NEMO Watershed Based Plan

Bill Williams Watershed

ADEQ Arizona Department of Environmental Quality

The University of Arizona, Tucson Arizona

Arizona Cooperative Extension, The University of Arizona • College of Agriculture and Life Sciences

Water Resources Research Center

Acknowledgements

Arizona NEMO acknowledges the University of Arizona Cooperative Extension Service, Arizona Department of Environmental Quality (ADEQ) Water Quality Division, the Water Resources Research Center, and the University of Arizona Advanced Resource Technology Lab (ART) for their technical support in producing the Watershed Based Plans.

Funding provided by the U.S. Environmental Protection Agency under the Clean Water Act and the Arizona Department of Environmental Quality's Water Quality Protection Division. Additional financial support is provided by the University of Arizona, Technology and Research Initiative Fund (TRIF), Water Sustainability Program through the Water Resources Research Center.

The NEMO website is www.ArizonaNEMO.org.

Written and prepared by:
Hoori Ajami, D. Phillip Guertin, Lainie R. Levick and Kristine Uhlman
University of Arizona
Tucson, Arizona

December 2005

Table of Contents

List of Figures

List of Tables

Appendices

Bill Williams Watershed Executive Summary

The objective of this study was to develop a watershed based plan for the Bill Williams Watershed that includes a characterization and classification of the watershed features. This watershed based plan identifies areas that are susceptible to water quality problems and nonpoint pollution sources that need to be controlled, and management measures that should be implemented to improve water quality throughout the watershed.

The first part of the project focused on watershed characterization identifying physical, biological and social characteristics of the Bill Williams Watershed from publicly available information. ArcGIS (Environmental Systems Research Institute, Inc.) software was used to construct a spatial database including topography, land cover, soil types and characteristics, geology, vegetation, hydrologic features, and population characteristics.

After developing the geographic information system (GIS) spatial database, watershed classifications were performed to identify important resources and rank 10-digit HUC (hydrologic unit code) subwatershed areas based on likelihood of nonpoint source pollutant contribution to stream water quality degradation. A HUC is a means of subdividing watersheds into successively smaller hydrologic units of surface water drainage features.

To achieve the objective of developing a watershed based plan, a fuzzy logic knowledge-based methodology was applied to integrate the various spatial and non-spatial data types. Fuzzy logic is an approach to handle vagueness or uncertainty, and has been characterized as a method by which to quantify common sense. This methodology has been selected as the basis by which subwatershed areas and stream reaches were prioritized for proposed implementation of Best Management Practices to assure load reductions of constituents of concern.

The water quality results reported in Arizona's Integrated 305(b) Assessment and 303(d) Listing Report (ADEQ, 2003), and EPA's (U.S. Environmental Protection Agency) revisions of Arizona's final 2004 303d List for water quality results were reviewed and summarized for each monitored stream reach in the Bill Williams Watershed. Based on exceedances of water quality standards in each reach and the designated use classification system, each stream reach was classified as extreme, high, medium or low risk of impairment. Each subwatershed was then ranked using a scale of 0-1 based on the stream reach condition in each 10-digit HUC and downstream reach condition.

Subwatershed classification ranking data were then created based on calculated parameters for each of the water quality constituent groups and by simulating hydrologic response using the GIS data. For each constituent group several parameters were calculated in each subwatershed and a fuzzy membership value (FMV) was developed in order to assign a ranked value (0-1) to each 10-digit HUC subwatershed. The FMV for each parameter and the ranked water quality assessment data were combined, and each subwatershed was ranked and categorized as either low or high risk for nonpoint source pollution problems.

The Revised Universal Soil Loss Equation (RUSLE) model (USDA, 1997) was used to estimate sediment yield due to land use or land use change. The Soil and Water Assessment Tool (SWAT) hydrologic model (Arnold et al., 1994) within the Automated Geospatial Watershed Assessment Tool (AGWA) (Burns et al., 2004) was also applied to simulate sediment yield and runoff for each 10-digit HUC subwatershed area.

Unique Waters of the state, mapped wilderness areas and preserves, riparian areas, and critical habitat for endangered species were used to identify important Natural Resource Areas (NRA) at the scale of 10-digit HUC subwatersheds in the Upper Gila Watershed. These were then used to recommend management actions specific to the conditions in each NRA.

Best Management Practices (BMPs) for each subwatershed were proposed based on the watershed assessment data and available ADEQ Total Maximum Daily Load (TMDL) reports. The management section of the document includes general watershed management methods, recommended strategies for addressing existing impairment in the watershed, stream channel and riparian restoration, and proposed education programs.

Based on the watershed classifications, a watershed-based plan was proposed that included potential water quality improvement projects for subwatersheds that were most susceptible to known water quality concerns. The plan discusses the pollutant type and source, load reduction calculations, and sample management measures.

References:

Arizona Department of Environmental Quality, ADEQ. DRAFT 2003, Status of Water Quality in Arizona – 2004: Arizona's Integrated 305(b) Assessment and 303(d) Listing Report, 1110 West Washington Ave., Phoenix, Arizona, 85007 www.adeq.state.az.us/environ/water/assessment/assess.html.

Arnold, J.G., J. R. Williams, R. Srinivasan, K.W. King, and R. H. Griggs. 1994. SWAT - Soil and 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/

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. Washington D.C.

Section 1: Introduction

Background

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 contamination of water resources from nonpoint sources of pollution. Nonpoint source pollution is the leading cause of water quality degradation across the United States, and is differentiated from point source pollution in that there are no regulatory mechanisms by which to enforce clean up of nonpoint source pollution.

Nonpoint source pollution originates 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, estuaries, coastal waters and ground water.

Nationally, the Nonpoint Education for Municipal Officials (NEMO) program has been very successful in helping to mitigate nonpoint source pollution. The goal of NEMO is to educate land-use decision makers to make proactive voluntary choices 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 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), Arizona Cooperative Extension at the University of Arizona (U of A) has initiated the Arizona NEMO program. Arizona NEMO is an attempt to adopt the 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's), education on water conservation, and riparian water quality restoration.

In collaboration with 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 for the Bill Williams Watershed. 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.

Based on 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.

- 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 this plan that is reasonably expeditious.
- Element 7: *Measurable Milestones.* A schedule of interim, measurable milestones for determining whether the management measures, Best Management Practices, or other control actions are being implemented.
- Element 8: *Evaluation of Progress.* A set of criteria that can be used to determine whether loading 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.

Watershed-based plans are holistic documents that are 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 will deliver proactive measures to protect water bodies. In watersheds where a TMDