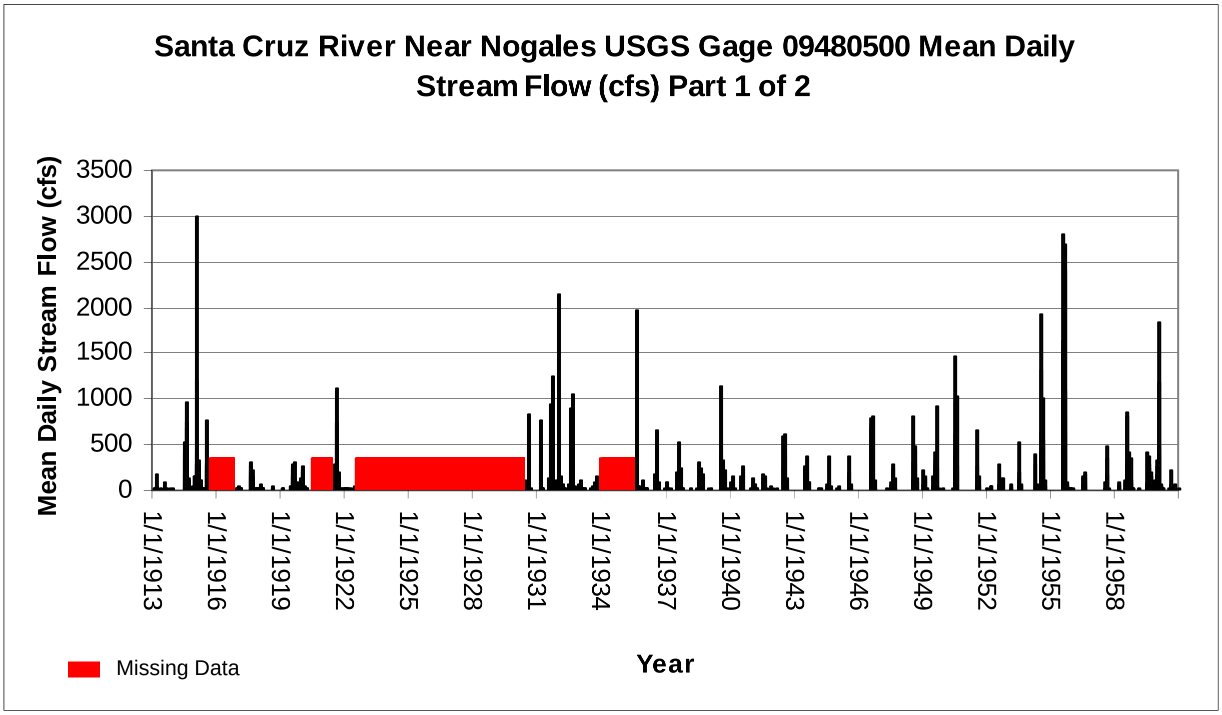

Figure 2-9: Santa Cruz River Near Nogales USGS Gage 09480500, Mean Daily Stream Flow (cfs) Hydrograph (Part 1 of 2).

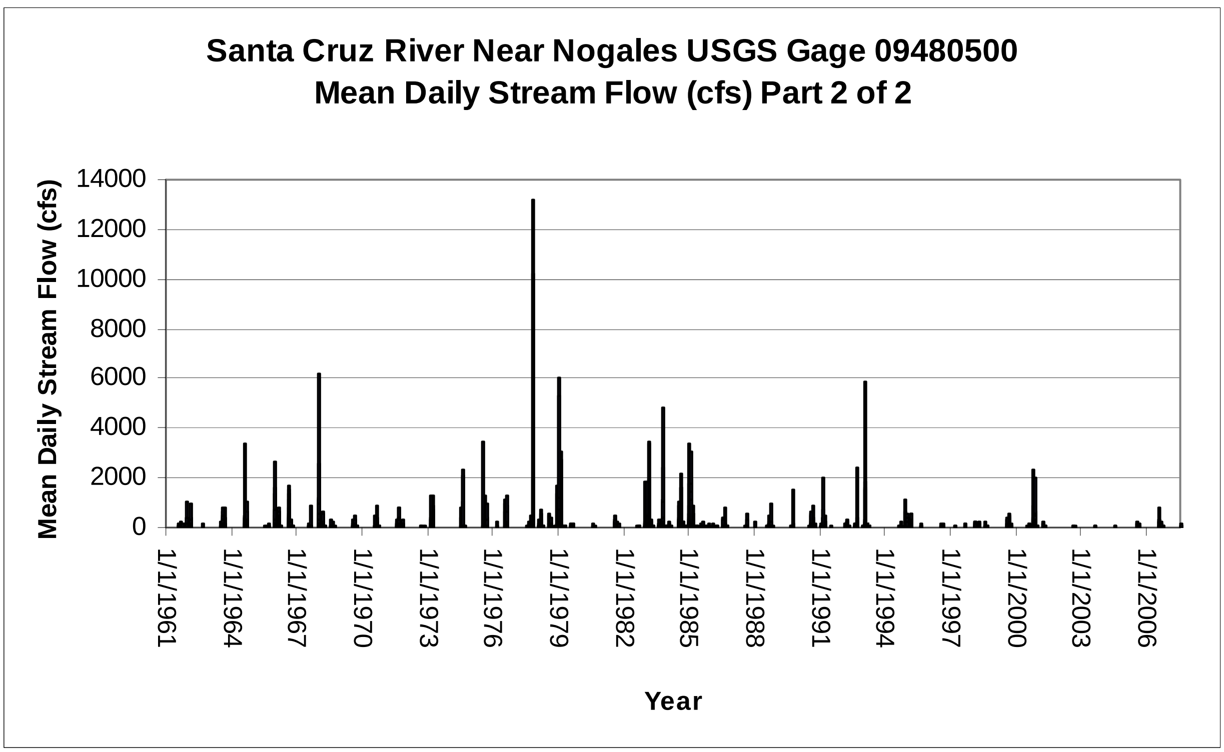

Figure 2-9: Santa Cruz River Near Nogales USGS Gage 09480500, Mean Daily Stream Flow (cfs) Hydrograph (Part 2 of 2).

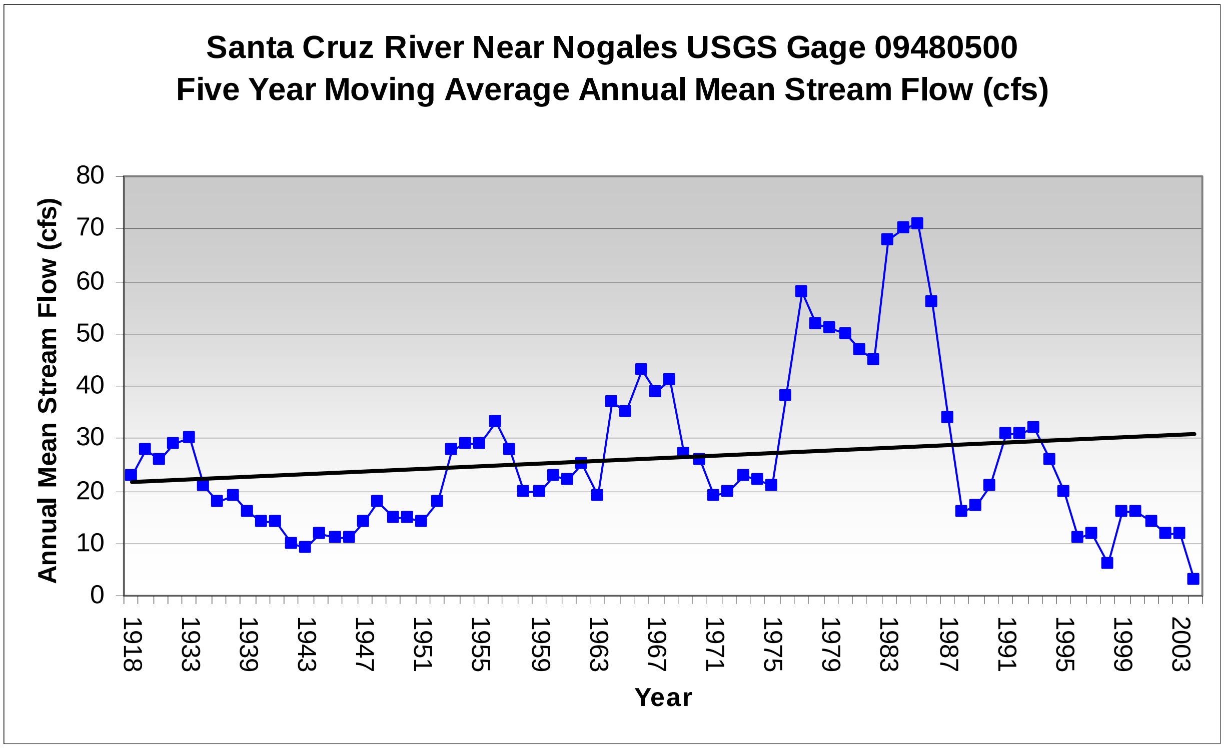

Figure 2-10: Santa Cruz River Near Nogales USGS Gage 09480500, Five Year Moving Average Annual Stream Flow (cfs) Hydrograph.

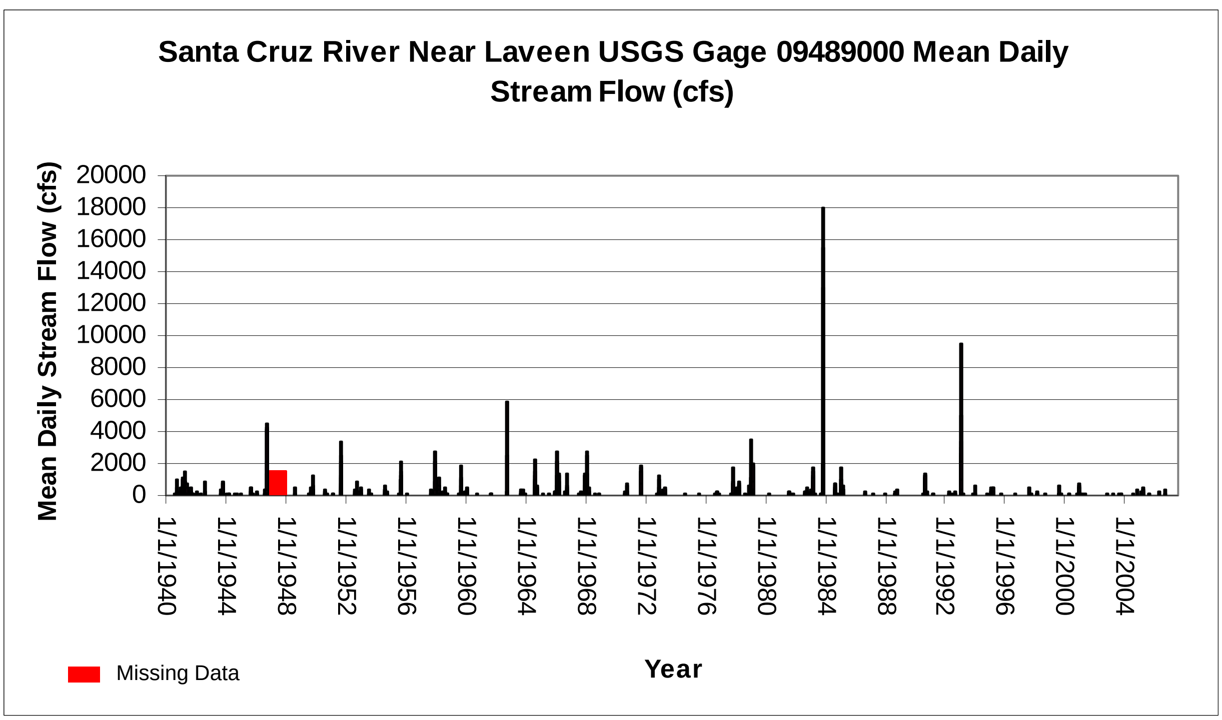

Figure 2-11: Santa Cruz River Near Laveen USGS Gage 09489000, Mean Daily Stream Flow (cfs) Hydrograph.

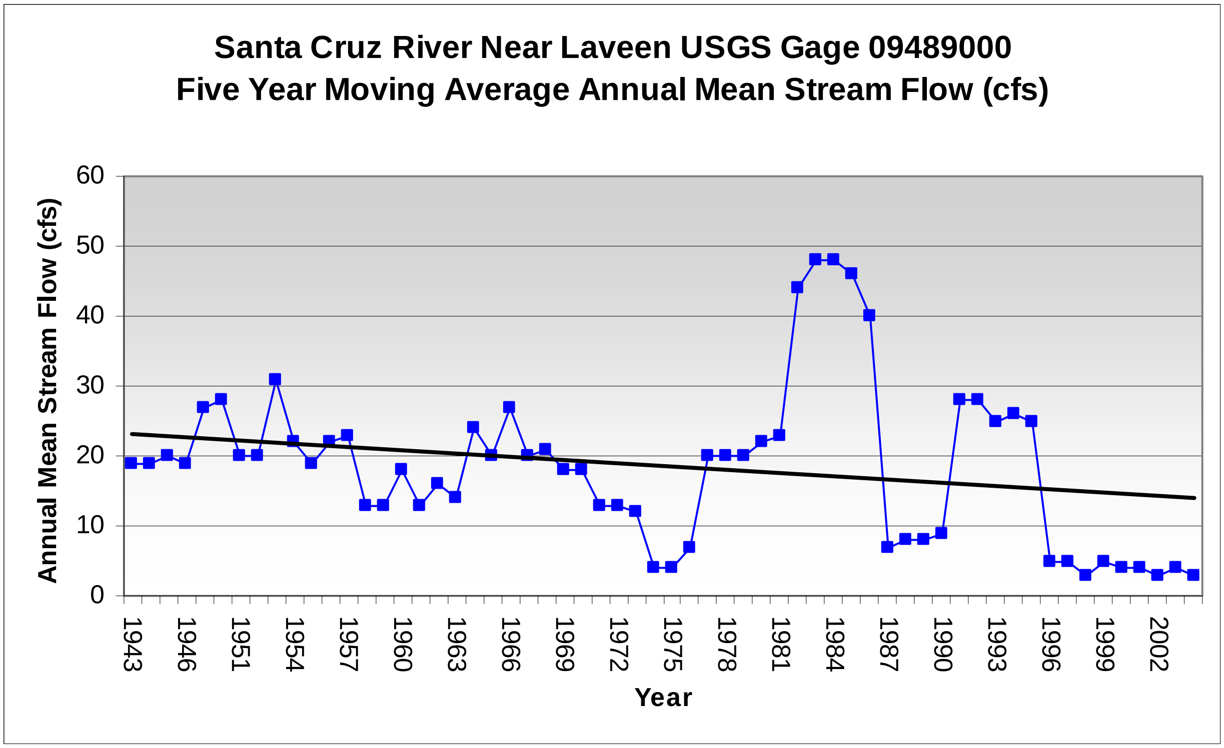

Figure 2-12: Santa Cruz River Near Laveen USGS Gage 09489000, Five Year Moving Average Annual Stream Flow (cfs) Hydrograph.

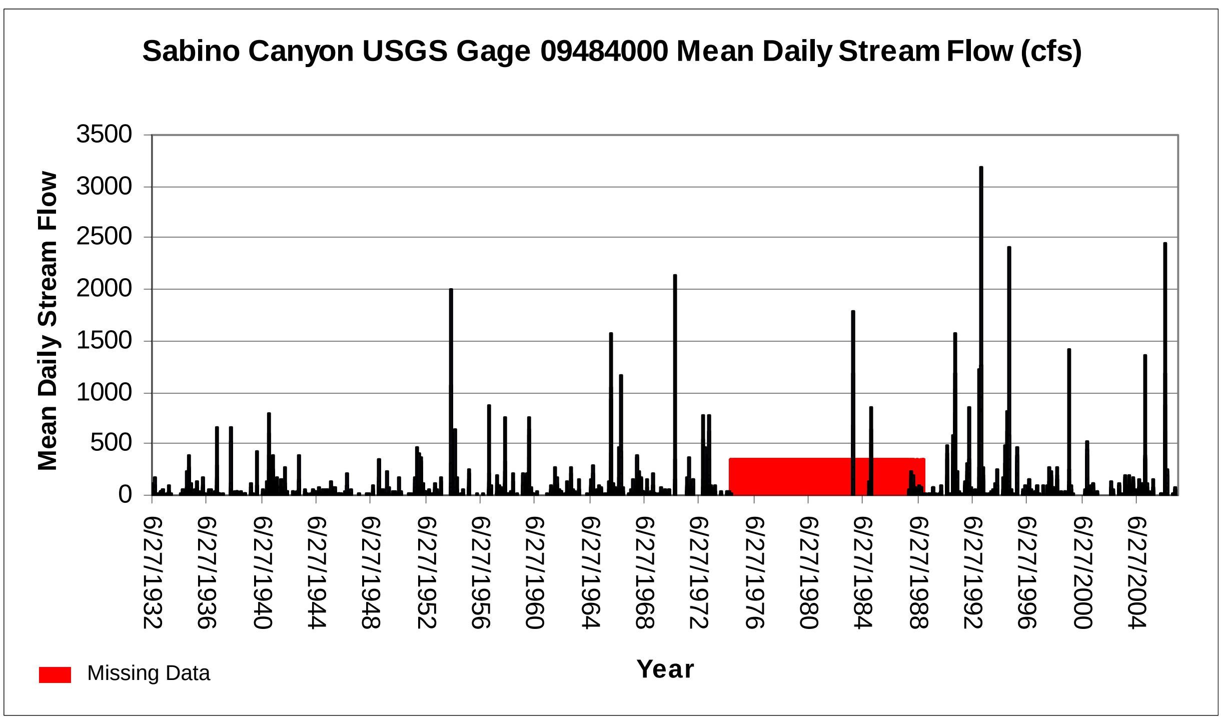

Figure 2-13: Sabino Creek Near Tucson, AZ USGS Gage 09484000, Mean Daily Stream Flow (cfs) Hydrograph.

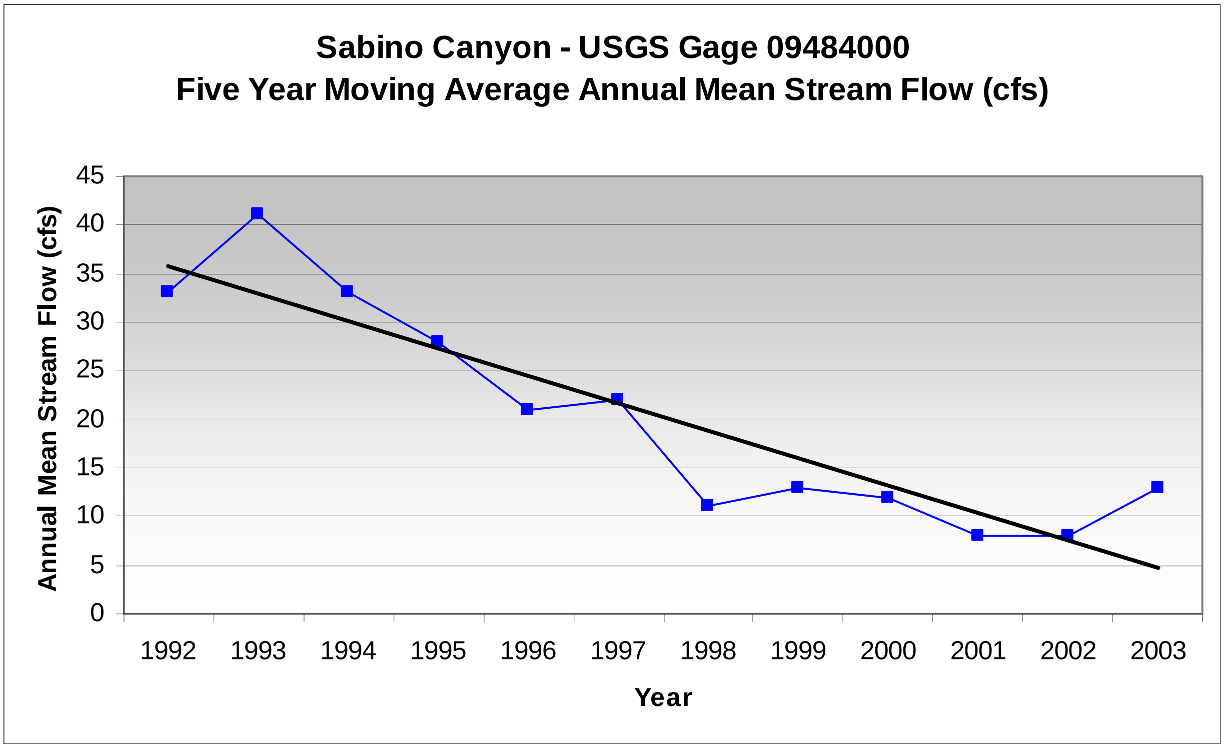

Figure 2-14: Sabino Creek Near Tucson, AZ USGS Gage 09484000, Five Year Moving Average Annual Stream Flow (cfs) Hydrograph.

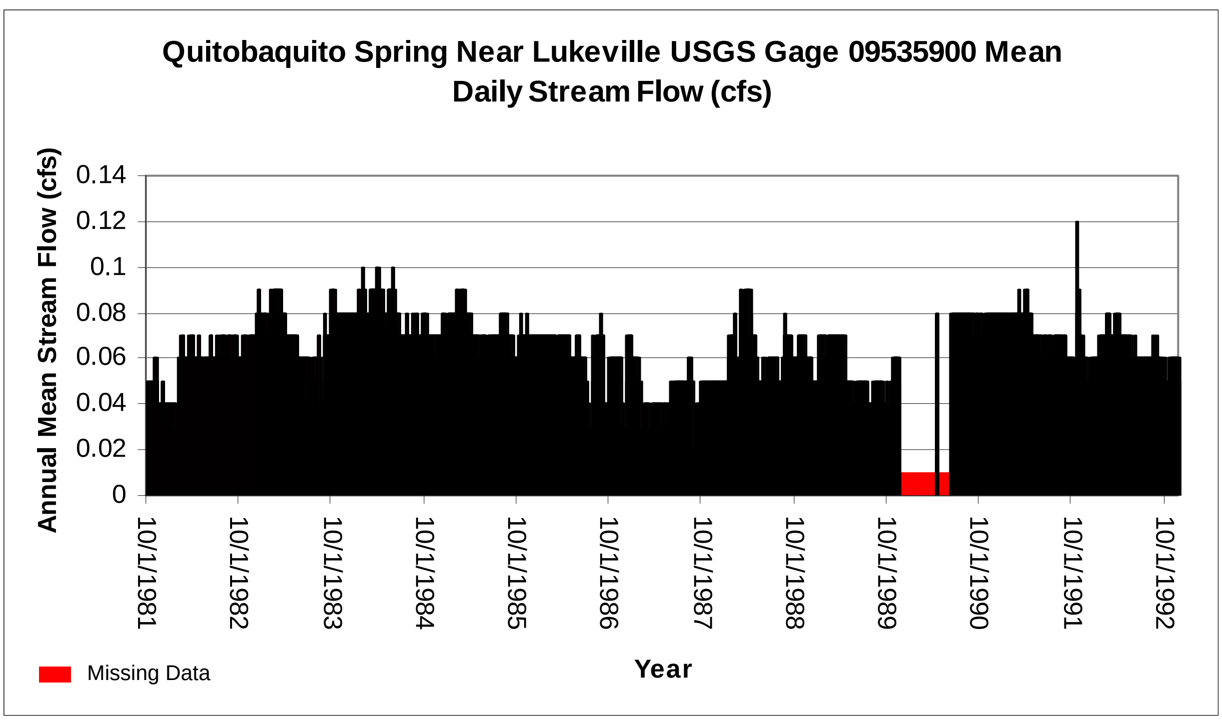

Figure 2-15 Quitobaquito Spring Near Lukeville USGS Gage 09535900, Mean Daily Stream Flow (cfs) Hydrograph.

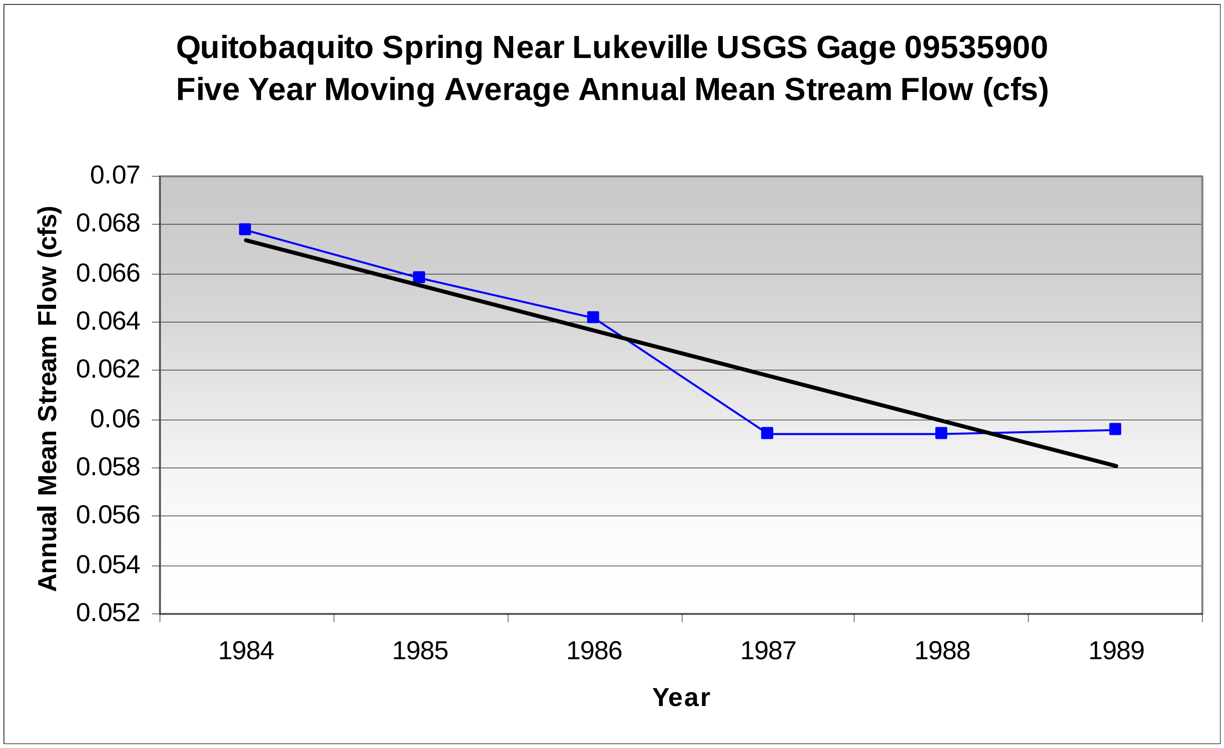

Figure 2-16: Quitobaquito Spring Near Lukeville USGS Gage 09535900, Five Year Moving Average Annual Stream Flow (cfs) Hydrograph.

Water Quality

The Arizona Department of Environmental Quality (ADEQ) assesses surface water quality to identify which surface waters are impaired or attaining designed uses and to prioritize future monitoring (ADEQ, 2006). Impaired waters, as defined by Section 303(d) of the federal Clean Water Act, are those waters that are not meeting the state's water quality standards for designated uses. Attaining waters meet state water quality standards for designated uses. Strategies are implemented on impaired waters to reduce pollutant loadings so that surface water quality standards will be met, unless impairment is *solely* due to natural conditions.

Once a surface water stream or lake has been identified as impaired, activities in the watershed that might contribute further loadings of the pollutant are not allowed (ADEQ, 2006). Agencies and individuals planning future projects in the watershed must be sure that activities will not further degrade these impaired waters and are encouraged through grants to implement strategies to reduce loading. One of the first steps is the development of a Total Maximum Daily Load (TMDL) analysis to empirically determine the load reduction needed to meet standards.

The Santa Cruz Watershed has three stream reaches assessed as impaired in Arizona’s 303(d) List of Impaired Waters (ADEQ, 2006) (Figure 2-17.1):

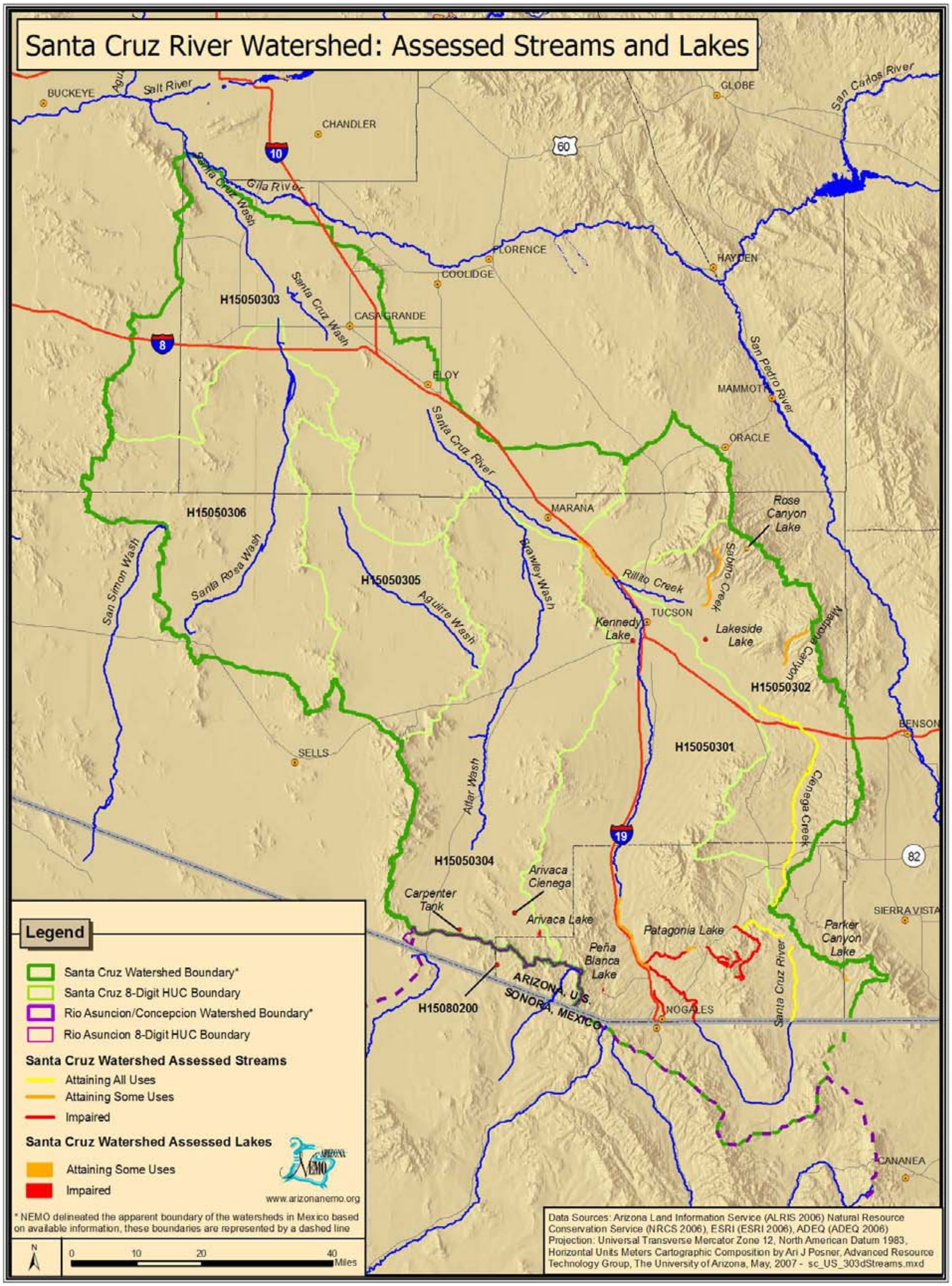

Figure 2-17.1: Santa Cruz Watershed Assessed Streams and Lakes

- Nogales Wash, from Mexico border to Potrero Creek, cooper, ammonia, *E. coli*, and chlorine (15050301-011)
- Santa Cruz River from Mexico border to Nogales International Wastewater Treatment Plant discharge, *E coli* (15050301-010)
- Sonoita Creek, from 750 feet below Patagonia WWTP discharge to Santa Cruz River, zinc (15050301-013C)

A stream reach or lake is classified as "non-attaining" when one or more designated use is assessed as "impaired." Fourteen river reaches and lakes are assessed as "not attaining." (ADEQ, 2006)

- Alum Gulch, from 312820/1104351 to 31917/1104425 (intermittent flow) (150503001-561B), cadmium, copper, zinc, and pH.
- Alum Gulch, from 312820/1104351 to 31917/1104425 (intermittent flow) (150503001-561A), cadmium, copper, zinc, and pH.
- Arivaca Lake (150505304-0080), mercury in fish tissue.
- Cox Gulch, from headwaters to Three R Canyon (15050301-560), cadmium, copper, zinc, and pH.
- Harshaw Creek, from headwaters to Sonoita Creek (15050301-340), cadmium, copper, zinc, and pH.
- Humbolt Canyon (15050301-025) from headwaters to Alum Gulch, cadmium, copper, zinc, and pH
- Lakeside Lake (15050302-0760), ammonia, low dissolved oxygen.
- Pena Blanca Lake (1505030201-1070), mercury in fish tissue.
- Three R Canyon fro 312827/1104712 to Sonoita Creek (15050301-558C), cadmium, copper, zinc, and pH.
- Three R Canyon from 312835/1104719 to Sonoita Creek (15050301-558B), cadmium, copper, zinc, and pH.
- Three R Canyon from 312827/1104619 to Sonoita Creek (15050301-558A), cadmium, copper, zinc, and pH.
- Unnamed tributary to Cox Gulch from headwaters to Cox Gulch (15050301-890), cadmium, copper, zinc, and pH.
- Unnamed tributary to Harshaw Creek (Endless Chain Mine tributary) (15050301-888), cadmium, copper, zinc, and pH.
- Unnamed tributary to Three R Canyon (15050301) from headwaters to Three R Canyon, cadmium, copper, zinc, and pH.

The remaining reaches and lakes are listed as either "attaining" or "inconclusive" due to insufficient monitoring data (ADEQ, 2006). An explanation of the 303(d) listing process is found in Section 1, Introduction, and a tabulation of the water quality attributes can be found in Section 6, Watershed Assessment. The constituents analyzed for each stream and lake are listed in Appendix A, Table 1.

Geology

The Santa Cruz Watershed is located within Arizona's Basin and Range Province. The Basin and Range Province of southern and western Arizona is an area where the Earth's crust has been stretched and broken by numerous faults so that mountain ranges and basins (broad valleys) have formed by the vertical motion of large crustal blocks.

The Basin and Range Province was formed from 28 to 12 million years ago as the Baja California portion of the Earth's tectonic Pacific Oceanic plate began diverging from the continental plate, stretching the continental plate and forming the equivalent of stretch marks in the earth's crust, nearly parallel to the strike (direction) of the plate boundary. This stretching is evident in the alignment of mountain peaks and valleys in the Santa Cruz Watershed in a general northwest-southeast alignment pattern, referred to geologically as lineation. As the earth's crust is stretched, blocks of crust break and drop in a pattern of valley basins and high peak ranges, and is known as the Basin and Range Province within Arizona and other regions of Mexico and the western United States.

Observation of high-altitude aerial photographs or topographic maps of the region show obvious lineations within the Basin and Range. The vertical displacement between the base of the basin and mountain peak may exceed 20,000 feet, but over time the basin fills with sediments eroded from the mountains, with some basins filling with alluvium over 12,000 feet in thickness. The sedimentary material within the Basin and Range valley alluvium forms the major aquifers of the Santa Cruz Watershed, as well as the significant water supply aquifers across Arizona and the arid west.

The Santa Cruz Watershed basin floor is generally level, with several primary and secondary drainage channels draining to the northwest. These channels convey surface runoff and alluvial sediment northward and westward through the basin after eroding from the Santa Catalina, Rincon, Tucson and Tortillita ranges in the U.S., and the San Antonio, El Pinito and El Chivato ranges in Mexico.

The mountains surrounding the Santa Cruz Watershed are composed of metamorphic, sedimentary, and intrusive igneous rock extending beneath the alluvial material filling the basin (Pima County, 2006). This relatively impermeable material provides a physical boundary that forms the area's ground water basins. Over time, erosion or weathering of the mountainous areas has resulted in the deposition of alluvium up to 7,000 feet thick in areas south and southeast of Tucson. A stratigraphic section through the basin reveals, from the ground surface downward, superficial deposits (primarily stream channel and terrace deposits) of the Fort Lowell Formation, the Tinaja beds, and the Pantano Formation.

The Pantano Formation is composed primarily of Catalina granite and gneiss, ranging from loosely packed to weakly cemented into place. The Tinaja beds are a series of beds composed of Catalina gneiss changing to volcanics with increasing depth, ranging from sandy gravel along the basin's margins to gypsiferous clayey silt and mudstone in the center of the basin. The thickness of each unit varies throughout the basin, with the deeper beds generally thicker than those overlying them. The Fort Lowell Formation overlies the Tinaja beds, and is composed of loosely packed to weakly cemented Quaternary sediments (Coes 1998).

The basin is interwoven with deep geologic faults, all of which are considered to be inactive. Figure 2-18.1 and Figure 2-18.2 show the geology of the watersheds. Tables 2-11.1 and Table 2-11.2 list geologic units by subwatershed, and Tables 2-12.1 and 2-12.2 list the percentage of each rock types.

Alluvial Aquifers

Alluvial deposits, eroded from the surrounding block-faulted mountains, comprise the basin fill of the Santa Cruz Watershed. The basin fill alluvium forms a regional aquifer throughout the watershed, with a small local aquifer in the alluvial material of the flood plains of the Santa Cruz River and its tributaries, identifiable as the Young Alluvium. The availability of ground water in the shallow flood plain alluvium is intermittent, dependent on flow in the river channel. Most of the year ground water is not present in the Santa Cruz Young Alluvium. The regional basin-fill aquifer ranges from unconfined to partly confined, and a zone of perched water is reported to exist near the Tucson Mountains. The Young Alluvium is of Quaternary age, and ranges in depth from a few meters to tens of meters thick (Coes 1998).

Figure 2-19.1 shows alluvial geology for the Santa Cruz Watershed. There is no alluvial geology data for the Sonoyta Watershed.

Ground Water Resources

The majority of public-supply, household, agricultural, and industrial water needs in the Santa Cruz Watershed are fulfilled by ground water. The Arizona Department of Water Resources (ADWR) permits and registers ground water wells throughout the state by ground water basins. These ground water basin designations are based on geographic locations and boundaries that do not necessarily correlate with geologic aquifer boundaries.

In the case of the Santa Cruz Watershed, the ADWR ground water administrative basins boundaries do not correspond exactly to the watershed boundaries, but include at least portions of the following ADWR basins: Cienega Creek, Phoenix AMA, Pinal AMA, San Rafael, Santa Cruz AMA, and Tucson AMA (Figure 2-20.1). The Rio Asuncion Watershed includes a section of the Tucson AMA. The Rio Sonoyta Watershed includes portions of the Tucson AMA and Western Mexican Drainage (Figure 2-20.2). The U.S. Geological Survey (USGS) has also delineated ground water basins in the Santa Cruz, the Rio Asuncion, and the Rio Sonoyta Watersheds, as shown in Figure 2-21.1 and 2-21.2. The boundaries of the USGS basins tend to follow the watershed boundaries but are different from the basins delineated by ADWR.

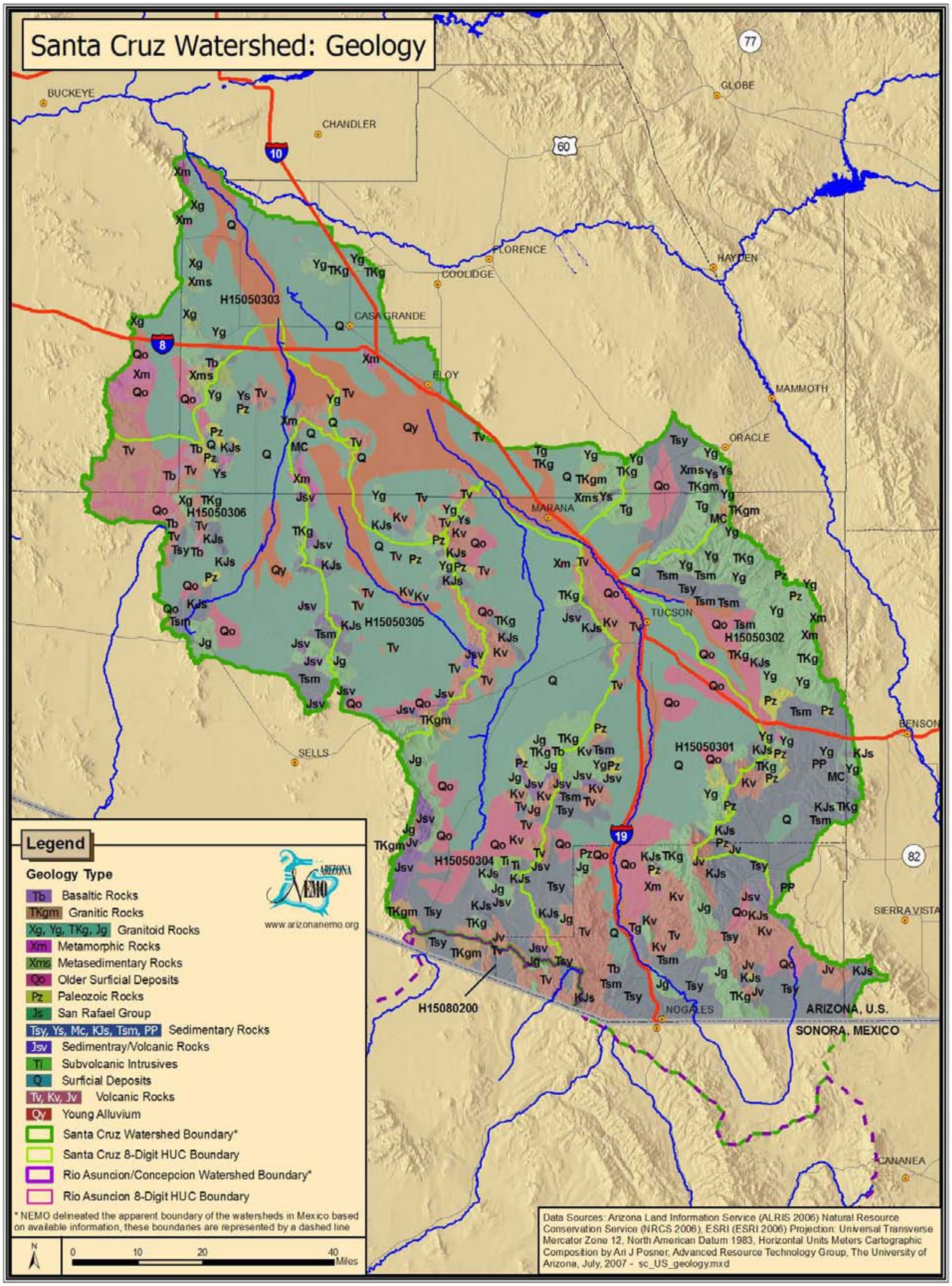

Figure 2-18.1: Santa Cruz Watershed Geology

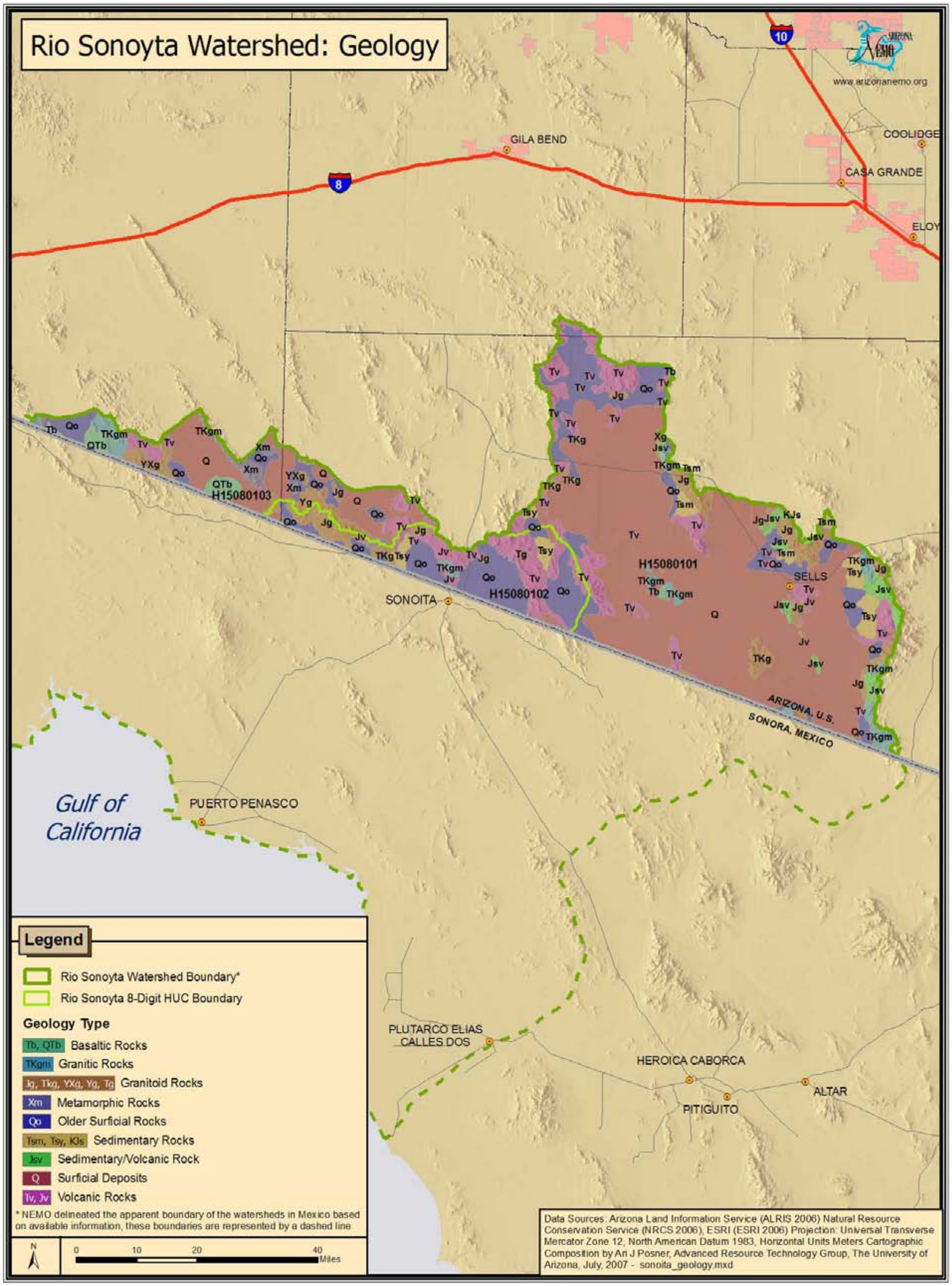

Figure 2-18.2: Rio Sonoyta Watershed Geology

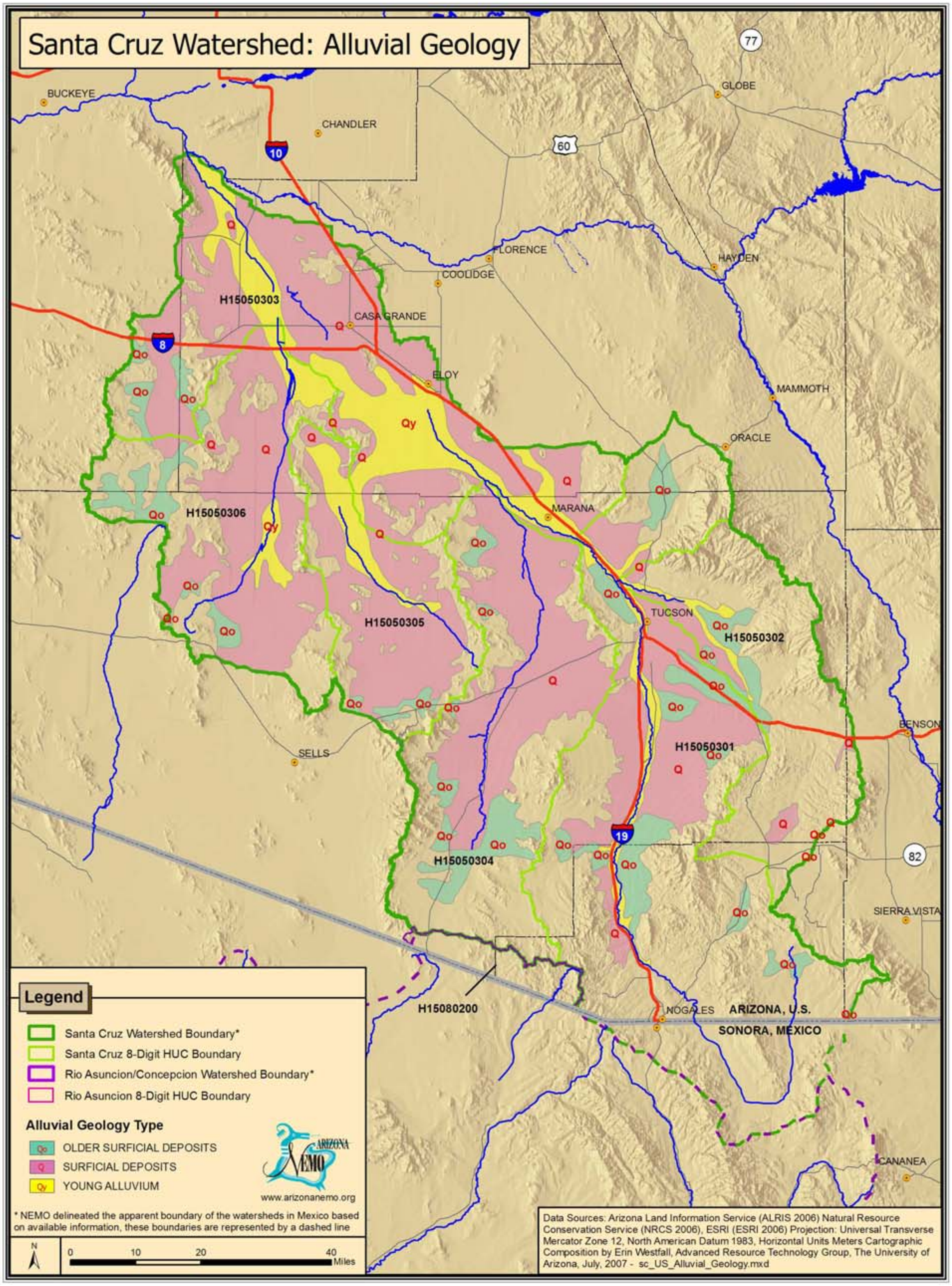

Figure 2-19.1: Santa Cruz Watershed Alluvial Geology

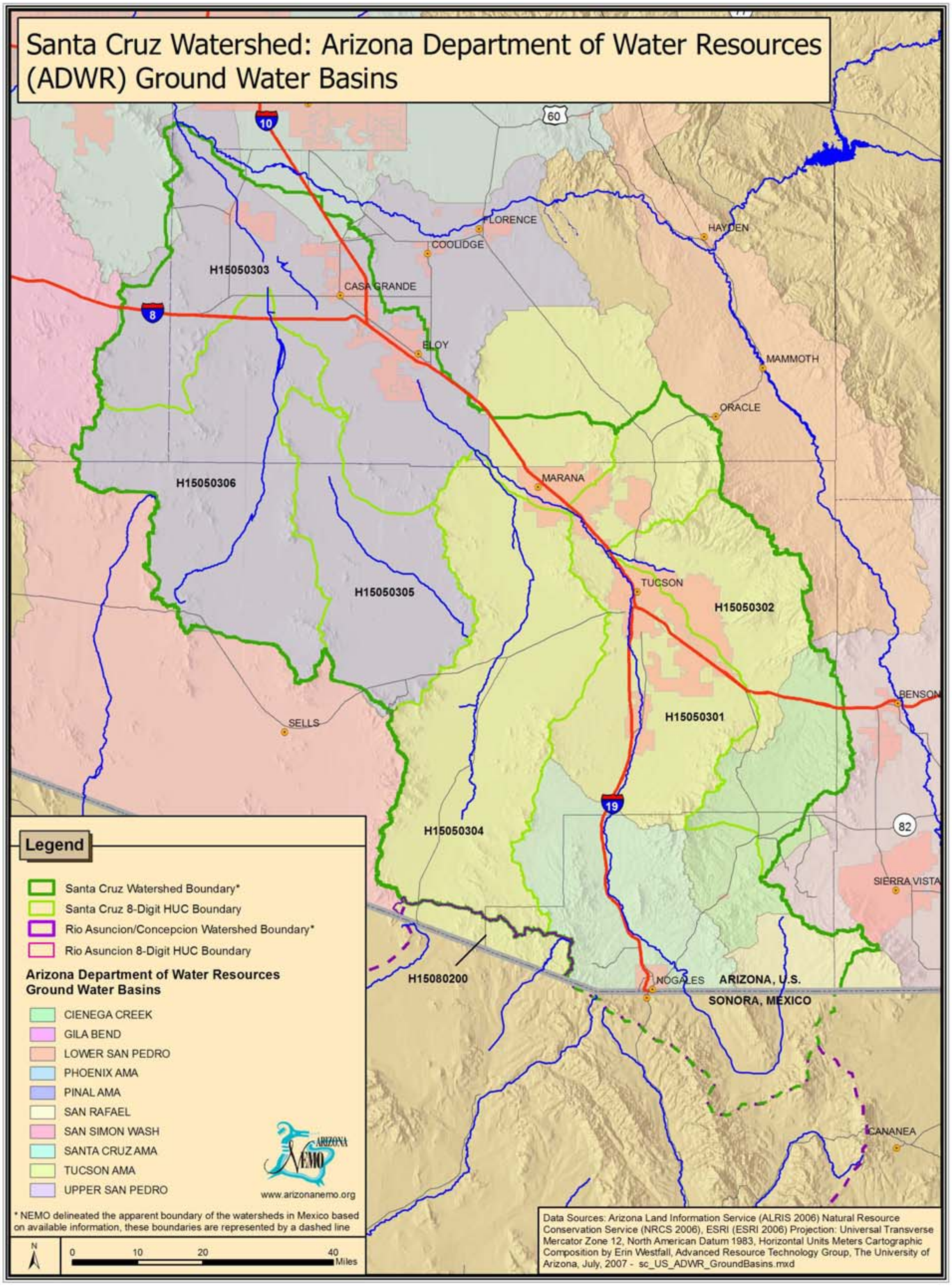

Figure 2-20.1: Santa Cruz Watershed ADWR Ground Water Basins

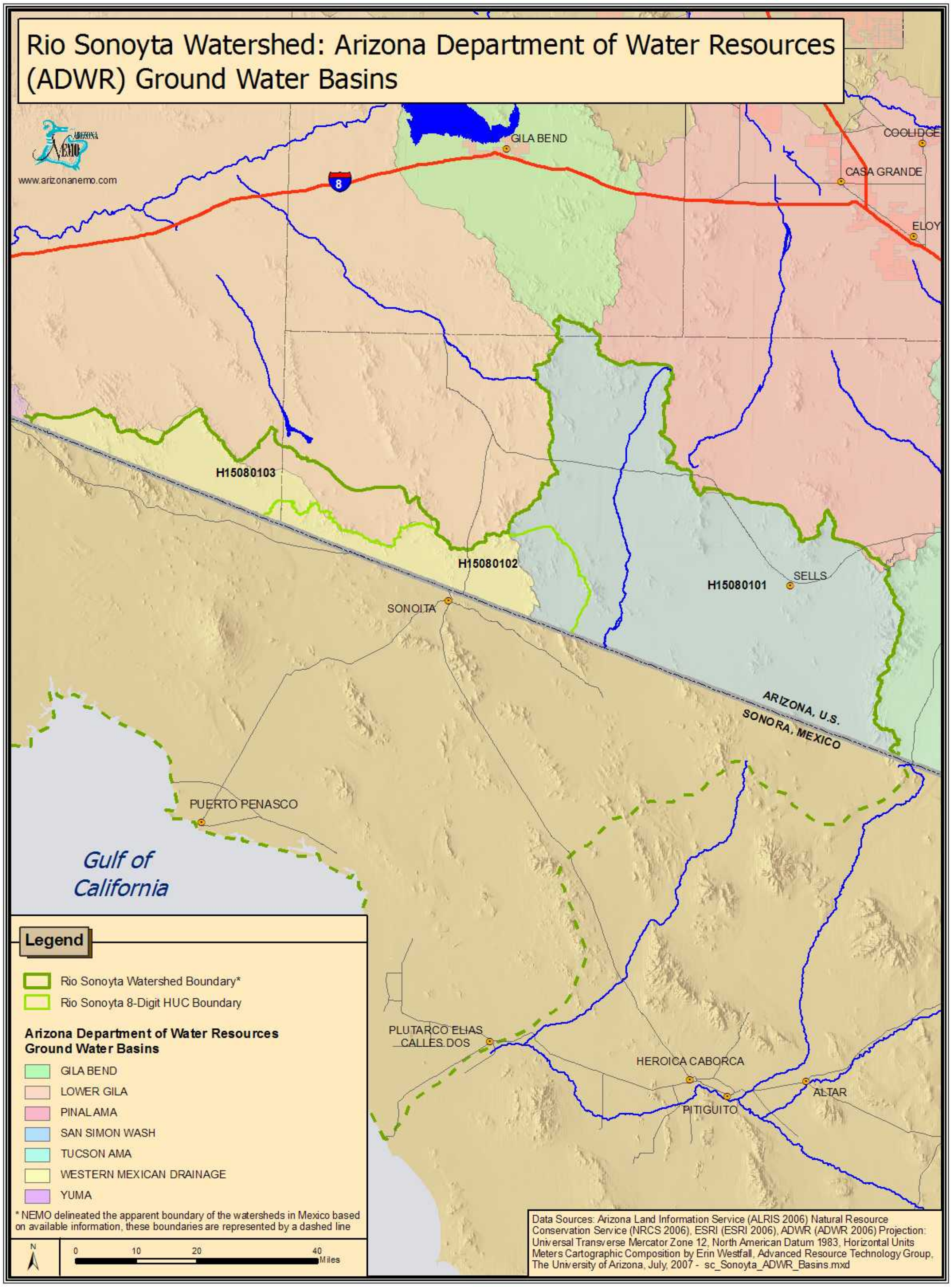

Figure 2-20.2: Rio Sonoyta Watershed ADWR Ground Water Basins

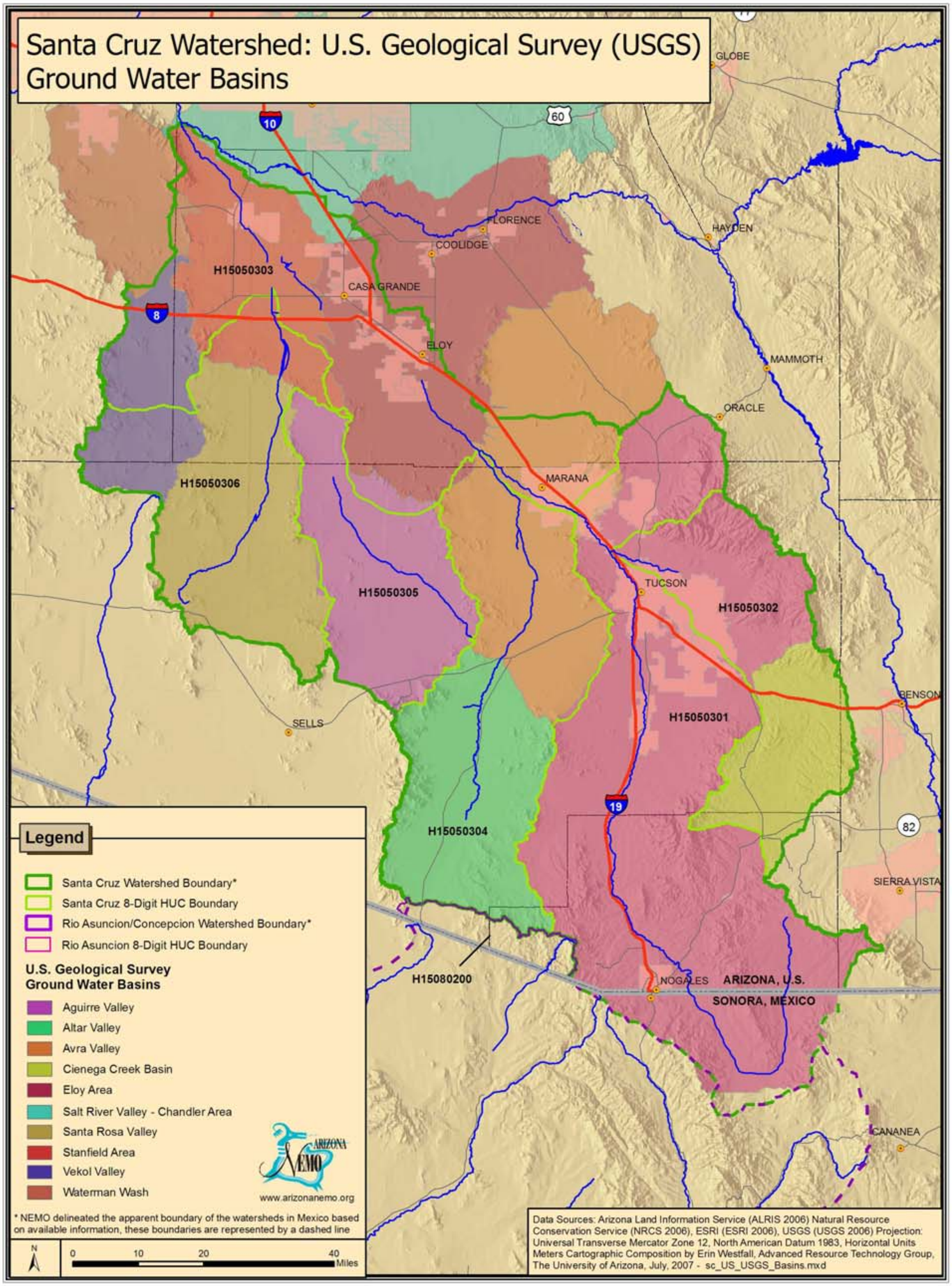

Figure 2-21.1: Santa Cruz Watershed USGS Ground Water Basins

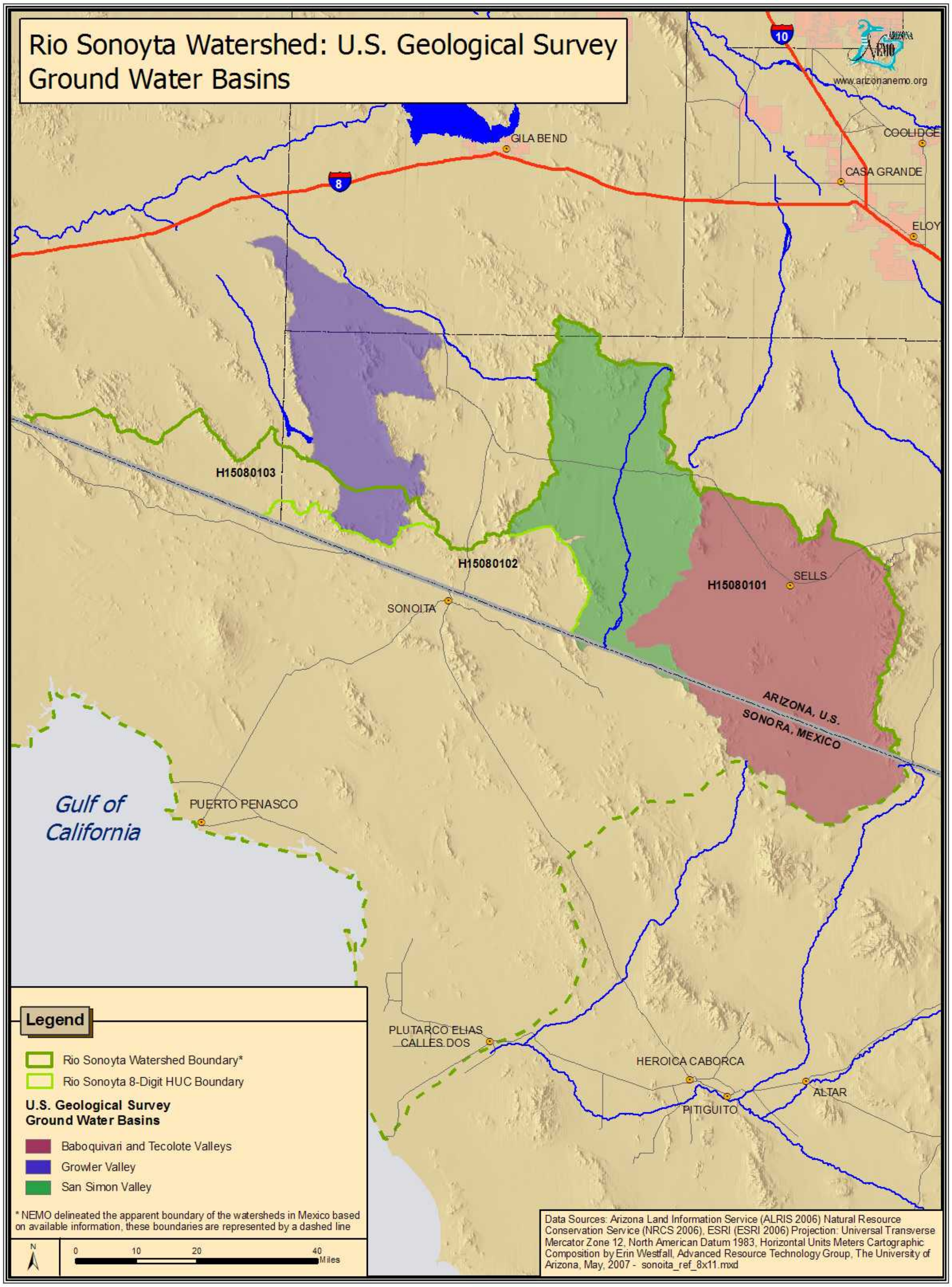

Figure 2-21.2: Rio Sonoyta Watershed USGS Ground Water Basins

The Arizona Groundwater Code was established in 1980 to combat severe ground water overdraft, and designated areas of the state where water competition is most severe as Active Management Areas (AMAs). The Santa Cruz Watershed encompasses three AMAs, each with a distinct primary objective within the general framework of ground water management and conservation. In the Pinal AMA, the goal is to protect the predominately agricultural economy (Pinal AMA); the Santa Cruz AMA was established to address the unique hydrology and international water management issues of the Upper Santa Cruz River Basin (Santa Cruz AMA); and the Tucson AMA strives to attain safe-yield by the year 2025 or earlier (Tucson AMA).

Prior to 1940, recharge from natural sources equaled discharge from the Santa Cruz Watershed, meaning that the hydrologic system in the area was in a state of relative equilibrium (Coes 1998). Since 1940, however, growing development and demand for water has resulted in escalating overdraft from the aquifers in the basin. It is estimated that ground water in the Santa Cruz Watershed is used at twice the rate it is replenished; consequently, the amount of ground water in storage has decreased by 6 to 8 million acre-feet since the time when the system was in equilibrium. This overdraft has caused significant depletion of the upper layer of the aquifer. Land surface subsidence and resulting earth fissures in the area are the visible signs of decreased ground water supplies (Tucson AMA).

Water from the Central Arizona Project (CAP) plays an integral part in maintaining the water resources of the Santa Cruz Watershed. Through the Central Arizona Project, 1.5 million acre-feet of Arizona's allocation of Colorado River water is transported annually from western Arizona through a series of aqueducts to municipal and agricultural users in central and southern Arizona (Tucson AMA). In the Santa Cruz Watershed, a portion of the area's CAP water is dedicated for recharge projects. Recharge may be direct, in the case of infiltration into underlying aquifers via basins, streambeds, or injection wells; or indirect, through groundwater savings programs designed to substitute CAP water for groundwater (Tucson AMA).

Artificial recharge of the Santa Cruz Watershed's ground water resources occurs at the Clearwater Renewable Resource Facility, operated by the city of Tucson. The facility's recharge projects were initiated in 1996, and have an average annual recharge and recovery rate of 60,000 acre-feet. As of late 2003, a total of 123,989 acre-feet of CAP water had been recharged at Clearwater. The Pima Association of Governments, Tucson Water, and the University of Arizona Laboratory of Isotope Geochemistry conduct monitoring of recharged CAP water within the aquifer using stable isotopes (PAG 2004).

Table 2-11.1: Santa Cruz Watershed Geology (part 1 of 2).*

Geologic Unit	Geologic Code	Aguirre Wash Tat Momoli Wash H15050305	Brawley Wash – Los Robles Wash H15050304	Lower Santa Cruz River H15050303	Pantano Wash – Rillito River H15050302	Santa Rosa Wash 15050306
BASALTIC ROCKS (late to middle Miocene; 8 to 16 Ma.)	Tb	-	0.1%	0.2%	-	0.3%
GRANITIC ROCKS (early Tertiary to late Cretaceous; 45 to 75 Ma.)	TKgm	0.4%	2.1%	0.1%	0.3%	0.1%
GRANITOID ROCKS (early Miocene to Oligocene; 18 to 38 Ma.)	Tg	-	-	0.4%	-	-
GRANITOID ROCKS (early Tertiary to late Cretaceous; 55 to 85 Ma.)	TKg	0.5%	2.3%	0.9%	8.4%	0.2%
GRANITOID ROCKS (Jurassic)	Jg	2.1%	3.9%	-	-	1.6%
GRANITOID ROCKS (early Proterozoic; 1400 Ma. Or 1650 to 1750Ma.)	Xg	-	-	0.7%	-	0.2%
GRANITOID ROCKS (middle Proterozoic; 1400 Ma.)	Yg	0.1%	0.3%	1.3%	5.5%	0.3%
METAMORPHIC ROCKS (early Proterozoic; 1650 to 1800 Ma.)	Xm	0.2%	-	0.8%	0.2%	0.2%
METASEDIMENTARY ROCKS (early Proterozoic; 1650 to 1800 Ma.)	Xms	-	-	0.3%	-	0.2%
OLDER SURFICIAL DEPOSITS (middle Pleistocene to latest Pliocene)	Qo	0.7%	4.0%	0.9%	3.5%	8.1%
PALEOZOIC ROCKS (undifferentiated)	Pz	0.2%	0.3%	-	1.1%	0.2%
SAN RAFAEL GROUP (late to middle Jurassic)	Js	-	-	-	-	-
SEDIMENTA1.6RY AND VOLCANIC ROCKS (Jurassic)	Jsv	0.7%	3.0%	-	0.2%	0.5%
SEDIMENTARY ROCKS (middle Miocene to Oligocene; 15 to 38 Ma.)	Tsm	0.3%	0.3%	-	1.6%	0.7%
SEDIMENTARY ROCKS (middle Proterozoic)	Ys	0.1%	-	0.1%	-	0.2%
SEDIMENTARY ROCKS (Mississippian to Cambrian)	MC	0.1%	-	-	0.4%	0.1%

Geologic Unit	Geologic Code	Aguirre Wash Tat Momoli Wash H15050305	Brawley Wash – Los Robles Wash H15050304	Lower Santa Cruz River H15050303	Pantano Wash – Rillito River H15050302	Santa Rosa Wash 15050306
SEDIMENTARY ROCKS (Permian and Pennsylvanian)	PP	-	-	-	1.3%	-
SEDIMENTARY ROCKS (Pliocene to middle Miocene)	Tsy	-	5.0%	-	10.7%	0.2%
SEDIMENTARY ROCKS WITH LOCAL VOLCANIC UNITS (Cretaceous to late Jurassic)	KJs	0.6%	3.1%	-	4.1%	0.6%
SUBVOLCANIC INTRUSIVE ROCKS (Middle Miocene to Oligocene)	Ti	-	0.2%	-	-	-
SURFICIAL DEPOSITS (Holocene to middle Pleistocene)	Q	62.4%	21.5%	66.6%	15.3%	57.2%
VOLCANIC ROCKS (Jurassic; locally latest Triassic)	Jv	1.8%	1.5%	-	0.8%	-
VOLCANIC ROCKS (late Cretaceous; early Tertiary near Safford)	Kv	1.0%	4.2%	0.4%	0.6%	8.7%
VOLCANIC ROCKS (middle Miocene to Oligocene; 15 to 38 Ma.)	Tv	28.8%	6.1%	8.1%	-	20.3%
YOUNG ALLUVIUM (Holocene to latest Pleistocene)	Qy		41.9%	19.0%	45.8%	-
Area (Sq. Miles)		*733*	*1,408*	*1,682*	*920*	*1,208*

*Data pertains to the U.S. Only.

*Table 2-11.1: Santa Cruz Watershed Geology (part 2 of 2).**

Geologic Unit	Geologic Code	Upper Santa Cruz River H15050301	Rio Asuncion H15080200
BASALTIC ROCKS (late to middle Miocene; 8 to 16 Ma.)	Tb	0.0%	-
GRANITIC ROCKS (early Tertiary to late Cretaceous; 45 to 75 Ma.)	TKgm	0.2%	14.7%
GRANITOID ROCKS (early Miocene to Oligocene; 18 to 38 Ma.)	Tg	1.0%	-

Geologic Unit	Geologic Code	Upper Santa Cruz River H15050301	Rio Asuncion H15080200
GRANITOID ROCKS (early Tertiary to late Cretaceous; 55 to 85 Ma.)	TKg	6.8%	-
GRANITOID ROCKS (Jurassic)	Jg	1.2%	1.6%
GRANITOID ROCKS (early Proterozoic; 1400 Ma. Or 1650 to 1750Ma.)	Xg	-	-
GRANITOID ROCKS (middle Proterozoic; 1400 Ma.)	Yg	1.4%	-
METAMORPHIC ROCKS (early Proterozoic; 1650 to 1800 Ma.)	Xm	0.0%	-
METASEDIMENTARY ROCKS (early Proterozoic; 1650 to 1800 Ma.)	Xms	0.0%	-
OLDER SURFICIAL DEPOSITS (middle Pleistocene to latest Pliocene)	Qo	4.4%	-
PALEOZOIC ROCKS (undifferentiated)	Pz	0.5%	-
SAN RAFAEL GROUP (late to middle Jurassic)	Js	0.0%	-
SEDIMENTA1.6RY AND VOLCANIC ROCKS (Jurassic)	Jsv	0.3%	1.4%
SEDIMENTARY ROCKS (middle Miocene to Oligocene; 15 to 38 Ma.)	Tsm	0.9%	0.8%
SEDIMENTARY ROCKS (middle Proterozoic)	Ys	0.3%	-
SEDIMENTARY ROCKS (Mississippian to Cambrian)	MC	0.1%	-
SEDIMENTARY ROCKS (Permian and Pennsylvanian)	PP	0.4%	-
SEDIMENTARY ROCKS (Pliocene to middle Miocene)	Tsy	13.3%	28.8%
SEDIMENTARY ROCKS WITH LOCAL VOLCANIC UNITS (Cretaceous to late Jurassic)	KJs	2.6%	1.2%

Geologic Unit	Geologic Code	Upper Santa Cruz River H15050301	Rio Asuncion H15080200
SUBVOLCANIC INTRUSIVE ROCKS (Middle Miocene to Oligocene)	Ti	-	-
SURFICIAL DEPOSITS (Holocene to middle Pleistocene)	Q	35.8%	-
VOLCANIC ROCKS (Jurassic; locally latest Triassic)	Jv	1.5%	13.5%
VOLCANIC ROCKS (late Cretaceous; early Tertiary near Safford)	Kv	2.9%	-
VOLCANIC ROCKS (middle Miocene to Oligocene; 15 to 38 Ma.)	Tv	3.3%	38.0%
YOUNG ALLUVIUM (Holocene to latest Pleistocene)	Qy	22.9%	-
Area (Sq. Miles)		*2,227*	*128*

*Data pertains to the U.S. Only.

*Table 2-11.2: Sonoyta Watershed Geology.**

Geologic Unit	Geologic Code	San Simon Wash H15080101	Rio Sonoyta H15080102	Tule Desert Area H15080103
BASALTIC ROCKS (Holocene to late Miocene; 0 to 4 Ma.)	QTb	-	-	0.8%
BASALTIC ROCKS (late to middle Miocene; 8 to 16 Ma.)	Tb	0.1%	-	0.1%
GRANITIC ROCKS (early Tertiary to late Cretaceous; 45 to 75 Ma.)	TKgm	1.5%	0.1%	3.8%
GRANITOID ROCKS (early Tertiary to late Cretaceous; 55 to 85 Ma.)	TKg	0.8%	0.1%	0.4%
GRANITOID ROCKS (Jurassic)	Jg	4.3%	0.6%	1.2%
GRANITOID ROCKS (middle Proterozoic; 1400 Ma. or 1650 to 1750 Ma.)	YXg	-	-	0.7%
GRANITOID ROCKS (middle to early Proterozoic; 1400 Ma.)	Yg	-	0.4%	0.7%
METAMORPHIC ROCKS (early Proterozoic; 1650 to 1800 Ma.)	Xm	-	0.1%	1.0%
OLDER SURFICIAL DEPOSITS (middle Pleistocene to latest Pliocene)	Qo	13.9%	10.0%	17.9%
SEDIMENTA1.6RY AND VOLCANIC ROCKS (Jurassic)	Jsv	2.1%	-	-
SEDIMENTARY ROCKS (middle Miocene to Oligocene; 15 to 38 Ma.)	Tsm	1.0%	-	-
SEDIMENTARY ROCKS (Pliocene to middle Miocene)	Tsy	0.8%	0.3%	-
SEDIMENTARY ROCKS WITH LOCAL VOLCANIC UNITS (Cretaceous to late Jurassic)	KJs	0.1%	-	-
SURFICIAL DEPOSITS (Holocene to middle Pleistocene)	Q	58.9%	83.3%	68.0%
VOLCANIC ROCKS (Jurassic; locally latest Triassic)	Jv	0.2%	0.4%	-

Geologic Unit	Geologic Code	San Simon Wash H15080101	Rio Sonoyta H15080102	Tule Desert Area H15080103
VOLCANIC ROCKS (middle Miocene to Oligocene; 15 to 38 Ma.)	Tv	16.3%	4.7%	5.3%
Area (Sq. Miles)		*2,154*	*424*	*497*

*Data pertains to the U.S. Only.

*Table 2-12.1: Santa Cruz Watershed Rock Types, percent by Subwatershed (part 1 of 2).**

Rock Type	Aguirre Wash Tat Momoli Wash H15050305	Brawley Wash – Los Robles Wash H15050304	Lower Santa Cruz River H15050303	Pantano Wash – Rillito River H15050302	Santa Rosa Wash 15050306
Basaltic and Volcanic Rocks	7.1%	11.9%	5.1%	2.5%	13.9%
Granitic Rocks	9.8%	13.5%	12.6%	37.5%	10.4%
Sedimentary Rocks	8.5%	18.7%	0.5%	42.2%	11.1%
Surficial Deposits	61.8%	55.7%	55.7%	14.2%	56.7%
Young Alluvium	12.8%	0.17%	25.2%	3.6%	7.9%
Area (sq. miles)	*733*	*1,408*	*1,682*	*920*	*1,208*

*Data pertains to the U.S. Only.

*Table 2-12.1: Santa Cruz Watershed Rock Types, percent by Subwatershed (part 2 of 2).**

Rock Type	Upper Santa Cruz River H15050301	Rio Asuncion H15080200
Basaltic and Volcanic Rocks	18.2%	42.0%
Granitic Rocks	16.3%	21.8%
Sedimentary Rocks	26.4%	36.5%
Surficial Deposits	34.0%	-
Young Alluvium	5.1%	-
Area (sq. miles)	*2,227*	*128*

*Data pertains to the U.S. Only.

Table 2-12.2: Rio Sonoyta Watershed Rock Types, percent by Subwatershed.

Rock Type	San Simon Wash H15080101	Rio Sonoyta H15080102	Tule Desert Area H15080103
Basaltic and Volcanic Rocks	10.8%	30.9%	16.2%
Granitic Rocks	8.6%	14.3%	25.2%

Rock Type	San Simon Wash H15080101	Rio Sonoyta H15080102	Tule Desert Area H15080103
Sedimentary Rocks	5.3%	4.9	-
Surficial Deposits	75.4%	49.9%	58.7%
Area (sq. miles)	*2,154*	*424*	*497*

Data pertains to the U.S. Only.

Soils

Based on the soil characteristics for the Santa Cruz Watershed two types of maps were created: a soil texture map (Figure 2-22.1 and Figure 2-22.2) and a soil erodibility map (Figure 2-23.1 and Figure 2-23.2). Soil erodibility is generated from the soil texture characteristics.
There are 18 different soil textures in the Santa Cruz Watershed, 4 different textures for the Rio Asuncion, and 12 different textures for the Rio Sonoyta (Table 2-13.1 and Table 2-13.2). Loam is the most common soil texture in the Santa Cruz Watershed, covering 21% of the watershed. Unweathered Bedrock and Extremely Gravelly Fine Sandy Loam are the most common soil textures in the Rio Asuncion and Rio Sonoyta, covering 55.5% and 33.3% of the watersheds, respectively.

Soil erosion is a naturally occurring process. However, accelerated erosion occurs when soils are disturbed by agriculture, mining, construction, or when natural ground cover is removed and the soil is left unprotected. Erosion and sedimentation in streams are major environmental problems in the western United States.

Soils differ in their susceptibility to disturbance by water due to different inherent physical, chemical and mineralogical properties. Properties known to affect erodibility include particle size distribution, organic matter content, soil structure, texture, moisture content, vegetation cover, and precipitation amount and intensity.

Erosion caused by precipitation and running water and the factors affecting soil loss have been summarized in the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978). The USLE is a model for predicting long-term average soil losses based in part on factors of slope and erosive energy. It has been revised to reflect updates in the calculations, and additional analysis of the research data, and is now referred to as the Revised Universal Soil Loss Equation, or RUSLE.

Within the RUSLE equation, the Soil Erodibility Factor (K) represents the rate of soil loss per rainfall erosion index unit. Soil erodibility can be thought of as the ease with which soil is detached by splash during rainfall or by surface flow or both. It is estimated in the units of mass per unit area, or tons per acre per year, and is based on soil texture, with a range of values between 0.0 (no erosion potential) to 1.0 (USDA, 1997). Tables 2-14.1 and 2-

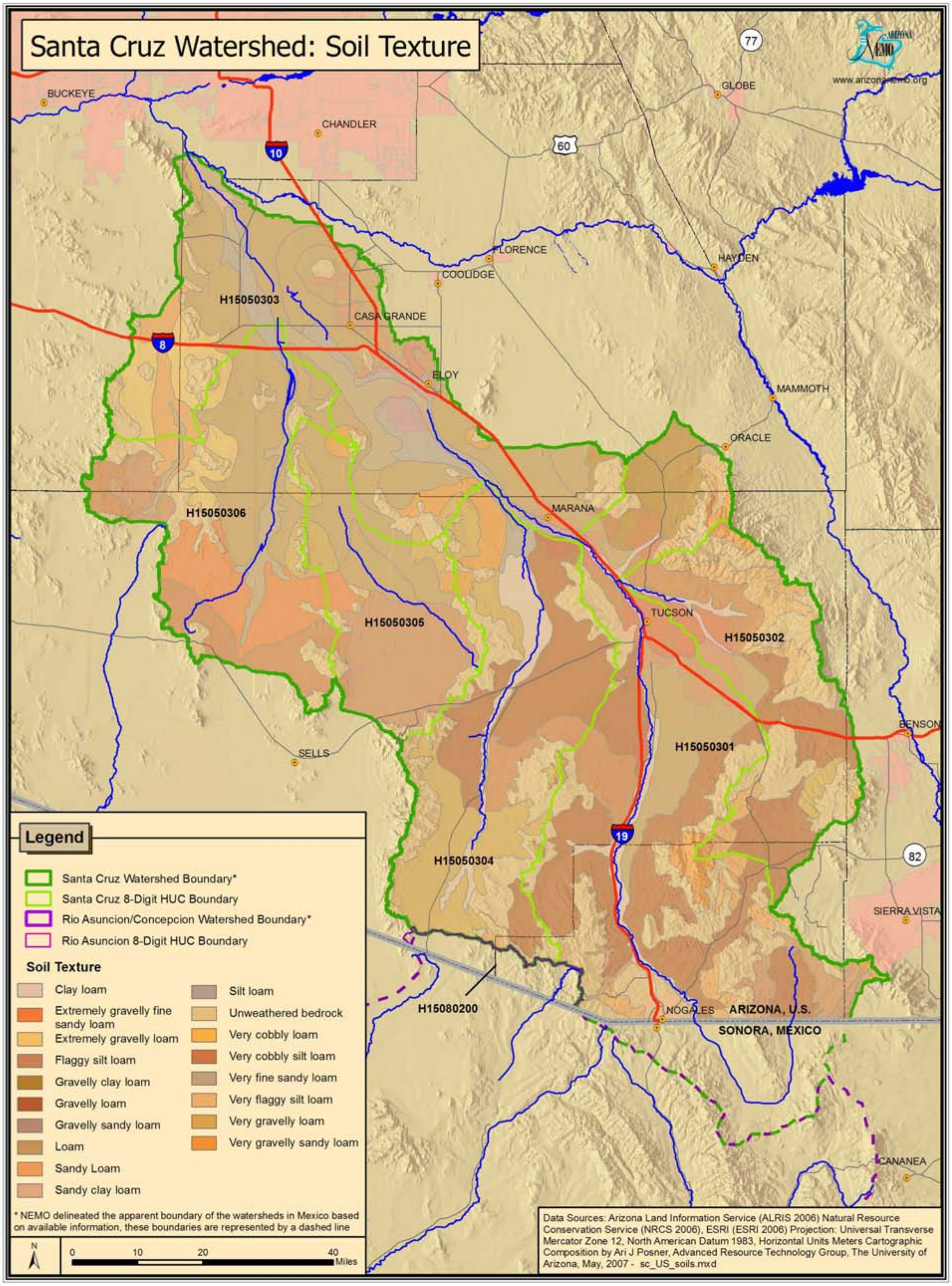

Figure 2-22.1: Santa Cruz Watershed Soil Texture

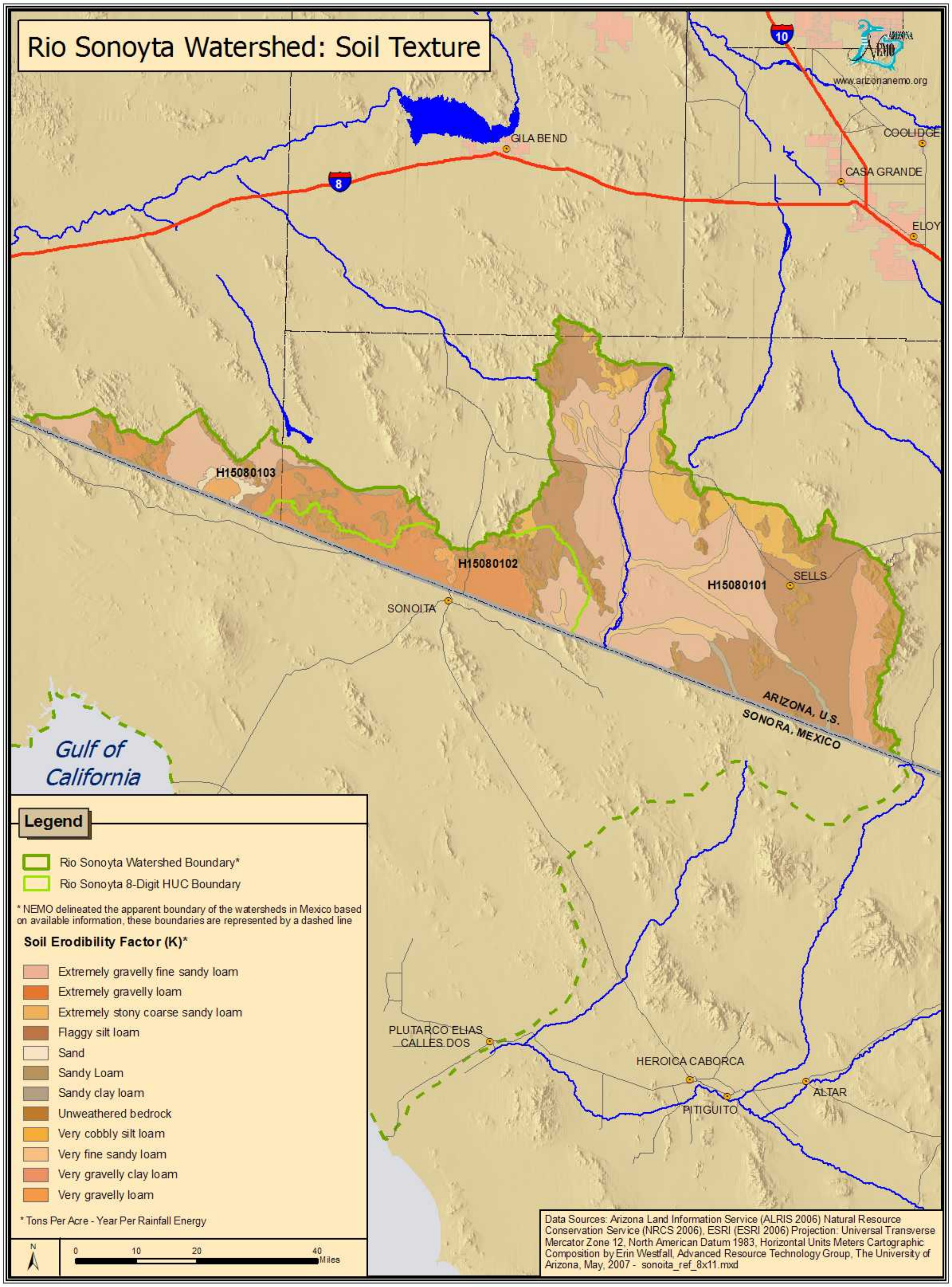

Figure 2-22.2: Rio Sonoyta Watershed Soil Texture

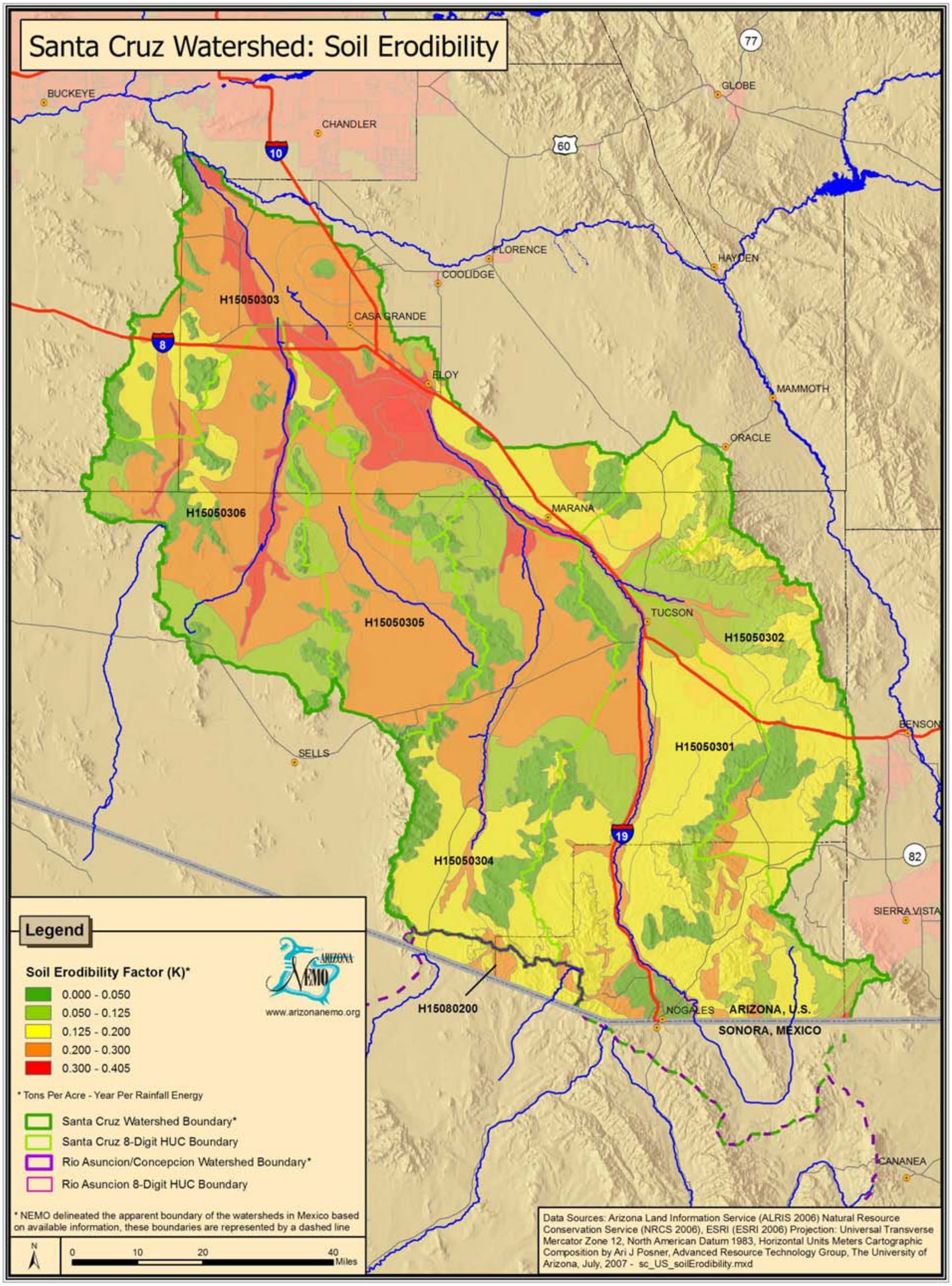

Figure 2-23.1: Santa Cruz Watershed Soil Erodiblity

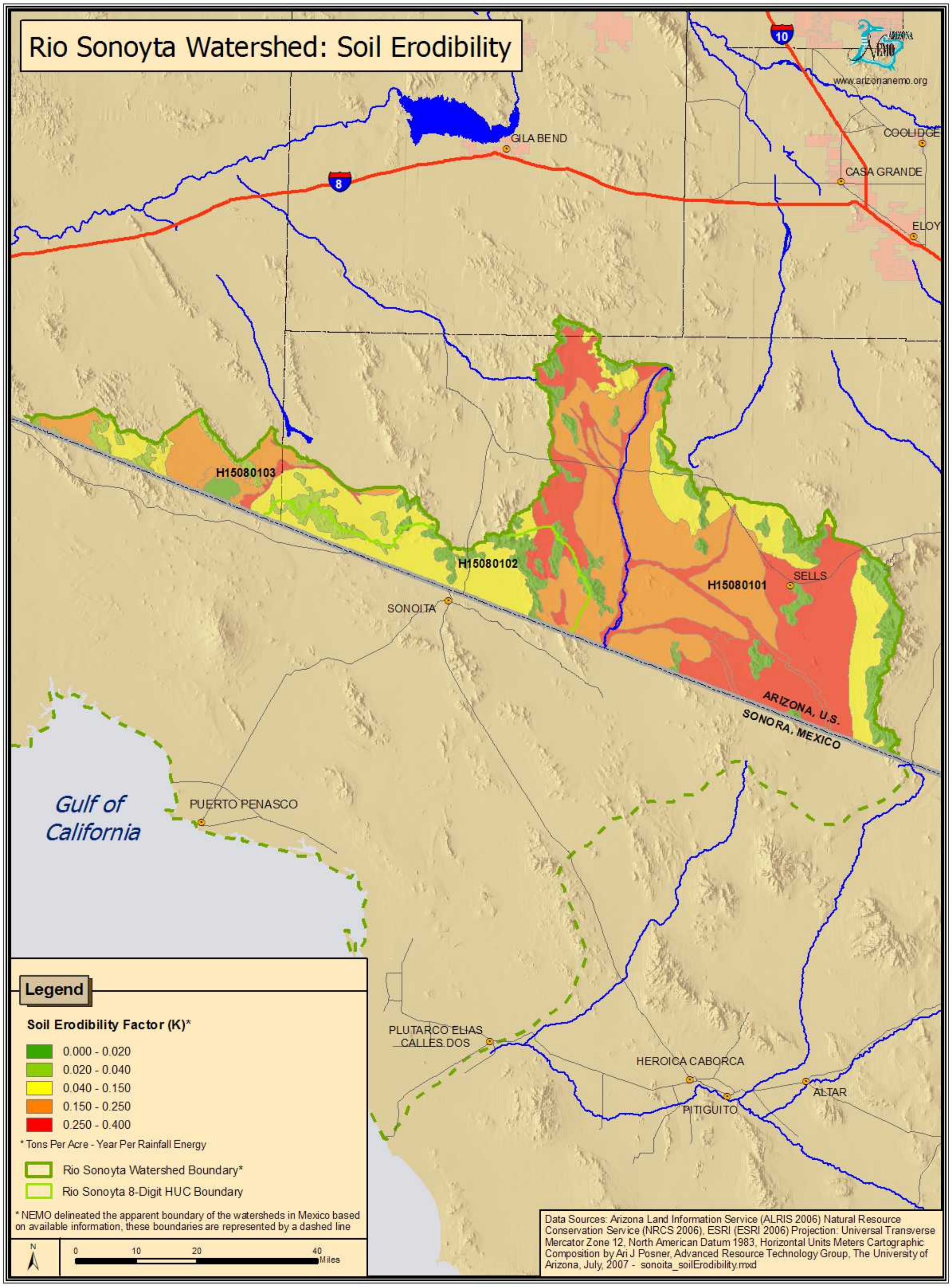

Figure 2-23.2: Rio Sonoyta Watershed Soil Erodibility

14.2 show these values for each subwatershed.

The Upper Santa Cruz River and the Lower Santa Cruz River subwatersheds had the highest weighted average Soil Erodibility Factors, with K = 0.148 and 0.146 respectively. The Aguirre Wash-Tat Momoli Wash subwatershed had the lowest weighted mean K at 0.084. The weighted average K for the whole Santa Cruz Watershed is 0.114. The Rio Asuncion watershed had a weighted average of 0.178, while the Rio Sonoyta Watershed weighted average was 0.183.

Table 2-13.1: Santa Cruz Watershed Soil Texture – Percent by Subwatershed (part 1 of 2).*

Soil Texture	**Aguirre Wash Tat Momoli Wash H15050305**	**Brawley Wash Los Robles Wash H15050304**	**Lower Santa Cruz River H15050303**	**Pantano Wash Rillito River H15050302**	**Santa Rosa Wash H15050306**
Clay Loam	-	3.9%	2.4%	5.5%	-
Extremely Gravelly Fine Sandy Loam	18.1%	-	-	-	11.5%
Extremely Gravelly Loam	-	-	12.5%	-	20.9%
Flaggy silt loam	24.8%	18.7%	2.7%	-	1.8%
Gravelly clay loam	-		13.0%	-	-
Gravelly loam	-	20.7%	5.8%	39.4%	-
Gravelly sandy loam	-	-	-	0.6%	-
Loam	12.6%	-	36.1%	12.1%	27.2%
Sandy Clay Loam	-	-	1.7%	-	-
Sandy Loam	-	1.2%	2.0%	2.6%	3.2%
Silt Loam	-	5.1%	3.7%	-	1.5%
Unweathered bedrock	16.2%	22.6%	11.8%	21.4%	15.7%
Very cobbly loam			-	0.5%	
Very cobbly silt loam	12.7%	5.1%	-	7.5%	10.0%
Very Fine Sandy Loam	9.0%	6.8%	4.8%	-	6.1%
Very flaggy silt loam	-	-	-	5.8%	-
Very gravelly loam	5.3%	13.1%	1.7%	1.0%	1.7%
Very gravelly sandy loam	1.4%	3.0%	1.7%	3.5%	0.4%

*Data pertains to the U.S. portion of the watershed only.

Table 2-13.1: Santa Cruz Watershed Soil Texture – Percent by Subwatershed (part 2 of 2).*

Soil Texture	**Upper Santa Cruz River H15050301**	***Santa Cruz River Watershed***	**Rio Asuncion H15080200**	***Rio Asuncion Watershed***
Clay Loam	2.5%	*3.4%*	-	-
Extremely Gravelly Fine Sandy Loam	-	*3.0%*	-	-
Extremely Gravelly Loam	-	*2.3%*	-	-
Flaggy silt loam	3.0%	*6.0%*	0.4%	*0.4%*
Gravelly clay loam	13.8%	*2.4%*	-	-
Gravelly loam	29.3%	*15.9%*	-	-
Gravelly sandy loam	2.8%	*0.1%*	-	-
Loam	10.1%	*21.0%*	-	-
Sandy Clay Loam	-	*0.2%*	-	-
Sandy Loam	2.2%	*3.0%*	6.4%	*6.4%*
Silt Loam	1.9%	*2.8%*	-	-

Soil Texture	Upper Santa Cruz River H15050301	*Santa Cruz River Watershed*	Rio Asuncion H15080200	*Rio Asuncion Watershed*
Unweathered bedrock	20.7%	*18.7%*	55.5%	*55.5%*
Very cobbly loam	0.1%	*0.2%*	-	-
Very cobbly silt loam	6.8%	*7.4%*	-	-
Very Fine Sandy Loam	-	*3.2%*	-	-
Very flaggy silt loam	2.6%	*1.2%*	-	-
Very gravelly loam	1.5%	*6.1%*	37.7%	*37.7%*
Very gravelly sandy loam	2.6%	*2.6%*	-	-

*Data pertains to the U.S. portion of the watershed only.

*Table 2-13.2: Rio Sonoyta Watershed Soil Texture – Percent by Subwatershed**

Soil Texture	San Simon Wash H15080101	Rio Sonoyta H15080102	Tule Desert Area H15080103	*Rio Sonoyta Watershed*
Extremely Gravelly Fine Sandy Loam	29.4%	21.7%	32.0%	*33.3%*
Extremely Gravelly Loam	-	47.6%	18.8%	*12.5%*
Flaggy silt loam	29.2%	13.2%	2.7%	*22.0%*
Sandy Clay Loam	0.6%	-	-	*0.6%*
Sandy Loam	-	-	35.8%	*0.2%*
Unweathered bedrock	22.7%	13.5%	9.6%	*15%*
Very cobbly silt loam	11.4%	2.6%		*6.3%*
Very Fine Sandy Loam	3.6%	0.5%		*4.7%*
Very gravelly loam		0.8%	0.5%	*0.9%*
Very Gravelly Clay Loam	3.0%	-	-	*3.6%*
Extremely Stony Coarse Sandy Loam	0.3%	-	-	*0.3%*
Sand	-	-	0.5%	*0.7%*

*Data pertains to the U.S. portion of the watershed only.

*Table 2-14.1: Santa Cruz Watershed Soil Erodibility Factor K.**

Subwatershed Name	Min K	Max K	Weighted Average
Upper Santa Cruz River 15050301	0.0	0.405	0.148
Pantano Wash-Rillito River 15050302	0.0	0.235	0.128
Lower Santa Cruz River 15050303	0.0	0.405	0.146
Brawley Wash-Los Robles Wash 15050304	0.0	0.405	0.138
Aguirre Wash-Tat Momoli Wash 15050305	0.0	0.318	0.084
Santa Rosa Wash 15050306	0.0	0.405	0.114
Santa Cruz Watershed	*0.0*	*0.405*	*0.114*
Rio Asuncion H15080200	0.0	0.256	0.178
Rio Asuncion Watershed	*0.0*	*0.256*	*0.178*

The K factor is derived from the Revised Universal Soil Loss Equation (RUSLE) (USDA, 1997).
*Data pertains to the U.S. portion of the watershed only.

*Table 2-14.2: Rio Sonoyta Watershed Soil Erodibility Factor K.**

Subwatershed Name	Min K	Max K	Weighted Average
San Simon Wash H15080101	0.0	0.338	0.202
Rio Sonoyta H15080102	0.013	0.318	0.110
Tule Desert Area H15080103	0.013	0.264	0.140
Rio Sonoyta Watershed	*0.0*	*0.338*	*0.183*

The K factor is derived from the Revised Universal Soil Loss Equation (RUSLE) (USDA, 1997).
*Data pertains to the U.S. portion of the watershed only.

Climate

Precipitation

Nineteen weather stations in the Santa Cruz Watershed and two stations in the Rio Sonoyta Watershed were used for watershed modeling (Tables 2-15.1 and 2-15.2) because of consistency and duration of the data. No stations in the Rio Asuncion Watershed were used for modeling. Meterological station locations and distribution of precipitation over the watershed are shown in Figure 2-24.1 and Figure 2-25.2.

Based on the 30 years (1961-1990) of precipitation data used in this report, the average annual precipitation is 14 inches for the Santa Cruz Watershed (Table 2-16.1 and Figure 2-24.1), 19 inches for the Rio Asuncion Watershed, and 11 inches for the Rio Sonoyta Watershed (Table 2-16.2 and Figure 2-25.2). For the Santa Cruz Watershed, Pantano Wash Rillito River Subwatershed receives the most annual

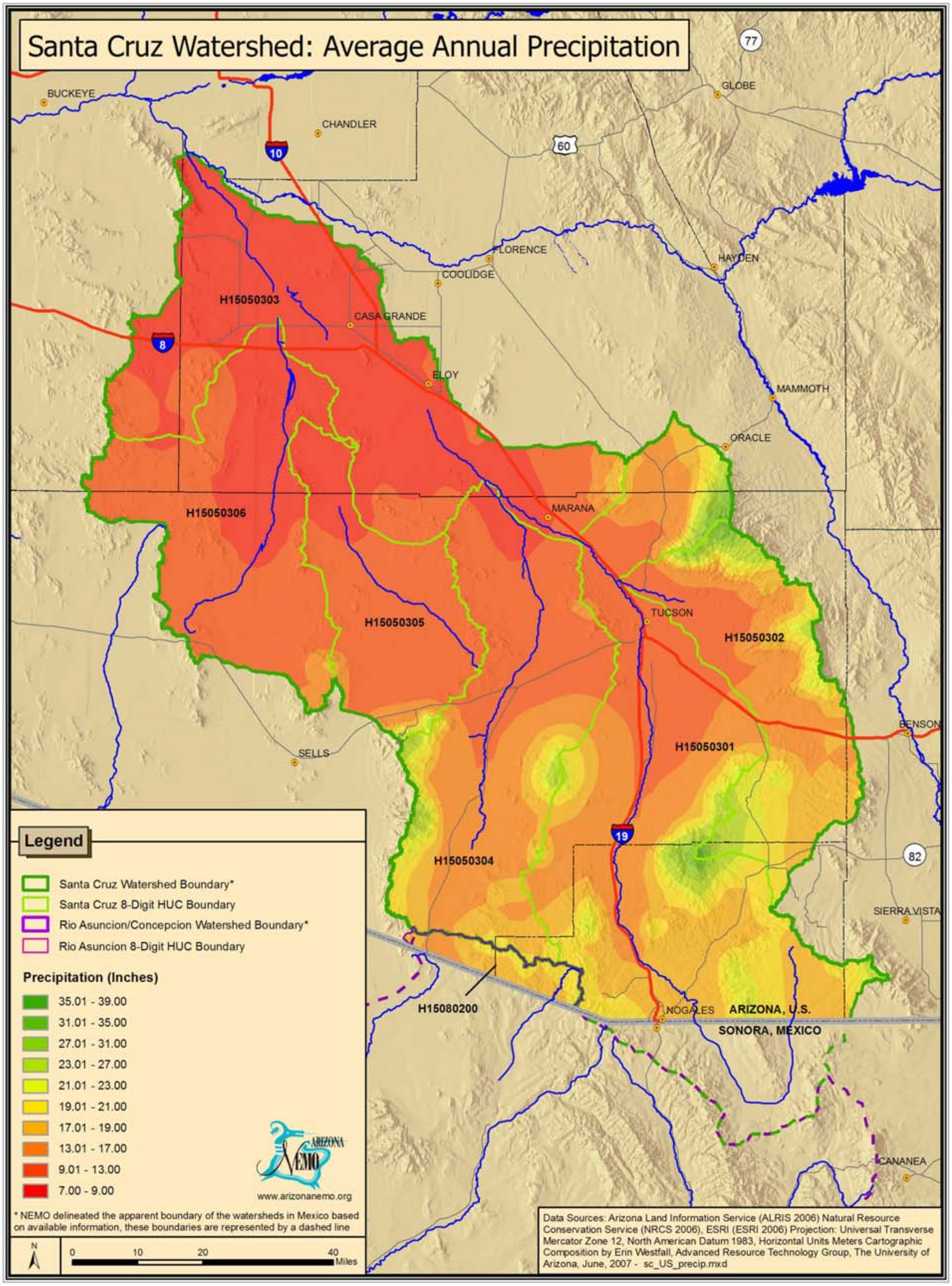

Figure 2-24.1: Santa Cruz Watershed Average Annual Precipitation

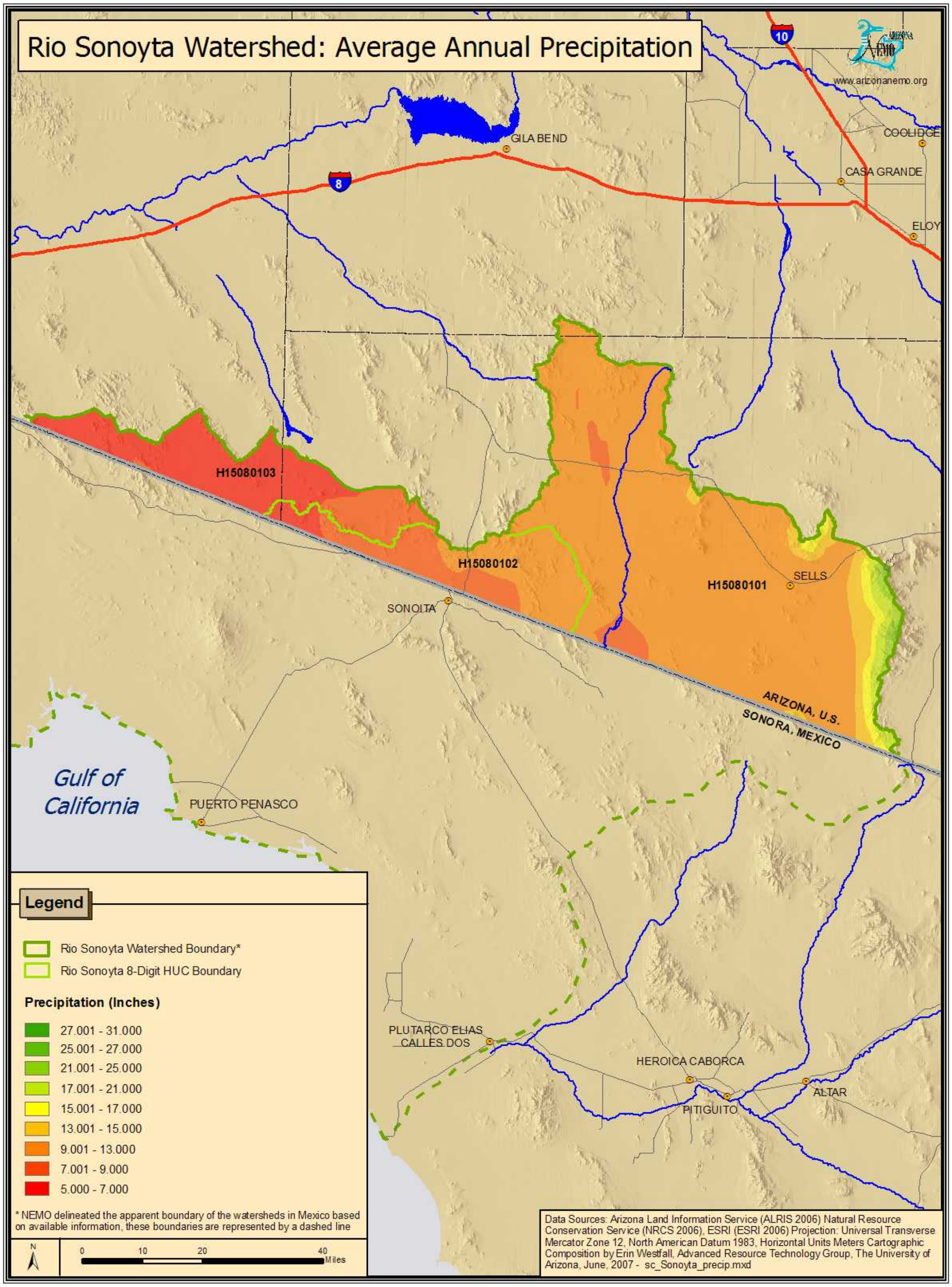

Figure 2-24.2: Rio Sonoyta Watershed Average Annual Precipitation

rainfall with 19 inches, while the Lower Santa Cruz River Subwatershed receives the least annual rainfall with only 10 inches. In the Rio Sonoyta Watershed, San Simon Wash Subwatershed has the highest annual rainfall with 12 inches, while Tule Desert Subwatershed has the least annual rainfall with 7 inches.

Table 2-15.1: Santa Cruz Watershed Summary of Temperature Data for 19 Weather Stations with Sufficient Data.*

ID	Gage	Average Annual Max. Temperature (F)	Average Annual Min Temperature (F)	Average Annual Temperature (F)
020287-7	ANVIL RANCH	83.5	48.9	66.2
021306-6	CASA GRANDE	87.1	53.3	70.2
022159-7	CORTARO 3 SW	85.7	51.5	68.6
022807-6	ELOY	86.8	53.8	70.3
024675-7	KITT PEAK	64.4	45.9	55.2
025270-6	MARICOPA 4 N	86.9	52.7	69.8
025921-7	NOGALES	79.0	42.0	60.5
025924-7	NOGALES 6 N	79.6	42.8	61.2
025922-W	NOGALES OLD NOGALES	79.7	45.9	62.8
027058-6	RED ROCK 6 SW	85.1	52.8	69.0
027355-7	SABINO CANYON	84.6	53.0	68.8
027403-7	SAHUARITA 2 NW	84.7	48.1	66.4
027555-7	SAN RAFAEL RANCH	76.1	38.8	57.5
027593-7	SANTA RITA EXPERMENT RA	76.4	51.9	64.15
028796-7	TUCSON CAMP AVE EXP FM	84.2	50.4	67.3
028800-7	TUCSON MAGNETIC OBSY	83.3	50.4	66.9
028817-7	TUCSON U OF ARIZ # 1	85.0	54.1	69.6
028820-7	TUCSON WSO AIRPORT	82.6	54.8	68.7
028865-7	TUMACACORI NATL MONUMENT	81.9	46.3	64.1

*Data pertains to the U.S. portion of the watershed only.
http://www.wrcc.dri.edu/summary/climsmaz.html

Table 2-15.2: Rio Sonoyta Watershed Summary of Temperature Data for 2 Weather Stations with Sufficient Data.*

ID	Gage	Average Annual Max. Temperature (F)	Average Annual Min Temperature (F)	Average Annual Temperature (F)
026132-7	ORGAN PIPE CACTUS N M	86.0	54.1	70.1
027726-7	SELLS	84.3	52.9	68.6

*Data pertains to the U.S. portion of the watershed only.
http://www.wrcc.dri.edu/summary/climsmaz.html

Table 2-16.1: Santa Cruz Watershed Average Annual Precipitation (in/yr)

Subwatershed Name	Min (in/yr)	Max (in/yr)	Weighted Average
Aguirre Wash Tat Momoli Wash H15050305	9	29	12
Brawley Wash Los Robles Wash H15050304	9	31	15
Lower Santa Cruz River H15050303	7	21	10
Pantano Wash Rillito River H15050302	11	39	19
Santa Rosa Wash H15050306	9	21	11
Upper Santa Cruz River H15050301	11	37	18
Santa Cruz River Watershed	*7*	*39*	*14*
Rio Asuncion H15080200	17	21	19
Rio Asuncion H15080200	*17*	*21*	*19*

Water and Climage Center of the NRCS 1998
*Data pertains to the U.S. portion of the watershed only.

Table 2-16.2: Rio Sonoyta Watershed Average Annual Precipitation (in/yr)

Subwatershed Name	Min (in/yr)	Max (in/yr)	Weighted Average
Rio Sonoyta H15080102	5	15	10
San Simon Wash H15080101	9	31	12
Tule Desert H15080103	5	9	7
Rio Sonoyta Watershed	*5*	*31*	*11*

Water and Climage Center of the NRCS 1998
*Data pertains to the U.S. portion of the watershed only.

Temperature

Weather stations for the Santa Cruz Watershed are shown in Figures 2-25.1 and 2-25.2. For the 30 years (1961 – 1990) of temperature data, the average annual temperature for the Santa Cruz Watershed is 66° Fahrenheit (Table 2-17.1). The Rio Asuncion Watershed has an average temperature of 63° Fahrenheit, and the average temperature for the Rio Sonoyta Watershed is 68° Fahrenheit (Table 2-17.2). Figure 2-26.1 and Figure 2-26.2 map the temperature ranges for each sub-watershed.

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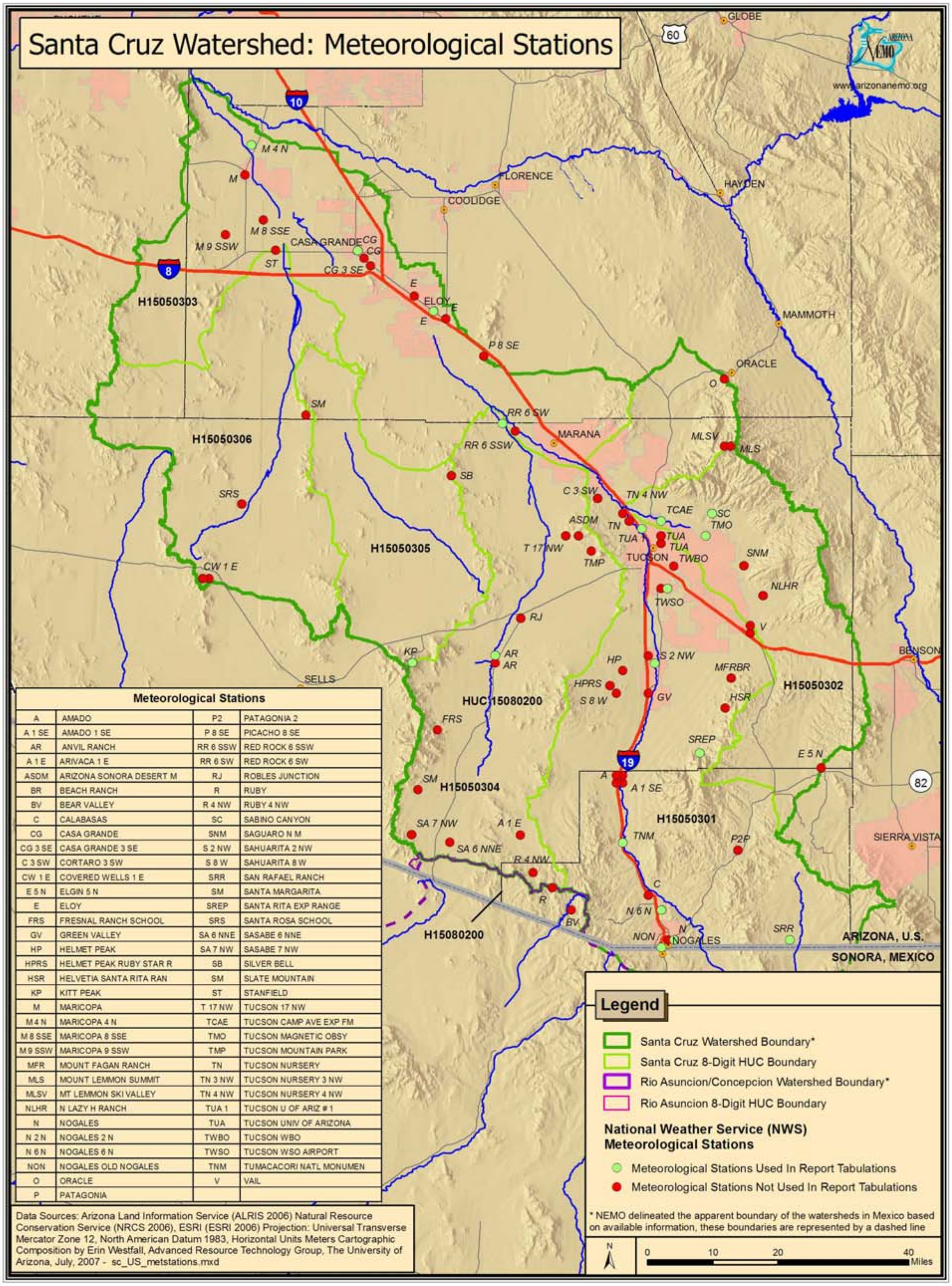

Figure 2-25.1: Santa Cruz Watershed Meteorological Stations

Figure 2-25.2: Rio Sonoyta Watershed Meteorological Stations

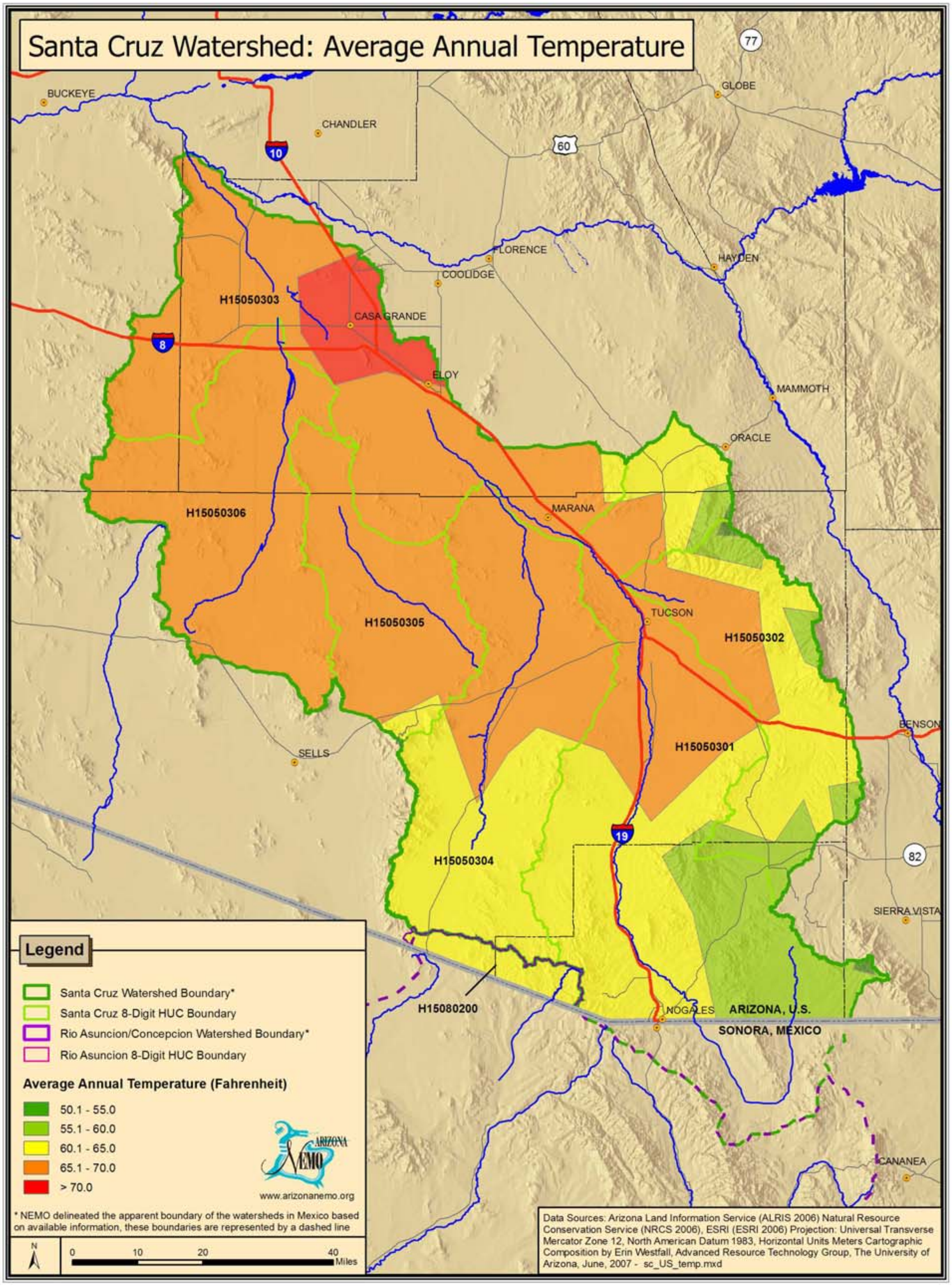

Figure 2-26.1: Santa Cruz Watershed Average Annual Temperature

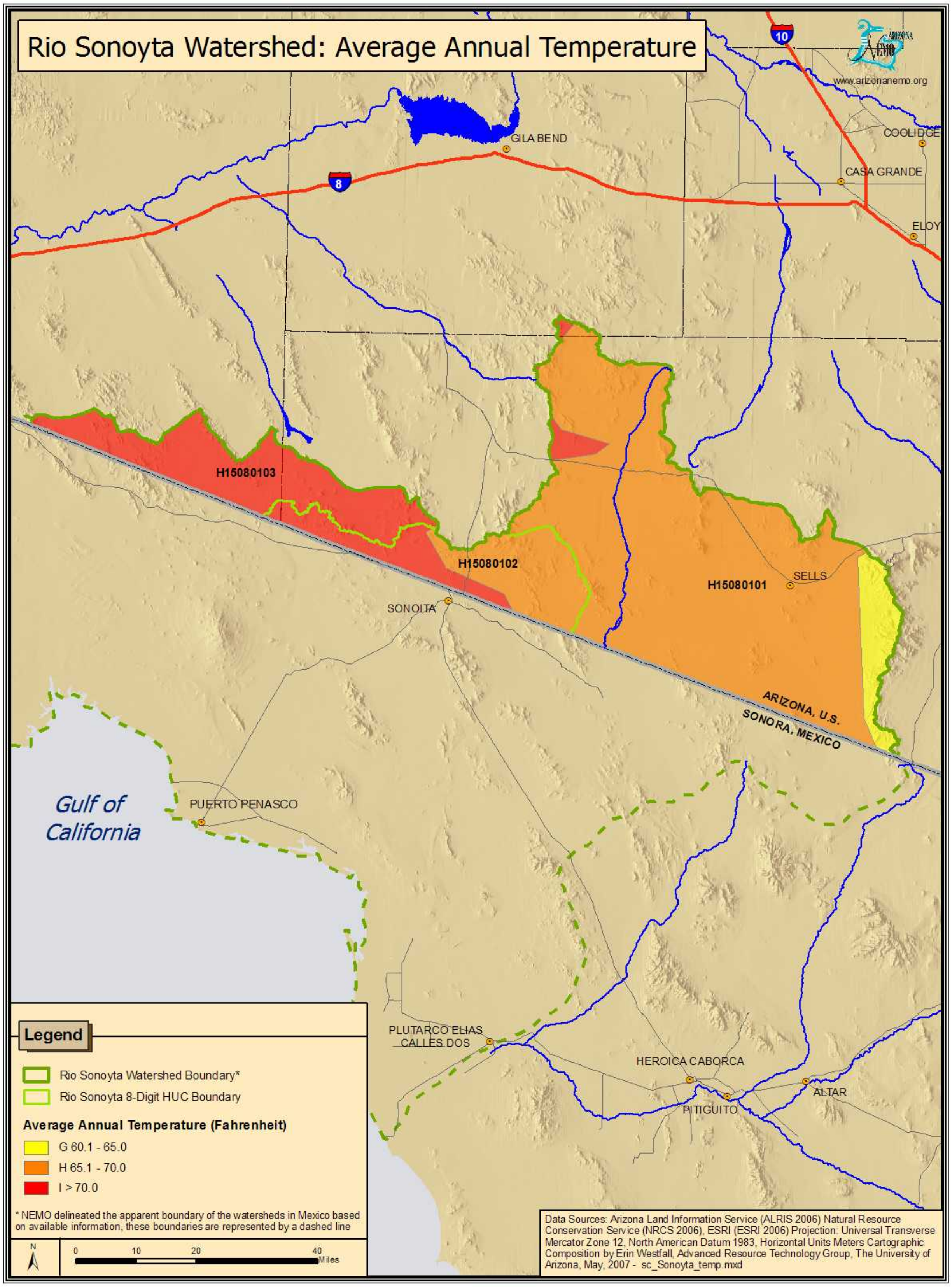

Figure 2-26.2: Rio Sonoyta Watershed Average Annual Temperature

Table 2-17.1: Santa Cruz Watershed Average Annual Temperature (ºF).*

Subwatershed	Avg Annual Temp (ºF)
Aguirre Wash Tat Momoli Wash H15050305	68
Brawley Wash Los Robles Wash H15050304	66
Lower Santa Cruz River H15050303	68
Pantano Wash Rillito River H15050302	63
Santa Rosa Wash H15050306	68
Upper Santa Cruz River H15050301	63
Santa Cruz River Watershed	*66*
Rio Asuncion H15080200	63
Rio Asuncion Watershed	*63*

(NOAA, 2003)
**Data pertains to the U.S. portion of the watershed only.*

Table 2-17.2: Rio Sonoyta Watershed Average Annual Temperature (ºF).*

Subwatershed	Avg Annual Temp (ºF)
Rio Sonoyta H15080102	69
San Simon Wash H15080101	68
Tule Desert Area H15080103	70
Rio Sonoyta Watershed	*68*

(NOAA, 2003)
**Data pertains to the U.S. portion of the watershed only.*

References:

Arizona Department of Environmental Quality. 2007. Antidegradation Implementation Procedures, Draft, http://www.azdeq.gov/environ/water/standards/download/antideg.pdf.

Arizona Department of Environmental Quality. 2007. Water Quality Improvement Grant Manual, http://www.azdeq.gov/environ/water/watershed/download/manual.pdf

Arizona Department of Environmental Quality. 2006. The Status of Water Quality in Arizona (Draft). Arizona Department of Environmental Quality. Phoenix, Arizona.

Arizona Department of Environmental Quality. 2002. The Status of Water Quality in Arizona). Arizona Department of Environmental Quality. Phoenix, Arizona.

Arizona Department of Water Resources (ADWR). 1997. A Guide to Filing Applications for Instream Flow Water Rights in Arizona. http://www.azwater.gov/dwr/Content/Find_by_Program/Hydrology/files/ISF_Guidelines_and_App.pdf

Arizona Department of Water Resources (ADWR). Pinal Active Management Area. www.azwater.gov/WaterManagement_2005/Content/AMAs/PinalAMA/default.htm Website accessed July 16, 2007.

Arizona Department of Water Resources (ADWR). Tucson Active Management Area. www.azwater.gov/WaterManagement_2005/Content/AMAs/TucsonAMA/default.htm Website accessed July 16, 2007.

Arizona Department of Water Resources (ADWR). Santa Cruz Active Management Area. www.azwater.gov/WaterManagement_2005/Content/AMAs/SantacruzAMA/default.htm Website accessed July 16, 2007.

ADWR.1999. Third Management Plan for the Santa Cruz Active Management Area, 2000-2010 http://www.azwater.gov/dwr/content/Publications/files/ThirdMgmtPlan/tmpfinal/default.htm#Santa

City of Tucson Webpage, http://www.tucsonaz.gov/planning/data/tucsonupdate/tudocs/population.html#

Pima Association of Governments (PAG), Clearwater Renewable Resource Facility Stable Isotope Study, 2004, Pima Association of Governments.

Coes, Alissa and D.J. Gellenbeck, Douglas C. Towne, and Maureen C. Freark. Ground-water quality in the Upper Santa Cruz Basin, Arizona, 1998. USGS Water-Resources Investigations Report 00-4117

Dunne, T. and L.B. Leopold. 1978. Water in Environmental Planning. W.H. Freeman and Company, New York.

Gordon, N.D., T.A. McMahon, and B.L. Finlayson. 1992. Stream Hydrology; Chapter 4 - Getting to know your stream. John Wiley & Sons, New York, New York.

USDA. 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). United States Department of Agriculture, Agriculture Handbook No. 703. USDA Washington D.C.

Wischmeier, W.H., and D.D. Smith. 1978. Predicting Rainfall-Erosion Losses. Agricultural Handbook No. 537. USDA SEA Washington, D.C.

Woodhouse, B., M.E. Flynn, J.T.C. Parker, and J.P. Hoffmann. 2002. Investigation of the Geology and Hydrology of the Upper and Middle Agua Fria River Watershed of Central Arizona: A Project of the Arizona Rural Watershed Initiative: U.S. Geological Survey Fact-Sheet 059-02, 4p.

Data Sources:*

Arizona State Land Department, Arizona Land Resource Information System (ALRIS), http://www.land.state.az.us/alris/index.html
Arizona State Boundary map. June 12, 2003.
Geology map. February 7, 2003.
Lakes and Reservoirs map. February 7, 2003.
Streams map. October, 10, 2002.

Chronic, Halka. 1983. Roadside Geology of Arizona. Mountain Press Publishing Company, Montana.

United States Department of Agriculture, Natural Resources Conservation Service, http://www.ncgc.nrcs.usda.gov/products/datasets/climate/data/
PRISM Precipitation Map. February 26, 2003.

United States Department of Agriculture, Natural Resources Conservation Service, http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/
State Soil Geographic Database (STATSGO) Soils map. April 17, 2003.

United States Department of Agriculture. 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). United States Department of Agriculture, Agriculture Handbook No. 703. USDA Washington D.C.

United States Department of the Interior, U.S. Geological Survey, National Elevation Dataset (NED), http://edc.usgs.gov/geodata/
30-Meter Digital Elevation Models (DEMs). April 8, 2003.

University of Arizona, Arizona Electronic Atlas. http://atlas.library.arizona.edu/atlas/index.jsp?theme=NaturalResources.Temperature map. February 13, 2003.

Western Regional Climate Center (WRCC). http://www.wrcc.dri.edu/summary/climsmaz.html, (1971-2000). Temperature data. July 15, 2004.

**Note: Dates for each data set refer to when data was downloaded from the website. Metadata (information about how and when the GIS data were created) is available from the website in most cases. Metadata includes the original source of the data, when it was created, its geographic projection and scale, the name(s) of the contact person and/or organization, and general description of the data.*

Background Information

Ambrust, Beth (and Rick Brusca), 2005, Inventory of Aquatic Invertebrates in the Santa Cruz River: Report for Tumacacori National Historic Park. Arizona-Sonoran Desert Museum, Tucson, Arizona.

Anning, David, 2003, Assessment of Selected Inorganic Constituents in Streams in the Central Arizona Basins Study Area, Arizona and Northern Mexico, through 1998.

Arizona Department of Environmental Quality, 1995, Upper Santa Cruz River Intensive Survey: A Volunteer Driven Study fo the Water Quality and Biology of an Effluent Dominated Desert Grassland Stream in Southeast Arizona, pp. 66.

Arizona Department of Environmental Quality, Occurrence of Enteric Pathogens in Surface Water of the Santa Cruz River Basin, Results from the ADEQ/ADHS Surveillance Parasite and Virus Monitoring Program, September 1990 through June 1991

Arizona Department of Environmental Quality, Sixth Periodic Data Report of the ADEQ Fixed Station Network for Monitoring Surface Water Quality, January – September, 1989, Point Source and Monitoring Unit, Water Assessment Section, ADEQ, December 1991.

Arizona Department of Environmental Quality, Groundwater Quality Conditions in the Upper Santa Cruz Valley, 1997, OFR-07.

Arizona Department of Environmental Quality, *Arizona's 2006 Not Attaining Waters (Draft)*, Arizona Department of Environmental Quality, Phoenix, Arizona.

Arizona Department of Environmental Quality, *Arizona's 2006 303(d) Impaired Waters (Draft)*, Arizona Department of Environmental Quality, Phoenix, Arizona.

Arizona Department of Environmental Quality, 2006, *Santa Cruz River Watershed*, Chapter 2 in 2006 Status of Water Quality in Arizona (Draft), Arizona Department of Environmental Quality, Phoenix, Arizona.

Balluz, Lina, Rosanne Philen, Cathy Mausbaugh, John Brock, Dana Barr, Stepahnie Kieszak, Norman Peterson, Cecilia Rosales, Luis Ortega, Bridget Walsh, and Oscar Gluck, Investigation of Systemic Lupus Erythematosus, Nogales, Arizona, Centers for Disease Control and Prevention and Arizona Department of Health Services, November 14, 2000.

Barnes, Kimberlee, Dana Kolpin, Michael, Meyer, Michael Thurman, Edward Furlong, Steven Zaugg, and Larry Barber, 2002, Water Quality Data for Pharmaceuticals, Hormones, and Other Organic Wastewater Contaminants in the U.S. Streams, 1999-2000, USGS Open File Report 02-94.
Arizona Department of Environmental Quality, NIWTP Data (Quarterly Reports), April 2006- March 2007

Hansen, Homer, 2005, *Surface Water Quality Sample Collection & Analysis,* Aplomado Environmental, LLC, October 19.

International Boundary and Water Commission, NIWTP raw data from the IBWC (Monthly Reports), Jan. 2005-Feb. 2007.

King, Kirke A., and Brenda J. Andrews, 1997, *Environmental Contaminants in Ducks Collected From Wastewater Treatment Plant Ponds, Nogales*, Arizona 1996, U.S. Fish and Wildlife Service, Region 2, Contaminants Program, 13 pp.

King, Kirke A., Brenda J. Zaun, and Anthony L. Velasco, 1999, *Contaminants as a Limitig Factor of Fish and Wildlife Populations in the Santa Cruz River, Arizona*, U.S. Fish and Wildlife Service, Region 2, Contaminants Program, 57 pp.

Kolpin, Dana, Edward Furlong, Michael Meyer, Michael Thurman, Steven Zaugg, and Larry Barber, Herbert Buxton, 2002, Pharmaceuticals, Hormones, and Other Organic Wastewater Contaminants in U.S. Streams, 1999-2000: A National Reconnaissance, Environmental Science & Technology, Vol. 36, No. 6, 1202-1211.

National Park Service, 2003, *Baseline Water Quality Data, Inventory and Analysis, Tumacacori National Historical Park*, Water Resources Division and Servicewide Inventory and Monitoring Program, Nation Park Service, Technical Report NPS/NRWRD/NRTR-2001/284, 545 pp.

Patten, Duncan, Juliet Stromberg, and Milton Sommerfeld, 1993, Water and Riparian Resources of the Santa Cruz River Basin: Best Management Practices for Water and Resource Quality, SCERP Report WQ93-12

Pima County, Sonoran Desert Conservation Plan, Pima County Administrator's Office, Tucson, Arizona.
http://www.pima.gov/cmo/sdcp/index.html

Scott, Paul S., Robert D. Mac Nish, and Thomas Maddock III, 1997, Effluent Rechage to the Upper Santa Cruz River Floodplain Aquifer, Santa Cruz County, Arizona, Arizona Research Laboratory for Riparian Studies, University of Arizona.

Sonoran Institute, 2007, Sustainable Water Management: Guidelines for Meeting the Needs of People and Nature in the Arid West,
http://sonoran.org/index.php?option=com_docman&task=doc_view&gid=131&Itemid=5

Sprouse, Terry, Robert Emanuel, Barbara Tellman, 2002, Surface Water Quality Monitoring Overview and Assessment, Sonoran Desert Network, National Park Service, Water Resources Research Center, University of Arizona.

Sprouse, Terry, Robert M. Emanuel, and Sara A. Storer, 2004, Water Quality Monitoring Program for High-Priority Water Bodies in the Sonoran Desert Network. Report to the National Parks Service, U.S. Department of the Interior, Sonoran Desert Network. Project Number: CA-1248-002, September 15, 2004.

Walker, David, Christine Goforth, and Samuel Rector, 2005?, *An Exploration of Nutrient and Community Variables in Effluent Dependent Streams in Arizona*, 156 pp.

Section 3: Biological Resources

Ecoregions

The effects of latitude, continental position, and elevation, together with other climatic factors, combine to form the world's ecoclimatic zones, which are referred to as ecosystem regions or ecoregions. Ecoregion maps show climatically determined ecological units. Because macroclimates are among the most significant factors affecting the distribution of life on earth, as the macroclimate changes, the other components of the ecosystem change in response.

Bailey's Ecoregion classification (Bailey, 1976) provides a general description of the ecosystem geography of the United States. This classification system was applied to the Santa Cruz Watershed, based on subwatersheds, which are identified using the USGS eight digit Hydrologic Unit Codes (HUC).

In Bailey's classification system, there are four *Domains*: polar, humid temperate, humid tropical and dry. The first three are differentiated based on humidity and thermal characteristics. The fourth, the dry domain, is defined on the basis of moisture alone. Each domain is divided into divisions, which are further subdivided into provinces, on the basis of macrofeatures of the vegetation.

This classification places all of the Santa Cruz Watershed, the Rio Asuncion Watershed and the Rio Sonoyta Watershed in the dry domain, with 100% of the subwatersheds in the Tropical/Subtropical Desert Division. Figures 3-1.1, 3-1.2, 3-2.1, 3-2.2 and 3-3.1 and 3-3.2 , and Tables 3-1.1, 3-1.2, 3-2.1, 3-2.2 and 3-3.1 and 3-3.2 show these divisions.

The following descriptions are from Bailey's Ecosystem Classification (Bailey, 1995). The Dry Domain characterizes a dry climate where annual losses of water through evaporation at the earth's surface exceed annual water gain from precipitation. Due to the resulting water deficiency, no permanent streams originate in dry climate zones. Dry climates occupy one-fourth or more of the earth's land surface.

The Division present in the Santa Cruz, Rio Asuncion, and Rio Sonoyta Watersheds is the Tropical/Subtropical Desert Division.

The Tropical/Subtropical Desert Division occurs in the entire area of the watersheds (Figures 3-1.1 & 3-1.2 and Tables 3-1.1 & 3-1.2). It is characterized by extreme aridity, extremely high air and soil temperatures, with extreme variations between day and night temperatures. Annual precipitation can be less than 8 inches (200 mm) in many places. The dry-desert vegetation, a class of xerophytic plants, is widely dispersed and provides negligible ground cover.

A dominant pedogenic process is salinization, which produces areas of salt crust where only salt-loving (halophytic) plants can survive. Calcification is conspicuous on well-drained uplands, where encrustations and deposits of calcium carbonate (caliche) are common. Humus is lacking and soils are mostly Aridisols (dry, high in calcium-carbonate, clays and salts, not suitable for agriculture without irrigation), and dry Entisols (young, diverse, some suitable for agriculture).

The Tropical/Subtropical Steppe Division is a hot, semiarid climate where potential evaporation exceeds precipitation, and where all months have temperatures above 32ºF.

Steppes are typically grasslands with short grasses and other herbs, and with locally developed shrubland and woodland. Pinyon-juniper woodland occurs on the Colorado Plateau, while to the east, in Texas, the grasslands grade into savanna woodland or semi deserts composed of xerophytic shrubs, cactus or trees, and the climate becomes semiarid-subtropical. These areas are able to support limited grazing, but generally require supplemental irrigation for crop cultivation. Soils are commonly Mollisols and Aridisols, containing some humus.

Bailey's Ecoregion classification defines two Provinces in the Santa Cruz Watershed: the American Semi-Desert and Desert Province, and the Chihuahuan Semi-Desert Province (Figure 3-2.1 and Table 3-2.2).

Both the U.S. region of the Rio Asuncion Watershed and the Rio Sonoyta Watershed are 100% American Semi-Desert and Desert Province (Figure 3-2.2 and Table 3-2.2).

The Sonoran Mojave Desert Section is found in the majority of the Santa Cruz Watershed, while the Basin and Range Section is found in the south east corner of the watershed. (Figure 3-3.1 and Table 3-3.1)

The U.S. portions of the Rio Asuncion and Rio Sonoyta Watersheds are classified as strictly Sonoran Mojave Desert Sections (Figure 3-3.2 and Table 3-3.2).

In the Basin and Range physiographic province there are widely separated short ranges in desert plains. This Section has as its major landforms plains, fans, and terraces. Elevation ranges from 300 to 3,500 ft (91 to 1,064 m).

Precipitation ranges from 3 to 8 in (80 to 200 mm). It is bimodal, occurring as winter rain and high intensity summer thunderstorms, with more than half of the annual precipitation falling during the winter. Temperature ranges from 61 to 75º F (16 to 24º C) and winters are mild. The growing season lasts 250 to 350 days.

The American Semi-Desert and Desert Province and Sonoran Mohave Desert Section occur in the southern portion of the watershed, and are characterized by extensive plains, most gently undulating, from which isolated mountains and buttes rise abruptly. Summers are long and hot, with convective thunderstorms. Winters are moderate, with gentle, widespread rains. Washes generally flow only after rains.

Vegetation consists of cactus and shrubs such as the creosote bush, and

Mesquite trees. Some places have a near-woodland appearance, due to the treelike saguaro cactus, prickly pear cactus, ocotillo, creosote bush, and smoke tree.

Table 3-1.1: Santa Cruz Watershed Ecoregions - Divisions.

Subwatersheds	Tropical/Subtropical Desert Divisions		Area (sq. miles)
	percent	area (sq. miles)	
Aguirre Wash Tat Momoli Wash H15050305	100%	733	733
Brawley Wash Los Robles Wash H15050304	100%	1,408	1,408
Lower Santa Cruz River H15050303	100%	1,682	1,682
Pantano Wash Rillito River H15050302	100%	920	920
Santa Rosa Wash H15050306	100%	1,208	1,208
Upper Santa Cruz River H15050301	100%	2,227	2,227
Santa Cruz River Watershed	*100%*	*8.178*	*8.178*
Rio Asuncion H15080200	100%	128	128
Rio Asuncion Watershed	*100%*	*128*	*128*

*Data pertains to the U.S. portion of the watershed only.

Table 3-1.2: Rio Sonoyta Watershed Ecoregions - Divisions.

Subwatersheds	Tropical/Subtropical Desert Divisions		Area (sq. miles)
	percent	area (sq. miles)	
Rio Sonoyta H15080102	100%	424	424
San Simon Wash H15080101	100%	2,154	2,154
Tule Desert H15080103	100%	497	497
Rio Sonoyta Watershed	*100%*	*3,075*	*3,075*

*Data pertains to the U.S. portion of the watershed only.

Table 3-2.1: Santa Cruz Watershed Ecoregions - Provinces.

Subwatersheds	American Semi-Desert and Desert Province		Chihuahuan Semi-Desert Province		Area (sq. miles)
	percent	area (sq. miles)	percent	area (sq. miles)	
Aguirre Wash Tat Momoli Wash H15050305	-	-	100%	733	733
Brawley Wash Los Robles Wash H15050304	-	-	100%	1,408	1,408
Lower Santa Cruz River H15050303	-	-	100%	1,682	1,682
Pantano Wash Rillito River H15050302	70%	640	30%	280	920
Santa Rosa Wash H15050306	-	-	100%	1,208	1,208
Upper Santa Cruz River H15050301	20%	440	80%	1,774	2,227
Santa Cruz River Watershed	*13%*	*1,080*	*87%*	*7,083*	*8,178*
Rio Asuncion H15080200	-	-	100%	128	128
Rio Asuncion Watershed	-	-	*100%*	*128*	*128*

*Data pertains to the U.S. portion of the watershed only.

Table 3-2.2: Rio Sonoyta Watershed Ecoregions - Provinces.

Subwatersheds	American Semi-Desert and Desert Province		Area (sq. miles)
	percent	area (sq. miles)	
Rio Sonoyta H15080102	100%	424	424
San Simon Wash H15080101	100%	2,154	2,154
Tule Desert H15080103	100%	497	497
Rio Sonoyta Watershed	*100%*	*3,075*	*3,075*

*Data pertains to the U.S. portion of the watershed only.

Table 3-3.1: Santa Cruz Watershed Ecoregions - Sections.

Subwatersheds	Basin and Range Section		Sonoran Mojave Desert Section		Area (sq. miles)
	percent	area (sq. miles)	percent	area (sq. miles)	
Aguirre Wash Tat Momoli Wash H15050305	-	-	100%	733	733
Brawley Wash Los Robles Wash H15050304	-	-	100%	1,408	1,408
Lower Santa Cruz River H15050303	-	-	100%	1,682	1,682
Pantano Wash Rillito River H15050302	70%	640	30%	280	920
Santa Rosa Wash H15050306	-	-	100%	1,208	1,208
Upper Santa Cruz River H15050301	20%	440	80%	1,774	2,227
Santa Cruz River Watershed	*13%*	*1,080*	*87%*	*7,083*	*8,178*
Rio Asuncion H15080200	-	-	100%	128	128
Rio Asuncion Watershed	-	-	*100%*	*128*	*128*

*Data pertains to the U.S. portion of the watershed only.

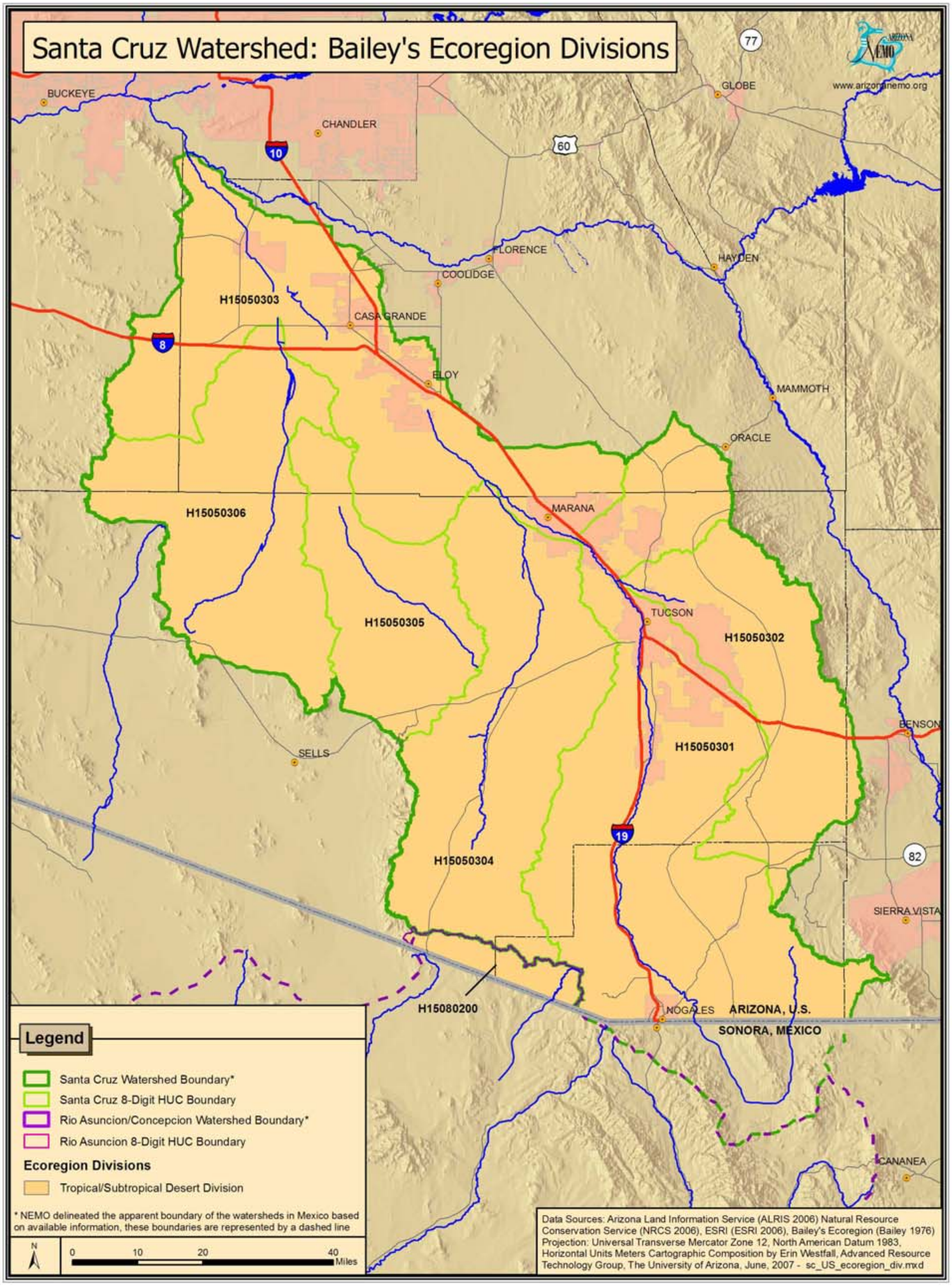

Figure 3-1.1: Santa Cruz Watershed, Bailey's Ecoregion Divisions

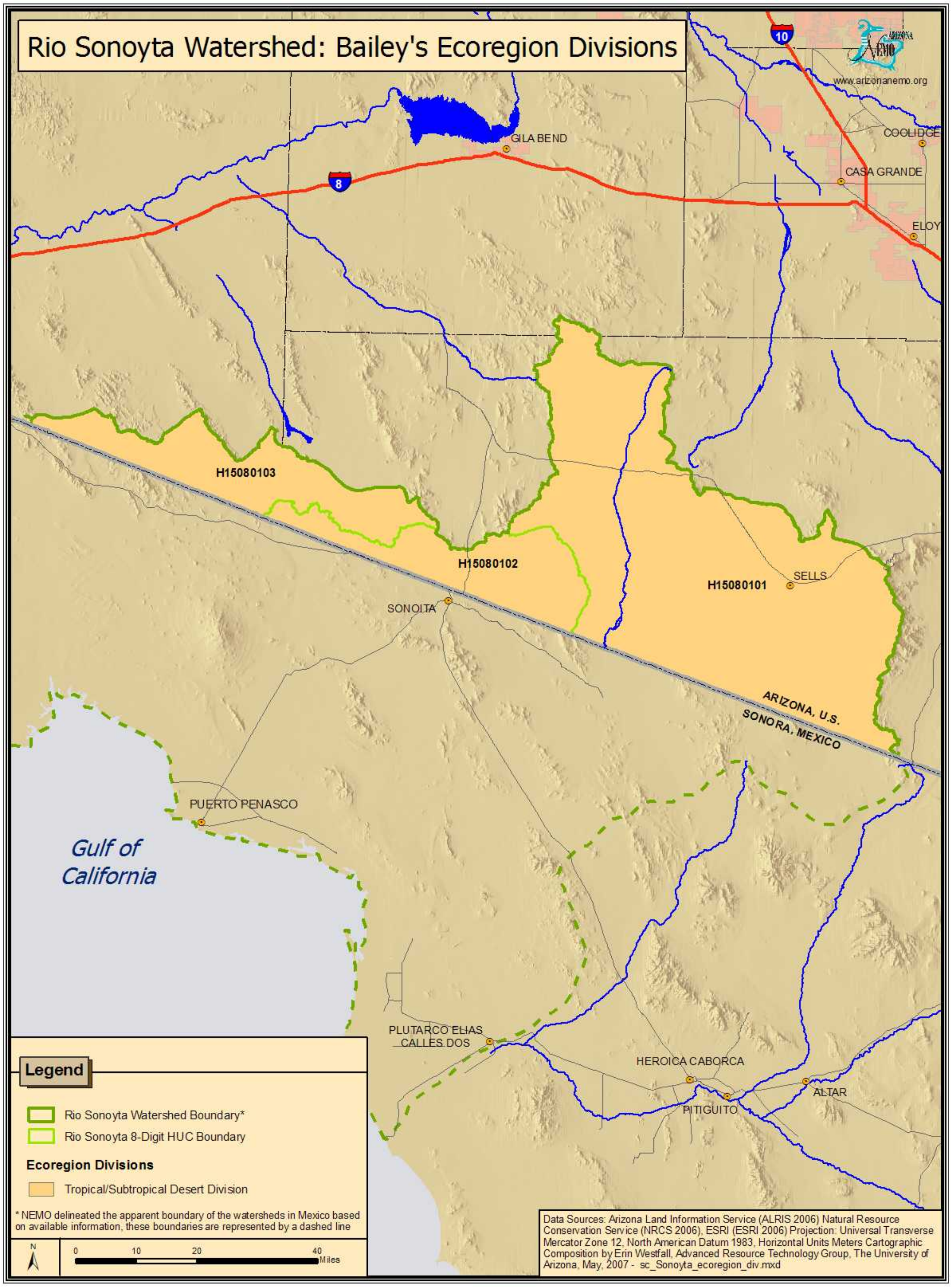

Figure 3-1.2: Rio Sonoyta Watershed, Bailey's Ecoregion Divisions

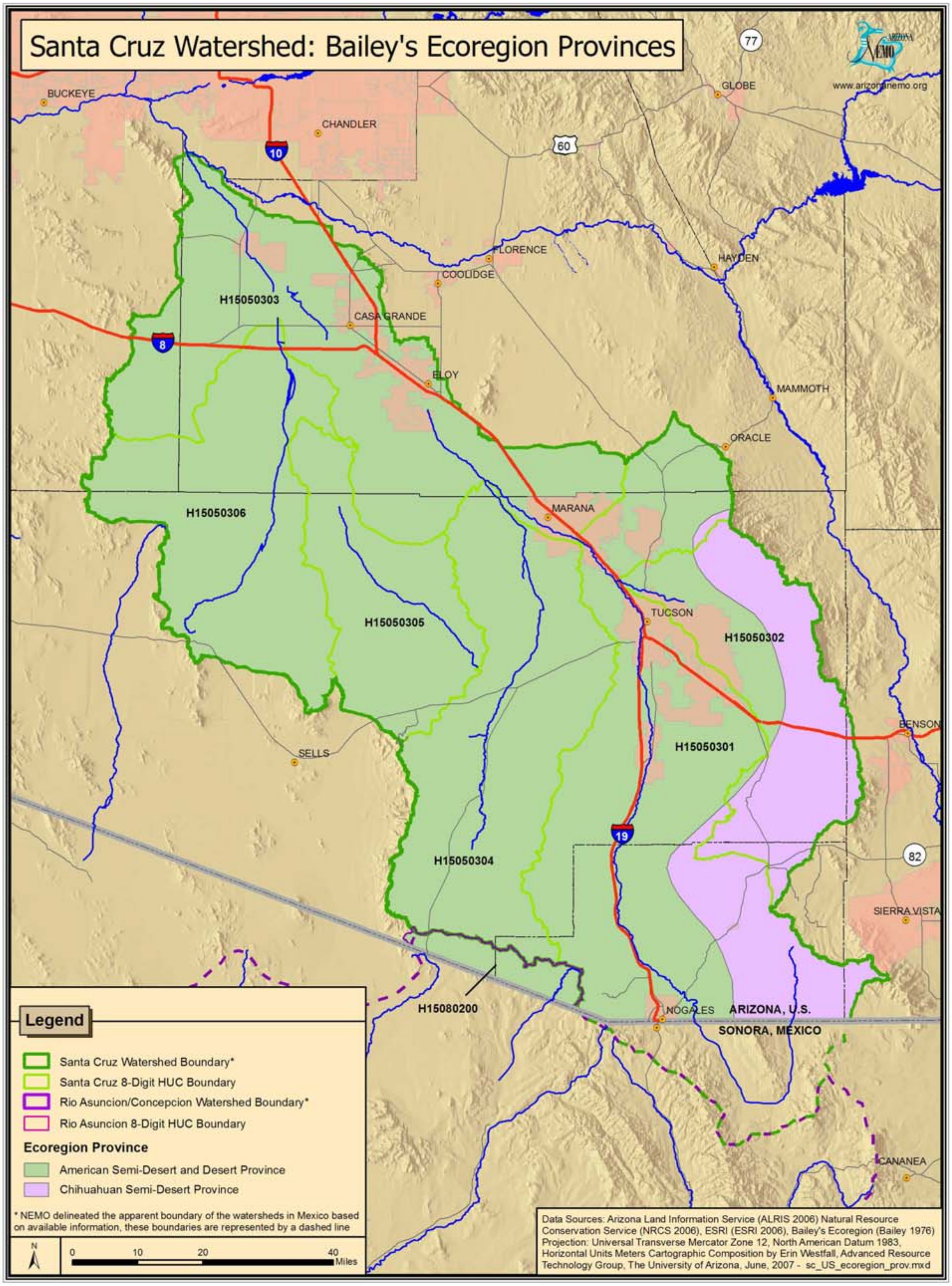

Figure 3-2.1: Santa Cruz Watershed, Bailey's Ecoregion Provinces

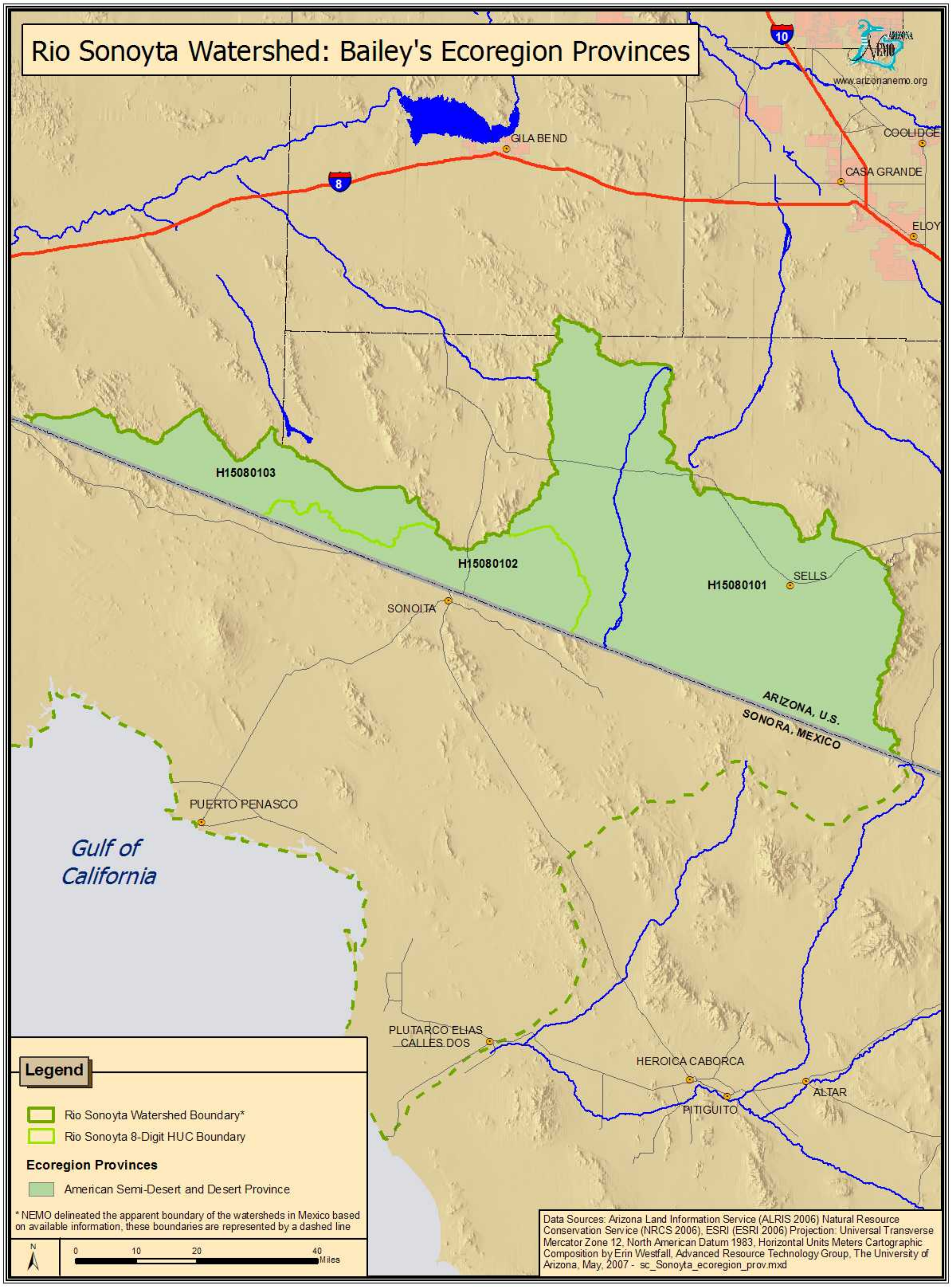

Figure 3-2.2: Rio Sonoyta Watershed, Bailey's Ecoregion Provinces

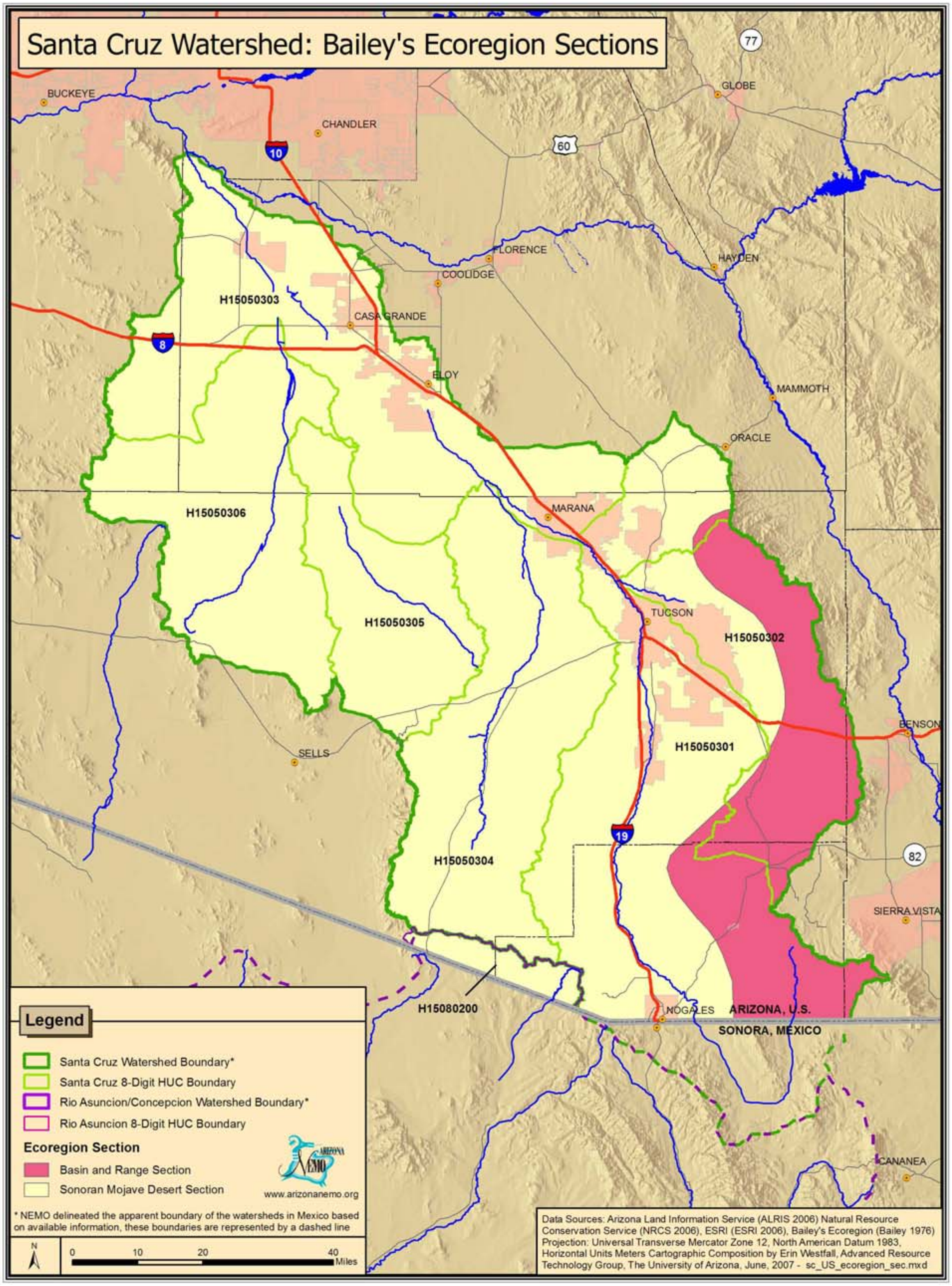

Figure 3-3.1: Santa Cruz Watershed, Bailey's Ecoregion Sections

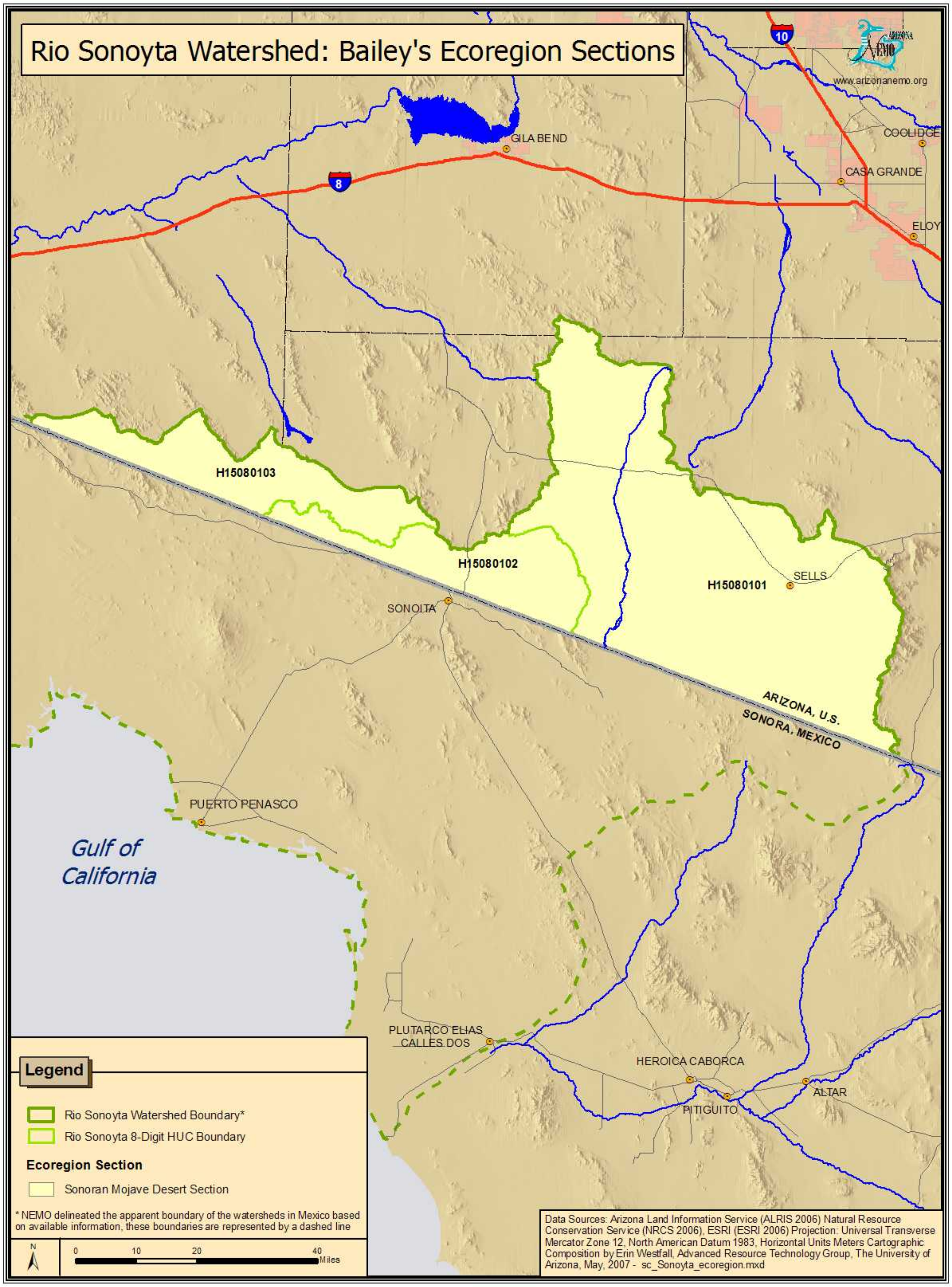

Figure 3-3.2: Rio Sonoyta Watershed, Bailey's Ecoregion Sections

Table 3-3.2: Rio Sonoyta Watershed Ecoregions - Sections.

Subwatersheds	Sonoran Mojave Desert Section		Area (sq. miles)
	percent	**area (sq. miles)**	
Rio Sonoyta H15080102	100%	424	424
San Simon Wash H15080101	100%	2,154	2,154
Tule Desert H15080103	100%	497	497
Rio Sonoyta Watershed	*100%*	*3,075*	*3,075*

*Data pertains to the U.S. portion of the watershed only.

Vegetation

Two different vegetation maps were created for the Santa Cruz Watershed, one based on biotic (vegetation) communities and the other based on land cover.

The first map is based on the classification of biotic communities that was published by Brown, Lowe, and Pace (Brown et al., 1979). These biotic zones are general categories indicating where vegetation communities would most likely exist (Figure 3-4.1 and 3-4.2). Tables 3-4.1 and 3-4.2 show the percentage of each biotic community in each subwatershed. Under this classification there are eight different biotic communities in the Santa Cruz Watershed. The primary community types over the entire watershed are Arizona Upland Sonoran Desert Chub, comprising 38% of the watershed, the Semi-desert Grasslands, 28%, and the Lower Colorado River Sonoran Desert Scrub comprising 21%.

The U.S. portion of the Rio Asuncion Watershed contains 58% Semi-desert Grassland and 43% Madrean Evergreen Woodland. The U.S. portion of the Rio Sonoyta Watershed is comprised of 55% Arizona Upland Sonoran Desert Scrub, and 43% Lower Colorado Sonoran Desert Scrub

The second vegetation map was created from the Southwest Regional Gap Analysis Project land cover map (Lowry et. al, 2005). According to this map, 35 different land cover types are found within the Santa Cruz Watershed, including vegetation communities, developed land, open water, and agriculture (Table 3-5.1). The most common land cover type over the entire watershed is Sonoran Paloverde Mixed Cacti Desert Scrub encompassing 35.76% of the watershed. The next most common types are Sonoran - Mojave Creosote - White Bursage Desert Scrub (13.37%), and Apacherian-Chihuahuan Mesquite Upland Scrub (11.39%). Figure 3-5.1 is a map of the Southwest Regional GAP Land Cover for the Santa Cruz Watershed.

The U.S. portion of the Rio Asuncion Watershed contains 20 different cover types. The most common land cover for the entire watershed is Apacherian-Chihuahuan Mesquite Upland Scrub with 34.04% of the watershed. The next most common types are Madrean Encinal with 19.57% and Chihuahuan Mixed Salt Desert Scrub.

The U.S. section of the Rio Sonoyta Watershed is comprised of 30 different cover types. The most prominent are Sonoran Paloverde-Mixed Cacti Desert Scrub with 44%, Barren Lands, 4.72%, and the Apacherian-Chiuahuan Mesquite Upland Scrub with 3.34% (Table 3-5.2).

Table 3-4.1: Santa Cruz Watershed Brown, Lowe and Pace Biotic Communities, Percent by Subwatershed (part 1 of 2).*

Biotic Community	Aguirre Wash Tat Momoli Wash H15050305	Brawley Wash Los Robles Wash H15050304	Lower Santa Cruz River H15050303	Pantano Wash Rillito River H15050302	Santa Rosa Wash H15050306
Arizona Upland Sonoran Desert Scrub	73%	36%	31%	23%	72%
Chihuahuan Desert Scrub	-	-	-	6%	-
Interior Chaparral	-	0.1%	0.1%	2%	-
Lower Colorado Sonoran Desert Scrub	16%	12%	68%	-	27%
Madrean Evergreen Woodland	1%	6%	-	20%	-
Petran Mountane Conifer Forest	-	-	-	2%	-
Plains and Great Basin Grassland	-	-	-	4%	-
Semi-desert Grassland	10%	46%	1%	44%	1%
Area (square miles)	*733*	*1,408*	*1,682*	*920*	*1,208*

**Data pertains to the U.S. portion of the watershed only.*

Table 3-4.1: Santa Cruz Watershed Brown, Lowe and Pace Biotic Communities, Percent by Subwatershed (part 2 of 2).*

Biotic Community	Upper Santa Cruz River H15050301	Santa Cruz River Watershed	Rio Asuncion H15080200	Rio Asuncion Watershed
Arizona Upland Sonoran Desert Scrub	23%	38%	-	-
Chihuahuan Desert Scrub	-	0.6%	-	-
Interior Chaparral	1%	0.5%	-	-
Lower Colorado Sonoran Desert Scrub	0.1%	21%	-	-
Madrean Evergreen Woodland	20%	9%	43%	43%
Petran Mountane Conifer Forest	0.4%	0.3%	-	-
Plains and Great Basin Grassland	4%	2%	-	-
Semi-desert Grassland	52%	28%	58%	58%
Area (square miles)	*2,227*	*8,178*	*128*	*128*

**Data pertains to the U.S. portion of the watershed only.*

Table 3-4.2: Rio Sonoyta Watershed Brown, Lowe and Pace Biotic Communities, Percent by Subwatershed.*

Biotic Community	**Rio Sonoyta H15080102**	**San Simon Wash H15080101**	**Tule Desert H15080103**	**Rio Sonoyta Watershed**
Arizona Upland Sonoran Desert Scrub	84%	59%	8%	55%
Lower Colorado Sonoran Desert Scrub	16%	37%	92%	43%
Madrean Evergreen Woodland	-	0.6%	-	0.4%
Semidesert Grassland	0.04%	3%	-	2%
Area (square miles)	*424*	*2,154*	*497*	*3,075*

**Data pertains to the U.S. portion of the watershed only.*

Table 3-5.1: Santa Cruz Watershed Southwest Regional GAP Analysis Project Land Cover, Percent of Subwatershed (Part 1 of 2).

Land Cover	**Aguirre Wash Tat Momoli Wash H15050305**	**Brawley Wash Los Robles Wash H15050304**	**Lower Santa Cruz River H15050303**	**Pantano Wash Rillito River H15050302**
Agriculture	0.38%	2.30%	20.62%	-
Apacherian-Chihuahuan Mesquite Upland Scrub	4.67%	21.18%	0.31%	15.75%
Apacherian-Chihuahuan Piedmont Semi-Desert Grassland and Steppe	0.24%	7.69%	-	14.72%
Barren Lands	4.58%	1.18%	0.60%	0.07%
Chihuahuan Creosotebush, Mixed Desert and Thorn Scrub	0.11%	2.18%	-	8.95%
Chihuahuan Mixed Salt Desert Scrub	0.07%	3.29%	-	6.90%
Chihuahuan Sandy Plains Semi-Desert and Thorn Scrub	> 0.00%	> 0.00%	-	0.02%
Chihuahuan Stabalized Coppice Dune and Sand Flat Scrub	-	0.01%	-	0.09%
Chihuahuan Succulent Desert Scrub	0.01%	0.06%	-	0.23%
Developed, Medium – High Intensity	-	3.41%	2.61%	5.43%
Developed, Open Space – Low Intensity	-	0.29%	1.60%	10.55%
Invasive Southwest Riparian Woodland and Shrubland	> 0.00%	> 0.00%	0.11%	-
Madrean Encinal	0.83%	5.35%	-	11.23%
Madrean Juniper Savanna	> 0.00%	0.04%	-	0.10%
Madrean Pine-Oak Forest and Woodland	0.17%	0.12%	-	2.99%
Madrean Pinyon-Juniper Woodland	0.42%	0.66%	0.08%	4.81%

Land Cover	Aguirre Wash Tat Momoli Wash H15050305	Brawley Wash Los Robles Wash H15050304	Lower Santa Cruz River H15050303	Pantano Wash Rillito River H15050302
Madrean Upper Montane Conifer-Oak Forest and Woodland	-	> 0.00%	-	0.66%
Mogollon Chaparral	0.05%	0.39%	0.14%	2.77%
North American Arid West Emergent Marsh	0.18%	0.14%	-	> 0.00%
North American Warm Desert Bedrock Cliff and Outcrop	-	0.57%	-	2.79%
North American Warm Desert Lower Montane Riparian Woodland and Shrubland	0.03%	0.05%	-	0.13%
North American Warm Desert Pavement	-	-	-	0.01%
North American Warm Desert Riparian Mesquite Bosque	1.57%	1.73%	0.30%	0.54%
North American Warm Desert Riparian Woodland and Shrubland	0.10%	0.14%	0.16%	0.12%
North American Warm Desert Volcanic Rockland	-	0.02%	-	0.25%
North American Warm Desert Wash	-	> 0.00	0.02%	0.06%
Open Water	> 0.00%	0.03	0.03%	> 0.00%
Recently Burned	-	0.28%	-	-
Recently Mined or Quarried	0.12%	0.21%	0.33%	-
Rocky Mountain Aspen Forest and Woodland	-	-	-	0.31%
Sonora-Mojave Creosote-White Bursage Desert Scrub	25.79%	5.07%	27.79%	1.24%
Sonora-Mojave Mixed Salt Desert Scrub	> 0.00%	> 0.00%	6.71%	0.04%
Sonoran Mid-Elevation Desert Scrub	0.94%	1.77%	1.29%	0.36%
Sonoran Paloverde-Mixed Cacti Desert Scrub	59.73%	41.81%	37.31%	8.91%
Southern Rocky Mountain Pinyon-Juniper Woodland	-	-	-	> 0.00%
Area (square miles)	*733*	*1,408*	*1,682*	*920*

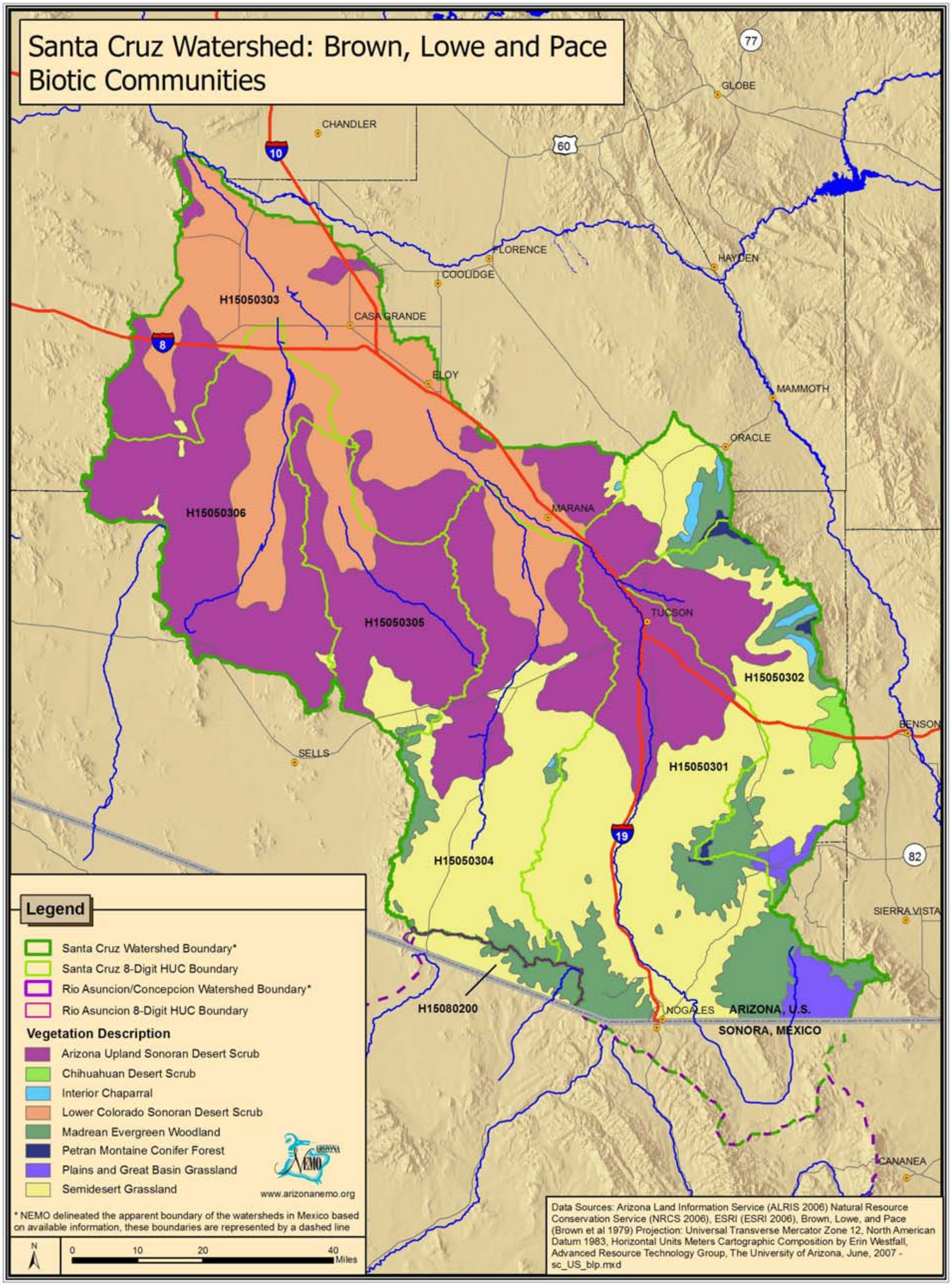

Figure 3-4.1: Santa Cruz Watershed, Brown, Lowe, and Pace Biotic Communities

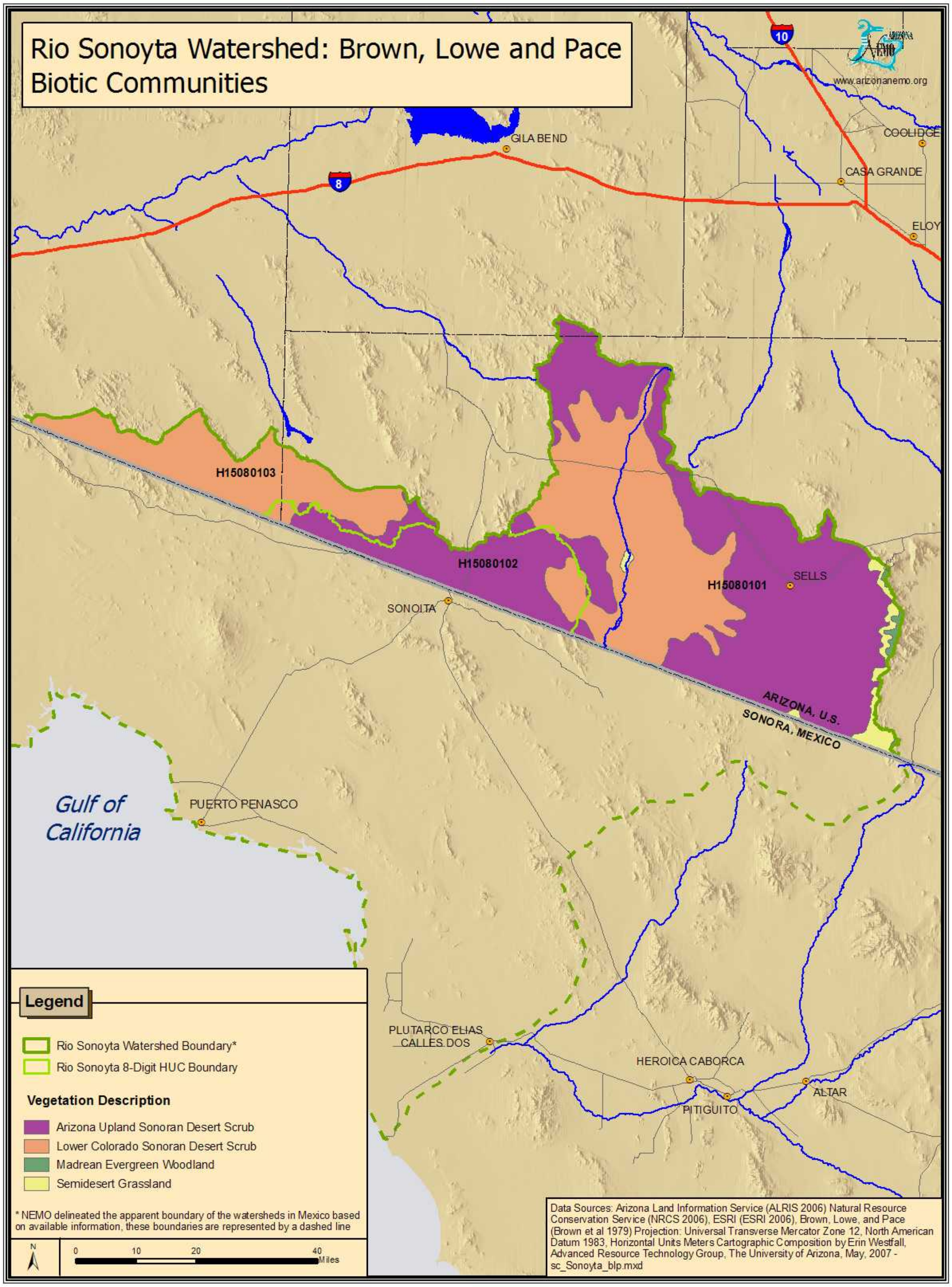

Figure 3-4.2: Rio Sonoyta Watershed, Brown, Lowe, and Pace Biotic Communities

Table 3-5.1: Santa Cruz Watershed Southwest Regional GAP Analysis Project Land Cover, Percent of Subwatershed (Part 2 of 2).

Land Cover	**Santa Rosa Wash H15050306**	**Upper Santa Cruz River H15050301**	***Santa Cruz River Watershed****	**Rio Asuncion H15080200**	***Rio Asuncion Watershed****
Agriculture	1.63%	0.74%	*5.12%*	-	-
Apacherian-Chihuahuan Mesquite Upland Scrub	1.14%	19.54%	*11.39%*	34.04	*34.04*
Apacherian-Chihuahuan Piedmont Semi-Desert Grassland and Steppe	-	11.85%	*6.23%*	16.46	*16.46*
Barren Lands	2.84%	0.01%	*1.17%*	-	-
Chihuahuan Creosotebush, Mixed Desert and Thorn Scrub	-	3.93%	*2.46%*	2.94%	*2.94%*
Chihuahuan Mixed Salt Desert Scrub	-	5.24%	*2.78%*	17.76%	*17.76%*
Chihuahuan Sandy Plains Semi-Desert and Thorn Scrub	-	0.02%	*0.01%*	-	-
Chihuahuan Stabalized Coppice Dune and Sand Flat Scrub	-	0.03%	*0.02%*	0.01%	*0.01%*
Chihuahuan Succulent Desert Scrub	-	0.08%	*0.06%*	0.01%	*0.01%*
Developed, Medium – High Intensity	0.04%	4.39%	*3.51%*	-	-
Developed, Open Space – Low Intensity	0.07%	7.12%	*2.94%*	-	-
Invasive Southwest Riparian Woodland and Shrubland	> 0.00%	-	*0.02%*	-	-
Madrean Encinal	-	12.17%	*5.57%*	19.57%	*19.57%*
Madrean Juniper Savanna	-	0.07%	*0.77%*	0.07%	*0.07%*
Madrean Pine-Oak Forest and Woodland	-	1.45%	*0.04%*	0.14%	*0.14%*
Madrean Pinyon-Juniper Woodland	0.07%	3.92%	*1.79%*	0.47%	*0.47%*
Madrean Upper Montane Conifer-Oak Forest and Woodland	-	0.15%	*0.12%*	-	-
Mogollon Chaparral	0.12%	1.72%	*0.90%*	0.16%	*0.16%*
North American Arid West Emergent Marsh	-	0.02%	*0.03%*	> 0.00%	*> 0.00%*
North American Warm Desert Bedrock Cliff and Outcrop	-	0.94%	*0.68%*	3.28%	*3.28%*
North American Warm Desert Lower Montane Riparian Woodland and Shrubland	-	0.10%	*0.05%*	0.06%	*0.06%*
North American Warm Desert Pavement	-	> 0.00%	*> 0.00%*	-	-
North American Warm Desert Riparian Mesquite Bosque	0.92%	0.68%	*0.88%*	1.01%	*1.01%*

Land Cover	Santa Rosa Wash H15050306	Upper Santa Cruz River H15050301	*Santa Cruz River Watershed**	Rio Asuncion H15080200	*Rio Asuncion Watershed**
North American Warm Desert Riparian Woodland and Shrubland	0.01%	0.05%	*0.09%*	0.05%	*0.05%*
North American Warm Desert Volcanic Rockland	-	0.08%	*0.05%*	0.09%	*0.09%*
North American Warm Desert Wash	0.01%	0.04%	*0.02%*	0.01%	*0.01%*
Open Water	0.01%	0.04%	*0.02%*	-	-
Recently Burned	-	-	*0.05%*	3.69%	*3.69%*
Recently Mined or Quarried	0.21%	1.93%	*0.67%*	-	-
Rocky Mountain Aspen Forest and Woodland	-	0.03%	*0.04%*	-	-
Sonora-Mojave Creosote-White Bursage Desert Scrub	24.26%	2.74%	*13.37%*	-	-
Sonora-Mojave Mixed Salt Desert Scrub	2.00%	0.02%	*1.69%*	-	-
Sonoran Mid-Elevation Desert Scrub	0.72%	3.28%	*1.69%*	-	-
Sonoran Paloverde-Mixed Cacti Desert Scrub	65.94%	17.60%	*35.76%*	0.06%	*0.06%*
Southern Rocky Mountain Pinyon-Juniper Woodland	-	> 0.00%	*> 0.00%*	-	-
Area (square miles)	*1,208*	*2,227*	*8,178*	*128*	*128*

*Data pertains to the U.S. portion of the watershed only.

Table 3-5.2: Rio Sonoyta Watershed Southwest Regional GAP Analysis Project Land Cover, Percent of Subwatershed.

Land Cover	Rio Sonoyta H15080102	San Simon Wash H15080101	Tule Desert Area H15080103	*Rio Sonoyta Watershed**
Agriculture	-	0.15%	-	*0.10%*
Apacherian-Chihuahuan Mesquite Upland Scrub	0.01%	4.77%	> 0.00%	*3.34%*
Apacherian-Chihuahuan Piedmont Semi-Desert Grassland and Steppe	-	0.29%	-	*0.20%*
Barren Lands	0.19%	6.70%	0.03%	*4.72%*
Chihuahuan Creosotebush, Mixed Desert and Thorn Scrub	-	0.29%	-	*0.20%*
Chihuahuan Mixed Salt Desert Scrub	-	0.50%	-	*0.35%*
Chihuahuan Sandy Plains Semi-Desert and Thorn Scrub	-	0.01%	-	*> 0.00%*
Chihuahuan Stabalized Coppice Dune and Sand Flat Scrub	-	> 0.00%	-	*> 0.00%*
Chihuahuan Succulent Desert Scrub	-	0.03%	-	*0.02%*

Land Cover	**Rio Sonoyta H15080102**	**San Simon Wash H15080101**	**Tule Desert Area H15080103**	***Rio Sonoyta Watershed****
Developed, Medium – High Intensity	0.01%	> 0.00%	-	*> 0.00%*
Developed, Open Space – Low Intensity	-	0.10%	-	*0.07%*
Invasive Southwest Riparian Woodland and Shrubland	0.01%	-	> 0.00%	*> 0.00%*
Madrean Encinal	-	0.97%	-	*0.68%*
Madrean Juniper Savanna	-	0.03%	-	*0.02%*
Madrean Pine-Oak Forest and Woodland	-	0.10%	-	*0.07%*
Madrean Pinyon-Juniper Woodland	0.01%	0.56%	-	*0.39%*
Madrean Upper Montane Conifer-Oak Forest and Woodland	-	> 0.00%	-	*> 0.00%*
Mogollon Chaparral	0.07%	0.12%	-	*0.09%*
North American Arid West Emergent Marsh	-	> 0.00%	-	*> 0.00%*
North American Warm Desert Active and Stabilized Dune	-	-	9.80%	*1.58%*
North American Warm Desert Bedrock Cliff and Outcrop	-	0.32%	0.95%	*0.38%*
North American Warm Desert Lower Montane Riparian Woodland and Shrubland	-	0.06%	-	*0.04%*
North American Warm Desert Pavement	-	-	-	-
North American Warm Desert Riparian Mesquite Bosque	0.79%	4.51%	> 0.00%	*3.27%*
North American Warm Desert Riparian Woodland and Shrubland	0.02%	0.11%	> 0.00%	*0.08%*
North American Warm Desert Volcanic Rockland	-	> 0.00%	1.73%	*> 0.00%*
North American Warm Desert Wash	-	> 0.00%	-	*> 0.00%*
Open Water	0.01%	0.00%	-	*> 0.00%*
Recently Burned	-	-	-	-
Recently Mined or Quarried	-	-	-	-
Rocky Mountain Aspen Forest and Woodland	-	-	-	-
Sonora-Mojave Creosote-White Bursage Desert Scrub	27.37%	35.40%	62.59%	*38.69%*
Sonora-Mojave Mixed Salt Desert Scrub	0.12%	0.95%	0.16%	*0.71%*
Sonoran Mid-Elevation Desert Scrub	0.26%	0.94%	> 0.00%	*0.70%*
Sonoran Paloverde-Mixed Cacti Desert Scrub	71.14%	43.09%	24.74%	*44.00%*

Land Cover	Rio Sonoyta H15080102	San Simon Wash H15080101	Tule Desert Area H15080103	*Rio Sonoyta Watershed**
Southern Rocky Mountain Pinyon-Juniper Woodland	-	-	-	-
Area (square miles)	*424*	*2,154*	*497*	*3,075*

*Data pertains to the U.S. portion of the watershed only.

<u>Habitats (Riparian and Wetland Areas)</u>

The Arizona Game & Fish Department has identified riparian vegetation associated with perennial waters and has mapped the data in response to the requirements of the state Riparian Protection Program (July 1994). This map was used to identify riparian areas in the Santa Cruz Watershed (Figure 3-6.1).

Nine of the ten different types of riparian areas occur within this watershed (Table 3-6.1). Riparian areas encompass approximately 7,393 acres (11.6 square miles) or 0.1% of the entire watershed. Mesquite comprises about 3,362 acres (5.3 square miles, or 46%) of the riparian areas, and Mixed Broadleaf comprises about 1,513 acres (2.4 square miles, or 21%) of the riparian area, Strand (the area alongside the stream channel) 1260 acres (2 square miles or 17%) of the riparian area and Cottonwood Willow 1,020 acres (1.6 square miles or 14%) of the riparian area.

The Upper Santa Cruz River and Pantano Wash-Rillito River subwatersheds have the only quantifiable amounts of riparian vegetation in the watershed , comprising about 5,212 acres (8.1 square miles or 70%) and 2,182 acres (3.4 square miles or 30%) of the riparian area, respectively.

Neither U.S. sections of the Rio Asuncion or Rio Sonoyta Watersheds contain quantifiable amounts of riparian areas (Table 3.6.1 and Table 3.6.2).

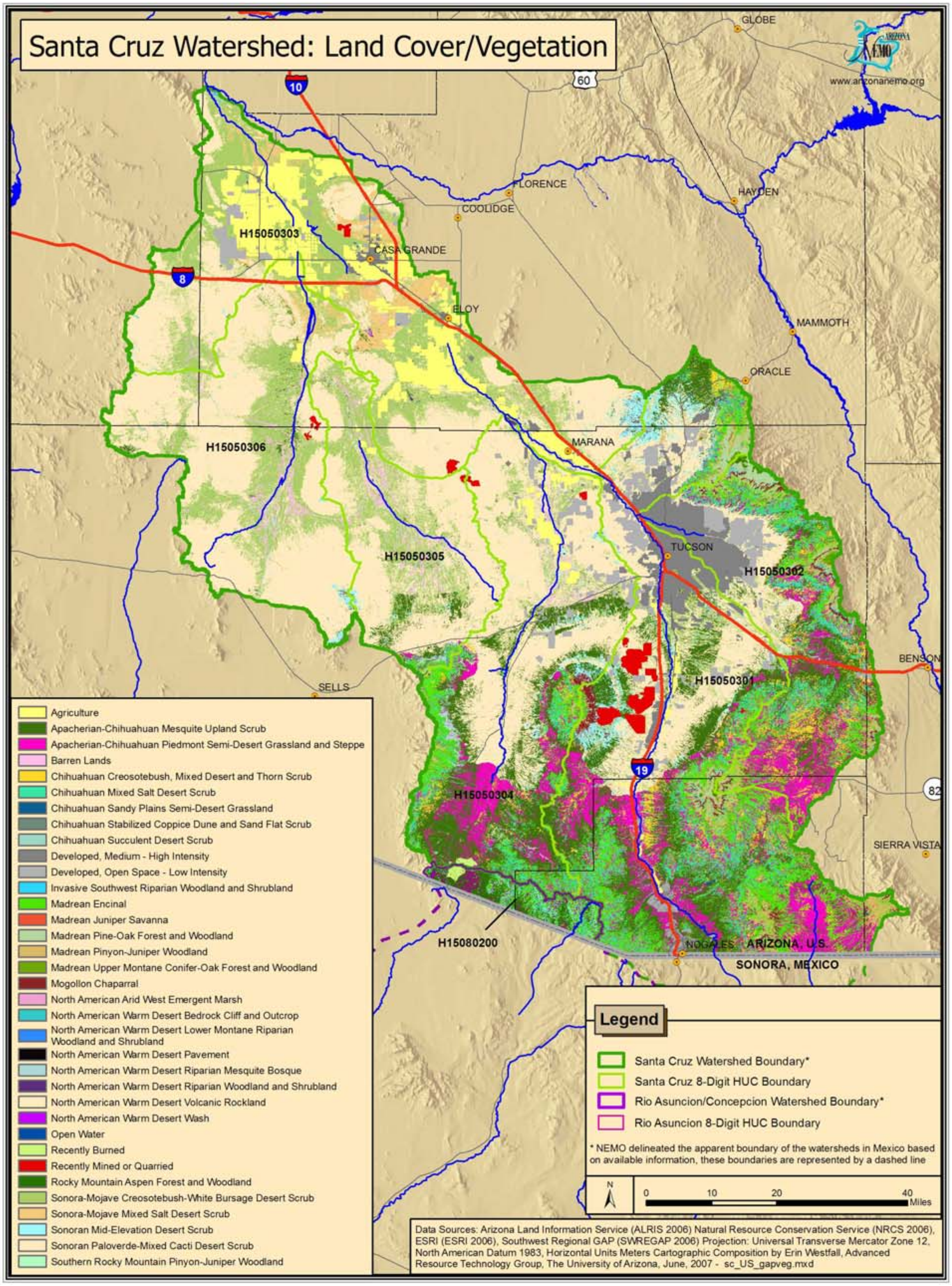

Figure 3-5.1: Santa Cruz Watershed Land Cover/Vegetation

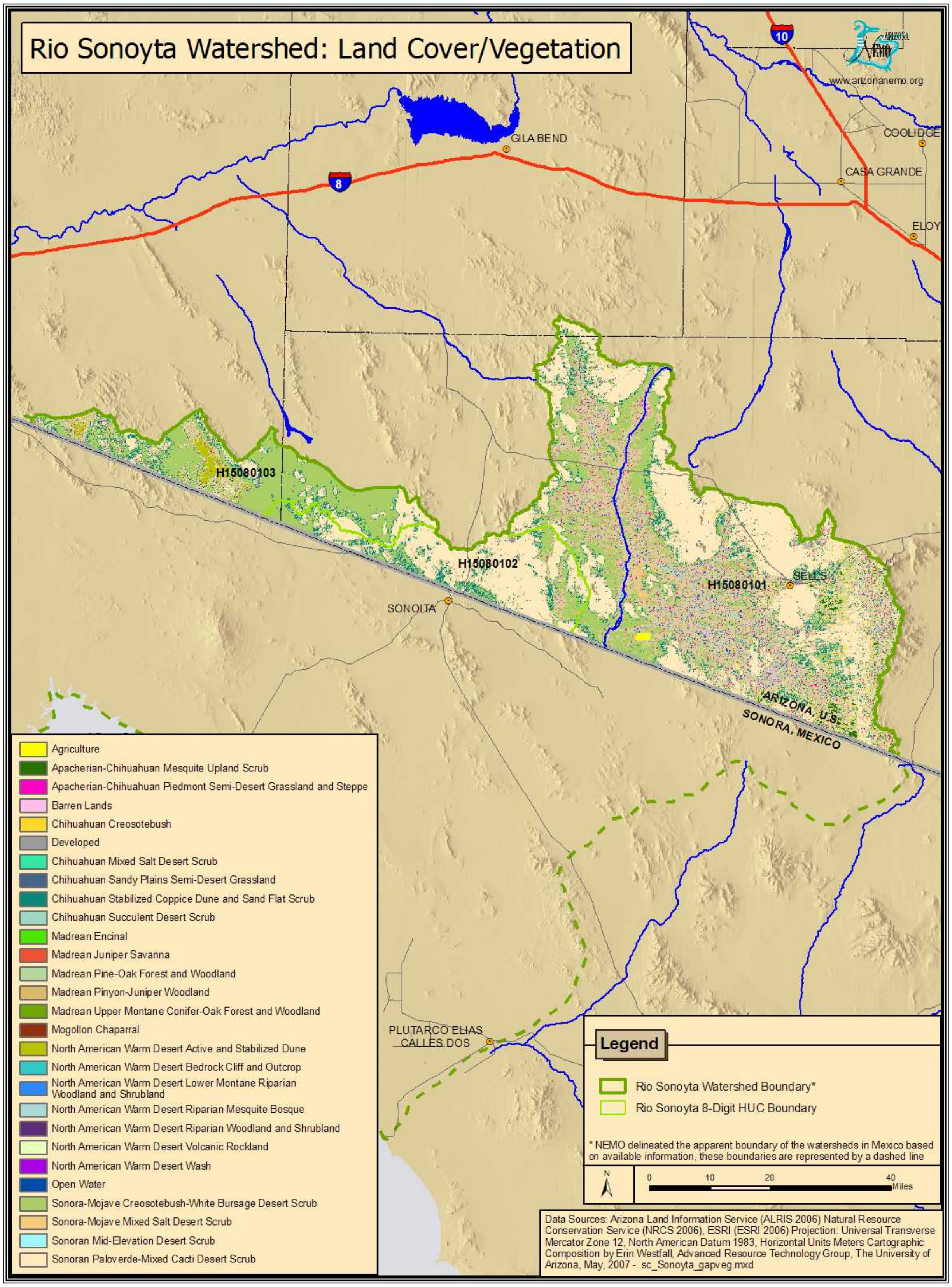

Figure 3-5.2: Rio Sonoyta Watershed Land Cover/Vegetation

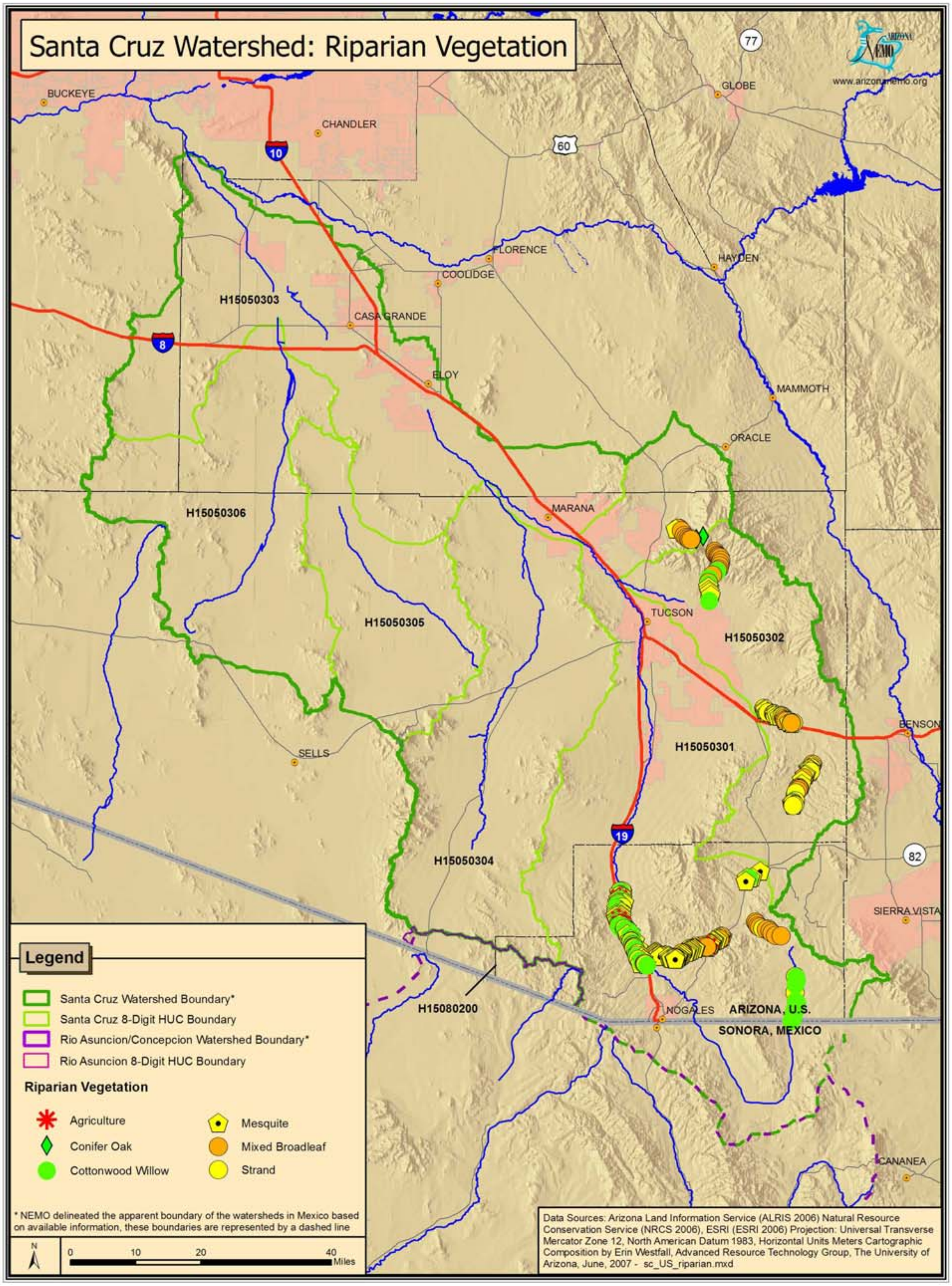

Figure 3-6.1: Santa Cruz Watershed Riparian Vegetation

Critical Habitat

Critical habitat is a specific geographic area(s) that is essential for the conservation of a threatened or endangered species and that may require special management and protection (US FWS, 2008). Critical habitat may include an area that is not currently occupied by the species but that will be needed for its recovery.

Critical habitat exits in the Santa Cruz River Watershed for the Gila Chub, the Huachuca Water Umbel and the Mexican Spotted Owl (Figure 3-7). Critical habitat exists for the eastern section (of the U.S. portion) of the Rio Asuncion Watershed. There is no critical habitat located in the Rio Sonoyta Watershed.

Major Land Resource Areas (MLRAs)

Major Land Resource Areas, or MLRA's, are ecosystem divisions in Arizona. There are two different MLRA's in the Santa Cruz Watershed (Figure 3-8.1): Central Arizona Basin and Range and Southeastern Arizona Basin and Range (Table 3-7.1). The Central Arizona Basin and Range MLRA has the largest representation with 58% (4,743 square miles) of the watershed. The Southeastern Arizona Basin and Range MLRA (Cassady, 2000) makes up the rest of the watershed with 42% (3,435 square miles).

The portion of the Rio Asuncion MLRA in Arizona (128 square miles) is exclusively comprised of Southeastern Arizona Basin and Range. The Rio Sonoyta Watershed MLRA is comprised of three areas, the Southeastern Arizona Basin and Range, representing 9% (277 square miles) of the watershed, Sonoran Basin and Range, representing 24% (738 square miles) of the watershed, and the Central Arizona Basin and Range, representing 67% (2060 square miles) of the watershed (Figure 3-8.2 and Table 3-7.2).

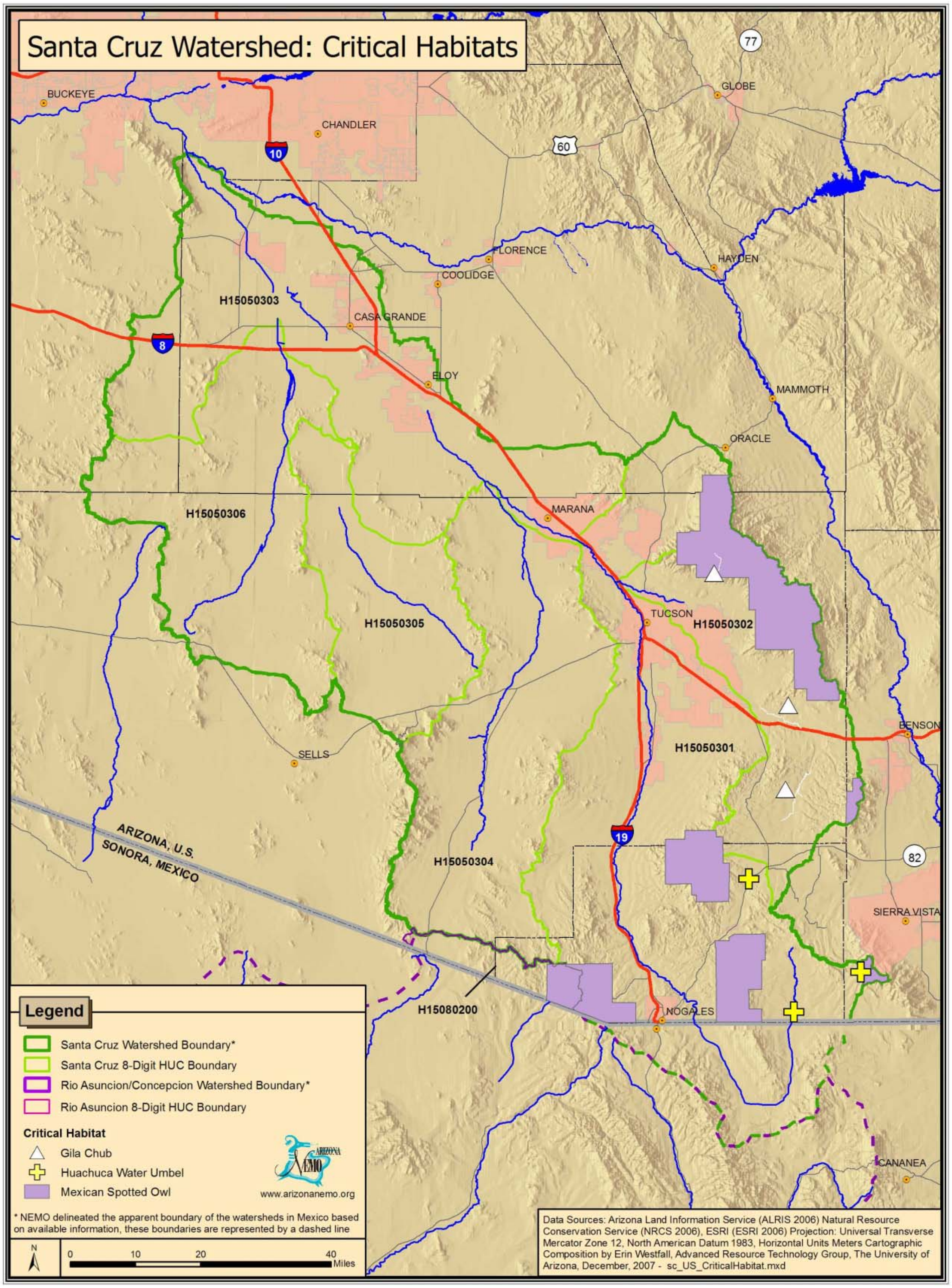

Figure 3-7: Santa Cruz Watershed Critical Habitats

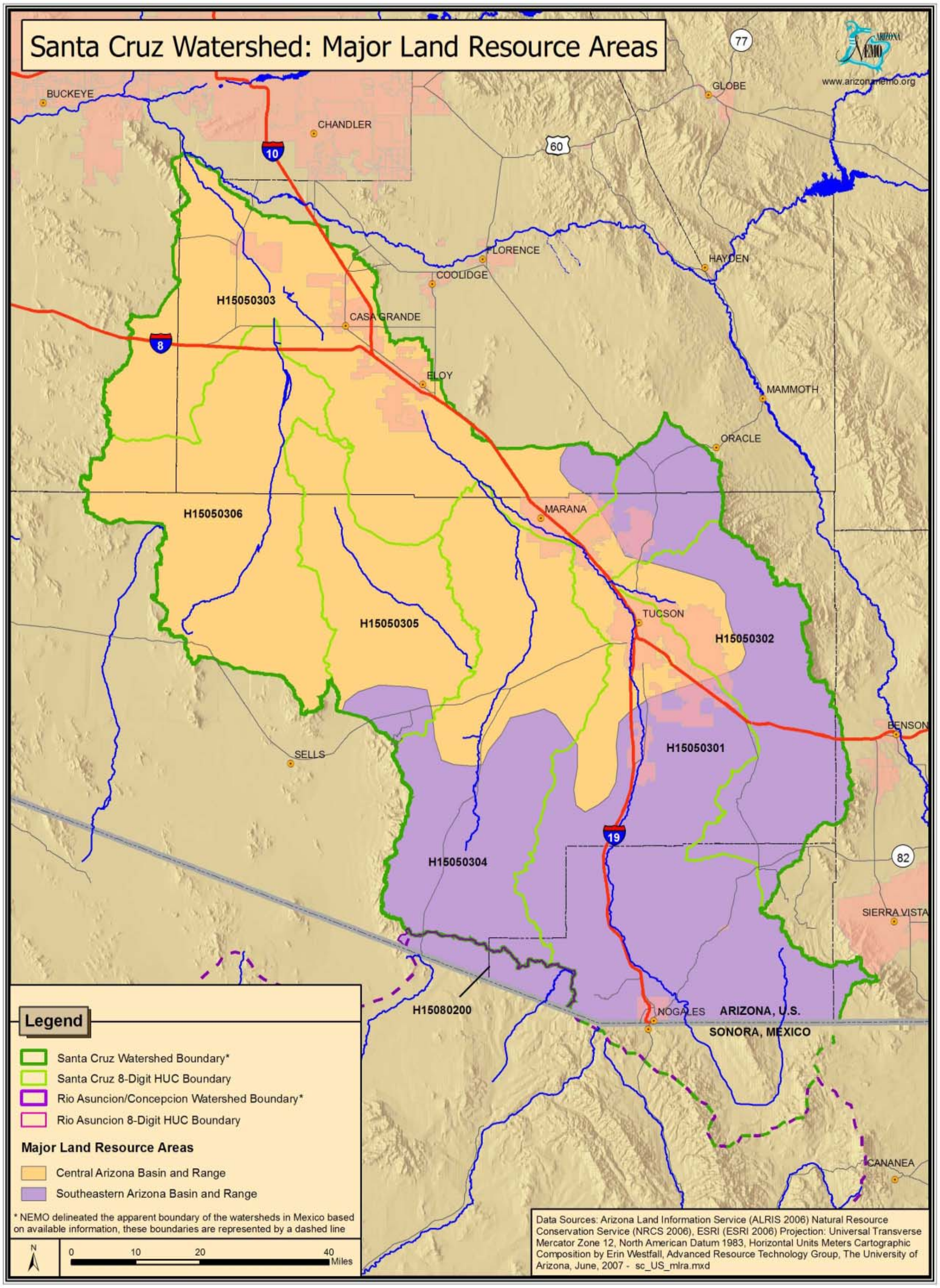

Figure 3-8.1: Major Land Resource Areas

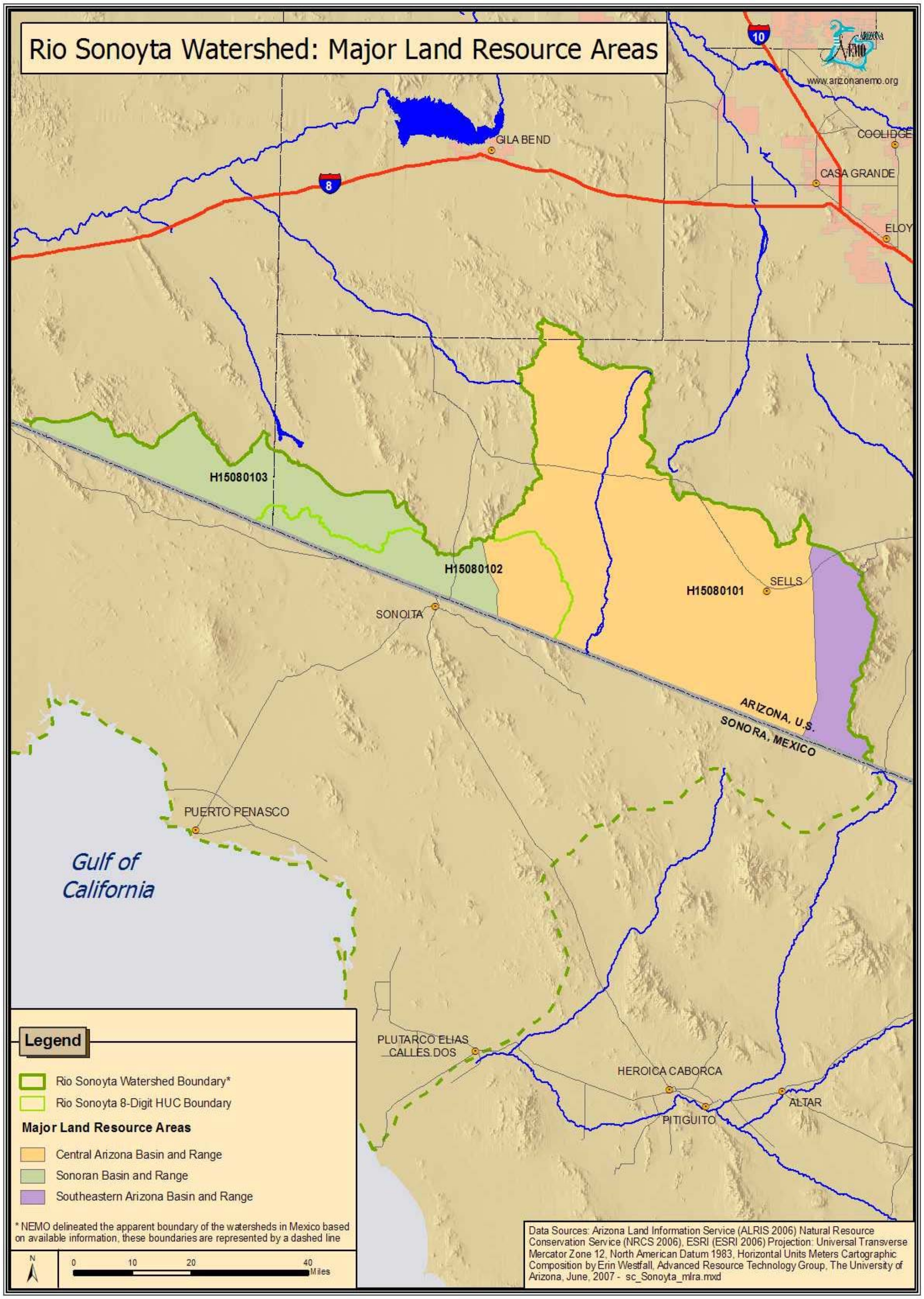

Figure 3.8-2: Rio Sonoyta Watershed: Major Land Resource Areas

Table 3-6.1: Santa Cruz Watershed Riparian and Wetland Areas (acres) by Subwatershed (Part 1 of 2).*

Riparian Vegetation Community	Aguirre Wash Tat Momoli Wash H15050305	Brawley Wash Los Robles Wash H15050304	Lower Santa Cruz River H15050303	Pantano Wash Rillito River H15050302	Santa Rosa Wash H15050306
Agriculture	-	-	-	-	-
Conifer Oak	-	-	-	-	-
Cottonwood Willow	-	-	-	136	-
Flood Scoured	-	-	-	-	-
Marsh	-	-	-	-	-
Mesquite	-	-	-	1,029	-
Mixed Broadleaf	-	-	-	844	-
Strand	-	-	-	173	-
Tamarisk	-	-	-	-	-
Total Area (acres)	-	-	-	*2,182*	-

Data pertains to the U.S. portion of the watershed only.

Table 3-6.1: Santa Cruz Watershed Riparian and Wetland Areas (acres) by Subwatershed (Part 2 of 2).*

Riparian Vegetation Community	Upper Santa Cruz River H15050301	*Santa Cruz River Watershed*	*Rio Asuncion H15080200*	*Rio Asuncion Watershed*
Agriculture	55	55	-	-
Conifer Oak	67	67	-	-
Cottonwood Willow	884	1,020	-	-
Flood Scoured	17	17	-	-
Marsh	51	51	-	-
Mesquite	2,332	3,362	-	-
Mixed Broadleaf	670	1,513	-	-
Strand	1,088	1,260	-	-
Tamarisk	48	48	-	-
Total Area (acres)	*5,212*	*7,393*	-	-

Data pertains to the U.S. portion of the watershed only.

Table 3-6.2: Rio Sonoyta Watershed Riparian and Wetland Areas (acres) by Subwatershed.*

Riparian Vegetation Community	Rio Sonoyta H15080102	San Simon Wash H15080101	Tule Desert H15080103	Rio Sonoyta Watershed
Agriculture	-	-	-	-
Conifer Oak	-	-	-	-
Cottonwood Willow	-	-	-	-
Flood Scoured	-	-	-	-
Marsh	-	-	-	-
Mesquite	-	-	-	-
Mixed Broadleaf	-	-	-	-
Strand	-	-	-	-
Tamarisk	-	-	-	-
Total Area (acres)	-	-	-	-

**Data pertains to the U.S. portion of the watershed only.*
Note: There is no riparian data recorded in this watershed.

Table 3-7.1: Santa Cruz Watershed - Major Land Resource Areas (percent per Subwatershed).

Subwatershed	Major Land Resource Areas, Area (percent per subwatershed)		Santa Cruz River Watershed Area (square miles)
	Southeastern Arizona Basin and Range	Central Arizona Basin and Range	
Aguirre Wash Tat Momoli Wash H15050305	11%	89%	*733*
Brawley Wash Los Robles Wash H15050304	51%	50%	*1,408*
Lower Santana Cruz River H15050303	4%	96%	*1,682*
Pantano Wash Rillito River H15050302	81%	19%	*920*
Santa Rosa Wash H15050306	-	100%	*1,208*
Upper Santa Cruz River H15050301	83%	17%	*2,227*
*Santa Cruz River Watershed (percent)**	*42%*	*58%*	*8,178*
Rio Asuncion H15080200	100%	-	*128*
*Rio Asuncion Watershed (percent)**	*100%*	-	*128*

**Data pertains to the U.S. portion of the watershed only.*

Table 3-7.2: Rio Sonoyta Watershed - Major Land Resource Areas (percent per Subwatershed).

Subwatershed	Major Land Resource Areas, Area (percent per subwatershed)			
	Southeastern Arizona Basin and Range	**Sonoran Basin and Range**	**Central Arizona Basin and Range**	**Rio Sonoyta Watershed Area (square miles)**
Rio Sonoyta H15080102	-	57%	43%	*424*
San Simon Wash H15080101	13%	-	87%	*2,154*
Tule Desert H15080103	-	100%	-	*497*
*Rio Sonoyta Watershed (percent)**	*9%*	*24%*	*67%*	*3,075*

**Data pertains to the U.S. portion of the watershed only.*

References:

Bailey, R.G. 1976. "Ecoregions of the United States" map, Aug. 17, 2001, unnumbered publication. Intermountain Region, USDA Forest Service, Ogden, Utah. http://www.fs.fed.us/land/ecosysmgmt/ecoreg1_home.html

Bailey, R.G. 1995. Description of the Ecoregions of the United States, Aug. 17, 2001. U.S. Forest Service, USDA. http://www.fs.fed.us/land/ecosysmgmt/ecoreg1_home.html

Brown, D.E., C.H. Lowe, and C.P. Pace. 1979. A digitized classification system for the biotic communities of North America, with community (series) and association examples for the Southwest, J. Arizona-Nevada Acad. Sci., 14 (Suppl. 1), 1–16, 1979

Cassady, Stephen. 2000. Arizona's Major Land Resource Areas. Proceedings, Arizona Ecological site Symposium, August 17-19, 2000.

Lowry, J. H, Jr., R. D. Ramsey, K. Boykin, D. Bradford, P. Comer, S. Falzarano, W. Kepner, J. Kirby, L. Langs, J. Prior-Magee, G. Manis, L. O'Brien, T. Sajwaj, K. A. Thomas, W. Rieth, S. Schrader, D. Schrupp, K. Schulz, B. Thompson, C. Velasquez, C. Wallace, E. Waller and B. Wolk. 2005. *Southwest Regional Gap Analysis Project: Final Report on Land Cover Mapping Methods*, RS/GIS Laboratory, Utah State University, Logan, Utah. http://fws-nmcfwru.nmsu.edu/swregap/

Data Sources:*

Arizona State Land Department, Arizona Land Resource Information System (ALRIS), http://www.land.state.az.us/alris/alrishome.html
Habitats (Riparian & Wetland Areas). June 12, 2003.

Interior Columbian Basin Ecosystem Management Project.
http://www.icbemp.gov/spatial/phys/
Bailey's Ecoregions - Divisions map. June 12, 2003.
Bailey's Ecoregions - Provinces map. June 12, 2003.
Bailey's Ecoregions - Sections map. June 12, 2003

Southern Arizona Data Services Program, University of Arizona. Published by the USGS Sonoran Desert Field Station, University of Arizona. http://sdrsnet.srnr.arizona.edu/index.php

Brown, Lowe and Pace Biotic Communities map. June 12, 2003. This dataset was digitized by the Arizona Game and Fish Department, Habitat Branch from the August 1980 David E. Brown & Charles H. Lowe 1:1,000,000 scale, 'Biotic Communities of the Southwest'.

U.S. Department of Agriculture, Natural Resources Conservation Service. ftp-fc.sc.egov.usda.gov/NHQ/pub/land/arc_export/us48mlra.e00.zip Major Land Resource Area Map. July 15, 2003.

United States Fish and Wildlife Service, 2008, Critical Habitat, What is it?, http://www.fs.fed.us/r9/wildlife/tes/docs/esa_references/critical_habitat.pdf

U.S. Geological Survey National Gap Analysis Program. 2004. Provisional Digital Land Cover Map for the Southwestern United States. Version 1.0. RS/GIS Laboratory, College of Natural Resources, Utah State University. http://earth.gis.usu.edu/swgap/landcover.html Southwest Regional Gap Analysis Project Land Cover map, 2005.

**Note: Dates for each data set refer to when data was downloaded from the website. Metadata (information about how and when the GIS data were created) is available from the website in most cases. Metadata includes the original source of the data, when it was created, its geographic projection and scale, the name(s) of the contact person and/or organization, and general description of the data.*

Section 4: Social/Economic Characteristics

County Governments

Understanding which governmental entities hold jurisdiction over the land in a given watershed helps a watershed partnership understand the significance of each stakeholder's influence on the watershed. The Santa Cruz Watershed is located in five counties: Cochise, Maricopa, Pima, Pinal and Santa Cruz Counties, as shown in Figure 4-1.1. The vast majority of the watershed is found in three counties, with 60% in Pima County, 24% in Pinal County, and 13% in Santa Cruz County (Table 4-1.1).

The U.S. portion of the Rio Asuncion is split between two counties, with 44% in Pima County and 56% in Santa Cruz County (Table 4-1.1). The U.S. section of the Rio Sonoyta Watershed lies in three counties, with 89% in Pima County, 10% in Yuma County and 1% in Maricopa County (Table 4-1.2 and Figure 4-1.2).

Council of Governments (COGs)

Four Councils of Governments (COGs) are present in the Santa Cruz Watershed: the Central Arizona Association of Governments (CAAG), the Maricopa Association of Governments (MAG), the Pima Association of Governments (PAG), and the South Eastern Arizona Governments Organization (SEAGO) (Figure 4-2.1). These four COGs match up with the counties described above. The PAG represents the Pima County portion (60% of the watershed), the CAAG represents the Pinal County portion (24% of the watershed), the SEAGO represents Cochise County (13% of the watershed), and MAG represents Maricopa County (44% of the watershed) (Table 4-2.1).

Three COGs are present in the Rio Sonoyta Watershed: the MAG, the PAG and YMPO (the Yuma Metropolitan Planning Organization). These COGs represent 1%, 89%, and 10% of the watershed, respectively (Table 4-2.2 and Figure 4-2.1).

Table 4-1.1: Santa Cruz Watershed, Percent of Subwatershed by County.

Subwatershed and HUC Santa Cruz River Watershed	Area (sq. mi.)	Cochise	Maricopa	Pima	Pinal	Santa Cruz
Aguirre Wash-Tat Momoli Wash – H15050305	733	-	-	89%	11%	-
Brawley Wash-Los Robles Wash – H15050304	1,408	-	-	97%	1%	2%
Lower Santa Cruz River – H15050303	1,682	-	12%	11%	78%	-
Pantano Wash-Rillito River – H15050302	920	3%	-	90%	-	7%
Santa Rosa Wash – H15050306	1,208	-	9%	58%	33%	-
Upper Santa Cruz River – H15050301	2,227	1%	-	51%	6%	42%

Subwatershed and HUC Santa Cruz River Watershed	**Area (sq. mi.)**	**Cochise**	**Maricopa**	**Pima**	**Pinal**	**Santa Cruz**
*Total Santa Cruz River Watershed**	8,178	*1%*	*4%*	*60%*	*24%*	*13%*
Subwatershed and HUC Rio Asuncion Watershed	*Area (sq. mi.)*	Cochise	Maricopa	Pima	Pinal	Santa Cruz
Rio Asuncion – H15080200	128	-	-	44%	-	56%
*Total Rio Asuncion Watershed**	*128*	-	-	*44%*	-	*56%*

*Data pertains to the U.S. portion of the watershed only.

Table 4-1.2: Rio Sonoyta Watershed, Percent of Subwatershed by County.

Subwatershed and HUC Rio Sonoyta Watershed	**Area (sq. mi.)**	**Maricopa**	**Pima**	**Yuma**
Rio Sonoyta - H15080102	424	-	98%	2%
San Simon Wash – H15080101	2,154	1%	99%	-
Tule Desert Area – H15080103	497	-	37%	63%
*Total Rio Sonoyta Watershed**	*3,075*	*1%*	*89%*	*10%*

*Data pertains to the U.S. portion of the watershed only.

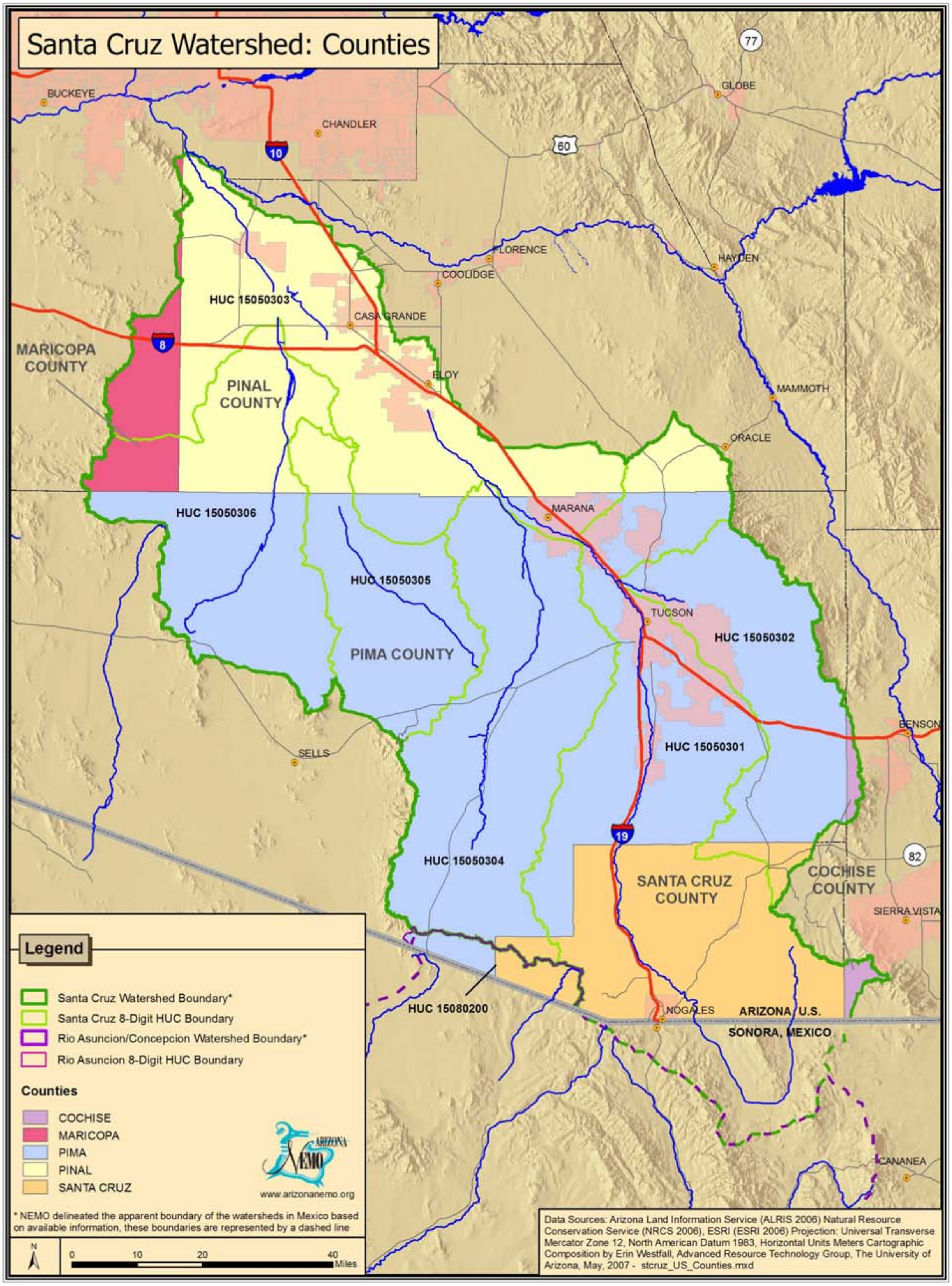

Figure 4-1.1: Santa Cruz Watershed Counties

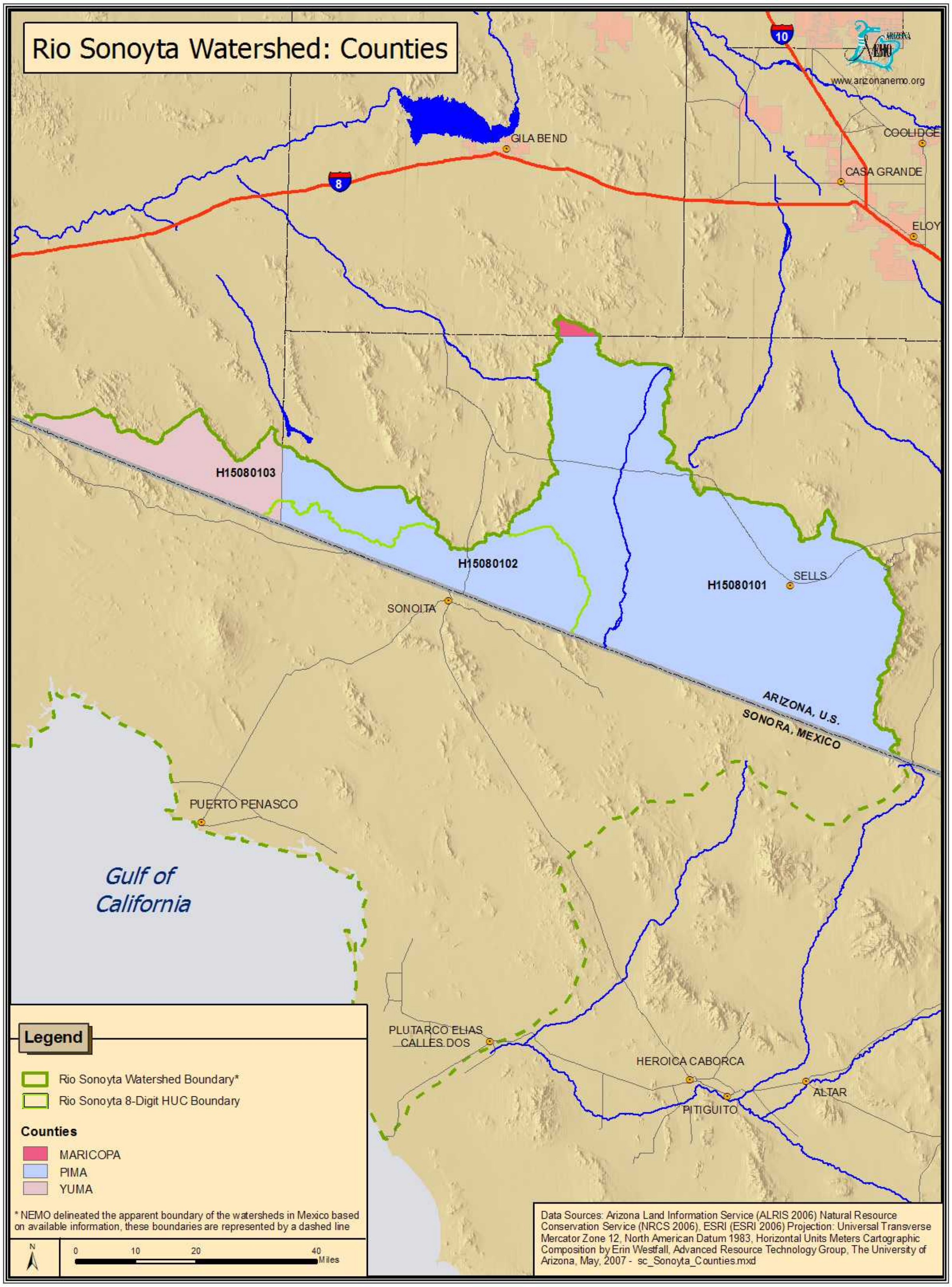

Figure 4-1.2: Rio Sonoyta Watershed Counties

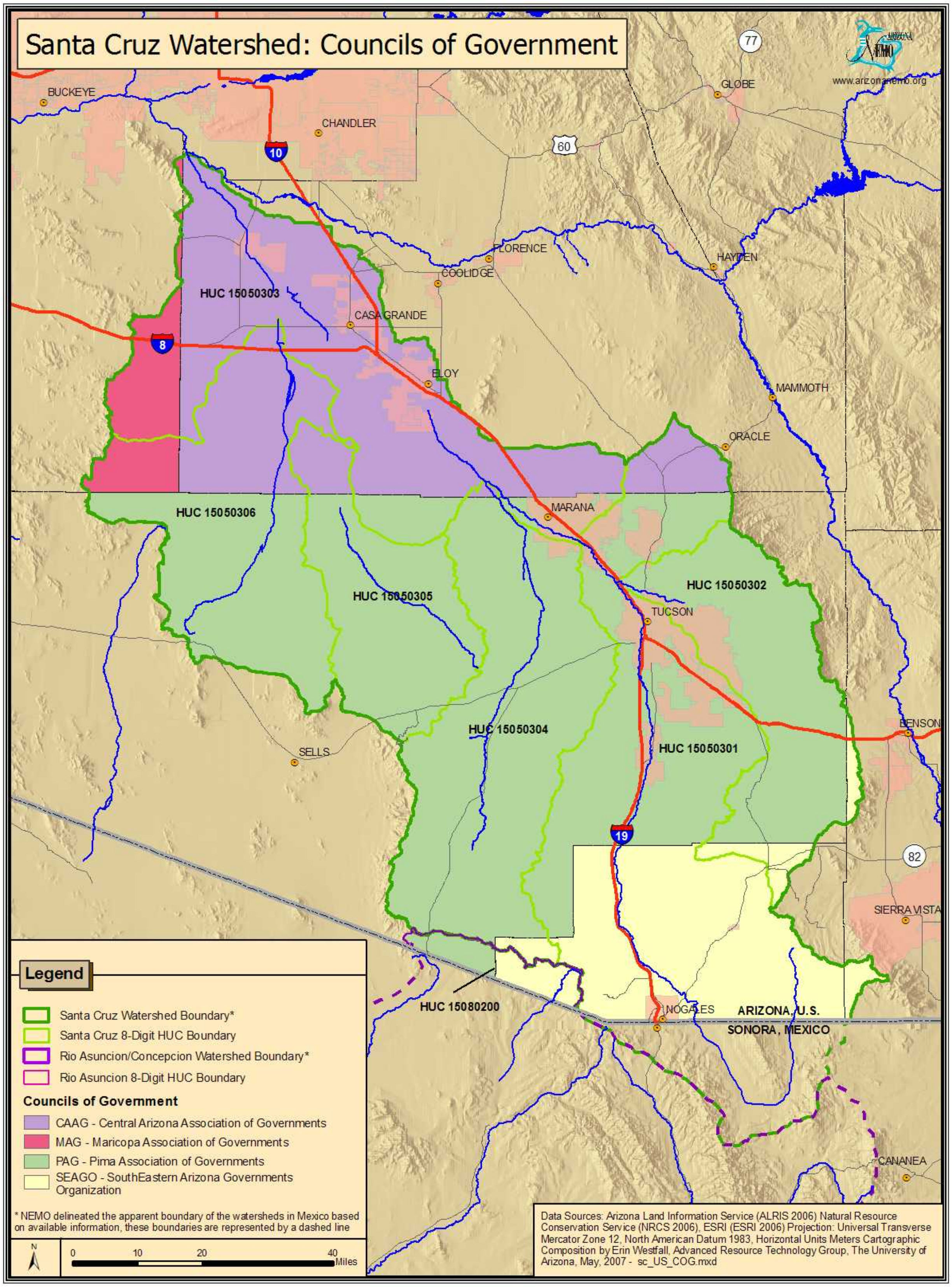

Figure 4-2.1: Santa Cruz Watershed Councils of Government

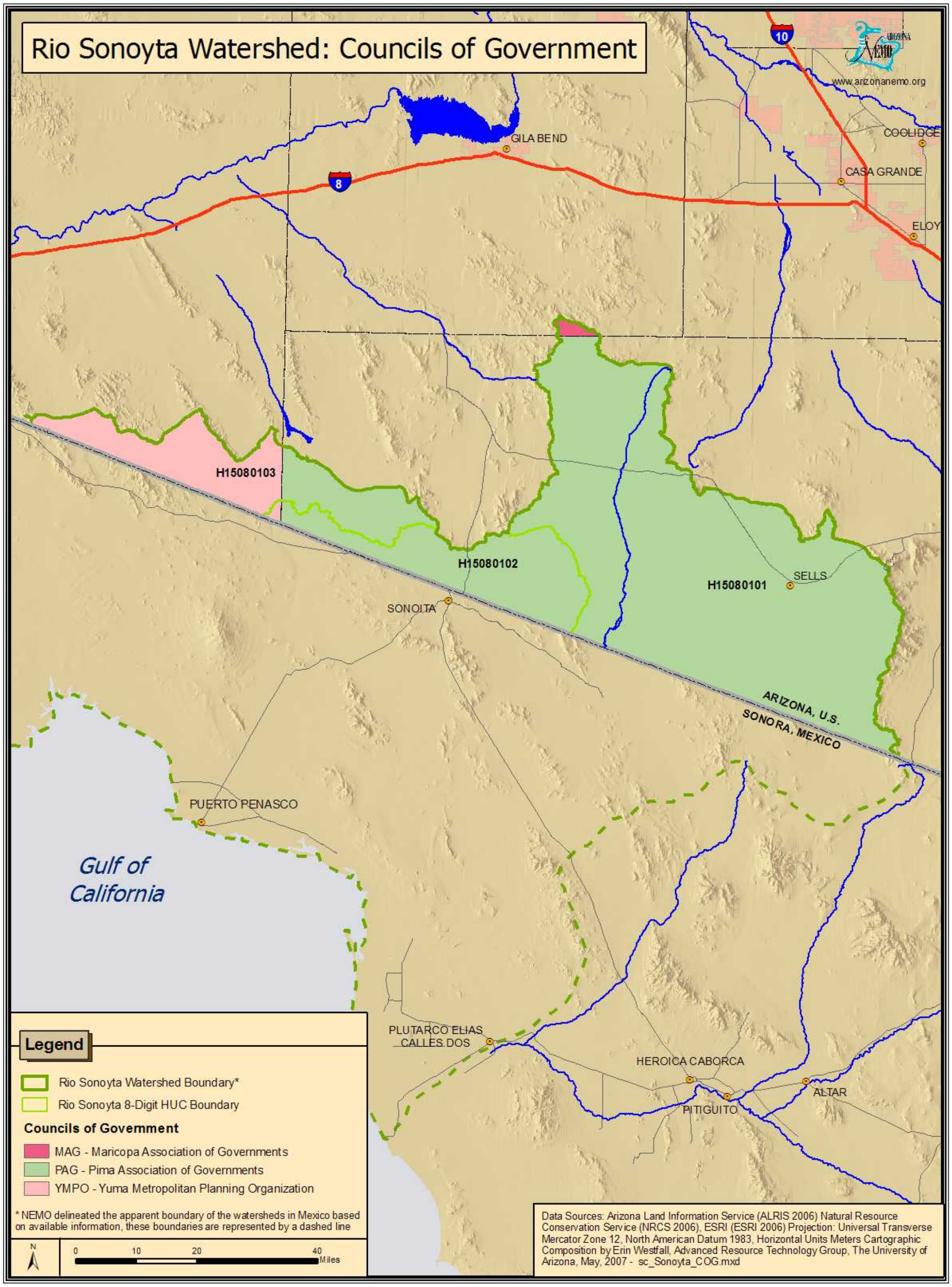

Figure 4-2.2: Rio Sonoyta Watershed Councils of Government

Table 4-2.1: Santa Cruz Watershed Councils of Governments, Percent by Subwatershed.

Subwatershed Name and HUC	**Councils Of Governments**			
	CAAG[1]	**MAG[2]**	**PAG[3]**	**SEAGO[4]**
Aguirre Wash-Tat Momoli Wash –H15050305	11%	-	89%	-
Brawley Wash-Los Robles Wash – H15050304	1%	-	97%	2%
Lower Santa Cruz River – H15050303	78%	12%	11%	-
Pantano Wash-Rillito River – H15050302	-	-	90%	10%
Santa Rosa Wash – H15050306	33%	9%	58%	-
Upper Santa Cruz River – H15050301	6%	-	51%	43%
*Total Santa Cruz River Watershed**	*24%*	*4%*	*60%*	*13%*
Rio Asuncion – H1580200	-	-	44%	56%
*Total Rio Sonoyta Watershed**	-	-	*44%*	*56%*

*Data pertains to the U.S. portion of the watershed only.
1 Central Arizona Association of Governments
2 Maricopa Association of Governments
3 Pima Association of Governments
4 Southeastern Arizona Governments Organization

Table 4-2.2: Rio Sonoyta Watershed Councils of Governments, Percent by Subwatershed.

Subwatershed Name and HUC	**Councils Of Governments**		
	MAG[1]	**PAG[2]**	**YMPO[3]**
Rio Sonoyta H15080102	-	98%	2%
San Simon Wash H15080101	1%	99%	-
Tule Desert Area H15080103	-	37%	63%
*Total Rio Sonoyta Watershed**	*1%*	*89%*	*10%*

*Data pertains to the U.S. portion of the watershed only.
1 Maricopa Association of Governments
2 Pima Association of Governments
3 Yuma Metropolitan Planning Organization

Urban Areas

The U.S. Census Bureau categorizes various types of population centers based on population figures and density. Densely settled territory that contains 50,000 or more people is defined as an urban area (www.census.gov/geo/www/geo_defn.html). Based on that definition and Census Bureau data, there are eleven major urban areas that lie partially within the Santa Cruz Watershed: Casa Grande, Eloy, Marana, Maricopa, Nogales, Oro Valley, Patagonia, Sahuarita, Sierra Vista, South Tucson, and Tucson (Figure 4-3.1). Tucson has the largest area with 143,052 acres (224 square miles), most of which lies within the Upper Santa Cruz River Subwatershed. Table 4-3 tabulates these areas.

There are no major population centers in the Rio Asuncion Watershed (Table 4-3) or in the Rio Sonoyta Watershed (no figure).

A population density map was created using 2000 census block population data. Areas with a population density greater than 1,000 persons per square mile were determined (Figure 4-4). This classification yielded three urban areas: Nogales, Tucson, and South Tucson. South Tucson had the greatest density with 5,361 persons per square mile (Table 4-4). There is no figure for the Rio Sonoyta Watershed.

Table 4-3: Santa Cruz Watershed Urban Areas (acres), Table 1 of 2.

Sub-watershed Name	**Urban Area (acres)**					
	Casa Grande	**Eloy**	**Marana**	**Maricopa**	**Nogales**	**Oro Valley**
Aguirre Wash - Tat Momoli Wash-H15050305	-	-	-	-	-	-
Brawley Wash-Los Robles Wash-H15050304	-	-	8,573	-	-	-
Lower Santa Cruz River – H15050303	34,648	46,425	40,961	18,817	-	-
Pantano Wash – Rillito River – H15050302	-	-	104	-	-	648
Santa Rosa Wash – H15050306	-	-	-	-	-	-
Upper Santa Cruz River – H15050301	-	-	25,306	-	13,030	20,337
*Santa Cruz River Watershed**	*64,648*	*46,425*	*74,944*	*18,817*	*13,030*	*20,985*
Sub-watershed Name	Casa Grande	Eloy	Marana	Maricopa	Nogales	Oro Valley
Rio Asuncion – H1580200	-	-	-	-	-	-
*Rio Asuncion Watershed**	-	-	-	-	-	-

*Data pertains to the U.S. portion of the watershed only.

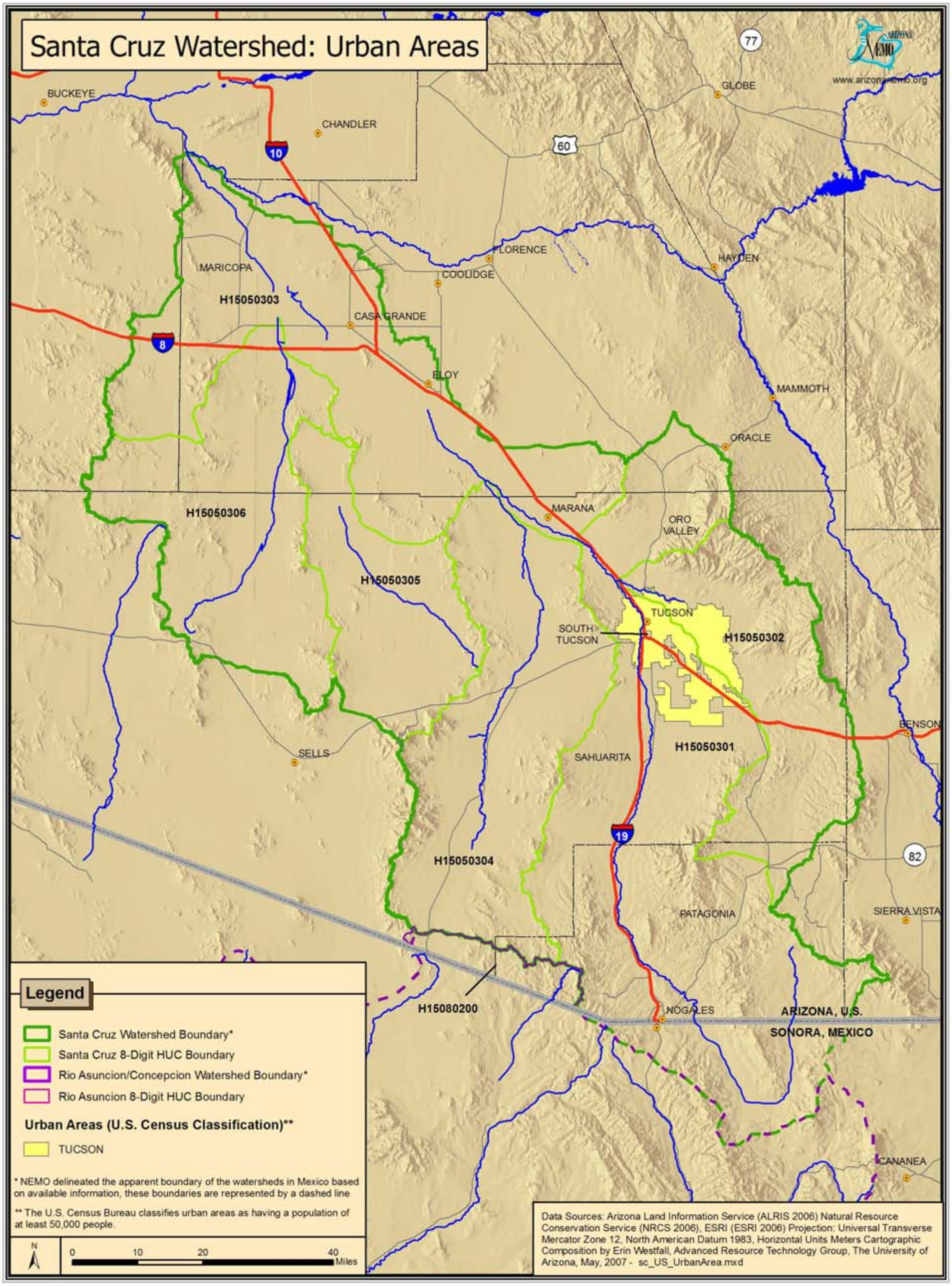

Figure 4-3: Santa Cruz Watershed Urban Areas

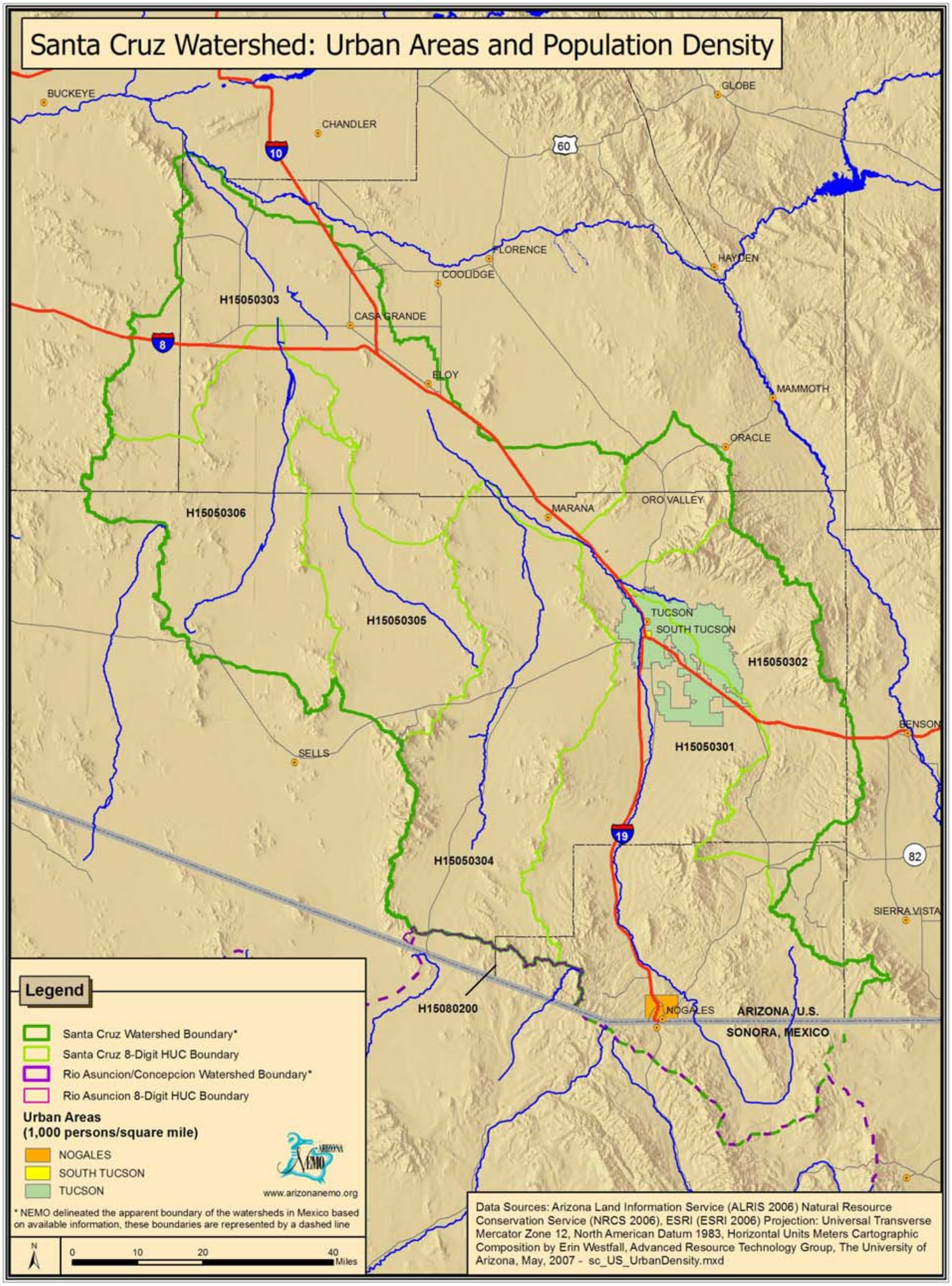

Figure 4-4: Santa Cruz Watershed Urban Areas and Population Density

Table 4-3: Santa Cruz Watershed Urban Areas (acres), Table 2 of 2.

Sub-watershed Name	**Urban Area (acres)**				
	Patagonia	**Sahuarita**	**Sierra Vista**	**South Tucson**	**Tucson**
Aguirre Wash - Tat Momoli Wash- H15050305	-	-	-	-	-
Brawley Wash- Los Robles Wash- H15050304	-	-	-	-	-
Lower Santa Cruz River – H15050303	-	-	-	-	-
Pantano Wash – Rillito River – H15050302	-	-	-	-	46,306
Santa Rosa Wash – H15050306	-	-	-	-	-
Upper Santa Cruz River – H15050301	765	18,772	6	655	96,746
*Santa Cruz River Watershed**	*765*	*18,772*	*6*	*655*	*143,052*
Sub-watershed Name	Patagonia	Sahuarita	Sierra Vista	South Tucson	Tucson
Rio Asuncion – H1580200	-	-	-	-	-
*Rio Asuncion Watershed**	-	-	-	-	-

*Data pertains to the U.S. portion of the watershed only.

Table 4-4: Santa Cruz Watershed Urban Areas Based on 2000 Population Density (1,000 persons/square mile).

Urban Areas	**Population 2000**	**Area (square miles)**	**Urban Area Density persons / sq. mi.**
Nogales	21,240	20	1,025
Tucson	51,4725	228	2,132
South Tucson	5,550	1	5,361

*Data pertains to the U.S. portion of the watershed only.

** Population data obtained from 2000 census data

Population

Census Population Densities in 1990

Census block statistics for 1990 were compiled from a CD prepared by Geo-Lytics (Geo-Lytics, 1998). These data were linked with census block data and a normalization process using a grid of 7 km squares was used to create a density map (Figures 4-5.1 and 4-5.2). This process involved calculating density per census block and intersecting it with the grid, which was then used to calculate the number of people and thus density per grid square.

Table 4-5.1 shows the tabulated minimum, maximum and mean number of persons per square mile in 1990 for each subwatershed in the Santa Cruz Watershed. In 1990, the mean population density for the entire watershed was 84.89 persons per square mile. The Pantano Wash-Rillito River Subwatershed had the highest mean population density with a 315.50 persons per square mile, and the Upper Santa Cruz River Subwatershed had the highest maximum population of 10,858.8 persons per square mile. The Aguirre Wash-Tat Moli Wash Subwatershed had a mean of only 0.43 persons per square mile.

The U.S. portion of the Rio Asuncion Watershed had a mean population of 0.35 persons per square mile and a maximum population of 2.0 persons per square mile. The U.S. portion of the Rio Sonoyta Watershed had a mean of 1.88 people per square mile and a maximum of 725.3 people per square mile (Table 4-5.2)

Table 4-5.1: Santa Cruz Watershed 1990 Population Density (persons/square mile).

Sub-watershed Name	**Area (sq. miles)**	**Min**	**Max**	**Mean**
Aguirre Wash-Tat Momoli Wash – H15050305	733	0	16	0.43
Brawley Wash-Los Robles Wash – H15050304	1,408	0	1,277.4	19.34
Lower Santa Cruz River – H15050303	1,682	0	4,152.9	24.45
Pantano Wash-Rillito River – H15050302	920	0	7,221.0	315.50
Santa Rosa Wash – H15050306	1,208	0	352.2	2.09
Upper Santa Cruz River – H15050301	2,227	0	10,858.8	178.08
Total Santa Cruz River Watershed	*8,178*	*0*	*10,858.8*	*84.98*
Rio Asuncion – H15080200	128	0	2.0	0.35
*Total Rio Asuncion *Watershed*	*128*	*0*	*2.0*	*0.35*

*Data pertains to the U.S. portion of the watershed only.
Note: Adjacent watersheds may share a grid square.

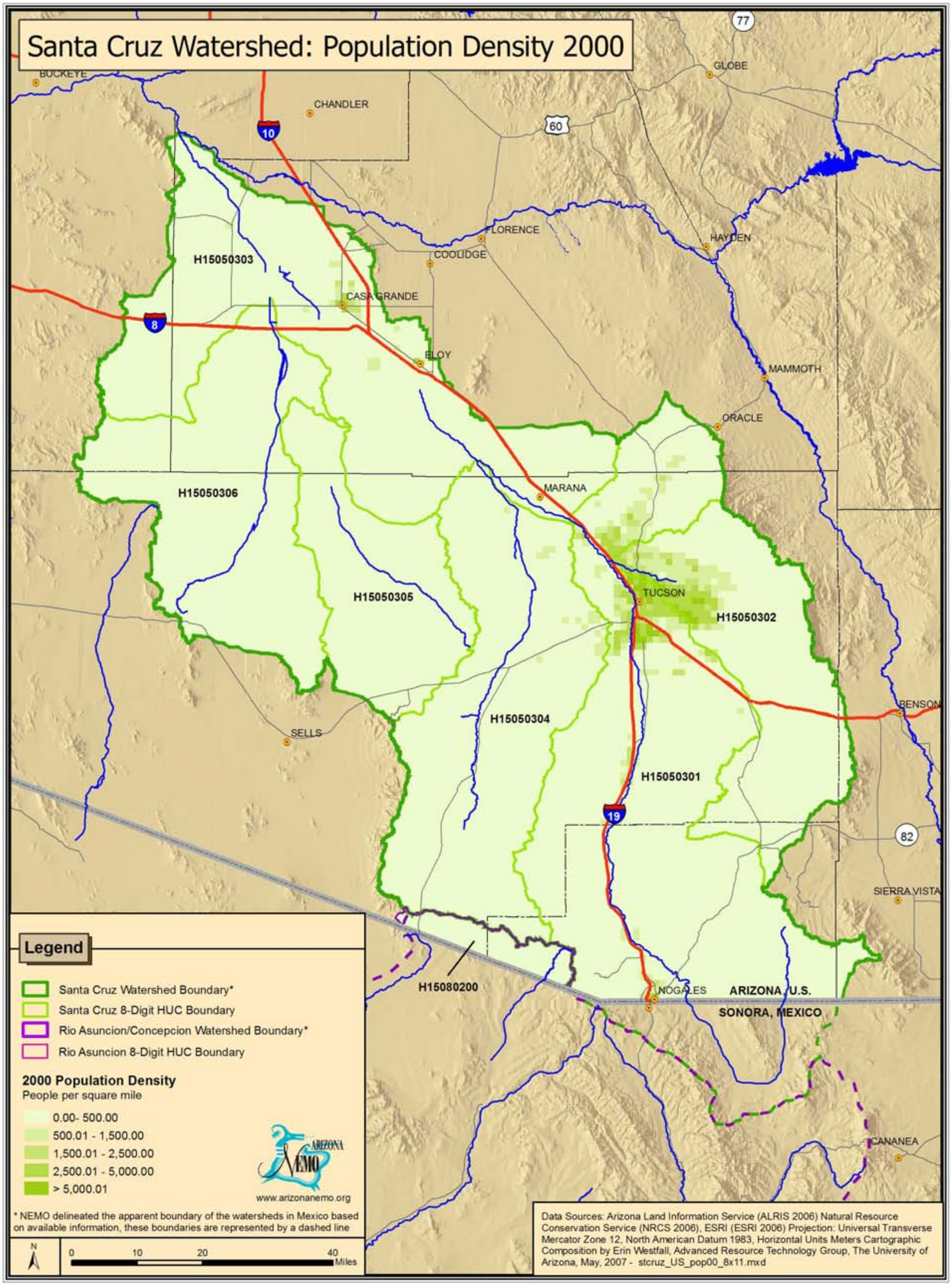

Figure 4-5.1: Santa Cruz Watershed Population Density 1990

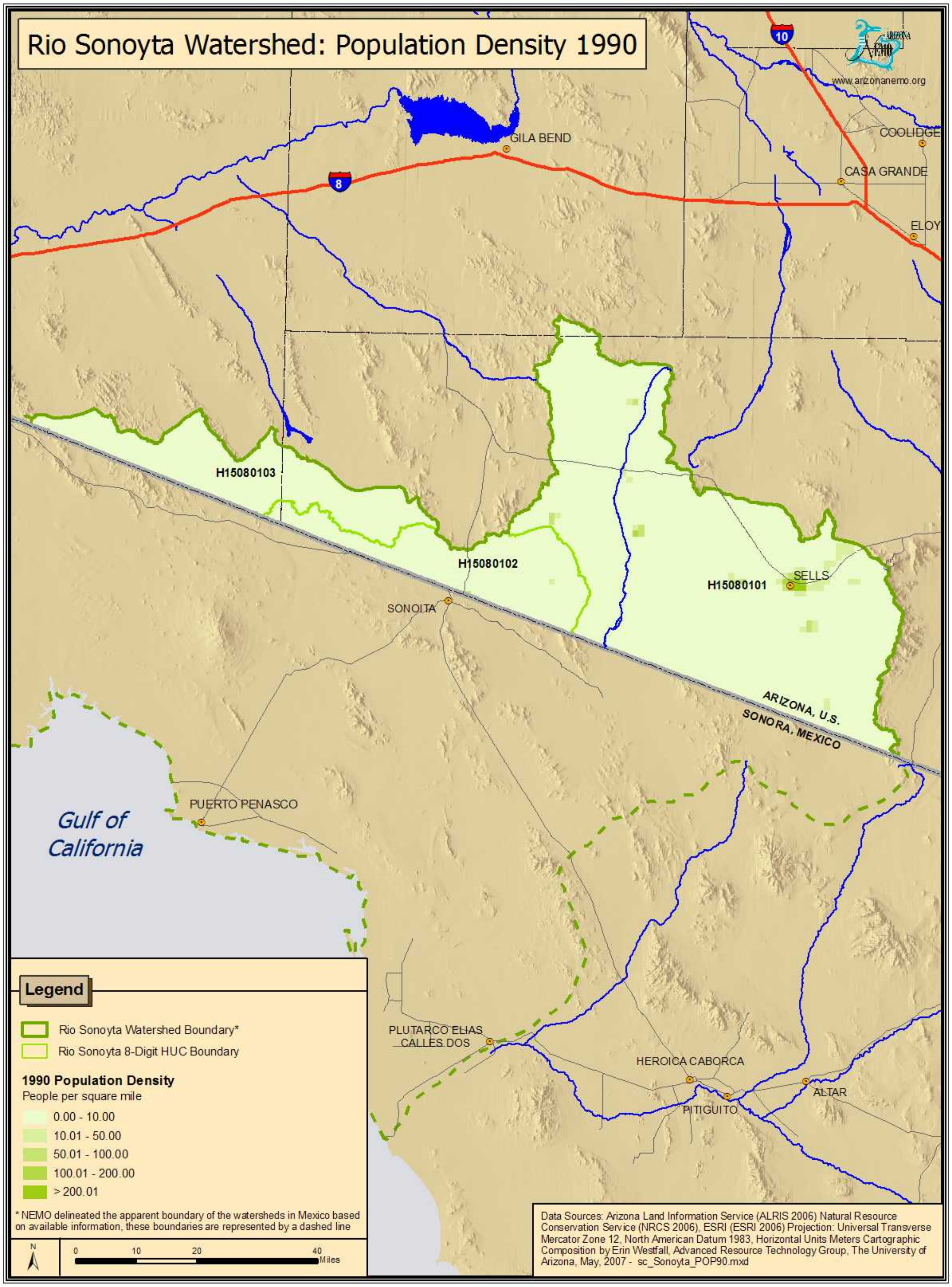

Figure 4-5.2: Rio Sonoyta Watershed Population Density 1990

Table 4-5.2: Rio Sonoyta Watershed 1990 Population Density (persons/square mile).

Sub-watershed Name	Area (sq. miles)	Min	Max	Mean
Rio Sonoyta H15080102	424	0	69.8	0.76
San Simon Wash H15080101	2,154	0	725.3	2.57
Tule Desert Area H15080103	497	0	0	0
*Total Rio Sonoyta Watershed**	*3,075*	*0*	*725.3*	*1.88*

*Data pertains to the U.S. portion of the watershed only.
Note: Adjacent watersheds may share a grid square.

Census Population Densities in 2000

The Census Block 2000 statistics data were downloaded from the Environmental Systems Research Institute (ESRI) website (ESRI Data Products, 2003) and are shown in Table 4-6.1. A population density map (Figure 4-6.1) was created from these data. The Santa Cruz Watershed mean population density in 2000 was 109.23 persons per acre. The Pantano Wash – Rillito River and the Upper Santa Cruz River Watersheds had the highest mean density population at 369.10 and 233.01 persons per square mile, respectively. The highest maximum population density was found in the same two watersheds, which shared the same total of 7811.7 persons per square mile.

The Rio Asuncion and the Rio Sonoyta Watersheds had 2000 mean population densities of 0.68 and 1.76 persons/square mile, and had maximum population densities of 23.1 and 816.5 persons per square mile, respectively (Table 4-6-2 and Figure 4-6.2).

Population Change

The 1990 and 2000 population density maps were used to create a population density change map. The resulting map (Figure 4-7.1 and Table 4-7.1) shows population increase or decrease over the ten year time frame. Overall, Santa Cruz Watershed population density increased by an average of 24 persons per square mile during this ten year time period. Two subwatersheds had decreases in average population: Aguirre Wash – Tat Momoli and Santa Rosa Wash, 0.01 and 0.16 persons per square mile, respectively.

The Rio Asuncion Watershed registered a 0.40 increase in persons per square mile over the ten year period. Table 4-7.2 and Figure 4-7.2 show that the Rio Sonoyta Watershed experienced a decrease in population density, from 1990 to 2000, of 0.07 persons per square mile.

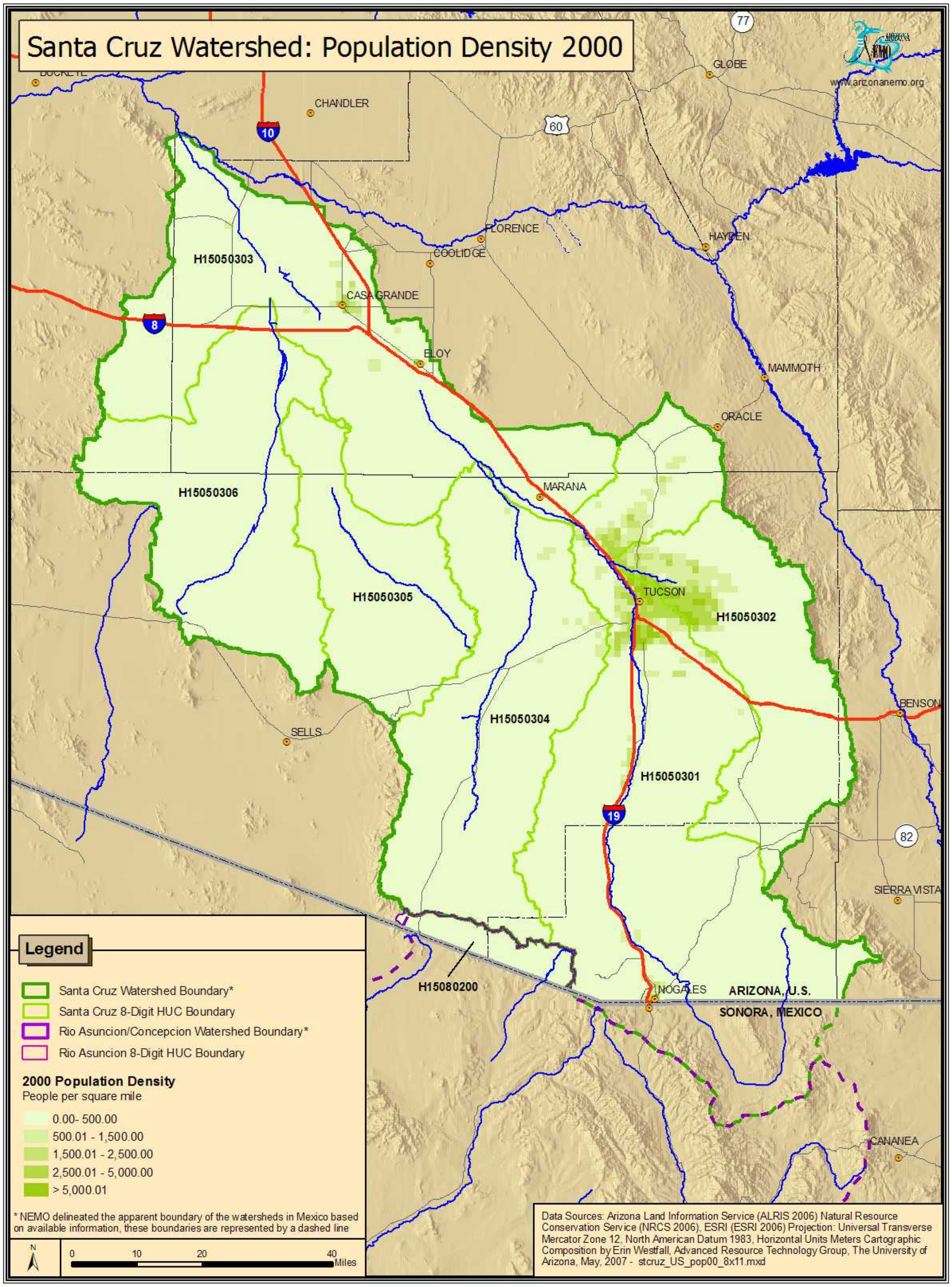

Figure 4-6.1: Santa Cruz Watershed Population Density 2000

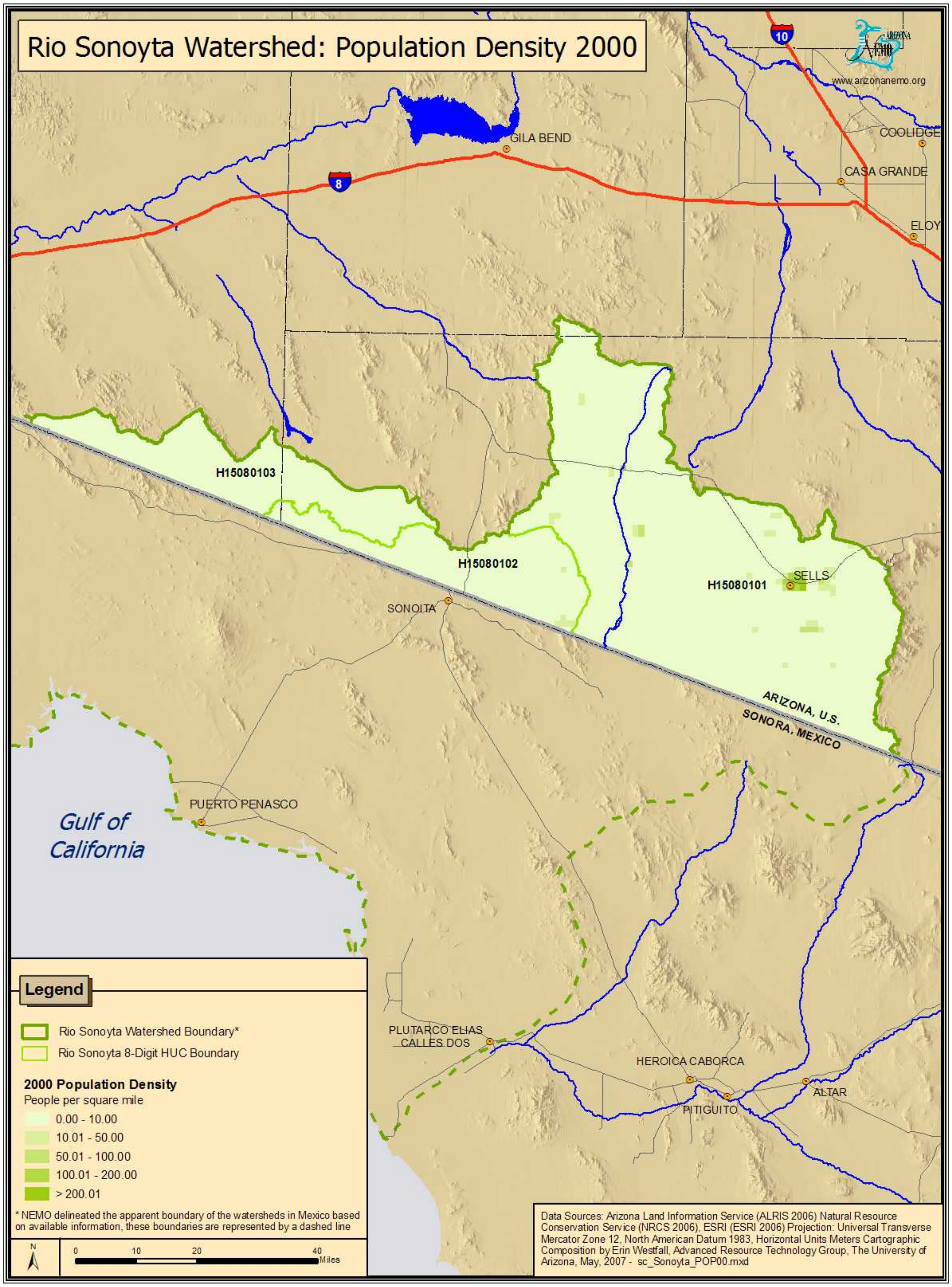

Figure 4-6.2: Rio Sonoyta Watershed Population Density 2000

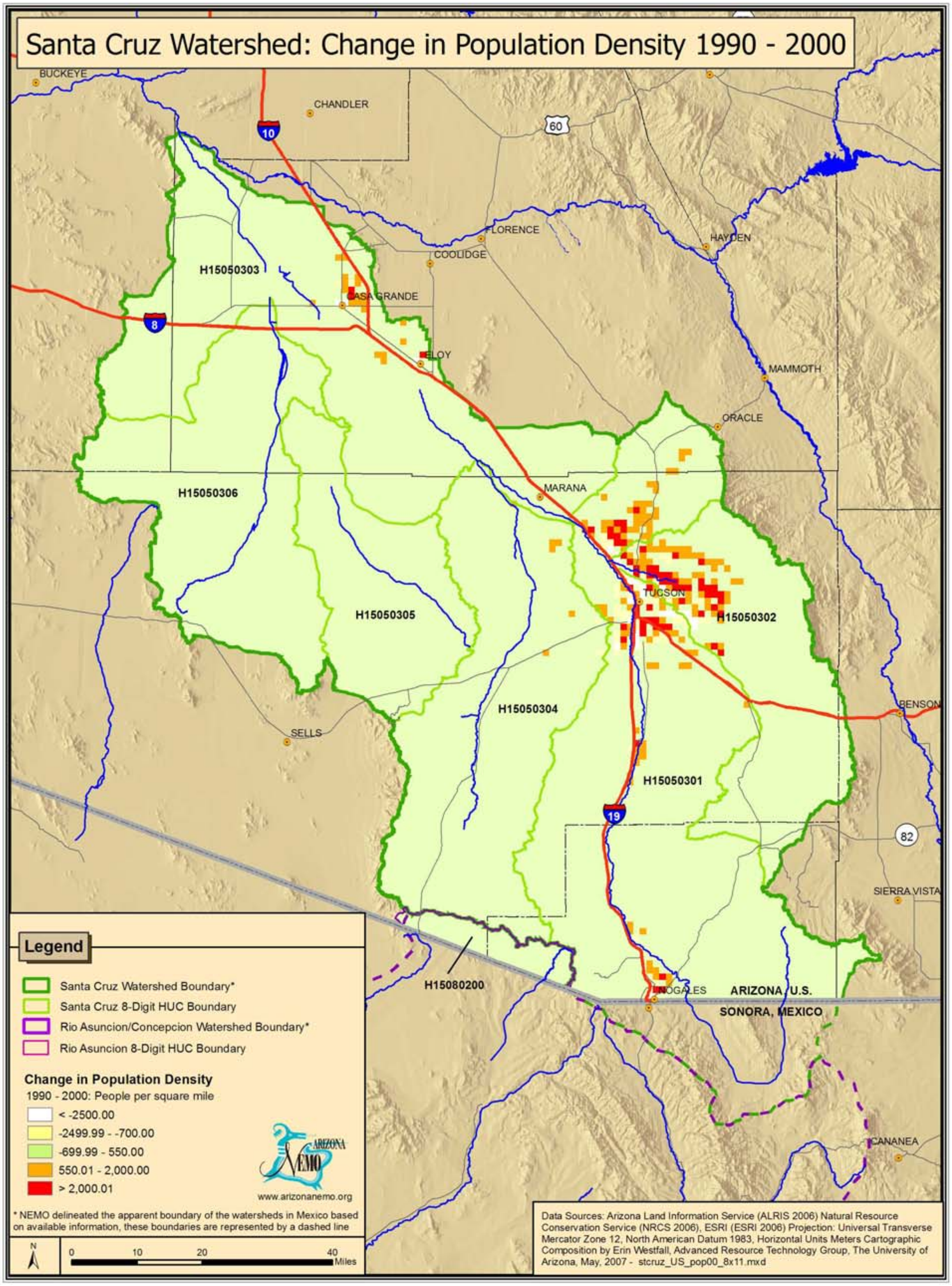

Figure 4-7.1: Santa Cruz Watershed Change in Population Density 1990-2000

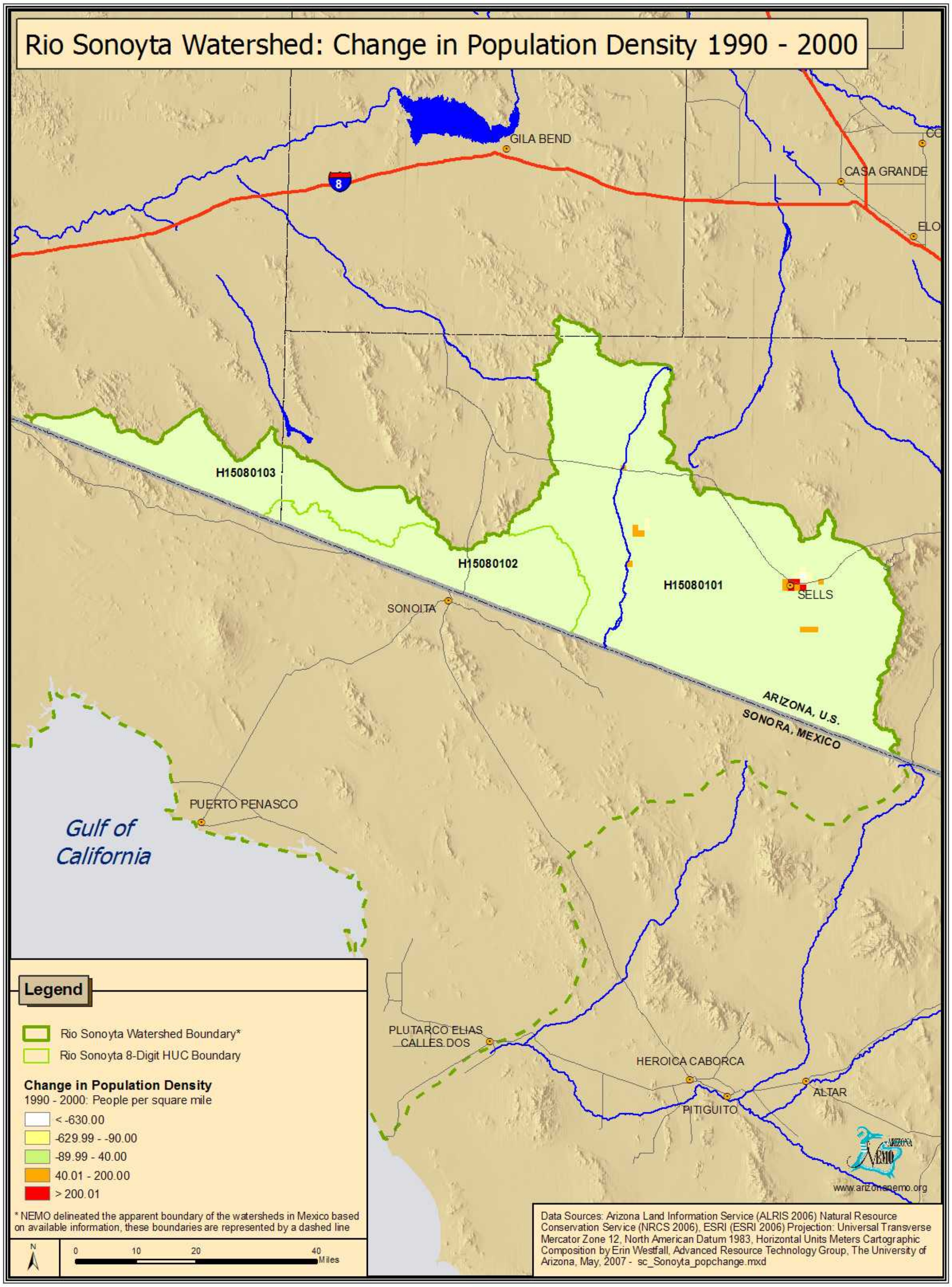

Figure 4-7.2: Rio Sonoyta Watershed Change in Population Density 1990-2000

Table 4-6.1: Santa Cruz Watershed 2000 Population Density (persons/square mile).

Sub-watershed Name	Area (sq. miles)	Min	Max	Mean
Aguirre Wash-Tat Momoli Wash – H15050305	733	0	21.5	0.39
Brawley Wash-Los Robles Wash – H15050304	1,408	0	1,461.1	29.51
Lower Santa Cruz River – H15050303	1,682	0	4,674.6	34.82
Pantano Wash-Rillito River – H15050302	920	0	7,811.7	369.10
Santa Rosa Wash – H15050306	1,208	0	326.1	2.15
Upper Santa Cruz River – H15050301	2,227	0	7,811.7	233.01
*Total Santa Cruz River Watershed**	*8,178*	*0*	*7,811.7*	*109.23*
Rio Asuncion – H15080200	128	0	23.1	0.68
*Total Rio Asuncion Watershed**	*128*	*0*	*23.1*	*0.68*

*Data pertains to the U.S. portion of the watershed only.
Note: Adjacent watersheds may share a grid square.

Table 4-6.2: Rio Sonoyta Watershed 2000 Population Density (persons/square mile).

Sub-watershed Name	Area (sq. miles)	Min	Max	Mean
Rio Sonoyta H15080102	424	0	31.9	0.62
San Simon Wash H15080101	2,154	0	816.5	2.43
Tule Desert Area H15080103	497	0	0.25	0.013
*Total Rio Sonoyta Watershed**	*3,075*	*0*	*816.5*	*1.76*

*Data pertains to the U.S. portion of the watershed only.
Note: Adjacent watersheds may share a grid square.

Table 4-7.1: Santa Cruz River Watershed Population Density Change 1990-2000 (persons/square mile).

Sub-watershed Name	**Area (sq. miles)**	**Min**	**Max**	**Mean**
Aguirre Wash-Tat Momoli Wash – H15050305	733	-15.9	21.2	-0.01
Brawley Wash-Los Robles Wash – H15050304	1,408	-960.9	1,219.3	5.9
Lower Santa Cruz River – H15050303	1,682	-4,152.7	4,662.5	10.3
Pantano Wash-Rillito River – H15050302	920	-5,295.9	5,655.0	110.4
Santa Rosa Wash – H15050306	1,208	-350.4	323.6	-0.16
Upper Santa Cruz River – H15050301	2,227	-8,330.7	5,234.1	17.5
*Total Santa Cruz River Watershed**	*8,178*	*-8,330.7*	*5,655.0*	*24.25*
Sub-watershed Name	Area (sq. miles)	Min	Max	Mean
Rio Asuncion – H15080200	128	-1.9	22.9	0.40
*Total Rio Asuncion Watershed**	*128*	*-1.9*	*22.9*	*0.40*

*Data pertains to the U.S. portion of the watershed only.
Note: Adjacent watersheds may share a grid square.

Table 4-7.2: Rio Sonoyta Watershed Population Density Change 1990-2000 (persons/square mile).

Sub-watershed Name	**Area (sq. miles)**	**Min**	**Max**	**Mean**
Rio Sonoyta H15080102	424	-69.7	30.3	-0.09
San Simon Wash H15080101	2154	-630.1	536.9	-0.08
Tule Desert Area H15080103	497	0	0.3	0.01
*Total Rio Sonoyta Watershed**	*3,075*	*-630.1*	*536.9*	*-0.07*

*Data pertains to the U.S. portion of the watershed only.
Note: Adjacent watersheds may share a grid square

Housing Density, 2000 and 2030

The Watershed Housing Density Maps for the years 2000 and 2030 were created with data developed by David M. Theobald (Theobald, 2005). Theobald created a nationwide housing density model that incorporates a thorough way to account for land-use change beyond the “urban fringe.”

Exurban regions are the “urban fringe”, or areas outside suburban areas, having population densities greater than 0.68 – 16.18 ha (1.68 – 40 acres) per unit. Theobald stresses that exurban areas are increasing at a much faster rate than urban sprawl, are consuming much more land, and are having a greater impact on ecological health, habitat fragmentation and other resource concerns.

Theobald estimates that the exurban density class has increased at a much faster rate than the urban/suburban density classes. Theobald's model forecasts that this trend will continue and may even accelerate by 2030. This indicates that development patterns are shifting more towards exurban, lower density, housing units, and are thereby consuming more land. He suggests that exurban development has a greater overall effect on natural resources because of the larger footprint and disturbance zone, a higher percent of impervious surfaces, and higher pollution because of more vehicle miles traveled to work and shopping.

Figure 4-8.1 and Table 4-8.1, Santa Cruz Watershed Housing Density for 2000, identify that 78.07% of housing is located in "undeveloped private" areas, while 15.74% is located in "exurban" areas. Figure 4-9.1 and Table 4-9.1, Housing Density for 2030, projects "undeveloped private" areas decreasing to 24.53% and "exurban" areas increasing to 57.50%.

For the U.S. sections of the Rio Asuncion and Rio Sonoyta Watersheds, "undeveloped private" areas in 2000 constitute 24.03% and 88.03% of the area, respectively (Table 4.8.2 and Figure 4-8.2) In 2030, "undeveloped private" area in the Rio Asuncion and Rio Sonoyta decreased to 4.78% and to 0.72% , respectively (Table 4-9.2 and Figure 4-9.2). "Exurban" areas increased from 15.74% and 0.79% to 77.44% and 98.54%, respectively, from 2000 to 2030.

Table 4.8.1: Santa Cruz Watershed 2000 Housing Density (Percent of Watershed) (part 1 of 2).*

Housing Density	Aguirre Wash Tat Momoli Wash H15050305	Brawley Wash Los Robles Wash H15050304	Lower Santa Cruz River H15050303	Pantano Wash Rillito River H15050302	Santa Rosa Wash H15050306
Undeveloped Private	97.14%	63.07%	62.78%	21.46%	93.74%
Rural	2.84%	27.02%	29.17%	58.75%	5.92%
Exurban	0.02%	9.51%	6.88%	19.31%	0.33%
Suburban	-	0.33%	0.72%	0.25%	0.01%
Urban	-	0.07%	0.45%	0.23%	-

** These figures report the percent of the watershed that contains housing density data, and does not take into account null values. Some areas of the watershed do not contain data due to the modeling techniques utilized by the creator of the data.*
Data Sources: Theobald, D. 2005. Landscape patterns of exurban growth in the USA from 1980 to 2020. Ecology and Society 10(1): 32. [online] URL: http://www.ecologyandsociety.org/vol10/iss1/art32/

Table 4.8.1: Santa Cruz Watershed 2000 Housing Density (Percent of Watershed) (part 2 of 2).*

Housing Density	Upper Santa Cruz River H15050301	Santa Cruz River Watershed**	Rio Asuncion H15080200	Rio Asuncion Watershed**
Undeveloped Private	39.05%	78.07%	24.03%	24.03%
Rural	35.19%	16.71%	60.17%	60.17%
Exurban	22.42%	4.64%	15.74%	15.74%
Suburban	2.32%	0.38%	0.06%	0.06%
Urban	1.02%	0.20%	-	-

** These figures report the percent of the watershed that contains housing density data, and does not take into account null values. Some areas of the watershed do not contain data due to the modeling techniques utilized by the creator of the data.*
***Data pertains to the U.S. portion of the watershed only.*
Data Sources: Theobald, D. 2005. Landscape patterns of exurban growth in the USA from 1980 to 2020. Ecology and Society 10(1): 32. [online] URL: http://www.ecologyandsociety.org/vol10/iss1/art32/

Table 4.8.2: Rio Sonoyta Watershed 2000 Housing Density (Percent of Watershed).*

Housing Density	Rio Sonoyta H15080101	San Simon Wash H15080101	Tule Desert Area H15080103	Rio Sonoyta Watershed**
Undeveloped Private	79.59%	88.56%	100.00%	88.03%
Rural	19.85%	10.61%	-	11.17%
Exurban	0.55%	0.81%	-	0.79%
Suburban	0.01%	0.01%	-	0.01%
Urban	-	> 0.00%	-	> 0.00%

** These figures report the percent of the watershed that contains housing density data, and does not take into account null values. Some areas of the watershed do not contain data due to the modeling techniques utilized by the creator of the data.*
***Data pertains to the U.S. portion of the watershed only.*
Data Sources: Theobald, D. 2005. Landscape patterns of exurban growth in the USA from 1980 to 2020. Ecology and Society 10(1): 32. [online] URL: http://www.ecologyandsociety.org/vol10/iss1/art32/

Table 4-9.1: Santa Cruz Watershed 2030 Housing Density (Percent of Watershed) (part 1 of 2).*

Housing Density	Aguirre Wash Tat Momoli Wash H15050305	Brawley Wash Los Robles Wash H15050304	Lower Santa Cruz River H15050303	Pantano Wash Rillito River H15050302	Santa Rosa Wash H15050306
Undeveloped Private	10.15%	5.41%	32.03%	3.30%	35.67%
Rural	0.88%	6.83%	44.06%	8.21%	2.85%
Exurban	88.97%	81.92%	21.00%	80.39%	61.24%
Suburban	-	1.73%	2.28%	5.18%	0.18%
Urban	-	4.11%	0.63%	2.92%	0.07%

** These figures report the percent of the watershed that contains housing density data, and does not take into account null values. Some areas of the watershed do not contain data due to the modeling techniques utilized by the creator of the data.*
Data Sources: Theobald, D. 2005. Landscape patterns of exurban growth in the USA from 1980 to 2020. Ecology and Society 10(1): 32. [online] URL: http://www.ecologyandsociety.org/vol10/iss1/art32/

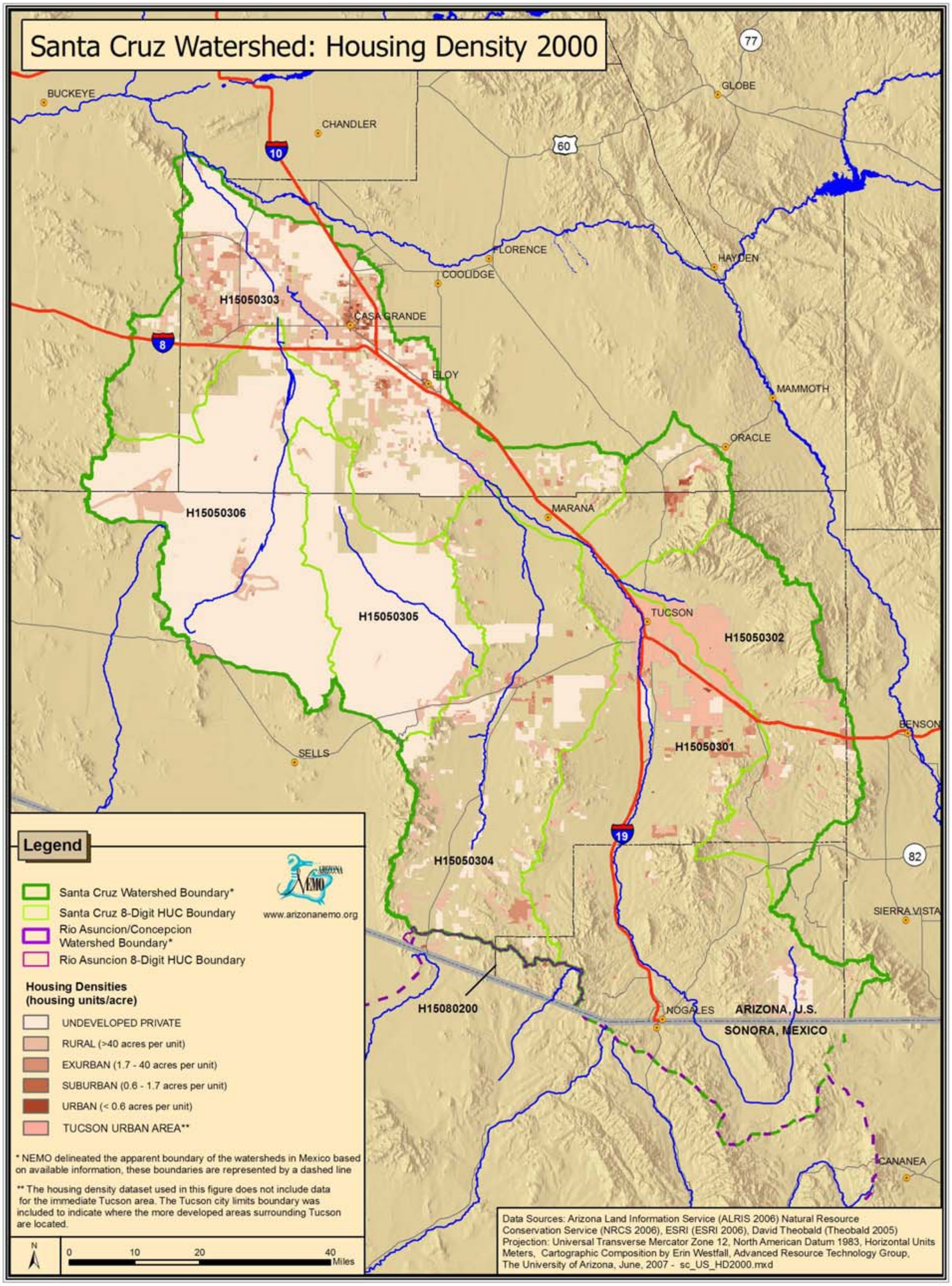

Figure 4-8.1: Santa Cruz Watershed Housing Density 2000

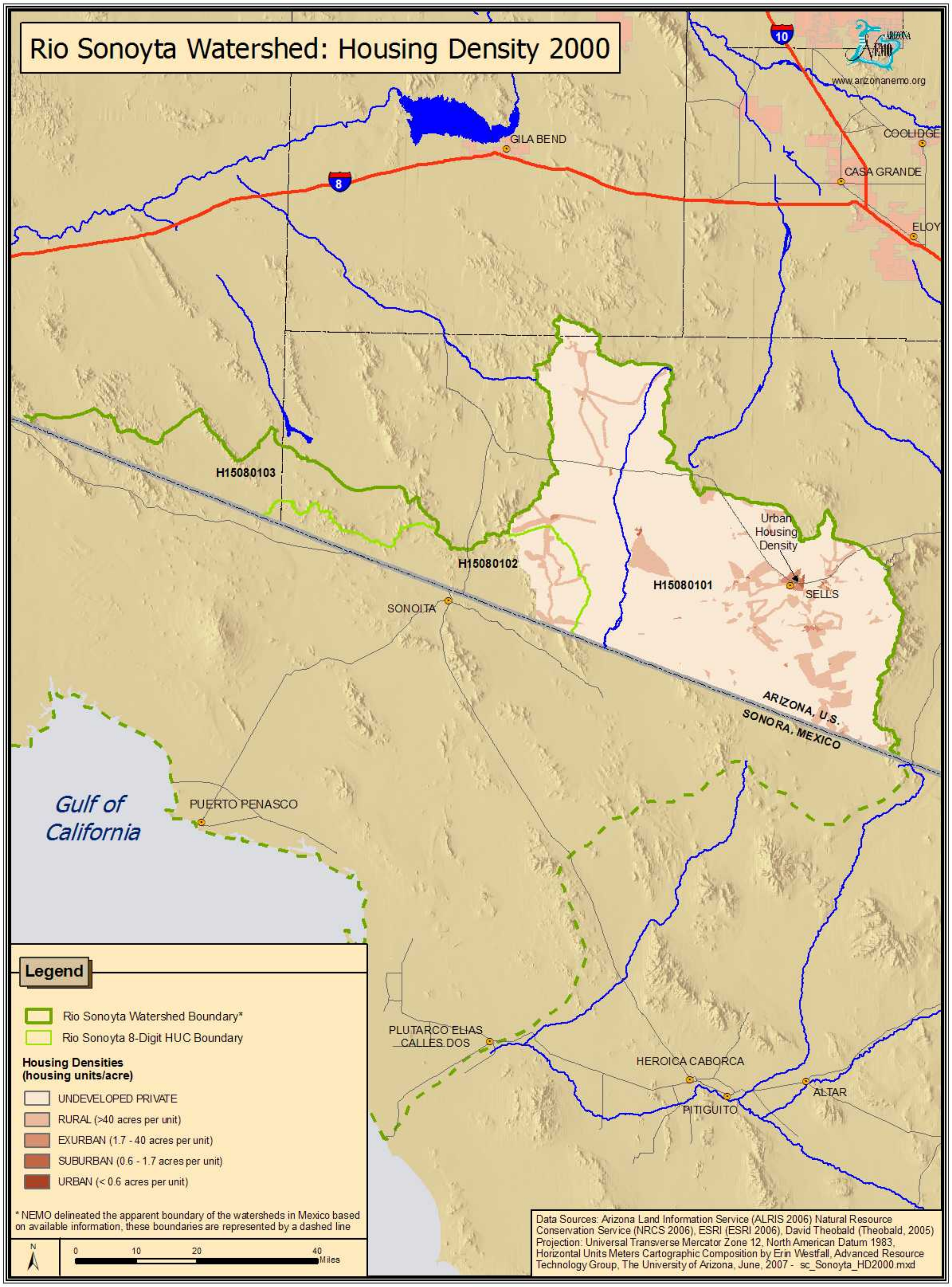

Figure 4-8.2: Rio Sonoyta Watershed Housing Density 2000

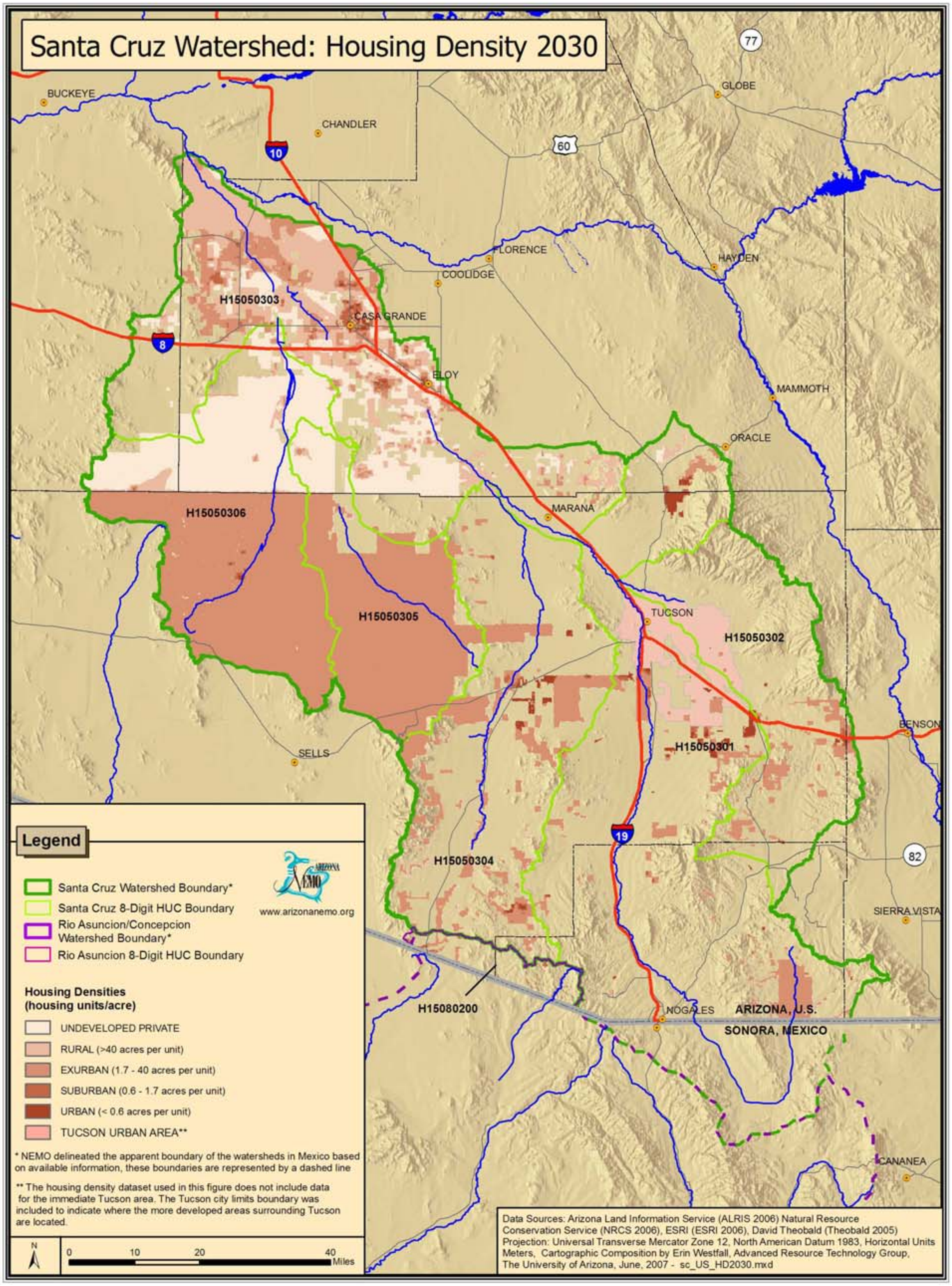

Figure 4-9.1: Santa Cruz Watershed Housing Density 2030

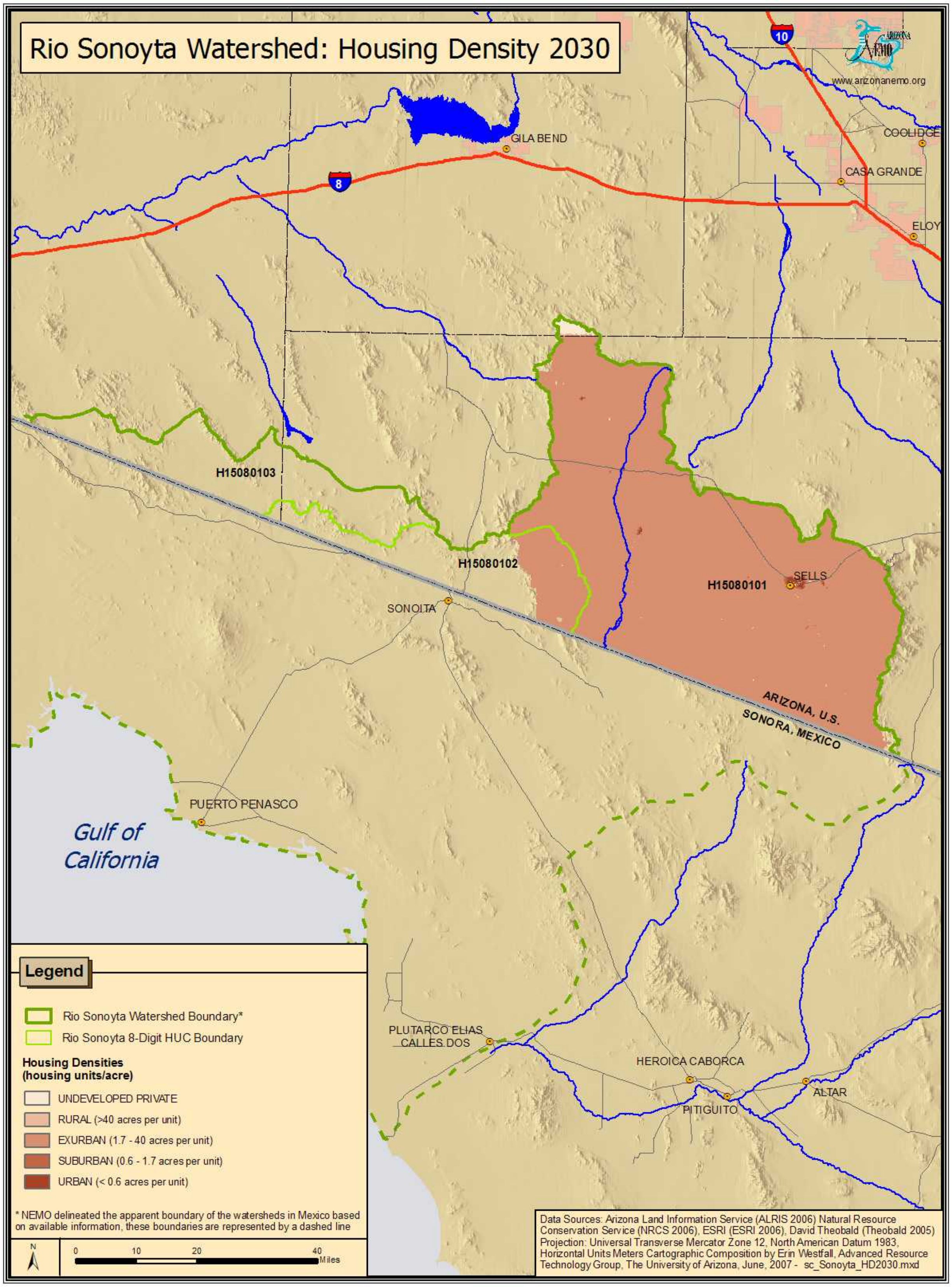

Figure 4-9.2: Rio Sonoyta Watershed Housing Density 2030

Table 4-9.1: Santa Cruz Watershed 2030 Housing Density (Percent of Watershed) (part 2 of 2).*

Housing Density	Upper Santa Cruz River H15050301	Santa Cruz River Watershed**	Rio Asuncion H15080200	Rio Asuncion Watershed**
Undeveloped Private	4.79%	24.53%	4.78%	4.78%
Rural	8.21%	15.27%	15.74%	15.74%
Exurban	69.86%	57.60%	77.44%	77.44%
Suburban	4.80%	1.27%	2.04%	2.04%
Urban	12.34%	1.33%	-	-

** These figures report the percent of the watershed that contains housing density data, and does not take into account null values. Some areas of the watershed do not contain data due to the modeling techniques utilized by the creator of the data.*
***Data pertains to the U.S. portion of the watershed only.*
Data Sources: Theobald, D. 2005. Landscape patterns of exurban growth in the USA from 1980 to 2020. Ecology and Society 10(1): 32. [online] URL: http://www.ecologyandsociety.org/vol10/iss1/art32/

Table 4-9.2: Rio Sonoyta Watershed 2030 Housing Density (Percent of Watershed).*

Housing Density	Rio Sonoyta H15080101	San Simon Wash H15080101	Tule Desert Area H15080103	Rio Sonoyta Watershed**
Undeveloped Private	0.43%	0.73%	100.00%	0.72%
Rural	0.32%	0.33%	-	0.33%
Exurban	99.10%	98.51%	-	98.54%
Suburban	0.01%	0.24%	-	0.22%
Urban	0.14%	0.19%	-	0.19%

** These figures report the percent of the watershed that contains housing density data, and does not take into account null values. Some areas of the watershed do not contain data due to the modeling techniques utilized by the creator of the data.*
***Data pertains to the U.S. portion of the watershed only.*
Data Sources: Theobald, D. 2005. Landscape patterns of exurban growth in the USA from 1980 to 2020. Ecology and Society 10(1): 32. [online] URL: http://www.ecologyandsociety.org/vol10/iss1/art32/

Roads

Roads are important to consider in a watershed classification because they can impact water quality by increasing runoff and, especially in construction areas or where the roads are unpaved, can increase sediment yield.

The total road length in the Santa Cruz Watershed is 1,746.4 miles (Table 4-10.1 and Figure 4-10.1). The predominant road type, based on the Census Classification, is “County road” with 638.2 miles, or 36.54% of the total road length. The total road length in the U.S. portion of the Rio Asuncion Watershed Is 13.6 miles, with

"Unimproved Roads" listed as having the longest road length at 10.3 miles, or 75.90% of the total road length. The U.S. section of the Rio Sonoyta Watershed has a total road length of 475.5 miles (Table 4-10.2 and Figure 4-10.2). The majority of the watershed's roads, 274.7 miles, or 57.77% of the total road length are on "Unimproved Roads."

Within the Santa Cruz Watershed, the Upper Santa Cruz River Subwatershed has the greatest accumulated length of roads with 608.7 miles, or 34.9% of the total watershed road length. The greatest accumulated road length within the Rio Sonoyta Watershed is the San Simon Subwatershed with 401.8 miles, or 84.48% of the total watershed roads. Tables 4-11.1 and 4-11.2 list road lengths in each subwatershed.

Table 4-10.1: Santa Cruz Watershed Road Types.

Census Classification Code Santa Cruz Watershed	Road Length (miles)	Percent of Total Length
Interstate	**211.3**	**12.10%**
U.S. and State Hwys	**328.4**	**18.81%**
County Roads	**638.2**	**36.54%**
Unimproved Roads	**568.5**	**32.55%**
Total Road Length (miles)*	***1,746.4***	***100.00%***
Census Classification Code Rio Asuncion Watershed	**Road Length (miles)**	**Percent of Total Length**
Interstate	**-**	**-**
U.S. and State Hwys	**3.3**	**24.10%**
County Roads	**-**	**-**
Unimproved Roads	**10.3**	**75.90%**
Total Road Length (miles)*	***13.6***	***100.00%***

*Data pertains to the U.S. portion of the watershed only.

Table 4-10.2: Rio Sonoyta Watershed Road Types.

Census Classification Code Santa Cruz Watershed	Road Length (miles)	Percent of Total Length
Interstate	0	0
U.S. and State Hwys	66.9	14.08%
County Roads	133.9	28.15%
Unimproved Roads	274.7	57.77%
*Total Road Length (miles)**	*475.5*	*100.00%*

*Data pertains to the U.S. portion of the watershed only.

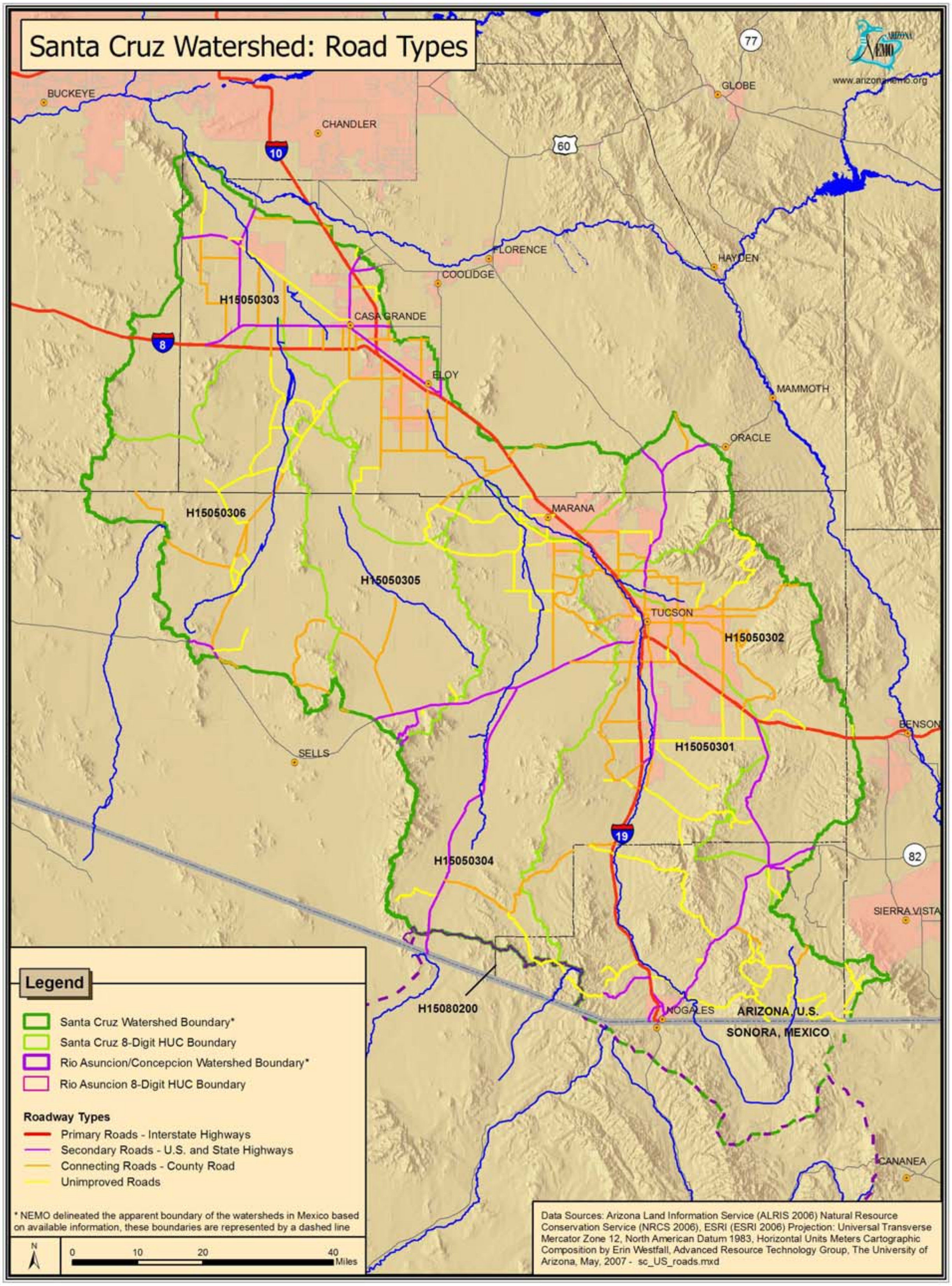

Figure 4-10.1: Santa Cruz Watershed Road Types

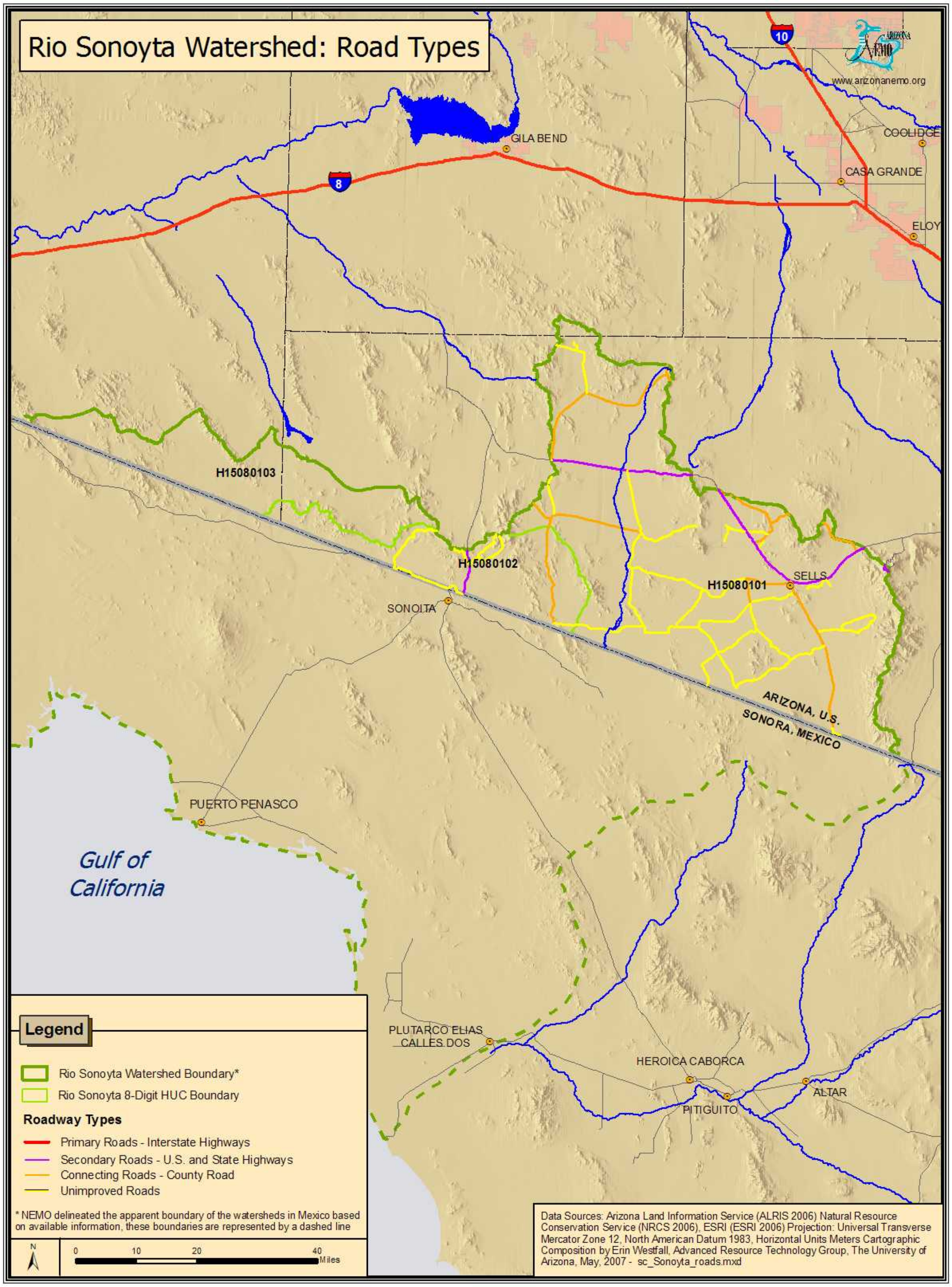

Figure 4-10.2: Rio Sonoyta Watershed Road Types

Table 4-11.1: Santa Cruz Watershed Road Lengths by Subwatershed.

Subwatershed Name	Road Length (miles)	Percent of Total Length
Aguirre Wash-Tat Momoli Wash – H15050305	61.5	3.5%
Brawley Wash-Los Robles Wash - H15050304	225.7	12.9%
Lower Santa Cruz River – H15050303	457.6	26.2%
Pantano Wash-Rillito River – H15050302	217.6	12.5%
Santa Rosa Wash – H15050306	184.1	10.5%
Upper Santa Cruz River – H15050301	608.7	34.9%
*Total Santa Cruz River Watershed**	*1,746.4*	*100.0%*
Subwatershed Name	**Road Length (miles)**	**Percent of Total Length**
Rio Asuncion – H1580200	13.6	100.0%
*Total Rio Asuncion Watershed**	*13.6*	*100.0%*

*Data pertains to the U.S. portion of the watershed only.

Table 4-11.2: Rio Sonoyta Watershed Road Lengths by Subwatershed.

Subwatershed Name	Road Length (miles)	Percent of Total Length
Rio Sonoyta - H15080102	73.5	15.46%
San Simon Wash – H15080101	401.8	84.48%
Tule Desert Area – H15080103	0.26	0.06%
*Total Rio Sonoyta Watershed**	*475.5*	*100.0%*

*Data pertains to the U.S. portion of the watershed only

Mines

There are 1,411 mineral extraction mines recorded with the Office of the Arizona State Mine Inspector in the Santa Cruz Watershed. The Upper Santa Cruz Subwatershed has the highest number of mines (583), while the Aguirre Wash- Tat Momoli Wash Subwatershed has only 65 mines (Table 4-12.1 and Figure 4-11.1). There are eleven different types of mines reported (including “well” and “unknown”), of which 449 (32%) are “underground mines”.

In the U.S. sections of the Rio Asuncion and Rio Sonoyta Watersheds there are 56 and 195 mines, respectively. The majority of the mines in the Rio Sonoyta Watershed (173) are in the San Simon Wash Subwatershed (Table 4-12.2).

Rio Asuncion and Rio Sonoyta watershed mine activity contain 11 and 9 different types of mines, respectively (Table 4-12.2 and Figure 4-11.2). The majority of mines in the Rio Asuncion Watershed are “underground” mines (34 mines), while the majority of mines in the Rio Sonoyta Watershed are of "unknown" type (64 mines).

The Santa Cruz Watershed contains seven different types of mine "status" ranging from "past producer" to "explored prospect," or "unknown" status (Table 4-13.1 and Figure 4-12.1). There are 823 (71%) mines listed as "past producer". One hundred ninety-five (14%) are "explored prospect," and 167 (12%) are "unknown".

Table 4-14.1 and Figure 4-13.1 show the types of ores being mined in the Santa Cruz Watershed. The most common known ore types are copper (339 mines), silver (203 (mines), gold (195 mines), and lead (186 mines). There is no ore data for the Rio Asuncion Watershed.

The major ore types mined in the Rio Sonoyta Watershed (Table 4-14.2 and Figure 4-13.2) are gold, geothermal and copper.

Table 4-12.1: Santa Cruz Watershed Mine Types (part 1 of 2).

Mine Types	Aguirre Wash Tat Momoli Wash H15050305	Brawley Wash - Los Robles Wash H15050304	Lower Santa Cruz River H15050303	Pantano Wash – Rillito River H15050302	Santa Rosa Wash H15050306
Leach	-	1	-	-	1
Mineral Locatable	-	4	-	-	1
Placer	-	5	-	-	-
Processing Plant	-	3	4	-	3
Prospect	4	63	46	37	17
Surface/Underground	10	27	18	9	26
Surface	3	11	58	23	12
Underground	12	68	18	39	24
Underwater	-	-	-	1	-
Unknown	23	129	8	59	23
Well	6	11	7	4	10
*Total Mines**	*65*	*322*	*159*	*172*	*117*

*Data pertains to the U.S. portion of the watershed only.

Table 4-12.1: Santa Cruz Watershed Mine Types (part 2 of 2).

Mine Types	Upper Santa Cruz River H15050301	Santa Cruz Watershed	Rio Asuncion H15080200	Rio Asuncion Watershed
Leach	1	3	-	-
Mineral Locatable	2	7	2	2
Placer	3	8	3	3
Processing Plant	9	19	-	-
Prospect	87	254	6	6
Surface/Underground	64	154	4	4
Surface	54	161	1	1
Underground	288	449	34	34
Underwater	12	13	4	4
Unknown	50	292	2	2
Well	13	51	-	-
*Total Mines**	*583*	*1411*	*56*	*56*

*Data pertains to the U.S. portion of the watershed only.

Table 4-12.2: Rio Sonoyta Watershed Mine Types.

Mine Types	Rio Sonoyta H15080102	San Simon Wash H15080101	Tule Desert Area H15080103	Rio Sonoyta Watershed
Mineral Locatable	-	1	-	1
Placer	-	1	-	1
Processing Plant	-	2	-	2
Prospect	1	19	3	23
Surface/Underground	2	20	-	22
Surface	1	3	-	4
Underground	1	33	2	36
Unknown	5	55	4	64
Well	3	39	-	42
*Total Mines**	*13*	*173*	*9*	*195*

*Data pertains to the U.S. portion of the watershed only.

Table 4-13.1: Santa Cruz Watershed Mine Status (part 1 of 2).

Mine Types	Aguirre Wash Tat Momoli Wash H15050305	Brawley Wash - Los Robles Wash H15050304	Lower Santa Cruz River H15050303	Pantano Wash – Rillito River H15050302	Santa Rosa Wash H15050306
Developed Deposit	3	3	19	-	6
Explored Prospect	5	40	42	7	16
Past Producer	38	202	60	99	64
Producer	1	2	10	14	4
Raw Prospect	6	28	9	19	13
Temporary Shutdown	-	1	-	-	-
Unknown	5	46	19	33	14
*Total Mines**	*58*	*322*	*159*	*172*	*117*

*Data pertains to the U.S. portion of the watershed only.

Table 4-13.1: Santa Cruz Watershed Mine Status (part 2 of 2).

Mine Types	Upper Santa Cruz River H15050301	Santa Cruz Watershed	Rio Asuncion H15080200	Rio Asuncion Watershed
Developed Deposit	13	44	1	1
Explored Prospect	85	195	14	14
Past Producer	360	823	35	35
Producer	35	66	-	-
Raw Prospect	24	99	1	1
Temporary Shutdown	16	17	4	4
Unknown	50	167	1	1
*Total Mines**	*583*	*1411*	*56*	*56*

*Data pertains to the U.S. portion of the watershed only.

Table 4-13.2: Rio Sonoyta Watershed Mine Status.

Mine Types	Rio Sonoyta H15080102	San Simon Wash H15080101	Tule Desert Area H15080103	Rio Sonoyta Watershed
Explored Prospect	1	8	1	10
Past Producer	3	94	4	101
Producer	1	-	-	1
Raw Prospect	2	47	-	49
Unknown	6	24	4	34
*Total Mines**	*13*	*173*	*9*	*195*

*Data pertains to the U.S. portion of the watershed only.

Table 4-14.1: Santa Cruz Watershed Mines – Ore Type.

Ore Type	Total Number of Mines
Abrasive	1
Aluminum	2
Asbestos	6
Barium	1
Beryllium	4
Clay	10
Copper	339
Feldspar	1
Fluorine	8
Gemstone	3
Geothermal	52
Gold	195
Gypsum	15
Iron	12
Lead	186
Lithium	1
Manganese	52
Mica	5
Molybdenum	7
Perlite	2
Pumice	1
Quartz Crystal	2
Rare Earth	2
Sand & Gravel	82
Silicon	5
Silver	203
Stone	30
Sulfur	1
Tungsten	25
Uranium	26
Wollastonite	1
Zeolites	1
Zinc	39
Zirconium	1
Unknown	90

*Data pertains to the U.S. portion of the watershed only.
Note: If a mine contains more than one ore, only the major ore is noted.

Table 4-14.2: Rio Sonoyta Watershed Mines – Ore Type.

Ore Type	Total Number of Mines
Copper	37
Fluorine	1
Geothermal	42
Gold	44
Iron	6
Lead	6
Manganese	1
Nickel	1
Rare Earth	1
Silicon	3
Silver	25
Tungsten	17
Uranium	4
Unknown	7

*Data pertains to the U.S. portion of the watershed only.

Note: If a mine contains more than one ore, only the major ore is noted.

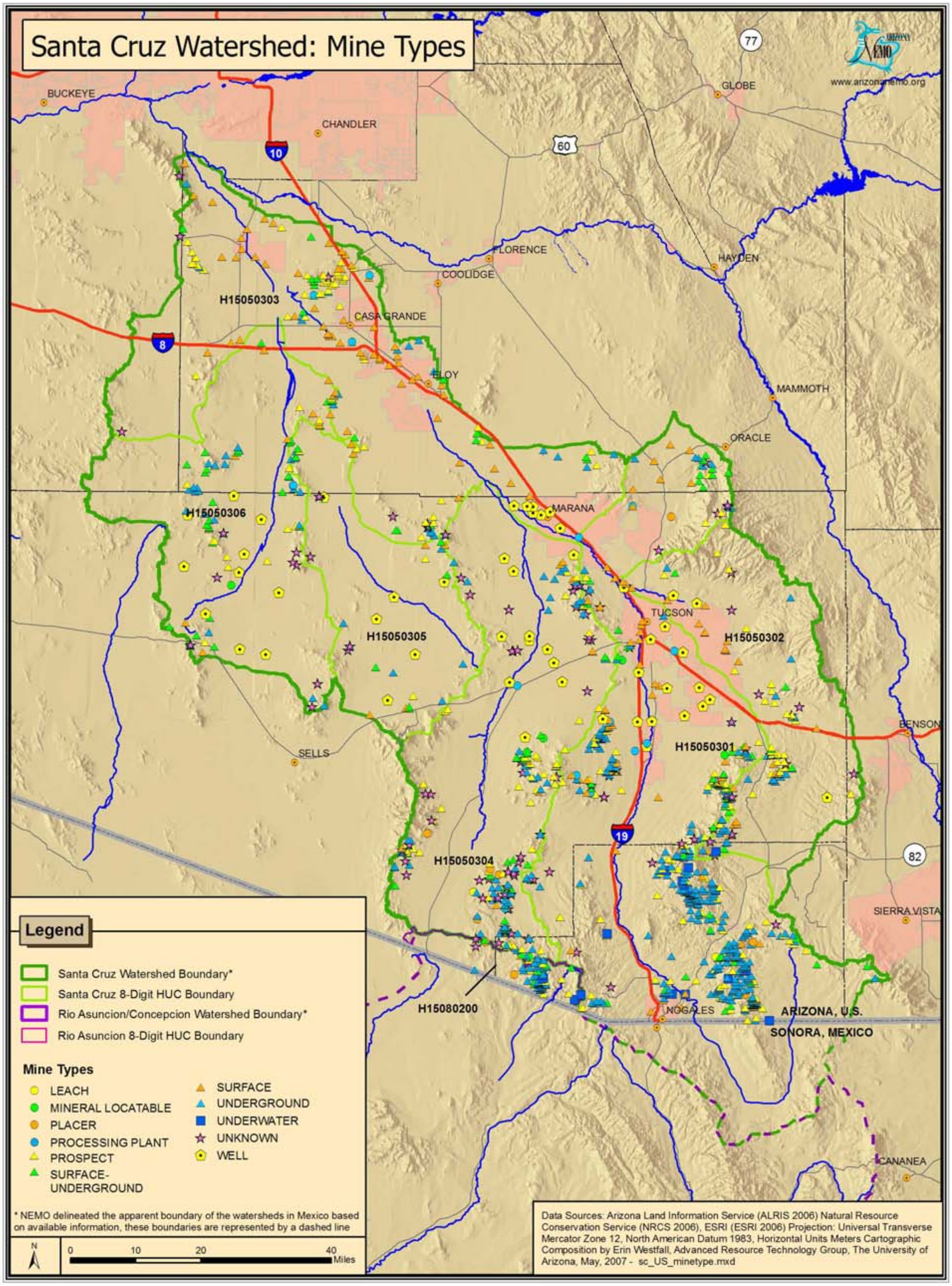

Figure 4-11.1: Santa Cruz Watershed Mine Types

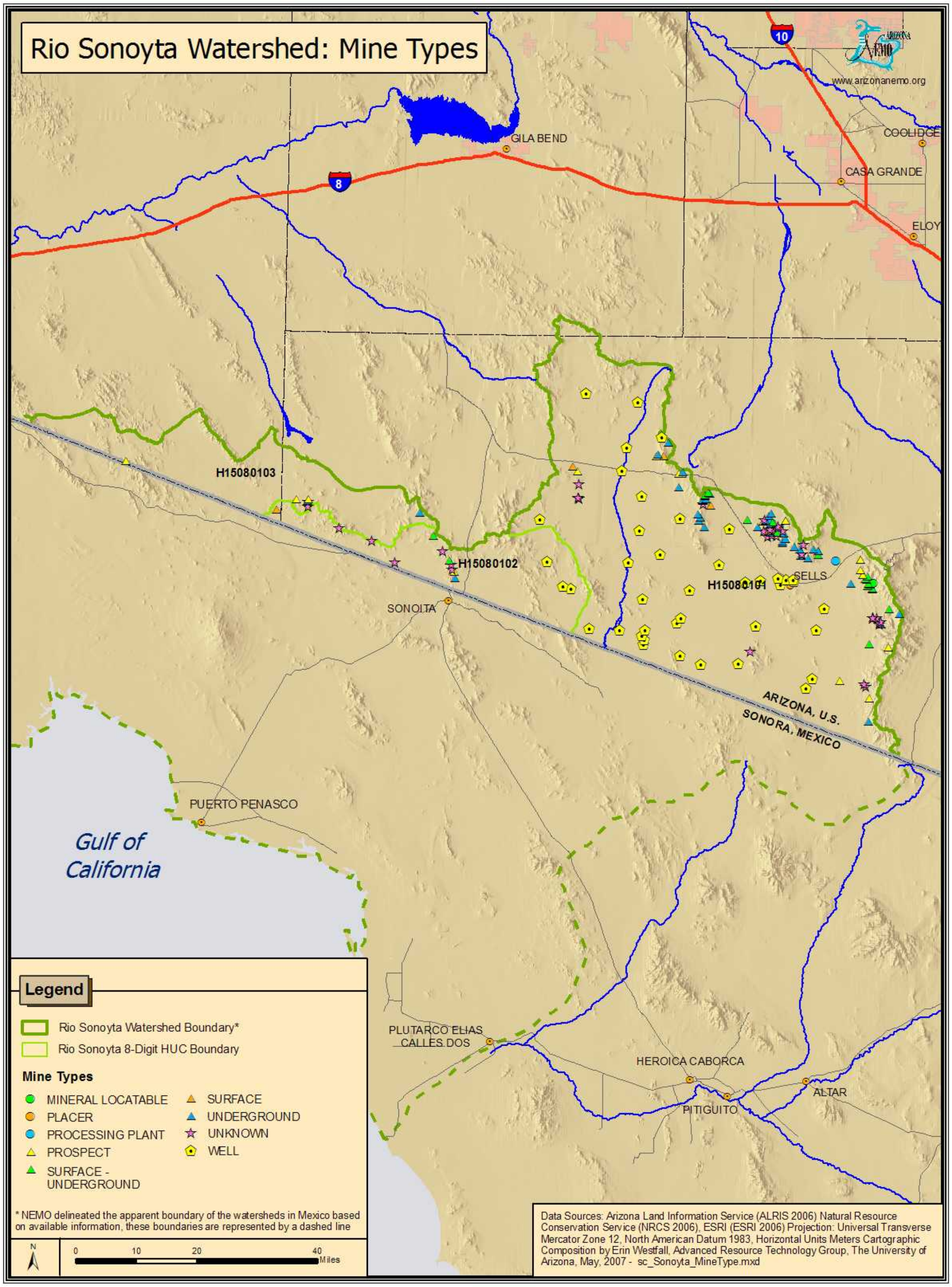

Figure 4-11.2: Rio Sonoyta Watershed Mine Types

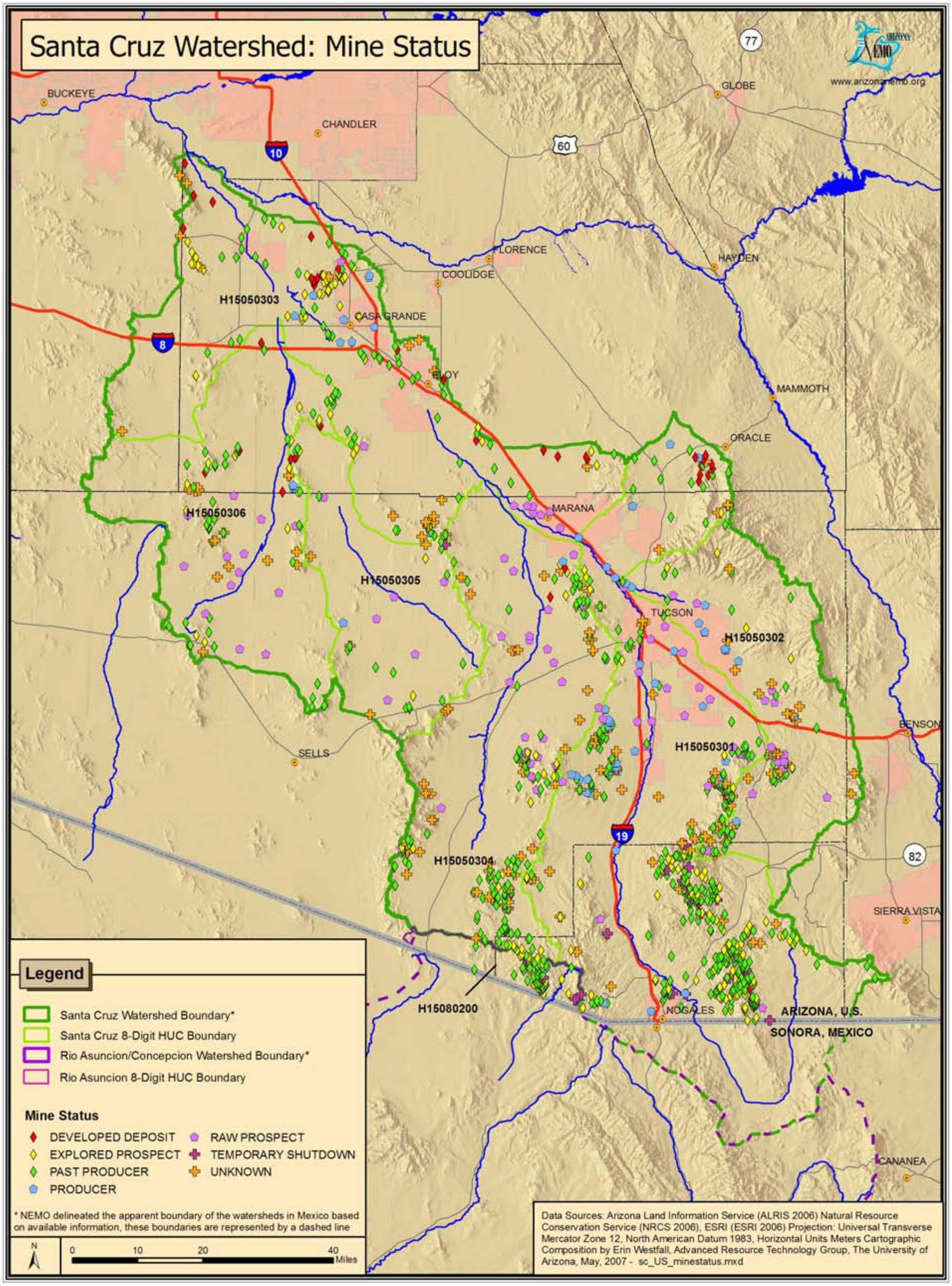

Figure 4-12.1: Santa Cruz Watershed Mine Status

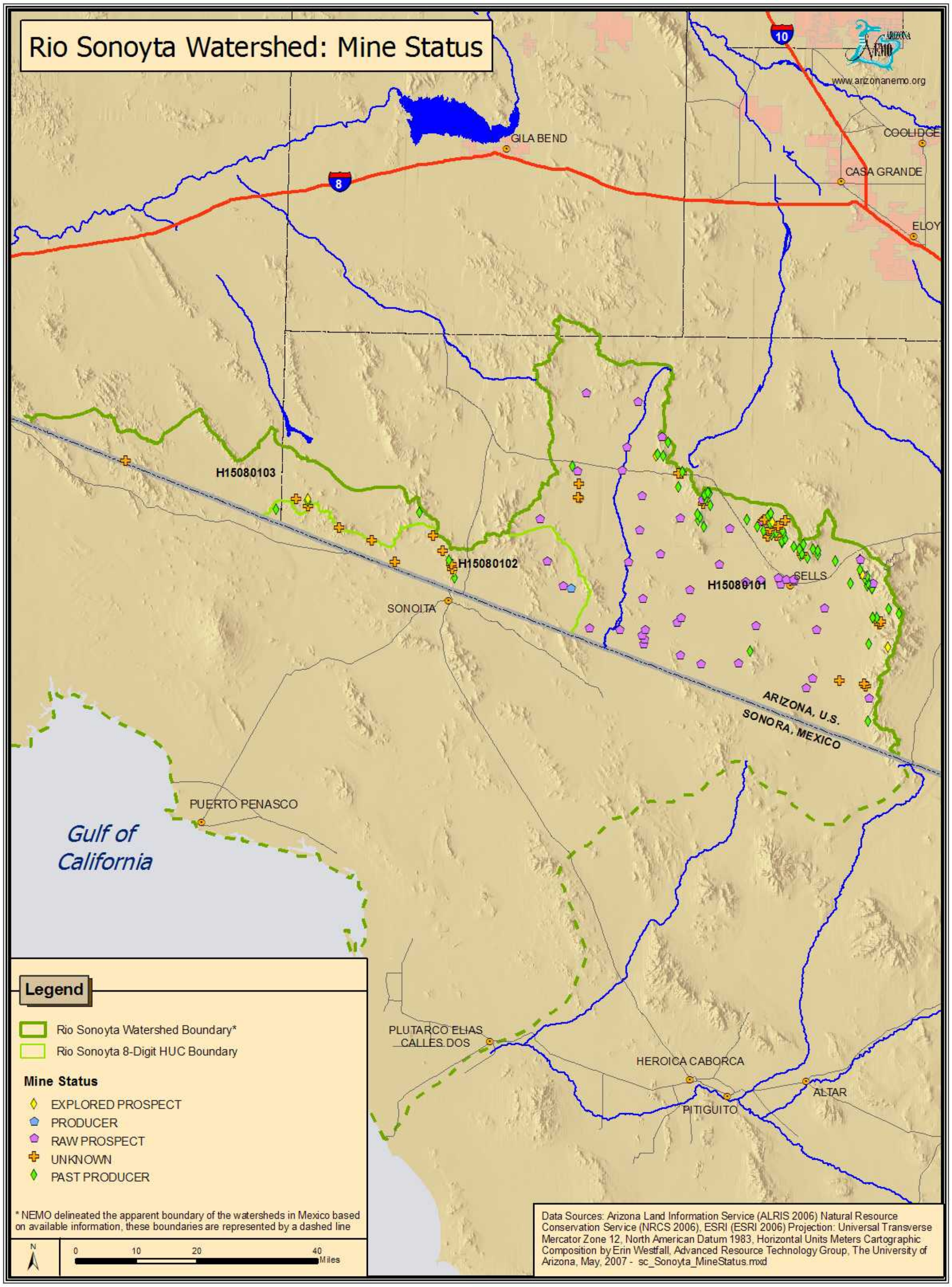

Figure 4-12.2: Rio Sonoyta Watershed Mine Status

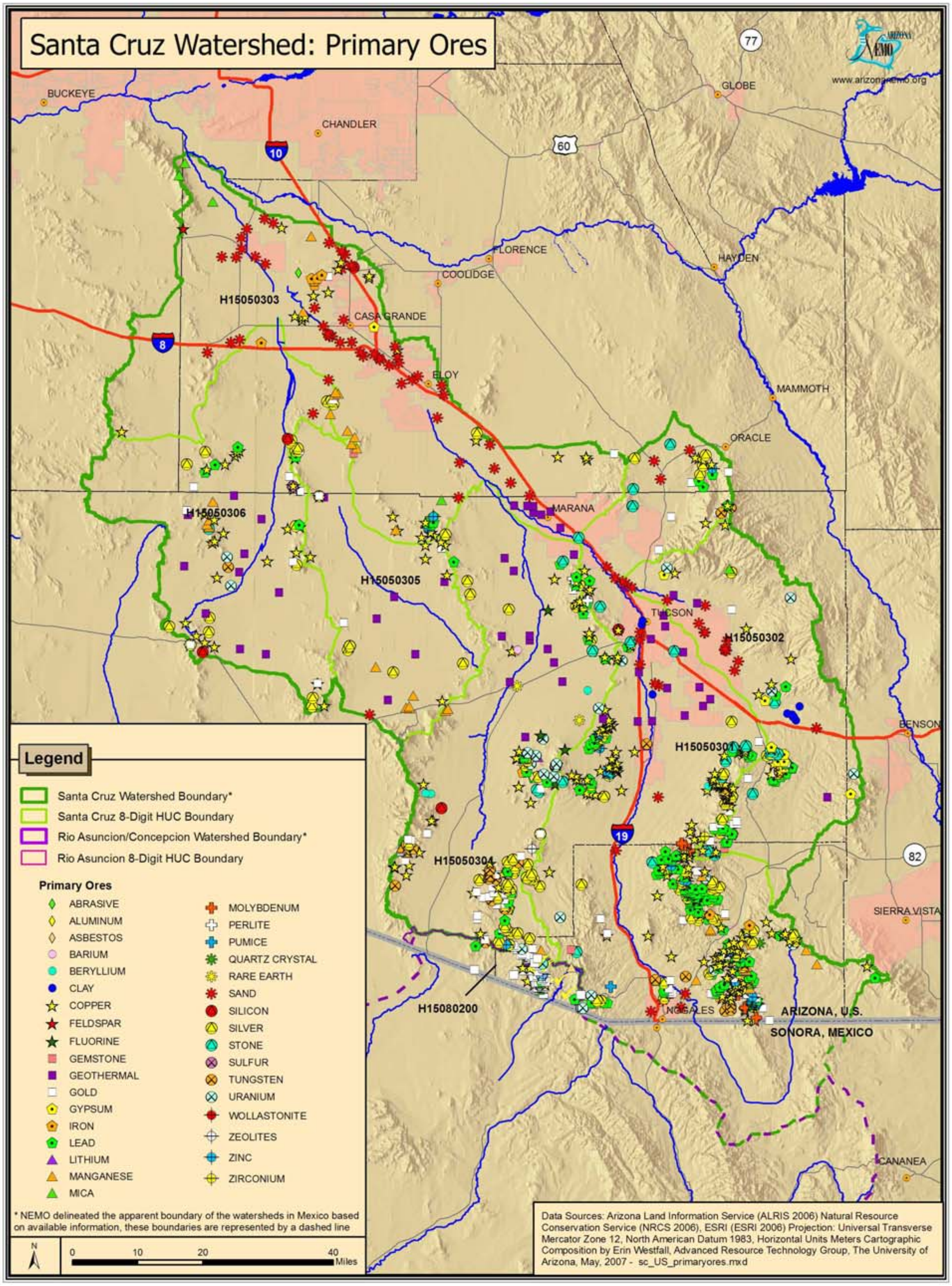

Figure 4-13.1: Santa Cruz Watershed Primary Ores

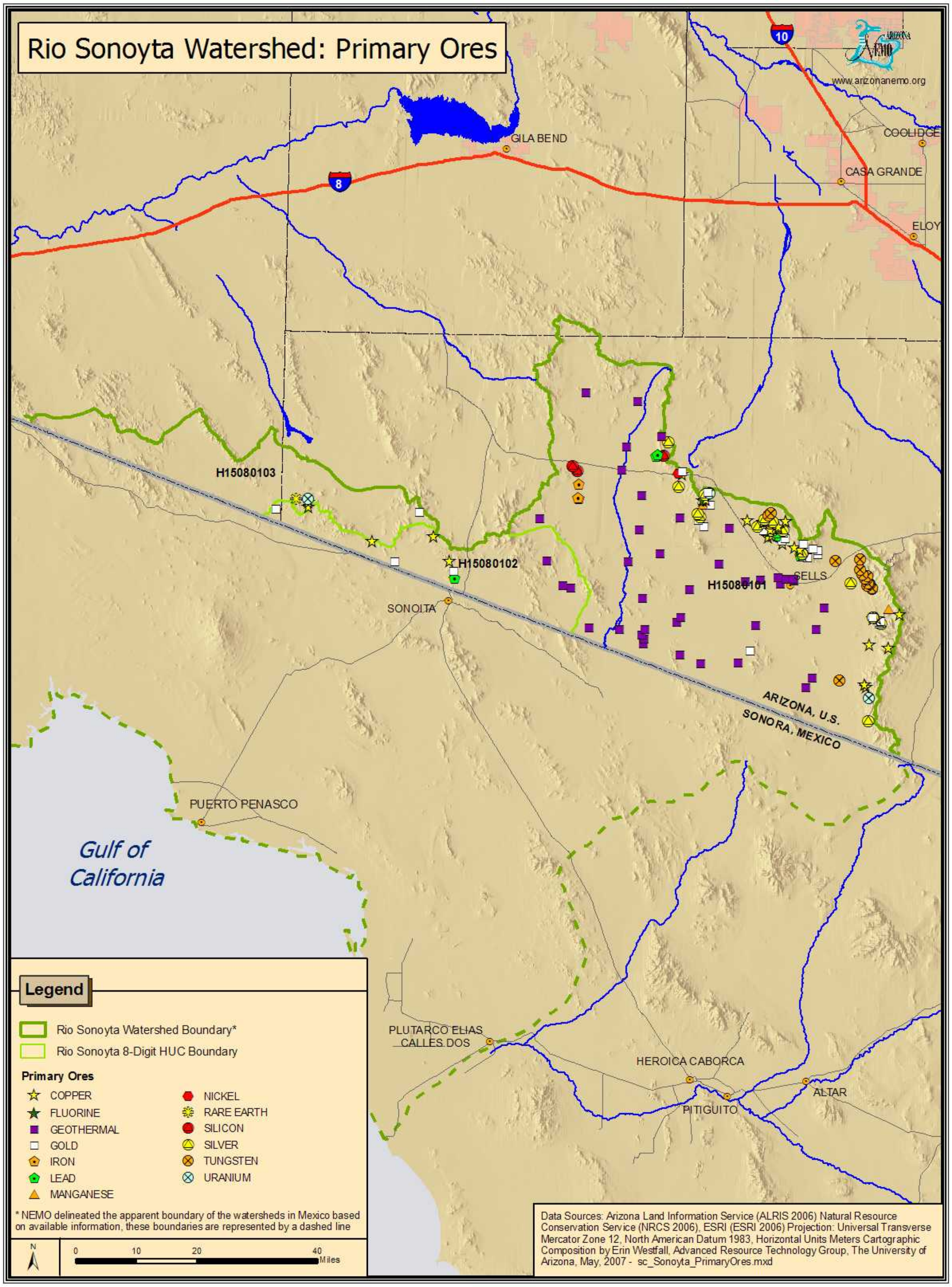

Figure 4-13.2: Rio Sonoyta Watershed Primary Ores

Land Use

The land cover condition during the early 1990's was determined using the National Land Cover Dataset (NLCD). The NLCD classification contains 21 different land cover categories; however, these categories were consolidated into six land cover types (Figures 4-14.1 & 4-14.2 and Tables 4-15.1 & 4-15.2). The six groupings for the land cover categories are:

1. *Agriculture*: Confined feeding operations; Cropland and pasture; Orchards, groves, vineyards, nurseries and ornamental horticulture; Other agricultural land.
2. *Evergreen forest land*: Evergreen forest land (no change in category).
3. *Lakes and Wetlands*: Forested wetland; Lakes; Nonforested wetland.
4. *Rangeland*: Herbaceous rangeland; Mixed rangeland; Shrub and brush rangeland.
5. *Industrial and commercial complexes or Mixed urban built-up land*: Commercial and services; Industrial; Industrial and commercial complexes; Mixed urban or built-up land; Other urban or built-up land; Strip mines quarries and gravel pits; Transportation, communication and utilities.
6. *Residential*: Residential (no change in category).

The most common land cover type is Rangeland, which makes up 88% of the Santa Cruz Watershed, 100% of the Rio Asuncion Watershed, and virtually 100% of the Rio Sonoyta Watershed.

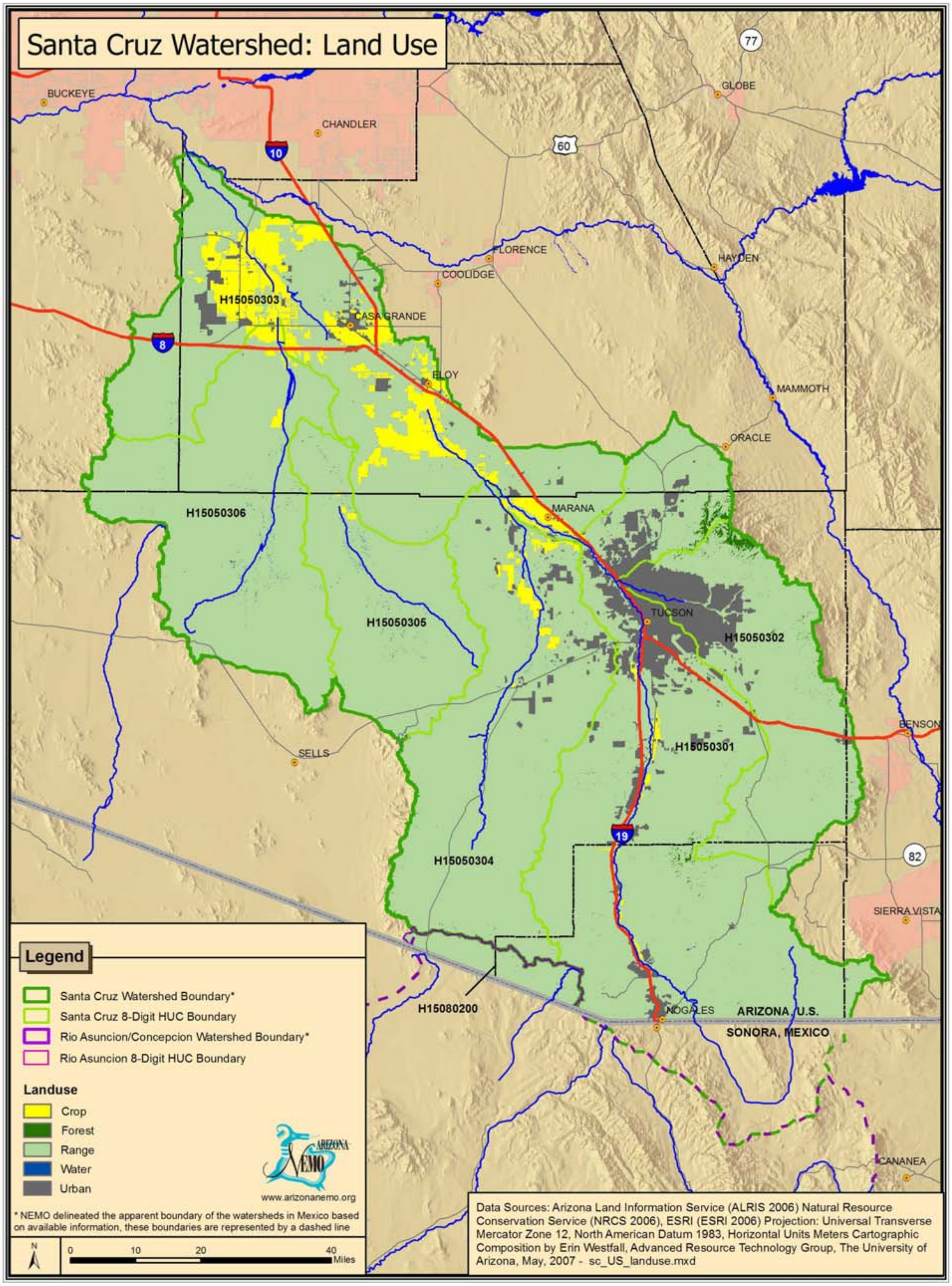

Figure 4-14.1: Santa Cruz Watershed Land Use

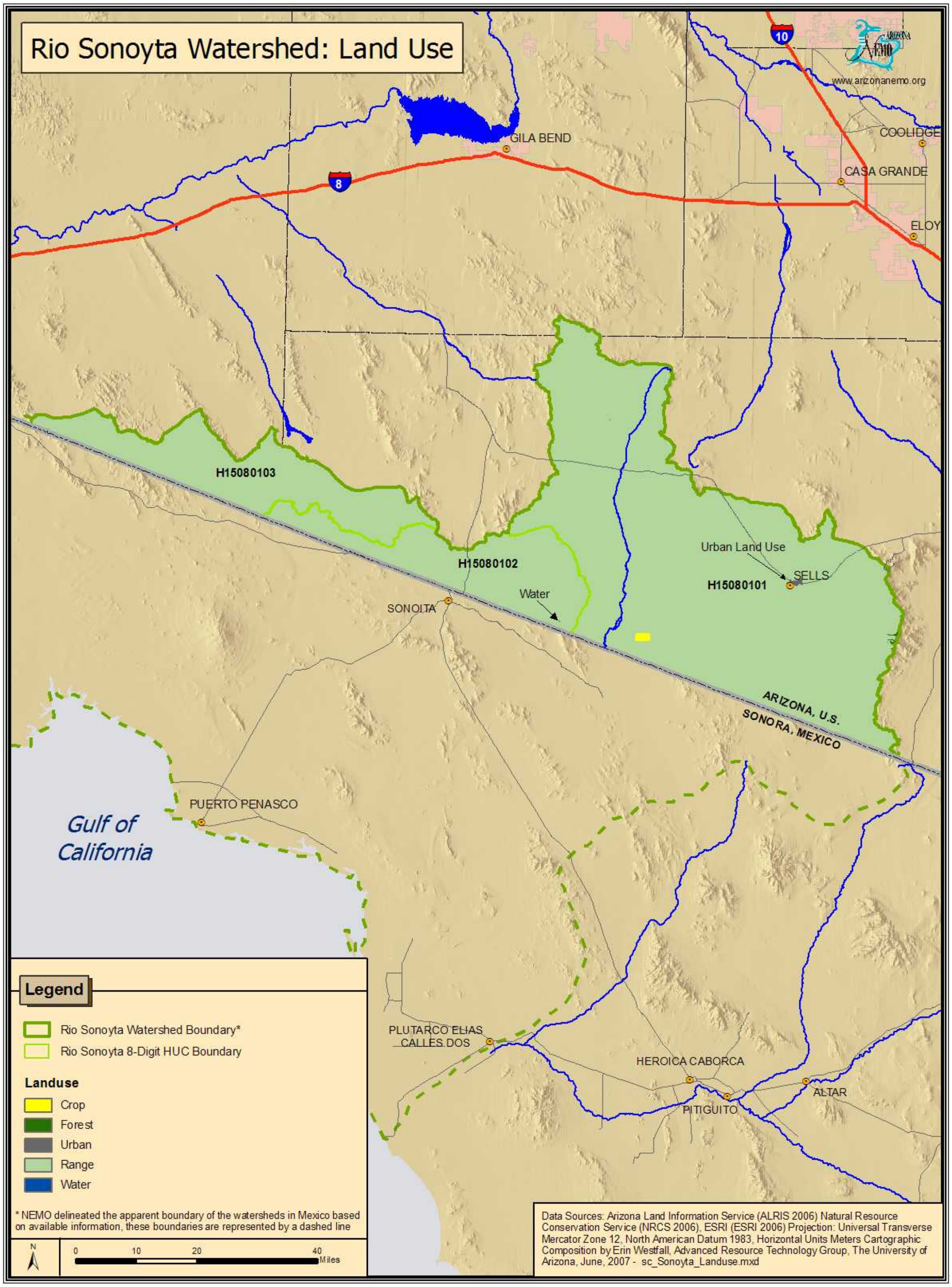

Figure 4-14-.2: Rio Sonoyta Watershed Land Use

Table 4-15.1: Santa Cruz Watershed Land Use (part 1 of 2).

Land Use	Aguirre Wash Tat Momoli Wash H15050305	Brawley Wash – Los Robles Wash H15050304	Lower Santa Cruz River H15050303	Pantano Wash – Rillito River H15050302	Santa Rosa Wash H15050306
Agriculture	0.4%	2%	21%	-	2%
Forest	-	-	-	-	-
Range	99.6%	96%	75%	84%	98%
Urban	-	3%	4%	16%	0.1%
Water	-	> 0%	>0%	-	> 0%
Total Area (square miles)*	*733*	*1,408*	*1,682*	*920*	*1,208*

*Data pertains to the U.S. portion of the watershed only.

Table 4-15.1: Santa Cruz Watershed Land Use (part 2 of 2).

Land Use	Upper Santa Cruz River H15050301	***Santa Cruz Watershed***	Rio Asuncion H15080200	***Rio Asuncion Watershed***
Agriculture	1%	*5.1%*	-	-
Forest	-	*0.8%*	-	-
Range	88%	*87.6%*	100%	*100%*
Urban	12%	*6.4%*	-	-
Water	>0%	*>0%*	-	-
Total Area (square miles)*	*2,227*	*8,178*	*128*	*128*

*Data pertains to the U.S. portion of the watershed only.

Table 4-15.2: Rio Sonoyta Watershed Land Use.

Land Use	Rio Sonoyta H15080102	San Simon Wash H15080101	Tule Desert Area H15080103	***Rio Sonoyta Watershed***
Agriculture	-	0.1%	-	*0.1%*
Forest	-	0.1%	-	*0.1%*
Range	100%	99.6%	100%	*99.8%*
Urban	> 0%	0.1%	-	*0.1%*
Water	> 0%	> 0%	-	*>0%*
Total Area (square miles)*	*424*	*2,154*	*497*	*3,075*

*Data pertains to the U.S. portion of the watershed only.

Land Ownership

In the Santa Cruz Watershed, there are 11 different land ownership entities (Figure 4-15.1 and Table 4-16.1). Private individuals are the largest land owners, representing 28% of the watershed. Indian Reservations and the State Land are the next most significant land owners with 27% and 21% of the watershed, respectively.

There are 4 different land ownership entities for the Rio Asuncion Watershed and 7 entities in the Rio Sonoyta (Figure 4-15.2 and Table 4-16.2). Forest Service land comprises 74% of the Rio Asuncion Watershed, while Indian Reservations make up 74% of the Rio Sonoyta Watershed.

Table 4-16.1: Santa Cruz Watershed Land Ownership (Percent of each Subwatershed) (part 1 of 2).

Land Owner	Aguirre Wash Tat Momoli Wash H15050305	Brawley Wash – Los Robles Wash H15050304	Lower Santa Cruz River H15050303	Pantano Wash – Rillito River H15050302	Santa Rosa Wash H15050306
BLM	7%	10%	17%	7%	3%
Bureau of Reclamation	-	0.2%	0.2%	-	> 0%
US Forest Service	-	3%	-	29%	-
Game and Fish	-	0.2%	-	-	-
Indian Reservation	86%	8%	16%	-	92%
Military Lands	-	-	3%	0.7%	0.9%
National Fish and Wildlife Refuge	-	11%	-	-	-
National Park Service	-	2%	-	9%	-
Parks and Recreation	-	1%	0.3%	-	-
Private Land	2%	24%	42%	32%	3%
State Land	5%	41%	21	22%	1%
Area (square miles)*	*733*	*1,408*	*1,682*	*920*	*1,208*

*Data pertains to the U.S. portion of the watershed only.

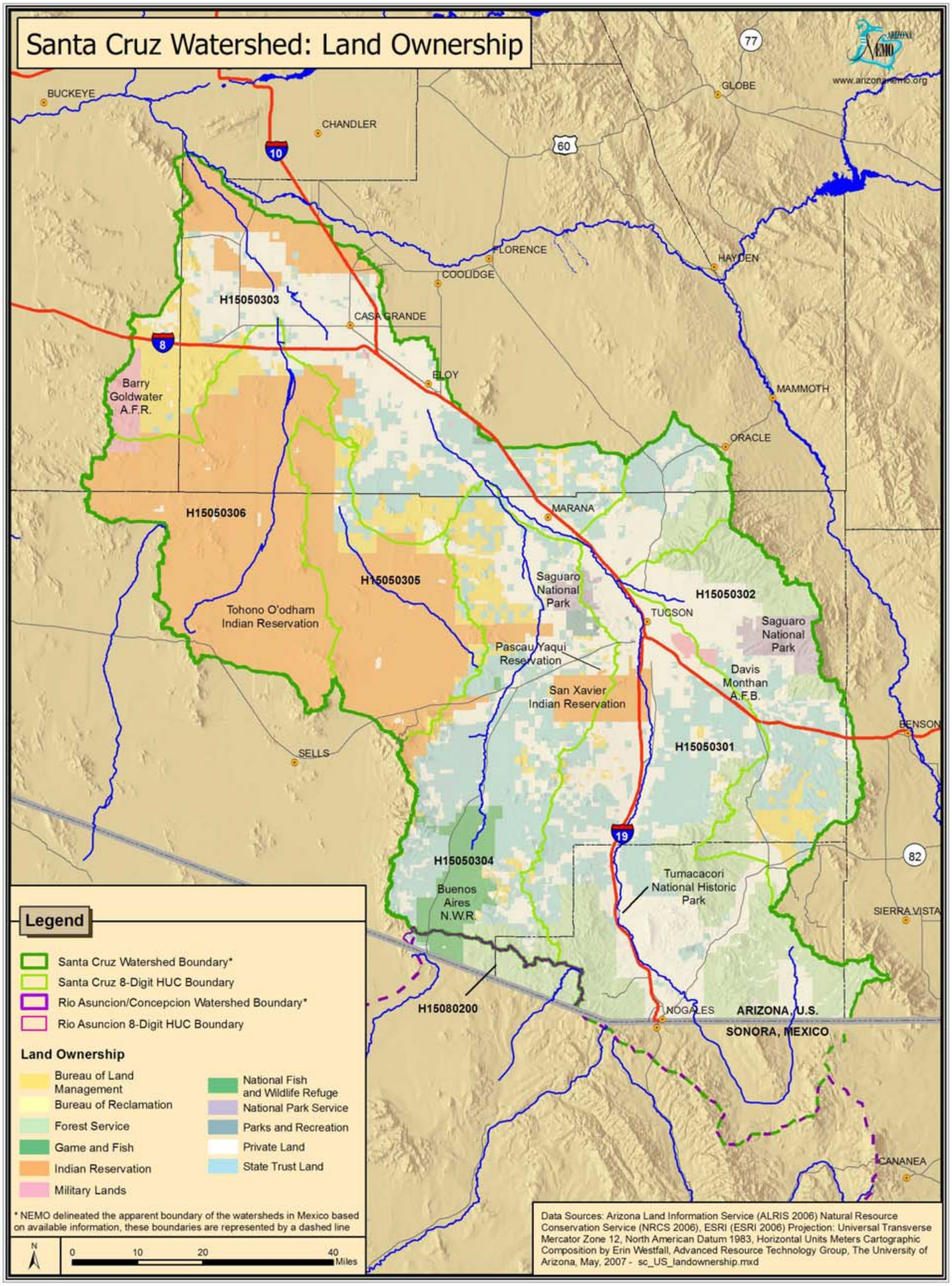

Figure 4-15.1: Santa Cruz Watershed Land Ownership

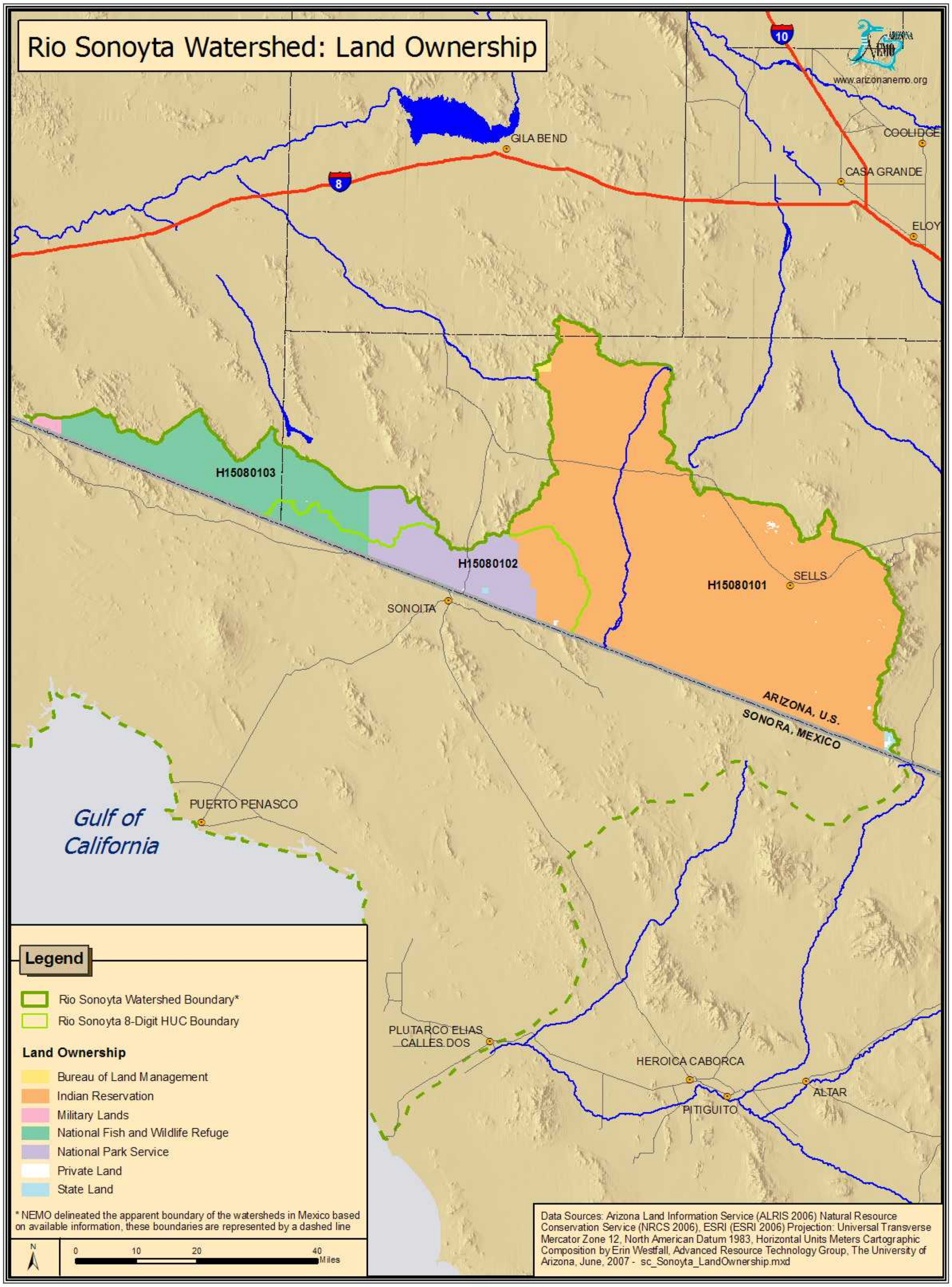

Figure 4-15.2: Rio Sonoyta Watershed Land Ownership

Table 4-16.1: Santa Cruz Watershed Land Ownership (Percent of each Subwatershed) (part 2 of 2).

Land Owner	Upper Santa Cruz River H15050301	Santa Cruz Watershed	Rio Asuncion H15080200	Rio Asuncion Watershed
BLM	1%	7%	-	-
Bureau of Reclamation	-	>0%	-	-
US Forest Service	30%	12%	74%	74%
Game and Fish	-	>0%	-	-
Indian Reservation	3%	27%	-	-
Military Lands	1%	1%	-	-
National Fish and Wildlife Refuge	-	2%	20%	20%
National Park Service	1%	1%	-	-
Parks and Recreation	0.1%	>0%	-	-
Private Land	42%	28%	3%	3%
State Land	24%	21%	3%	3%
Area (square miles)*	*2,227*	8,178	*128*	*128*

*Data pertains to the U.S. portion of the watershed only.

Table 4-16.2: Rio Sonoyta Watershed Land Ownership (Percent of each Subwatershed).

Land Owner	Rio Sonoyta H15080102	San Simon Wash H15080101	Tule Desert Area H15080103	Rio Sonoyta Watershed
BLM	-	0.2%	-	>0%
Indian Reservation	32%	99%	-	74%
Military Lands	-	-	3%	>0%
National Fish and Wildlife Refuge	15%	-	84%	16%
National Park Service	52%	-	14%	9%
Private Land	0.3%	0.2%	> 0%	>0%
State Land	0.2%	0.2%	-	>0%
Area (square miles)*	*424*	*2,154*	*497*	*3,075*

*Data pertains to the U.S. portion of the watershed only.

Special Areas

Preserves:

Preserves listed here are part of the Arizona Preserve Initiative (API). The API was passed by the Arizona State Legislature as HB 2555 and signed into law by the Governor in the spring of 1996. It is designed to encourage the preservation of select parcels of State Trust land in and around urban areas for open space to benefit future generations. The law lays out a process by which Trust land can be leased for up to 50 years or sold for conservation purposes. Leases and sales must both occur at a public auction (http://www.land.state.az.us/programs/operations/api.htm).

Figure 4-16 shows the boundaries of the preserve lands within the Santa Cruz Watershed. The State Trust lands within these 1,255 square miles, or 803,122 acres, are eligible for conservation purposes. Table 4-17.1 show the API areas for each subwatershed. There are no preserve lands within the U.S. portion of the Rio Asuncion and Rio Sonoyta Watersheds (Table 4-17.2).

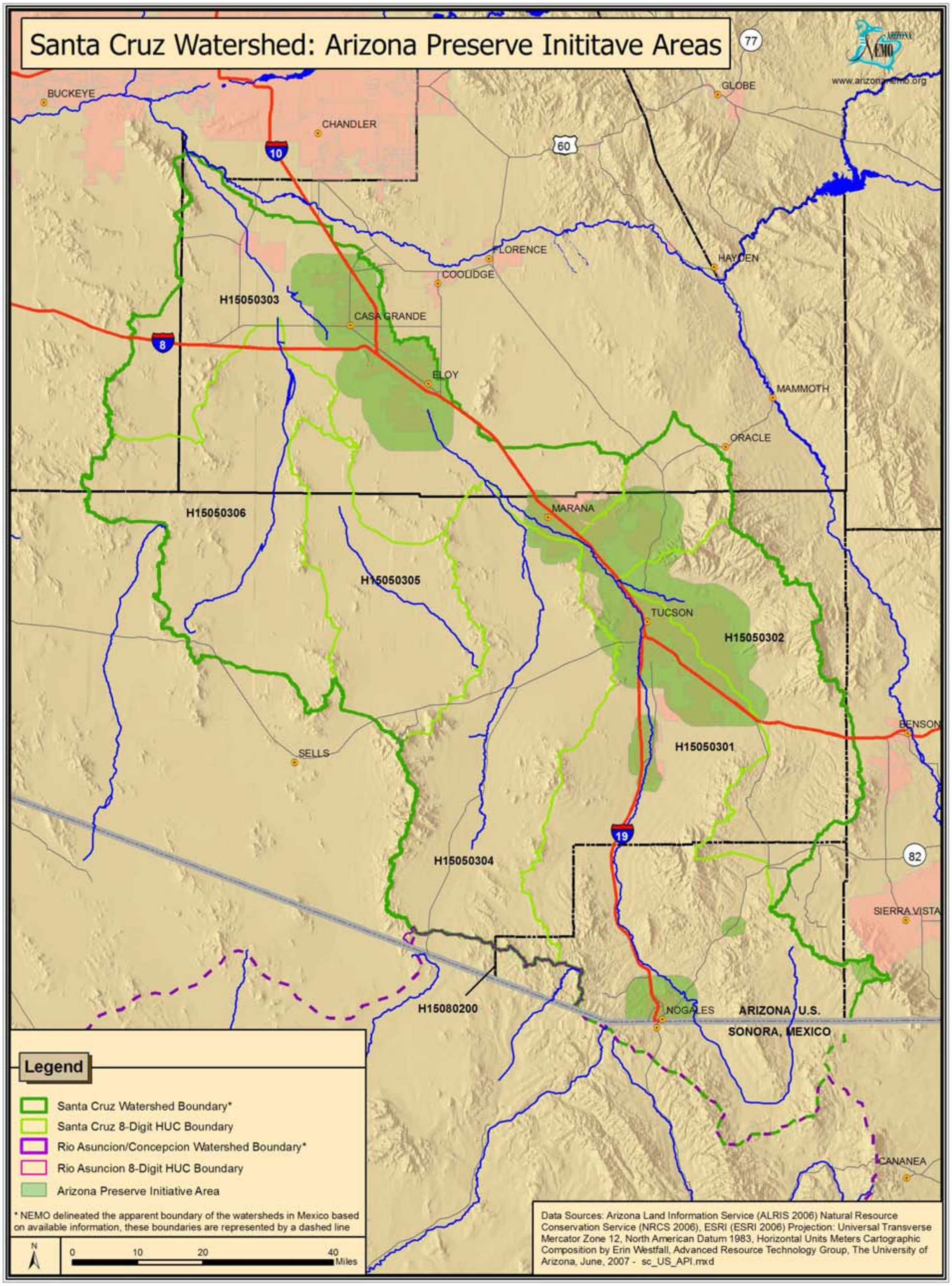

Figure 4-16: Santa Cruz Watershed, Arizona Preserve Initiative Areas

Table 4-17.1: Santa Cruz Watershed Areas of Arizona Preserve Initiative Lands.

Subwatershed Name	Subwatershed Area (square miles)	Preserve Areas (square miles)	Preserve Areas (acre)	Percent of Subwatershed
Aguirre Wash Tat Momoli Wash H15050305	733	-	-	-
Brawley Wash – Los Robles Wash H15050304	1,408	39	25,022	3%
Lower Santa Cruz River H15050303	1,682	460	294,578	27%
Pantano Wash – Rillito River H15050302	920	199	127,776	22%
Santa Rosa Wash H15050306	1,208	-	-	-
Upper Santa Cruz River H15050301	2,227	556	355,746	25%
*Total Santa Cruz River Watershed**	*8,178*	*1,255*	*803,122*	*15%*
Rio Asuncion H15080200	128	-	-	-
*Total Rio Asuncion Watershed**	*128*	-	-	-

*Data pertains to the U.S. portion of the watershed only.

Table 4-17.2: Rio Sonoyta Watershed Areas of Arizona Preserve Initiative Lands.

Subwatershed Name	Subwatershed Area (square miles)	Preserve Areas (square miles)	Preserve Areas (acre)	Percent of Subwatershed
Rio Sonoyta H15080102	424	-	-	-
San Simon Wash H15080101	2,154	-	-	-
Tule Desert Area H15080103	497	-	-	-
*Total Rio Sonoyta Watershed**	*3,075*	-	-	-

*Data pertains to the U.S. portion of the watershed only.

Wilderness Areas:

There are 13 different Wilderness Areas within the Santa Cruz Watershed. Tables 4-18.1 and Figure 4-17.1 list each area and the acreage in each subwatershed.
There are a total of 302,540 acres (473 square miles) of wilderness areas within the Santa Cruz Watershed, or approximately 5.8% of the watershed. The largest wilderness area is the Buenos Aires Wilderness Area with approximately 89,290 acres, almost all within the Brawley Wash-Los Robles Wash Subwatershed.

There are two wilderness areas within the 18,972 acre Rio Asuncion Watershed. The largest is the Buenos Aires Wilderness Area which contains 11,444 acres. The Rio Sonoyta Watershed has three wilderness areas, the largest being the the Cabeza Prieta Wilderness within the Cabeza Prieta Wildlife Refuge with 302,978 acres (Table 4-18.2 and Figure 4-17.2).

Table 4-18.1: Santa Cruz Watershed Wilderness Areas (acres) (part 1 of 2).

Wilderness Area	Aguirre Wash Tat Momoli Wash H15050305	Brawley Wash Los Robles Wash H15050304	Lower Santa Cruz River H15050303	Pantano Wash Rillito River H15050302	Santa Rosa Wash H15050306
Baboquivari Peak	-	2,041	-	-	-
Buenos Aires	-	89,285	-	5	-
Coyote Mountains	1,326	3,749	-	-	-
East Saguaro	-	-	-	49,484	-
Miller Peak	-	-	-	-	-
Mt. Wrightson	-	-	-	2,718	-
Pajarita	-	-	-	-	-
Pusch Ridge	-	-	-	42,571	-
Rincon Mountain	-	-	-	19,751	-
Sierra Estrella	-	-	1,878	-	-
South Maricopa Mountains	-	-	3,049	-	-
Table Top	-	-	25,340	-	8,991
West Saguaro	-	11,011	-	-	-
*Total Wilderness Area (acre)**	*1,326*	*106,086*	*30,267*	*114,529*	*8,991*

*Data pertains to the U.S. portion of the watershed only.

Table 4-18.1: Santa Cruz Watershed Wilderness Areas (acres) (part 2 of 2).

Wilderness Area	Upper Santa Cruz River H15050301	Santa Cruz Watershed	Rio Asuncion H15080200	Rio Asuncion Watershed
Baboquivari Peak	-	2,041	-	-
Buenos Aires	-	89,290	11,444	11,444
Coyote Mountains	-	5,075	-	-
East Saguaro	-	49,484	-	-
Miller Peak	2,578	2,578	-	-
Mt. Wrightson	22,385	25,103	-	-
Pajarita	1	1	7,528	7,528
Pusch Ridge	14,348	56,919	-	-
Rincon Mountain	-	19,751	-	-
Sierra Estrella	-	1,878	-	-
South Maricopa Mountains	-	3,049	-	-
Table Top	-	34,331	-	-
West Saguaro	2,029	13,040	-	-
*Total Wilderness Area (acre)**	*41,341*	*302,540*	*18,972*	*18,972*

*Data pertains to the U.S. portion of the watershed only.

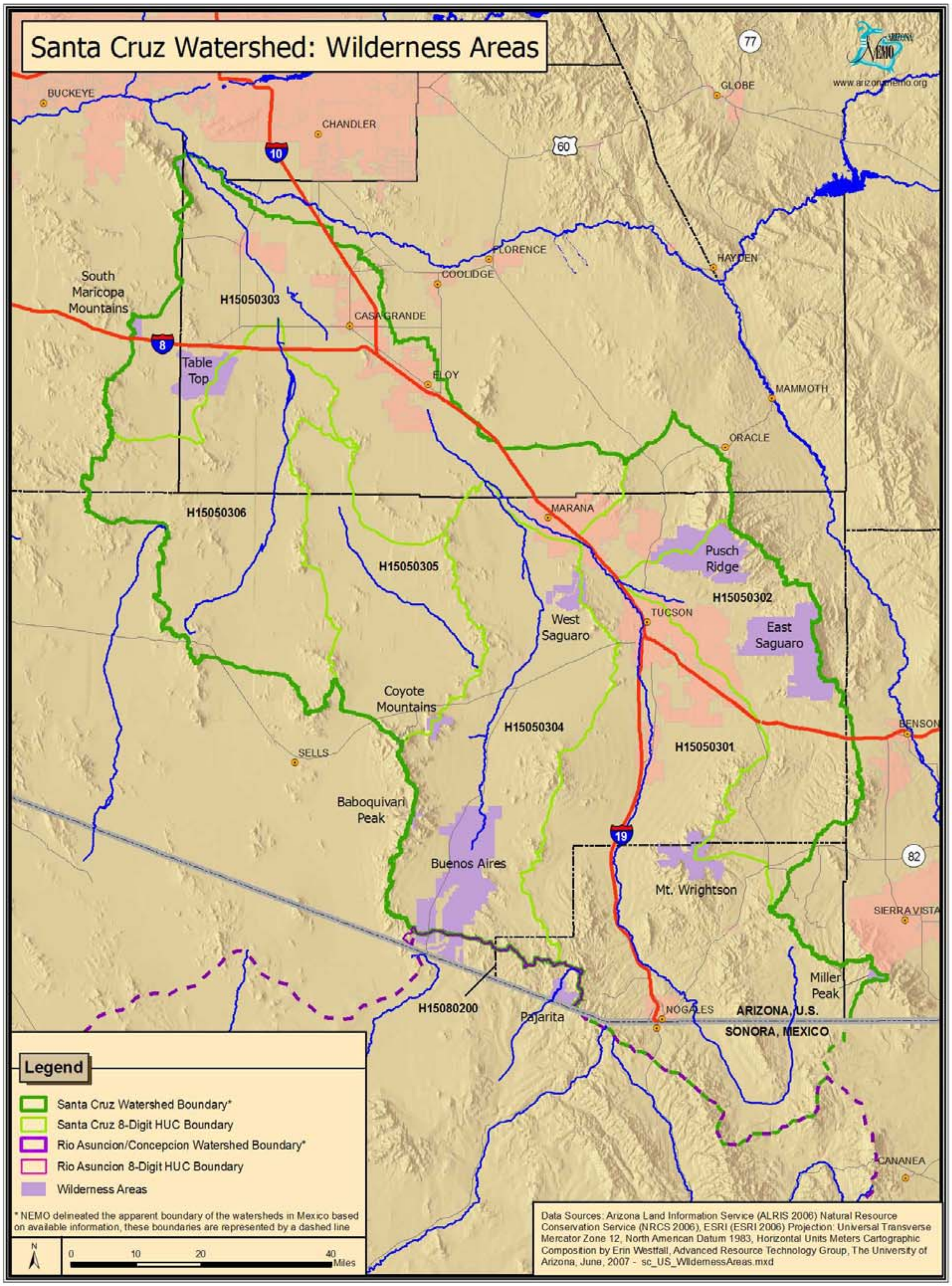

Figure 4-17.1: Santa Cruz Watershed Wilderness Areas

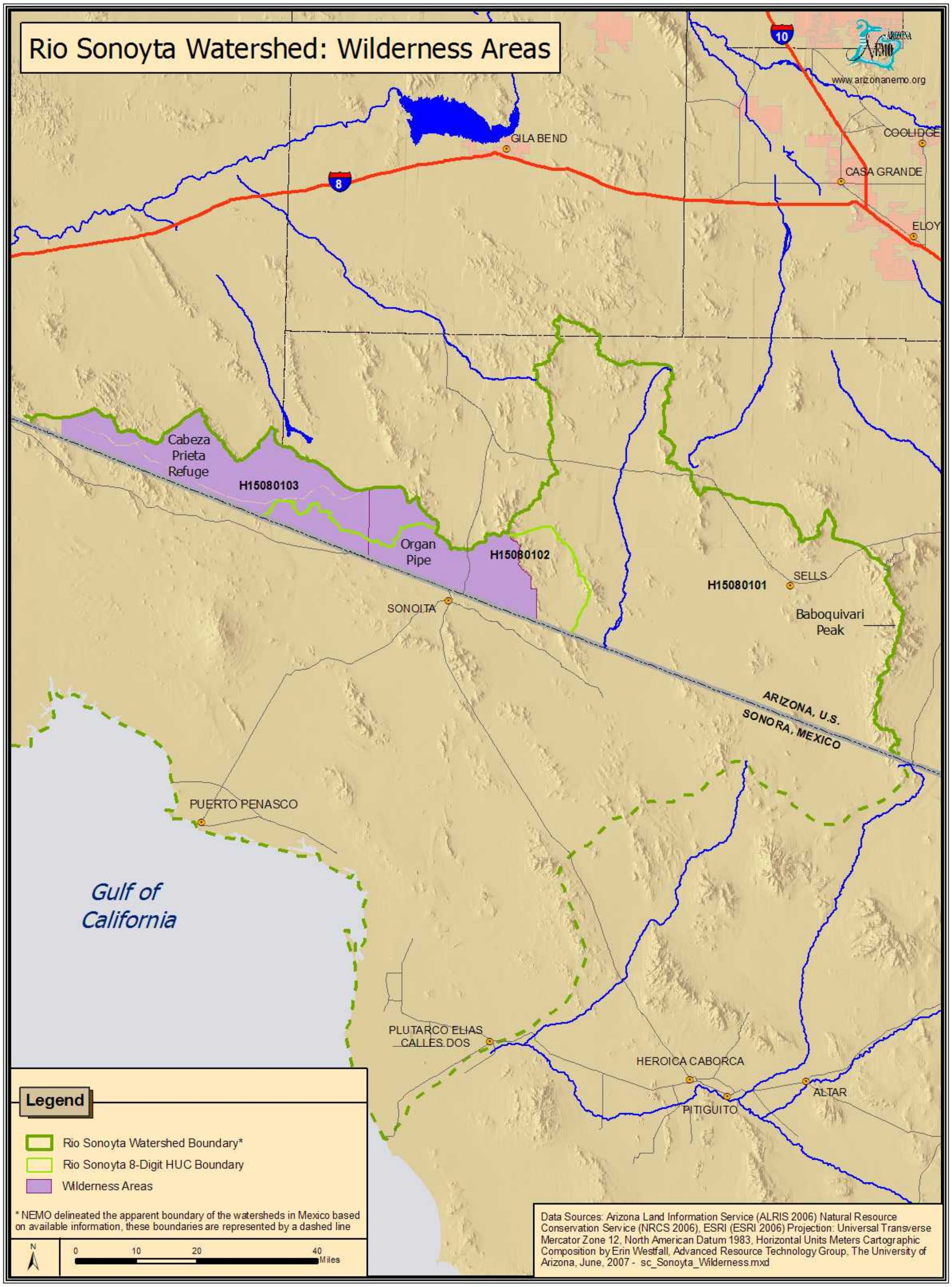

Figure 4-17.2: Rio Sonoyta Watershed Wilderness Areas

Table 4-18.2: Rio Sonoyta Watershed Wilderness Areas (acres).

Wilderness Area	**Rio Sonoyta H15080102**	**San Simon Wash H15080101**	**Tule Desert Area H15080103**	**Rio Sonoyta Watershed**
Baboquivari Peak	-	14	-	14
Cabeza Prieta	41,095	-	261,883	302,978
Organ Pipe	143,239	3	43,919	187,161
*Total Wilderness Area (acre)**	*184,334*	*17*	*305,802*	*490,153*

*Data pertains to the U.S. portion of the watershed only.

Golf Courses

There are 10 mapped golf courses within the Santa Cruz Watershed, shown as purple circles in Figure 4-18. Most are located in the central part of the watershed, near the Tucson metropolitan area. Additional golf courses may exist in the Santa Cruz Watershed that were not included in the 2001 GIS data layer used for this analysis (ESRI Data and Maps, 2003). There are no golf courses in either the Rio Asuncion or the Rio Sonoyta Watersheds.

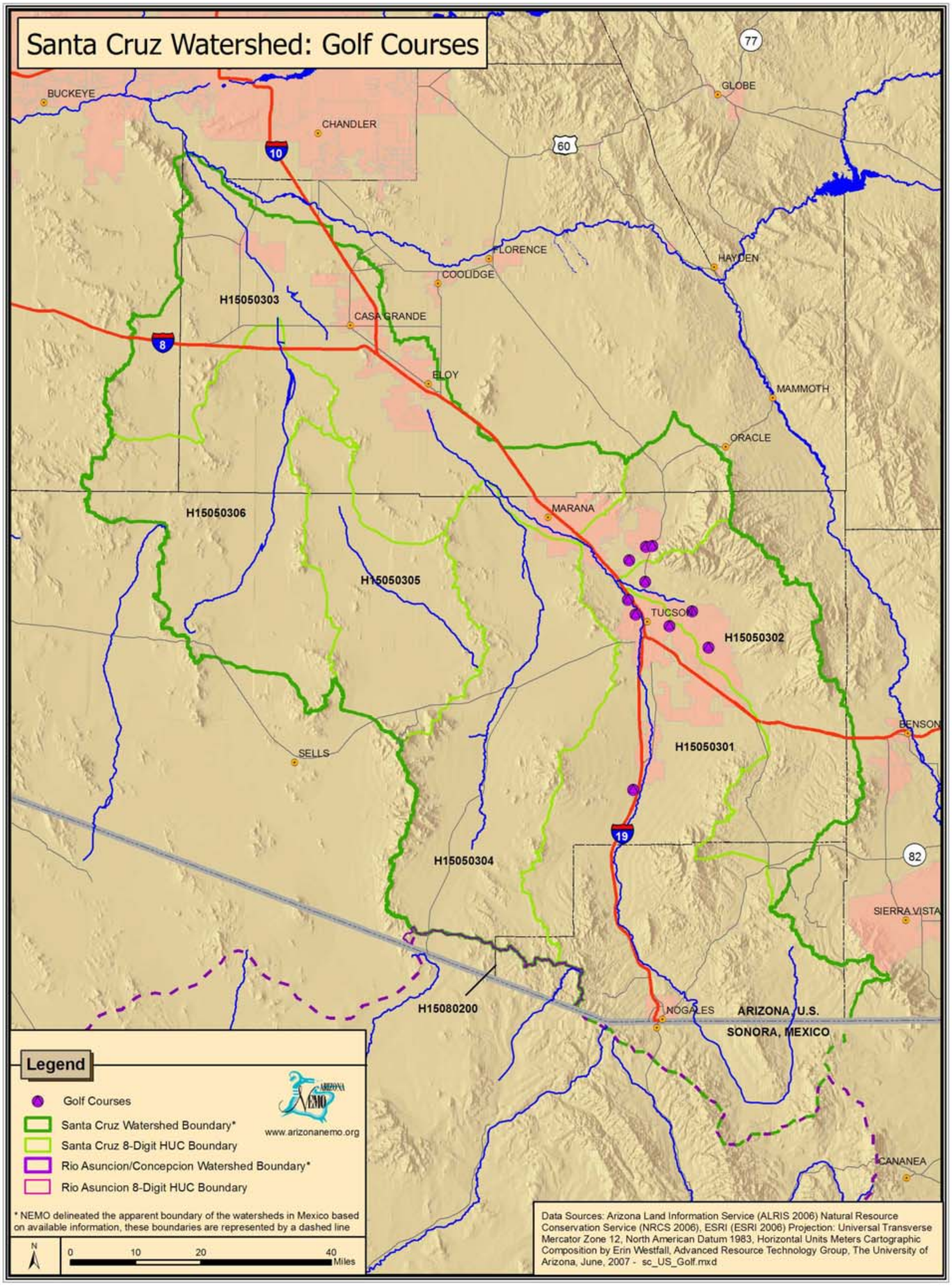

Figure 4-18.1: Santa Cruz Watershed Golf Courses

References:

GeoLytics, Inc. 1998. Census 1990. Census CD + Maps. Release 3.0.

Data Sources:*

Arizona State Land Department, Arizona Land Resource Information System (ALRIS), http://www.land.state.az.us/alris/index.html
County Governments. June 6, 2003.
Council of Governments. June 6, 2003
Land ownership. February 7, 2002.
Mines. February 7, 2002.
Preserve Areas. July 31, 2003.
Wilderness Areas. June 9, 2003.

ESRI Data Products, http://arcdata.esri.com/data/tiger2000/tiger_download.cfm
Census 2000. October 17, 2003.

ESRI Data and Maps. 2001. 7 CD set: CD 3, no.85913.
Golf Courses. 2003

Southern Arizona Data Services Program, University of Arizona. Published by the U.S. Geological Survey, Sonoran Desert Field Station, University of Arizona. http://sdrsnet.srnr.arizona.edu/index.php
Roads. February 17, 2003.

U.S. Census Bureau. http://www.census.gov/geo/www/cob/ua2000.html
Urban Areas 2000. July 22, 2003.

U.S. Department of the Interior, U.S. Geological Survey, http://landcover.usgs.gov/natllandcover.asp
Land use. July 21, 2003.

**Note: Dates for each data set refer to when data was downloaded from the website. Metadata (information about how and when the GIS data were created) is available from the website in most cases. Metadata includes the original source of the data, when it was created, its geographic projection and scale, the name(s) of the contact person and/or organization, and a general description of the data.*

Section 5: Important Resources

The Santa Cruz Watershed has extensive and important natural resources, with national, regional and local significance. The watershed contains critical riparian habitat for the Mexican Spotted Owl (U.S. Fish & Wildlife Service, 2004). The watershed also contains important recreational resources including extensive wilderness areas with hiking, bird watching and fishing.

As a result of our analysis, three Natural Resource Areas (NRAs) have been identified for protection based on the combination of natural resource values. Factors that were considered in delineating these areas include: legal status (outstanding waters, critical habitat for threatened and endangered species, national monument areas and wilderness), the presence of perennial waters and riparian areas, the presence of state parks and forests, recreational resources and local values.

The NRAs have been categorized within the 10-digit HUC subwatershed area where they are located. Several 10-digit contiguous HUCs have been combined to form a unique NRA based on criteria such as State Parks, Forests, Wilderness areas and endangered species they have in common. The significance of each area is discussed in the following paragraphs. The three identified Natural Resource Areas consist of the following groupings of 10-digit HUCS:

1. *Upper Santa Cruz River NRA*:
San Rafael, Sonoita, Portrero Creek, Sopari Wash Josephine Canyon, Demetrie Wash, Box Canyon Wash, Canada del Oro, Julian Wash, Cienega Creek, Agua Verde Creek, Tanque Verde Creek, Arivaca Creek, Puertocito Wash, Altar Wash, Upper Brawley Wash, Lower Brawley Wash.

2. *Lower Santa Cruz NRA:*
Guild Wash, Agua Verde Creek, Greene Wash, Upper Vekol Wash, Lower Vekol Wash, Lower Santa Cruz Wash, Viopuli Wash, Upper Aguirre Wash, Lower Aguirre Wash, Tat Momoli Wash, Upper Santa Rosa Wash, Kohatk Wash, Middle Santa Rosa Wash, Lower Santa Rosa Wash.

3. *Sonoyta-Asuncion NRA*:
Rio Alta Headwaters, Rio El Sasabe Headwaters, San Simon Wash, Hickiwan Wash, Upper San Simon Wash, Upper Vamori Wash, Sells Wash, Lower Vamori Wash, Middle San Simon Wash, Chukut Kuk Wash, Rio San Francisquito, Lower San Simon Wash, Pai Oik Wash-Menagers Lake, Sonoyra Valley Area, Davidson Canyon, Aguajita Wash, Pinacate Valley-Las Playas, Puente Cuates, La Jolla Wash.

Upper Santa Cruz River NRA

The Upper Santa Cruz River NRA includes 17 10-digit HUC subwatersheds: San Rafael, Sonoita, Portrero Creek, Sopari Wash Josephine Canyon, Demetrie Wash, Box Canyon Wash, Canada del Oro, Julian Wash, Cienega Creek, Agua

Verde Creek, Tanque Verde Creek, Arivaca Creek, Puertocito Wash, Altar Wash, Upper Brawley Wash, Lower Brawley Wash. This NRA contains Tumacacori National Historical Park, Saguaro National Park, extensive riparian vegetation along the Santa Cruz River and its tributaries, important perennial streams, five wilderness areas, critical wildlife habitat and national forests.

Also within the Upper Santa Cruz NRA, portions of two areas are currently protected as Outstanding Arizona Waters: Cienega Creek and Davidson Canyon (Figure 2-5). Table 2-5.2 shows that 28.3 miles of Cienega Creek is currently recognized as an OAW, while 17 miles of stream in Davidson Canyon, from its headwaters to Cienega Creek, is currently under consideration for OAW classification (OAW candidate waters are afforded protection during the course of the approval process) (ADEQ 2007).

Critical habitat exists in the Upper Santa Cruz NRA for the Huachuca Water Umbel, the Gila Chub and the Mexican Spotted Owl (Figure 3-7.1 and Table 3-7)

The following description of Tumacacori National Historical Park is from the National Park Service website (http://www.nps.gov/tuma/naturescience/index.htm)

Tumacacori National Monument (now National Historical Park) was established in 1908 to protect, preserve and tell the story of the old Spanish and O'odham mission church. In 2005, more than 300 acres were added to the park, reuniting the church grounds with a small piece of historical mission property and placing more than a mile of Santa Cruz River riparian environment, mesquite bosque (forest) and a section of the Juan Bautista de Anza National Historical Trail ("Anza Trail") within the park.

The 4.5 mile stretch of Anza Trail that extends from Tumacacori to the Tubac Presidio State Historic Park in Tubac was the first stretch of this trail to be established in Arizona. The trail follows the river in the shade of mesquite, hackberry, elderberry, cottonwood, and willow trees.

The riparian, mesquite bosque and surrounding desert scrub environments within the park provide shelter to more than 200 species of birds.

Other animals take refuge in the park, including mammals such as coyote, javelina, and raccoon, twenty-four documented species of reptiles and amphibians, and notable insects such as the giant mesquite bug, tarantula, tarantula hawk, and velvet ant.

The following description of Saguaro National Monument is from the National Park Service website (http://www.nps.gov/sagu/naturescience/index.htm)

Saguaro National Park is composed of two distinct districts: The Rincon Mountain District and the Tucson Mountain District. The Tucson Mountain District lies on the west side of Tucson, Arizona, while the Rincon Mountain District lies on the east side of Tucson. Both districts were formed to protect and exhibit forests of their namesake plant: the Saguaro Cactus.

Most people think of Saguaro National Park as being a desert park. True, the lower elevations of the park encompass Sonoran Desert Vegetation, but there is much more to Saguaro National Park than just cacti.

The Tucson Mountain District of Saguaro National Park ranges from an elevation of 2,180 ft to 4,687 ft and contains 2 biotic communities, desert scrub, and desert grassland. Average annual precipitation is approximately 10.27 in. Common wildlife include the coyote, Gambel's quail, and desert tortoise.

The Rincon Mountain District of Saguaro National Park ranges from an elevation of 2,670 ft to 8,666 ft and contains 6 biotic communities. The biotic communities (starting from the lowest elevation) include desert scrub, desert grassland, oak woodland, pine-oak woodland, pine forest and mixed conifer forest. Average annual precipitation is approximately 12.30 in. The Rincon Mountains peak at a considerably higher elevation than the Tucson Mountains, therefore there are more biotic communities and increased plant and wildlife diversity. Because of the higher elevation in the Rincons, animals like the black bear, Mexican spotted owl, Arizona mountain king snake, and white-tailed deer live in this district.

Lower Santa Cruz NRA

The Lower Santa Cruz NRA includes 14 10-digit HUC subwatersheds: Guild Wash, Agua Verde Creek, Greene Wash, Upper Vekol Wash, Lower Vekol Wash, Lower Santa Cruz Wash, Viopuli Wash, Upper Aguirre Wash, Lower Aguirre Wash, Tat Momoli Wash, Upper Santa Rosa Wash, Kohatk Wash, Middle Santa Rosa Wash, Lower Santa Rosa Wash. The Lower Santa Cruz NRA contains Casa Grande Ruins National Park, and Table Top Wilderness Area, and it contains critical habitat for the Mexican Spotted Owl, the Gila Chub, and the Huachuca Water Umbel.

The following description of Casa Grande Ruins National Monument is from the National Park Service website *(http://www.nps.gov/cagr/historyculture/index.htm)*

The Casa Grande, or "Big House," built around 1350 C.E. is one of the largest prehistoric structures ever built in North America. However, its purpose remains as much a mystery as the people who built it. Archeologists have discovered evidence of wide-scale irrigation farming and trade which lasted over a thousand years and ended about 1450. Today the ancient ones are remembered as the "Hohokam," an

O'odham word meaning "Those Who Are Gone."

When the Hohokam lived in the Sonoran Desert hundreds of years ago, there was more surface water available to help them survive than what we have today. Most of the major rivers in Arizona ran all year round. Along the river beds were riparian areas. These areas included many water-loving plants like reeds, grasses, and cottonwood trees. Fish lived in the rivers and the Hohokam hunted them for food.

The following description of Table Top Wilderness is from Wilderness.net (*http://www.wilderness.net/index.cfm?fuse=NWPS&sec=wildView&WID=592*)

Table Top Wilderness has a total of 34,400 acres and is managed by the Bureau of Land Management. Visible from Phoenix to the south, 4,373-foot-high Table Top Mountain rises to a flat 40-acre summit of desert grassland, the highest point in the Wilderness. Below the summit on the southwest side grows a dense forest of saguaro cacti. Surrounding the mountain are flat-topped mesas, narrow ridges descending to bajadas, wide canyons, lava flows, and washes lined with mesquite and ironwood. Vegetation includes abundant cacti, paloverde, and creosote. The giant spotted whiptail lizard and the Ajo Mountain whipsnake share their domain with desert bighorn sheep, desert tortoises, coyotes, quail, and javelina (a gregarious, nocturnal piglike peccary).

Sonoyta-Asuncion NRA

The Sonoyta-Asuncion NRA contains 18 10-digit HUC subwatersheds: Rio Alta Headwaters, Rio El Sasabe Headwaters, San Simon Wash, Hickiwan Wash, Upper San Simon Wash, Upper Vamori Wash, Sells Wash, Lower Vamori Wash, Middle San Simon Wash, Chukut Kuk Wash, Rio San Francisquito, Lower San Simon Wash, Pai Oik Wash-Menagers Lake, Sonoyra Valley Area, Davidson Canyon, Aguajita Wash, and Pinacate Valley-Las Playas.

The Sonoyta-Asuncion NRA includes Organ Pipe Cactus National Monument, Cabeza Prieta National Wildlife Refuge, Pajarita Wilderness, and the southern part of the Buenos Aires National Wildlife Refuge. The eastern corner of the Sonoyta-Asuncion NRA contains critical habitat for the Mexican Spotted Owl (Figure 3-7.1 and Table 3-7).

The following description of Organ Pipe Cactus National Monument is from the National Park Service Webpage (*http://www.nps.gov/orpi/naturescience/index.htm*)

Organ Pipe Cactus National Monument exhibits an extraordinary collection of plants and animals of the Sonoran Desert. This is a showcase for creatures who have adapted themselves to the extreme temperatures, intense sunlight, and little rainfall that characterize this Southwest region. Twenty-six species of cactus have mastered the art of living in this place, including the park's namesake and the giant saguaro.

As a protected area, Organ Pipe Cactus National Monument allows the life of the Sonoran Desert to flourish under nearly ideal wilderness conditions. The monument is an outstanding natural preserve where one of the of the Earth's major ecosystems survives almost unspoiled. Recognizing its significance, the United Nations in 1976 designated the monument as an International Biosphere Reserve.

The following description of Cabeza Prieta National Wildlife Refuge is from Wikipedia (http://en.wikipedia.org/wiki/Cabeza_Prieta_National_Wildlife_Refuge)

The Cabeza Prieta National Wildlife Refuge is located in the Sonoran Desert in southwestern Arizona in the United States. The refuge, established in 1939 to protect Desert Bighorn Sheep, is located along 56 miles of the U.S.-Mexican border, and covers 860,010 acres (3,480 km^2) — larger than the land area of the state of Rhode Island. 803,418 acres (3,251 km^2) were preserved in 1990 as the Cabeza Prieta Refuge Wilderness. The refuge may be temporarily closed for training exercises on the Barry M. Goldwater Air Force Range. It is the third largest national wildlife refuge in the lower 48 states. Spanish for "dark head," the refuge's name comes from a mountain in its northwest corner.

The following description of Pajarita Wilderness is from the US Forest Service Webpage (http://www.fs.fed.us/r3/coronado/forest/recreation/wilderness/pajarita.shtml.)
Pajarita is a Spanish word meaning “little bird.” It is an appropriate name for this 7,420-acre area, for a couple of reasons. For one, the international border with Mexico forms the area’s southern boundary.

For another, the area’s rugged canyons, which point south toward the subtropical environments of Mexico and Central America, provide a natural migration route for a surprising diversity of birds. The lush riparian habitat of Sycamore Canyon, the area’s most prominent natural feature, also supports a number of resident species. As many as 160 species of birds have been observed in and around Sycamore Canyon.

Though the area’s rolling hills are predominantly covered with desert savannas and oak woodlands, its riparian areas are home of an astonishingly diverse vegetative community. Over 600 species of plants, some of which are extremely rare, have been identified in these productive habitats. Part of the Wilderness lies within the

Goodding Research Natural Area, established in this area precisely because of the amazing diversity found here.

Two major trails lead into the Pajarita Wilderness, the only Wilderness in the Coronado National Forest not located on the high slopes of a mountain range. The Sycamore Canyon Trail #40 leads downstream in that showplace of biological diversity, past riffles and pools that hold water year-round. The Border Trail #45 skirts the international border from the Summit Motorway, a rough 4-wheel drive road that parallels the eastern edge of the Wilderness, to a junction with the Sycamore Canyon Trail #40.

References:

National Park Service, Casa Grande Ruins National Monument, (http://www.nps.gov/cagr/historyculture/index.htm)

National Park Service, Organ Pipe Cactus National Monument, *http://www.nps.gov/orpi/naturescience/index.htm*

National Park Service, Saguaro National Monument, http://www.nps.gov/sagu/naturescience/index.htm

National Park Service, Tumacacori National Historical Park, http://www.nps.gov/tuma/naturescience/index.htm

U.S. Fish & Wildlife Service. 2004.
Mexican Spotter Owl, http://www.fws.gov/ifw2es/Documents/R2ES/MSO Recovery Plan.pdf

U.S. Forest Service, Pajarita Wilderness, *(http://www.fs.fed.us/r3/coronado/forest/recreation/wilderness/pajarita.shtml*

Wikipedia.org, Cabeza Prieta National Wildlife Refuge, *http://en.wikipedia.org/wiki/Cabeza_Prieta_National_Wildlife_Refuge*

Wilderness.net, Table Top Wilderness, *(http://www.wilderness.net/index.cfm?fuse=NWPS&sec=wildView&WID=592)*

Section 6: Watershed Classification

This watershed classification was conducted on the thirty subwatersheds that comprise the Santa Cruz Watershed, the two subwatersheds in the Rio Asuncion Watershed, and the sixteen subwatersheds that comprise the Rio Sonoyta Watershed. For purposes of map display, there will be separate maps for the Santa Cruz Watershed, the Rio Sonoyta Watershed and the Rio Asuncion Watershed. However, in the text, they will collectively be referred to as the Santa Cruz Watershed.

In this watershed classification, each 10-digit subwatershed in the Santa Cruz Watershed is classified or ranked based on susceptibility to water quality problems and pollution sources that need to be controlled through implementation of nonpoint source Best Management Practices (BMPs). This classification also prioritizes subwatersheds for available water quality improvement grants, based on known water quality concerns.

<u>Methods</u>

The general approach used to classify subwatersheds was to integrate watershed characteristics, water quality measurements, and results from modeling within a multi-parameter ranking system based on the fuzzy logic knowledge-based approach (described below), as shown schematically in Figure 6-1.

The process was implemented within a GIS interface to create the subwatershed classifications using five primary steps:

1. Define the goal of the watershed classification: to prioritize which 10-digit subwatersheds are most susceptible to known water quality concerns, and therefore, where BMPs should be implemented to reduce nonpoint source pollution;

2. Assemble GIS data and other observational data;

3. Define watershed characteristics through:

    a. Water quality assessment data provided by Arizona’s Integrated 305(b) Assessment and 303(d) Listing Report (ADEQ. 2006a);

    b. GIS mapping analysis; and

    c. Modeling / simulation of erosion vulnerability and potential for stream impairment (in this case, from soils in mine site areas and proximity of mines sites to riparian areas).

4. Use fuzzy membership functions to transform the potential vulnerability / impairment metrics into fuzzy membership values with scales from 0 to 1; and

5. Determine a composite fuzzy score representing the ranking of the combined attributes, and interpret the results.

GIS and Hydrologic Modeling

GIS and hydrologic modeling were the major tools used to develop this watershed-based plan. Planning and

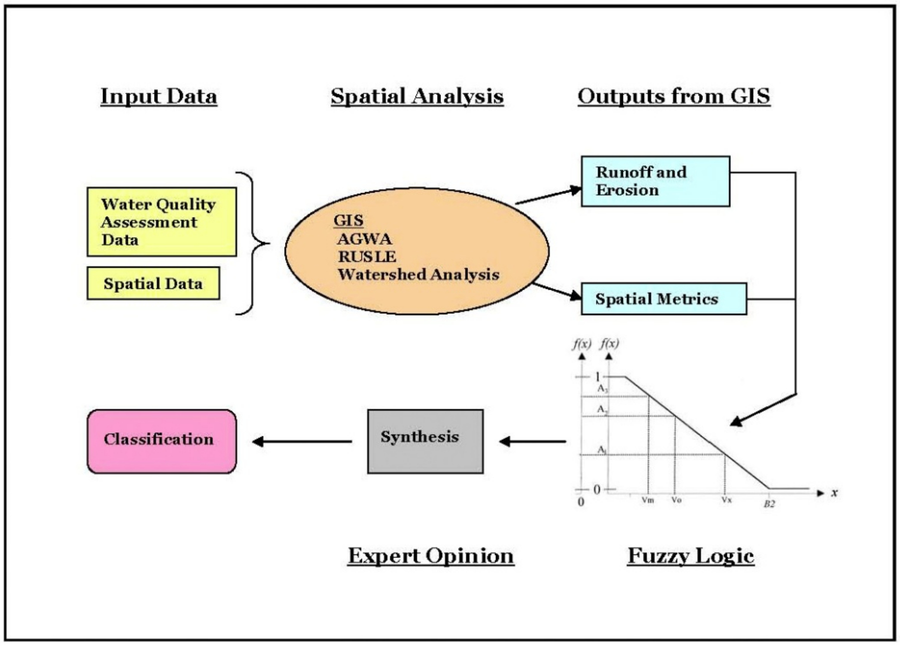

Figure 6-1: Transformation of Input Data via a GIS, Fuzzy Logic Approach, and Synthesis of Results into a Watershed Classification.

assessment in land and water resource management require spatial modeling tools so as to incorporate complex watershed-scale attributes into the assessment process. Modeling tools applied to the Santa Cruz Watershed include AGWA, SWAT, and SEDMOD/RUSLE, as described below and in Appendices C and D.

The Automated Geospatial Watershed Assessment Tool (AGWA) is a GIS-based hydrologic modeling tool designed to evaluate the effects of land use change (Burns et al., 2004). AGWA provides the functionality to conduct all phases of a watershed assessment. It facilitates the use of the Soil and Water Assessment Tool (SWAT), a hydrologic model, by preparing the inputs, running the model, and presenting the results visually in the GIS. AGWA has been used to illustrate the impacts of urbanization and other landscape changes on runoff and sediment load in a watershed. AGWA was developed under a joint project between the Environmental Protection Agency (EPA), Agricultural Research Service (ARS), and the University of Arizona. SWAT was developed by the ARS, and is able to predict the impacts of land management practices on water, sediment and chemical yields in complex watersheds with varying soils, land use and management conditions (Arnold et al., 1994). The SEDMOD model (Van Remortel et al., 2006), which uses the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997), was used to estimate soil erosion and sediment delivery from different land use types.

The watershed classification within this plan incorporates GIS-based hydrologic modeling results and other data to describe watershed conditions upstream from an impaired stream reach identified within Arizona's Integrated 305(b) Assessment and 303(d) Listing Report (ADEQ. 2006a). In addition, impacts due to mine sites (e.g. erosion and metals pollution) and grazing (e.g. erosion and pollutant nutrients) are simulated.

Fuzzy Logic

To rank the 10-digit HUC subwatershed areas that are susceptible to water quality problems and pollution, and to identify sources that need to be controlled, a fuzzy logic knowledge-based methodology was applied to integrate the various spatial and non-spatial data types (Guertin et al., 2000; Miller et al., 2002; Reynolds et al., 2001). This methodology has been selected as the basis by which subwatershed areas and stream reaches are prioritized for the implementation of BMPs to assure nonpoint source pollution is managed.

Fuzzy logic is an approach to set theory that handles vagueness or uncertainty, and has been described as a method by which to quantify common sense. In classical set theory, an object is either a member of the set or excluded from the set. Fuzzy logic allows for an object to be a partial member of a set, and converts the range in values between different data factors to the same scale (0.0 -1.0) using fuzzy membership functions. Fuzzy membership functions can be discrete or continuous depending on the input characteristics.

The development of a fuzzy membership function can be based on published data, expert opinions, stakeholder values or institutional policy, and can be created in a data-poor environment. A benefit of this approach is that it provides for the use of different methods for combining individual factors to create the final classification and the goal set. Fuzzy membership functions and weighting schemes can also be changed based on watershed concerns and conditions.

Subwatershed Classifications

This classification was conducted at the 10-digit HUC subwatershed scale. Table 6-1 lists the 10-digit HUC numerical identifications and subwatershed names for all thirty subwatersheds in the Santa Cruz River Watershed, the sixteen subwatersheds in the Rio Sonoyta Watershed, and the two subwatersheds in the Rio Asuncion Watershed.

Table 6-1: HUC 10-Digit Designation and Subwatershed Name.

HUC 10	**Subwatershed Name**
	SANTA CRUZ WATERSHED
1505030101	San Rafael Valley-Upper Santa Cruz River
1505030102	Sonoita Creek
1505030103	Potrero Creek-Upper Santa Cruz River
1505030104	Sopori Wash
1505030105	Josephine Canyon-Upper Santa Cruz River
1505030106	Demetrie Wash-Upper Santa Cruz River
1505030107	Box Canyon Wash-Upper Santa Cruz River
1505030108	Canada del Oro
1505030109	Julian Wash-Upper Santa Cruz River
1505030201	Cienega Creek
1505030202	Agua Verde Creek-Pantano Wash
1505030203	Tanque Verde Creek-Rillito River

HUC 10	Subwatershed Name
1505030301	Guild Wash-Lower Santa Cruz River
1505030302	Lower Santa Cruz River-North Branch Santa Cruz Wash
1505030303	Greene Wash - Upper Santa Cruz Wash
1505030304	Upper Vekol Wash
1505030305	Lower Vekol Wash
1505030306	Lower Santa Cruz Wash
1505030401	Arivaca Creek
1505030402	Puertocito Wash
1505030403	Altar Wash
1505030404	Upper Brawley Wash
1505030405	Lower Brawley Wash
1505030406	Los Robles Wash
1505030501	Viopuli Wash
1505030502	Upper Aguirre Wash
1505030503	Lower Aguirre Wash
1505030504	Tat Momoli Wash
1505030601	Upper Santa Rosa Wash
1505030602	Kohatk Wash
1505030603	Middle Santa Rosa Wash
1505030604	Lower Santa Rosa Wash
	RIO SONOYTA WATERSHED
1508010101	Hickiwan Wash
1508010102	Upper San Simon Wash
1508010103	Upper Vamori Wash
1508010104	Sells Wash
1508010105	Lower Vamori Wash
1508010106	Middle San Simon Wash
1508010107	Chukut Kuk Wash
1508010108	Rio San Francisquito
1508010109	Lower San Simon Wash
1508010201	Pia Oik Wash-Menagers Lake
1508010202	Sonoyta Valley Area
1508010203	Davidson Canyon
1508010204	Aguajita Wash-Rio Sonoyta
1508010301	Pinacate Valley-Las Playas
1508010302	Puente Cuates
1508010303	La Jolla Wash
	RIO ASUNCION WATERSHED
1508020001	Rio Altar Headwaters
1508020002	Rio El Sasabe Headwaters

Classifications were conducted on individual or groups of water quality parameters, and potential for impairment for a water quality parameter based on the biophysical characteristics of the watershed. Constituent groups were evaluated for the Santa Cruz and Rio Sonoyta Watersheds. The Rio Asuncion was evaluated but not modeled with AGWA/SWAT or SEDMOD because only small portions of two subwatersheds occur in the US, and they both drain to Mexico. The constituent groups are:

- Metals (cadmium, mercury, copper, zinc, lead, arsenic), with cadmium used as an index since it is the most common parameter sampled in the watershed;
- Sediment (turbidity is used as an index since it was the previous standard and represents most of the sampling data);
- Organics (concerns include *Escherichia coli (E. coli)*, nutrients, high pH and dissolved oxygen, and are related to organic material being introduced into the aquatic system); and
- Selenium.

The development of the fuzzy logic approach for each constituent is described below.

Water Quality Assessment Data

ADEQ's water quality assessment criteria and assessment definitions are found in Arizona's Integrated 305(b)

Assessment and 303(d) Listing Report (ADEQ. 2006a). These data were used to define the current level of impairment of each HUC-10 subwatershed using fuzzy membership values. For more information see the ADEQ website: http://www.azdeq.gov/environ/water/assessment/assess.html.

Surface waters assessed as "impaired" and included in the 303(d) List of Impaired Waters are scheduled for completion of a Total Maximum Daily Load (TMDL) quantitative and analysis plan. A TMDL is the maximum amount (load) of a water quality parameter which can be carried by a surface water body, on a daily basis, without causing an exceedance of surface water quality standards (ADEQ. 2006b). Although all monitored water bodies will be reviewed in this watershed-based plan, only those assessed as impaired will be discussed for best management practices (Section 7 of this Watershed-Based Plan).

Appendix A Table 1 is a summary of the ADEQ water quality monitoring data (ADEQ. 2006a) and 10-digit HUC subwatershed classification results for the entire Santa Cruz Watershed. The water quality data were used to classify each monitored stream reach or water body based on its relative risk of impairment for the constituent groups. It should be noted that not every 10-digit HUC subwatershed contained a water quality sampling site.

The four levels of risk used to classify each water body are: Extreme, High, Moderate and Low.

- Extreme risk - If a surface water body within the subwatershed is currently assessed as being "impaired" by ADEQ for one of the constituent groups.

- High risk - If a surface water body within the subwatershed is assessed as "inconclusive" because of limited data, but the available sampling indicates water quality exceedances occurred.

- Moderate risk - If either:
    - A surface water body within the subwatershed was assessed as "inconclusive" or "attaining", but there are still a low number of samples exceeding standards for a constituent group (i.e. less than 10% of samples); or

    - There were no water quality measurements available for a constituent group at any site within the subwatershed.

- Low risk - If no exceedances exist in a constituent group and there were sufficient data to make an assessment.

An overall risk classification is assigned to the 10-digit HUC subwatershed based on the worst case risk classification of the water bodies in that subwatershed (see Appendix A, Table 1). Fuzzy membership values (FMV) were assigned to each subwatershed using the criteria in Table 6-2.

The FMVs in Table 6-3 are based on two considerations: 1) Subwatershed relative risk of impairment (described above), and 2) Downstream subwatershed risk of impairment.

The status of downstream surface waters provides a way to evaluate the possibility that the subwatershed is contributing to downstream water quality problems. This is particularly important where water quality data is limited and few surface water quality samples may have been collected within the subwatershed.

Water bodies classified as either extreme (impaired) or low (no exceedances) risk had a higher influence than high or moderate classified water bodies in determining downstream water quality condition because they were less ambiguous than the other levels of risk. For example, if a water body was classified as extreme risk, it was used to define the water quality condition, and the subwatershed was given an FMV of 1.0. Likewise, if a water body along the pathway was classified as low risk, then that water body was used to define the downstream water quality condition (see Table 6-2).

Table 6-2: Fuzzy Membership Values (FMV) for HUC-10 Subwatersheds Based on ADEQ Water Quality Assessment Results

Subwatershed Classification	Downstream Subwatershed Classification	FMV
Extreme	N/A	1.0
High	Extreme	1.0
High	High	0.8
High	Moderate/Low	0.7
Moderate	Extreme	0.7
Moderate	High	0.6
Moderate	Moderate	0.5
Moderate	Low	0.3
Low	N/A	0.0

Metals

Metals are one of the most significant water quality problems in these watersheds because of the potential toxicity to aquatic life. Parts of the region have a long history of metal mining, and this use has left many stream segments and lakes with elevated levels of total and dissolved metals. Arizona's Integrated 305(b) Assessment and 303(d) Listing Report (ADEQ. 2006a) has designated several streams or lakes as Category 4 or 5, Impaired for metals (see Appendix A, Table 1). However, some stream reaches have not been sampled for metals.

The primary sources for metals are probably runoff and erosion from active and abandoned mines since there are a high number of mines in the area. However, developed urban areas are also considered to be a nonpoint source for metals pollutants.

The factors used for the metals classification were:

- ADEQ water quality assessment results;
- Presence of mines within a watershed;
- Presence of mines within the riparian zone; and
- Potential contribution of mines to sediment yield.
- Percent urbanized areas

Water Quality Assessment - Metals

Arizona's Integrated 305(b) Assessment and 303(d) Listing Report (ADEQ. 2006a) was used to define the current level of impairment for metals for each stream reach. Each subwatershed was then assigned a risk level based on the worst case stream reach. The FMV was assigned based on the location of the subwatershed relative to an impaired water (Table 6-2).

Table 6-2 lists the fuzzy membership values used for different watershed conditions based on watershed location and water quality assessment results. Table 6-3 contains the fuzzy membership values assigned to each 10-digit HUC subwatershed for metals, based on the criteria defined in Table 6-2. The justification used to determine the FMV is also included in Table 6-3.

Table 6-3: Fuzzy Membership Values (FMV) Assigned to each 10-digit HUC Subwatershed, Based on Water Quality Assessment Results for Metals.

Subwatershed Name	Metals WQA FMV	Justification
SANTA CRUZ WATERSHED		
San Rafael Valley-Upper Santa Cruz River 1505030101	1.0	Classified as extreme risk, drains to Mexico, then to Potrero Creek-Upper Santa Cruz River that is classified as extreme.
Sonoita Creek 1505030102	1.0	Classified as extreme risk, drains to Josephine Canyon-Upper Santa Cruz River that is classified as moderate.
Potrero Creek-Upper Santa Cruz River 1505030103	1.0	Classified as extreme risk, drains to Josephine Canyon-Upper Santa Cruz River that is classified as moderate.
Sopori Wash 1505030104	0.5	Classified as moderate risk, drains to Demetrie Wash-Upper Santa Cruz River that is classified as moderate.
Josephine Canyon-Upper Santa Cruz River 1505030105	0.5	Classified as moderate risk, drains to Demetrie Wash-Upper Santa Cruz River that is classified as moderate.
Demetrie Wash-Upper Santa Cruz River 1505030106	0.5	Classified as moderate risk, drains to Box Canyon Wash-Upper Santa Cruz River that is classified as moderate.
Box Canyon Wash-Upper Santa Cruz River 1505030107	0.5	Classified as moderate risk, drains to Julian Wash-Upper Santa Cruz River that is classified as moderate.
Canada del Oro 1505030108	0.5	Classified as moderate risk, drains to Julian Wash-Upper Santa Cruz River that is classified as moderate.
Julian Wash-Upper Santa Cruz River 1505030109	0.5	Classified as moderate risk, drains to Guild Wash-Lower Santa Cruz River that is classified as moderate.
Cienega Creek 1505030201	0.0	Classified as low risk, drains to Agua Verde Creek-Pantano Wash that is classified as moderate.

Subwatershed Name	Metals WQA FMV	Justification
Agua Verde Creek-Pantano Wash 1505030202	0.6	Classified as moderate risk, drains to Tanque Verde Creek-Rillito River that is classified as high.
Tanque Verde Creek-Rillito River 1505030203	0.7	Classified as high risk, drains to Julian Wash-Upper Santa Cruz River that is classified as moderate.
Guild Wash-Lower Santa Cruz River 1505030301	0.5	Classified as moderate risk, drains to Greene Wash - Upper Santa Cruz Wash that is classified as moderate.
Lower Santa Cruz River-North Branch Santa Cruz Wash 1505030302	0.5	Classified as moderate risk, drains to Lower Santa Cruz Wash that is classified as moderate.
Greene Wash - Upper Santa Cruz Wash 1505030303	0.5	Classified as moderate risk, drains to Lower Santa Cruz Wash that is classified as moderate.
Upper Vekol Wash 1505030304	0.5	Classified as moderate risk, drains to Lower Vekol Wash that is classified as moderate.
Lower Vekol Wash 1505030305	0.5	Classified as moderate risk, drains to Lower Santa Cruz Wash that is classified as moderate.
Lower Santa Cruz Wash 1505030306	0.5	Classified as moderate risk, drains out of the 8-digit HUC
Arivaca Creek 1505030401	0.7	Classified as high risk, drains to Altar Wash that is classified as moderate.
Puertocito Wash 1505030402	0.5	Classified as moderate risk, drains to Altar Wash that is classified as moderate.
Altar Wash 1505030403	0.5	Classified as moderate risk, drains to Upper Brawley Wash that is classified as moderate.
Upper Brawley Wash 1505030404	0.5	Classified as moderate risk, drains to Lower Brawley Wash that is classified as moderate.
Lower Brawley Wash 1505030405	0.5	Classified as moderate risk, drains to Los Robles Wash that is classified as moderate.
Los Robles Wash 1505030406	0.5	Classified as moderate risk, drains to Greene Wash - Upper Santa Cruz Wash that is classified as moderate.
Viopuli Wash 1505030501	0.5	Classified as moderate risk, drains to Upper Aguirre Wash that is classified as moderate.
Upper Aguirre Wash 1505030502	0.5	Classified as moderate risk, drains to Lower Aguirre Wash that is classified as moderate.
Lower Aguirre Wash 1505030503	0.5	Classified as moderate risk, drains to Tat Momoli Wash that is classified as moderate.
Tat Momoli Wash 1505030504	0.5	Classified as moderate risk, drains to Lower Santa Rosa Wash that is classified as moderate.
Upper Santa Rosa Wash 1505030601	0.5	Classified as moderate risk, drains to Middle Santa Rosa Wash that is classified as moderate.
Kohatk Wash 1505030602	0.5	Classified as moderate risk, drains to Middle Santa Rosa Wash that is classified as moderate.
Middle Santa Rosa Wash 1505030603	0.5	Classified as moderate risk, drains to Lower Santa Rosa Wash that is classified as moderate.
Lower Santa Rosa Wash 1505030604	0.5	Classified as moderate risk, drains to Lower Santa Cruz Wash that is classified as moderate.

Subwatershed Name	Metals WQA FMV	Justification
RIO SONOYTA WATERSHED		
Hickiwan Wash 1508010101	0.5	Classified as moderate risk, drains to Middle San Simon Wash that is classified as moderate.
Upper San Simon Wash 1508010102	0.5	Classified as moderate risk, drains to Middle San Simon Wash that is classified as moderate.
Upper Vamori Wash 1508010103	0.5	Classified as moderate risk, drains to Lower Vamori Wash that is classified as moderate.
Sells Wash 1508010104	0.5	Classified as moderate risk, drains to Lower Vamori Wash that is classified as moderate.
Lower Vamori Wash 1508010105	0.5	Classified as moderate risk, drains to Lower San Simon Wash that is classified as moderate.
Middle San Simon Wash 1508010106	0.5	Classified as moderate risk, drains to Lower San Simon Wash that is classified as moderate.
Chukut Kuk Wash 1508010107	0.5	Classified as moderate risk, drains to Mexico.
Rio San Francisquito 1508010108	0.5	Classified as moderate risk, drains to Mexico.
Lower San Simon Wash 1508010109	0.5	Classified as moderate risk, drains to Mexico.
Pia Oik Wash-Menagers Lake 1508010201	0.5	Classified as moderate risk, drains to Mexico.
Sonoyta Valley Area 1508010202	0.5	Classified as moderate risk, drains to Mexico.
Davidson Canyon 1508010203	0.5	Classified as moderate risk, drains to Mexico.
Aguajita Wash-Rio Sonoyta 1508010204	0.5	Classified as moderate risk, drains to Mexico.
Pinacate Valley-Las Playas 1508010301	0.5	Classified as moderate risk, drains to Mexico.
Puente Cuates 1508010302	0.5	Classified as moderate risk, drains to Mexico.
La Jolla Wash 1508010303	0.5	Classified as moderate risk, drains to Mexico.
RIO ASUNCION WATERSHED		
Rio Altar Headwaters 1508020001	0.5	Classified as moderate risk, drains to Mexico.
Rio El Sasabe Headwaters 1508020002	0.5	Classified as moderate risk, drains to Mexico.

Location of Mining Activities

The type and location of a mine within a watershed and in relation to a riparian zone determines its potential for impact on nearby water quality.

Mining generally causes soil disturbance, which results in erosion and sediment yield to streams. In addition, since mines by definition occur in mineralized areas, it is assumed that the eroded soil is also high in metals. More thorough discussions of the geologic conditions and location of mine sites and mine types across the watershed are found in Section 2, Physical Characteristics and Section 4, Social/Economic Characteristics. The spatial data described in those sections were used along with the ADEQ water quality assessment data to classify each subwatershed for susceptibility to erosion and risk for metals pollution using the methodology described below.

The number of mines in a subwatershed and within the riparian zone (<= 250 m from a stream) were determined in the GIS. The results were used to assign an FMV to each subwatershed based on the following criteria.

Number of mines per watershed:

FMV = 0 if (# of mines <= 2)
FMV = (# of mines – 2) / 8
FMV = 1 if (# of mines >= 10)

Number of mines in riparian zone:

FMV = 0 if (# of mines < 1)
FMV = (# of mines) / 5
FMV = 1 if (# of mines >= 5)

Table 6-4 contains the fuzzy membership values assigned to each 10-digit HUC subwatershed based on the number of and location of mines. These values were used in the summary analysis to assess the relative impact of mining on the concentration of dissolved and total metals in the subwatershed.

Table 6-4: FMV for each Subwatershed Based on the Number and Location of Mines.

Subwatershed	FMV #mines /HUC	FMV #mines/ riparian
SANTA CRUZ WATERSHED		
San Rafael Valley-Upper Santa Cruz River 1505030101	1.0	1.0
Sonoita Creek 1505030102	1.0	1.0
Potrero Creek-Upper Santa Cruz River 1505030103	1.0	1.0
Sopori Wash 1505030104	1.4	1.0
Josephine Canyon-Upper Santa Cruz River 1505030105	1.0	1.0
Demetrie Wash-Upper Santa Cruz River 1505030106	1.0	1.0
Box Canyon Wash-Upper Santa Cruz River 1505030107	1.0	1.0
Canada del Oro 1505030108	1.0	1.0
Julian Wash-Upper Santa Cruz River 1505030109	1.0	1.0
Cienega Creek 1505030201	1.0	1.0
Agua Verde Creek-Pantano Wash 1505030202	1.0	1.0
Tanque Verde Creek-Rillito River 1505030203	1.0	1.0
Guild Wash-Lower Santa Cruz River 1505030301	1.0	1.0
Lower Santa Cruz River-North Branch Santa Cruz Wash 1505030302	1.0	1.0
Greene Wash - Upper Santa Cruz Wash 1505030303	1.0	1.0
Upper Vekol Wash 1505030304	0.0	0.2
Lower Vekol Wash 1505030305	1.0	0.6
Lower Santa Cruz Wash 1505030306	1.0	1.0
Arivaca Creek 1505030401	1.0	1.0
Puertocito Wash 1505030402	1.0	1.0
Altar Wash 1505030403	1.0	1.0
Upper Brawley Wash 1505030404	1.0	1.0
Lower Brawley Wash 1505030405	1.0	1.0
Los Robles Wash 1505030406	1.0	0.4
Viopuli Wash 1505030501	0.8	0.4

Subwatershed	FMV #mines /HUC	FMV #mines/ riparian
Upper Aguirre Wash 1505030502	0.4	0.6
Lower Aguirre Wash 1505030503	1.0	1.0
Tat Momoli Wash 1505030504	1.0	0.2
Upper Santa Rosa Wash 1505030601	1.0	1.0
Kohatk Wash 1505030602	1.0	0.6
Middle Santa Rosa Wash 1505030603	1.0	1.0
Lower Santa Rosa Wash 1505030604	1.0	0.4
RIO SONOYTA WATERSHED		
Hickiwan Wash 1508010101	0.0	0.2
Upper San Simon Wash 1508010102	1.0	1.0
Upper Vamori Wash 1508010103	0.8	1.0
Sells Wash 1508010104	1.0	1.0
Lower Vamori Wash 1508010105	1.0	1.0
Middle San Simon Wash 1508010106	1.0	1.0
Chukut Kuk Wash 1508010107	1.0	0.8
Rio San Francisquito 1508010108	0.0	0.0
Lower San Simon Wash 1508010109	0.0	0.2
Pia Oik Wash-Menagers Lake 1508010201	0.1	0.4
Sonoyta Valley Area 1508010202	0.0	0.0
Davidson Canyon 1508010203	0.0	0.2
Aguajita Wash-Rio Sonoyta 1508010204	0.8	1.0
Pinacate Valley-Las Playas 1508010301	0.8	1.0
Puente Cuates 1508010302	0.0	0.2
La Jolla Wash 1508010303	0.0	0.0
RIO ASUNCION WATERSHED		
Rio Altar Headwaters 1508020001	1.0	1.0
Rio El Sasabe Headwaters 1508020002	0.1	0.0

Potential Contribution of Mines to Soil Erosion

Gross soil erosion in kg/ha/yr was determined for each subwatershed using the SEDMOD model (Van Remortel et al., 2006), which is based on RUSLE (Renard et al., 1997; see Appendix C). Since this watershed based plan assumes that mine sites contribute to erosion and the resulting sediments are high in metals, the potential for erosion from mines to contribute to the risk for metals impairment for a subwatershed was evaluated.

The model results for soil loss (RUSLE "a" value) were imported into the GIS and reclassified into 6 categories. Table 6-5 tabulates the values for soil loss in kg/ha/yr for each subwatershed.

Table 6-6 shows the erosion category and fuzzy membership value for each subwatershed. The range of erosion values were classified into six erosion categories, where category 1 represents zero potential for metals contribution (i.e. low sediment yield), and category 6 represents a high potential (i.e. high sediment yield). The fuzzy membership values ranged from 0.0 to 1.0, and were increased by 0.20 for each higher erosion category and Figures 6-2.1 and 6-2.2 show these results

Table 6-5: RUSLE Calculated Soil Loss "A" (kg/ha/yr)

Subwatershed	RUSLE Soil Loss "A" (kg/ha/yr)
SANTA CRUZ WATERSHED	
San Rafael Valley-Upper Santa Cruz River 1505030101	5,808
Sonoita Creek 1505030102	12,429
Potrero Creek-Upper Santa Cruz River 1505030103	7,301
Sopori Wash 1505030104	5,748
Josephine Canyon-Upper Santa Cruz River 1505030105	11,926
Demetrie Wash-Upper Santa Cruz River 1505030106	9,239
Box Canyon Wash-Upper Santa Cruz River 1505030107	5,627
Canada del Oro 1505030108	5,563
Julian Wash-Upper Santa Cruz River 1505030109	1,031
Cienega Creek 1505030201	6,086
Agua Verde Creek-Pantano Wash 1505030202	6,852
Tanque Verde Creek-Rillito River 1505030203	7,313
Guild Wash-Lower Santa Cruz River 1505030301	734
Lower Santa Cruz River-North Branch Santa Cruz Wash 1505030302	226
Greene Wash - Upper Santa Cruz Wash 1505030303	411
Upper Vekol Wash 1505030304	356
Lower Vekol Wash 1505030305	408
Lower Santa Cruz Wash 1505030306	372
Arivaca Creek 1505030401	6,023
Puertocito Wash 1505030402	2,663
Altar Wash 1505030403	3,987
Upper Brawley Wash 1505030404	4,193
Lower Brawley Wash 1505030405	958
Los Robles Wash 1505030406	661
Viopuli Wash 1505030501	1,983
Upper Aguirre Wash 1505030502	1,461
Lower Aguirre Wash 1505030503	708
Tat Momoli Wash 1505030504	700
Upper Santa Rosa Wash 1505030601	716
Kohatk Wash 1505030602	807
Middle Santa Rosa Wash 1505030603	798

Subwatershed	RUSLE Soil Loss "A" (kg/ha/yr)
Lower Santa Rosa Wash 1505030604	508
RIO SONOYTA WATERSHED	
Hickiwan Wash 1508010101	149
Upper San Simon Wash 1508010102	103
Upper Vamori Wash 1508010103	318
Sells Wash 1508010104	233
Lower Vamori Wash 1508010105	222
Middle San Simon Wash 1508010106	86
Chukut Kuk Wash 1508010107	75
Rio San Francisquito 1508010108	55
Lower San Simon Wash 1508010109	80
Pia Oik Wash-Menagers Lake 1508010201	157
Sonoyta Valley Area 1508010202	96
Davidson Canyon 1508010203	33
Aguajita Wash-Rio Sonoyta 1508010204	87
Pinacate Valley-Las Playas 1508010301	58
Puente Cuates 1508010302	81
La Jolla Wash 1508010303	162
RIO ASUNCION WATERSHED	
Rio Altar Headwaters 1508020001	1374
Rio El Sasabe Headwaters 1508020002	644

Table 6-6: Fuzzy Membership Values per Erosion Category.

Subwatershed	Erosion Category	FMV
SANTA CRUZ WATERSHED		
San Rafael Valley-Upper Santa Cruz River 1505030101	5	0.8
Sonoita Creek 1505030102	6	1.0
Potrero Creek-Upper Santa Cruz River 1505030103	4	0.6
Sopori Wash 1505030104	5	0.8
Josephine Canyon-Upper Santa Cruz River 1505030105	6	1.0
Demetrie Wash-Upper Santa Cruz River 1505030106	6	1.0
Box Canyon Wash-Upper Santa Cruz River 1505030107	5	0.8
Canada del Oro 1505030108	5	0.8
Julian Wash-Upper Santa Cruz River 1505030109	2	0.2
Cienega Creek 1505030201	4	0.6
Agua Verde Creek-Pantano Wash 1505030202	4	0.6
Tanque Verde Creek-Rillito River 1505030203	5	0.8
Guild Wash-Lower Santa Cruz River 1505030301	2	0.2
Lower Santa Cruz River-North Branch Santa Cruz Wash 1505030302	1	0.0
Greene Wash - Upper Santa Cruz Wash 1505030303	1	0.0
Upper Vekol Wash 1505030304	1	0.0
Lower Vekol Wash 1505030305	1	0.0
Lower Santa Cruz Wash 1505030306	1	0.0
Arivaca Creek 1505030401	4	0.6
Puertocito Wash 1505030402	3	0.4
Altar Wash 1505030403	3	0.4
Upper Brawley Wash 1505030404	4	0.6
Lower Brawley Wash 1505030405	2	0.2
Los Robles Wash 1505030406	2	0.2
Viopuli Wash 1505030501	3	0.4
Upper Aguirre Wash 1505030502	2	0.2
Lower Aguirre Wash 1505030503	2	0.2
Tat Momoli Wash 1505030504	2	0.2
Upper Santa Rosa Wash 1505030601	2	0.2
Kohatk Wash 1505030602	2	0.2
Middle Santa Rosa Wash 1505030603	2	0.2
Lower Santa Rosa Wash 1505030604	1	0.0

Subwatershed	Erosion Category	FMV
RIO SONOYTA WATERSHED		
Hickiwan Wash 1508010101	3	0.4
Upper San Simon Wash 1508010102	2	0.2
Upper Vamori Wash 1508010103	4	0.6
Sells Wash 1508010104	4	0.6
Lower Vamori Wash 1508010105	4	0.6
Middle San Simon Wash 1508010106	2	0.2
Chukut Kuk Wash 1508010107	2	0.2
Rio San Francisquito 1508010108	1	0.0
Lower San Simon Wash 1508010109	2	0.2
Pia Oik Wash-Menagers Lake 1508010201	3	0.4

Subwatershed	Erosion Category	FMV
Sonoyta Valley Area 1508010202	2	0.2
Davidson Canyon 1508010203	1	0.0
Aguajita Wash-Rio Sonoyta 1508010204	2	0.2
Pinacate Valley-Las Playas 1508010301	1	0.0
Puente Cuates 1508010302	2	0.2
La Jolla Wash 1508010303	3	0.4
RIO ASUNCION WATERSHED		
Rio Altar Headwaters 1508020001	6	1.0
Rio El Sasabe Headwaters 1508020002	5	0.8

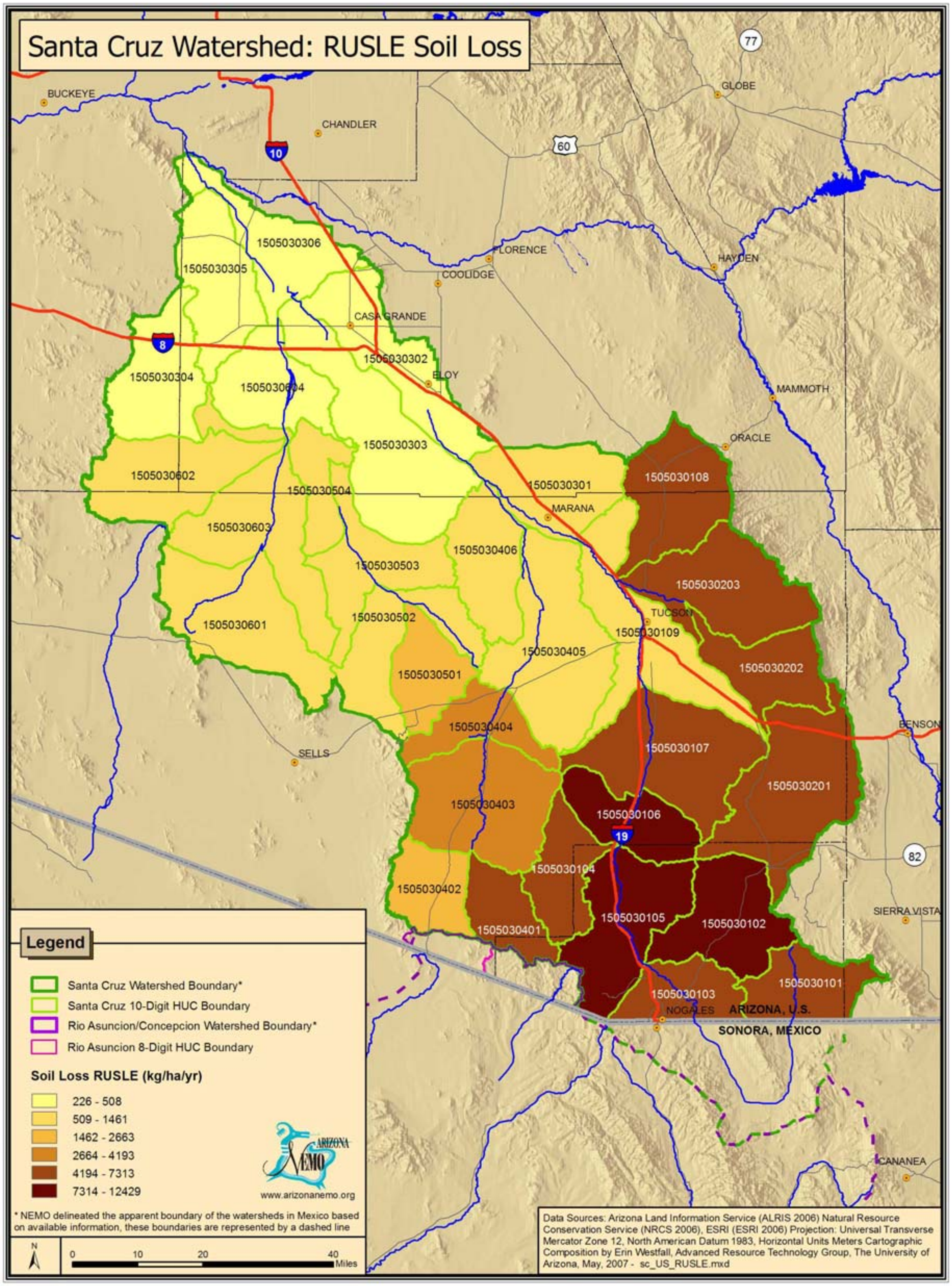

Figure 6-2.1: Santa Cruz Watershed, RUSLE Soil Loss "A" (kg/ha/yr) by Subwatershed

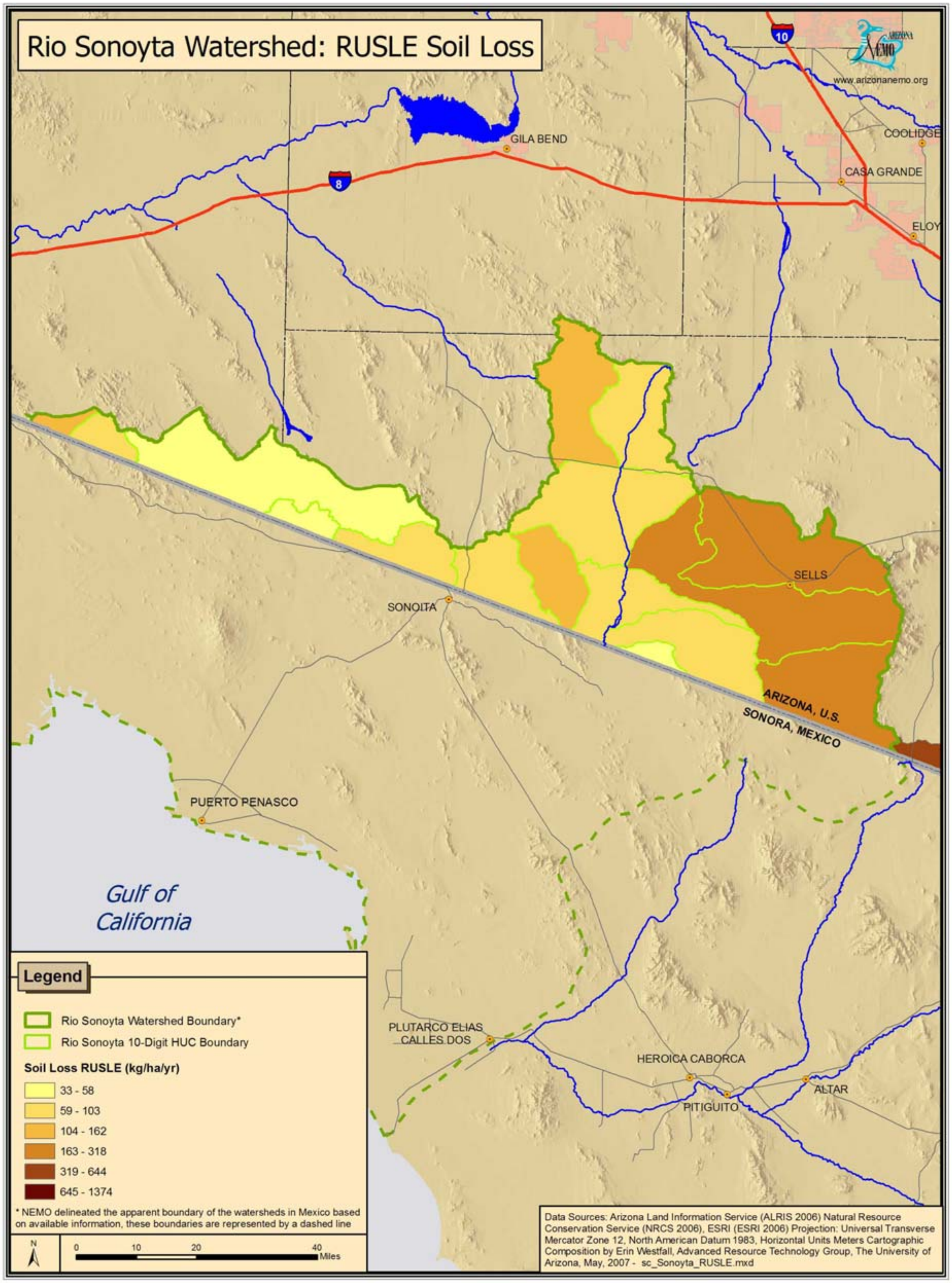

Figure 6-2.2: Rio Sonoyta Watershed, RUSLE Soil Loss "A" (kg/ha/yr) by Subwatershed Urbanized Areas

Various studies have shown that semiarid stream systems become irreparably impaired once the impervious surfaces within the watershed exceed about 10%, and will experience dramatic morphological changes once that percentage exceeds about 20% (Coleman et. al., 2005; Miltner et al., 2003). The final values for the fuzzy membership functions (FMV) were selected based on these studies and are shown in Table 6-7. The FMVs for the percentage of urban land within a 10-digit HUC subwatershed is shown below.

FMV = 0 if (% Urban < 5)
FMV = (5 < = % Urban < 12) / 12
FMV = 1 if (% Urban >= 12)

Table 6-7: Fuzzy Membership Values for Urbanized Areas.

Subwatershed	Percent Urban	FMV
SANTA CRUZ WATERSHED		
San Rafael Valley-Upper Santa Cruz River 1505030101	0.01	0.0
Sonoita Creek 1505030102	0.32	0.0
Potrero Creek-Upper Santa Cruz River 1505030103	8.70	0.73
Sopori Wash 1505030104	0.0	0.0
Josephine Canyon-Upper Santa Cruz River 1505030105	0.79	0.0
Demetrie Wash-Upper Santa Cruz River 1505030106	2.05	0.0
Box Canyon Wash-Upper Santa Cruz River 1505030107	2.80	0.0
Canada del Oro 1505030108	14.32	1.0
Julian Wash-Upper Santa Cruz River 1505030109	37.51	1.0
Cienega Creek 1505030201	0.0	0.0
Agua Verde Creek-Pantano Wash 1505030202	8.62	0.72
Tanque Verde Creek-Rillito River 1505030203	34.62	1.0
Guild Wash-Lower Santa Cruz River 1505030301	0.0	0.0
Lower Santa Cruz River-North Branch Santa Cruz Wash 1505030302	6.29	0.52
Greene Wash - Upper Santa Cruz Wash 1505030303	0.85	0.0
Upper Vekol Wash 1505030304	0.0	0.0
Lower Vekol Wash 1505030305	0.0	0.0
Lower Santa Cruz Wash 1505030306	0.0	0.0
Arivaca Creek 1505030401	0.0	0.0
Puertocito Wash 1505030402	0.0	0.0
Altar Wash 1505030403	0.0	0.0
Upper Brawley Wash 1505030404	0.0	0.0
Lower Brawley Wash 1505030405	4.49	0.0
Los Robles Wash 1505030406	1.33	0.0
Viopuli Wash 1505030501	0.0	0.0
Upper Aguirre Wash 1505030502	0.0	0.0
Lower Aguirre Wash 1505030503	0.0	0.0
Tat Momoli Wash 1505030504	0.0	0.0
Upper Santa Rosa Wash 1505030601	0.0	0.0
Kohatk Wash 1505030602	0.0	0.0
Middle Santa Rosa Wash 1505030603	0.0	0.0
Lower Santa Rosa Wash 1505030604	0.0	0.0
RIO SONOYTA WATERSHED		
Hickiwan Wash 1508010101	0.0	0.0
Upper San Simon Wash 1508010102	0.0	0.0
Upper Vamori Wash 1508010103	0.0	0.0
Sells Wash 1508010104	0.52	0.04
Lower Vamori Wash 1508010105	0.05	0.0
Middle San Simon Wash 1508010106	0.0	0.0

Subwatershed	Percent Urban	FMV
Chukut Kuk Wash 1508010107	0.0	0.0
Rio San Francisquito 1508010108	0.0	0.0
Lower San Simon Wash 1508010109	0.0	0.0
Pia Oik Wash-Menagers Lake 1508010201	0.0	0.0
Sonoyta Valley Area 1508010202	0.02	0.0
Davidson Canyon 1508010203	0.0	0.0
Aguajita Wash-Rio Sonoyta 1508010204	0.0	0.0
Pinacate Valley-Las Playas 1508010301	0.0	0.0
Puente Cuates 1508010302	0.0	0.0
La Jolla Wash 1508010303	0.0	0.0
RIO ASUNCION WATERSHED		
Rio Altar Headwaters 1508020001	0.0	0.0
Rio El Sasabe Headwaters 1508020002	0.0	0.0

Metals Results

The fuzzy membership values for the number of mines, urbanized area, and for the erosion category were used to create a combined fuzzy score for each subwatershed using the weighted combination method.

This method uses a weighting scheme (weighted combination method) which was developed in cooperation with ADEQ. The weights consider the proximity of mines to the riparian area, the percent urbanized area, the susceptibility to erosion, and the ADEQ water quality results. The overall number of mines within the subwatershed (but removed from the riparian area) was not considered as pertinent to the classification, so this weight was set at 0.05, as opposed to 0.3 for mines in the riparian area.

The results are found in Table 6-8, and the weights are listed at the bottom of the table. Each of the assigned weights were multiplied with the FMV, and then added to produce the weighted FMV ranking.

Using the weighted FMV values, the subwatershed areas were classified into 'high' or 'low" risk for impairment due to metals based on natural breaks. Figures 6-3.1 and 6-3.2 show the results of the weighted combination method classified into high and low risk for metals.

Table 6-8: Summary Results for Metals Based on the Fuzzy Logic Approach – Weighted Combination Approach.

Subwatershed	FMV WQA[1]	FMV # Mines / HUC	FMV # Mines / Riparian	FMV Erosion Category	FMV Urban Areas	FMV Weighted
SANTA CRUZ WATERSHED						
San Rafael Valley-Upper Santa Cruz River 1505030101	1.0	1.0	1.0	0.8	0.0	0.85
Sonoita Creek 1505030102	1.0	1.0	1.0	1.0	0.0	0.90
Potrero Creek-Upper Santa Cruz River 1505030103	1.0	1.0	1.0	0.6	0.73	0.87
Sopori Wash 1505030104	0.5	1.4	1.0	0.8	0.0	0.72

Subwatershed	FMV WQA[1]	FMV # Mines / HUC	FMV # Mines / Riparian	FMV Erosion Category	FMV Urban Areas	FMV Weighted
Josephine Canyon-Upper Santa Cruz River 1505030105	0.5	1.0	1.0	1.0	0.0	0.75
Demetrie Wash-Upper Santa Cruz River 1505030106	0.5	1.0	1.0	1.0	0.0	0.75
Box Canyon Wash-Upper Santa Cruz River 1505030107	0.5	1.0	1.0	0.8	0.0	0.70
Canada del Oro 1505030108	0.5	1.0	1.0	0.8	1.0	0.80
Julian Wash-Upper Santa Cruz River 1505030109	0.5	1.0	1.0	0.2	1.0	0.65
Cienega Creek 1505030201	0.0	1.0	1.0	0.6	0.0	0.50
Agua Verde Creek-Pantano Wash 1505030202	0.6	1.0	1.0	0.6	0.72	0.75
Tanque Verde Creek-Rillito River 1505030203	0.7	1.0	1.0	0.8	1.0	0.86
Guild Wash-Lower Santa Cruz River 1505030301	0.5	1.0	1.0	0.2	0.0	0.55
Lower Santa Cruz River-North Branch Santa Cruz Wash 1505030302	0.5	1.0	1.0	0.0	0.52	0.55
Greene Wash - Upper Santa Cruz Wash 1505030303	0.5	1.0	1.0	0.0	0.0	0.50
Upper Vekol Wash 1505030304	0.5	0.0	0.2	0.0	0.0	0.21
Lower Vekol Wash 1505030305	0.5	1.0	0.6	0.0	0.0	0.38
Lower Santa Cruz Wash 1505030306	0.5	1.0	1.0	0.0	0.0	0.50
Arivaca Creek 1505030401	0.7	1.0	1.0	0.6	0.0	0.71
Puertocito Wash 1505030402	0.5	1.0	1.0	0.4	0.0	0.60
Altar Wash 1505030403	0.5	1.0	1.0	0.4	0.0	0.60
Upper Brawley Wash 1505030404	0.5	1.0	1.0	0.6	0.0	0.65
Lower Brawley Wash 1505030405	0.5	1.0	1.0	0.2	0.0	0.55
Los Robles Wash 1505030406	0.5	1.0	0.4	0.2	0.0	0.37
Viopuli Wash 1505030501	0.5	0.8	0.4	0.4	0.0	0.41
Upper Aguirre Wash 1505030502	0.5	0.4	0.6	0.2	0.0	0.40
Lower Aguirre Wash 1505030503	0.5	1.0	1.0	0.2	0.0	0.55
Tat Momoli Wash 1505030504	0.5	1.0	0.2	0.2	0.0	0.31
Upper Santa Rosa Wash 1505030601	0.5	1.0	1.0	0.2	0.0	0.55
Kohatk Wash 1505030602	0.5	1.0	0.6	0.2	0.0	0.43
Middle Santa Rosa Wash 1505030603	0.5	1.0	1.0	0.2	0.0	0.55
Lower Santa Rosa Wash 1505030604	0.5	1.0	0.4	0.0	0.0	0.32
RIO SONOYTA WATERSHED						
Hickiwan Wash 1508010101	0.5	0.0	0.2	0.4	0.0	0.31
Upper San Simon Wash 1508010102	0.5	1.0	1.0	0.2	0.0	0.55
Upper Vamori Wash 1508010103	0.5	0.8	1.0	0.6	0.0	0.64
Sells Wash 1508010104	0.5	1.0	1.0	0.6	0.04	0.65

Subwatershed	FMV WQA[1]	FMV # Mines / HUC	FMV # Mines / Riparian	FMV Erosion Category	FMV Urban Areas	FMV Weighted
Lower Vamori Wash 1508010105	0.5	1.0	1.0	0.6	0.0	0.65
Middle San Simon Wash 1508010106	0.5	1.0	1.0	0.2	0.0	0.55
Chukut Kuk Wash 1508010107	0.5	1.0	0.8	0.2	0.0	0.49
Rio San Francisquito 1508010108	0.5	0.0	0.0	0.0	0.0	0.15
Lower San Simon Wash 1508010109	0.5	0.0	0.2	0.2	0.0	0.26
Pia Oik Wash-Menagers Lake 1508010201	0.5	0.1	0.4	0.4	0.0	0.38
Sonoyta Valley Area 1508010202	0.5	0.0	0.0	0.2	0.0	0.20
Davidson Canyon 1508010203	0.5	0.0	0.2	0.0	0.0	0.21
Aguajita Wash-Rio Sonoyta 1508010204	0.5	0.8	1.0	0.2	0.0	0.54
Pinacate Valley-Las Playas 1508010301	0.5	0.8	1.0	0.0	0.0	0.49
Puente Cuates 1508010302	0.5	0.0	0.2	0.2	0.0	0.26
La Jolla Wash 1508010303	0.5	0.0	0.0	0.4	0.0	0.25
RIO ASUNCION WATERSHED						
Rio Altar Headwaters 1508020001	0.5	1.0	1.0	1.0	0.0	0.75
Rio El Sasabe Headwaters 1508020002	0.5	0.1	0.0	0.8	0.0	0.36
Weights	*0.30*	*0.05*	*0.30*	*0.25*	*0.10*	

[1]Water Quality Assessment results, from Table 6-3.

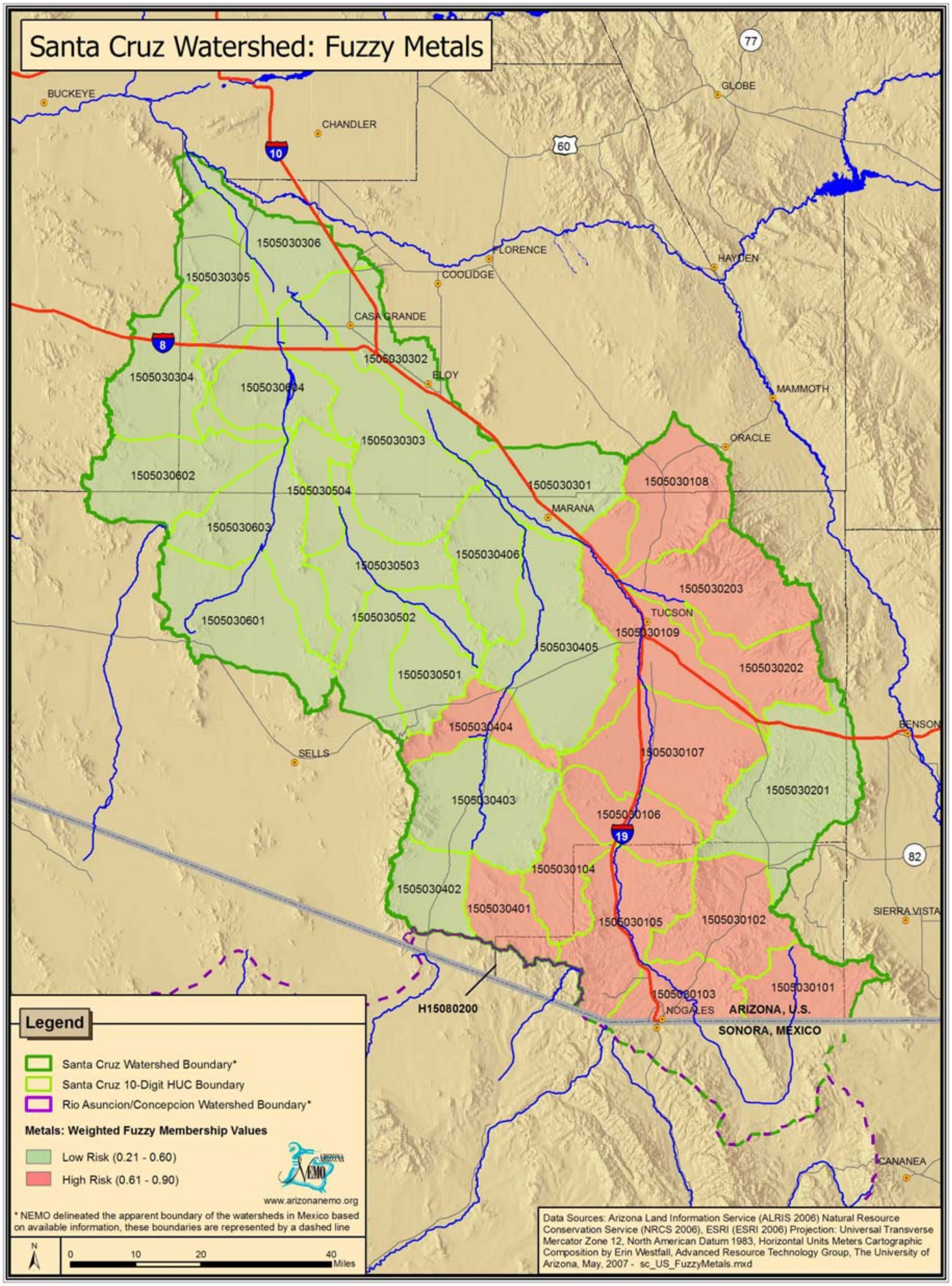

Figure 6-3.1: Santa Cruz Watershed, Results for Fuzzy Logic Classification for Metals Based on the Weighted Combination Approach (See Table 6-1 for subwatershed names).

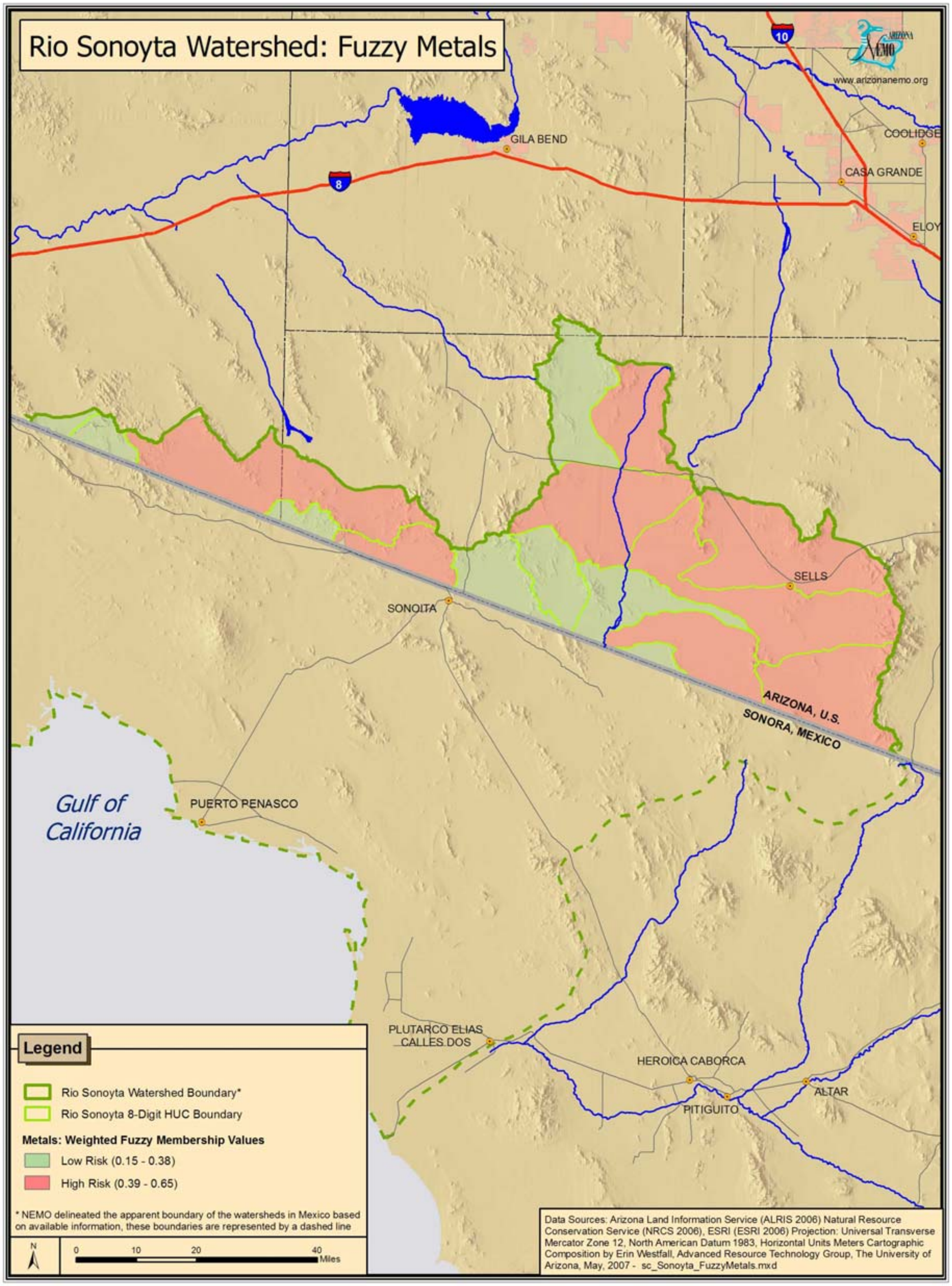

Figure 6-3.2: Rio Sonoyta Watershed, Results for Fuzzy Logic Classification for Metals Based on the Weighted Combination Approach (See Table 6-1 for subwatershed names)

Sediment

Erosion and sedimentation are major environmental concerns in arid and semiarid regions. Sediment is the chief source of impairment in the southwestern United States, not only to our few aquatic systems, but also to our riparian areas which are at risk from channel degradation.

The factors used for the sediment classification are:

- ADEQ water quality assessment results (turbidity data is used where sediment results are not available);
- Land ownership;
- Human use within a subwatershed and riparian area;
- Estimated current runoff and sediment yield; and
- Percent urbanized area.

Because available water quality data are limited, more weight was placed on subwatershed characteristics and modeling results when performing the classification.

Water Quality Assessment Data - Sediment

Arizona's Integrated 305(b) Assessment and 303(d) Listing Report (ADEQ, 2006a) was used to define the current water quality based on water monitoring results. In assigning fuzzy membership values, the location of a subwatershed relative to an impaired water was considered. As discussed under the metals classification section, Table 6-2 contains the fuzzy membership values used for different subwatershed conditions based on the water quality classification results. Table 6-9 contains the fuzzy membership values assigned to each 10-digit HUC subwatershed based on turbidity data.

Table 6-9: Fuzzy Membership Values for Sediment, Assigned to each 10-Digit HUC Subwatershed, Based on Water Quality Assessment Results.

Subwatershed Name	FMV	Justification
SANTA CRUZ WATERSHED		
San Rafael Valley-Upper Santa Cruz River 1505030101	0.7	Classified as moderate risk, drains to Mexico, then to Potrero Creek-Upper Santa Cruz River that is classified as extreme.
Sonoita Creek 1505030102	0.5	Classified as moderate risk, drains to Josephine Canyon-Upper Santa Cruz River that is classified as moderate.
Potrero Creek-Upper Santa Cruz River 1505030103	1.0	Classified as extreme risk, drains to Josephine Canyon-Upper Santa Cruz River that is classified as moderate.
Sopori Wash 1505030104	0.3	Classified as moderate risk, drains to Demetrie Wash-Upper Santa Cruz River that is classified as low.
Josephine Canyon-Upper Santa Cruz River 1505030105	0.3	Classified as moderate risk, drains to Demetrie Wash-Upper Santa Cruz River that is classified as low.
Demetrie Wash-Upper Santa Cruz River 1505030106	0.0	Classified as low risk, drains to Box Canyon Wash-Upper Santa Cruz River that is classified as moderate.
Box Canyon Wash-Upper Santa Cruz River 1505030107	0.5	Classified as moderate risk, drains to Julian Wash-Upper Santa Cruz River that is classified as moderate.

Subwatershed Name	FMV	Justification
Canada del Oro 1505030108	0.5	Classified as moderate risk, drains to Julian Wash-Upper Santa Cruz River that is classified as moderate.
Julian Wash-Upper Santa Cruz River 1505030109	0.5	Classified as moderate risk, drains to Guild Wash-Lower Santa Cruz River that is classified as moderate.
Cienega Creek 1505030201	0.0	Classified as low risk, drains to Agua Verde Creek-Pantano Wash that is classified as moderate.
Agua Verde Creek-Pantano Wash 1505030202	0.5	Classified as moderate risk, drains to Tanque Verde Creek-Rillito River that is classified as moderate.
Tanque Verde Creek-Rillito River 1505030203	0.5	Classified as moderate risk, drains to Julian Wash-Upper Santa Cruz River that is classified as moderate.
Guild Wash-Lower Santa Cruz River 1505030301	0.5	Classified as moderate risk, drains to Greene Wash - Upper Santa Cruz Wash that is classified as moderate.
Lower Santa Cruz River-North Branch Santa Cruz Wash 1505030302	0.5	Classified as moderate risk, drains to Lower Santa Cruz Wash that is classified as moderate.
Greene Wash - Upper Santa Cruz Wash 1505030303	0.5	Classified as moderate risk, drains to Lower Santa Cruz Wash that is classified as moderate.
Upper Vekol Wash 1505030304	0.5	Classified as moderate risk, drains to Lower Vekol Wash that is classified as moderate.
Lower Vekol Wash 1505030305	0.5	Classified as moderate risk, drains to Lower Santa Cruz Wash that is classified as moderate.
Lower Santa Cruz Wash 1505030306	0.5	Classified as moderate risk, drains out of the 8-digit HUC
Arivaca Creek 1505030401	0.5	Classified as moderate risk, drains to Altar Wash that is classified as moderate.
Puertocito Wash 1505030402	0.5	Classified as moderate risk, drains to Altar Wash that is classified as moderate.
Altar Wash 1505030403	0.5	Classified as moderate risk, drains to Upper Brawley Wash that is classified as moderate.
Upper Brawley Wash 1505030404	0.5	Classified as moderate risk, drains to Lower Brawley Wash that is classified as moderate.
Lower Brawley Wash 1505030405	0.5	Classified as moderate risk, drains to Los Robles Wash that is classified as moderate.
Los Robles Wash 1505030406	0.5	Classified as moderate risk, drains to Greene Wash - Upper Santa Cruz Wash that is classified as moderate.
Viopuli Wash 1505030501	0.5	Classified as moderate risk, drains to Upper Aguirre Wash that is classified as moderate.
Upper Aguirre Wash 1505030502	0.5	Classified as moderate risk, drains to Lower Aguirre Wash that is classified as moderate.
Lower Aguirre Wash 1505030503	0.5	Classified as moderate risk, drains to Tat Momoli Wash that is classified as moderate.
Tat Momoli Wash 1505030504	0.5	Classified as moderate risk, drains to Lower Santa Rosa Wash that is classified as moderate.
Upper Santa Rosa Wash 1505030601	0.5	Classified as moderate risk, drains to Middle Santa Rosa Wash that is classified as moderate.
Kohatk Wash 1505030602	0.5	Classified as moderate risk, drains to Middle Santa Rosa Wash that is classified as moderate.
Middle Santa Rosa Wash 1505030603	0.5	Classified as moderate risk, drains to Lower Santa Rosa Wash that is classified as moderate.

Subwatershed Name	FMV	Justification
Lower Santa Rosa Wash 1505030604	0.5	Classified as moderate risk, drains to Lower Santa Cruz Wash that is classified as moderate.
RIO SONOYTA WATERSHED		
Hickiwan Wash 1508010101	0.5	Classified as moderate risk, drains to Middle San Simon Wash that is classified as moderate.
Upper San Simon Wash 1508010102	0.5	Classified as moderate risk, drains to Middle San Simon Wash that is classified as moderate.
Upper Vamori Wash 1508010103	0.5	Classified as moderate risk, drains to Lower Vamori Wash that is classified as moderate.
Sells Wash 1508010104	0.5	Classified as moderate risk, drains to Lower Vamori Wash that is classified as moderate.
Lower Vamori Wash 1508010105	0.5	Classified as moderate risk, drains to Lower San Simon Wash that is classified as moderate.
Middle San Simon Wash 1508010106	0.5	Classified as moderate risk, drains to Lower San Simon Wash that is classified as moderate.
Chukut Kuk Wash 1508010107	0.5	Classified as moderate risk, drains to Mexico.
Rio San Francisquito 1508010108	0.5	Classified as moderate risk, drains to Mexico.
Lower San Simon Wash 1508010109	0.5	Classified as moderate risk, drains to Mexico.
Pia Oik Wash-Menagers Lake 1508010201	0.5	Classified as moderate risk, drains to Mexico.
Sonoyta Valley Area 1508010202	0.5	Classified as moderate risk, drains to Mexico.
Davidson Canyon 1508010203	0.5	Classified as moderate risk, drains to Mexico.
Aguajita Wash-Rio Sonoyta 1508010204	0.5	Classified as moderate risk, drains to Mexico.
Pinacate Valley-Las Playas 1508010301	0.5	Classified as moderate risk, drains to Mexico.
Puente Cuates 1508010302	0.5	Classified as moderate risk, drains to Mexico.
La Jolla Wash 1508010303	0.5	Classified as moderate risk, drains to Mexico.
RIO ASUNCION WATERSHED		
Rio Altar Headwaters 1508020001	0.5	Classified as moderate risk, drains to Mexico.
Rio El Sasabe Headwaters 1508020002	0.5	Classified as moderate risk, drains to Mexico.

Land ownership - Sediment

One of the principal land uses in the Santa Cruz Watershed is livestock grazing. Livestock grazing occurs primarily on land owned by the federal government (Bureau of Land Management (BLM), and U.S. Forest Service (USFS)), which comprises approximately 71.3% of the total watershed area. The remaining lands where grazing occurs are Arizona State

Trust Lands (approximately 12.4%), and privately owned land (approximately 13.9%). Section 4, Social Characteristics, contains a brief discussion of land ownership, with more detail provided in Section 7, Watershed Management, where individual management practices and target stakeholders are discussed.

Given that Federal lands must have management plans that include best management practices, the following classification will highlight State and private lands that may not have a water management plan in place. The fuzzy membership function for the percentage of land in state or private ownership within a 10-digit HUC subwatershed is shown below.

$$FMV = 0 \text{ if } (\%State + private <= 10)$$
$$FMV = (\%State + private - 10) / 15$$
$$FMV = 1 \text{ if } (\%State + private >= 25)$$

Table 6-10 contains the fuzzy membership values assigned to each 10-digit HUC subwatershed in the Santa Cruz Watershed based on land ownership.

Table 6-10: Fuzzy Membership Values for Sediment Based on Land Ownership.

Subwatershed	% State + Private	FMV
SANTA CRUZ WATERSHED		
San Rafael Valley-Upper Santa Cruz River 1505030101	33.1	1.0
Sonoita Creek 1505030102	77.3	1.0
Potrero Creek-Upper Santa Cruz River 1505030103	57.9	1.0
Sopori Wash 1505030104	74.3	1.0
Josephine Canyon-Upper Santa Cruz River 1505030105	55.0	1.0
Demetrie Wash-Upper Santa Cruz River 1505030106	80.7	1.0
Box Canyon Wash-Upper Santa Cruz River 1505030107	83.3	1.0
Canada del Oro 1505030108	66.2	1.0
Julian Wash-Upper Santa Cruz River 1505030109	83.8	1.0
Cienega Creek 1505030201	54.3	1.0
Agua Verde Creek-Pantano Wash 1505030202	75.7	1.0
Tanque Verde Creek-Rillito River 1505030203	47.5	1.0
Guild Wash-Lower Santa Cruz River 1505030301	91.9	1.0
Lower Santa Cruz River-North Branch Santa Cruz Wash 1505030302	95.2	1.0
Greene Wash - Upper Santa Cruz Wash 1505030303	75.6	1.0
Upper Vekol Wash 1505030304	9.2	0.0
Lower Vekol Wash 1505030305	52.6	1.0
Lower Santa Cruz Wash 1505030306	33.3	1.0
Arivaca Creek 1505030401	34.3	1.0
Puertocito Wash 1505030402	51.8	1.0
Altar Wash 1505030403	79.4	1.0
Upper Brawley Wash 1505030404	75.9	1.0

Subwatershed	% State + Private	FMV
Lower Brawley Wash 1505030405	68.5	1.0
Los Robles Wash 1505030406	49.2	1.0
Viopuli Wash 1505030501	4.9	0.0
Upper Aguirre Wash 1505030502	3.3	0.0
Lower Aguirre Wash 1505030503	14.0	0.27
Tat Momoli Wash 1505030504	6.1	0.0
Upper Santa Rosa Wash 1505030601	0.2	0.0
Kohatk Wash 1505030602	1.9	0.0
Middle Santa Rosa Wash 1505030603	0.7	0.0
Lower Santa Rosa Wash 1505030604	20.1	0.67
RIO SONOYTA WATERSHED		
Hickiwan Wash 1508010101	0.0	0.0
Upper San Simon Wash 1508010102	0.0	0.0
Upper Vamori Wash 1508010103	2.8	0.0
Sells Wash 1508010104	0.6	0.0
Lower Vamori Wash 1508010105	0.09	0.0
Middle San Simon Wash 1508010106	0.0	0.0
Chukut Kuk Wash 1508010107	0.0	0.0
Rio San Francisquito 1508010108	0.0	0.0
Lower San Simon Wash 1508010109	0.0	0.0
Pia Oik Wash-Menagers Lake 1508010201	0.4	0.0
Sonoyta Valley Area 1508010202	1.2	0.0
Davidson Canyon 1508010203	0.0	0.0

Subwatershed	% State + Private	FMV
Aguajita Wash-Rio Sonoyta 1508010204	0.0	0.0
Pinacate Valley-Las Playas 1508010301	0.0	0.0
Puente Cuates 1508010302	0.0	0.0
La Jolla Wash 1508010303	0.0	0.0
RIO ASUNCION WATERSHED		
Rio Altar Headwaters 1508020001	0.0	0.0
Rio El Sasabe Headwaters 1508020002	0.0	0.0

Human Use Index - Sediment

The Human Use Index was used to assess the relative impact of urban development on sediment load in streams. The Human Use Index is defined as the percentage of a subwatershed that is characterized as developed for human use. In the Santa Cruz Watershed, human use consists of developed areas as defined by the Southwest Regional GAP land cover data set as residential land use, agriculture, mining and roads (RS/GIS Laboratory, 2004).

Human use was assessed at both the subwatershed and riparian scale (<= 250 meters from a stream). The fuzzy membership functions for both conditions are:

Human Use Index (HUI)/watershed:

FMV = 0 if (HUI <= 5%)
FMV = (HUI – 5) / 15

FMV = 1 if (HUI >= 20%)

Human Use Index/riparian:

FMV = 0 if (HUI <= 1%)
FMV = (HUI - 1) / 4
FMV = 1 if (HUI >= 5%)

Table 6-11 contains the fuzzy membership values assigned to each 10-digit HUC subwatershed in the Santa Cruz Watershed based on the Human Use Index.

Table 6-11: Fuzzy Membership Values for Sediment Based on the Human Use Index (HUI).

Subwatershed	FMV - HUI Watershed	FMV - HUI Riparian
SANTA CRUZ WATERSHED		
San Rafael Valley-Upper Santa Cruz River 1505030101	0.00	0.00
Sonoita Creek 1505030102	0.00	0.08
Potrero Creek-Upper Santa Cruz River 1505030103	0.43	1.00
Sopori Wash 1505030104	0.00	0.00
Josephine Canyon-Upper Santa Cruz River 1505030105	0.00	0.62
Demetrie Wash-Upper Santa Cruz River 1505030106	0.37	1.00
Box Canyon Wash-Upper Santa Cruz River 1505030107	0.85	1.00
Canada del Oro 1505030108	0.65	1.00
Julian Wash-Upper Santa Cruz River 1505030109	1.00	1.00
Cienega Creek 1505030201	0.00.	0.00
Agua Verde Creek-Pantano Wash 1505030202	0.58	1.00
Tanque Verde Creek-Rillito River 1505030203	1.00	1.00
Guild Wash-Lower Santa Cruz River 1505030301	1.00	1.00
Lower Santa Cruz River-North Branch Santa Cruz Wash 1505030302	1.00	1.00
Greene Wash - Upper Santa Cruz Wash 1505030303	1.00	1.00
Upper Vekol Wash 1505030304	0.00	0.00
Lower Vekol Wash 1505030305	1.00	1.00
Lower Santa Cruz Wash 1505030306	1.00	1.00
Arivaca Creek 1505030401	0.00	0.00
Puertocito Wash 1505030402	0.00	0.00
Altar Wash 1505030403	0.00	0.00
Upper Brawley Wash 1505030404	0.00	0.00
Lower Brawley Wash 1505030405	0.77	1.00
Los Robles Wash 1505030406	0.24	1.00
Viopuli Wash 1505030501	0.00	0.00
Upper Aguirre Wash 1505030502	0.00	0.00
Lower Aguirre Wash 1505030503	0.00	0.00
Tat Momoli Wash 1505030504	0.00	0.00
Upper Santa Rosa Wash 1505030601	0.00	0.00
Kohatk Wash 1505030602	0.00	0.00
Middle Santa Rosa Wash 1505030603	0.00	0.00
Lower Santa Rosa Wash 1505030604	0.32	1.00
RIO SONOYTA WATERSHED		

Subwatershed	FMV - HUI Watershed	FMV - HUI Riparian
Hickiwan Wash 1508010101	0.00	0.00
Upper San Simon Wash 1508010102	0.00	0.00
Upper Vamori Wash 1508010103	0.00	0.00
Sells Wash 1508010104	0.00	0.00
Lower Vamori Wash 1508010105	0.00	0.00
Middle San Simon Wash 1508010106	0.00	0.00
Chukut Kuk Wash 1508010107	0.00	0.00
Rio San Francisquito 1508010108	0.00	0.00
Lower San Simon Wash 1508010109	0.00	0.00
Pia Oik Wash-Menagers Lake 1508010201	0.00	0.00
Sonoyta Valley Area 1508010202	0.00	0.00
Davidson Canyon 1508010203	0.00	0.00
Aguajita Wash-Rio Sonoyta 1508010204	0.00	0.00
Pinacate Valley-Las Playas 1508010301	0.00	0.00
Puente Cuates 1508010302	0.00	0.00
La Jolla Wash 1508010303	0.00	0.00
RIO ASUNCION WATERSHED		
Rio Altar Headwaters 1508020001	0.00	0.00
Rio El Sasabe Headwaters 1508020002	0.00	0.00

AGWA/SWAT Modeling

Runoff, Erosion and Sediment Yield

AGWA/SWAT was used to evaluate the potential runoff and sediment yield (see Appendix D for a description of AGWA/SWAT) for a subwatershed area. Runoff can be used to evaluate potential sediment yield, which is a measure of the rate of erosion. Both runoff and sediment yield depend on a combination of soil properties, topography, climate and land cover.

The modeling results were reclassified into 6 categories, with the first category given a fuzzy membership value of 0.0. The fuzzy membership values were increased by 0.2 for each higher category. Table 6-12 shows the runoff categories and associated FMV, and Table 6-12 shows the erosion categories and associated FMV. Figures 6-4.1 and 6-4.2 show erosion as sediment yield for each subwatershed. Figures 6-5.1 and 6-5.2 show runoff as water yield for each of the subwatersheds.

Table 6-12: Fuzzy Membership Values and Runoff Categories.

Subwatershed	Runoff Category	FMV
SANTA CRUZ WATERSHED		
San Rafael Valley-Upper Santa Cruz River 1505030101	1	0.0
Sonoita Creek 1505030102	4	0.6
Potrero Creek-Upper Santa Cruz River 1505030103	1	0.0
Sopori Wash 1505030104	2	0.2
Josephine Canyon-Upper Santa Cruz River 1505030105	4	0.6
Demetrie Wash-Upper Santa Cruz River 1505030106	2	0.2
Box Canyon Wash-Upper Santa Cruz River 1505030107	4	0.6
Canada del Oro 1505030108	6	1.0

Subwatershed	Runoff Category	FMV
Julian Wash-Upper Santa Cruz River 1505030109	4	0.6
Cienega Creek 1505030201	6	1.0
Agua Verde Creek-Pantano Wash 1505030202	4	0.6
Tanque Verde Creek-Rillito River 1505030203	5	0.8
Guild Wash-Lower Santa Cruz River 1505030301	4	0.6
Lower Santa Cruz River-North Branch Santa Cruz Wash 1505030302	4	0.6
Greene Wash - Upper Santa Cruz Wash 1505030303	6	1.0
Upper Vekol Wash 1505030304	3	0.4
Lower Vekol Wash 1505030305	5	0.8
Lower Santa Cruz Wash 1505030306	6	1.0
Arivaca Creek 1505030401	2	0.2
Puertocito Wash 1505030402	1	0.0
Altar Wash 1505030403	2	0.2
Upper Brawley Wash 1505030404	2	0.2
Lower Brawley Wash 1505030405	3	0.4
Los Robles Wash 1505030406	4	0.6
Viopuli Wash 1505030501	1	0.0
Upper Aguirre Wash 1505030502	3	0.4
Lower Aguirre Wash 1505030503	4	0.6
Tat Momoli Wash 1505030504	4	0.6
Upper Santa Rosa Wash 1505030601	2	0.2
Kohatk Wash 1505030602	3	0.4
Middle Santa Rosa Wash 1505030603	4	0.6
Lower Santa Rosa Wash 1505030604	6	1.0
RIO SONOYTA WATERSHED		
Hickiwan Wash 1508010101	2	0.2
Upper San Simon Wash 1508010102	2	0.2
Upper Vamori Wash 1508010103	2	0.2
Sells Wash 1508010104	3	0.4
Lower Vamori Wash 1508010105	3	0.4
Middle San Simon Wash 1508010106	3	0.4
Chukut Kuk Wash 1508010107	3	0.4
Rio San Francisquito 1508010108	2	0.2
Lower San Simon Wash 1508010109	4	0.6
Pia Oik Wash-Menagers Lake 1508010201	2	0.2
Sonoyta Valley Area 1508010202	2	0.2
Davidson Canyon 1508010203	3	0.4
Aguajita Wash-Rio Sonoyta 1508010204	4	0.6
Pinacate Valley-Las Playas 1508010301	5	0.8
Puente Cuates 1508010302	6	1.0
La Jolla Wash 1508010303	6	1.0
RIO ASUNCION WATERSHED		
Rio Altar Headwaters 1508020001	n/a	n/a
Rio El Sasabe Headwaters 1508020002	1	0.0

Table 6-13: Fuzzy Membership Values and Erosion Categories.

Subwatershed	Erosion Category	FMV
SANTA CRUZ WATERSHED		

Subwatershed	Erosion Category	FMV
San Rafael Valley-Upper Santa Cruz River 1505030101	3	0.4
Sonoita Creek 1505030102	4	0.6
Potrero Creek-Upper Santa Cruz River 1505030103	3	0.4
Sopori Wash 1505030104	3	0.4
Josephine Canyon-Upper Santa Cruz River 1505030105	4	0.6
Demetrie Wash-Upper Santa Cruz River 1505030106	3	0.4
Box Canyon Wash-Upper Santa Cruz River 1505030107	5	0.8
Canada del Oro 1505030108	5	0.8
Julian Wash-Upper Santa Cruz River 1505030109	5	0.8
Cienega Creek 1505030201	6	1.0
Agua Verde Creek-Pantano Wash 1505030202	6	1.0
Tanque Verde Creek-Rillito River 1505030203	6	1.0
Guild Wash-Lower Santa Cruz River 1505030301	2	0.2
Lower Santa Cruz River-North Branch Santa Cruz Wash 1505030302	1	0.0
Greene Wash - Upper Santa Cruz Wash 1505030303	2	0.2
Upper Vekol Wash 1505030304	2	0.2
Lower Vekol Wash 1505030305	3	0.4
Lower Santa Cruz Wash 1505030306	2	0.2
Arivaca Creek 1505030401	3	0.4
Puertocito Wash 1505030402	1	0.0
Altar Wash 1505030403	3	0.4
Upper Brawley Wash 1505030404	2	0.2
Lower Brawley Wash 1505030405	3	4.0
Los Robles Wash 1505030406	2	0.2
Viopuli Wash 1505030501	1	0.0
Upper Aguirre Wash 1505030502	1	0.0

Subwatershed	Erosion Category	FMV
Lower Aguirre Wash 1505030503	2	0.2
Tat Momoli Wash 1505030504	2	0.2
Upper Santa Rosa Wash 1505030601	1	0.0
Kohatk Wash 1505030602	2	0.2
Middle Santa Rosa Wash 1505030603	2	0.2
Lower Santa Rosa Wash 1505030604	2	0.2

RIO SONOYTA WATERSHED		
Hickiwan Wash 1508010101	2	0.2
Upper San Simon Wash 1508010102	2	0.2
Upper Vamori Wash 1508010103	2	0.2
Sells Wash 1508010104	4	0.6
Lower Vamori Wash 1508010105	4	0.6
Middle San Simon Wash 1508010106	2	0.2
Chukut Kuk Wash 1508010107	2	0.2
Rio San Francisquito 1508010108	2	0.0
Lower San Simon Wash 1508010109	3	0.4
Pia Oik Wash-Menagers Lake 1508010201	1	0.0
Sonoyta Valley Area 1508010202	1	0.0
Davidson Canyon 1508010203	3	0.4
Aguajita Wash-Rio Sonoyta 1508010204	3	0.4
Pinacate Valley-Las Playas 1508010301	4	0.6
Puente Cuates 1508010302	6	1.0
La Jolla Wash 1508010303	5	0.8
RIO ASUNCION WATERSHED		
Rio Altar Headwaters 1508020001	n/a	n/a
Rio El Sasabe Headwaters 1508020002	2	0.2

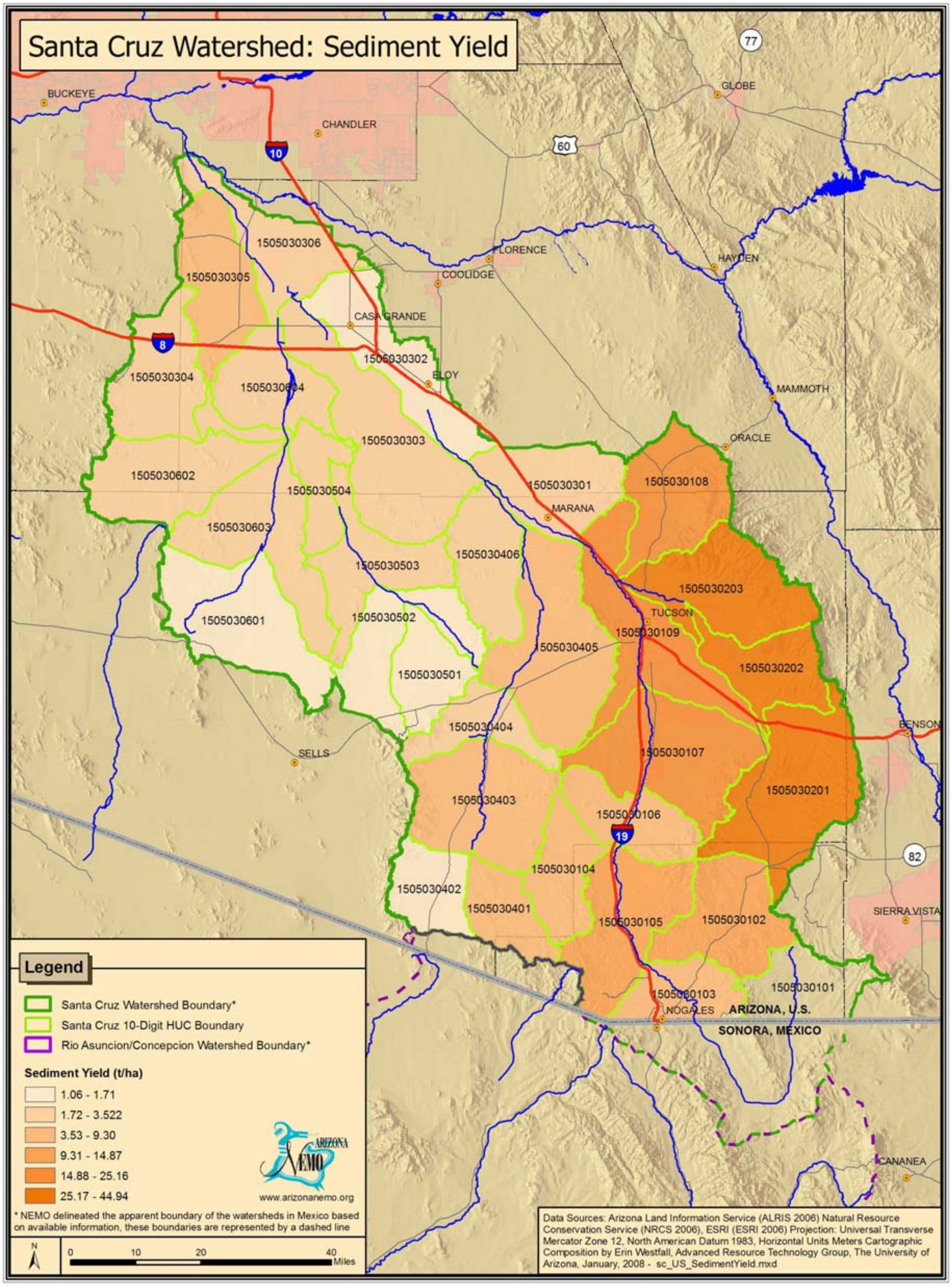

Figure 6-4.1: Santa Cruz Watershed, Sediment Yield by subwatershed (See Table 6-1 for subwatershed names).

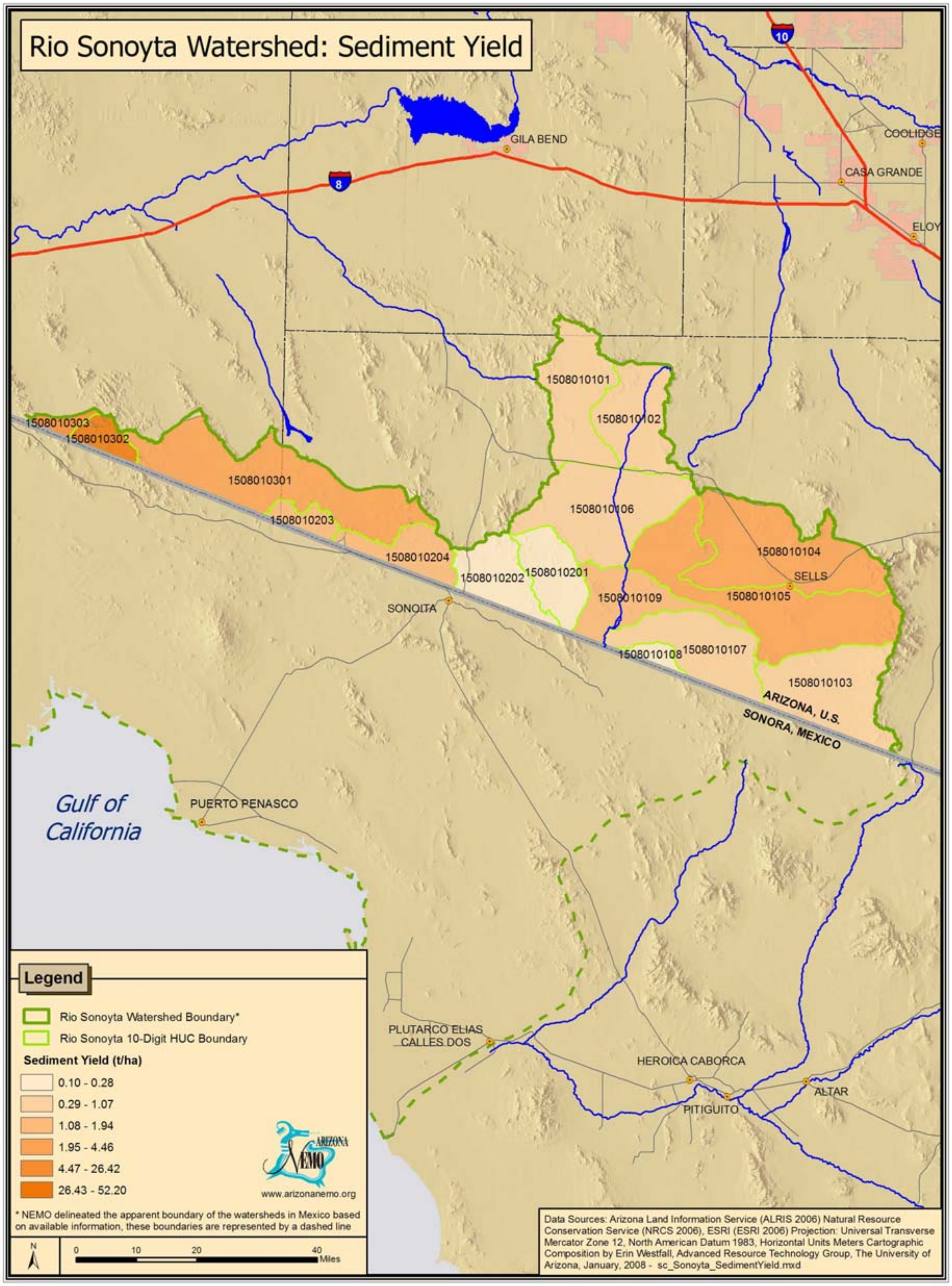

Figure 6-4.2: Rio Sonoyta Watershed, Sediment Yield by subwatershed (See Table 6-1 for subwatershed names).

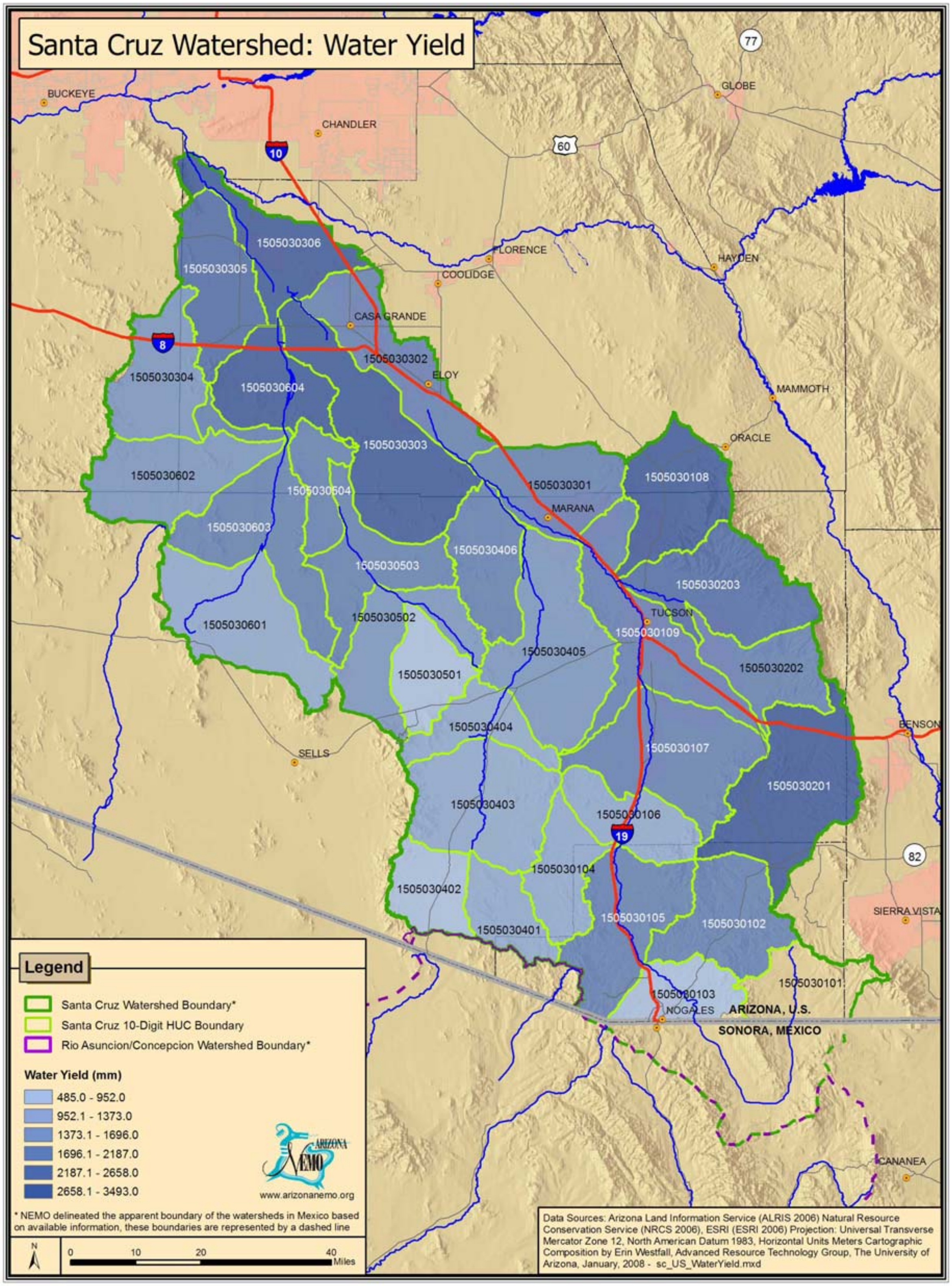

Figure 6-5.1: Santa Cruz Watershed, Water Yield by subwatershed (See Table 6-1 for subwatershed names).

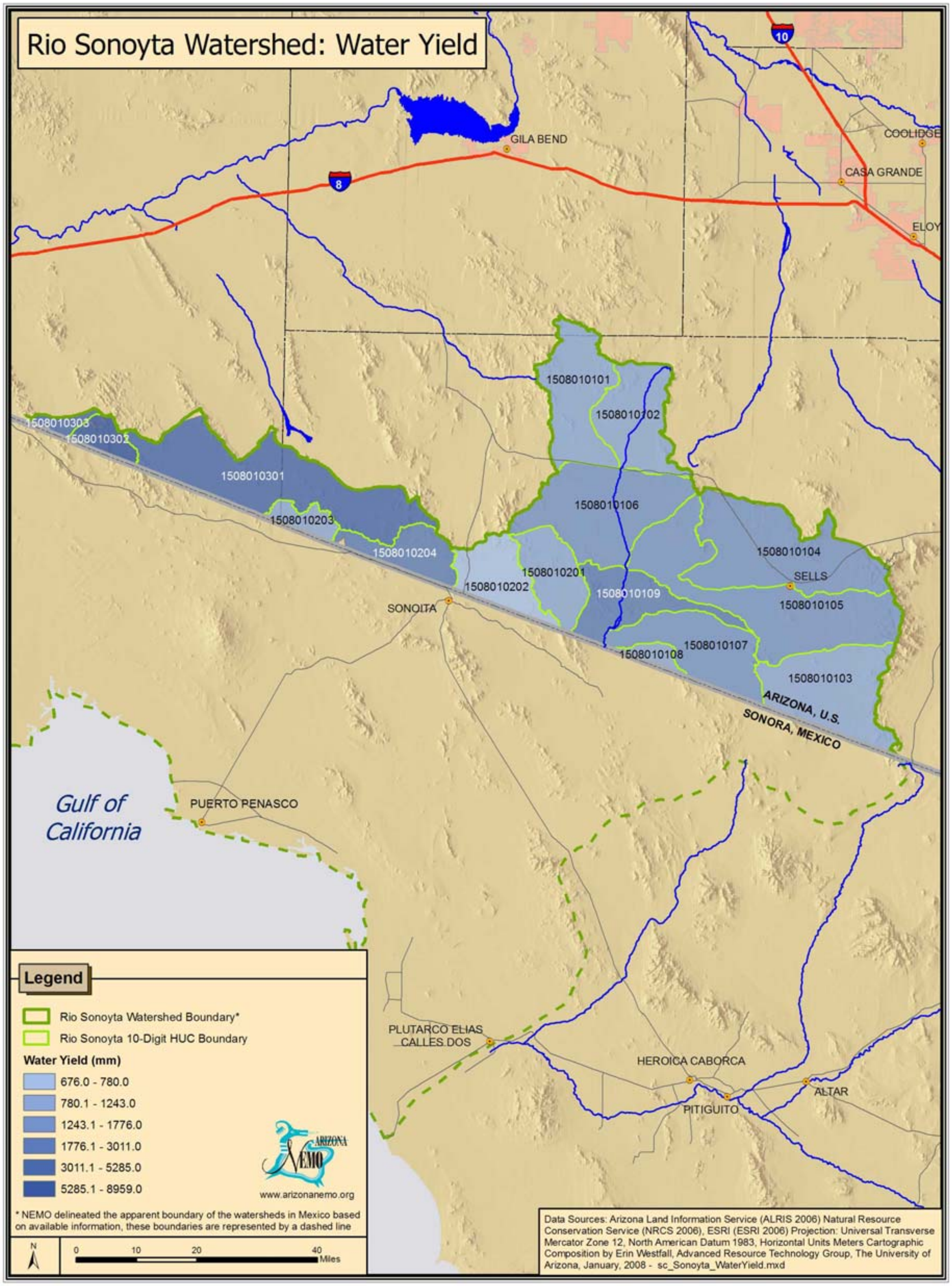

Figure 6-5.2: Rio Sonoyta Watershed, Water Yield by subwatershed (See Table 6-1 for subwatershed names).

Urbanized Areas - Sediment

Urbanized areas can increase sediment content in stream systems in various ways. For example, new construction of roads and buildings causes increased sediment in runoff. In addition the runoff from impervious surfaces is sediment starved, and when this water reaches the streams, increased erosion results (Booth, 1990; Chin and Gregory, 2004). Various studies have shown that semiarid stream systems become irreparably impaired once the impervious surfaces within the watershed exceed about 10%, and will experience dramatic morphological changes once that percentage exceeds about 20% (Coleman et. al., 2005; Miltner et al., 2003). The final values for the fuzzy membership functions (FMV) were selected based on these studies and are shown in Table 6-14. The FMVs for the percentage of urban land within a 10-digit HUC subwatershed is shown below.

FMV = 0 if (% Urban < 5)
FMV = (5 < = % Urban < 12) / 12
FMV = 1 if (% Urban >= 12)

Table 6-14: Fuzzy Membership Values for Urbanized Areas for Sediment.

Subwatershed	Percent Urban	FMV
SANTA CRUZ WATERSHED		
San Rafael Valley-Upper Santa Cruz River 1505030101	0.01	0.0
Sonoita Creek 1505030102	0.32	0.0
Potrero Creek-Upper Santa Cruz River 1505030103	8.70	0.73
Sopori Wash 1505030104	0	0.0
Josephine Canyon-Upper Santa Cruz River 1505030105	0.79	0.0
Demetrie Wash-Upper Santa Cruz River 1505030106	2.05	0.0
Box Canyon Wash-Upper Santa Cruz River 1505030107	2.80	0.0
Canada del Oro 1505030108	14.32	1.0
Julian Wash-Upper Santa Cruz River 1505030109	37.51	1.0
Cienega Creek 1505030201	0	0.0
Agua Verde Creek-Pantano Wash 1505030202	8.62	0.72
Tanque Verde Creek-Rillito River 1505030203	34.62	1.0
Guild Wash-Lower Santa Cruz River 1505030301	0	0.0
Lower Santa Cruz River-North Branch Santa Cruz Wash 1505030302	6.29	0.52
Greene Wash - Upper Santa Cruz Wash 1505030303	0.85	0.0
Upper Vekol Wash 1505030304	0	0.0
Lower Vekol Wash 1505030305	0	0.0
Lower Santa Cruz Wash 1505030306	0	0.0
Arivaca Creek 1505030401	0	0.0
Puertocito Wash 1505030402	0	0.0
Altar Wash 1505030403	0	0.0
Upper Brawley Wash 1505030404	0	0.0
Lower Brawley Wash 1505030405	4.49	0.0
Los Robles Wash 1505030406	1.33	0.0
Viopuli Wash 1505030501	0	0.0
Upper Aguirre Wash 1505030502	0	0.0
Lower Aguirre Wash 1505030503	0	0.0
Tat Momoli Wash 1505030504	0	0.0
Upper Santa Rosa Wash 1505030601	0	0.0
Kohatk Wash 1505030602	0	0.0
Middle Santa Rosa Wash 1505030603	0	0.0
Lower Santa Rosa Wash 1505030604	0	0.0
RIO SONOYTA WATERSHED		
Hickiwan Wash 1508010101	0	0.0
Upper San Simon Wash 1508010102	0	0.0
Upper Vamori Wash 1508010103	0	0.0

Subwatershed	Percent Urban	FMV
Sells Wash 1508010104	0	0.0
Lower Vamori Wash 1508010105	0	0.0
Middle San Simon Wash 1508010106	0	0.0
Chukut Kuk Wash 1508010107	0	0.0
Rio San Francisquito 1508010108	0	0.0
Lower San Simon Wash 1508010109	0	0.0
Pia Oik Wash-Menagers Lake 1508010201	0	0.0
Sonoyta Valley Area 1508010202	0	0.0
Davidson Canyon 1508010203	0	0.0
Aguajita Wash-Rio Sonoyta 1508010204	0	0.0
Pinacate Valley-Las Playas 1508010301	0	0.0
Puente Cuates 1508010302	0	0.0
La Jolla Wash 1508010303	0	0.0
RIO ASUNCION WATERSHED		
Rio Altar Headwaters 1508020001	0	0.0
Rio El Sasabe Headwaters 1508020002	0	0.0

Sediment Results

The weighted combination approach was used to create combined fuzzy scores to rank sediment results, as shown in Table 6-15. Figures 6-6.1 and 6-6.2 show the results of the weighted combination method classified into high and low priority for sediment. The weights used in the classification are also found in Table 6-15.

Table 6-15: Summary Results for Sediment Based on the Fuzzy Logic Approach – Weighted Combination Approach.

Subwatershed Name	FMV WQA[1]	FMV Land Ownership	FMV HU Index / Watershed	FMV HU Index / Riparian	FMV Runoff	FMV Erosion	FMV Urban Area	FMV Weighted
SANTA CRUZ WATERSHED								
San Rafael Valley-Upper Santa Cruz River 1505030101	0.7	1.0	0.00	0.00	0.0	0.4	0.0	0.23
Sonoita Creek 1505030102	0.5	1.0	0.00	0.08	0.6	0.6	0.0	0.47
Potrero Creek-Upper Santa Cruz River 1505030103	1.0	1.0	0.43	1.00	0.0	0.4	0.73	0.44
Sopori Wash 1505030104	0.3	1.0	0.00	0.00	0.2	0.4	0.0	0.26
Josephine Canyon-Upper Santa Cruz River 1505030105	0.3	1.0	0.00	0.62	0.6	0.6	0.0	0.55
Demetrie Wash-Upper Santa Cruz River 1505030106	0.0	1.0	0.37	1.00	0.2	0.4	0.0	0.44
Box Canyon Wash-Upper Santa Cruz River 1505030107	0.5	1.0	0.85	1.0	0.6	0.8	0.0	0.75
Canada del Oro 1505030108	0.5	1.0	0.65	1.0	1.0	0.8	1.0	0.86
Julian Wash-Upper Santa Cruz River 1505030109	0.5	1.0	1.0	1.0	0.6	0.8	1.0	0.76

Subwatershed Name	FMV WQA[1]	FMV Land Ownership	FMV HU Index / Watershed	FMV HU Index / Riparian	FMV Runoff	FMV Erosion	FMV Urban Area	FMV Weighted
Cienega Creek 1505030201	0.0	1.0	0.0	0.0	1.0	1.0	0.0	0.69
Agua Verde Creek-Pantano Wash 1505030202	0.5	1.0	0.58	1.0	0.6	1.0	0.72	0.80
Tanque Verde Creek-Rillito River 1505030203	0.5	1.0	1.0	1.0	0.8	1.0	1.0	0.88
Guild Wash-Lower Santa Cruz River 1505030301	0.5	1.0	1.0	1.0	0.6	0.2	0.0	0.56
Lower Santa Cruz River-North Branch Santa Cruz Wash 1505030302	0.5	1.0	1.0	1.0	0.6	0.0	0.52	0.49
Greene Wash - Upper Santa Cruz Wash 1505030303	0.5	1.0	1.0	1.0	1.0	0.2	0.0	0.68
Upper Vekol Wash 1505030304	0.5	0.0	0.0	0.0	0.4	0.2	0.0	0.21
Lower Vekol Wash 1505030305	0.5	1.0	1.0	1.0	0.8	0.4	0.0	0.68
Lower Santa Cruz Wash 1505030306	0.5	1.0	1.0	1.0	1.0	0.2	0.0	0.68
Arivaca Creek 1505030401	0.5	1.0	0.0	0.0	0.2	0.4	0.0	0.27
Puertocito Wash 1505030402	0.5	1.0	0.0	0.0	0.0	0.0	0.0	0.08
Altar Wash 1505030403	0.5	1.0	0.0	0.0	0.2	0.4	0.0	0.27
Upper Brawley Wash 1505030404	0.5	1.0	0.0	0.0	0.2	0.2	0.0	0.21
Lower Brawley Wash 1505030405	0.5	1.0	0.77	1.0	0.4	4.0	0.0	1.74
Los Robles Wash 1505030406	0.5	1.0	0.24	1.0	0.6	0.2	0.0	0.51
Viopuli Wash 1505030501	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.03
Upper Aguirre Wash 1505030502	0.5	0.0	0.0	0.0	0.4	0.0	0.0	0.15
Lower Aguirre Wash 1505030503	0.5	0.27	0.0	0.0	0.6	0.2	0.0	0.29
Tat Momoli Wash 1505030504	0.5	0.0	0.0	0.0	0.6	0.2	0.0	0.27
Upper Santa Rosa Wash 1505030601	0.5	0.0	0.0	0.0	0.2	0.0	0.0	0.09
Kohatk Wash 1505030602	0.5	0.0	0.0	0.0	0.4	0.2	0.0	0.21
Middle Santa Rosa Wash 1505030603	0.5	0.0	0.0	0.0	0.6	0.2	0.0	0.27
Lower Santa Rosa Wash 1505030604	0.5	0.67	0.32	1.0	1.0	0.2	0.0	0.62
RIO SONOYTA WATERSHED								
Hickiwan Wash 1508010101	0.5	0.0	0.0	0.0	0.2	0.2	0.0	0.15
Upper San Simon Wash 1508010102	0.5	0.0	0.0	0.0	0.2	0.2	0.0	0.15

Subwatershed Name	FMV WQA[1]	FMV Land Ownership	FMV HU Index / Watershed	FMV HU Index / Riparian	FMV Runoff	FMV Erosion	FMV Urban Area	FMV Weighted
Upper Vamori Wash 1508010103	0.5	0.0	0.0	0.0	0.2	0.2	0.0	0.15
Sells Wash 1508010104	0.5	0.0	0.0	0.0	0.4	0.6	0.0	0.33
Lower Vamori Wash 1508010105	0.5	0.0	0.0	0.0	0.4	0.6	0.0	0.33
Middle San Simon Wash 1508010106	0.5	0.0	0.0	0.0	0.4	0.2	0.0	0.21
Chukut Kuk Wash 1508010107	0.5	0.0	0.0	0.0	0.4	0.2	0.0	0.21
Rio San Francisquito 1508010108	0.5	0.0	0.0	0.0	0.2	0.0	0.0	0.09
Lower San Simon Wash 1508010109	0.5	0.0	0.0	0.0	0.6	0.4	0.0	0.33
Pia Oik Wash-Menagers Lake 1508010201	0.5	0.0	0.0	0.0	0.2	0.0	0.0	0.09
Sonoyta Valley Area 1508010202	0.5	0.0	0.0	0.0	0.2	0.0	0.0	0.09
Davidson Canyon 1508010203	0.5	0.0	0.0	0.0	0.4	0.4	0.0	0.27
Aguajita Wash-Rio Sonoyta 1508010204	0.5	0.0	0.0	0.0	0.6	0.4	0.0	0.33
Pinacate Valley-Las Playas 1508010301	0.5	0.0	0.0	0.0	0.8	0.6	0.0	0.45
Puente Cuates 1508010302	0.5	0.0	0.0	0.0	1.0	1.0	0.0	0.63
La Jolla Wash 1508010303	0.5	0.0	0.0	0.0	1.0	0.8	0.0	0.57
RIO ASUNCION WATERSHED								
Rio Altar Headwaters 1508020001	0.5	0.0	0.0	0.0	n/a	n/a	0.0	0.03
Rio El Sasabe Headwaters 1508020002	0.5	0.0	0.0	0.0	0.0	0.2	0.0	0.09
Weights	*0.05*	*0.05*	*0.05*	*0.15*	*0.3*	*0.3*	*0.1*	

[1]WQA = Water Quality Assessment results, Table 6-8

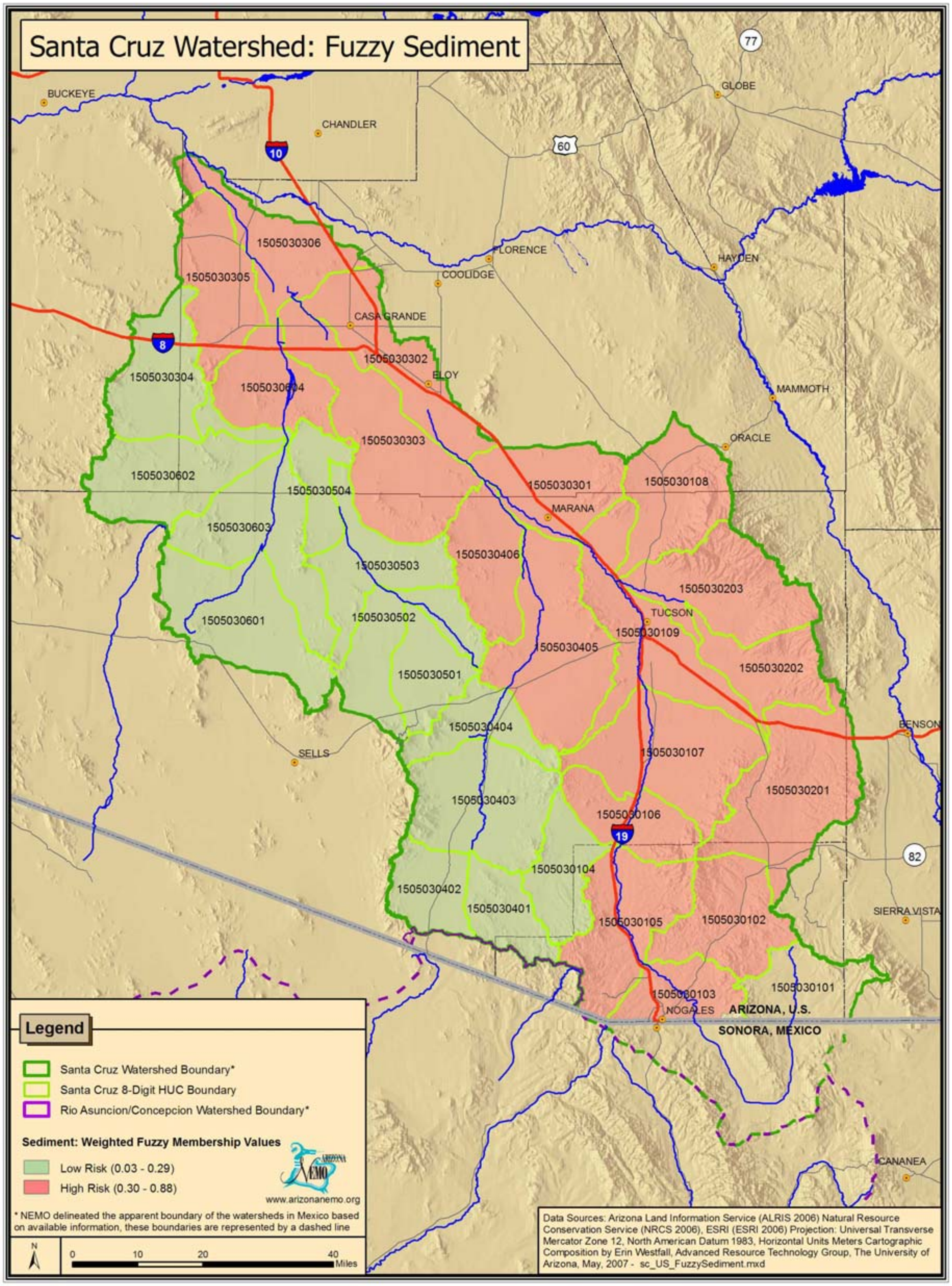

Figure 6-6.1: Santa Cruz Watershed, Results for Fuzzy Logic Classification for Sediment Based on the Weighted Combination Approach (See Table 6-1 for subwatershed names).

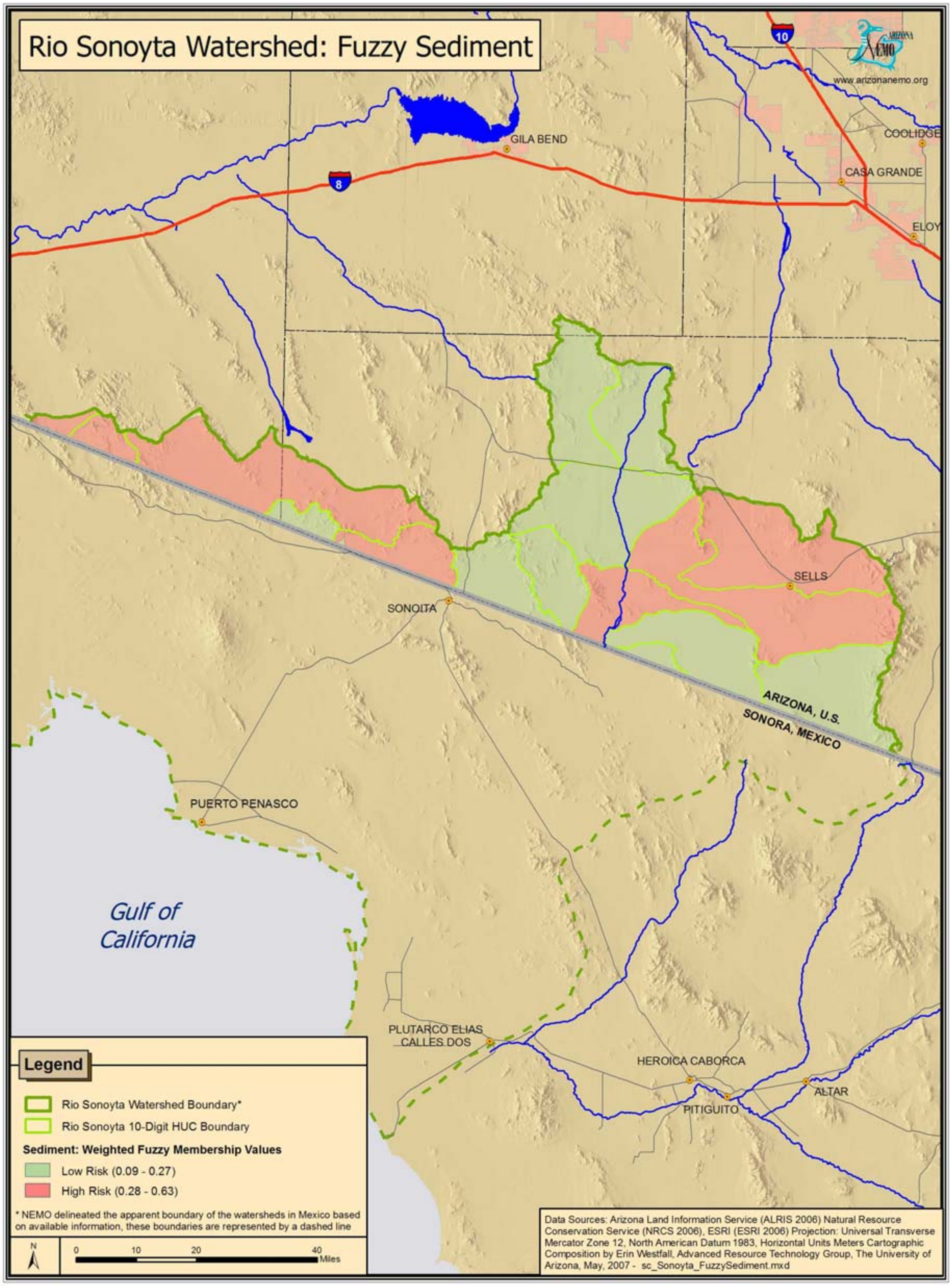

Figure 6-6.2: Rio Sonoyta Watershed, Results for Fuzzy Logic Classification for Sediment Based on the Weighted Combination Approach (See Table 6-1 for subwatershed names).

Organics

Several water quality parameters that have been identified as concerns in the Santa Cruz Watershed are related to the introduction of organic material to a water body. Several monitored reaches had past pH exceedances associated with metals exceedances from historic mining activity. Two reaches north of the international border had *E. coli* exceedances. Three lakes had organics exceedances: Pena Blanca Lake, Lakeside Lake, and Arivaca Lake. Several other waterbodies had limited or insufficient data for organics.

The factors that were used for organic material classification are:

- ADEQ water quality assessment results for organic parameters, including dissolved oxygen, nitrates and TDS;

- Human use index within both the overall subwatershed and within the riparian area; and

- Land use, including grazing and agriculture.

Water Quality Assessment - Organics

Arizona's Integrated 305(b) Assessment and 303(d) Listing Report (ADEQ, 2004) was used to define the current water quality conditions based on water quality measurements. In assigning fuzzy membership values, the location of the 10-digit HUC subwatershed relative to an impaired water or reach was considered. Table 6-2 contains the fuzzy membership values used for different subwatershed conditions based on the water quality assessment results. Table 6-16 contains the fuzzy membership values assigned to each 10-digit HUC subwatershed for organics classification.

Human Use Index - Organics

The Human Use Index was used to assess the relative impact of urban development on the presence of organics in stream water. The Human Use Index is defined as the percentage of a subwatershed that is disturbed by development and human use. In the Santa Cruz Watershed, human use consists of developed areas as defined by the Southwest Regional GAP land cover data as residential land use, mining and roads (RS/GIS Laboratory, 2004).

Human activity can introduce organic material to a water body by disposal of organic compounds, waste and sewage. Most of the residential developments outside of urban areas in the Santa Cruz Watershed utilize onsite septic sewage systems. Currently, the construction of new septic systems requires a permit from ADEQ in the State of Arizona (some exemptions apply), and an inspection of the septic system is required when a property is sold if it was originally approved for use on or after Jan. 1, 2001 by ADEQ or a delegated county agency (http://www.azdeq.gov/environ/water/permits/wastewater.html).

However, there are no requirements for regular inspections of older septic systems and as a result, rural areas may have a significant impact on the introduction of organic material to the environment.

Table 6-16: Fuzzy Membership Values for Organics, Assigned to each 10-digit HUC Subwatershed Based on Water Quality Assessment Results for Organics.

Subwatershed Name	FMV	Justification
SANTA CRUZ WATERSHED		
San Rafael Valley-Upper Santa Cruz River 1505030101	0.7	Classified as moderate risk, drains to Mexico, then to Potrero Creek-Upper Santa Cruz River that is classified as extreme.
Sonoita Creek 1505030102	1.0	Classified as extreme risk, drains to Josephine Canyon-Upper Santa Cruz River that is classified as high.
Potrero Creek-Upper Santa Cruz River 1505030103	1.0	Classified as extreme risk, drains to Josephine Canyon-Upper Santa Cruz River that is classified as high
Sopori Wash 1505030104	0.3	Classified as moderate risk, drains to Demetrie Wash-Upper Santa Cruz River that is classified as low.
Josephine Canyon-Upper Santa Cruz River 1505030105	0.7	Classified as high risk, drains to Demetrie Wash-Upper Santa Cruz River that is classified as low.
Demetrie Wash-Upper Santa Cruz River 1505030106	0.0	Classified as low risk, drains to Box Canyon Wash-Upper Santa Cruz River that is classified as moderate.
Box Canyon Wash-Upper Santa Cruz River 1505030107	0.5	Classified as moderate risk, drains to Julian Wash-Upper Santa Cruz River that is classified as moderate.
Canada del Oro 1505030108	0.5	Classified as moderate risk, drains to Julian Wash-Upper Santa Cruz River that is classified as moderate.
Julian Wash-Upper Santa Cruz River 1505030109	0.5	Classified as moderate risk, drains to Guild Wash-Lower Santa Cruz River that is classified as moderate.
Cienega Creek 1505030201	0.0	Classified as low risk, drains to Agua Verde Creek-Pantano Wash that is classified as extreme.
Agua Verde Creek-Pantano Wash 1505030202	1.0	Classified as extreme risk, drains to Tanque Verde Creek-Rillito River that is classified as high.
Tanque Verde Creek-Rillito River 1505030203	0.7	Classified as high risk, drains to Julian Wash-Upper Santa Cruz River that is classified as moderate.
Guild Wash-Lower Santa Cruz River 1505030301	0.5	Classified as moderate risk, drains to Greene Wash - Upper Santa Cruz Wash that is classified as moderate.
Lower Santa Cruz River-North Branch Santa Cruz Wash 1505030302	0.5	Classified as moderate risk, drains to Lower Santa Cruz Wash that is classified as moderate.
Greene Wash - Upper Santa Cruz Wash 1505030303	0.5	Classified as moderate risk, drains to Lower Santa Cruz Wash that is classified as moderate.
Upper Vekol Wash 1505030304	0.5	Classified as moderate risk, drains to Lower Vekol Wash that is classified as moderate.
Lower Vekol Wash 1505030305	0.5	Classified as moderate risk, drains to Lower Santa Cruz Wash that is classified as moderate.
Lower Santa Cruz Wash 1505030306	0.5	Classified as moderate risk, drains out of the 8-digit HUC
Arivaca Creek 1505030401	0.7	Classified as high risk, drains to Altar Wash that is classified as moderate.
Puertocito Wash 1505030402	0.5	Classified as moderate risk, drains to Altar Wash that is classified as moderate.
Altar Wash 1505030403	0.5	Classified as moderate risk, drains to Upper Brawley Wash that is classified as moderate.
Upper Brawley Wash 1505030404	0.5	Classified as moderate risk, drains to Lower Brawley Wash that is classified as moderate.

Subwatershed Name	FMV	Justification
Lower Brawley Wash 1505030405	0.5	Classified as moderate risk, drains to Los Robles Wash that is classified as moderate.
Los Robles Wash 1505030406	0.5	Classified as moderate risk, drains to Greene Wash - Upper Santa Cruz Wash that is classified as moderate.
Viopuli Wash 1505030501	0.5	Classified as moderate risk, drains to Upper Aguirre Wash that is classified as moderate.
Upper Aguirre Wash 1505030502	0.5	Classified as moderate risk, drains to Lower Aguirre Wash that is classified as moderate.
Lower Aguirre Wash 1505030503	0.5	Classified as moderate risk, drains to Tat Momoli Wash that is classified as moderate.
Tat Momoli Wash 1505030504	0.5	Classified as moderate risk, drains to Lower Santa Rosa Wash that is classified as moderate.
Upper Santa Rosa Wash 1505030601	0.5	Classified as moderate risk, drains to Middle Santa Rosa Wash that is classified as moderate.
Kohatk Wash 1505030602	0.5	Classified as moderate risk, drains to Middle Santa Rosa Wash that is classified as moderate.
Middle Santa Rosa Wash 1505030603	0.5	Classified as moderate risk, drains to Lower Santa Rosa Wash that is classified as moderate.
Lower Santa Rosa Wash 1505030604	0.5	Classified as moderate risk, drains to Lower Santa Cruz Wash that is classified as moderate.
RIO SONOYTA WATERSHED		
Hickiwan Wash 1508010101	0.5	Classified as moderate risk, drains to Middle San Simon Wash that is classified as moderate.
Upper San Simon Wash 1508010102	0.5	Classified as moderate risk, drains to Middle San Simon Wash that is classified as moderate.
Upper Vamori Wash 1508010103	0.5	Classified as moderate risk, drains to Lower Vamori Wash that is classified as moderate.
Sells Wash 1508010104	0.5	Classified as moderate risk, drains to Lower Vamori Wash that is classified as moderate.
Lower Vamori Wash 1508010105	0.5	Classified as moderate risk, drains to Lower San Simon Wash that is classified as moderate.
Middle San Simon Wash 1508010106	0.5	Classified as moderate risk, drains to Lower San Simon Wash that is classified as moderate.
Chukut Kuk Wash 1508010107	0.5	Classified as moderate risk, drains to Mexico.
Rio San Francisquito 1508010108	0.5	Classified as moderate risk, drains to Mexico.
Lower San Simon Wash 1508010109	0.5	Classified as moderate risk, drains to Mexico.
Pia Oik Wash-Menagers Lake 1508010201	0.5	Classified as moderate risk, drains to Mexico.
Sonoyta Valley Area 1508010202	0.5	Classified as moderate risk, drains to Mexico.
Davidson Canyon 1508010203	0.5	Classified as moderate risk, drains to Mexico.
Aguajita Wash-Rio Sonoyta 1508010204	0.5	Classified as moderate risk, drains to Mexico.
Pinacate Valley-Las Playas 1508010301	0.5	Classified as moderate risk, drains to Mexico.
Puente Cuates 1508010302	0.5	Classified as moderate risk, drains to Mexico.

Subwatershed Name	FMV	Justification
La Jolla Wash 1508010303	0.5	Classified as moderate risk, drains to Mexico.
RIO ASUNCION WATERSHED	0.5	Classified as moderate risk, drains to Mexico.
Rio El Sasabe Headwaters 1508020002	0.5	Classified as moderate risk, drains to Mexico.

Human use has been assessed at both the subwatershed and riparian area scale (<= 250 meters from a stream). The fuzzy membership functions for both conditions are as follows:

Human Use Index (HUI)/ HUC watershed:

FMV = 0 if (HUI <= 1%)
FMV = (HUI – 1) / 3
FMV = 1 if (HUI >= 4%)

Human Use Index/Riparian:

FMV = 0 if (HUI <= 0%)
FMV = (HUI - 0) / 4
FMV = 1 if (HUI >= 4%)

Table 6-17 contains the fuzzy membership values assigned to each 10- digit HUC subwatershed in the Santa Cruz Watershed for organics based on the Human Use Index.

Table 6-17: Fuzzy Membership Values for Organics Based on the Human Use Index.

Subwatershed	FMV HU Index Watershed	FMV HU Index Riparian
SANTA CRUZ WATERSHED		
San Rafael Valley-Upper Santa Cruz River 1505030101	0.0	0.0
Sonoita Creek 1505030102	0.01	0.0
Potrero Creek-Upper Santa Cruz River 1505030103	1.0	1.0
Sopori Wash 1505030104	0.0	0.0
Josephine Canyon-Upper Santa Cruz River 1505030105	1.0	0.0
Demetrie Wash-Upper Santa Cruz River 1505030106	1.0	1.0
Box Canyon Wash-Upper Santa Cruz River 1505030107	1.0	1.0
Canada del Oro 1505030108	1.0	1.0
Julian Wash-Upper Santa Cruz River 1505030109	1.0	1.0
Cienega Creek 1505030201	0.02	0.0
Agua Verde Creek-Pantano Wash 1505030202	1.0	1.0
Tanque Verde Creek-Rillito River 1505030203	1.0	1.0
Guild Wash-Lower Santa Cruz River 1505030301	1.0	0.0
Lower Santa Cruz River-North Branch Santa Cruz Wash 1505030302	1.0	1.0
Greene Wash - Upper Santa Cruz Wash 1505030303	1.0	1.0
Upper Vekol Wash 1505030304	0.0	0.0
Lower Vekol Wash 1505030305	1.0	1.0

Subwatershed	FMV HU Index Watershed	FMV HU Index Riparian
Lower Santa Cruz Wash 1505030306	1.0	1.0
Arivaca Creek 1505030401	0.0	0.0
Puertocito Wash 1505030402	0.0	0.0
Altar Wash 1505030403	0.0	0.0
Upper Brawley Wash 1505030404	0.0	0.0
Lower Brawley Wash 1505030405	0.0	1.0
Los Robles Wash 1505030406	0.0	1.0
Viopuli Wash 1505030501	0.0	0.0
Upper Aguirre Wash 1505030502	0.0	0.0
Lower Aguirre Wash 1505030503	0.19	0.0
Tat Momoli Wash 1505030504	0.0	0.0
Upper Santa Rosa Wash 1505030601	0.0	0.0
Kohatk Wash 1505030602	0.0	0.0
Middle Santa Rosa Wash 1505030603	0.0	0.0
Lower Santa Rosa Wash 1505030604	1.0	1.0
RIO SONOYTA WATERSHED		
Hickiwan Wash 1508010101	0.0	0.0
Upper San Simon Wash 1508010102	0.0	0.0
Upper Vamori Wash 1508010103	0.0	0.0
Sells Wash 1508010104	0.0	0.0
Lower Vamori Wash 1508010105	0.0	0.0
Middle San Simon Wash 1508010106	0.0	0.0
Chukut Kuk Wash 1508010107	0.0	0.0
Rio San Francisquito 1508010108	0.0	0.0

Subwatershed	FMV HU Index Watershed	FMV HU Index Riparian
Lower San Simon Wash 1508010109	0.0	0.0
Pia Oik Wash-Menagers Lake 1508010201	0.0	0.0
Sonoyta Valley Area 1508010202	0.0	0.0
Davidson Canyon 1508010203	0.0	0.0
Aguajita Wash-Rio Sonoyta 1508010204	0.0	0.0
Pinacate Valley-Las Playas 1508010301	0.0	0.0
Puente Cuates 1508010302	0.0	0.0
La Jolla Wash 1508010303	0.0	0.0
RIO ASUNCION WATERSHED		
Rio Altar Headwaters 1508020001	0.0	0.0
Rio El Sasabe Headwaters 1508020002	0.0	0.0

Land Use - Organics

The major land uses in the Santa Cruz Watershed are agriculture, livestock grazing, and urban lands, which all contribute to organics in the watershed. Livestock grazing occurs on most land ownership types, including federal government land (BLM and USFS), Arizona State Trust Land, tribal lands and privately owned land. Therefore, each 10-digit HUC watershed was assigned a fuzzy membership value based on its primary land use relative to livestock grazing.

All subwatersheds were initially assigned a value of 1.0 as most of the land is state, federal, tribal or privately owned, and was assumed to be used for livestock grazing, agriculture, or urban areas.

Urbanized Areas – Organics

Urbanized areas can contribute to an increase in organics in stream systems from human activities such as the use of fertilizers or leaking septic systems. Because these contributions can be significant, urbanized areas were included as an additional category in these calculations. The final values for the fuzzy membership functions (FMV) were selected based on this information and are shown in Table 6-18. The FMVs for the percentage of urban land within a 10-digit HUC subwatershed is shown below.

FMV = 0 if (% Urban < 5)
FMV = (5 < = % Urban < 12) / 12
FMV = 1 if (% Urban >= 12)

Table 6-18: Fuzzy Membership Values for Urbanized Areas for Organics.

Subwatershed	Percent Urban	FMV
SANTA CRUZ WATERSHED		
San Rafael Valley-Upper Santa Cruz River 1505030101	0.01	0.0
Sonoita Creek 1505030102	0.32	0.0
Potrero Creek-Upper Santa Cruz River 1505030103	8.70	0.73
Sopori Wash 1505030104	0.0	0.0
Josephine Canyon-Upper Santa Cruz River 1505030105	0.79	0.0
Demetrie Wash-Upper Santa Cruz River 1505030106	2.05	0.0
Box Canyon Wash-Upper Santa Cruz River 1505030107	2.80	0.0
Canada del Oro 1505030108	14.32	1.0
Julian Wash-Upper Santa Cruz River 1505030109	37.51	1.0
Cienega Creek 1505030201	0.0	0.0
Agua Verde Creek-Pantano Wash 1505030202	8.62	0.72
Tanque Verde Creek-Rillito River 1505030203	34.62	1.0
Guild Wash-Lower Santa Cruz River 1505030301	0.0	0.0
Lower Santa Cruz River-North Branch Santa Cruz Wash 1505030302	6.29	0.52
Greene Wash - Upper Santa Cruz Wash 1505030303	0.85	0.0
Upper Vekol Wash 1505030304	0.0	0.0
Lower Vekol Wash 1505030305	0.0	0.0
Lower Santa Cruz Wash 1505030306	0.0	0.0
Arivaca Creek 1505030401	0.0	0.0
Puertocito Wash 1505030402	0.0	0.0
Altar Wash 1505030403	0.0	0.0
Upper Brawley Wash 1505030404	0.0	0.0
Lower Brawley Wash 1505030405	4.49	0.0
Los Robles Wash 1505030406	1.33	0.0
Viopuli Wash 1505030501	0.0	0.0
Upper Aguirre Wash 1505030502	0.0	0.0
Lower Aguirre Wash 1505030503	0.0	0.0
Tat Momoli Wash 1505030504	0.0	0.0
Upper Santa Rosa Wash 1505030601	0.0	0.0
Kohatk Wash 1505030602	0.0	0.0
Middle Santa Rosa Wash 1505030603	0.0	0.0
Lower Santa Rosa Wash 1505030604	0.0	0.0
RIO SONOYTA WATERSHED		
Hickiwan Wash 1508010101	0.0	0.0
Upper San Simon Wash 1508010102	0.0	0.0
Upper Vamori Wash 1508010103	0.0	0.0
Sells Wash 1508010104	0.0	0.0
Lower Vamori Wash 1508010105	0.0	0.0
Middle San Simon Wash 1508010106	0.0	0.0
Chukut Kuk Wash 1508010107	0.0	0.0

Subwatershed	Percent Urban	FMV
Rio San Francisquito 1508010108	0.0	0.0
Lower San Simon Wash 1508010109	0.0	0.0
Pia Oik Wash-Menagers Lake 1508010201	0.0	0.0
Sonoyta Valley Area 1508010202	0.0	0.0
Davidson Canyon 1508010203	0.0	0.0
Aguajita Wash-Rio Sonoyta 1508010204	0.0	0.0
Pinacate Valley-Las Playas 1508010301	0.0	0.0
Puente Cuates 1508010302	0.0	0.0
La Jolla Wash 1508010303	0.0	0.0
RIO ASUNCION WATERSHED		
Rio Altar Headwaters 1508020001	0.0	0.0
Rio El Sasabe Headwaters 1508020002	0.0	0.0

Nutrients

According to Arizona's Integrated 305(b) Assessment and 303(d) Listing Report (ADEQ. 2006a), five waterbodies had exceedances for nutrients:

1. Santa Cruz River from Mexico border to Nogales WWTP, for *E. coli*, and dissolved oxygen.
2. Nogales Wash from Mexico border to Potrero Creek, for ammonia and *E. coli.*
3. Pena Blanca Lake, for dissolved oxygen.
4. Lakeside Lake, for ammonia, and dissolved oxygen.
5. Arivaca Lake, for dissolved oxygen.

In addition, there were insufficient monitoring data for many of the waterbodies, resulting in "inconclusive" assessments. Nutrient exceedances can be caused by runoff from residential areas where landscapes are fertilized, or from animal waste where grazing is prevalent.

pH

According to Arizona's Integrated 305(b) Assessment and 303(d) Listing Report (ADEQ. 2006a), several waterbodies have exceedances for pH levels. Non-compliant pH measurements can be an indication of lake eutrophication, or can be associated with past mining activities (acid mine drainage). Typical unpolluted flowing water will have pH values ranging from 6.5 to 8.5 (unitless); however, where photosynthesis by aquatic organisms takes up dissolved carbon dioxide during daylight hours, a diurnal pH fluctuation may occur and the maximum pH value may sometimes reach as high as 9.0. Studies have found that in poorly buffered lake water, pH fluctuations occur with maximum pH values exceeding 12 (Hem, 1970). The fluctuation in pH has been found to be more pronounced in warm, arid lakes.

Some mine sites may produce acid mine drainage, or low pH conditions, due to the exposure of sulfates to oxygen and water. The acid mine drainage dissolves naturally occurring metals in the soils, increasing the dissolved metal concentrations to sometimes toxic levels. Low pH in aquatic systems can be fatal to many organisms, including fish, or may affect reproduction, causing deformities. In addition, low pH can result in the release of heavy metals, which oxidize and accumulate in the gills of fish, causing asphyxiation (des.nh.gov/wet/Aug04Institute/chemical.pdf).

Organics Results

The weighted combination approach was used to create the combined fuzzy score, and the results are found in Table 6-19, along with the weights used in the classification. Figures 6-7.1 and 6-7.2 show the results of the weighted combination method classified into high and low priority for organics.

Table 6-19: Summary Results for Organics Based on the Fuzzy Logic – Weighted Combination Approach.

Subwatershed	FMV WQA[1]	FMV HUI / subws	FMV HUI / riparian	FMV Land Use	FMV Urban Areas	FMV Weighted
SANTA CRUZ WATERSHED						
San Rafael Valley-Upper Santa Cruz River 1505030101	0.7	0.0	0.0	1.0	0.0	0.31
Sonoita Creek 1505030102	1.0	0.01	0.0	1.0	0.0	0.40
Potrero Creek-Upper Santa Cruz River 1505030103	1.0	1.0	1.0	1.0	0.73	0.97
Sopori Wash 1505030104	0.3	0.0	0.0	1.0	0.0	0.19
Josephine Canyon-Upper Santa Cruz River 1505030105	0.7	1.0	0.0	1.0	0.0	0.51
Demetrie Wash-Upper Santa Cruz River 1505030106	0.0	1.0	1.0	1.0	0.0	0.60
Box Canyon Wash-Upper Santa Cruz River 1505030107	0.5	1.0	1.0	1.0	0.0	0.75
Canada del Oro 1505030108	0.5	1.0	1.0	1.0	1.0	0.85
Julian Wash-Upper Santa Cruz River 1505030109	0.5	1.0	1.0	1.0	1.0	0.85
Cienega Creek 1505030201	0.0	0.02	0.0	1.0	0.0	0.10
Agua Verde Creek-Pantano Wash 1505030202	1.0	1.0	1.0	1.0	0.72	0.97
Tanque Verde Creek-Rillito River 1505030203	0.7	1.0	1.0	1.0	1.0	0.91
Guild Wash-Lower Santa Cruz River 1505030301	0.5	1.0	0.0	1.0	0.0	0.45
Lower Santa Cruz River-North Branch Santa Cruz Wash 1505030302	0.5	1.0	1.0	1.0	0.52	0.80
Greene Wash - Upper Santa Cruz Wash 1505030303	0.5	1.0	1.0	1.0	0.0	0.75
Upper Vekol Wash 1505030304	0.5	0.0	0.0	1.0	0.0	0.25
Lower Vekol Wash 1505030305	0.5	1.0	1.0	1.0	0.0	0.75

Subwatershed	FMV WQA[1]	FMV HUI / subws	FMV HUI / riparian	FMV Land Use	FMV Urban Areas	FMV Weighted
Lower Santa Cruz Wash 1505030306	0.5	1.0	1.0	1.0	0.0	0.75
Arivaca Creek 1505030401	0.7	0.0	0.0	1.0	0.0	0.31
Puertocito Wash 1505030402	0.5	0.0	0.0	1.0	0.0	0.25
Altar Wash 1505030403	0.5	0.0	0.0	1.0	0.0	0.25
Upper Brawley Wash 1505030404	0.5	0.0	0.0	1.0	0.0	0.25
Lower Brawley Wash 1505030405	0.5	0.0	1.0	1.0	0.0	0.55
Los Robles Wash 1505030406	0.5	0.0	1.0	1.0	0.0	0.55
Viopuli Wash 1505030501	0.5	0.0	0.0	1.0	0.0	0.25
Upper Aguirre Wash 1505030502	0.5	0.0	0.0	1.0	0.0	0.25
Lower Aguirre Wash 1505030503	0.5	0.19	0.0	1.0	0.0	0.29
Tat Momoli Wash 1505030504	0.5	0.0	0.0	1.0	0.0	0.25
Upper Santa Rosa Wash 1505030601	0.5	0.0	0.0	1.0	0.0	0.25
Kohatk Wash 1505030602	0.5	0.0	0.0	1.0	0.0	0.25
Middle Santa Rosa Wash 1505030603	0.5	0.0	0.0	1.0	0.0	0.25
Lower Santa Rosa Wash 1505030604	0.5	1.0	1.0	1.0	0.0	0.75
RIO SONOYTA WATERSHED						
Hickiwan Wash 1508010101	0.5	0.0	0.0	1.0	0.0	0.25
Upper San Simon Wash 1508010102	0.5	0.0	0.0	1.0	0.0	0.25
Upper Vamori Wash 1508010103	0.5	0.0	0.0	1.0	0.0	0.25
Sells Wash 1508010104	0.5	0.0	0.0	1.0	0.0	0.25
Lower Vamori Wash 1508010105	0.5	0.0	0.0	1.0	0.0	0.25
Middle San Simon Wash 1508010106	0.5	0.0	0.0	1.0	0.0	0.25
Chukut Kuk Wash 1508010107	0.5	0.0	0.0	1.0	0.0	0.25
Rio San Francisquito 1508010108	0.5	0.0	0.0	1.0	0.0	0.25
Lower San Simon Wash 1508010109	0.5	0.0	0.0	1.0	0.0	0.25
Pia Oik Wash-Menagers Lake 1508010201	0.5	0.0	0.0	1.0	0.0	0.25
Sonoyta Valley Area 1508010202	0.5	0.0	0.0	1.0	0.0	0.25
Davidson Canyon 1508010203	0.5	0.0	0.0	1.0	0.0	0.25
Aguajita Wash-Rio Sonoyta 1508010204	0.5	0.0	0.0	1.0	0.0	0.25
Pinacate Valley-Las Playas 1508010301	0.5	0.0	0.0	1.0	0.0	0.25
Puente Cuates 1508010302	0.5	0.0	0.0	1.0	0.0	0.25
La Jolla Wash 1508010303	0.5	0.0	0.0	1.0	0.0	0.25
RIO ASUNCION WATERSHED						
Rio Altar Headwaters 1508020001	0.5	0.0	0.0	1.0	0.0	0.25

Subwatershed	FMV WQA[1]	FMV HUI / subws	FMV HUI / riparian	FMV Land Use	FMV Urban Areas	FMV Weighted
Rio El Sasabe Headwaters 1508020002	0.5	0.0	0.0	1.0	0.0	0.25
Weights	*0.3*	*0.2*	*0.3*	*0.1*	*0.1*	

[1]WQA = Water Quality Assessment results

Selenium

There were insufficient selenium data to assess most waterbodies, although in locations where monitoring occurred, three exceedancew were noted in the ADEQ Water Quality Assessment Report (2004).

- Sabino Canyon from unnamed tributary at 32 23 28/110 47 00 to Tanque Verde Wash
- Arivaca Lake
- Tanque Verde Creek-Rillito River

High values for selenium may be associated with high values for metals, and are likely to be naturally occurring in highly mineralized soils, or after a severe fire. In addition, high values may be associated with mining evaporation or tailing ponds, where evaporation would increase the relative concentration of selenium, as well as other constituents. One common source of elevated selenium in the western United States is agricultural drainage water ("tail water") from seleniferous irrigated soils (Hem, 1970).

Water Quality Assessment Data-Selenium

The ADEQ Water Quality Assessment Report (2006a) results were used to define the current water quality based on water monitoring results. In assigning fuzzy membership values, the location of a subwatershed relative to an impaired water was considered. Table 6-20 contains the fuzzy membership values for selenium for each subwatershed based on the water quality assessment results.

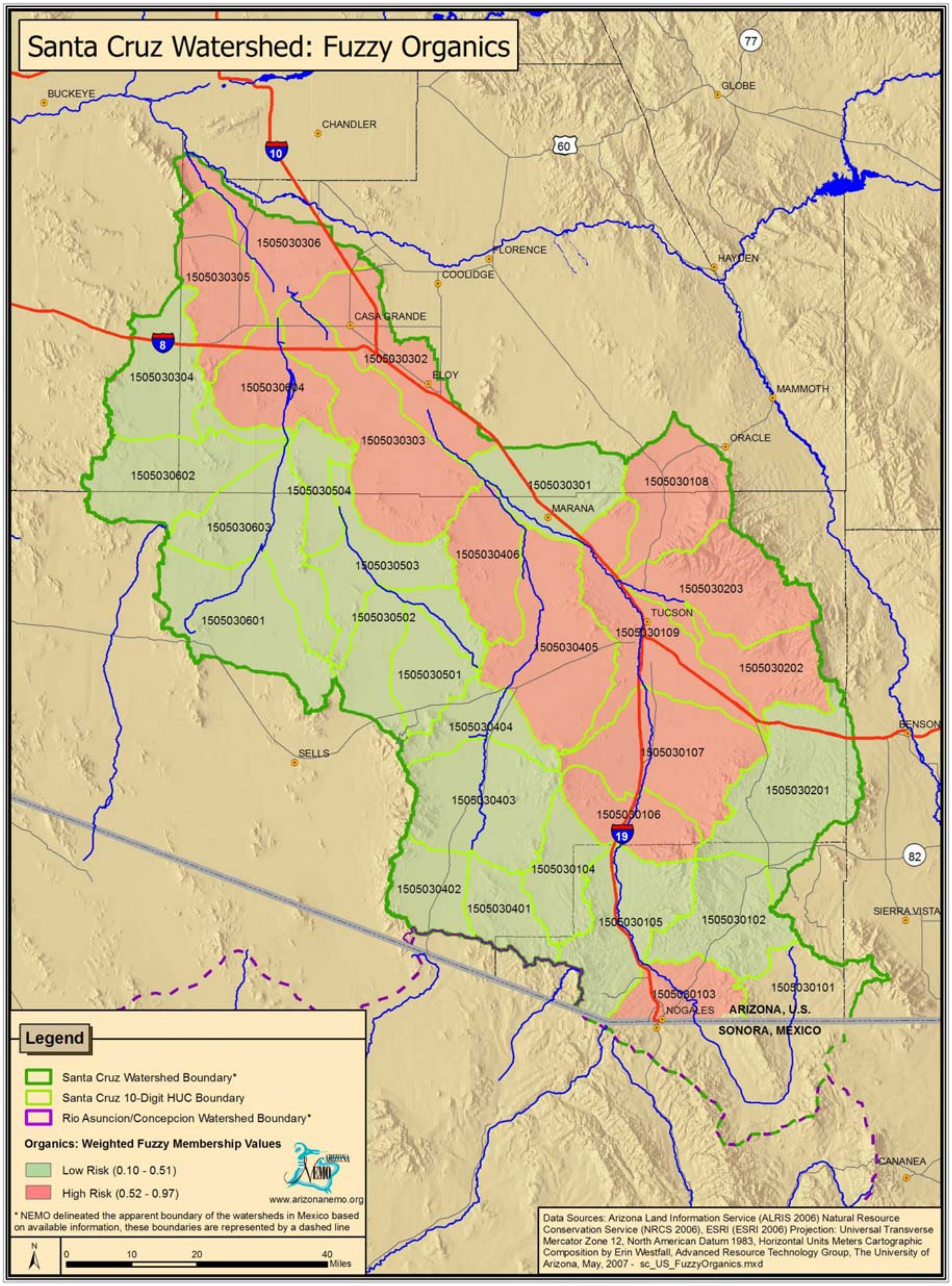

Figure 6-7.1: Santa Cruz Watershed, Results for Fuzzy Logic Classification for Organics Based on the Weighted Combination Approach (See Table 6-1 for subwatershed names).

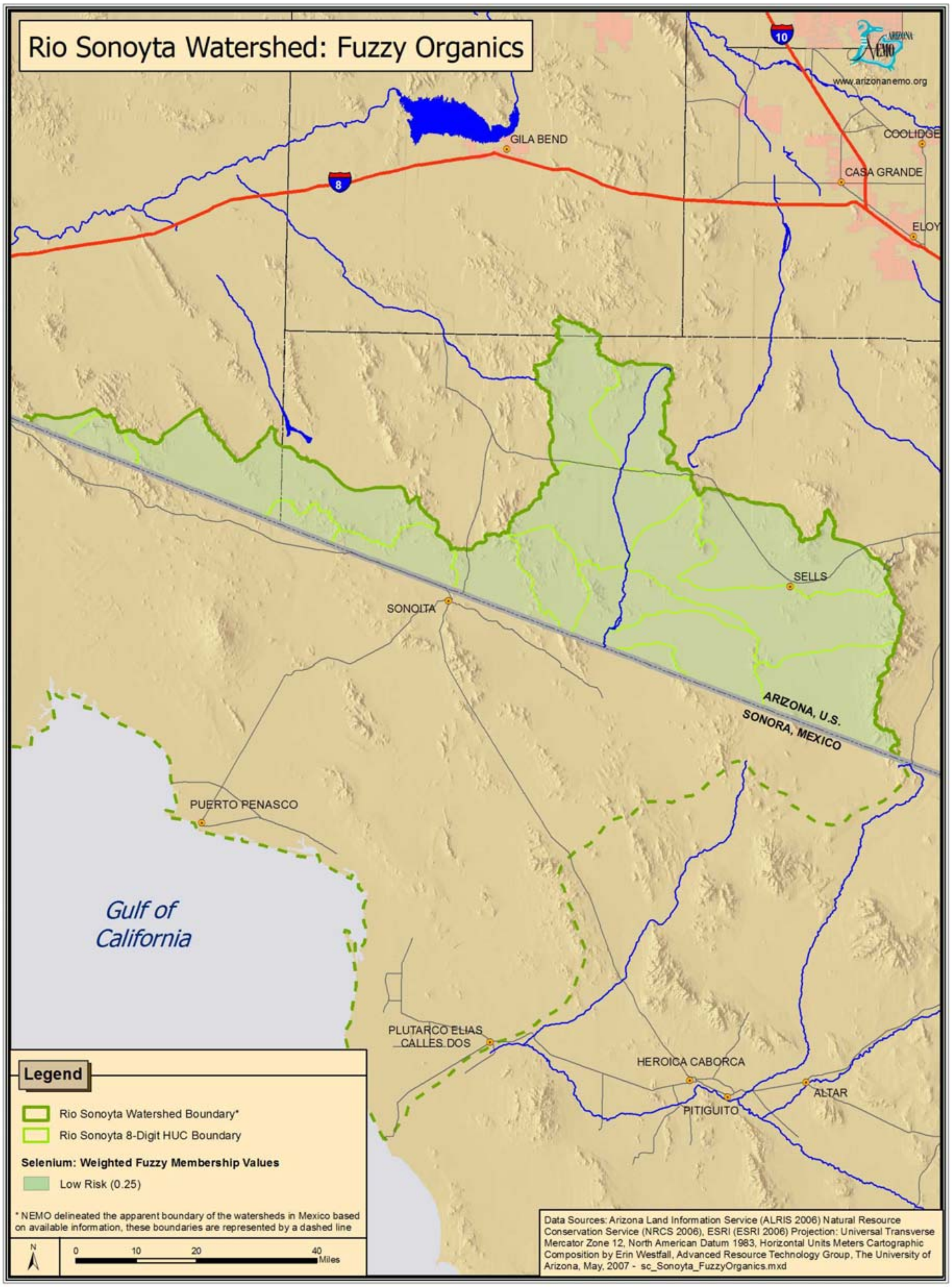

Figure 6-7.2: Rio Sonoyta Watershed, Results for Fuzzy Logic Classification for Organics Based on the Weighted Combination Approach (See Table 6-1 for subwatershed names).

Table 6-20: Fuzzy Membership Values for Selenium Assigned to each 10-digit HUC Subwatershed Based on Water Quality Assessment Results.

Subwatershed Name	FMV	Justification
SANTA CRUZ WATERSHED		
San Rafael Valley-Upper Santa Cruz River 1505030101	0.5	Classified as moderate risk, drains to Mexico, then to Potrero Creek-Upper Santa Cruz River that is classified as moderate.
Sonoita Creek 1505030102	0.5	Classified as moderate risk, drains to Josephine Canyon-Upper Santa Cruz River that is classified as moderate.
Potrero Creek-Upper Santa Cruz River 1505030103	0.5	Classified as moderate risk, drains to Josephine Canyon-Upper Santa Cruz River that is classified as moderate.
Sopori Wash 1505030104	0.5	Classified as moderate risk, drains to Demetrie Wash-Upper Santa Cruz River that is classified as moderate.
Josephine Canyon-Upper Santa Cruz River 1505030105	0.5	Classified as moderate risk, drains to Demetrie Wash-Upper Santa Cruz River that is classified as moderate.
Demetrie Wash-Upper Santa Cruz River 1505030106	0.5	Classified as moderate risk, drains to Box Canyon Wash-Upper Santa Cruz River that is classified as moderate.
Box Canyon Wash-Upper Santa Cruz River 1505030107	0.5	Classified as moderate risk, drains to Julian Wash-Upper Santa Cruz River that is classified as moderate.
Canada del Oro 1505030108	0.5	Classified as moderate risk, drains to Julian Wash-Upper Santa Cruz River that is classified as moderate.
Julian Wash-Upper Santa Cruz River 1505030109	0.5	Classified as moderate risk, drains to Guild Wash-Lower Santa Cruz River that is classified as moderate.
Cienega Creek 1505030201	0.0	Classified as low risk, drains to Agua Verde Creek-Pantano Wash that is classified as moderate.
Agua Verde Creek-Pantano Wash 1505030202	0.6	Classified as moderate risk, drains to Tanque Verde Creek-Rillito River that is classified as high.
Tanque Verde Creek-Rillito River 1505030203	0.7	Classified as high risk, drains to Julian Wash-Upper Santa Cruz River that is classified as moderate.
Guild Wash-Lower Santa Cruz River 1505030301	0.5	Classified as moderate risk, drains to Greene Wash - Upper Santa Cruz Wash that is classified as moderate.
Lower Santa Cruz River-North Branch Santa Cruz Wash 1505030302	0.5	Classified as moderate risk, drains to Lower Santa Cruz Wash that is classified as moderate.
Greene Wash - Upper Santa Cruz Wash 1505030303	05.	Classified as moderate risk, drains to Lower Santa Cruz Wash that is classified as moderate.
Upper Vekol Wash 1505030304	0.5	Classified as moderate risk, drains to Lower Vekol Wash that is classified as moderate.
Lower Vekol Wash 1505030305	0.5	Classified as moderate risk, drains to Lower Santa Cruz Wash that is classified as moderate.
Lower Santa Cruz Wash 1505030306	0.5	Classified as moderate risk, drains out of the 8-digit HUC
Arivaca Creek 1505030401	0.7	Classified as high risk, drains to Altar Wash that is classified as moderate.
Puertocito Wash 1505030402	0.5	Classified as moderate risk, drains to Altar Wash that is classified as moderate.
Altar Wash 1505030403	0.5	Classified as moderate risk, drains to Upper Brawley Wash that is classified as moderate.
Upper Brawley Wash 1505030404	0.5	Classified as moderate risk, drains to Lower Brawley Wash that is classified as moderate.

Subwatershed Name	FMV	Justification
Lower Brawley Wash 1505030405	0.5	Classified as moderate risk, drains to Los Robles Wash that is classified as moderate.
Los Robles Wash 1505030406	0.5	Classified as moderate risk, drains to Greene Wash - Upper Santa Cruz Wash that is classified as moderate.
Viopuli Wash 1505030501	0.5	Classified as moderate risk, drains to Upper Aguirre Wash that is classified as moderate.
Upper Aguirre Wash 1505030502	0.5	Classified as moderate risk, drains to Lower Aguirre Wash that is classified as moderate.
Lower Aguirre Wash 1505030503	0.5	Classified as moderate risk, drains to Tat Momoli Wash that is classified as moderate.
Tat Momoli Wash 1505030504	0.5	Classified as moderate risk, drains to Lower Santa Rosa Wash that is classified as moderate.
Upper Santa Rosa Wash 1505030601	0.5	Classified as moderate risk, drains to Middle Santa Rosa Wash that is classified as moderate.
Kohatk Wash 1505030602	0.5	Classified as moderate risk, drains to Middle Santa Rosa Wash that is classified as moderate.
Middle Santa Rosa Wash 1505030603	0.5	Classified as moderate risk, drains to Lower Santa Rosa Wash that is classified as moderate.
Lower Santa Rosa Wash 1505030604	0.5	Classified as moderate risk, drains to Lower Santa Cruz Wash that is classified as moderate.
RIO SONOYTA WATERSHED		
Hickiwan Wash 1508010101	0.5	Classified as moderate risk, drains to Middle San Simon Wash that is classified as moderate.
Upper San Simon Wash 1508010102	0.5	Classified as moderate risk, drains to Middle San Simon Wash that is classified as moderate.
Upper Vamori Wash 1508010103	0.5	Classified as moderate risk, drains to Lower Vamori Wash that is classified as moderate.
Sells Wash 1508010104	0.5	Classified as moderate risk, drains to Lower Vamori Wash that is classified as moderate.
Lower Vamori Wash 1508010105	0.5	Classified as moderate risk, drains to Lower San Simon Wash that is classified as moderate.
Middle San Simon Wash 1508010106	0.5	Classified as moderate risk, drains to Lower San Simon Wash that is classified as moderate.
Chukut Kuk Wash 1508010107	0.5	Classified as moderate risk, drains to Mexico.
Rio San Francisquito 1508010108	0.5	Classified as moderate risk, drains to Mexico.
Lower San Simon Wash 1508010109	0.5	Classified as moderate risk, drains to Mexico.
Pia Oik Wash-Menagers Lake 1508010201	0.5	Classified as moderate risk, drains to Mexico.
Sonoyta Valley Area 1508010202	0.5	Classified as moderate risk, drains to Mexico.
Davidson Canyon 1508010203	0.5	Classified as moderate risk, drains to Mexico.
Aguajita Wash-Rio Sonoyta 1508010204	0.5	Classified as moderate risk, drains to Mexico.
Pinacate Valley-Las Playas 1508010301	0.5	Classified as moderate risk, drains to Mexico.
Puente Cuates 1508010302	0.5	Classified as moderate risk, drains to Mexico.

Subwatershed Name	FMV	Justification
La Jolla Wash 1508010303	0.5	Classified as moderate risk, drains to Mexico.
RIO ASUNCION WATERSHED		
Rio Altar Headwaters 1508020001	0.5	Classified as moderate risk, drains to Mexico.
Rio El Sasabe Headwaters 1508020002	0.5	Classified as moderate risk, drains to Mexico.

Agricultural Lands

The percentage of the agricultural lands in each 10-digit HUC subwatershed was calculated as shown in Table 6-21.

The fuzzy membership function was defined as follows:

FMV = 0 if (% Agricultural land = 0)
FMV = (% Agricultural land / 10)
FMV = 1 if (% Agric. land >= 10)

Number of Mines per Watershed

Elevated concentrations of selenium in the waters of the Santa Cruz Watershed are likely due to naturally occurring selenium in the metal-rich soils and rocks. To classify subwatersheds likely to exhibit exceedance in selenium, the number of mines in each 10-digit HUC subwatershed was calculated and a fuzzy membership value assigned as shown in Table 6-22.

Table 6-21: Percentage of Agricultural Lands in each Subwatershed.

Subwatershed Name	% Agricultural Land	FMV Agricul. Land
SANTA CRUZ WATERSHED		
San Rafael Valley-Upper Santa Cruz River 1505030101	0.0	0.0
Sonoita Creek 1505030102	0.1	0.01
Potrero Creek-Upper Santa Cruz River 1505030103	0.0	0.0
Sopori Wash 1505030104	0.39	0.04
Josephine Canyon-Upper Santa Cruz River 1505030105	1.16	0.12
Demetrie Wash-Upper Santa Cruz River 1505030106	1.07	0.11
Box Canyon Wash-Upper Santa Cruz River 1505030107	2.13	0.21
Canada del Oro 1505030108	0.0	0.0
Julian Wash-Upper Santa Cruz River 1505030109	0.65	0.07
Cienega Creek 1505030201	0.0	0.0
Agua Verde Creek-Pantano Wash 1505030202	0.0	0.0
Tanque Verde Creek-Rillito River 1505030203	0.0	0.0
Guild Wash-Lower Santa Cruz River 1505030301	12.78	1.0
Lower Santa Cruz River-North Branch Santa Cruz Wash 1505030302	29.98	1.0
Greene Wash - Upper Santa Cruz Wash 1505030303	17.95	1.0
Upper Vekol Wash 1505030304	0.0	0.0
Lower Vekol Wash 1505030305	31.04	1.0

Subwatershed Name	% Agricultural Land	FMV Agricul. Land
Lower Santa Cruz Wash 1505030306	33.60	1.0
Arivaca Creek 1505030401	0.0	0.0
Puertocito Wash 1505030402	0.0	0.0
Altar Wash 1505030403	0.0	0.0
Upper Brawley Wash 1505030404	0.19	0.02
Lower Brawley Wash 1505030405	6.04	0.60
Los Robles Wash 1505030406	3.51	0.35
Viopuli Wash 1505030501	0.0	0.0
Upper Aguirre Wash 1505030502	0.0	0.0
Lower Aguirre Wash 1505030503	1.2	0.12
Tat Momoli Wash 1505030504	0.0	0.0
Upper Santa Rosa Wash 1505030601	0.0	0.0
Kohatk Wash 1505030602	0.0	0.0
Middle Santa Rosa Wash 1505030603	0.0	0.0
Lower Santa Rosa Wash 1505030604	9.25	0.93
RIO SONOYTA WATERSHED		
Hickiwan Wash 1508010101	0.0	0.0
Upper San Simon Wash 1508010102	0.0	0.0
Upper Vamori Wash 1508010103	0.0	0.0
Sells Wash 1508010104	0.0	0.0
Lower Vamori Wash 1508010105	0.0	0.0
Middle San Simon Wash 1508010106	0.0	0.0
Chukut Kuk Wash 1508010107	1.5	0.15
Rio San Francisquito 1508010108	0.0	0.0
Lower San Simon Wash 1508010109	0.0	0.0
Pia Oik Wash-Menagers Lake 1508010201	0.0	0.0
Sonoyta Valley Area 1508010202	0.0	0.0
Davidson Canyon 1508010203	0.0	0.0
Aguajita Wash-Rio Sonoyta 1508010204	0.0	0.0
Pinacate Valley-Las Playas 1508010301	0.0	0.0
Puente Cuates 1508010302	0.0	0.0
La Jolla Wash 1508010303	0.0	0.0
RIO ASUNCION WATERSHED		
Rio Altar Headwaters 1508020001	0.0	0.0
Rio El Sasabe Headwaters 1508020002	0.0	0.0

Table 6-22: Fuzzy Membership Values Based on Number of Mines in each 10-digit HUC Subwatershed.

Number of Mines in Each Subwatershed	FMV
0-10	0.0
11-25	0.33
26-50	0.66
> 50	1.00

Table 6-23 shows the fuzzy membership values for each 10-digit HUC subwatershed based on the number of mines.

Table 6-23: Fuzzy Membership Values for Selenium for each 10-digit HUC Subwatershed Based on the Number of Mines.

Subwatershed Name	Number of mines	FMV mines/HUC
SANTA CRUZ WATERSHED		
San Rafael Valley-Upper Santa Cruz River 1505030101	56	1.0
Sonoita Creek 1505030102	122	1.0
Potrero Creek-Upper Santa Cruz River 1505030103	61	1.0
Sopori Wash 1505030104	13	1.0
Josephine Canyon-Upper Santa Cruz River 1505030105	68	1.0
Demetrie Wash-Upper Santa Cruz River 1505030106	64	1.0
Box Canyon Wash-Upper Santa Cruz River 1505030107	118	1.0
Canada del Oro 1505030108	31	1.0
Julian Wash-Upper Santa Cruz River 1505030109	50	1.0
Cienega Creek 1505030201	136	1.0
Agua Verde Creek-Pantano Wash 1505030202	17	1.0
Tanque Verde Creek-Rillito River 1505030203	19	1.0
Guild Wash-Lower Santa Cruz River 1505030301	18	1.0
Lower Santa Cruz River-North Branch Santa Cruz Wash 1505030302	54	1.0
Greene Wash - Upper Santa Cruz Wash 1505030303	37	1.0
Upper Vekol Wash 1505030304	2	0.0
Lower Vekol Wash 1505030305	17	1.0
Lower Santa Cruz Wash 1505030306	31	1.0
Arivaca Creek 1505030401	148	1.0
Puertocito Wash 1505030402	22	1.0
Altar Wash 1505030403	67	1.0
Upper Brawley Wash 1505030404	14	1.0
Lower Brawley Wash 1505030405	59	1.0
Los Robles Wash 1505030406	12	1.0
Viopuli Wash 1505030501	8	0.8
Upper Aguirre Wash 1505030502	5	0.4
Lower Aguirre Wash 1505030503	23	1.0
Tat Momoli Wash 1505030504	22	1.0
Upper Santa Rosa Wash 1505030601	37	1.0
Kohatk Wash 1505030602	21	1.0
Middle Santa Rosa Wash 1505030603	42	1.0
Lower Santa Rosa Wash 1505030604	17	1.0
RIO SONOYTA WATERSHED		
Hickiwan Wash 1508010101	1	0.0
Upper San Simon Wash 1508010102	10	1.0
Upper Vamori Wash 1508010103	8	0.8
Sells Wash 1508010104	92	1.0
Lower Vamori Wash 1508010105	37	1.0
Middle San Simon Wash 1508010106	12	1.0
Chukut Kuk Wash 1508010107	11	1.0
Rio San Francisquito 1508010108	0	0.0
Lower San Simon Wash 1508010109	2	0.0

Subwatershed Name	Number of mines	FMV mines/HUC
Pia Oik Wash-Menagers Lake 1508010201	3	0.1
Sonoyta Valley Area 1508010202	0	0.0
Davidson Canyon 1508010203	2	0.0
Aguajita Wash-Rio Sonoyta 1508010204	8	0.8
Pinacate Valley-Las Playas 1508010301	8	0.8
Puente Cuates 1508010302	1	0.0
La Jolla Wash 1508010303	0	0.0
RIO ASUNCION WATERSHED		
Rio Altar Headwaters 1508020001	53	1.0
Rio El Sasabe Headwaters 1508020002	3	0.1

Selenium Results

The weighted combination approach was used to create the combined fuzzy score, and the results are found in Table 6-24, along with the weights used in the classification. Figures 6-8.1 and 6-8.2 show the results of the weighted combination method classified into high and low priority for selenium.

Table 6-24: Summary Results for Selenium Based on the Fuzzy Logic - Weighted Combination Approach.

Subwatershed Name	FMV WQA[1]	FMV mines/HUC	FMV % Agricultural Land	FMV Weighted
SANTA CRUZ WATERSHED				
San Rafael Valley-Upper Santa Cruz River 1505030101	0.5	1.0	0.0	0.50
Sonoita Creek 1505030102	0.5	1.0	0.01	0.50
Potrero Creek-Upper Santa Cruz River 1505030103	0.5	1.0	0.0	0.50
Sopori Wash 1505030104	0.5	1.0	0.04	0.61
Josephine Canyon-Upper Santa Cruz River 1505030105	0.5	1.0	0.12	0.53
Demetrie Wash-Upper Santa Cruz River 1505030106	0.5	1.0	0.11	0.53
Box Canyon Wash-Upper Santa Cruz River 1505030107	0.5	1.0	0.21	0.55
Canada del Oro 1505030108	0.5	1.0	0.0	0.50
Julian Wash-Upper Santa Cruz River 1505030109	0.5	1.0	0.07	0.52
Cienega Creek 1505030201	0.0	1.0	0.0	0.25

Subwatershed Name	FMV WQA[1]	FMV mines/HUC	FMV % Agricultural Land	FMV Weighted
Agua Verde Creek-Pantano Wash 1505030202	0.6	1.0	0.0	0.55
Tanque Verde Creek-Rillito River 1505030203	0.7	1.0	0.0	0.60
Guild Wash-Lower Santa Cruz River 1505030301	0.5	1.0	1.0	0.75
Lower Santa Cruz River-North Branch Santa Cruz Wash 1505030302	0.5	1.0	1.0	0.75
Greene Wash - Upper Santa Cruz Wash 1505030303	0.5	1.0	1.0	0.75
Upper Vekol Wash 1505030304	0.5	0.0	0.0	0.25
Lower Vekol Wash 1505030305	0.5	1.0	1.0	0.75
Lower Santa Cruz Wash 1505030306	0.5	1.0	1.0	0.75
Arivaca Creek 1505030401	0.7	1.0	0.0	0.60
Puertocito Wash 1505030402	0.5	1.0	0.0	0.50
Altar Wash 1505030403	0.5	1.0	0.0	0.50
Upper Brawley Wash 1505030404	0.5	1.0	0.02	0.51
Lower Brawley Wash 1505030405	0.5	1.0	0.60	0.65
Los Robles Wash 1505030406	0.5	1.0	0.35	0.59
Viopuli Wash 1505030501	0.5	0.8	0.0	0.45
Upper Aguirre Wash 1505030502	0.5	0.4	0.0	0.35
Lower Aguirre Wash 1505030503	0.5	1.0	0.12	0.53
Tat Momoli Wash 1505030504	0.5	1.0	0.0	0.50
Upper Santa Rosa Wash 1505030601	0.5	1.0	0.0	0.50
Kohatk Wash 1505030602	0.5	1.0	0.0	0.50
Middle Santa Rosa Wash 1505030603	0.5	1.0	0.0	0.50
Lower Santa Rosa Wash 1505030604	0.5	1.0	0.93	0.73
RIO SONOYTA WATERSHED				
Hickiwan Wash 1508010101	0.5	0.0	0.0	0.25
Upper San Simon Wash 1508010102	0.5	1.0	0.0	0.50
Upper Vamori Wash 1508010103	0.5	0.8	0.0	0.45
Sells Wash 1508010104	0.5	1.0	0.0	0.50
Lower Vamori Wash 1508010105	0.5	1.0	0.0	0.50
Middle San Simon Wash 1508010106	0.5	1.0	0.0	0.50
Chukut Kuk Wash 1508010107	0.5	1.0	0.15	0.54
Rio San Francisquito 1508010108	0.5	0.0	0.0	0.25
Lower San Simon Wash 1508010109	0.5	0.0	0.0	0.25
Pia Oik Wash-Menagers Lake 1508010201	0.5	0.1	0.0	0.28
Sonoyta Valley Area 1508010202	0.5	0.0	0.0	0.25

Subwatershed Name	FMV WQA[1]	FMV mines/HUC	FMV % Agricultural Land		FMV Weighted
Davidson Canyon 1508010203	0.5	0.0	0.0		0.25
Aguajita Wash-Rio Sonoyta 1508010204	0.5	0.8	0.0		0.45
Pinacate Valley-Las Playas 1508010301	0.5	0.8	0.0		0.45
Puente Cuates 1508010302	0.5	0.0	0.0		0.25
La Jolla Wash 1508010303	0.5	0.0	0.0		0.25
RIO ASUNCION WATERSHED					
Rio Altar Headwaters 1508020001		0.5	1.0	0.0	0.50
Rio El Sasabe Headwaters 1508020002		0.5	0.1	0.0	0.28
Weights		*0.5*	*0.25*	*0.25*	

[1]WQA = Water Quality Assessment results

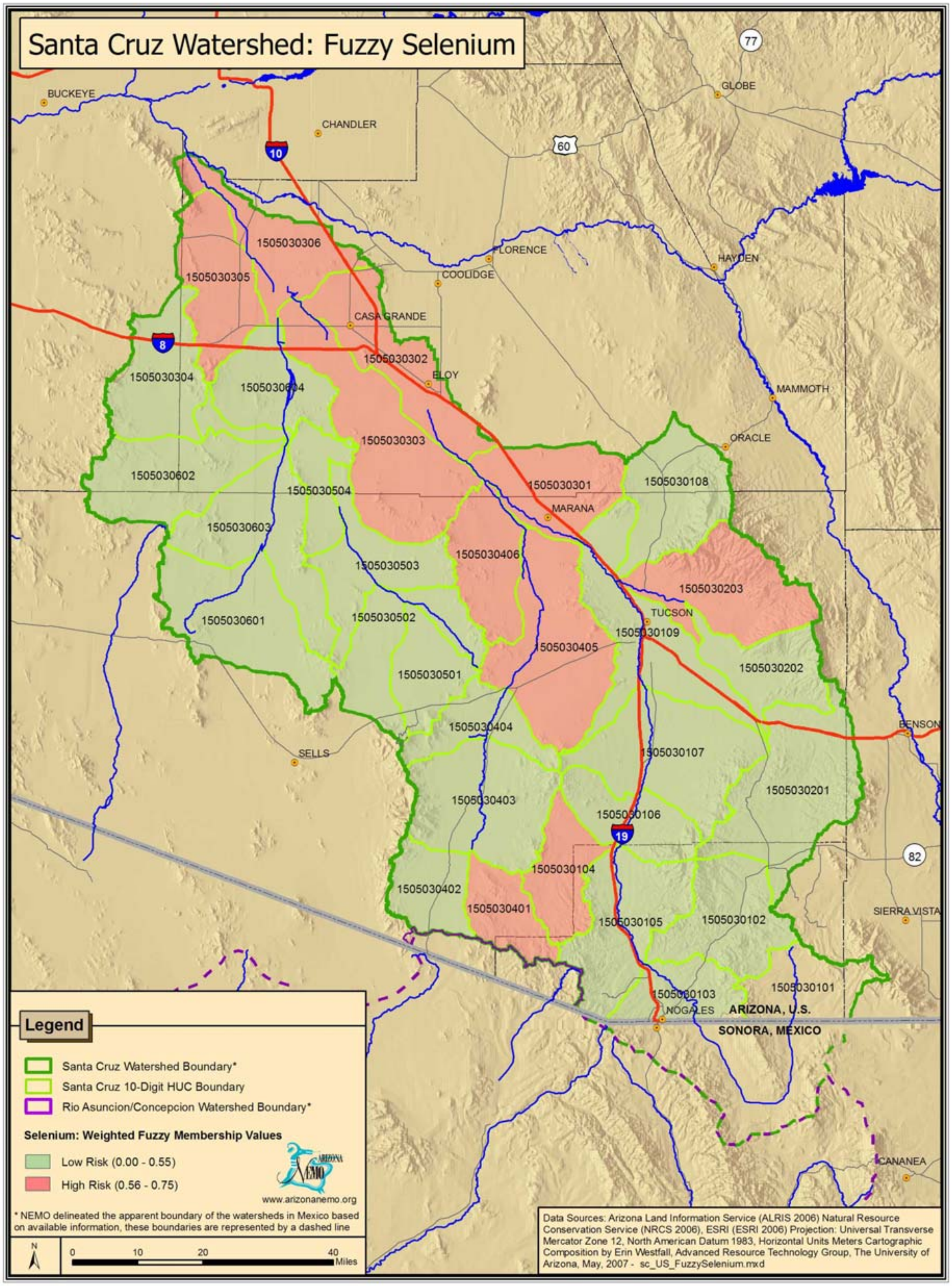

Figure 6-8.1: Santa Cruz Watershed, Results for Fuzzy Logic Classification for Selenium Based on the Weighted Combination Approach (See Table 6-1 for subwatershed names).

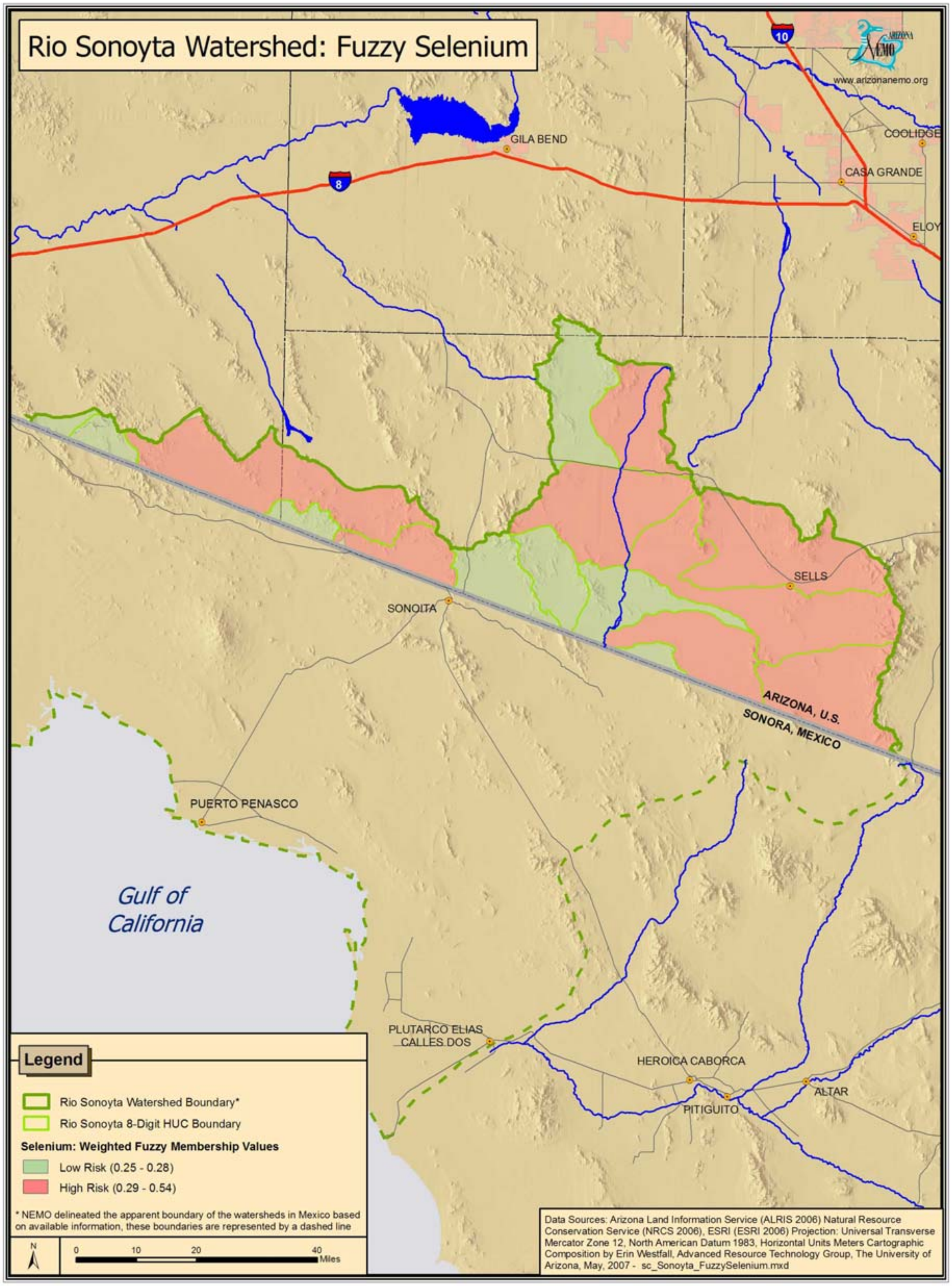

Figure 6-8.2: Rio Sonoyta Watershed, Results for Fuzzy Logic Classification for Selenium Based on the Weighted Combination Approach (See Table 6-1 for subwatershed names).

References:

Arizona Department of Environmental Quality, ADEQ. 2006a. The Status Ambient Surface Water Quality in Arizona: Arizona's Integrated 305(b) Assessment and 303(d) Listing Report, 1110 West Washington Ave., Phoenix, Arizona, 85007, from http://www.azdeq.gov/environ/water/assessment/download/2006/integrated.pdf.

Arizona Department of Environmental Quality, ADEQ. 2006b. TMDL Program, from http://www.azdeq.gov/environ/water/assessment/tmdl.html.

Arnold, J.G., J. R. Williams, R. Srinivasan, K.W. King, and R. H. Griggs. 1994. SWAT - Soil & Water Assessment Tool. USDA, Agricultural Research Service, Grassland, Soil and Water Research Laboratory, Temple, Texas.

Booth, D.B., 1990. Stream channel incision following drainage basin urbanization. Water Resources Bulletin, v. 26, n. 3, p. 407-417.

Burns, I.S., S. Scott, L. Levick, M. Hernandez, D.C. Goodrich, S.N. Miller, D.J. Semmens, and W.G. Kepner. 2004. Automated Geospatial Watershed Assessment (AGWA) - A GIS-Based Hydrologic Modeling Tool: Documentation and User Manual *Version 1.4,* from http://www.tucson.ars.ag.gov/agwa/

Chin, A., and K.J. Gregory. 2001. Urbanization and adjustment of ephemeral stream channels. Annals of the Association of American Geographers, v. 91, n. 4, pp. 595-608.

Coleman, D., C. MacRae, E.D. Stein. 2005. Effect of Increases in Peak Flows and Imperviousness on the Morphology of Southern California Streams. Southern California Coastal Water Research Project, Westminster, CA. Technical Report #450.

Guertin, D.P., R.H. Fiedler, S.N. Miller, and D.C. Goodrich. 2000. Fuzzy Logic for Watershed Assessment. Proceedings of the ASCE Conference on Science and Technology for the New Millennium: Watershed Management 2000, Fort Collins, CO, June 21-24, 2000.

Hem, J.D. 1970. Study and Interpretation of the Chemical Characteristics of Natural Water, 2nd Edition. U.S. Geological Survey Water-Supply Paper 1473.

Miller, S.N., W.G. Kepner, M.H. Mehaffrey, M. Hernandez, R.C. Miller, D.C. Goodrich, K.K. Devonald, D.T. Heggem, and W.P. Miller. 2002. Integrating Landscape Assessment and Hydrologic Modeling for Land Cover Change Analysis, in Journal of the American Water Resources Association, Vol. 38, No. 4, August. P. 915- 929.

Miltner, R. J., D. White, C. Yoder. 2003. The biotic integrity of streams in urban and suburbanizing landscapes. Landscape and Urban Planning Vol. 69, p. 87-100.

Reynolds, K.M. 2001. Fuzzy Logic Knowledge Bases in Integrated Landscape Assessment: Examples and Possibilities. General Technical Report PNW-GTR-521. USDA Forest Service, Pacific Northwest Research Station. 24 pp.

Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, and D.C. Yoder. 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE), U. S. Department of Agriculture, Agriculture Handbook No. 703. 404 pp.

Van Remortel, R. and D. Heggem. 2006. SEDMOD, Version 2 (Update 1) of Soil & Landform Metrics: Programs and U.S. Geodatasets (CD). U.S. Environmental Protection Agency, Environmental Sciences Division, Landscape Ecology Branch, Las Vegas, NV.

<u>Data Sources:*</u>

Arizona State Land Department, Arizona Land Resource Information System (ALRIS), http://www.land.state.az.us/alris/index.html
Landownership. February 7, 2002.
Mines. February 7, 2002.

RS/GIS Laboratory, 2004. Provisional Landcover. http://earth.gis.usu.edu/swgap
Land cover / land use. Sept. 24, 2004.

**Note: Dates for each data set refer to when data was downloaded from the website. Metadata (information about how and when the GIS data were created) is available from the website in most cases. Metadata includes the original source of the data, when it was created, its geographic projection and scale, the name(s) of the contact person and/or organization, and general description of the data.*

Section 7: Watershed Management

This section discusses the recommended watershed management activities to address nonpoint source pollution concerns in the Agua Fria Watershed. These recommendations are subject to revision by land use decision makers and stakeholders, and may be revised based on new data as it becomes available. It is understood that the application of any management activities will require site-specific design and may require licensed engineering design. These recommendations are only general in nature and are presented herein so as to allow land use decision makers and watershed stakeholders to conceptualize how best to address watershed management.

Total Maximum Daily Load (TMDL) plans for Alum Gulch, Arivaca Lake, Harwhaw Creek, Lakeside Park, Three R Canyon and Cox Gulch, Pena Blanca Lake, Nogales Wash, Santa Cruz River, Sonoita Creek and Parker Canyon Lake are also summarized within this section. A TMDL plan is a study for an impaired water body that defines the maximum amount of a specific water quality parameter or pollutant that can be carried by a waterbody without causing an exceedance of water quality standards.

Management Methods

The section includes general watershed management methods, recommended strategies for addressing existing impairment in the watershed, stream channel and riparian restoration, and proposed education programs. The general watershed management methods include:

- Site management on new development;
- Monitoring and enforcement activities;
- Water quality improvement and restoration projects; and
- Education.

Each of these methods is defined further below, and is addressed within each of the three classifications: metals, organics, and nutrient nonpoint source pollutant water quality concerns.

Site Management on New Development:

Control the quantity and quality of water run-off from new development sites. The primary sources for future development in the Agua Fria Watershed include new housing developments and increased urbanization, new road construction, and the mining industry. Upper Santa Cruz River and the Lower Santa Cruz River subwatersheds are particularly at risk to future housing development due to the large percentage of private land within the area.

Although it is recognized that ADEQ requires Aquifer Protection Permitting and the issuance of Stormwater Management Plans for active mine sites, new mine development in the watersheds should continue to be monitored. It is important to promote the application of nonpoint source management measures on all new development sites through cooperation with local government, developers and private land owners.

Monitoring and Enforcement Activities:

- Continue and expand water quality monitoring programs in the watershed to measure the effectiveness of management practices on protecting and restoring the waters of the Agua Fria Watershed.
- Promote septic tank inspections and certification of septic systems by local government entities.
- Promote construction site inspection and enforcement action for new development.

Water Quality Improvement and Restoration Projects:

- Promote efforts to protect and restore the natural functions and characteristics of impaired water bodies. Potential projects are discussed below.
- Integrate adaptive management methods and activities across the watershed to address existing and future problems.

Education:

- Develop programs to increase the awareness and participation of citizens, developers and local decision makers in the watershed management efforts. Education programs are discussed below.

Strategy for Addressing Existing Impairment

The major sources of water quality impairment and environmental damage in the Santa Cruz waters are elevated concentrations of dissolved and particulate metals, sediment and organics. The high priority 10-digit HUC subwatersheds were identified for each constituent group in the previous section on Watershed Classification (Section 6).

The goal of this section is to describe a strategy for dealing with the sources of impairment for each constituent group. The management measures discussed herein are brief and meant to provide initial guidance to the land use decision makers and watershed stakeholders.

Detailed descriptions of the following management measures, in addition to a manual of nonpoint source best management practices (BMPs), can be found at the NEMO website www.ArizonaNEMO.org.

Metals

The primary nonpoint source of anthropogenic metals in the Santa Cruz Watershed is abandoned or inactive mines, although it is recognized that naturally occurring metals originating from local highly mineralized soils may contribute to elevated background concentrations in streams and lakes. Industrial and urban sources of metals are also important due to the amount of development in the watershed. Portions of the Santa Cruz Watershed have a long history of mining, with many abandoned and several active mines found across the watershed. In most cases the original owner or responsible party for an abandoned mine is unknown and the responsibility for the orphaned mine falls to the current landowner.

Abandoned / orphaned mines are found on all classes of land ownership in the Santa Cruz Watershed, including federal, state and private lands, with a majority of the mines located on land administered by the Federal government and the State of Arizona. Surface runoff and erosion from mine waste / tailings is the principal source of nonpoint source contamination. Subsurface drainage from mine waste / tailings can also be a concern. The recommended actions include:

- Inventory of existing abandoned mines;
- Revegetation of disturbed mined lands;
- Erosion control;
- Runoff and sediment capture;
- Tailings and mine waste removal; and
- Education.

Load reduction potential, maintenance, cost and estimated life of revegetation and erosion control treatments for addressing metals from abandoned mines are found in Table 7-1.

Inventory of Existing Abandoned Mines:

All existing abandoned mines are not equal sources for elevated concentrations of metals. One of the difficulties in developing this assessment is the lack of thorough and centralized data on abandoned mine sites. Some of the mapped abandoned mine sites are prospector claims with limited land disturbance, while others are remote and disconnected from natural drainage features and represent a low risk pollutant source.

Table 7-1. Proposed Treatments for Addressing Metals from Abandoned Mines.

Action	Load Reduction Potential	Estimated Time Load Reduction	Expected Maintenance	Expected Cost	Estimated Life of Treatment
Revegetation	Medium	< 2 years	Low	Low-Medium	Long
Erosion Control Fabric	High	Immediate	Low	Low-Medium	Short
Plant Mulch	Low	Immediate	Low	Low	Short
Rock Mulch	High	Immediate	Medium	Low-High	Long
Toe Drains	High	Immediate	Medium	Medium	Medium
Detention Basin	High	Immediate	High	High	Medium-Long
Silt Fence	Medium	Immediate	Medium	Low	Short-Medium
Straw Roll/bale	Medium	Immediate	High	Low	Short
Removal	High	Immediate	Low	High	Long

NOTE: The actual cost, load reduction, or life expectancy of any treatment is dependent on site specific conditions. The terms used in this table express relative differences between treatments to assist users in evaluating potential alternatives. Only after a site-specific evaluation can these factors be quantified more rigorously.

At sites where water and oxygen are in contact with waste rock containing sulfates, sulfuric acid is formed. As the water becomes more acidic, metals are leached from the soils and rock, generating toxic concentrations of heavy metals in the water. Acid rock drainage, also known as acid mine drainage, can be a significant water quality concern. Management of this important source of watershed impairment begins with compiling available information from the responsible agencies. This information can be used to conduct an onsite inventory to clarify the degree of risk the site exhibits towards discharging elevated concentrations of metals to a water body.

Risk factors to be assessed include: area and volume of waste/tailings; metal species present and toxicity; site drainage features and metal transport characteristics (air dispersion, sediment transport, acid mine drainage, etc.); distance to a water body; and evidence of active site erosion. Abandoned mine sites can then be ranked and prioritized for site management and restoration.

Revegetation:

Revegetation of the mine site is the only long-term, low maintenance restoration alternative in the absence of funding to install engineered site containment and capping. In semi-arid environments, revegetation of a disturbed site is relatively difficult even under optimal conditions. The amount of effort required to revegetate an abandoned mine site depends on the chemical composition of the mine waste/tailings, which may be too toxic to sustain growth.
The addition of soil amendments, buffering agents, or capping with top soil to sustain vegetation often approaches the costs associated with engineered capping. If acid mine drainage is a significant concern, intercepting and managing the acidic water may necessitate extensive site drainage control systems and water treatment, a significant increase in cost and requiring on-going site operation and maintenance.

Reclaimed Mine Site
(Dept. of the Interior, Office of Surface Mining, http://www.osmre.gov/awardwy.htm)

Erosion Control:

If revegetation of the mine site is impractical, site drainage and erosion control treatments are alternatives. Erosion control actions can also be applied in combination with revegetation to control erosion as the vegetation cover is established. Erosion control fabric and plant mulch are two short-term treatments that are usually applied in combination with revegetation.

Rock mulch (i.e. rock riprap) is a long-term treatment, but can be costly and impractical on an isolated site. Rock mulch can be an inexpensive acid buffering treatment if carbonate rocks (limestone) are locally available. As the acidic mine drainage comes in contact with the rock mulch, the water looses it's acidity and dissolved metals precipitate out of the water column. A disadvantage of erosion control treatments is that they do not assist in dewatering a site and may have little impact on subsurface acidic leaching.

Runoff and Sediment Capture:

The capture and containment of site runoff and sediment, and prevention of the waste rock and tailings from contact with a water body are other management approaches. Short-term treatments include installing straw roll/bale or silt fence barriers at the toe of the source area to capture sediment. Long-term treatments include trenching the toe of the source area to capture the runoff and sediment. If the source area is large, the construction of a detention basin may be warranted.

Disadvantages of runoff and sediment capture and containment treatments are that they may concentrate the contaminated material, especially if dissolved metals are concentrated by evaporation in retention ponds. Structural failure can lead to downstream transport of pollutants. The retention / detention of site runoff can also escalate subsurface drainage problems by ponding water.

Load reduction potential, maintenance, cost and estimated life of runoff and sediment control treatments such as toe drains, basins, and silt fences are found in Table 7-2.

Table 7-2. Proposed Treatments for Addressing Erosion and Sedimentation.

Action	**Load Reduction Potential**	**Estimated Time to Load Reduction**	**Expected Maintenance**	**Expected Cost**	**Estimated Life of Treatment**
Grazing Mgt.	Medium	< 2 years	Low	Low	Long
Filter Strips	High	< 2 years	Low	Low	Long
Fencing	Low	Immediate	Low	Low	Medium
Watering Facility	Medium	Immediate	Low	Low-Medium	Medium
Rock Riprap	High	Immediate	Medium	Medium-High	Long
Erosion Control Fabric	High	Immediate	Low	Low-Medium	Short
Toe Rock	High	Immediate	Low	Medium	Long
Water Bars	Medium	Immediate	Medium	Medium	Medium
Road Surface	High	Immediate	Medium	High	Long

Note: The actual cost, load reduction, or life expectancy of any treatment is dependant on site specific conditions. Low costs could range from nominal to $10,000, medium costs could range between $5,000 and $50,000, and high costs could be anything greater than $25,000. The terms used in this table express relative differences between treatments to assist users in evaluating potential alternatives. Only after a site-specific evaluation can these factors be quantified more rigorously.

Removal:

The mine waste/tailing material can be excavated and removed for pollution control. This treatment is very expensive and infeasible for some sites due to lack of accessibility.

Rock Rip-Rap Sediment Control
(Dept. of the Interior, Office of Surface Mining, http://www.osmre.gov/ocphoto.htm)

Education:

Land use decision makers and stakeholders need to be educated on the problems associated with abandoned mines and the available treatments to mitigate the problems. In addition, abandoned mine sites are health and safety concerns and the public should be warned about entering open shafts that may collapse, or traversing unstable slopes. Due to the financial liability associated with site restoration, legal and regulatory constraints must also be addressed.

The target audiences for education programs are private land owners, watershed groups, local officials and land management agencies (U.S. Forest Service, Bureau of Land Management, and Tribal entities).

Rock Structure for Runoff Control
(Dept. of the Interior, Office of Surface Mining, http://www.osmre.gov/ocphoto.htm)

Figures 7-1.1 and 7-1.2 show land ownership across the 10-digit HUCs, and Tables 7-3.1 and 7-3.2 provides listings of percentage of land ownership as distributed across the Santa Cruz, the Rio Asuncion, and the Sonoyta subwatershed areas. These tables provides a basis from which to identify stakeholders pertinent to each subwatershed area, and is repeated here in more detail after a brief discussion of land ownership in Section 4, Social and Economic Characteristics of the watershed.

The only subwatershed area prioritized for educational outreach to address metals based on Section 6 analysis is Sonoita Creek.

Alum Gulch TMDL for Cadmium, Copper, Zinc, and Low pH

Alum Gulch and a tributary (Humboldt Canyon) are impaired by cadmium, copper, zinc, and low pH (acidity). Pollution by these metals and acid mine drainage pose a risk to aquatic life and wildlife. TMDL analyses were completed and approved in 2003.

Based on this study, primarily loading originates from the World's Fair Mine area and Humboldt Canyon with relatively minor contributions from Trench Camp Mine and the January Adit. It appears that the remediation efforts at Trench Camp and the January Adit have been relatively successful. To achieve standards, ADEQ will be working with landowners and interested stakeholders to implement the following remediation actions and strategies recommended in the TMDL:

• Remove mine residue dumps from the stream banks,

• Remove mine-waste sediments from the streambeds, and

• Isolate and treat mine-impacted ground water discharges (springs and adits).

Arivaca Lake TMDL for Mercury

Arivaca Lake is impaired by mercury. A fish consumption advisory concerning mercury in fish tissue has been issued at this lake because mercury poses a health problem to humans. Mercury also poses risks to other species that eat the fish. EPA collaborated with ADEQ and completed a mercury TMDL in 1999. The primary sources of mercury were identified as: atmospheric deposition (particulates in the air) and natural deposition from local substrates. Because atmospheric deposition is not readily controllable, and the primary land use is grazing, improvements in livestock management to reduce soil erosion were targeted in the TMDL implementation plan. ADEQ is working with interested landowners and stakeholders to implement these improvements.

Harshaw Creek TMDL for Copper and Low pH

Harshaw Creek is impaired by copper and low pH (acidity). Copper and acid mine drainage can negatively impact aquatic life and wildlife. TMDL loading analyses were completed in 2003. This report identified abandoned or inactive mines that were the primary sources of the copper and acid mine waste. To achieve standards, ADEQ will be working with landowners and interested stakeholders to implement the following remediation actions and strategies recommended in the TMDL:

• Remove mine residue dumps from the stream banks,

• Remove mine-waste sediments from the streambeds, and

• Isolate and treat mine-impacted ground water discharges (springs and adits).

Three R Canyon and Cox Canyon TMDL for Beryllium, Cadmium, Copper, Zinc, and low pH

Three R (3R) Canyon and Cox Gulch are impaired by beryllium, cadmium, copper, zinc, and low pH (acidity). These metals and acid mine drainage represent a risk to aquatic and wildlife. TMDLs were completed in 2003 and quantified contributions from 3R Mine and unnamed springs. However, a Phase II TMDL is needed to determine if there are other significant contributions in the basin. To achieve standards, ADEQ will be working with landowners and interested stakeholders to implement the following remediation actions and strategies recommended in the TMDL:

- Remove mine residue dumps from the stream banks,
- Remove mine-waste sediments from the streambeds, and
- Isolate and treat mine-impacted ground water discharges (springs and adits).

Pena Blanca Lake TMDL for Mercury

A fish consumption advisory concerning mercury in fish tissue has been issued at this lake because mercury poses a health problem to humans. Mercury also poses risks to other species that eat the fish. EPA collaborated with ADEQ and completed a mercury TMDL in 1999. The study identified three sources of mercury: atmospheric deposition (particulates in the air), St. Patrick Mine ball mill site, and generalized natural deposition from local substrates. To meet standards, the TMDL analysis and implementation plan indicated that the tailings and sediment should be removed from the ball mill site. ADEQ is to conduct further monitoring on fish tissue to determine whether these measures were sufficient.

Nogales Wash TMDL for Ammonia, E. Coli, Copper, and Chlorine

Nogales Wash is impaired by ammonia, *Escherichia coli*, copper, and chlorine. Exceedances of the *E. coli* standard may represent a significant public health concern if people are swimming or even wading in the water. Ammonia, chlorine and copper pose a threat to aquatic life and wildlife. Wastewater infrastructure has deteriorated in Mexico and must be replaced. To protect the human health, chlorine is added directly to the wash continuously via drip systems and manual introduction of chlorine tables. Chlorine residuals are monitored daily in an attempt to keep chlorine residuals at or above 1 mg/L at the US and Mexico border (which is 100 times above the standard for aquatic life use). Although these conditions pose significant threats to human health and aquatic life, actions to correct the situation are dependent on ongoing international negotiations between several government officials (representing the United States, Arizona, Mexico, the cities of Nogales Arizona and Nogales Sonora, and the Mexican state of Sonora). The source loadings are known and the technical means to correct the problem have been determined. These TMDLs will be developed if needed after facility upgrades are completed.

Sonoita Creek TMDL for Zinc

Sonoita Creek is impaired by zinc in the 14-mile segment just above its confluence with the Santa Cruz River. The federally protected Gila topminnow occurs in this reach and could be negatively impacted by dissolved zinc. Sources of the zinc have not been investigated but are likely related to transport of zinc during storm flows from its tributaries (e.g., Alum Gulch and 3R Canyon). Monitoring will be used to determine if strategies implemented on these tributaries reduce zinc transport sufficiently to eliminate exceedances on Sonoita Creek.

Parker Canyon Lake TMDL for Mercury

A fish consumption advisory concerning mercury in fish tissue has been issued at this lake because mercury poses a health problem to humans. Mercury also poses risks to other species that eat the fish. A TMDL investigation is ongoing.

A TMDL analysis is a tool for implementing state surface water quality standards and is based on the relationship between pollution sources and in-stream water quality conditions. The TMDL process is a method used in balancing the pollution concerns for a waterbody and allocating the acceptable pollutant loads among the different point and non-point sources allowing the selection and implementation of suitable control measures to attain water quality standards.

<u>Sediment</u>

Erosion and sedimentation are major environment problems in the western United States, including the Santa Cruz Watershed. In semiarid regions, the primary source of sediment is from channel scour. Excessive channel scour and down-cutting can lead to deterioration of riparian systems' extent and condition. Increases in channel scour are caused by increased surface runoff produced by changing watershed conditions. Restoration of impaired channel riparian areas can also mitigate erosion damage.
The primary land uses in the Santa Cruz Watershed that can contribute to erosion are livestock grazing and mining. Development, which also contributes to erosion, is increasing in some portions of the watershed. Impervious land surfaces accelerate surface runoff, increase flow velocity, and exacerbates channel scour. Dirt roads can be an important source of sediment as well. The recommended sediment management actions (see Table 7-2) are:

- Grazing Management
- Filter Strips
- Fencing
- Watering Facilities
- Rock Riprap
- Erosion Control Fabrics
- Toe Rock
- Water Bars
- Erosion Control on Dirt Roads
- Education

Grazing Management:

Livestock grazing is currently practiced in the Santa Cruz Watershed. Implementing grazing management practices to improve or maintain the health and vigor of plant communities will lead to reductions in surface runoff and erosion. Sustainable livestock grazing can be achieved in all plant communities by changing the duration, frequency and intensity of grazing.

Management may include exclusion of land such as riparian areas from grazing, seasonal rotation, rest or some combination of these options. Proper grazing land management provides for a healthy riparian plant community that stabilizes stream banks, creates habitat and slows flood velocities.

Filter Strips:

A filter strip along a stream, lake or other water body will retard the movement of sediment, and may remove pollutants from runoff before the material enters the body of water. Filter strips will protect channel and riparian systems from livestock grazing and tramping. Fencing the filter strip is usually required when livestock are present. Filter strips and fencing can be used to protect other sensitive ecological resources.

Fencing:

Restricting access to riparian corridors by fencing will allow for the reestablishment of riparian vegetation. Straw bale fencing slows runoff and traps sediment from sheet flow or channelized flow in areas of soil disturbance.

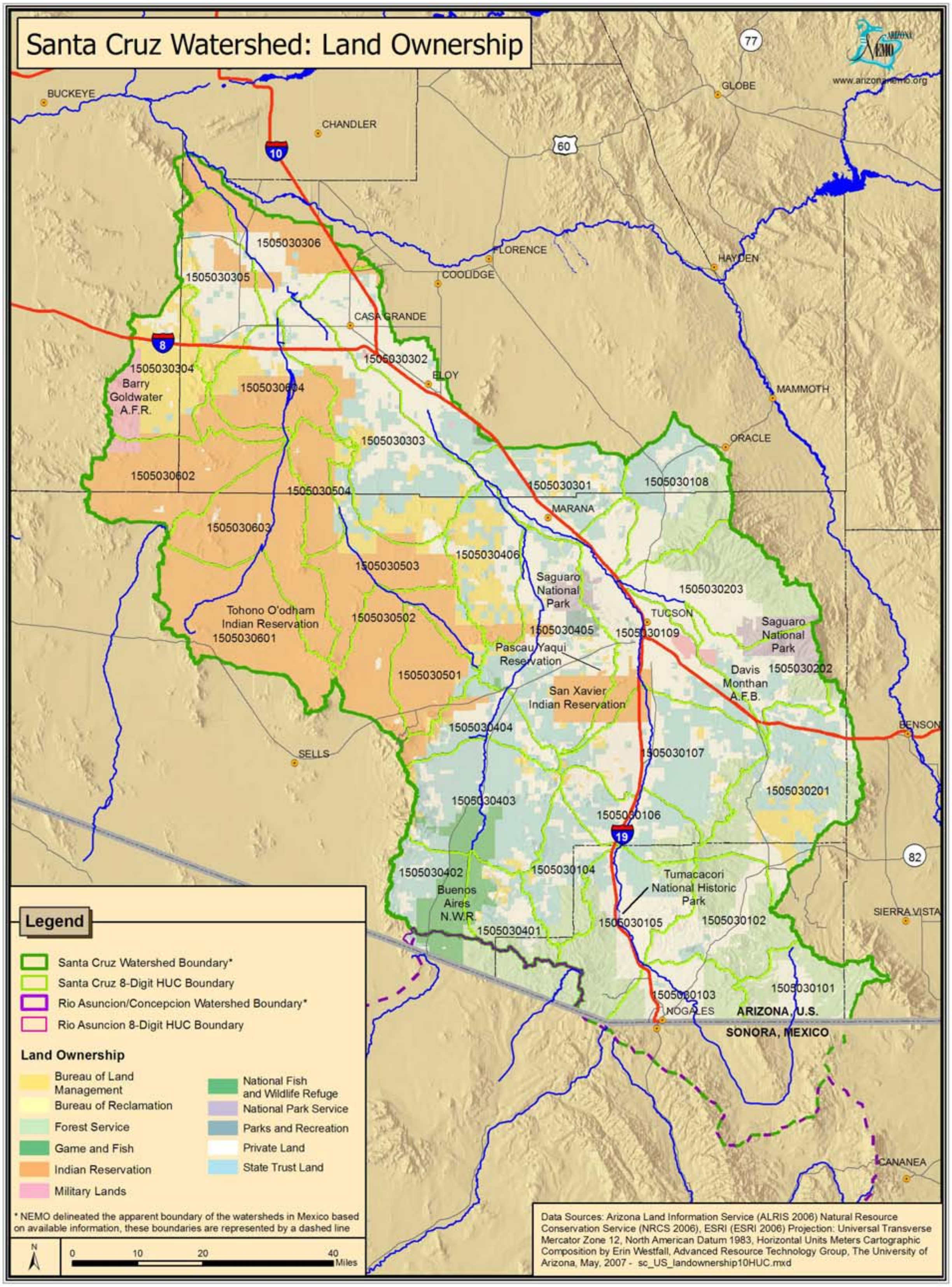

Figure 7-1.1: Santa Cruz Watershed Land Ownership

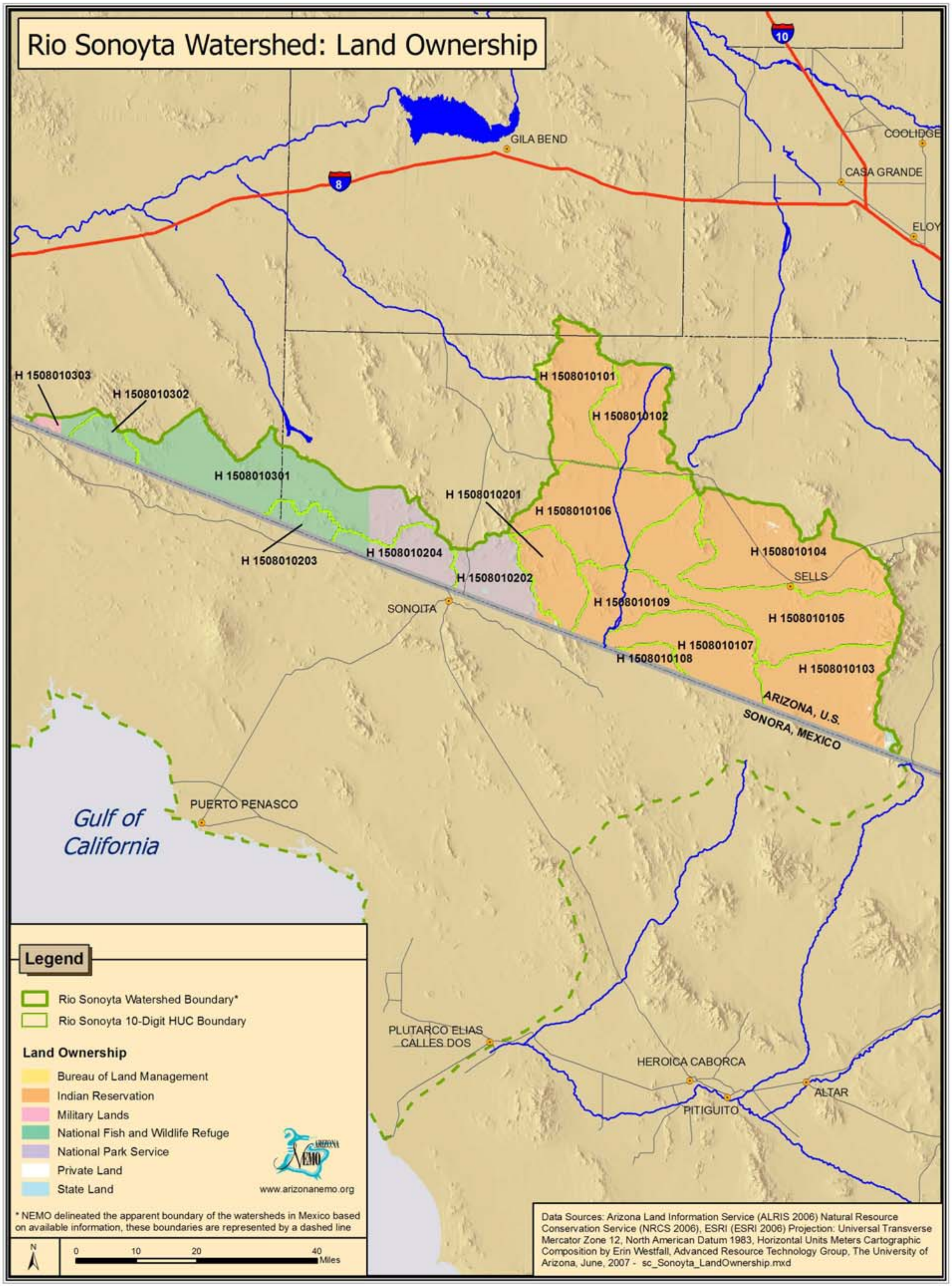

Figure 7-1.2: Rio Sonoyta Watershed Land Ownership

Table 7-3.1: Santa Cruz Watershed Land Ownership (Percent of each Subwatershed) (part 1 of 2)

Land Owner	**Aguirre Wash Tat Momoli Wash H15050305**	**Brawley Wash – Los Robles Wash H15050304**	**Lower Santa Cruz River H15050303**	**Pantano Wash – Rillito River H15050302**	**Santa Rosa Wash H15050306**
BLM	7%	10%	17%	7%	3%
Bureau of Reclamation	-	0.2%	0.2%	-	> 0%
US Forest Service	-	3%	-	29%	-
Game and Fish	-	0.2%	-	-	-
Indian Reservation	86%	8%	16%	-	92%
Military Lands	-	-	3%	0.7%	0.9%
National Fish and Wildlife Refuge	-	11%	-	-	-
National Park Service	-	2%	-	9%	-
Parks and Recreation	-	1%	0.3%	-	-
Private Land	2%	24%	42%	32%	3%
State Land	5%	41%	21%	22%	1%
Area (square miles)*	*733*	*1,408*	*1,682*	*920*	*1,208*

*Data pertains to the U.S. portion of the watershed only.

Table 7-3.1: Santa Cruz Watershed Land Ownership (Percent of each Subwatershed) (part 2 of 2)

Land Owner	**Upper Santa Cruz River H15050301**	**Santa Cruz Watershed**	**Rio Asuncion H15080200**	**Rio Asuncion Watershed**
BLM	1%	7%	-	-
Bureau of Reclamation	-	>0%	-	-
US Forest Service	30%	12%	74%	74%
Game and Fish	-	>0%	-	-
Indian Reservation	3%	27%	-	-
Military Lands	1%	1%	-	-
National Fish and Wildlife Refuge	-	2%	20%	20%
National Park Service	1%	1%	-	-
Parks and Recreation	0.1%	>0%	-	-
Private Land	42%	28%	3%	3%
State Land	24%	21%	3%	3%
Area* (square miles)	2,227	8,178	128	128

*Data pertains to the U.S. portion of the watershed only.

Table 7-3.2: Rio Sonoyta Watershed Land Ownership (Percent of each Subwatershed)

Land Owner	Rio Sonoyta H15080102	San Simon Wash H15080101	Tule Desert Area H15080103	Rio Sonoyta Watershed
BLM	-	0.2%	-	>0%
Indian Reservation	32%	99%	-	74%
Military Lands	-	-	3%	>0%
National Fish and Wildlife Refuge	15%	-	84%	16%
National Park Service	52%	-	14%	9%
Private Land	0.3%	0.2%	> 0%	>0%
State Land	0.2%	0.2%	-	>0%
Area (square miles)*	*424*	*2,154*	*497*	*3,075*

*Data pertains to the U.S. portion of the watershed only.

Watering Facilities:

Alternative watering facilities, such as a tank, trough, or other watertight container at a location removed from the waterbody, can provide animal access to water, protect and enhance

vegetative cover, provide erosion control through better management of grazing stock and wildlife, and protect streams, ponds and water supplies from biological contamination. Providing alternative water sources is usually required when creating filter strips.

Alternative cattle watering facilities
(http://www.2gosolar.com/typical_installations.htm)

Rock Riprap:

Large diameter rock riprap reduces erosion when installed along stream channels and in areas subject to head cutting. Regrading may be necessary before placing the rocks, boulders or coarse stones, and best management practices should be applied to reduce erosion during regrading.

Erosion Control Fabric:

Geotextile filter fabrics reduce the potential for soil erosion as well as volunteer (weed) vegetation, and are often installed beneath rock riprap.

Rock Riprap and Jute Matting
Erosion Control along a stream.
(Photo: Lainie Levick)

Toe Rock:

Placement of rock and riprap along the toe of soil slopes reduces erosion and increases slope stability.

Water Bars:

A water bar is a shallow trench with mounding long the down-slope edge that intercepts and redirects runoff water in areas of soil disturbance. This erosion control method is most frequently used at tailings piles or on dirt roads.

Erosion Control on Dirt Roads:

In collaboration with responsible parties, implement runoff and erosion control treatments on dirt roads and other disturbed areas. Dirt roads can contribute significant quantities of runoff and sediment if not properly constructed and managed. Water bars and surfacing are potential treatments. When a road is adjacent to a stream, it may be necessary to use engineered road stabilization treatments.

The stabilization of roads and embankments reduces sediment input from erosion and protects the related infrastructure. Traditional stabilization relied on expensive rock (riprap) treatments. Other options to stabilize banks include the use of erosion control fabric, toe rock and revegetation.

Bank Stabilization and Erosion Control
along a highway
(Photo: Lainie Levick)

Channel and Riparian Restoration:

Restoration or reconstruction of a stream reach is used when the stream reach has approached or crossed a threshold of stability from which natural recovery may take too long or be unachievable. This practice significantly reduces sediment input to a system and will promote the riparian recovery process. Channel and riparian restoration will be discussed in more detail below.

Education:

The development of education programs will help address the impact of livestock grazing and promote the implementation of erosion control treatments. Education programs should address stormwater management from land development and target citizen groups, developers and watershed partnerships.

Based on the sediment and erosion classification completed in Section 6, the subwatershed area prioritized for educational outreach to address erosion control is Tanque Verde Creek-Rillito River.

Organics

At several locations within the Santa Cruz Watershed, water quality problems associated with the introduction of animal waste were observed. The two primary sources of animal waste in the watershed are livestock grazing in riparian areas and failing septic systems. Livestock grazing is common across the entire watershed.

The recommended actions (see Table 7-4) for management of organics are:

- Filter Strips
- Fencing
- Watering Facilities
- Septic System Repair
- Education

Filter Strips:

Creating a filter strip along a water body will reduce and may remove pollutants from runoff before the material enters a body of water. Filter strips have been found to be very effective in removing animal waste due to livestock grazing, allowing the organics to bio-attenuate (i.e. be used by the plants) and degrade. Fencing the filter strip is usually required when dealing with livestock.

Table 7-4. Proposed Treatments for Addressing Organics.

Action	Load Reduction Potential	Estimated Time to Load Reduction	Expected Maintenance	Expected Cost	Estimated Life of Treatment
Filter Strips	High	< 2 years	Low	Low	Long
Fencing	Low	Immediate	Low	Low	Medium
Watering Facility	Medium	Immediate	Low	Low-Medium	Medium
Septic System Repair	High	Medium	High	High	Medium

Note: The actual cost, load reduction, or life expectancy of any treatment is dependant on site specific conditions. Low costs could range from nominal to $10,000, medium costs could range between $5,000 and $20,000, and high costs could be anything greater than $15,000. The terms used in this table express relative differences between treatments to assist users in evaluating potential alternatives. Only after a site-specific evaluation can these factors be quantified more rigorously.

Fencing:

Restricting access to riparian corridors by fencing will allow for the reestablishment of riparian vegetation. Straw bale or silt fencing slows runoff and traps organics from sheet flow or channelized flow in areas of soil disturbance.

Filter strip near waterbody
(http://jasperswcd.org/practices.htm)

Watering Facilities:

Alternative watering facilities, such as a tank, trough, or other watertight container at a location removed from the waterbody, can provide animal access to water and protect streams, ponds and water supplies from biological contamination by grazing cattle. Providing alternative water sources is usually required when creating filter strips.

Septic System Repair:

One of the difficulties in assessing the impact of failing septic systems to streams is the lack of thorough and centralized data on septic systems. Although it can be assumed that residential development in areas not served by sanitary sewers will rely on private on-site septic systems, the condition of the systems are usually unknown until failure is obvious to the home owner.

Currently, the construction of new septic systems requires a permit from ADEQ in the State of Arizona (some exemptions apply). In addition, ADEQ requires that the septic system be inspected when a property is sold if it was originally approved for use on or after Jan. 1, 2001 by ADEQ or a delegated county agency. This is to help selling and buying property owners understand the physical and operational condition of the septic system serving the home or business. The ADEQ website with more information on permitting septic systems is: http://www.azdeq.gov/environ/water/permits/wastewater.html.

Although not required by ADEQ, older septic systems should be inspected when purchasing a home with an existing system.

At a minimum, conduct an inventory of locations where private septic systems occur to clarify the degree of risk a stream reach may exhibit due to failure of these systems. Risk factors can be assessed with GIS mapping tools, such as: proximity to a waterbody, soil type, depth to the water table, and density of development. Septic system sites can then be ranked and prioritized for further evaluation.

Education:

Develop educational programs that explain the sources of organics, address the impacts of livestock grazing, and promote the implementation of filter strips, fencing and alternative watering facilities. In addition, the programs should promote residential septic system maintenance, septic tank inspections and certification of septic systems by local municipalities or government entities.

Based on the results of the organics classification and ranking in Section 6, the subwatershed areas prioritized for educational outreach to address organics are Potrero Creek-Upper Santa Cruz River and Agua Verde Creek-Pantano Wash.

Lakeside Lake TMDL form Nutrients, High pH, Ammonia, and Dissolved Oxygen

Lakeside Lake in Tucson is impaired by nutrients, ammonia, high pH, and low levels of dissolved oxygen.
Excess nutrients (nitrogen) may result in low dissolved oxygen and high pH and potentially toxic algal blooms and fish kills. High levels of ammonia may also pose a risk to aquatic life. TMDL analyses were completed in 2005 and indicated that the water sources supplying the lake were the primary source of nutrients to the lake. Lakeside Lake receives secondary-treated reclaimed effluent, ground water, Central Arizona Project (CAP) water from the Colorado River, and occasional storm water runoff from Atterbury Wash.

ADEQ has been working with the city of Tucson, Pima County Wastewater Management Department, and other interested stakeholders to mitigate these problems. The city of Tucson has been testing aerators that physically increase dissolved oxygen levels in the water column. However, increased agitation and vertical mixing stimulated greater algal productivity, high pH levels, and did not reduce the ammonia concentration. Tucson is also testing the use of alum to reduce phosphorus loading in the lake. ADEQ is reopening formal permit negotiations for the discharge of reclaimed water to Lakeside Lake.

Santa Cruz River TMDL for E. coli Bacteria

The Santa Cruz River from Mexico to the Nogales International Wastewater Treatment Plant discharge is impaired by *Escherichia coli* bacteria. Exceedances of the *E. coli* standard may represent a significant public health concern if people are swimming or even wading in the water. Completing this TMDL may be complex due to probable sources in Mexico and intermittent stream flow. Drought conditions have slowed collection of adequate data to determine source loadings. A TMDL will be initiated when flow resumes.

Selenium

Selenium occurs naturally in the environment; however, it can enter groundwater or surface water from hazardous waste-sites or irrigated farmland. The recommended action for the management of selenium is to avoid flood irrigation of croplands, and install a mechanized irrigation system.

Mechanized irrigation systems include center pivot, linear move, gated pipe, wheel line or drip irrigation. Based on a 1998 study (Hoffman and Willett,

1998) costs range from a low of $340 per acre for the PVC gated pipe to a high of $1,095 per acre for the linear move. The center pivot cost per acre is $550, and wheel line is $805 per acre.

Education:

Develop educational programs that explain the sources of selenium, and illustrate the various alternative irrigation systems.

Agriculture represents a very small portion of the land use in the Santa Cruz Watershed. Based on the results of the selenium classification and ranking in Section 6, the subwatershed areas that are prioritized for educational outreach to address selenium are Guild Wash-Lower Santa Cruz River, Greene Wash-Upper Santa Cruz Wash, Lower Vekol Wash, and Lower Santa Cruz Wash.

<u>Strategy for Channel and Riparian Protection and Restoration</u>

Riparian areas are one of the most critical resources in the Santa Cruz Watershed. Healthy riparian areas stabilize stream banks, decrease channel erosion and sedimentation, remove pollutants from surface runoff, create wildlife habitat, slow flood velocities, promote aquifer recharge and provide recreational opportunities. As ground water resources are tapped for water supply, many riparian areas across the watershed are in danger of being dewatered as the water table drops below the base of the stream channel. A large portion of the riparian systems in the watershed are managed by federal agencies, principally the Bureau of Land Management and the Forest Service. In cooperation with responsible management agencies, riparian protection and restoration efforts should be implemented across the watershed.

The creation of filter strips should be considered surrounding all important water bodies and riparian systems within the three natural resource areas, including the extensive riparian forests and perennial streams of the Upper Santa Cruz River NRA, Lower Santa Cruz River NRA, and the Sonoyta-Asuncion NRA.

This will require fencing and, in many cases, providing alternative water sources for livestock and wildlife. Riparian areas have been an important source of forage for most livestock growers, but to protect these delicate ecosystems, low impact riparian grazing systems should be developed and applied where feasible.
In impaired stream reaches restoration treatments maybe necessary. Treatments may involve engineered channel re-alignment, grade control and bank stabilization structures and a variety of revegetation and other bio-engineering practices.

Additional information will need to be collected on the existing impairment of stream reaches and riparian areas to better understand which stream segments should be prioritized for restoration projects. Data needs include:

- Studying the existing stream corridor structure, function and disturbances.

- Determining the natural stream conditions before disturbance. This entails identifying a "reference site" that illustrates the potential pristine stream conditions.

- Identifying the causes for the impairment and restoration alternatives.

- Identifying stream reaches that have a high potential to successfully respond to restoration treatments.

This watershed classification is one method used to identify stream impairment and restoration alternatives, but other data needs may also include identifying important issues, examining historic conditions, evaluating present conditions and processes, and determining the effects of human activities. It can mean describing the parts and processes of the whole watershed and analyzing their functions in general or relative to some standard (such as a water quality standard or historic condition). It also can mean focusing on particular concerns about human activities, conditions or processes in the watershed.

Stream and riparian restoration projects are costly and should be viewed as a long-term endeavor. Stream and riparian restoration projects cannot be conducted in isolation from other watershed activities. If the root cause of channel and riparian impairment is due to upstream watershed conditions, onsite restoration efforts are likely to fail unless the overall watershed conditions are also improved. This requires an integrated approach that addresses the entire watershed.

Citizen groups also have a role in the restoration efforts. Volunteers can be used in the tree planting and seeding treatments, and can also be used for grade control and bank stabilization construction. Education programs, such as "Adopt A Stream", should be developed to encourage public understanding of the importance of maintaining natural riparian systems and restoration of degraded streams.

Education Programs:

The education effort will be partly conducted by the Arizona Nonpoint Education of Municipal Officials (NEMO) program. Arizona NEMO works through the University of Arizona Cooperative Extension Service, in partnership with the Arizona Department of Environmental Quality (ADEQ) Water Quality Division, and the Water Resources Research Center. The goal of Arizona NEMO is to educate land use decision-makers to take voluntary actions that will mitigate nonpoint source pollution and protect our natural resources.

Education needs:

Education programs need to be developed for land use decision makers and stakeholders that will address the various sources of water quality degradation and present management options. The key sources of concern for educational programs are:

- *Abandoned Mines* (control of runoff and sediment)

- *Grazing Management* (erosion control treatments and riparian area protection)

- *Streamside Protection* (filter strips and alternative watering facilities)

- *Riparian Management* (bank stabilization, filter strips and livestock fencing)

- *Septic Systems* (residential septic system maintenance, licensing and inspection programs)

- *Stormwater Management* (control of stormwater runoff from urbanized and developing areas)

- *Water Conservation* (for private residents and to prevent dewatering of natural stream flow and riparian areas)

Target Audiences:

The targeted audiences will include developers, private land owners and managers, livestock growers, home owners and citizen groups. Several programs, including those addressing mine reclamation, septic systems, stormwater management and water conservation, will be considered. Development of an "Adopt a Stream" Program will also be considered.

References

Arizona Department of Environmental Quality, ADEQ. 2006. Arizona's Integrated 305(b) Water Quality Assessment and 303(d) Listing Report, http://www.azdeq.gov/environ/water/assessment/download/2006/integrated.pdf

Hoffman, T.R. and G.S. Willett. 1998. The Economics of Alternative Irrigation Systems in the Kittitas Valley of Washington State. Cooperative Extension, Washington State University, pub. EB1875. http://cru84.cahe.wsu.edu/cgi-bin/pubs/EB1875.html

Data Sources*:

Arizona State Land Department, Arizona Land Resource Information System (ALRIS), http://www.land.state.az.us/alris/index.html
Land ownership. February 7, 2002.

**Note: Dates for each data set refer to when data was downloaded from the website. Metadata (information about how and when the GIS data were created) is available from the website in most cases. Metadata includes the original source of the data, when it was created, its geographic projection and scale, the name(s) of the contact person and/or organization, and general description of the data.*

Section 8: Local Watershed Planning

The first component of the watershed-based planning process is to summarize all readily available natural resource information and other data for a given watershed. As seen in Sections 2 though 5 of this document, these data are at a broad-based, large watershed scale and include information on water quality, land use and cover, natural resources and wildlife habitat.

It is anticipated that stakeholder-groups will develop their own planning documents. The stakeholder-group watershed-based plans may cover a subwatershed area within the NEMO Watershed-based Plan, or include the entire 8-digit HUC watershed area.

In addition, stakeholder-group local watershed-based plans should incorporate local knowledge and concerns gleaned from stakeholder involvement and could include:

- A description of the stakeholder / partnership process;
- A well-stated, overarching goal aimed at protecting, preserving, and restoring habitat and water quality, and encouragement of land stewardship;
- A plan to coordinate natural resource protection and planning efforts;
- A detailed and prioritized description of natural resource management objectives; and
- A detailed and prioritized discussion of best management practices, strategies and projects to be implemented by the partnership.

EPA's *2003 Guidelines for the Award of Section 319 Nonpoint Source Grants* (EPA, 2003) suggests that a watershed-based plan should include all nine elements listed in Section 1 of this document to be considered for funding. The nine planning elements help provide reasonable assurance that the nonpoint source of pollution will be managed to improve and protect water quality, and to assure that public funds to address impaired waters are used effectively.

<u>Potential Water Quality Improvement Projects</u>

GIS, hydrologic modeling and fuzzy logic were used to rank and prioritize the 10-digit HUC subwatersheds for known water quality concerns (Section 6, Watershed Classification). These rankings are used to identify where water quality improvement projects should be implemented to reduce nonpoint source pollution in the Upper Santa Cruz Watershed. This methodology ranked fifty subwatersheds for four key nonpoint source water quality concerns:

1. Metals originating from abandoned mine sites;
2. Stream sedimentation due to urbanization;
3. Organic and nutrient pollution due to land use activities; and
4. Selenium due to agricultural practices.

Table 8-1 lists the eight subwatersheds and their final weighted fuzzy membership value for each of these four constituents. Values highlighted with a shaded box indicate high risk for water quality degradation. The highest ranking value in each category is highlighted with a bold cell outline. The rankings range from a low risk of 0.0 to higher risk values approaching 1.0. See Section 6 for a full discussion on the derivation of these values.

Table 8-1. Summary of Weighted Fuzzy Membership Values for each Subwatershed

Subwatershed	FMV Weighted			
	Metals	**Sediment**	**Organics**	**Selenium**
SANTA CRUZ WATERSHED				
San Rafael Valley-Upper Santa Cruz River 1505030101	**0.85**	**0.23**	**0.40**	**0.50**
Sonoita Creek 1505030102	**0.90**	**0.47**	**0.42**	**0.50**
Potrero Creek-Upper Santa Cruz River 1505030103	**0.72**	**0.44**	**0.97**	**0.50**
Sopori Wash 1505030104	**0.72**	**0.26**	**0.19**	**0.61**
Josephine Canyon-Upper Santa Cruz River 1505030105	**0.75**	**0.55**	**0.51**	**0.53**
Demetrie Wash-Upper Santa Cruz River 1505030106	**0.75**	**0.44**	**0.60**	**0.53**
Box Canyon Wash-Upper Santa Cruz River 1505030107	**0.70**	**0.75**	**0.75**	**0.55**
Canada del Oro 1505030108	**0.80**	**0.86**	**0.85**	**0.50**
Julian Wash-Upper Santa Cruz River 1505030109	**0.65**	**0.76**	**0.85**	**0.52**
Cienega Creek 1505030201	**0.50**	**0.69**	**0.10**	**0.25**
Agua Verde Creek-Pantano Wash 1505030202	**0.75**	**0.80**	**0.97**	**0.55**
Tanque Verde Creek-Rillito River 1505030203	**0.86**	**0.88**	**0.91**	**0.60**
Guild Wash-Lower Santa Cruz River 1505030301	**0.55**	**0.56**	**0.45**	**0.75**
Lower Santa Cruz River-North Branch Santa Cruz Wash 1505030302	**0.55**	**0.49**	**0.80**	**0.75**
Greene Wash-Upper Santa Cruz Wash 1505030303	**0.50**	**0.68**	**0.75**	**0.75**
Upper Vekol Wash 1505030304	**0.21**	**0.21**	**0.25**	**0.25**
Lower Vekol Wash 1505030305	**0.38**	**0.68**	**0.75**	**0.75**
Lower Santa Cruz Wash 1505030306	**0.50**	**0.68**	**0.75**	**0.75**
Arivaca Creek 1505030401	**0.80**	**0.27**	**0.31**	**0.60**
Puertocito Wash 1505030402	**0.60**	**0.08**	**0.25**	**0.50**
Altar Wash 1505030403	**0.60**	**0.27**	**0.25**	**0.50**
Upper Brawley Wash 1505030404	**0.65**	**0.21**	**0.25**	**0.51**
Lower Brawley Wash 1505030405	**0.55**	**1.74**	**0.55**	**0.65**

Subwatershed	FMV Weighted			
	Metals	Sediment	Organics	Selenium
Los Robles Wash 1505030406	**0.37**	**0.51**	**0.55**	**0.59**
Viopuli Wash 1505030501	**0.41**	**0.03**	**0.25**	**0.45**
Upper Aguirre Wash 1505030502	**0.40**	**0.15**	**0.25**	**0.35**
Lower Aguirre Wash 1505030503	**0.55**	**0.29**	**0.29**	**0.53**
Tat Momoli Wash 1505030504	**0.31**	**0.27**	**0.25**	**0.50**
Upper Santa Rosa Wash 1505030601	**0.55**	**0.09**	**0.25**	**0.50**
Kohatk Wash 1505030602	**0.43**	**0.21**	**0.25**	**0.50**
Middle Santa Rosa Wash 1505030603	**0.55**	**0.27**	**0.25**	**0.50**
Lower Santa Rosa Wash 1505030604	**0.32**	**0.62**	**0.75**	**0.73**
RIO SONOYTA WATERSHED				
Hickiwan Wash 1508010101	**0.31**	**0.15**	**0.25**	**0.25**
Upper San Simon Wash 1508010102	**0.55**	**0.15**	**0.25**	**0.50**
Upper Vamori Wash 1508010103	**0.64**	**0.15**	**0.25**	**0.45**
Sells Wash 1508010104	**0.65**	**0.33**	**0.25**	**0.50**
Lower Vamori Wash 1508010105	**0.65**	**0.33**	**0.25**	**0.50**
Middle San Simon Wash 1508010106	**0.55**	**0.21**	**0.25**	**0.50**
Chukut Kuk Wash 1508010107	**0.49**	**0.21**	**0.25**	**0.54**
Rio San Francisquito 1508010108	**0.15**	**0.09**	**0.25**	**0.25**
Lower San Simon Wash 1508010109	**0.26**	**0.33**	**0.25**	**0.25**
Pia Oik Wash-Menagers Lake 1508010201	**0.38**	**0.09**	**0.25**	**0.28**
Sonoyta Valley Area 1508010202	**0.20**	**0.09**	**0.25**	**0.25**
Davidson Canyon 1508010203	**0.21**	**0.27**	**0.25**	**0.25**
Aguajita Wast-Rio Sonoyta 1508010204	**0.54**	**0.33**	**0.25**	**0.45**
Pinacate Valley-Las Playas 1508010301	**0.49**	**0.45**	**0.25**	**0.45**
Puente Cuates 1508010302	**0.26**	**0.63**	**0.25**	**0.25**
La Jolla Wash 1508010303	**0.25**	**0.57**	**0.25**	**0.25**
RIO ASUNCION WATERSHED				
Rio Altar Headwaters 1508020001	**0.75**	**0.03**	**0.25**	**0.50**
Rio El Sasabe Headwaters 1508020002	**0.36**	**0.09**	**0.25**	**0.28**

Based on these fuzzy membership values, the subwatershed that ranked the highest for each of the nonpoint sources was selected for an example water quality improvement project.

The example subwatershed projects that will be discussed here are:

1. Sonoita Creek Subwatershed, for metals pollution;
2. Tanque Verde Creek-Rillito River Subwatershed, for sediment pollution;
3. Potrero Creek-Upper Santa Cruz River Subwatershed and Agua Verde Creek-Pantano Wash Subwatershed, for organics pollution;

4. Guild Wash-Lower Santa Cruz River for selenium due to agricultural practices.

Example projects with best management practices to reduce metals, sediment, organic, nutrient and selenium pollution are discussed below. Management measures and their associated costs must be designed and calculated based on site-specific conditions; however, sample costs are included in Section 7.

Methods for calculating and documenting pollutant reductions for sediment, sediment-borne phosphorus and nitrogen, feedlot runoff, and commercial fertilizer, pesticides and manure utilization can be found on the NEMO web site in the Best Management Practices (BMP) Manual, under Links (www.ArizonaNEMO.org). It is expected that the local stakeholder partnership watershed-based plan will identify projects and locations important to their community, and may differ from the example project locations proposed here.

1. Sonoita Creek Subwatershed Example Project

Pollutant Type and Source:
Metal-laden sediment originating from an abandoned tailings or spoil pile at an assumed abandoned mine site within the riparian area.

The Sonoita Creek Subwatershed has the highest risk in the Santa Cruz Watershed to be impacted by metals related to abandoned mine sites (i.e. highest fuzzy membership value for metals). A project to control the movement of metal-laden sediment is recommended.

The major land owners within this subwatershed are private land owners (42%). The U.S. Forest Service (30%), State Land (24%), Indian Reservation (3%), Bureau of Land Management (1%), Military Lands (1%), National Parks Service (1%), and Parks and Recreation (0.1%) are responsible for the remainder of the watershed (Table 7-3). Projects implemented on federal or state lands must obtain the permission of the owner and must comply with all local, state and federal permits.

Load Reductions:
Calculate and document sediment delivery and pollutant reductions for sediment-borne metals using Michigan DEQ (1999) methodology (found in the NEMO BMP Manual under "Links"). Although this manual addresses sediment reduction with respect to nutrients, the methods can be applied when addressing metals. Particulate metals that generate dissolved metals in the water column and dissolved metals have a tendency to behave like nutrients in the water column.

Management Measures:
Various options are available to restore a mine site, ranging from erosion control fabrics and revegetation to the removal and relocation of the tailings material. Section 7 and Table 7-1 present these management measures along with associated load reduction potential, maintenance, and anticipated costs. It should be recognized that only after a site-specific evaluation can the best treatment option be identified and that the installation of engineered

erosion control systems and/or the relocation of the tailings will necessitate project design by a licensed engineer.

2. Tanque Verde Creek-Rillito River Subwatershed Example Project

Pollutant Type and Source: sediment pollution due to urbanization.

Tanque Verde Creek-Rillito River subwatershed of the Santa Cruz River ranked as the most critical area impacted by land use activities, and for purposes of outlining an example project it will be assumed that urbanization within the riparian area has exacerbated erosion. The land owners within this subwatershed (Table 7-3) include private lands (32%), U.S. Forest Service (29%), State Lands (22%), National Parks Service (9%), the U.S. Bureau of Land Management (7%), and Military (0.7%). The subwatershed is 16% urban and 84% rangeland (Table 4-15.1). Projects implemented on private, federal or state lands must obtain the permission of the owner and must comply with all local, state and federal permits.

Load Reductions:
The goal of this example is to reduce sediment pollution to the Tanque Verde Creek-Rillito River subwatershed. Because increased sediment load is assumed to be the result of increased urban stormwater concerns, some background information on current stormwater regulations is necessary.

The Environmental Protection Agency (EPA) has estimated that about 30 percent of known pollution to our nation's waters is attributable to stormwater runoff. In 1987, Congress directed EPA to develop a regulatory program to address the stormwater problem. EPA issued regulations in 1990 authorizing the creation of a National Pollution Discharge Elimination System (NPDES) permitting system for stormwater discharges. In Arizona, this program is called AZPDES, which stands for Arizona Pollutant Discharge Elimination System. Because stormwater runoff can transport pollutants to either a municipal storm sewer system or to a water of the United States, permits are required for those discharges.

Stormwater discharges generated during construction activities can also cause an array of physical, chemical, and biological water quality impacts. Water quality impairment occurs, in part, because a number of pollutants are preferentially absorbed onto mineral or organic particles found in fine sediment. The interconnected process of erosion (detachment of soil particles) and sediment transport during storm events results in water quality degradation. Stormwater runoff from construction sites can include pollutants other than sediment, which may become mobilized when land surfaces are disturbed. These include phosphorous, nitrogen, pesticides, petroleum derivatives, construction chemical and solid wastes.

ADEQ stormwater regulations address both small and large construction sites. Large construction activity refers to the disturbance of 5 or more acres. It also refers to the disturbance of less than 5 acres of total land area that is a part of a larger common plan of development or sale if the large common plan will ultimately disturb five acres or more (see 40 CFR 122.26(b)(14)(x)).

Small construction activity refers to the disturbance of 1 or more, but less than 5, acres of land. It also refers to the disturbance of less than 1 acre of total land area that is part of a larger common plan of development of sale if the larger common plan will ultimately disturb 1 or more, but less than 5 acres (see 40 CFR 122.26(b0(15)).

To obtain authorization for discharges of stormwater associated with construction activity, the operator must comply with all the requirements of the general permit and submit a Notice of Intent (NOI) and a Stormwater Management Plan (SWMP). More information about Arizona Stormwater Regulations and permitting can be found at http://azdeq.gov/environ.water/permits/stormwater.html.

Management Measures:
Municipal Ordinances addressing stormwater retention / detention, construction site management, housing density, drainage buffers, impermeable surfaces, and grading are the most effective management measures to address sediment pollution due to stormwater runoff. New ordinance proposals can be initiated by citizen groups within the jurisdiction of the municipality, such as the stake-holder group local watershed partnership.

Generally, properly implemented and enforced construction site ordinances effectively reduce sediment pollution. In many areas, however, the effectiveness of ordinances in reducing pollutants is limited due to inadequate information or incomplete compliance with local ordinances by construction site operators. Report of obvious construction site violations or local ordinances, for example, failure to manage site waste (messy housekeeping) and tracking of mud onto roadway can be performed by local citizens.

In addition to ordinances as a best management practices to address stormwater sediment ADEQ Stormwater Regulations require an outreach education component of the Stormwater Management Plans. Stakeholder-group local watershed partnerships can play an important role in educating the public about individual property owner responsibilities in protecting stream water quality.

3. Potrero Creek-Upper Santa Cruz River Subwatershed and Agua Verde Creek-Pantano Wash Subwatershed Example Projects

Potrero Creek-Upper Santa Cruz River Watershed Pollutant Type and Source: organic pollutants, specifically *E. coli,* assumed to originate from wildlife or cattle watering in the stream channel within Arizona, and, from stormwater runoff of wildlife, cattle and human waste in Mexico that enters Arizona through the Nogales Wash.

Potrero Creek-Upper Santa Cruz River is ranked as one of the most critical area impacted by land use activities. For purposes of outlining an example project it will be assumed that grazing within the riparian area has exacerbated erosion and introduced fecal matter into the stream. The major land owner within this subwatershed is private land owners (42%). The U.S. Forest Service (30%), State Land (24%), Indian Reservation (3%), Bureau of Land Management (1%), Military Lands (1%), National Parks Service (1%), and Parks and Recreation (0.1%) are responsible for the remainder of the watershed (Table 7-3). Projects implemented on federal or state lands must obtain the permission of the owner and must comply with all local, state and federal permits.

Load Reductions:
Prior to initiating a project to address bacteria pollution, it may benefit the watershed partnership to determine the source of bacterial contamination. Implementation of DNA fingerprinting technology will identify the actual sources of bacteria and clarify how best to target an implementation plan and project.

The field of bacteria source tracking continues to evolve rapidly and there are numerous methods available, each of which has its limitations and benefits. Despite the rapid and intensive research into existing methods, EPA recommends that bacteria source tracking "should be used by federal and state agencies to address sources of fecal pollution in water… [because it] represents the best tools available to determine pathogen TMDL load allocations and TMDL implementation plan development" (EPA, 2001).

Management Measures:
Implementing grazing management practices to improve or maintain riparian health will help reduce excess surface runoff and accelerated erosion. Management may include exclusion of the land from grazing and/or restricting access to riparian corridors by fencing, which will also reduce the introduction of fecal matter to the stream. Alternative watering facilities at a location removed from the waterbody may be necessary.

It should be recognized that a known source of pollutants originate from stormwater and enter Arizona from Mexico. Nogales, Arizona lies down gradient from Nogales, Mexico, and rainwater collects organic contaminants that flow through the Nogales Wash and into Arizona.

Table 7-2 presents load reduction potential, required maintenance, and anticipated costs associated with each project option. It should be recognized that only after a site-specific evaluation can the best treatment option be identified and that the installation of engineered erosion control systems and the installation of an alternative water source may necessitate project design by a licensed engineer.

Agua Verde Creek-Pantano Wash Subwatershed Pollutant Type and Source: E coli, low dissolved oxygen, ammonia, and pH exceedances from animals and eutrophication

For purposes of outlining an example project it will be assumed this subwatershed was ranked high due to Lakeside Lake. Lakeside Lake is a 13-acre urban impoundment along

Atterbury Wash in Tucson. Originally a storm water retention basin, the impoundment was engineered in 1985 to become a public park feature and recreational fishery.

With reclaimed nutrient levels that are orders of magnitude greater than groundwater levels, Lakeside Lake has become increasingly eutrophic over the years. These conditions have resulted in noxious algal blooms, high pH, low dissolved oxygen (DO), limited stocking, and periodic fish kills.

The major land owners within this subwatershed are private land owners (32%), the U.S. Forest Service (29%), State Land (22%), National Park Service (9%), Bureau of Land Management (7%), and Military Lands (0.7%) (Table 7-3).

Excess nutrients (nitrogen) may result in low dissolved oxygen and high pH and potentially toxic algal blooms and fish kills. High levels of ammonia may also pose a risk to aquatic life. A 2005 TMDL analyses indicated that the water sources supplying the lake were the primary source of nutrients to the lake. Lakeside Lake receives secondary-treated reclaimed effluent, ground water, Central Arizona Project (CAP) water from the Colorado River, and occasional storm water runoff from Atterbury Wash.

ADEQ is working with the city of Tucson, Pima County Wastewater Management Department, and other interested stakeholders to mitigate these problems.

Load Reductions:

By working with the Lakeside Lake TMDL Nutrients & Associated Parameters Report (ADEQ, 2005), load reductions will occur.

Management Measures:
Treatment options that were examined included:

Long-term options

- tertiary treatment of wastewater effluent
- wetlands to treat effluent
- use of well water or alternate source of water, e.g., CAP water
- treat stormwater runoff to remove settleable solids, using settling ponds
- constructed wetlands in wash using a membrane curtain designed to remove some nutrients and solids
- dredge lake every "x" number of years.

Less costly short-term options

- upgrade lake aeration system
- treat lake with alum to remove phosphorus
- treat lake with algaecides prior to bloom period (April/May)
- manage lake level, drop level during spring to minimize filamentous algae growth
- improve access (better ramp) during fish stocking to improve fish survival.

4. Guild Wash-Lower Santa Cruz River Subwatershed Example Project

Pollutant Type and Source:
Selenium pollution due to irrigation practices.

High selenium weighted fuzzy values are found in five Santa Cruz Watershed

subwatersheds. These subwatersheds are: Guild Wash-Lower Santa Cruz River, Lower Santa Cruz River-North Branch Santa Cruz Wash
Greene Wash-Upper Santa Cruz Wash, Lower Vekol Wash, Greene Wash-Upper Santa Cruz Wash, and Lower Santa Cruz Wash. While this section focuses on the Guild Wash-Lower Santa Cruz River Subwatershed, load reduction recommendations and management measures are applicable to all five subwatersheds.

The Guild Wash-Lower Santa Cruz River subwatershed of the Santa Cruz River ranked as the most critical area impacted by agricultural land use practices that exacerbate the concentration of naturally occurring selenium (i.e. Table 8-1, highest fuzzy membership values for Selenium).

For this example project it will be assumed that irrigation tail water has introduced elevated concentrations of selenium into the stream. The land owners within the Guild Wash-Lower Santa Cruz River subwatershed (Table 7-3) are primarily Private (42%), State Lands (21%), Bureau of Land Management (17%), and (16%) Indian Reservation, although the military, Parks and Recreation, and Bureau of Reclamation also hold property in the watershed. Land ownership percentages are the same for all five subwatersheds. Agriculture and rangeland are the most common land use in this subwatershed. Projects implemented on private, federal, tribal, or state lands must obtain the permission of the owner and must comply with all local, state and federal permits.

Load Reductions:
Naturally occurring selenium is concentrated in water by evaporation, and also when irrigation water leaches selenium from the soil. To calculate the load reduction resulting from implementation of a best management practice, an estimate of the reduction in volume of irrigation tail water that returns to the stream is required.

Support for calculating load reductions can be obtained from the local Agricultural Research Service or County Cooperative Extension office (http://cals.arizona.edu/extension/).

Management Measures:
Implementing agricultural irrigation practices to reduce tail water pollution will necessitate dramatic changes from the typical practice of flood irrigation. This may involve the installation of mechanized irrigation systems or on-site treatment.

As an example of a situation where drainage water must be managed, some watersheds in California have agricultural drainage water containing levels of selenium that approach the numeric criterion defining hazardous waste (above 1,000 parts per billion). This situation is being considered for permit regulation to manage drainage at the farm level (San Joaquin Valley Drainage Implementation Program, 1999).

Currently, Arizona is not considering such extreme measures, but selenium remains an important nonpoint source contaminant and a known risk to wildlife. The use of treatment technologies to reduce selenium concentrations include ion exchange, reverse osmosis, solar ponds, chemical reduction with iron, microalgal-bacterial treatment, biological precipitation, and constructed wetlands. Engineered water treatment systems, however, may be beyond the scope of a proposed best management practices project, and technologies are still in the research stage.

Section 7 briefly discusses load reduction potential, maintenance, and anticipated costs associated with the installation of mechanized irrigation systems. These types of systems allow for improved water conservation and improved management of limited water resources. It should be recognized that only after a site-specific evaluation can the best treatment option be identified and that the installation of mechanized irrigation systems involve capital expense and may necessitate project design by a licensed engineer.

Technical and Financial Assistance

Stakeholder-group local watershed-based plans should identify specific projects important to their partnership, and during the planning process should estimate the amounts of technical and financial assistance needed, associated costs, and/or the sources and authorities that will be relied upon to implement the plan. Technical support sources include NEMO, University of Arizona Cooperative Extension, government agencies, engineering contractors, volunteers, and other environmental professionals. Funding sources may include:

- Clean Water Act Section 319(h) funds;
- State revolving funds though the Arizona Department of Environmental Quality;
- Central Hazardous Materials Fund;
- USDA Environmental Quality Incentives Program and Conservation Security Program;
- Arizona Water Protection Fund through the Arizona Department of Water Resources;
- Water Infrastructure Finance Authority;
- Arizona Heritage Fund though Arizona State Parks and Arizona Game and Fish; and
- Private donations or non-profit organization donations.

In addition to the extensive listing of funding and grant sources on the NEMO web site (www.ArizonaNEMO.org), searchable grant funding databases can be found at the EPA grant opportunity web site www.grants.gov or www.epa.gov/owow/funding.html.

In Arizona, Clean Water Act Section 319(h) funds are managed by ADEQ and the funding cycle and grant application data can be found at: http://www.azdeq.gov/environ/water/watershed/fin.html

The Arizona legislature allocates funding to the Arizona Water Protection Fund. In addition, the fund is supplemented by income generated by water-banking agreements with the Central Arizona Project. Information can be found at http://www.awpf.state.az.us/

Most grants require matching funds in dollars or in-kind services. In-kind services may include volunteer labor, access to equipment and facilities, and a reduction on fee schedules / rates for subcontracted tasks. Grant matching and cost share strategies allow for creative management of limited financial resources to fund a project.

Education and Outreach

An information/education component is an important aspect of the Stakeholder-group local watershed-based plan that will be used to enhance public understanding of the project and encourage early and continued participation in selecting, designing and implementing management measures.
The Friends of the Santa Cruz River and the Friends of Sonoita Creek are two established stakeholder group that meet on a regular basis to plan water quality improvement projects and strategize funding opportunities. Education outreach is a regular part of their monthly meetings with their agenda usually including reports on the status of grant-funded projects. Arizona NEMO hosts a webpage for the groups at http://www.srnr.arizona.edu/nemo/index.php?page=groups.

The NEMO program offers each watershed partnership the opportunity to post information, fact sheets and status reports on the NEMO web site, and to announce important events on the NEMO calendar (www.ArizonaNEMO.org). In addition, a partnership can obtain guidance and technical support in designing an outreach program through the University of Arizona Cooperative Extension.

Implementation Schedules & Milestones

Necessary to the watershed planning process is a schedule for project selection, design, funding, implementation, reporting, operation and maintenance, and project closure. In the Santa Cruz Watershed, 10-digit HUC subwatershed areas have been prioritized in this plan for potential water quality improvement projects, but other locations across the watershed may hold greater interest by the stakeholders for project implementation. Private land owners, or partnerships of stakeholders, may propose discreet projects to respond to immediate water quality concerns, such as stream bank erosion exacerbated by a recent flooding event.

After project selection, implementation may be dependent on the availability of funds, and because of this most watershed partnerships find themselves planning around grant cycles. Table 8-2 depicts the planning process, and suggests that the stakeholder group may want to revisit the listing and ranking of proposed projects on a regular basis, giving the group the opportunity to address changing conditions.

As shown in the table, a ‘short’ one-year project actually may take as many as three years from conception, to implementation, and ultimate project closure. With the number of grants currently available in Arizona for water quality improvement projects, the watershed partnership may find themselves in a continual cycle of grant writing and project reporting, overlapping and managing several aspects of several projects simultaneously.

Table 8-2: Example Watershed Project Planning Schedule.

Watershed Project Planning Steps	Year				
	1	2	3	4	5
Stakeholder-Group 319 Plan Development	X				
Identify and rank priority projects	X				
Grant Cycle Year 1: Select Project(s)	X				
Project(s) Design, Mobilization, and Implementation	X	X			
Project(s) Reporting and Outreach		X			
Project(s) Operation and Maintenance, Closure		X	X		
Grant Cycle Year 2: Select Project(s)		X			
Project(s) Design, Mobilization, and Implementation		X	X		
Project(s) Reporting and Outreach			X		
Project(s) Operation and Maintenance, Closure			X	X	
Revisit Plan, Identify and re-rank priority projects			X		
Grant Cycle Year 3: Select Project(s)			X		
Project(s) Design, Mobilization, and Implementation			X	X	
Project(s) Reporting and Outreach				X	
Project(s) Operation and Maintenance, Closure				X	X

Most funding agencies operate on a reimbursement basis and will require reporting of project progress and reimbursement on a percent completion basis. In addition, the individual project schedule should be tied to important measurable milestones which should include both project implementation milestones and pollutant load reduction milestones. Implementation milestones may include interim tasks, such as shown in Table 8-3, and can be tied to grant funding-source reporting requirements.

Based on funding availability, the activities outlined in Table 8-3 could be broken down into three separate projects based on location (Stream Channel, Stream Bank or Flood Plain), or organized into activity-based projects (Wildcat Dump Cleanup, Engineered Culverts, etc).

Table 8-3: Example Project Schedule

Management Measures and Implementation Schedule Streambank Stabilization and Estimated Load Reduction					
			Water Quality Milestone Target Load Reduction: 100% Hazardous Materials 75% Sediment Load		
Milestone	**Date**	**Implementation Milestone**	**Area 1 Stream Channel**	**Area 2 Stream Bank**	**Area 3 Flood Plain**
Task 1: **Contract Administration**	**04/01/05 Thru 09/31/06**	**Contract signed Quarterly reports Final report**			
Task 2: **Wildcat Dump Clean-up**	**04/01/05 Thru 07/05/05**	**Select & Advertise Clean-up date** **Schedule Containers and removal**	**Remove hazardous materials from stream channel** **100% hazardous material removal**	**Remove tires and vehicle bodies from streambank** **100% hazardous material removal**	
Task 3: **Engineering Design**	**04/01/05 Thru 08/15/05**	**Conceptual design, select final design based on 75% load reduction**		**Gabions, culverts, calculate estimated load reduction**	**Re-contour, regrade, berms, water bars, gully plugs: calculate estimated load reduction.**
Task 4: **Permits**	**04/01/05 Thru 09/01/05**	**Confirm permit requirements and apply for necessary permits**	**US Army Corps of Engineers may require permits to conduct projects within the stream channel**	**Local government ordinances as well as the US Army Corps and State Historical Preservation permits may be needed.**	**In addition to local and State permits, the presence of listed or Endangered Species will require special permitting and reporting.**
Task 5: **Monitoring**	**07/05/05 thru 10/31/06**	**Establish photo points and water quality sample locations**	**Turbidity sampling, baseline and quarterly, compare to anticipated 75% Sediment load reduction**	**Photo points, baseline and quarterly, Calculate Sediment load reduction**	**Photo points, baseline and quarterly, Calculate Sediment load reduction**
Task 6: **Revegetation**	**08/15/05 thru 09/15/05**	**Survey and select appropriate vegetation**			**Willows, native grasses, cotton wood, mulch**
Task 7: **Mobilization**	**09/01/05 thru 10/31/05**	**Purchase, delivery and installation of engineered structures and revegetation material**		**Install gabions, resized culverts / professional and volunteer labor**	**Regrade, plant vegetation with protective wire screens around trees / install gully plugs and water bars, volunteer labor**

Milestone	Date	Implementation Milestone	Water Quality Milestone Target Load Reduction: 100% Hazardous Materials 75% Sediment Load Area 1 Stream Channel	Area 2 Stream Bank	Area 3 Flood Plain
Task 8: **Outreach**	**04/01/05 thru 10/31/06**	**Publication of news articles, posters, monthly reports during stakeholder-group local watershed meetings**			
Task 9: **Operation and Maintenance**	**09/01/05 thru 10/31/06**	**Documentation of routine operation and maintenance in project quarterly reports during contract period, continued internal record keeping after contract / project closure**		**Maintenance and routine repair of engineered structures**	**Maintenance / irrigation of new plantings until established, removal of weeds and invasive species**

Evaluation

The evaluation section of a watershed plan will provide a set of criteria that can be used to determine whether progress towards individual project goals is being achieved and/or the effectiveness of implementation is meeting expectations. These criteria will help define the course of action as milestones and monitoring activities are being reviewed.

The estimate of the load reductions expected for each of the management measures or best management practices to be implemented is an excellent criterion against which progress can be measured. Prior to project implementation, baselines should be established to track water quality improvements, and standard measurement protocols should be established so as to assure measurement methodology does not change during the life of the project.

To evaluate the example project outlined in Table 8-3, the following key evaluation attributes must be met:

- Schedule and timeliness: Grant applications, invoices and quarterly reports must be submitted to the funding source when due or risk cancellation of contracts. If permits are not obtained prior to project mobilization, the project crew may be subject to penalties or fines.

- Compliance with standards: Engineered designs must meet the standards of the Engineering Board of Licensing; water quality analytical work must be in compliance with State of Arizona

Laboratory Certification. Excellent evaluation criteria would include engineer-stamped 'as-built' construction diagrams and documentation of laboratory certification, for example. Methods for estimating load reduction must be consistent with established methodology, and the means by which load reductions are calculated throughout the life of the plan must be maintained.

- Consistency of measurement: The plan should identify what is being measured, the units of measurement, and the standard protocol for obtaining measurements. For example, turbidity can be measured in 'Nephlometric Units' or more qualitatively with a Siche disk. Water volume can be measured as Acre/feet, gallons, or cubic feet. Failure to train project staff to perform field activities consistently and to use comparable units of measure can result in project failure.

- Documentation and reporting: Field note books, spread sheets, and data reporting methodology must remain consistent throughout the project. Photo point locations must be permanently marked so as to assure changes identified over the life of the project are comparable. If the frequency of data collection changes or the methodology of reporting changes in the midst of the project, the project and overall plan looses credibility.

The project is a near success if the reports are on time, the engineered structures do not fail, data are reported accurately, and an independent person reviewing your project a year after project closure understands what was accomplished. The project is a full success if water quality improvement and load reductions have been made.

The criteria for determining whether the overall watershed plan needs to be revised are an appropriate function of the evaluation section as well. For example, successful implementation of a culvert redesign may reduce the urgency of a stream bank stabilization project downstream from the culvert, allowing for reprioritization of projects.

It is necessary to evaluate the progress of the overall watershed plan to determine effectiveness, project suitability, or the need to revise goals, BMPs or management measures. The criteria used to determine whether there has been success, failure or progress will also determine if objectives, strategies or plan activities need to be revised, as well as the watershed-based plan itself.

<u>Monitoring</u>

Monitoring of watershed management activities is intrinsically linked to the evaluation performed within the watershed because both track effectiveness. While monitoring evaluates the effectiveness of implementation measures over time, the criteria used to judge success/failure/progress is part of the Evaluation process.

Watershed monitoring will include the water quality data reported in Arizona's Integrated 305(b) Water Quality Assessment and 303(d) Listing Report, Santa Cruz Assessment (ADEQ, 2005), but the overall stakeholder group watershed plan will identify additional data collection activities that are tied to stakeholder concerns and goals.

For the Santa Cruz Watershed, Sonoita Creek, Tanque Verde creek-Rillito River, Potrero Creek-Upper Santa Cruz River, Agua Verde Creek-Pantano Wash, Guild Wash-Lower Santa Cruz River, Lower Santa Cruz River-North Branch Santa Cruz Wash, Greene Wash-Upper Santa Cruz Wash, Lower Veko Wash, and Lower Santa Cruz Wash subwatersheds are identified as vulnerable to water quality impairment due to metals, sediment, organics and nutrients, and selenium. Monitoring of stream reaches for these constituents require standard water sample collection methodology and sample analysis by a certified laboratory. If routine monitoring of these reaches is to be conducted, sample collection and analysis must be consistent with data collection by the ADEQ to support the (305) b Assessment Report.

Following the example of the project outlined in Table 8-3, other water quality and watershed health constituents to be monitored include:

- Turbidity. Measuring stream turbidity before, during and after project implementation will allow for quantification of load reduction.

- Stream flow and volume, presence or absence of flow in a wash following precipitation. Monitoring of these attributes is important especially after stream channel hydromodification.

- Presence / absence of waste material. This can be monitored with photo-points.

- Riparian health, based on diversity of vegetation and wildlife. Monitoring can include photo-points, wildlife surveys and plant mapping.

The monitoring section will determine if the partnership's watershed strategies/management plan is successful, and/or the need to revise implementation strategies, milestones or schedule. It is necessary to evaluate the progress of the plan to determine effectiveness, unsuitability, or need to revise goals or BMPs.

Water quality monitoring for chemical constituents that may expose the sampler to hazardous conditions will require appropriate health and safety training and the development of a Quality Assurance Project Plan (QAPP). Monitoring for metals derived from abandoned mine sites, pollutants due to organics, nutrients derived from land use, and selenium will require specialized sample collection and preservation techniques, in addition to laboratory analysis. Monitoring for sediment load reduction may be implemented in the field without extensive protocol development.

Resources to design a project monitoring program can be found at the EPA water quality and assessment web site: www.epa.gov/owow/monitoring/ as well as through the Master Watershed Steward Program available through the local county office of University of Arizona Cooperative Extension. In addition, ADEQ will provide assistance in reviewing a QAPP and monitoring program.

<u>Conclusions</u>

This watershed-based plan ranked or classified five, non-urban 10-digit HUC subwatersheds within the Santa Cruz Watershed for vulnerability to water quality degradation from nonpoint source pollutants (Section 6 and Table 8-1). This ranking was based on Arizona's Integrated 305(b) Water Quality Assessment and 303(d) Listing Report, for the Santa Cruz Watershed (ADEQ, 2005).

In addition to the subwatershed classifications, this plan contains information on the natural resources and socio-economic characteristics of the watershed (Sections 2 through 5). Based on the results of the Classification in Section 6, example best management practices and water quality improvement projects to reduce nonpoint source pollutants are also provided (Section 7).

The subwatershed rankings were determined for the four major constituent groups (metals, sediment, organics and selenium) using fuzzy logic (see Section 6 for more information on this methodology and the classification procedure). The final results are summarized in this section and are shown in Table 8-1. In addition, technical and financial assistance to implement the stakeholder-group local watershed-based plans are outlined in this section.

Of the fifty subwatersheds included in this assessment, the ten watersheds with the highest risk of water quality degradation are:

1. Sonoita Creek Subwatershed, for metals pollution;
2. Tanque Verde creek-Rillito River Subwatershed, for sediment pollution;
3. Potrero Creek-Upper Santa Cruz River Subwatershed, for organics pollution;
4. Agua Verde Creek-Pantano Wash Subwatershed for organics pollution;
5. Guild Wash-Lower Santa Cruz River Subwatershed for selenium due to agricultural practices.
6. Greene Wash-Upper Santa Cruz Wash Subwatershed for selenium due to agricultural practices.
7. Lower Veko Wash Subwatershed for selenium due to agricultural practices.
8. Lower Santa Cruz Wash Subwatershed for selenium due to agricultural practices.
9. Lower Santa Cruz River-North Branch Santa Cruz Wash for selenium due to agricultural practices.

This NEMO Watershed-Based Plan is consistent with EPA guidelines for CWA Section 319 Nonpoint Source Grant funding. The nine planning elements required to be eligible for 319 grant funding are discussed, including education and outreach, project scheduling and implementation, project evaluation, and monitoring.

Some basic elements are common to almost all forms of planning: data gathering, data analysis, project identification, implementation and monitoring. It is expected that local stakeholder groups and communities will identify specific projects important to their partnership, and will rely on the NEMO Plan in developing their own plans.

References:

EPA (U.S. Environmental Protection Agency). January 2001. Protocol for Developing Pathogen TMDLs, First Edition. United States Environmental Protection Agency, Office of Water, Washington DC. EPA 841-R-00-002.

ADEQ, Arizona Department of Environmental Quality. 2007. Arizona's Integrated 305(b) Water Quality Assessment and 303(d) Listing Report, Santa Cruz Watershed Assessment. http://www.azdeq.gov/environ/water/assessment/download/303-04/vd.pdf

ADEQ, Arizona Department of Environmental Quality. 2005. Lakeside Lake TMDL Nutrients & Associated Parameters, Open File Report 05-03. http://www.azdeq.gov/environ/water/assessment/download/lakeside.pdf

EPA (U.S. Environmental Protection Agency). 2003. Clean Water Act Section 319, Nonpoint Source Program and Grants Guidelines for States and Territories. http://www.epa.gov/owow/nps/Section319/319guide03.html

Michigan Department of Environmental Quality (Michigan DEQ). 1999. Pollutants Controlled Calculation and Documentation for Section 319 Watersheds Training Manual. Surface Water Quality Division, Nonpoint Source Unit. http://www.deq.state.mi.us/documents/deq-swq-nps-POLCNTRL.pdf

San Joaquin Valley Drainage Implementation Program. February 1999. Drainage Water Treatment Final Report. Drainage Water Treatment Technical Committee. Sacramento, California. http://wwwdpla.water.ca.gov/agriculture/drainage

Section 9: Summary of EPA's 9 Key Elements for Section 319 Funding

Introduction

All projects that apply for Section 319 funding under the Clean Water Act and administered through the Arizona Department of Environmental Quality must include nine key elements in their watershed-based plans. These elements are listed in Section 1 of this Watershed-Based Management Plan and are also discussed in the Nonpoint Source Guidance Document by the US EPA (http://www.epa.gov/owow/nps/319/index.html).

The nine key elements are described below and the corresponding sections of this NEMO Watershed-Based Management Plan are noted. Information and data to support this requirement can be found in these sections of this Plan.

Element 1: Causes and Sources.
NEMO Sections 6 and 7

The watershed-based plan must identify the sources that will need to be controlled to achieve load reductions established in the nonpoint source TMDL.

In addition, pollutants of concern must be identified, and the causes and sources (primary and secondary) of waterbody impairment (physical, chemical, and biological, both point and non-point sources) must be linked to each pollutant of concern.

Section 6 of the NEMO Watershed-based management plan prioritizes the subwatersheds for risk of impairment due to metals, sediment, organics and selenium nonpoint source pollution. In addition, the potential causes for each constituent are described so that the watershed group can begin identifying the source of the risk.

Section 7 of the NEMO plan discusses existing TMDLs in the watershed that identify known sources of waterbody impairment.

Element 2: Expected Load Reductions.
Not included in NEMO Plan

The plan must contain an overview of TMDL load reductions expected for each Best Management Practice, linked to an identifiable source (only required for sediment (tons/yr), nitrogen or phosphorus (lbs/yr)).

Element 3: Management Measures.
NEMO Sections 7 and 8

The plan must contain a description of the nonpoint source Best Management Practices or management measures and associated costs needed to achieve load reductions for the critical areas identified in which the measures will need to be implemented to achieve the nonpoint source TMDL.

Section 7 of the NEMO plan describes a variety of nonpoint source BMPs that may be applied for load reduction and management of metals, sediment, organics and selenium pollution.

Section 8 includes an example water quality improvement project for each of the four constituents (metals, sediment, organics and selenium) with specific example management measures.

Element 4: Technical and Financial Assistance.
NEMO Sections 7 and 8, and NEMO website www.ArizonaNEMO.org

The plan must include an estimate of the technical and financial assistance needed, including associated costs, and funding strategy (funding sources), and authorities the state anticipates having to rely on to implement the plan.

Section 7 includes several tables that include various management measures and their relative costs, life expectancy and load reduction potential.

Section 8 includes a list of possible funding sources and links for water quality improvement projects. In addition, the NEMO website (www.ArizonaNEMO.org) has an extensive list of links to a wide variety of funding sources.

Element 5: Information / Education Component.
NEMO Section 8

This is the information/education component intended to enhance public understanding and participation in selecting, designing, and implementing the nonpoint source management measures, including the outreach strategy with long and short term goals, and funding strategy.

Section 8 lists local resources that may be valuable in education and outreach to the local community or other targeted audiences. In addition, examples of local educational outreach projects are presented.

Element 6: Schedule.
NEMO Section 8

The plan must include a schedule for implementing, operating and maintaining the nonpoint source Best Management Practices identified in the plan.

Section 8 describes the importance of schedules in a water quality improvement project and presents an example schedule.

Element 7: Measurable Milestones.
NEMO Section 8

The plan must include a schedule of interim, measurable milestones for determining whether nonpoint source Best Management Practices or other control actions are being implemented and water quality improvements are occurring.

Section 8 describes some measurable milestones and presents an example schedule that includes milestones.

Element 8: Evaluation of Progress.
NEMO Section 8

The plan must contain a set of criteria used to determine whether load reductions are being achieved and substantial progress is being made towards attaining water quality standards, including criteria for determining whether the plan needs to be revised or if the Total Maximum Daily Load (TMDL) needs to be revised.

Section 8 describes how to evaluate the progress and success of a water quality improvement project and describes the key attributes that must be met for a successful project.

Element 9: Effectiveness Monitoring. Section 8

The plan must include a monitoring plan to evaluate the effectiveness of implementation efforts over time, measured against the set of criteria established in the Evaluation of Progress element (8).

Section 8 discusses the importance of project monitoring, and presents several example water quality and health constituents that should be monitored.

Conclusions

The NEMO Watershed based plans are structured to be a watershed wide, broad evaluation of the nine key elements. The community watershed groups, as they apply for 319 Grant Funds to implement projects, will need to readdress each of these 9 key elements for their specific watershed project.

Table 1: Subwatershed Classification for Risk of Impairment, Santa Cruz Watershed.

Arizona's Integrated 305(b) Assessment and 303(d) Listing Report (ADEQ, 2007) includes water quality data and assessments of water quality in several surface waterbodies across the Santa Cruz Watershed. This table summarizes the surface waterbody data used to assess the risk of impairment for each 10-digit HUC subwatershed; some HUCs may have more than one surface waterbody assessed within the watershed, some have none. Some surface water bodies are present in more than one 10-digit HUC. The table includes the ADEQ water quality data (sampling and assessment status) and the NEMO risk classification assigned to individual surface waterbodies within each subwatershed. It also includes the NEMO risk classification for each subwatershed, which is determined by the highest risk level of the surface waterbodies within that subwatershed.

The four levels of NEMO risk classification are defined in Section 6: extreme; high; moderate; and low. This table is organized to determine the relative risk of nonpoint source water quality degradation due to metals, sediment, organics and selenium for each 10-digit HUC subwatershed based on existing ADEQ water quality data. See the footnotes at the end of the table for more information and definitions of abbreviations, and Section 6 for the NEMO ranking values assigned to each risk classification.

<table>
<tr><td colspan="3">Subwatershed</td></tr>
<tr><td colspan="3">San Rafael Valley-Upper Santa Cruz River
HUC 1505030101
Combined Classification for Risk of Impairment:
• Metals: Extreme due to mercury in fish tissue at Parker Canyon Lake
• Sediment: Moderate due to insufficient data.
• Organics: High due to exceedances in dissolved oxygen.
• Selenium: Moderate due to insufficient data.</td></tr>
<tr><td>Surface Waterbody</td><td colspan="2">Water Quality Data:
Sampling and Assessment Status[1,2,3]</td></tr>
<tr><td>Parker Canyon Creek
From Parker Canyon Dam to tributary at 312417/1102844

ADEQ ID: 15050301-234A

One sampling site at this surface waterbody.</td><td>Sampling</td><td>• Metals: (d&t 1): Antimony, arsenic, beryllium, boron, cadmium, chromium, copper, lead, manganese, mercury, zinc.
fluoride (1).
• Sediment: total dissolved solids (2), suspended sediment concentration (2), turbidity (2).
• Organics: Ammonia, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen (1);
dissolved oxygen and pH (2); E. coli (2).
• Selenium: selenium</td></tr>
</table>

	Status	Parameters exceeding standards: dissolved oxygen due to low flow conditions and groundwater upwelling. Currently assessed as Category 3, "Inconclusive", due to insufficient data and missing core parameters. Surface Waterbody risk classification: • **Metals:** Moderate due to insufficient data. • **Sediment:** Moderate due to insufficient data. • **Organics:** High due to exceedances and insufficient data. • **Selenium:** Moderate due to insufficient data.
Santa Cruz River From headwaters to Mexico Border ADEQ ID: 15050301-268 One sampling site at this surface waterbody.	Sampling	• **Metals:** (d&t 4): Antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, nickel, silver, thallium, zinc; (t4): Boron, manganese, mercury. fluoride (4). • **Sediment:** total dissolved solids (4), turbidity (4). • **Organics:** Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen (4); *E. coli* (3). • **Selenium:** none
	Status	Parameters exceeding standards: none. Currently assessed as Category 1, "Attaining all uses". Surface Waterbody risk classification: • **Metals:** Low. • **Sediment:** Low. • **Organics:** Low. • **Selenium:** Low.
Parker Canyon Lake ADEQ ID: 15050301-1040 Two sampling sites at this surface waterbody. EPA listed mercury in 2004 due to fish consumption advisory.	Sampling	• **Metals:** (d&t 6-7): Cadmium, chromium, lead, nickel, zinc. (t7) and (d1): Antimony, arsenic, barium, beryllium, boron, copper, manganese, mercury; fluoride (7). • **Sediment:** total dissolved solids (3), turbidity (7). • **Organics:** Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen (6-7); *E. coli* (3). • **Selenium:** none

	Status	Parameters exceeding standards: dissolved oxygen Currently assessed as Category 2, "Attaining some uses", due to insufficient data (dissolved copper) and missing core parameters. EPA assessed as Category 5, "Impaired" due to mercury in fish tissue. Surface Waterbody risk classification: • **Metals:** Extreme due to insufficient data and mercury in fish tissue. • **Sediment:** Low. • **Organics:** Moderate due to insufficient data. • **Selenium:** Moderate due to insufficient data.

Subwatershed

Sonoita Creek
HUC 1505030102

Combined Classification for Risk of Impairment:

- **Metals:** Extreme due to exceedances at almost all water bodies.
- **Sediment:** Moderate due to insufficient data.
- **Organics:** Extreme due to exceedances.
- **Selenium:** Moderate due to insufficient data.

Surface Waterbody	Water Quality Data: Sampling and Assessment Status[1,2,3]	
Sonoita Creek From 750 feet below Patagonia WWTP discharge to Santa Cruz River ADEQ ID: 15050301-013C One sampling sites at this surface waterbody. Added zinc to 303(d) list in 2004. Moved low DO from 4B back to 5.	Sampling	• **Metals:** (d&t 4-5): Antimony, arsenic, barium, beryllium, boron, cadmium, chromium, copper, lead, nickel, silver, thallium, zinc; (t4) and (d0-1): Boron, manganese, mercury; fluoride (5). • **Sediment:** total dissolved solids (6), turbidity (6), suspended sediment concentration (1). • **Organics:** Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen (5); *E. coli* (6). • **Selenium:** selenium
	Status	Parameters exceeding standards: zinc Currently assessed as Category 5, "Impaired" due to zinc exceedances and low dissolved oxygen. Surface Waterbody risk classification: • **Metals:** Extreme due to exceedances. • **Sediment:** Low. • **Organics:** Extreme due to low DO. • **Selenium:** Moderate due to insufficient data.

Harshaw Creek, From headwaters to Sonoita Creek ADEQ ID: 15050301-025 No sampling sites at this surface waterbody. TMDL completed in 2003 for copper and pH.	Sampling	No current data.
	Status	Parameters exceeding standards: unknown. Currently assessed as Category 4A, Not attaining, “Impaired” due to past copper and pH exceedances; insufficient data and missing core parameters. Surface Waterbody risk classification: • **Metals:** Extreme due to past exceedances. • **Sediment:** Moderate due to insufficient data. • **Organics:** Extreme due to past pH exceedances due to acid mine drainage. Organics ranked “low”. • **Selenium:** Moderate due to insufficient data.
Humbolt Canyon From headwaters to Alum Gulch ADEQ ID: 15050301-340 No sampling sites at this surface waterbody. Copper loading was assigned to this reach during the Alum Gulch TMDL.	Sampling	No current data.
	Status	Parameters exceeding standards: unknown. Currently assessed as Category 4A, Not attaining, “Impaired”, due to past copper exceedances; insufficient data and missing core parameters. Surface Waterbody risk classification: • **Metals:** Extreme due to past exceedances. • **Sediment:** Moderate due to insufficient data. • **Organics:** Moderate due to insufficient data. • **Selenium:** Moderate due to insufficient data.
Three R Canyon From headwaters to 312835/1104619 (latitude/longitude where intermittent flow begins) ADEQ ID: 15050301-558A No sampling sites at this surface waterbody. TMDL completed in 2003.	Sampling	No current data.
	Status	Parameters exceeding standards: cadmium, copper, zinc and pH. Currently assessed as Category 4A, Not attaining, “Impaired”, due to past cadmium, copper, zinc and pH exceedances; insufficient data and missing core parameters. Surface Waterbody risk classification: • **Metals:** Extreme due to past exceedances. • **Sediment:** Moderate due to insufficient data. • **Organics:** Extreme due to past pH exceedances due to acid mine drainage. Organics ranked “low”. • **Selenium:** Moderate due to insufficient data.

Three R Canyon From 312835/1104619 to 312827/1104712 (intermittent flow) ADEQ ID: 15050301-558B One sampling sites at this surface waterbody. TMDL completed in 2003.	Sampling	• **Metals:** (t1) and (d1): beryllium, cadmium, copper, zinc. • **Sediment:** none. • **Organics:** pH (1). • **Selenium:** none.
	Status	Parameters exceeding standards: cadmium, copper, zinc and pH. Currently assessed as Category 4A, Not attaining, “Impaired”, due to past cadmium, copper, zinc and pH exceedances; insufficient data and missing core parameters. Surface Waterbody risk classification: • **Metals:** Extreme due to exceedances. • **Sediment:** Moderate due to insufficient data. • **Organics:** Extreme due to past pH exceedances due to acid mine drainage. Organics ranked “low”. • **Selenium:** Moderate due to insufficient data.
Three R Canyon From 312827/1104712 to Sonoita Creek (ephemeral segment ADEQ ID: 15050301-558C No sampling sites at this surface waterbody. TMDL completed in 2003.	Sampling	• **Metals:** none. • **Sediment:** none. • **Organics:** none. • **Selenium:** none.
	Status	Parameters exceeding standards: cadmium, copper, zinc and pH. Currently assessed as Category 4A, Not attaining, “Impaired”, due to past cadmium, copper, zinc and pH exceedances; insufficient data and missing core parameters. Surface Waterbody risk classification: • **Metals:** Extreme due to past exceedances. • **Sediment:** Moderate due to insufficient data. • **Organics:** Extreme due to past pH exceedances due to acid mine drainage. Organics ranked “low”. • **Selenium:** Moderate due to insufficient data.
Cox Gulch From headwaters to Three R Canyon ADEQ ID: 15050301-560 One sampling site at this surface	Sampling	• **Metals:** (t1) and (d1): beryllium, cadmium, copper, zinc. • **Sediment:** none. • **Organics:** pH (1). • **Selenium:** none.

waterbody. Samples in this reach were collected in support of the Three R Creek TMDL completed in 2003.	Status	Parameters exceeding standards: cadmium, copper (dissolved), lead, zinc (dissolved and total), pH. Currently assessed as Category 4A, Not attaining, “Impaired” due to cadmium, copper, zinc and pH exceedances; missing core parameters. Surface Waterbody risk classification: • **Metals:** Extreme due to exceedances. • **Sediment:** Moderate due to insufficient data. • **Organics:** Extreme due to past pH exceedances due to acid mine drainage. Organics ranked “low”. • **Selenium:** Moderate due to insufficient data.
Alum Gulch From headwaters to 312820/1104351 (to beginning of intermittent flow) ADEQ ID: 15050301-561A Two sampling sites at this surface waterbody. TMDL completed in 2003.	Sampling	• **Metals:** (t1) and (d2): Cadmium, copper, zinc. (d1): Barium, beryllium, boron, chromium, lead, manganese, nickel, silver. • **Organics:** dissolved oxygen and pH (2).
	Status	Parameters exceeding standards: cadmium, copper (dissolved), lead, zinc (dissolved and total), pH. Currently assessed as Category 4A, Not attaining, “Impaired”, due to cadmium, copper, zinc and pH exceedances. Surface Waterbody risk classification: • **Metals:** Extreme due to exceedances. • **Sediment:** Moderate due to insufficient data. • **Organics:** Extreme due to pH exceedances due to acid mine drainage. Organics ranked “low”. • **Selenium:** Moderate due to insufficient data.
Alum Gulch From 312820 /1104351to 312917/1104425 (intermittent flow) ADEQ ID: 15050301-561B	Sampling	• **Metals:** (t1) and (d1): Cadmium, copper, zinc. • **Sediment:** none • **Organics:** (1) dissolved oxygen and pH. • **Selenium:** none

One sampling site at this surface waterbody. TMDL completed in 2003.	Status	Parameters exceeding standards: cadmium, copper, zinc, pH. Currently assessed as Category 4A, Not attaining, “Impaired”, due to cadmium, copper, zinc and pH exceedances. Surface Waterbody risk classification: • **Metals:** Extreme due to exceedances. • **Sediment:** Moderate due to insufficient data. • **Organics:** Extreme due to pH exceedances due to acid mine drainage. Organics ranked “low”. • **Selenium:** Moderate due to insufficient data.
Redrock Canyon From headwaters to Harshaw Creek ADEQ ID: 15050301-576 One sampling site at this surface waterbody.	Sampling	• **Metals:** (t&d 4-5): Antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, nickel, silver, thallium, zinc; (t4): Boron, manganese; (4 total metals only): Mercury; fluoride (4). • **Sediment:** total dissolved solids (4), turbidity (4). • **Organics:** Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen (4); *E. coli (*4). • **Selenium:** selenium
	Status	Parameters exceeding standards: dissolved oxygen, naturally occurring due to low flows and ground water upwelling. Currently assessed as Category 1, “Attaining all uses”. Surface Waterbody risk classification: • **Metals:** Low. • **Sediment:** Low. • **Organics:** Low. • **Selenium:** Low.
Big Casa Blanca Canyon From headwaters to Sonoita Creek ADEQ ID: 15050301-606 Two sampling sites at this surface waterbody.	Sampling	• **Metals:** (t2): Arsenic, barium, beryllium, cadmium, chromium, copper, manganese, nickel, silver, zinc. • Sediment: none • Organics: none • Selenium: none

	Status	Parameters exceeding standards: none Currently assessed as Category 3, “Inconclusive” due to insufficient data and missing core parameters. Surface Waterbody risk classification: • **Metals:** Moderate due to insufficient data. • **Sediment:** Moderate due to insufficient data. • **Organics:** Moderate due to insufficient data. • **Selenium:** Moderate due to insufficient data.
Unnamed Tributary to Harshaw Creek (Endless Chain Mine Tributary) ADEQ ID: 15050301-888 No sampling sites at this surface waterbody. Samples were collected in this reach support of the Harshaw Creek TMDL completed in 2003 for copper and pH.	Sampling	No current data.
	Status	Parameters exceeding standards: unknown. Currently assessed as Category 4A, Not attaining, “Impaired”, due to past copper and pH exceedances; insufficient data and missing all core parameters. Surface Waterbody risk classification: • **Metals:** Extreme due to past exceedances. • **Sediment:** Moderate due to insufficient data. • **Organics:** Extreme due to past pH exceedances due to acid mine drainage. Organics ranked “low”. • **Selenium:** Moderate due to insufficient data.
Unnamed Tributary to Three R Canyon ADEQ ID: 15050301-889 No sampling sites at this surface waterbody. TMDL completed in 2003.	Sampling	No current data.
	Status	Parameters exceeding standards: cadmium, copper, zinc and pH. Currently assessed as Category 4A, Not attaining, “Impaired”, due to past cadmium, copper, zinc and pH exceedances; insufficient data and missing all core parameters. Surface Waterbody risk classification: • **Metals:** Extreme due to past exceedances. • **Sediment:** Moderate due to insufficient data. • **Organics:** Extreme due to pH exceedances due to acid mine drainage. Organics ranked “low”. • **Selenium:** Moderate due to insufficient data.
Unnamed Tributary to Cox Gulch, From headwaters to Cox Gulch	Sampling	No current data.

ADEQ ID: 15050301-890 One sampling site at this surface waterbody. Samples were collected in this reach support of the Three R Creek TMDL completed in 2003.	Status	Parameters exceeding standards: unknown. Currently assessed as Category 4A, Not attaining, “Impaired” due to past cadmium, copper, zinc and pH exceedances; insufficient data and missing core parameters. Surface Waterbody risk classification: • **Metals:** Extreme due to past exceedances. • **Sediment:** Moderate due to insufficient data. • **Organics:** Extreme due to past pH exceedances due to acid mine drainage. Organics ranked “low”. • **Selenium:** Moderate due to insufficient data.
Patagonia Lake ADEQ ID: 15050301-1050 One sampling site at this surface waterbody.	Sampling	• **Metals:** (t4) and (d0-1): Antimony, arsenic, barium, beryllium, boron, cadmium, chromium, copper, lead, manganese, mercury, nickel, selenium, silver, zinc; fluoride (3). • **Sediment:** total dissolved solids (1), turbidity (2). • **Organics:** Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen (3-4); *E. coli* (1). • **Selenium:** selenium
	Status	Parameters exceeding standards: dissolved oxygen Currently assessed as Category 2, “Attaining some uses”, due to insufficient data (dissolved copper, cadmium and zinc; and *E. coli*). Surface Waterbody risk classification: • **Metals:** Moderate due to insufficient data. • **Sediment:** Moderate due to insufficient data. • **Organics:** Moderate due to exceedances. • **Selenium:** Moderate due to insufficient data.

Subwatershed

Potrero Creek-Upper Santa Cruz River
HUC 1505030103

Combined Classification for Risk of Impairment:

- **Metals:** Extreme due to exceedances.
- **Sediment:** Extreme due to exceedances.
- **Organics:** Extreme due to exceedances.
- **Selenium:** Moderate.

Surface Waterbody	**Water Quality Data: Sampling and Assessment Status**[1,2,3]

Santa Cruz River From Mexico border to Nogales Intl WWTP discharge ADEQ ID: 15050301-010 Two sampling sites at this surface waterbody. Listed due to *E. coli* bacteria since 2002. TMDL has been delayed because drought has resulted in no stream flow.	Sampling	• **Metals:** (d&t 7-8): Antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, nickel, silver, thallium, zinc. (t8): Boron, manganese, mercury; fluoride (8). • **Sediment:** total dissolved solids (8), turbidity (18). • **Organics:** Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen (15-17); *E. coli* (8); solvents and petroleum products (3). • **Selenium:** none.
	Status	Parameters exceeding standards: *E. coli,* mercury, and dissolved oxygen (naturally occurring due to ground water upwelling and low flows), and old turbidity standard. Currently assessed as Category 5, "Impaired" due to exceedances. Surface Waterbody risk classification: • **Metals:** Moderate due to exceedances. • **Sediment:** Moderate due to exceedances. • **Organics:** Extreme due to exceedances. • **Selenium:** Moderate due to insufficient data.
Nogales Wash From Mexico border to Potrero Creek ADEQ ID: 15050301-011 One sampling site at this surface waterbody.	Sampling	• **Metals:** (d&t 17-25): Antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, zinc; (d&t 10-11): Barium, nickel silver, thallium; (t8): Boron, manganese; selenium (1); fluoride (23). • **Sediment:** total dissolved solids (23), suspended sediment concentration (12), turbidity (24). • **Organics:** Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen (23-24); *E. coli* (19); solvents and petroleum products (3). • **Selenium:** selenium
	Status	Parameters exceeding standards: ammonia, chlorine, dissolved copper, *E. coli*, lead, selenium, suspended sediment concentration. Currently assessed as Category 5, "Impaired". Surface Waterbody risk classification: • **Metals:** Extreme due to exceedances. • **Sediment:** Extreme due to exceedances. • **Organics:** Extreme due to exceedances. • **Selenium:** Moderate.

Potrero Creek From Interstate 19 to Santa Cruz River ADEQ ID: 15050301-500B One sampling site at this surface waterbody.	Sampling	• **Metals:** (d&t 3): Antimony, arsenic, barium, beryllium, cadmium, zinc; (d 3) and (t 2): Mercury; (t3): Boron, manganese; (d 3) and (t 1): Lead, copper; fluoride (2). • **Sediment:** total dissolved solids (3), suspended sediment concentration (2), turbidity (19). • **Organics:** Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen (17-23); *E. coli* (3). • **Selenium:** none
	Status	Parameters exceeding standards: *E. coli*. Currently assessed as Category 3, "Inconclusive" due to *E. coli* exceedances, insufficient dissolved and total copper, total lead and total mercury. Surface Waterbody risk classification: • **Metals:** Moderate due to insufficient data. • **Sediment:** Moderate due to insufficient data. • **Organics:** High due to exceedances. • **Selenium:** Moderate due to insufficient data.

Subwatershed

Sopori Wash
HUC 1505030104

Combined Classification for Risk of Impairment:

- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

<table>
<tr><td colspan="3">Subwatershed</td></tr>
<tr><td colspan="3">Josephine Canyon-Upper Santa Cruz River
HUC 1505030105
Combined Classification for Risk of Impairment:
• Metals: Moderate due to insufficient data.
• Sediment: Moderate due to insufficient data.
• Organics: High due to exceedances.
• Selenium: Moderate due to insufficient data.</td></tr>
<tr><td>Surface Waterbody</td><td colspan="2">Water Quality Data:
Sampling and Assessment Status[1,2,3]</td></tr>
<tr><td rowspan="2">Santa Cruz River
From Josephine Canyon to Tubac Bridge

ADEQ ID: 15050301-008A

Two sampling sites at this surface waterbody.</td><td>Sampling</td><td>• Metals: (d&t 4): Antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, nickel, silver, thallium, zinc.
(t4): Boron, manganese, mercury: fluoride (4);
• Sediment: total dissolved solids (4), turbidity (35).
• Organics: Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen (20-24); E. coli (3); solvents and petroleum products (3); chlorine, free residual (2).
• Selenium: selenium</td></tr>
<tr><td>Status</td><td>Parameters exceeding standards: chlorine

Currently assessed as Category 2, “Attaining some uses” due to insufficient dissolved and total metals.

Surface Waterbody risk classification:
• Metals: Low.
• Sediment: Low.
• Organics: Moderate due to insufficient data.
• Selenium: Moderate due to insufficient data.</td></tr>
<tr><td>Santa Cruz River
From Tubac Bridge to Sopori Wash

ADEQ ID: 15050301-008B

Two sampling sites at this surface waterbody.</td><td>Sampling</td><td>• Metals: (d&t 1): Antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, mercury, zinc.
(t1): Boron, manganese, selenium: fluoride (1).
• Sediment: total dissolved solids (1), turbidity (44), suspended sediment concentration (1).
• Organics: Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen (18-46); E. coli (1).
• Selenium: selenium</td></tr>
</table>

	Status	Parameters exceeding standards: *E.coli,* pH Currently assessed as Category 2, "Attaining some uses" due to insufficient dissolved and total metals. Surface Waterbody risk classification: • **Metals:** Moderate due to insufficient data. • **Sediment:** Low. • **Organics:** High due to exceedances and insufficient data. • **Selenium:** Moderate due to insufficient data.
Santa Cruz River From Nogales Intl WWTP discharge to Josephine Canyon ADEQ ID: 15050301-009 One sampling site at this surface waterbody.	Sampling	• **Metals:** (d&t 1): Antimony, arsenic, cadmium, chromium, zinc; (t1): Beryllium, boron, manganese; (d1): Chromium, copper, lead; (t4): Mercury: fluoride (1). • **Sediment:** total dissolved solids (1), turbidity (34), suspended sediment concentration (1). • **Organics:** Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen (17-32); *E. coli* (3); solvents and petroleum products (3). • **Selenium:** none.
	Status	Parameters exceeding standards: none. Currently assessed as Category 2, "Attaining some uses" due to insufficient dissolved and total metals. Surface Waterbody risk classification: • **Metals:** Moderate due to insufficient data. • **Sediment:** Moderate due to insufficient data. • **Organics:** Low. • **Selenium:** Moderate due to insufficient data.
Pena Blanca Lake ADEQ ID: 15050301-1070 Three sampling sites at this surface waterbody. TMDL for mercury was completed in 1999.	Sampling	• **Metals:** (d3-5) and (t7-11): Cadmium, chromium, lead, nickel, silver, thallium, zinc; (d0-1) and (t7-11): Antimony, arsenic, barium, beryllium, boron, copper, manganese, mercury selenium; fluoride (10). • **Sediment:** total dissolved solids (4), turbidity (10). • **Organics:** Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen (12); *E. coli* (2). • **Selenium:** selenium

<table>
<tr><td></td><td>Status</td><td>Parameters exceeding standards: dissolved oxygen, pH, old turbidity standard.

Currently assessed as Category 4A, Not attaining, “Impaired”, due to exceedances and mercury in fish tissue.

Surface Waterbody risk classification:
• Metals: Extreme due to exceedances.
• Sediment: High due to exceedances and insufficient data.
• Organics: High due to exceedances and insufficient data.
• Selenium: Moderate due to insufficient data.</td></tr>
<tr><td colspan="3">Subwatershed</td></tr>
<tr><td colspan="3">Demetrie Wash-Upper Santa Cruz River
HUC 1505030106
Combined Classification for Risk of Impairment:
• Metals: Moderate due to insufficient data.
• Sediment: Low.
• Organics: Low.
• Selenium: Moderate due to insufficient data.</td></tr>
<tr><td>Surface Waterbody</td><td colspan="2">Water Quality Data:
Sampling and Assessment Status[1,2,3]</td></tr>
<tr><td rowspan="2">Madera Canyon Creek
From headwaters to unnamed tributary at 314342/1105250

ADEQ ID: 15050301-322A

One sampling site at this surface waterbody.</td><td>Sampling</td><td>• Metals: (d&t 3): Antimony, arsenic, barium, beryllium, cadmium, copper, zinc;
(d&t 1-2): Barium, mercury, silver, thallium;
(t3): Boron, manganese;
t1 & d3): Lead; fluoride (3).
• Sediment: total dissolved solids (3), suspended sediment concentration (2), turbidity (4).
• Organics: Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen (3); E. coli (3).
• Selenium: selenium</td></tr>
<tr><td>Status</td><td>Parameters exceeding standards: none.

Currently assessed as Category 2, “Attaining some uses”. Insufficient total lead and mercury.

Surface Waterbody risk classification:
• Metals: Moderate due to insufficient data.
• Sediment: Low.
• Organics: Low.
• Selenium: Moderate due to insufficient data.</td></tr>
</table>

Subwatershed
Box Canyon Wash-Upper Santa Cruz River **HUC 1505030107** **Combined Classification for Risk of Impairment:** • **Metals:** Moderate due to lack of monitoring data. • **Sediment:** Moderate due to lack of monitoring data. • **Organics:** Moderate due to lack of monitoring data. • **Selenium:** Moderate due to lack of monitoring data.
Subwatershed
Canada del Oro **HUC 1505030108** **Combined Classification for Risk of Impairment:** • **Metals:** Moderate due to lack of monitoring data. • **Sediment:** Moderate due to lack of monitoring data. • **Organics:** Moderate due to lack of monitoring data. • **Selenium:** Moderate due to lack of monitoring data.

<table>
<tr><td colspan="3">Subwatershed</td></tr>
<tr><td colspan="3">Julian Wash-Upper Santa Cruz River
HUC 1505030109
Combined Classification for Risk of Impairment:
• Metals: Moderate due to insufficient data.
• Sediment: Moderate due to insufficient data.
• Organics: Moderate due to insufficient data.
• Selenium: Moderate due to insufficient data.</td></tr>
<tr><td>Surface Waterbody</td><td colspan="2">Water Quality Data:
Sampling and Assessment Status[1,2,3]</td></tr>
<tr><td rowspan="2">Santa Cruz River
From Canada del Oro to HUC boundary 15050301

ADEQ ID: 15050301-001

One sampling site at this surface waterbody.</td><td>Sampling</td><td>• Metals: (d&t 4-5): Antimony, arsenic, beryllium, cadmium, chromium, copper, lead, nickel, silver, thallium, zinc;
(t5): Boron, manganese;
(t5 metals only): Mercury; fluoride (5)
• Sediment: total dissolved solids (5), turbidity (4), suspended sediment concentration (1).
• Organics: Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen (5); E. coli (4); chlorine, free residual (3).
• Selenium: selenium</td></tr>
<tr><td>Status</td><td>Parameters exceeding standards: chlorine

Currently assessed as Category 3, “Inconclusive” due to insufficient data for chlorine.

Surface Waterbody risk classification:
• Metals: Low.
• Sediment: Low.
• Organics: Moderate due to insufficient data.
• Selenium: Moderate due to insufficient data.</td></tr>
<tr><td>Kennedy Lake

ADEQ ID: 15050301-0720

One sampling site at this surface waterbody.</td><td>Sampling</td><td>• Metals: (d1): Cadmium, chromium, copper, lead, nickel, selenium, zinc, mercury.
• Sediment: total dissolved solids (2).
• Organics: Ammonia, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen (2).
• Selenium: selenium</td></tr>
</table>

	Status	Parameters exceeding standards: none. Currently assessed as Category 3, "Inconclusive" due to insufficient data and missing core parameters. Surface Waterbody risk classification: • **Metals:** Moderate due to insufficient data. • **Sediment:** Moderate due to insufficient data. • **Organics:** Moderate due to insufficient data. • **Selenium:** Moderate due to insufficient data.
Subwatershed		
Cienega Creek **HUC 1505030201** **Combined Classification for Risk of Impairment:** • **Metals:** Low. • **Sediment:** Low. • **Organics:** Low. • **Selenium:** Low.		
Surface Waterbody	**Water Quality Data:** **Sampling and Assessment Status**[1,2,3]	
Cienega Creek From headwaters to Gardner Canyon ADEQ ID: 15050302-006A Three sampling sites at this surface waterbody.	Sampling	• **Metals:** (d&t 14-15): Antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, nickel, silver, thallium, zinc. (d0-2) and (t15): Boron, manganese, mercury; fluoride (14). • **Sediment:** total dissolved solids (14), turbidity (14), suspended sediment concentration (1). • **Organics:** Ammonia, total nitrogen, nitrite/nitrate, total Kjeldahl nitrogen, dissolved oxygen, pH. total phosphorus (10-13); *E. coli* (3). • **Selenium:** selenium
	Status	Parameters exceeding standards: dissolved oxygen due to natural conditions of low flow and ground water upwelling. Currently assessed as Category 1, "Attaining all uses". Surface Waterbody risk classification: • **Metals:** Low. • **Sediment:** Low. • **Organics:** Low. • **Selenium:** Low.

Cienega Creek From Gardner Canyon to USGS gage station (Pantano Wash) ADEQ ID: 15050302-006B Two sampling sites at this surface waterbody.	Sampling	• **Metals:** (d&t 10-14): Antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, nickel, silver, thallium, zinc. (d0-2) and (t14-15): Boron, manganese, mercury; fluoride (14). • **Sediment:** total dissolved solids (14), turbidity (15), suspended sediment concentration (2). • **Organics:** Ammonia, dissolved oxygen, pH, total nitrogen, nitrite/nitrate, total Kjeldahl nitrogen, total phosphorus (13-14); *E. coli* (3). • **Selenium:** selenium
	Status	Parameters exceeding standards: dissolved oxygen due to natural conditions of low flow and ground water upwelling. Currently assessed as Category 1, "Attaining all uses". Surface Waterbody risk classification: • **Metals:** Low. • **Sediment:** Low. • **Organics:** Low. • **Selenium:** Low.

Subwatershed

Agua Verde Creek-Pantano Wash
HUC 1505030202

Combined Classification for Risk of Impairment:

- **Metals:** Moderate due to insufficient data.
- **Sediment:** Moderate due to insufficient data.
- **Organics:** Extreme due to exceedances at Lakeside Lake.
- **Selenium:** Moderate due to insufficient data.

Surface Waterbody	**Water Quality Data: Sampling and Assessment Status**[1,2,3]	
Cienega Creek From Gardner Canyon to USGS gage station (Pantano Wash) ADEQ ID: 15050302-006B Two sampling sites at this surface waterbody.	Sampling	• **Metals:** (d&t 10-14): Antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, nickel, silver, thallium, zinc. (d0-2) and (t14-15): Boron, manganese, mercury; fluoride (14). • **Sediment:** total dissolved solids (14), turbidity (15), suspended sediment concentration (2). • **Organics:** Ammonia, dissolved oxygen, pH, total nitrogen, nitrite/nitrate, total Kjeldahl nitrogen, total phosphorus (13-14); *E. coli* (3). • **Selenium:** selenium

	Status	Parameters exceeding standards: dissolved oxygen due to natural conditions of low flow and ground water upwelling. Currently assessed as "Attaining all uses". Surface Waterbody risk classification: • **Metals:** Low. • **Sediment:** Low. • **Organics:** Low. • **Selenium:** Low.
Rincon Creek From headwaters to Pantano Wash ADEQ ID: 15050302-008 One sampling site at this surface waterbody.	Sampling	• **Metals:** (d1): Antimony, barium, beryllium, boron, cadmium, chromium, copper, lead, manganese, nickel, silver, uranium. • **Sediment:** **S**uspended sediment concentration (1). • **Organics:** Dissolved oxygen, pH (1). • **Selenium:** none.
	Status	Parameters exceeding standards: none. Currently assessed as Category 3, "Inconclusive" due to insufficient data. Surface Waterbody risk classification: • **Metals:** Moderate due to insufficient data. • **Sediment:** Moderate due to insufficient data. • **Organics:** Moderate due to insufficient data. • **Selenium:** Moderate due to insufficient data.
Madrona Creek From headwaters to Rincon Creek ADEQ ID: 15050302-138 One sampling site at this surface waterbody.	Sampling	• **Metals:** (d3-4) and (t0-1): Antimony, barium, beryllium, boron, cadmium, chromium, copper, lead, manganese, zinc. (d0-1) and (t0-1): Arsenic, mercury, selenium, nickel, silver, uranium; fluoride (1). • **Sediment:** total dissolved solids (3), suspended sediment concentration (2). • **Organics:** Ammonia, total nitrogen, nitrite/nitrate, total Kjeldahl nitrogen (1); dissolved oxygen (2); pH (7); total phosphorus (4). • **Selenium:** selenium

	Status	Parameters exceeding standards: none Currently assessed as Category 3, “Inconclusive”, due to insufficient total metals, *E. coli,* and dissolved oxygen. Surface Waterbody risk classification: • **Metals:** Moderate due to insufficient data. • **Sediment:** Moderate due to insufficient data. • **Organics:** Moderate due to insufficient data. • **Selenium:** Moderate due to insufficient data.
Chimenea Creek From headwaters to Rincon Creek ADEQ ID: 15050302-140 Two sampling sites at this surface waterbody.	Sampling	• **Metals:** (d4-5) and (t0-1): Antimony, beryllium, boron, cadmium, chromium, copper, lead, manganese, zinc; fluoride (1); (d0-1) and (t0-1): Arsenic, barium, mercury, nickel, selenium, silver, uranium. • **Sediment:** total dissolved solids (4), turbidity (1), suspended sediment concentration (1) • **Organics:** Ammonia, total nitrogen, nitrite/nitrate, total Kjeldahl nitrogen (1); dissolved oxygen (3); pH (7); total phosphorus (4). • **Selenium:** selenium
	Status	Parameters exceeding standards: none Currently assessed as Category 2, “Attaining some uses” due to insufficient total metals and *E.coli,* and missing core parameters. Surface Waterbody risk classification: • **Metals:** Moderate due to insufficient data. • **Sediment:** Moderate due to insufficient data. • **Organics:** Moderate due to insufficient data. • **Selenium:** Moderate due to insufficient data.
Lakeside Lake ADEQ ID: 15050302-0760 Three sampling sites at this surface waterbody. TMDL completed in 2005 for nutrient related pollutants.	Sampling	• **Metals:** (d&t 1): Cadmium, chromium, copper, lead, manganese, zinc; (t1): Antimony, arsenic, barium, boron, lead, mercury, nickel, selenium, silver; fluoride (2); • **Sediment:** total dissolved solids (46), turbidity (46). • **Organics:** Ammonia, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen, dissolved oxygen, pH (46-55); algal samples (46); chlorophyll samples (46). • **Selenium:** selenium

<table>
<tr><td></td><td>Status</td><td>Parameters exceeding standards: ammonia, dissolved oxygen, pH

Currently assessed as Category 4A, Not attaining, “Impaired”, due to insufficient data, and missing core parameters; and ammonia, dissolved oxygen and pH exceedances. EPA assessed as Category 4A, Not attaining, “Impaired”, due to chlorophyll, nitrogen and phosphorus.

Surface Waterbody risk classification:
• Metals: Moderate due to insufficient data.
• Sediment: Low.
• Organics: Extreme due to exceedances.
• Selenium: Moderate due to insufficient data.</td></tr>
<tr><td colspan="3">Subwatershed</td></tr>
<tr><td colspan="3">Tanque Verde Creek-Rillito River
HUC 1505030203
Combined Classification for Risk of Impairment:
• Metals: High due to exceedances.
• Sediment: Moderate due to insufficient data.
• Organics: High due to exceedances.
• Selenium: High due to exceedances.</td></tr>
<tr><td>Surface Waterbody</td><td colspan="2">Water Quality Data:
Sampling and Assessment Status[1,2,3]</td></tr>
<tr><td>Sabino Canyon
From unnamed tributary at 322328/1104700 to Tanque Verde Wash

ADEQ ID: 15050302-014B

Five sampling sites at this surface waterbody.</td><td>Sampling</td><td>• Metals: (d&t 6-9): Antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, nickel, silver, thallium, zinc;
(d0-1) and (t7): Boron, manganese, mercury; fluoride (8); cyanide (1).
• Sediment: total dissolved solids (7), turbidity (8), suspended sediment concentration (1).
• Organics: Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen, (8-9); E.coli (4).
• Selenium: selenium (1)</td></tr>
</table>

	Status	Parameters exceeding standards: Dissolved oxygen (due to natural conditions of very low flow and ground water upwelling); Cyanide, lead, manganese and selenium after the Aspen Fire. Subsequent monitoring contained only a lead exceedance. Currently assessed as Category 2, "Attaining some uses", due to exceedances. Surface Waterbody risk classification: • **Metals:** High due to exceedances and unknown long term fire effects. • **Sediment:** Moderate due to unknown long term fire effects. • **Organics:** Low. • **Selenium:** High due to exceedances and insufficient data.
Loma Verde From headwaters to Tanque Verde Wash ADEQ ID: 15050302-268 One sampling site at this surface waterbody.	Sampling	• **Metals:** (d4): Antimony, barium, beryllium, boron, cadmium, chromium, copper, lead, manganese, nickel, silver, uranium, zinc; (d1): Arsenic, selenium. • **Sediment:** total dissolved solids (4), turbidity (1). • **Organics:** Ammonia, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen, dissolved oxygen, pH (4); • **Selenium:** selenium
	Status	Parameters exceeding standards: dissolved oxygen Currently assessed as Category 3, "Inconclusive", due to insufficient total metals and *E. coli*; and dissolved oxygen exceedances. Surface Waterbody risk classification: • **Metals:** Moderate due to insufficient data. • **Sediment:** Moderate due to insufficient data. • **Organics:** High due to exceedances. • **Selenium:** Moderate due to insufficient data.
Rose Canyon Lake ADEQ ID: 15050302-1260 Two sampling sites at this surface waterbody.	Sampling	• **Metals:** (d4): Antimony, arsenic, barium, beryllium, boron, cadmium, chromium, copper, lead, manganese, mercury, nickel, selenium, silver, zinc; fluoride (4) • **Sediment:** total dissolved solids (4), turbidity (4). • **Organics:** Ammonia, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen (4); dissolved oxygen (3); pH (5); *E. Coli* (1) • **Selenium:** none

	Status	Parameters exceeding standards: pH Currently assessed as Category 2, "Attaining some uses". EPA Category 5, "Impaired" due to pH exceedances. EPA added pH to 303(d) list in 2004. Surface Waterbody risk classification: • **Metals:** Moderate due to insufficient data. • **Sediment:** Low. • **Organics:** High due to exceedances and insufficient data. • **Selenium:** Moderate due to insufficient data.

Subwatershed

Guild Wash-Lower Santa Cruz River
HUC 1505030301

Combined Classification for Risk of Impairment:

- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed

Lower Santa Cruz river-North Branch Santa Cruz Wash
HUC 1505030302

Combined Classification for Risk of Impairment:

- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed

Greene Wash-Upper Santa Cruz Wash
HUC 1505030303

Combined Classification for Risk of Impairment:

- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed

Upper Vekol Wash
HUC 1505030304

Combined Classification for Risk of Impairment:

- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed

Lower Vekol Wash
HUC 1505030305

Combined Classification for Risk of Impairment:

- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed

Lower Santa Cruz Wash
HUC 1505030306

Combined Classification for Risk of Impairment:

- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed

Arivaca Creek
HUC 1505030401

Combined Classification for Risk of Impairment:

- **Metals:** Extreme due to exceedances.
- **Sediment:** Moderate due to insufficient data.
- **Organics:** High due to exceedances.
- **Selenium:** High due to exceedances.

Surface Waterbody	**Water Quality Data: Sampling and Assessment Status[1,2,3]**	
Arivaca Cienega ADEQ ID: 15050304-0001 One sampling site at this surface waterbody.	Sampling	• **Metals:** (d1): Antimony, arsenic, barium, beryllium, boron, cadmium, chromium, copper, lead, manganese, nickel, selenium, silver, uranium, zinc. • **Sediment:** total dissolved solids (1), turbidity (1). • **Organics:** dissolved oxygen and pH (1). • **Selenium:** selenium
	Status	Parameters exceeding standards: None Currently assessed as Category 3, "Inconclusive" due to insufficient data and missing core parameters. Surface Waterbody risk classification: • **Metals:** Moderate due to insufficient data. • **Sediment:** Moderate due to insufficient data. • **Organics:** Moderate due to insufficient data. • **Selenium:** Moderate due to insufficient data.

Arivaca Lake ADEQ ID: 15050304-0080 Four sampling sites at this surface waterbody. Mercury TMDL completed in 1999.	Sampling	• **Metals:** (t6-7) and (d4): Cadmium, chromium, lead, nickel, zinc. (7t) and (1d): Antimony, arsenic, barium, beryllium, boron, copper, manganese, mercury; fluoride (7) • **Sediment:** total dissolved solids (3), turbidity (7). • **Organics:** Ammonia, dissolved oxygen, pH, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen (6-7); *E. coli* (3) • **Selenium:** selenium
	Status	Parameters exceeding standards: dissolved oxygen and selenium. Currently assessed as Category 4A, Not attaining, "Impaired", due to mercury in fish tissue, and dissolved oxygen and selenium exceedances. Surface Waterbody risk classification: • **Metals:** Extreme due to exceedances. • **Sediment:** Moderate due to insufficient data. • **Organics:** High due to exceedances and insufficient data. • **Selenium:** High due to exceedances and insufficient data.

Subwatershed

Puertocito Wash
HUC 1505030402

Combined Classification for Risk of Impairment:

- **Metals:** Moderate due to insufficient data.
- **Sediment:** Moderate due to insufficient data.
- **Organics:** Moderate due to insufficient data.
- **Selenium:** Moderate due to insufficient data.

Surface Waterbody	Water Quality Data: Sampling and Assessment Status[1,2,3]	
Carpenter Tank ADEQ ID: 15050304-0002 One sampling site at this surface waterbody.	Sampling	• **Metals:** (d1): Antimony, arsenic, barium, beryllium, boron, cadmium, chromium, copper, lead, manganese, nickel, selenium, silver, uranium, zinc. • **Sediment:** total dissolved solids (1), turbidity (1). • **Organics:** Ammonia, dissolved oxygen, pH (1). • **Selenium:** selenium

	Status	Parameters exceeding standards: none. Currently assessed as Category 3, “Inconclusive” due to insufficient data and missing core parameters. Surface Waterbody risk classification: • **Metals:** Moderate due to insufficient data. • **Sediment:** Moderate due to insufficient data. • **Organics:** Moderate due to insufficient data. • **Selenium:** Moderate due to insufficient data.

Subwatershed

Altar Wash
HUC 1505030403

Combined Classification for Risk of Impairment:
- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed

Upper Brawley Wash
HUC 1505030404

Combined Classification for Risk of Impairment:
- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed

Lower Brawley Wash
HUC 1505030405

Combined Classification for Risk of Impairment:
- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed

Los Robles Wash
HUC 1505030406

Combined Classification for Risk of Impairment:
- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed

Viopuli Wash
HUC 1505030501

Combined Classification for Risk of Impairment:
- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed

Upper Aguirre Wash
HUC 1505030502

Combined Classification for Risk of Impairment:
- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed

Lower Aquirre Wash
HUC 1505030503

Combined Classification for Risk of Impairment:
- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed

Tat Momoli Wash
HUC 1505030504

Combined Classification for Risk of Impairment:
- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed

Upper Santa Rosa Wash
HUC 1505030601

Combined Classification for Risk of Impairment:
- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed

Kohatk Wash
HUC 1505030602

Combined Classification for Risk of Impairment:

- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed

Middle Santa Rosa Wash
HUC 1505030603

Combined Classification for Risk of Impairment:

- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed

Lower Santa Rosa Wash
HUC 1505030604

Combined Classification for Risk of Impairment:

- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed

Hickiwan Wash
HUC 1508010101

Combined Classification for Risk of Impairment:

- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed

Upper San Simon Wash
HUC 1508010102

Combined Classification for Risk of Impairment:

- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed

Upper Vamori Wash
HUC 1508010103

Combined Classification for Risk of Impairment:
- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed

Sells Wash
HUC 1508010104

Combined Classification for Risk of Impairment:
- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed

Lower Vamori Wash
HUC 1508010105

Combined Classification for Risk of Impairment:
- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed

Middle San Simon Wash
HUC 1508010106

Combined Classification for Risk of Impairment:
- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed

Chukut Kuk Wash
HUC 1508010107

Combined Classification for Risk of Impairment:
- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed

Rio San Francisquito
HUC 1508010108

Combined Classification for Risk of Impairment:

- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed

Lower San Simon Wash
HUC 1508010109

Combined Classification for Risk of Impairment:

- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed

Pia Oik Wash-Menagers Lake
HUC 1508010201

Combined Classification for Risk of Impairment:

- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed

Sonoyta Valley Area
HUC 1508010202

Combined Classification for Risk of Impairment:

- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed

Davidson Canyon
HUC 1508010203

Combined Classification for Risk of Impairment:

- **Metals:** Moderate due to lack of monitoring data.
- **Sediment:** Moderate due to lack of monitoring data.
- **Organics:** Moderate due to lack of monitoring data.
- **Selenium:** Moderate due to lack of monitoring data.

Subwatershed
Aguajita Wash-Rio Sonoyta **HUC 1508010204** **Combined Classification for Risk of Impairment:** • **Metals:** Moderate due to lack of monitoring data. • **Sediment:** Moderate due to lack of monitoring data. • **Organics:** Moderate due to lack of monitoring data. • **Selenium:** Moderate due to lack of monitoring data.

Subwatershed
Pinacate Valley-Las Playas **HUC 1508010301** **Combined Classification for Risk of Impairment:** • **Metals:** Moderate due to lack of monitoring data. • **Sediment:** Moderate due to lack of monitoring data. • **Organics:** Moderate due to lack of monitoring data. • **Selenium:** Moderate due to lack of monitoring data.

Subwatershed
Puente Cuates **HUC 1508010302** **Combined Classification for Risk of Impairment:** • **Metals:** Moderate due to lack of monitoring data. • **Sediment:** Moderate due to lack of monitoring data. • **Organics:** Moderate due to lack of monitoring data. • **Selenium:** Moderate due to lack of monitoring data.

Subwatershed
La Jolla Wash **HUC 1508010303** **Combined Classification for Risk of Impairment:** • **Metals:** Moderate due to lack of monitoring data. • **Sediment:** Moderate due to lack of monitoring data. • **Organics:** Moderate due to lack of monitoring data. • **Selenium:** Moderate due to lack of monitoring data.

Subwatershed		
Rio Altar Headwaters **HUC 1508020001** **Combined Classification for Risk of Impairment:** • **Metals:** Moderate due to insufficient data. • **Sediment:** Moderate due to insufficient data. • **Organics:** Moderate due to insufficient data. • **Selenium:** Moderate due to insufficient data.		
Surface Waterbody	**Water Quality Data: Sampling and Assessment Status**[1,2,3]	
Sycamore Canyon ADEQ ID: 15080200-002 One sampling site at this surface waterbody.	Sampling	• **Metals:** (d&t 1): Antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, nickel, silver, thallium zinc; (t 1 metals only); Boron, manganese, mercury; fluoride (1). • **Sediment:** total dissolved solids (1), turbidity (1). • **Organics:** Ammonia, total nitrogen, total phosphorus, nitrite/nitrate, total Kjeldahl nitrogen, dissolved oxygen, pH (1). • **Selenium:** selenium
	Status	Parameters exceeding standards: none. Currently assessed as Category 3, "Inconclusive" due to insufficient data and missing core parameters. Surface Waterbody risk classification: • **Metals:** Moderate due to insufficient data. • **Sediment:** Moderate due to insufficient data. • **Organics:** Moderate due to insufficient data. • **Selenium:** Moderate due to insufficient data.
Subwatershed		
Rio El Sasabe Headwaters **HUC 1508020002** **Combined Classification for Risk of Impairment:** • **Metals:** Moderate due to lack of monitoring data. • **Sediment:** Moderate due to lack of monitoring data. • **Organics:** Moderate due to lack of monitoring data. • **Selenium:** Moderate due to lack of monitoring data.		

[1] All water quality constituents had a minimum of three samples unless otherwise indicated by numbers in parenthesis. For example, arsenic (2) indicates two samples have been taken for arsenic on this reach.
[2] The number of samples that exceed a standard is described by a ratio. For example, the statement "Exceedances reported for E. coli (1/2)," indicates that one from two samples has exceeded standards for E. coli.
[3] The acronyms used for the water quality parameters are defined below:

(d) = dissolved fraction of the metal or metalloid (after filtration), ug/L
(t) = total metal or metalloid (before filtration), ug/L
cadmium (d): Filtered water sample analyzed for dissolved cadmium.
cadmium (t): Unfiltered water sample and sediment/particulates suspended in the water sample analyzed for (t) cadmium content.
chromium (d): Filtered water sample analyzed for dissolved chromium.
chromium (t): Unfiltered water sample and sediment/particulates suspended in the water sample analyzed for (t) chromium content.
copper (d): Filtered water sample analyzed for dissolved copper.
copper (t): Unfiltered water sample and sediment/particulates suspended in the water sample analyzed for (t) copper content.
dissolved oxygen: O2 (mg/L)
E. coli: Escherichia coli bacteria (CFU/100mL)
lead (d): Filtered water sample analyzed for dissolved lead.
lead (t): Unfiltered water sample and sediment/particulates suspended in the water sample analyzed for (t) lead content.
manganese (d): Filtered water sample analyzed for dissolved manganese.
manganese (t): Unfiltered water sample and sediment/particulates suspended in the water sample analyzed for (t) manganese content.
mercury (d): Filtered water sample analyzed for dissolved mercury.
mercury (t): Unfiltered water sample and sediment/particulates suspended in the water sample analyzed for (t) mercury content.
nickel (d): Filtered water sample analyzed for dissolved nickel.
nickel (t): Unfiltered water sample and sediment/particulates suspended in the water sample analyzed for (t) nickel content.
nitrite/nitrate: Water sample analyzed for Nitrite/Nitrate content.
n-kjeldahl: Water sample analyzed by the Kjeldahl nitrogen analytical method which determines the nitrogen content of organic and inorganic substances by a process of sample acid digestion, distillation, and titration.
pH: Water sample analyzed for levels of acidity or alkalinity.
selenium (d): Filtered water sample analyzed for dissolved selenium.
selenium (t): Unfiltered water sample and sediment/particulates suspended in the water sample analyzed for (t) selenium content.
silver (d): Filtered water sample analyzed for dissolved silver.
silver (t): Unfiltered water sample and sediment/particulates suspended in the water sample analyzed for (t) silver content.
suspended sediment concentration: Suspended Sediment Concentration
temperature: Sample temperature
total dissolved solids: tds, (mg/L)
total solids: (t) Solids
total suspended solids: (t) Suspended Solids
turbidity: Measurement of suspended matter in water sample (NTU)
zinc (d): Filtered water sample analyzed for dissolved zinc.
zinc (t): Unfiltered water sample and sediment/particulates suspended in the water sample analyzed for (t) zinc content.

Designated Uses:
AgI: Agricultural Irrigation. Surface water is used for the irrigation of crops.
AgL: Agricultural Livestock Watering. Surface water is used as a supply of water for consumption by livestock.
A&Ww: Aquatic and Wildlife Warm water Fishery. Surface water used by animals, plants, or other organisms (excluding salmonid fish) for habitation, growth, or propagation, generally occurring at elevations less than 5000 feet.
FC: Fish Consumption. Surface water is used by humans for harvesting aquatic organisms for consumption. Harvestable aquatic organisms include, but are not limited to, fish, clams, crayfish, and frogs.

FBC: Full Body Contact. Surface water use causes the human body to come into direct contact with the water to the point of complete submergence (e.g., swimming). The use is such that ingestion of the water is likely to occur and certain sensitive body organs (e.g., eyes, ears, or nose) may be exposed to direct contact with the water.

References

Arizona Department of Environmental Quality, ADEQ. 2007. DRAFT. The Status of Water Quality in Arizona – 2006: Arizona's Integrated 305(b) Assessment and 303(d) Listing Report, 1110 West Washington Ave., Phoenix, Arizona, 85007, from http://www.azdeq.gov/environ/water/assessment/assess.html

Appendix B: Suggested Readings
Santa Cruz Watershed

1. Biological References

Arizona Department of Environmental Quality, Occurrence of enteric pathogens in surface water of the Santa Cruz River basin: Results from the ADEQ/ADHS Surveillance Parasite and Virus Monitoring Program, September 1990 through June 1991.

Arizona Department of Environmental Quality, 1991, Sixth periodic data report of the ADEQ Fixed Station Network for Monitoring Surface Water Quality, January – September, 1989, Point Source and Monitoring Unit, Water Assessment Section.

Arizona Department of Environmental Quality, 1995, Upper Santa Cruz River Intensive Survey: A Volunteer Driven Study of the Water Quality and Biology of an Effluent Dominated Desert Grassland Stream in Southeast Arizona, p. 66.

Ambrust, B. and Brusca, R., 2005, Inventory of Aquatic Invertebrates in the Santa Cruz River, Report for Tumacacori National Historic Park: Arizona-Sonoran Desert Museum, Tucson, Arizona.

Baker, Jr., M.B., Ffolliott, P.F., Debano, L.F., and Neary, D.G., 2004, Riparian areas of the Southwestern United States, Hydrology, Ecology, and Management: Lewis Publishers, New York.

Emmerich, W.E., 1990, Precipitation nutrient inputs in semiarid environments: Journal of Environmental Quality 19(3): 621-624.

Hendrickson, D.A., and Minckley, D.A., 1985, Cienegas – Vanishing climax communities of the American Southwest. Desert Plants, v. 6.

King, K.A., and Andrews, B.J., 1997, Environmental Contaminants in Ducks Collected From Wastewater Treatment Plant Ponds, Nogales, Arizona 1996: U.S. Fish and Wildlife Service, Region 2 Contaminants Program, 13 p

King, K.A., Zaun, B.J., and Velasco, A.L., 1999, Contaminants as a Limiting Factor of Fish and Wildlife Populations in the Santa Cruz River, Arizona: U.S. Fish and Wildlife Service, Region 2 Contaminants Program, 57 p.

Morton, H.L., Ibarra-F., F.A., Martin-R., M.H., and Cox, J.K, 1900, Creosotebush control and forage production in the Chihuahuan and Sonoran deserts: Journal of Range Management v. 43, p. 43-48.

Pima Association of Governments, 2003, Cienega Creek Natural Preserve non-native plant species study project report.

Pima Association of Governments, 2002, Water quality requirements of native aquatic species in Pima County.

Pima Association of Governments, 2001, Reducing the aquatic species threat in Pima County.

Werner, W.E., 2003, Conservation of native species through habitat conservation plans, safe harbor agreements, and similar mechanisms in Arizona: American Fisheries Society Annual Meeting, 2003; 133: 339.

2. Geophysical References

Bittson, A.G., 1976, Analysis of gravity data from the Cienega Creek area, Pima and Santa Cruz counties, Arizona: Tucson, University of Arizona, M.S. thesis, 76 p., 5 sheets, scale 1:62,500.

Drewes, H., 1971, Mesozoic stratigraphy of the Santa Rita Mountains, Southeast of Tucson, Arizona: U.S. Geological Survey Professional paper 658-C, 81 p.

Drewes, H., 1971, Geologic map of the Mount Wrightson quadrangle, southeast of Tucson, Santa Cruz and Pima Counties, Arizona: U.S. Geological Survey Miscellaneous Geologic Investigations I-614.

Drewes, H., 1971, Geologic map of the Sahuarita quadrangle, southeast of Tucson, Pima County, Arizona: U.S. Geological Survey Miscellaneous Geologic Investigations I-613.

Drewes, H., 1980, Tectonic map of southeast Arizona: U.S. Geological Survey Miscellaneous Geologic Investigations I-1109.

Drewes, H., 1996, Geologic map of the Arivaca quadrangle and vicinity, Pima and Santa Cruz counties, Arizona: U.S. Geological Survey Miscellaneous Field Studies Map 2320.

Drewes, H., 1998, Geologic map of the Bartlett Mountain Quadrangle, Pima and Santa Cruz counties, Arizona: U.S. Geological Survey IMAP 2624.

Gettings, M.E. and Houser, B.B., 1997, Basin geology of the upper Santa Cruz Valley, Pima and Santa Cruz Counties, southeastern Arizona: U.S. Geological Survey Open-File Report 97-676, 40 p.

Murphy, B. J. and Moore, R. T., 1980, Maps showing relative slope stability and relative erodibility, central Santa Cruz River Valley Tucson area, Arizona: U.S. Geological Survey Map 844-O, 2 sheets.

Oppenheimer, J.M., 1980, Gravity modeling of the alluvial basins, southern Arizona: Tucson, University of Arizona, M.S. thesis, 81 p.

Oppenheimer, J.M., and Sumner, J.S., 1980, Depth-to-bedrock map, Basin and Range province, Arizona: Tucson, University of Arizona, Department of Geosciences, Laboratory of Geophysics, 1 sheet, scale 1:1,000,000.

Oppenheimer, J.M., and Sumner, J.S., 1981, Gravity modeling of the basins in the Basin and Range province, Arizona: Arizona Geological Society Digest, v. 13, p. 111-115, 1 sheet, scale 1:1,000,000.

Ridley, W.I., and others, 1996, Contributions of mineralization and metal mining to the Santa Cruz River Drainage Basin, southern Arizona: evaluation of geologic factors: ibid. p. A-530.

Rystrom, V.L., Finn, C.A., King., T.V.V., 2002, Geologic interpretation of aeromagnetic maps in the Santa Cruz Basin; Patagonia Mountains area, south-central Arizona: U.S. Geological Survey Open-File Report 2002-100.

Simons, F.S., 1974, Geologic map and sections of the Nogales and Lochiel quadrangles, Santa Cruz County, Arizona: U.S. Geological Survey Miscellaneous Geologic Investigations I-762.

Tucci, P., 1989, Geophysical methods for water-resources studies in southern and central Arizona, in Symposium on the Application of Geophysics to Engineering and Environmental Problems, Proceedings: Denver, Society of Engineering and Mineral Exploration Geophysicists, p. 368-383.

Statewide Geophysics References

Aiken, C.L.V., 1976, The analysis of the gravity anomalies of Arizona: Tucson, University of Arizona, Ph.D dissertation, 127 p. [abstract in Dissertation Abstracts International, v. 37, p. 4946B, 1977].

Aiken, C.L.V., Lysonski, J.C., Sumner, J.S., and Hahman, W.R., Sr., 1981, A series of 1:250,000 complete residual Bouguer gravity anomaly maps of Arizona: Arizona Geological Society Digets, v. 13, p. 31-37.

Bond, K.R., and Zietz, Isidore, 1987, Composite magnetic anomaly map of the conterminous United States west of 96° longitude: U.S. Geological Survey Geophysical Investigations Map GP-977, 13 p., 2 sheets, scale 1:2,500,000.

Diment, W.H. and Urban, T.C., 1981, Average elevation of the conterminous United States (Gilluly averaging method): U.S. Geological Survey Geophysical Investigations Map GP-0933, 2 sheets, scale 1:2,500,000.

Hendricks, J.D. and Plescia, J.B., 1991, A review of the regional geophysics of the Arizona Transition Zone: Journal of Geophysical Research, v. 96, no. B7, p. 12,351-12,373.

Hildenbrand, T.G., Simpson, R.W., Godson, R.H., and Kane, M.F., 1982, Digital colored residual and regional Bouguer gravity maps of the conterminous United States with cut-off wavelengths of 250 km and 1000 km: U.S. Geological Geophysical Investigations Map GP 953A, 2 sheets, scale 1:7,500,000.

Hildenbrand, T.G., Simpson, R.W., Godson, R.H., and Kane, M.F., 1982, Digital colored residual and regional Bouguer gravity maps of the conterminous United States: U.S. Geological Survey Open-File Report 82-284, 31 p.

Hildenbrand, T.G., Simpson, R.W., Godson, R.H., and Kane, M.F., 1987, Digital colored Bouguer gravity, free-air gravity, station location, and terrain maps for the conterminous United States: U.S. Geological Survey Geophysical Investigations Map GP 953B, 2 sheets, scale 1:7,500,000.

Lysonski, J.C., 1980, The IGSN 71 residual Bouguer gravity anomaly map of Arizona: Tucson, University of Arizona, M.S. thesis, 74 p., 1 sheet, scale 1:500,000.

Lysonski, J.C., Aiken, C.L.V., and Sumner, J.S., 1981, The complete residual Bouguer gravity anomaly map [of Arizona]: Arizona Bureau of Geology and Mineral Technology Open-File Report 81-24, 2 p., 23 sheets, scale 1:250,000.

Lysonski, J.C., and Sumner, J.S., 1981, Free-air gravity anomaly map of Arizona: Tucson, University of Arizona, Department of Geosciences, Laboratory of Geophysics, 1 sheet, scale 1:1,000,000.

Lysonski, J.C., and Sumner, J.S., 1981, Free-air gravity anomaly map of Arizona: Tucson, University of Arizona, Department of Geosciences, Laboratory of Geophysics, 1 sheet, scale 1:500,000.

Lysonski, J.C., Sumner, J.S., Aiken, C.L.V., and Schmidt, J.S., 1980, The complete residual Bouguer gravity anomaly map of Arizona (IGSN 71): Arizona Bureau of Geology and Mineral Technology Open-File Report 80-15, 1 sheet, scale 1:1,000,000.

Lysonski, J.C., Sumner, J.S., Aiken, C.L.V., and Schmidt, J.S., 1980, Residual Bouguer gravity anomaly map of Arizona: Tucson, University of Arizona, Department of Geosciences, Laboratory of Geophysics, 1 sheet, scale 1:1,000,000.

Lysonski, J.C., Sumner, J.S., Aiken, C.L.V., and Schmidt, J.S., 1980, Residual Bouguer gravity anomaly map of Arizona: Tucson, University of Arizona, Department of Geosciences, Laboratory of Geophysics, 1 sheet, scale 1:500,000.

McGinnis, L.D., Wolf, M.G., Kohsmann, J.J., and Ervin, C.P., 1979, Regional free-air gravity anomalies and tectonic observations in the United States: Journal of Geophysical Research, v. 84, no B2, p. 591-601.

Saltus, R.W., 1982, A description of Bouguer anomaly and isostatic residual colored gravity maps of the southwestern Cordillera: U.S. Geological Survey Open-File Report 82-839, 8 p.

Saltus, R.W., and Jachens, R.C., 1995, Gravity and bains-depth maps of the Basin and Range Province, western United States: U.S. Geological Survey Geophysical Investigations Map GP-1012, 1 sheet, scale 1:2,500,000.

Sauck, W.A., 1972, Compilation and preliminary interpretation of the Arizona aeromagnetic map: Tucson, University of Arizona, Ph.D. dissertation, 147 p.

Sauck, W.A., and Sumner, J.S., 1970, Residual aeromagnetic map of Arizona: Tucson, University of Arizona, Department of Geosciences, 1 sheet, scale 1:1,000,000.

Schmidt, J.S., 1976, Geophysical bias and cartography of the complete Bouguer gravity anomaly map of Arizona: Tucson, University of Arizona, M.S. thesis, 55 p.

Schmucker, U., 1964, Anomalies of geomagnetic variation in the southwestern United States: Journal of Geomagnetism and Geolelectricity, v. 15, p. 193-221.

Simpson, R.W., Jachens, R.C., Blakely, R.J., and Saltus, R.W., 1986, A new isostatic residual gravity map of the conterminous United States with a discussion on the significance of isostatic residual anomalies: Journal of Geophysical Research, v. 91, no B8, p. 8348-8372.

Simpson, R.W., Jachens, R.C., Saltus, R.W., and Blakely, R.J., 1986, Isostatic residual gravity, topographic, and first-vertical-derivative gravity maps of the conterminous United States: U.S. Geological Survey Geophysical Investigations Map GP-975, 2 sheets, scale 1:7,500,000.

Stewart, J.H., 1978, Basin-Range structure in western North America: A review, in Smith, R.B., and Eaton, G.P., eds., Cenozoic tectonics and regional geophysics of the western Cordillera: Geological Society of America memoir 152, p. 1-31.

Stover, C.W., 1986, Seismicity map of the conterminous United States and adjacent areas, 1975-1984: U.S. Geological Survey Geophysical Investigations Map GP-984, 1 sheet, scale 1:5,000,000.

Sumner, J.S., 1965, Gravity measurements in Arizona: Eos, Transactions, American Geophysical Union, v. 46, p. 560-563.

Sumner, J.S., 1989, Regional geophysics of Arizona, in Jenney, J.P., and Reynolds, S.J., eds., Geologic evolution of Arizona: Arizona Geological Society Digest 17, p. 717-739.

Sumner, J.S., Schmidt, J.S., and Aiken, C.L.V., 1976, Free-air gravity anomaly map of Arizona, in Wilt, J.C., and Jenney, J.P., eds., Tectonic digest: Arizona Geological Society Digest, v. 10, p. 7-12, 1 sheet, scale 1:1,000,000.

Thompson, G.A., and Burke, G.B., 1974, Regional geophysics of the Basin and Range Province: Annual Review of Earth and Planetary Sciences, v. 2, p. 213-237.

West, R.E., 1972, A regional Bouguer gravity anomaly map of Arizona: Tucson, University of Arizona, Ph.D. dissertation, 186 p.

West, R.E., and Sumner, J.S., Regional Bouguer gravity map of Arizona: Tucson, University of Arizona, Department of Geosciences, Laboratory of Geophysics, 1 sheet, scale 1:1,000,000.

Woollard, G.P., and Joesting, H.R., 1964, Bouguer gravity anomaly map of the United States exclusive of Alaska and Hawaii: American Geophysical Union and U.S. Geological Survey Special Map, 2 sheets, scale 1:2,500,000.

3. Ground Water References

Agenbroad, L.D., 1984, Recent valley deposits in southern Arizona, in Smiley, T.L., Nations, J.D., Pewe, T.L., and Schafer, J.P., eds, Landscapes of Arizona – The geological story: Lanham, Md., University Press of America, p. 253-268.

Anderson, T.W., 1979, Development of groundwater models of alluvial basins in south-central Arizona, in Arizona Water Symposium, 23rd and 24th annual, Phoenix, September 27, 1979, and September 24, 1980, Proceedings: Arizona Department of Water Resources Report no. 2., p. 13-17.

Anderson, T.W., 1980, Study plan for the regional aquifer-system analysis of alluvial basins in south-central Arizona and adjacent states: U.S. Geological Survey Open-File Report 80-1197, 22 p.

Anderson, T.W., 1983, Implications of deep percolation to ground-water systems in south-central Arizona based on numerical-model studies, in Briggs, P.C., ed., Proceedings of the Deep Percolation Symposium, October 26, 1982: Arizona Department of Water Resources Report no. 4, p. 30-40.

Anderson, T.W., 1986, Study in southern and central Arizona and parts of adjacent states, in Sun, R.J., ed., Regional aquifer-system analysis program of the U.S. Geological Survey, summary of projects,1978-1984: U.S. Geological Survey Circular 1002, p. 116-131.

Anderson, T.W., 1986, Geohydrology of the southwest alluvial basins, Arizona, in Anderson, T.W., and Johnson, A.I., eds., Regional aquifer systems of the United States – southwest alluvial basins of Arizona: Bethesda, Md., American Water Resources Association Monograph Series no. 7, p. 99-111.

Anderson, T.W., 1995, Summary of the Southwest alluvial basins, regional aquifer-system analysis, south-central Arizona and parts of adjacent states: U.S. Geological Survey Professional Paper 1406-A, p.A1-A33.

Anderson, T.W., and Freethey, G.W., 1995, Simulation of groundwater flow in alluvial basins in south-central Arizona and parts of adjacent states, Regional Aquifer-System Analysis: U.S. Geological Survey Professional Paper 1406-D, 78 p.

Anderson, T.W., Freethey, G.W., and Tucci, P., 1990, Geohydrology and water resources of alluvial basins in south-central Arizona and parts of adjacent states: U.S. Geological Survey Open-File Report 89-378, 99 p., 3 sheets, scale 1:1,000,000.

Anderson, T.W., Freethey, G.W., and Tucci, P., 1992, Geohydrology and water resources of alluvial basins in south-central Arizona and parts of adjacent states: U.S. Geological Survey Professional Paper 1406-B, p. B1-B67, 3 sheets, scale 1:1,000,000.

Anderson, T.W., Welder, G.E., Lesser, G., and Trujillo, A., 1988, Region 7, Central Alluvial Basins, in Back, W., Rosenshein, J.S., and Seaber, P.R., eds., Hydrogeology: Geological Society of America, The Geology of North America, v. O-2, p. 81-86.

Anning, D.W., and Duet, N.R., 1994, Summary of ground-water conditions in Arizona, 1987-90: U.S. Geological Survey Open-File Report 94-476, 2 sheets, scales 1:1,000,000 and 1:2,500,000.

Arizona Department of Water Resources, 1994, Arizona water resources assessment, v.II, Hydrologic summary: Arizona Department of Water Resources Hydrology Division, 236 [266] p.

Arizona Department of Water Resources, 1994, Arizona water resources assessment v. I, Inventory and analysis: Arizona Department of Water Resources, 253 p.

Arizona Department of Water Resources, Basic Data Section, 1990, Map showing Arizona groundwater basins with index of cities, towns, settlements and sites: Arizona Department of Water Resources Open File Report no. 7, 1 sheet, scale 1:1,000,000.

Arizona Department of Water Resources, 1994, Arizona Riparian Protection Program legislative report: Arizona Department of Water Resources, 507 p., 3 sheets, scales 1:5,268, 1:48,941, and 1:66,858.

Arizona Water Commission, 1975, Arizona State Water Plan: Phase 1, Inventory of resource and uses: Arizona Water Commission, 224 p., 2 sheets, approx. scale 1:670,000.

Babcock, H.M.,1969, Annual report on ground water in Arizona, spring 1967 to spring 1968: Arizona State Land Department Water Resources Report no. 38, 54 p.

Babcock, H.M.,1969, Annual report on ground water in Arizona, spring 1968 to spring 1969: Arizona State Land Department Water Resources Report no. 42, 46 p.

Babcock, H.M.,1970, Annual report on ground water in Arizona, spring 1969 to spring 1970: Arizona State Land Department Water Resources Report no. 43, 44 p.

Babcock, H.M.,1972, Annual report on ground water in Arizona, spring 1970 to spring 1971: Arizona Water Commission Bulletin 1, 45 p.

Babcock, H.M.,1972, Bibliography of U.S. Geological Survey water-resources reports for Arizona, May 1965 through June 1971: Arizona Water Commission Bulletin Report 2, 60 p.

Babcock, H.M.,1973, Annual report on ground water in Arizona, spring 1971 to spring 1972: Arizona Water Commission Bulletin 5, 48 p.

Babcock, H.M.,1974, Annual report on ground water in Arizona, spring 1972 to spring 1973: Arizona Water Commission Bulletin 7, 46 p. 3 sheets, scale 1:250,000.

Babcock, H.M., 1976, Annual summary of ground-water conditions in Arizona, spring 1974 to spring 1975: U.S. Geological Survey Water-Resources Investigations Open-File Report 76-59, 2 sheets, scale 1:1,000,000.

Babcock, H.M., 1977, Annual summary of ground-water conditions in Arizona, spring 1975 to spring 1976: U.S. Geological Survey Water-Resources Investigations Open-File Report 77-10, 2 sheets, scale 1:1,000,000.

Babcock, H.M., 1977, Annual summary of ground-water conditions in Arizona, spring 1976 to spring 1977: U.S. Geological Survey Water-Resources Investigations Open-File Report 77-106, 2 sheets, scale 1:1,000,000.

Bedinger, M.S., Anderson, T.W., and Langer, W.H., 1984, Maps showing ground-water units and withdrawal, Basin and Range Province, Arizona: U.S. Geological Survey Water-Resources Investigations Report 83-4114-A, 2 sheets, scales 1:500,000 and 1:1,000,000.

Bedinger, M.S., Sargent, K.A., and Brady, B.T., 1985, Geologic and hydrologic characterization of the Basin and Range Province relative to the disposal of high-level radioactive waste, Part III, Geologic and hydrologic evaluation: U.S. Geological Survey Circular 904-C, 27 p.

Bedinger, M.S., Sargent, K.A., and Reed, J.E., 1984, Geologic and hydrologic characterization and evaluation of the Basin and Range Province relative to the disposal of high-level radioactive waste, Part I, Introduction and guidelines: U.S. Geological Survey Circular 904-A, 16 p.

Berger, B.R., Ridley, W.I., and Lichte, F.E., 1995. Toxic substance availability to the regional aquifer system from mineralized ground and mining activity in the northern Patagonia Mountains, Arizona: USGS Mineral Resources Program Administrative Report.

Boner, F.C., Garrett, W.B., and Konieczki, A.D., 1989, Water resources data, Arizona, water year 1988: U.S. Geological Survey Water-Data Report AZ-88-1, 391 p.

Boner, F.C., Konieczki, A.D., and Davis, R.G., 1991, Water resources data, Arizona, water year 1990: U.S. Geological Survey Water-Data Report AZ-90-1, 381 p.

Boner, F.C., Smith, C.F., Garrett, W.B., and Konieczki, A.D., 1990, Water resources data, Arizona, water year 1989: U.S. Geological Survey Water-Data Report AZ-89-1, 391 p.

Briggs, P.C., and Nemecek, E.A., 1986, Technical aspects of Arizona groundwater law, in Anderson, T.W., and Johnson, A.I., eds., Regional aquifer systems of the United States – southwest alluvial basins of Arizona: Bethesda, Md., American Water Resources Association Monograph Series no. 7, p. 93-98.

Carruth, R.L., 1995, Cross-sectional area of the shallow alluvial aquifer at selected sites along the upper Santa Cruz River, Arizona: U.S. Geological Survey Water-Resources Investigations Report 95-4112.

Clark, T.C., 1975, The Arizona Water Plan, a status report, in Arizona Watershed Symposium, 19th annual, Phoenix, September 24, 1975, Proceedings: Arizona Water Commission Report no. 7, p. 9-23.

Coes, A.L., Gellenbeck, D.J., Towne, D.C., Freark, M.C., 2000, Ground-water quality in the upper Santa Cruz basin, Arizona, 1998: U.S. Geological Survey Water-Resources Investigations Report 2000-4117.

Cordy, G.E., Gellenbeck, D.J., Gebler, J.B., Anning, D.W., Coes, A.L., Edmonds, R.J., Rees, J.A.H., and Sanger, H.W., 2000, Water quality in the central Arizona basins, Arizona, 1995-98: U.S. Geological Survey Circular 1213, 38 p.

Cordy, G.E., Rees, J.A., Edmonds, R.J., Gebler, J.B., Wirt, L., Gellenbeck, D.J., and Anning, D.W., 1998, Water-quality assessment of the central Arizona basins, Arizona and northern Mexico – Environmental setting and overview of water quality: U.S. Geological Survey Water-Resources Investigations Report 98-4097

Cox, C.J., and others, 1968, Annual report on ground water in Arizona, spring 1966 to spring 1967, Arizona State Land Department Water Resources Report no. 36, 43 p.

Daniel, D.L., 1981, Maps showing total dissolved solids content of groundwater in Arizona: Arizona Department of Water Resources Hydrologic Map Series Report no. 2, 2 sheets, scale 1:1,000,000.

Daquan, Tian, 1993, Rainfall spatial and seasonal variability analysis in semi-arid watersheds: Tucson, University of Arizona, M.S. thesis, 113 p.

Diment, D.W., and Urban, T.C., 1981, Average elevation of the conterminous United States (Gilluly averaging method): U.S. Geological Survey Geophysical Investigations Map GP-933, 2 sheets, scale 1:2,500,000.

Duncan, J.T., Spencer, J.E., Eshragi, P., and Emrick, S.M., 1993, A reconnaissance study of radon and other radionuclides in Arizona well water, in Spencer, J.E., ed., Radon in Arizona: Arizona Geological Survey Bulletin 199, p. 86-92.

Eberly, L.D., and Stanley, T.B., Jr., 1978, Cenozoic stratigraphy and geologic history of southwestern Arizona, Geological Society of America Bulletin, v. 89, no. 6, p. 921-940.

Feth, J.H., and others, 1964, Preliminary map of the conterminous United States showing depth to and quality of shallowest ground water containing more than 1,000 parts per million dissolved solids: U.S. Geological Survey Hydrologic Investigations Atlas HA-199, 31 p., 2 sheets, scale 1:3,168,000.

Fields, R.L., 1986, Data-processing activities of the southwest alluvial basins, RASA study, in Anderson, T.W., and Johnson, A.I., eds., Regional aquifer systems of the United States – southwest alluvial basins of Arizona: Bethesda, Md., American Water Resources Association Monograph Series no. 7, p. 17-23.

Freethey, G.W., 1984, Ground-water modeling, alluvial basins of Arizona, in Repogle, J.A., and Renard, K.G., eds., Water today and tomorrow, Specialty Conference, Irrigation and Drainage Division of the American Society of Civil Engineers, Flagstaff, Arizona, July 24-26, 1984, Proceedings: American Society of Civil Engineers, p. 57-67.

Freethey, G.W., 1986. Considerations in modeling ground-water flow in the alluvial basins of Arizona, in Anderson, T.W., and Johnson, A.I., eds., Regional aquifer systems of the United States – southwest alluvial basins of Arizona: Bethesda, Md., American Water Resources Association Monograph Series no. 7, p. 57-67.

Freethey, G.W., and Anderson, T.W., 1986, Predevelopment hydrologic conditions in the alluvial basins of Arizona and adjacent parts of California and New Mexico: U.S. Geological Survey Hydrologic Investigations Atlas HA-664, 3 sheets, scale 1:500,000.

Freethey, G.W., Pool, D.R., Anderson, T.W., and Tucci, P., 1986, Description and generalized distribution of aquifer materials in the alluvial basins of Arizona and adjacent parts of California and new Mexico: U.S. Geological Survey hydrologic Investigations Atlas HA-663.

Galyean, K.C., 1996, Infiltration of wastewater effluent in the Santa Cruz River Channel, Pima County, Arizona: U.S. Geological Survey Water-Resources Investigations Report 96-4021.

Garrett, J.M., and Gellenbeck, D.J., 1991, Basin characteristics and streamflow statistics in Arizona as of 1989: U.S. Geological Survey Water-Resources Investigations Report 91-4041, 612 p.

Gellenbeck, D.J., and Anning, A.W., 2002, Occurrence and distribution of pesticides and volatile organic compounds in ground water and surface water in central Arizona basins, 1996-98, and their relation to land use: U.S. Geological Survey Water-Resources Investigations Report 01-4144, 107 p.

Goodrich, D.C., 1990, Geometric simplification of a distributed rainfall-runoff model over a range of basin scales: Tucson, University of Arizona, Ph.D. dissertation, 361 p.

Hahman, W.R., Sr., Stone, C., and Witcher, J.C., comps., 1978, Preliminary map – Geothermal energy resources of Arizona: Arizona Bureau of Geology and Mineral Technology Geothermal Map No. 1 [also published as Arizona Geological Survey Map 15-1], 1 sheet, scale 1:1,000,000.

Halpenny, L.C., 1987, Groundwater and surface water interconnection in Arizona: Water Development Corporation, [variously paged].

Hardt, W.F., Cahill, J.M., and Booher, M.B., 1958, Annual report on ground water in Arizona, spring 1959 to spring 1960: Arizona State Land Department Water Resources Report no. 5, 60 p.

Hardt, W.F., Stulik, R.S., and Booher, M.B., 1960, Annual report on ground water in Arizona, spring 1959 to spring 1960: Arizona State Land Department Water Resources Report no. 7, [89 p.]

Hardt, W.F., Stulik, R.S., and Booher, M.B., 1959, Annual report on ground water in Arizona, spring 1958 to spring 1959: Arizona State Land Department Water Resources Report no. 6, 61 p.

Hanson, R.T., and Benedict, J.F., 1994, Simulation of ground-water flow and potential land subsidence, upper Santa Cruz basin, Arizona: U.S. Geological Survey, Water Resources Investigations Report 93-4196, 47 p.

Harshbarger, J.W., Lewis, D.D., Skibitzke, H.E., Heckler, W.L., and Kister, L.R., revised by H.L. Baldwin, 1966, Arizona water: U.S. Geological Survey Water-Supply Paper 1648, 85 p.

Harwood, G., and DeCook, K.J., eds., 1979, Hydrology and water resources in Arizona and the Southwest, v. 9: American Water Resources Association, Arizona Section, and Arizona Academy of Science, Hydrology Section, Annual Meeting, Tempe, Arizona, 1979, Proceedings, 173 p.

Heindl, L.A., 1965, Ground water in fractured volcanic rocks in southern Arizona, in Hydrology of fractured rocks: Gentbrugge, Belgium, International Association of Scientific Hydrology (IASH), Publication 74, v. 2, p. 503-513.

Hodges, E.B., and others, 1967, Annual report on ground water in Arizona, spring 1965 to spring 1966: Arizona State Land Department Water Resources Report no. 32, 61 p.

Holbert, K.E., Stweart, B.D., and Eshraghi, P., 1995, Measurement of radioactivity in Arizona groundwater using improved analytical techniques for samples with high dissolved solids: Health Physics, v. 68, no. 2, p. 185-194.

Keith, S.J., Paylore, P., DeCook, K.J., and Wilson, L.G., 1982, Bibliography on ground-water recharge in arid and semiarid areas: Tucson, University of Arizona, Water Resources Research Center, 149 p.,

Konieczki, A.D., and Wilson, R.P., 1992, Annual summary of ground-water conditions in Arizona, spring 1986 to spring 1987: U.S. Geological Survey Water-Resources Investigations Open-File Report 92-54, 2 sheets, scales 1:1,000,000 and 1:3,077,000.

Ligner, J.J., White, N.D., Kister, L.R., and Moss, M.E., 1969, Water resources: Part II of Mineral and Water Resources of Arizona: Arizona Bureau of Mines Bulletin 180, p. 471-580.

Longsworth, S.A., Van De Vanter, E.K., and Alwin, S.H., 1998, Activities of the Water Resources Division in Arizona, 1996-97, U.S. Geological Survey Open-File Report 98-195, 90 p.

Marie, J.R., Van De Vanter, E.K., and Moss, C.L., 1996, Activities of the Water Resources Division in Arizona, 1995-1996: U.S. Geological Survey Open-File Report 95-772, 69 p.

McGuinness, C.L., 1964, Generalized map showing annual runoff and productive aquifers in the conterminous United States: U.S. Geological Survey Hydrologic Investigations Atlas HA-194, scale 1:5,000,000

Montgomery, E.L., and Harshbarger, J.W., 1989, Arizona hydrogeology and water supply, in Jenny, J.P., and Reynolds, S.J., eds., Geologic evolution of Arizona: Arizona Geological Society Digest 17, p. 827-840.

Montgomery, E.L., and Harsharger, J.W., 1992, Arizona hydrogeology and water supply: Applied Hydrogeology, v. 1, no. 1, p. 25-37.

Oppenheimer, J.M., 1980, Gravity modeling of the alluvial basins, southern Arizona: Tucson, University of Arizona, M.S. thesis, 81 p.

Oppenheimer, J.M., and Sumner, J.S., 1981, Gravity modeling of the basins in the Basin and Range Province, Arizona: Arizona Geological Society Digest, v. 13, p. 111-115, 1 sheet, scale 1:1,000,000.

Peirce, H.W., and Scurlock, J.R., 1972, Arizona well information: Arizona Bureau of Mines Bulletin 185, 195 p. [reprinted 1988, Arizona Geological Survey].

Pima Association of Governments, 1998, Summary and evaluation of Cienega Creek surface water and groundwater monitoring program volumes I & II.

Pima Association of Governments, 1979, Upper Santa Cruz groundwater quality baseline report.

Pima Association of Governments, 2007, Water usage near shallow groundwater in Pima County.

Pima Association of Governments, 2005, Groundwater conditions in Sopori Basin.

Pima Association of Governments, 2005, Clearwater Renewable Resource Facility stable isotope study: 2004 monitoring report.

Pima Association of Governments, 1980, The Impact of Urban Runoff: Assessment of the Potential for Groundwater Pollution as a Result of Urban Runoff in the Tucson Area.

Pima Association of Governments, 1983, Assessment of nitrate in groundwater of the upper Santa Cruz basin.

Pool, D.R., 1984, Aquifer geology of alluvial basins of Arizona, in Repogle, J.A., and Renard, K.G., eds., Water today and tomorrow, Specialty Conference, Irrigation and Drainage Division of the American Society of Civil Engineers, Flagstaff, Arizona, July 24-26, 1984, Proceedings: American Society of Civil Engineers, p. 683-690.

Pool, D.R., 1986, Aquifer geology of alluvial basins of Arizona, in Anderson, T.W., and Johnson, A.I., eds., Regional aquifer systems of the United States – southwest alluvial basins of Arizona: Bethesda, Md., American Water Resources Association Monograph Series no. 7, p. 25-36.

Pool, D.R., 2005, Variations in climate and ephemeral channel recharge in southeastern Arizona, United States, Water Resources Research, v. 41, W11403, doi:10,1029/2004WR003255.

Robertson, F.N., 1984, Trace elements in ground water in southern Arizona [abs.], in Repogle, J.A., and Renard, K.G., eds., Water today and tomorrow, Specialty Conference, Irrigation and Drainage Division of the American Society of Civil Engineers, Flagstaff, Arizona, July 24-26, 1984, Proceedings: American Society of Civil Engineers, p. 674.

Robertson, F.N., 1986, Occurrence and solubility controls of trace elements in ground water in alluvial basins of Arizona, in Anderson, T.W., and Johnson, A.I., eds., Regional aquifer systems of the United States – southwest alluvial basins of Arizona: Bethesda, Md., American Water Resources Association Monograph Series no. 7, p. 69-80.

Robertson, F.N., 1989, Ground-water geochemistry and information transfer in alluvial basins in Arizona [abs.], in International Geological Congress, 28th, Washington, D.C., July 9-19, 1989, Abstracts, v. 2., p. 709-710: International Geological Congress, p. 2.709-2.710.

Robertson, F.N., 1989, Arsenic in ground-water under oxidizing conditions, south-west United States: Environmental Geochemistry and Health, v. 11, no. 3/4. p. 171-185.

Robertson, F.N., 1991, Geochemistry of ground water in alluvial basins of Arizona and adjacent parts of Nevada, New Mexico, and California, 1991: U.S. Geological Survey Professional Paper 1406-C, 90 pp.

Robertson, F.N., and Garrett, W.B., 1988, Distribution of fluoride in ground water in the alluvial basins of Arizona and adjacent parts of California, Nevada, and New Mexico: U.S. Geological Survey Hydrologic Investigations Atlas HA-665, 3 sheets, scale 1:500,000.

Robson, S.G., and Banta, E.R., 1995, Ground water atlas of the United States, Segment 2, Arizona, Colorado, New Mexico, Utah: U.S. Geological Survey Hydrologic Investigations Atlas HA-730-C, 32 p.

Saltus, R.W., and Jachens, R.C., Gravity and basin-depth maps of the Basin and Range Province, western United States: U.S. Geological Survey Geophysical Investigations Map GP-1012, 1 sheet, scale 1:2,500,000.

Sargent, K.A., and Bedinger, M.S., 1985, Geologic and hydrologic characterization and evaluation of the Basin and Range Province relative to the disposal of high-level radioactive waste, Part II, Geologic and hydrologic characterization: U.S. Geological Survey Circular 904-B, 30 p.

Schumann, H.H., 1988, U.S. Geological Survey ground-water studies in Arizona: U.S. Geological Survey Open-File Report 88-164, 2 p.

Schumann, H.H., Tosline, D.J., and Wrege, B.M., 1984, Occurrence and prediction of earth-fissure hazards caused by ground-water depletion in south-central Arizona, U.S.A. [abs.], *in* Repogle, J.A., and Renard, K.G., eds., Water today and tomorrow, Specialty Conference, Irrigation and Drainage Division of the American Society of Civil Engineers, Flagstaff, Arizona, July 24-26, 1984, Proceedings: American Society of Civil Engineers, p. 673.

Scott, P.S., Mac Nish, R.D. and Maddock, T. III, 1997, Effluent Recharge to the Upper Santa Cruz River Floodplain Aquifer, Santa Cruz County, Arizona: University of Arizona, Arizona Research Laboratory for Riparian Studies.

Simpson, R.W., Jachens, R.C., Saltus, R.W., and Blakely, R.J., 1986, Isostatic residual gravity, topographic, and first-vertical-derivative gravity maps of the conterminous United States: U.S. Geological Survey Geophysical Investigations Map GP-0975, 2 sheets, scale 1:7,500,000.

Smith, C.F., Anning, D.W., Duet, N.R., Fisk, G.G., McCormack, H.F., Pope, G.L., Rigas, P.D., and Wallace, B.L., 1995, Water resources data, Arizona, water year 1994: U.S. Geological Survey Water-Data Report AZ-94-1, 320 p.

Smith, C.F., Boner, F.C., Davis, R.G., Duet, N.R., and Rigas, P.D., 1993, Water resources data, Arizona, water year 1992: U.S. Geological Survey Water-Data Report AZ-92-1, 360 p.

Smith, C.F., Duet, N.R., Fisk, G.G., McCormack, H.F., Partin, C.K., Pope, G.L., Rigas, P.D., and Tadayon, S., 1996, Water resources data, Arizona, water year 1995: U.S. Geological Survey Water-Data Report AZ-95-1, 306 p.

Smith, C.F., Duet, N.R., Fisk, G.G., McCormack, H.F., Partin, C.K., Pope, G.L., and Rigas, P.D., 1997, Water resources data, Arizona, water year 1996: U.S. Geological Survey Water-Data Report AZ-96-1, 328 p.

Smith, C.F., Rigas, P.D., Ham, L.K., Duet, N.R., and Anning, D.W., 1994, Water resources data, Arizona, water year 1993: U.S. Geological Survey Water-Data Report AZ-93-1, 360 p.

Smith, G.E.P., 1938, The physiography of Arizona valleys and the occurrence of ground water: Tucson, University of Arizona, College of Agriculture, Agricultural Experiment Station, Technical Bulletin no. 77, 91 p.

Spencer, J.E., 2002, Natural occurrence of arsenic in Southwest ground water: Southwest Hydrology, v. 1, no. 1, p. 14-15.

Spicer, L.M., and Van De Vanter, E.K., comps., 1993, Activities of the Water Resources Division in Arizona, 1986-91: U.S. Geological Survey Open-File Report 93-165, 144 p.

Stone, C., and Witcher, J.C., 1982, Geothermal energy in Arizona – Final Contract Report: Arizona Bureau of Geology and Mineral Technology Open-File Report 83-12, 398 p.

Stover, C.W., 1986, Seismicity map of the conterminous United States and adjacent areas, 1975-1984: U.S. Geological Survey Geophysical Investigations Map GP-984, 1 sheet, scale 1:5,000,000.

Thomas, B.E., Hjalmarzon, H.W., and Waltemeyer, S.D., 1994, Methods for estimating magnitude and frequency of floods in the southwestern United States: U.S. Geological Survey Open-File Report 93-419, 211 p.

Tucci, P., 1989, Geophysical methods for water-resources studies in southern and central Arizona, in Symposium on the Application of Geophysics to Engineering and Environmental Problems, Proceedings: Denver, Society of Engineering and Mineral Exploration Geophysicists, p. 368-383.

Tucci, P., and Pool, D.R., 1986, Use of geophysics for geohydrologic studies in the alluvial basins of Arizona, *in* Anderson, T.W., and Johnson, A.I., eds., Regional aquifer systems of the United States – southwest alluvial basins of Arizona: Bethesda, Md., American Water Resources Association Monograph Series no. 7, p. 37-56.

Underground Water Commission 1953, The underground water resources of Arizona: Phoenix, Arizona., Underground Water Commission, 174 p.

U.S. Geological Survey, 1970, 1969 water resources data for Arizona – Part 1. Surface water records: U.S. Geological Survey, 251 p.

U.S. Geological Survey, 1971, 1971 water resources data for Arizona – Part 1. Surface water records: U.S. Geological Survey, 253 p. [NTIS PB-287 164].

U.S. Geological Survey, 1971, 1971 water resources data for Arizona – Part 2. Water quality records: U.S. Geological Survey Water-Resources Data Report, 167 p. [NTIS PB-287 165].

U.S. Geological Survey, 1972, 1972 water resources data for Arizona – Part 1. Surface water records: U.S. Geological Survey Water-Resources Data Report, 263 p. [NTIS PB-287 166].

U.S. Geological Survey, 1972, 1972 water resources data for Arizona – Part 2. Water quality records: U.S. Geological Survey Water-Resources Data Report, 166 p. [NTIS PB-287 167].

U.S. Geological Survey, 1973, 1973 water resources data for Arizona – Part 1. Surface water records: U.S. Geological Survey Water-Resources Data Report, 257 p. [NTIS PB-287 168].

U.S. Geological Survey, 1973, 1973 water resources data for Arizona – Part 2. Water quality records: U.S. Geological Survey Water-Resources Data Report, 188 p., [NTIS PB-287 169].

U.S. Geological Survey, 1974, 1974 water resources data for Arizona – Part 1. Surface water records: U.S. Geological Survey, [247] p. [NTIS PB-287 170].

U.S. Geological Survey, 1974, 1974 water resources data for Arizona – Part 2. Water quality records: U.S. Geological Survey, 192 p. [NTIS PB-287 171].

U.S. Geological Survey, 1976, Water resources data for Arizona, water year 1975: U.S. Geological Survey Water-Data Report AZ-75-1, 440 p.

U.S. Geological Survey, 1978, Water resources data for Arizona, water year 1977: U.S. Geological Survey Water-Data Report AZ-77-1, 550 p.

U.S. Geological Survey, 1978, Annual summary of ground-water conditions in Arizona, spring 1977 to spring 1978: U.S. Geological Survey Water-Resources Investigations Open-File Report 78-144, 1 sheet, scale 1:1,000,000.

U.S. Geological Survey, 1979, Water resources data for Arizona, water year 1978: U.S. Geological Survey Water-Data Report AZ-78-1, 604 p.

U.S. Geological Survey, 1980, Water resources data for Arizona, water year 1979: U.S. Geological Survey Water-Data Report AZ-79-1, 614 p.

U.S. Geological Survey, 1980, Annual summary of ground-water conditions in Arizona, spring 1978 to spring 1979: U.S. Geological Survey Water-Resources Investigations Open-File Report 80-330, 1 sheet, scale 1:1,000,000.

U.S. Geological Survey, 1981, Annual summary of ground-water conditions in Arizona, spring 1979 to spring 1980: U.S. Geological Survey Water-Resources Investigations Open-File Report 81-906, 2 sheets, scale 1:1,000,000.

U.S. Geological Survey, 1982, Annual summary of ground-water conditions in Arizona, spring 1980 to spring 1981: U.S. Geological Survey Water-Resources Investigations Open-File Report 82-368, 2 sheets, scale 1:1,000,000.

U.S. Geological Survey, 1982, Water resources data for Arizona, water year 1980: U.S. Geological Survey Water-Data Report AZ-80-1, 568 p.

U.S. Geological Survey, 1983, Water resources data for Arizona, water year 1981: U.S. Geological Survey Water-Data Report AZ-81-1, 532 p.

U.S. Geological Survey, 1983, Annual summary of ground-water conditions in Arizona, spring 1981 to spring 1982: U.S. Geological Survey Water-Resources Investigations Open-File Report 82-368, 2 sheets, scales 1:1,000,000 and 1:3,200,000.

U.S. Geological Survey, 1984, Annual summary of ground-water conditions in Arizona, spring 1982 to spring 1983: U.S. Geological Survey Water-Resources Investigations Open-File Report 84-428, 2 sheets, scales 1:1,000,000 and 1:3,300,000.

U.S. Geological Survey, 1985, Annual summary of ground-water conditions in Arizona, spring 1983 to spring 1984: U.S. Geological Survey Water-Resources Investigations Open-File Report 85-410, 2 sheets, scales 1:1,000,000 and 1:3,400,000.

U.S. Geological Survey, 1986, Annual summary of ground-water conditions in Arizona, spring 1984 to spring 1985: U.S. Geological Survey Water-Resources Investigations Open-File Report 86-422, 2 sheets, scales 1:1,000,000 and 1:3,300,000.

U.S. Geological Survey, [1962?], Surface water records of Arizona – 1961: U.S. Geological Survey, 167 p.

U.S. Geological Survey, [1963?], Surface water records of Arizona – 1962: U.S. Geological Survey, 185 p.

U.S. Geological Survey, [1964?], Surface water records of Arizona – 1963: U.S. Geological Survey, 191 p.

U.S. Geological Survey, [1965?], Surface water records of Arizona – 1964: U.S. Geological Survey, 206 p.

U.S. Geological Survey, [1965?], Water quality records in Arizona – 1964: U.S. Geological Survey, 80 p.

U.S. Geological Survey, [1966?], 1965 water resources data for Arizona – Part 2. Water quality records: U.S. Geological Survey, 89 p.

U.S. Geological Survey, [1966?], 1965 water resources data for Arizona – Part 1. Surface water records: U.S. Geological Survey, 212 p.

U.S. Geological Survey, [1967?], 1966 water resources data for Arizona – Part 1. Surface water records: U.S. Geological Survey, 230 p.

U.S. Geological Survey, [1968?], 1967 water resources data for Arizona – Part 2. Water quality records: U.S. Geological Survey, 85 p.

White, N.D., and others, 1967, Annual report on ground water in Arizona, spring 1964 to spring 1965: Arizona State Land Department Water Resources Report no. 24, 62 p.

White, N.D., and Garrett, W.B., 1984, Water resources data, Arizona, water year 1982: U.S. Geological Survey Water-Data Report AZ-82-1, 440 p.

White, N.D., and Garrett, W.B., 1986, Water resources data, Arizona, water year 1983: U.S. Geological Survey Water-Data Report AZ-83-1, 387 p.

White, N.D., and Garrett, W.B., 1987, Water resources data, Arizona, water year 1984: U.S. Geological Survey Water-Data Report AZ-84-1, 381 p.

White, N.D., and Garrett, W.B., 1988, Water resources data, Arizona, water year 1985: U.S. Geological Survey Water-Data Report AZ-85-1, 343 p.

White, N.D., Stulik, R.S., and others, 1962, Annual report on ground water in Arizona, spring 1961 to spring 1962: Arizona State Land Department Water Resources Report no. 11, 116 p.

White, N.D., Stulik, R.S., Morse, E.K., and others, 1961, Annual report on ground water in Arizona, spring 1960 to spring 1961: Arizona State Land Department Water Resources Report no. 10, 93 p.

White, N.D., Stulik, R.S., Morse, E.K., and others, 1963, Annual report on ground water in Arizona, spring 1962 to spring 1963: Arizona State Land Department Water Resources Report no. 15, 136 p.

White, N.D., Stulik, R.S., Morse, E.K., and others, 1964, Annual report on ground water in Arizona, spring 1963 to spring 1964: Arizona State Land Department Water Resources Report no. 19, 60 p.

Wilson, R.P., 1990, Arizona water supply and use, *in* Carr, J.E., Chase, E.B., Paulson, R.W., and Moody, D.W., National water summary 1987 – Hydrologic events and water supply and uses: U.S. Geological Survey Water-Supply Paper 2350, p. 157-164.

Wilson, R.P., and Garrett, W.B., 1988, Water resources data, Arizona, water year 1986: U.S. Geological Survey Water-Data Report AZ-86-1, 341 p.

Wilson, R.P., and Garrett, W.B., 1989, Water resources data, Arizona, water year 1987: U.S. Geological Survey Water-Data Report AZ-87-1, 385 p.

Witcher, J.C., 1979, Proven, potential, and inferred geothermal resources of Arizona and their heat contents: Arizona Bureau of Geology and Mineral Technology Open-File Report 79-05, 64 p., 1 sheet, scale 1:1,000,000 [also published in Pasadena, California Institute of Technology, Jet Propulsion Laboratory Publication 80-41, p. A-3 to A-74.

Witcher, J.C., Stone, C., and Haman, W.R., Sr., 1982, Geothermal resources of Arizona: Arizona Bureau of Geology and Mineral Technology [also listed as Arizona Geological Survey Map 15-2], 1 sheet, scale 1:500,000.

4. Surface Water Hydrology and Sediment References

Anderson, T.W., and White, N.D., 1986, Arizona surface-water resources, in Moody, D.W., Chase, E.B., and Aronson, D.A., comps., National water summary, 1985 – Hydrologic events and surface-water resources: U.S. Geological Survey Water-Supply Paper 2300.

Condes de la Torre, A., 1970, Streamflow in the upper Santa Cruz River basin, Santa Cruz and Pima Counties, Arizona: U.S. Geological Survey Water Supply Paper 1939-A.

Parker, J.T., Channel change on the Santa Cruz River, Pima County, Arizona, 1936-86: U.S. Geological Survey Water Supply Paper 2429.

Pima Association of Governments, 1998, Summary and evaluation of Cienega Creek surface water and groundwater monitoring program volumes I & II.

Pima Association of Governments, 2003, Geologic influences on the hydrology of lower Cienega Creek.

Pima Association of Governments, 2003, Contribution of Davidson Canyon to base flows in Cienega Creek.

Pima Association of Governments, 2002, The water quality of priority streams in Pima County.

Pima Association of Governments, 2002, Changes in channel morphology along lower Cienega Creek, Cienega Creek Natural Preserve, 1980-1998.

Pima Association of Governments, 2000, Cienega Creek stormflow analysis.

Pima Association of Governments, 2000, Lower Cienega basin source water study.

Pima Association of Governments, 2000, Sonoran Desert Conservation Plan, water usage along selected streams in Pima County, Arizona.

Pima Association of Governments, 2000, Sonoran Desert Conservation Plan, GIS coverages perennial streams, intermittent streams and areas of shallow groundwater.

Pima Association of Governments, 1990, Unique Waters final nomination report for Cienega Creek Natural Preserve, Pima County, Arizona.

Reich, B.M., and Davis, D.R., 1985, 1983 Santa Cruz Flood: How Should Highway Engineers Respond: Transportation Research Record no. 1017, p. 1-8,

Rhoads, B.L., 1991, Impact of Agricultural Development on Regional Drainage in the Lower Santa Cruz Valley, Arizona, U.S.A: Environmental Geology and Water Sciences EGWSEI, v. 18, no. 2, p. 119-135.

Webb, R. H., and Betancourt, J. L., 1990, Climatic variability and flood frequency of the Santa Cruz River, Pima County, Arizona: U.S. Geological Survey Open-File Report 90-553, 69 p.

5. General References

Tellman, B., Yarde, R., and Wallace, M.G., 1997, Arizona’s changing rivers: how people have affected the rivers, University of Arizona, Water Resources Research Center Issue Paper no. 19, 198 p.

Varady, R.G., and Mack, M.D., 1995, Transboundary water resources and public health in the U.S.-Mexico Border Region: Journal of Environmental Health, v. 57.

Appendix C: Revised Universal Soil Loss Equation (RUSLE) Modeling

The Revised Universal Soil Loss Equation (RUSLE) was used to model erosion potential. RUSLE computes average annual erosion from field slopes as (Renard, 1997):

$$A = R*K*L*S*C*P$$

Where:

A = computed average annual soil loss in tons/acre/year.
R = rainfall-runoff erosivity factor
K = soil erodibility factor
L = slope length factor
S = slope steepness factor
C = cover-management factor
P = Conservation Practice

The modeling was conducted in the ArcInfo Grid environment using SEDMOD, Van Remortel's (2006) Soil & Landform Metrics program. This is a series of Arc Macro Language (AML) programs and C++ executables that are run sequentially to prepare the data and run the RUSLE model. A 30-meter cell size was used to correspond to the requirements of the program.

All of the required input spatial data layers were converted to the projection required by the program (USGS Albers NAD83) and placed in the appropriate directories. The input data layers include:

- USGS Digital Elevation Model (DEM). The DEM was modified by multiplying it by 100 and converting it to an integer grid as prescribed by the program.
- Master watershed boundary grid (created from USGS DEM).
- National Land Cover Dataset (NLCD) land cover grid.
- Land mask grid for open waters, such as oceans or bays, derived from the NLCD land cover data. No oceans or bays are present in this watershed, so no cells were masked.

The first component AML of the program sets up the 'master' soil and landform spatial datasets for the study area. This includes extracting the STATSGO soil map and attributes as well as the R, C, and P factors, from datasets that are provided with the program. The R-factor is rainfall-runoff erosivity, or the potential of rainfall-runoff to cause erosion. The C-factor considers the type of cover or land management on the land surface. The P-factor looks at conservation practices, such as conservation tillage.

Additionally, a stream network is delineated from the DEM using the default threshold of 100 30x30 meter cells as the contributing area for stream delineation. The AML also creates the K factor grid. The K factor considers how susceptible a soil type is to erosion.

The second component AML sets up additional directory structures for any defined subwatersheds. In this use of the model the entire Salt Watershed was modeled as a single unit, with 27 subwatersheds.

The third component AML iteratively computes a set of soil parameters derived from the National Resource Conservation Service's State Soil Geographic (STATSGO) Dataset.

The fourth component AML calculates the LS factor according to the RUSLE criteria using DEM-based elevation and flow path. The L and S factors take into account hill slope length and hill slope steepness.

The fifth component AML runs RUSLE and outputs R, K, LS, C, P factor grids and an A value grid that contains the modeled estimate of erosion in tons/acre/year for each cell.

References:

Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, and D.C. Yoder. 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). United States Department of Agriculture, Agriculture Handbook No. 703. USDA, Washington D.C.

Van Remortel, R. and D. Heggem. 2006. SEDMOD, Version 2 (Update 1) of Soil & Landform Metrics: Programs and U.S. Geodatasets (CD). U.S. Environmental Protection Agency, Environmental Sciences Division, Landscape Ecology Branch, Las Vegas, NV.

Data Sources*:

U.S. Department of Agriculture, Natural Resources Conservation Service.
Major Land Resource Area Map, National Land Cover Dataset (NLCD). July 15, 2003. ftp-fc.sc.egov.usda.gov/NHQ/pub/land/arc_export/us48mlra.e00.zip

State Soils Geographic (STATSGO) Dataset. April 17, 2003. http://www.ncgc.nrcs.usda.gov/branch/ssb/products/statsgo/

U.S. Geological Survey.
National Elevation Dataset 30-Meter Digital Elevation Models (DEMs). April 8, 2003. http://gisdata.usgs.net/NED/default.asp

**Note: Dates for each data set refer to when data was downloaded from the website. Metadata (information about how and when the GIS data were created) is available from the website in most cases. Metadata includes the original source of the data, when it was created, its geographic projection and scale, the name(s) of the contact person and/or organization, and general description of the data.*

Appendix D: Automated Geospatial Watershed Assessment Tool – AGWA

The Automated Geospatial Watershed Assessment (AGWA) tool is a multipurpose hydrologic analysis system for use by watershed, water resource, land use, and biological resource managers and scientists in performing watershed- and basin-scale studies (Burns et al., 2004). It was developed by the U.S.D.A. Agricultural Research Service's Southwest Watershed Research Center. AGWA is an extension for the Environmental Systems Research Institute's (ESRI) ArcView 3.x or ArcMap 9.x, widely used geographic information system (GIS) software packages.

AGWA provides the functionality to conduct all phases of a watershed assessment for two widely used watershed hydrologic models: the Soil and Water Assessment Tool (SWAT); and the KINematic Runoff and EROSion model, KINEROS2.

The watershed assessment for the Salt Watershed was performed with the Soil and Water Assessment Tool. SWAT (Arnold et al., 1994) was developed by the USDA Agricultural Research Service (ARS) to predict the effect of alternative land management decisions on water, sediment and chemical yields with reasonable accuracy for ungaged rural watersheds. It is a distributed, lumped-parameter model that will evaluate large, complex watersheds with varying soils, land use and management conditions over long periods of time (> 1 year). SWAT is a continuous-time model, i.e. a long-term yield model, using daily average input values, and is not designed to simulate detailed, single-event flood routing. Major components of the model include: hydrology, weather generator, sedimentation, soil temperature, crop growth, nutrients, pesticides, groundwater and lateral flow, and agricultural management. The Curve Number method is used to compute rainfall excess, and flow is routed through the channels using a variable storage coefficient method developed by Williams (1969). Additional information and the latest model updates for SWAT can be found at http://www.brc.tamus.edu/swat/.

Data used in AGWA include Digital Elevation Models (DEMs), land cover grids, soil data and precipitation data.

For this study data were obtained from the following sources:

- DEM: United States Geological Survey Seamless Data Distribution System, National Elevation Dataset, 30-Meter Digital Elevation Models (DEMs). April 10, 2008. http://seamless.usgs.gov/website/seamless/index.htm

- Soils: USDA Natural Resource Conservation Service, STATSGO Soils. April 17, 2003. http://www.soils.usda.gov/survey/geography/statsgo/

- Land cover: Southwest GAP Analysis Project Regional Provisional Land Cover dataset. September, 2004. http://earth.gis.usu.edu/swgap/

- Precipitation Data: Cooperative Summary of the Day TD3200: Includes daily weather data from the Western United States and the Pacific Islands. Version 1.0. August 2002. National Oceanic and Atmospheric Administration/National Climatic Data Center, Asheville, North Carolina.

The AGWA Tools menu is designed to reflect the order of tasks necessary to conduct a watershed assessment, which are broken out into five major steps, as shown in Figure 1 and listed below:

1. Watershed delineation and discretization;
2. Land cover and soils parameterization;
3. Writing the precipitation file for model input;
4. Writing the input parameter file and running the chosen model; and
5. Viewing the results.

When following these steps, the user first creates a watershed outline, which is a grid based on the accumulated flow to the designated outlet (pour point) of the study area. The user then specifies the contributing area for the establishment of stream channels and subwatersheds (model elements) as required by the model of choice.

From this point, the tasks are specific to the model that will be used, which in this case is SWAT. If internal runoff gages for model validation or ponds/reservoirs are present in the discretization, they can be used to further subdivide the watershed.

The application of AGWA is dependent on the presence of both land cover and soil GIS coverages. The watershed is intersected with these data, and parameters necessary for the hydrologic model runs are determined through a series of look-up tables. The hydrologic parameters are added to the watershed polygon and stream channel tables.

For SWAT, the user must provide daily rainfall values for rainfall gages within and near the watershed. If multiple gages are present, AGWA will build a Thiessen polygon map and create an area-weighted rainfall file. Precipitation files for model input are written from uniform (single gage) rainfall or distributed (multiple gage) rainfall data.

In this modeling process, the precipitation file was created for a 10-year period (1990-2000) based on data from the National Climatic Data Center. In each study watershed multiple gages were selected based on the adequacy of the data for this time period. The precipitation data file for model input was created from distributed rainfall data.

After all necessary input data have been prepared, the watershed has been subdivided into model elements, hydrologic parameters have been determined for each element, and rainfall files have been prepared, the user can run the hydrologic model of choice. SWAT was used in this application.

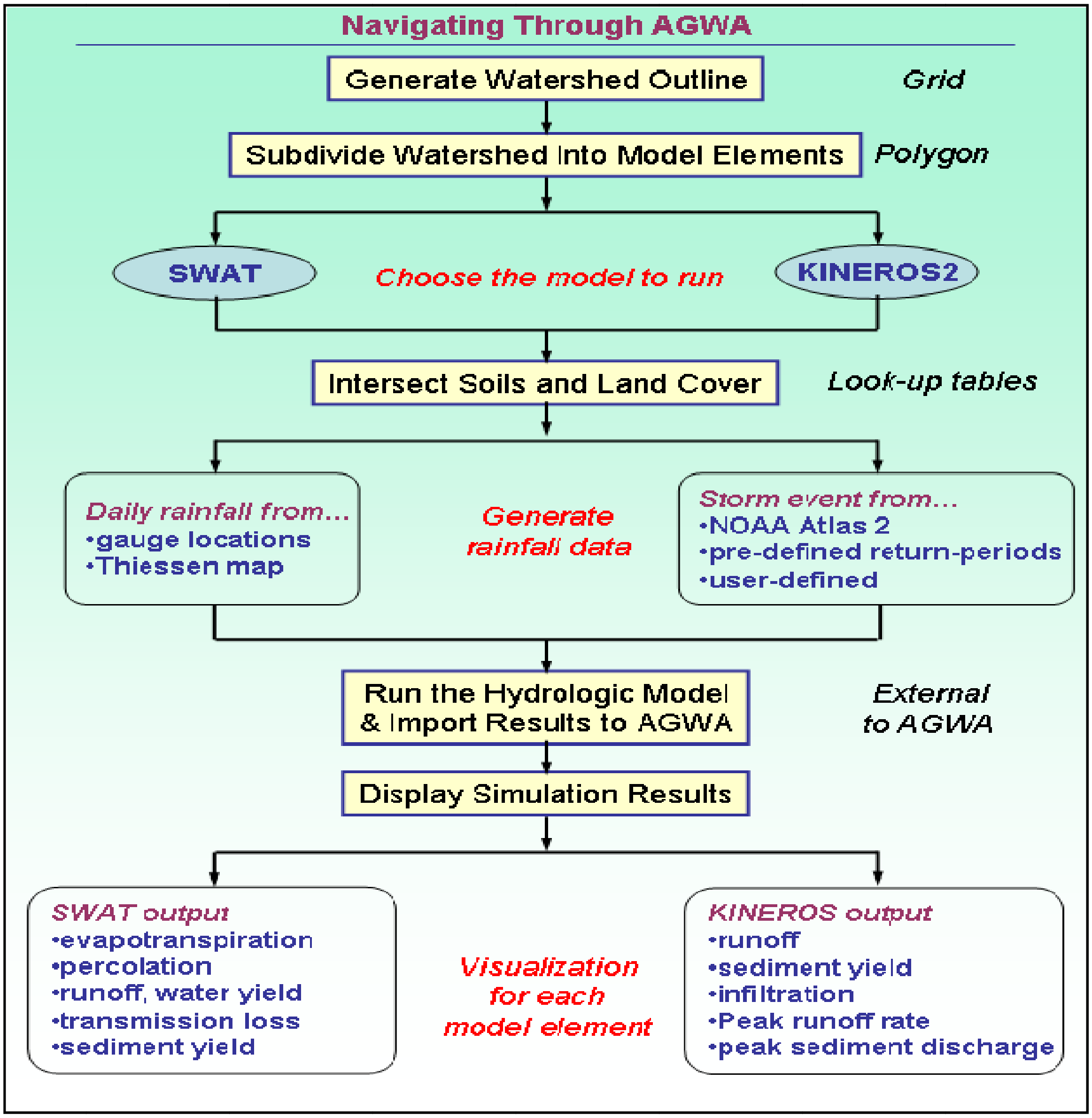

Figure D-1: Flow chart showing the general framework for using KINEROS2 and SWAT in AGWA.

After the model has run to completion, AGWA will automatically import the model results and add them to the polygon and stream map tables for display. A separate module within AGWA controls the visualization of model results. The user can toggle between viewing the total depth or accumulated volume of runoff, erosion, and infiltration output for both upland and channel elements. This enables problem areas to be identified visually so that limited resources can be focused for maximum effectiveness. Model results can also be overlaid with other digital data layers to further prioritize management activities.

Output variables available in AGWA/SWAT are:

- Channel Discharge (m^3/day);
- Evapotranspiration (ET) (mm);
- Percolation (mm);
- Surface Runoff (mm);
- Transmission loss (mm);
- Water yield (mm);
- Sediment yield (t/ha); and
- Precipitation (mm).

It is important to note that AGWA is designed to evaluate relative change and can only provide qualitative estimates of runoff and erosion. It cannot provide reliable quantitative estimates of runoff and erosion without careful calibration. It is also subject to the assumptions and limitations of its component models, and should always be applied with these in mind.

References:

Arnold, J.G., J. R. Williams, R. Srinivasan, K.W. King, and R. H. Griggs. 1994. SWAT-Soil & Water Assessment Tool. USDA, Agricultural Research Service, Grassland, Soil and Water Research Laboratory, Temple, Texas.

Burns, I.S., S. Scott, L. Levick, M. Hernandez, D.C. Goodrich, S.N. Miller, D.J. Semmens, and W.G. Kepner. 2004. Automated Geospatial Watershed Assessment (AGWA) - A GIS-Based Hydrologic Modeling Tool: Documentation and User Manual *Version 1.4*. http://www.tucson.ars.ag.gov/agwa/

RS/GIS Laboratory, 2004. Southwest Gap Regional Provisional Landcover. http://earth.gis.usu.edu/swgap
Land cover / land use. Sept. 24, 2004.

Williams, J.R. 1969. Flood routing with variable travel time or variable storage coefficients. Trans. ASAE 12(1):100-103.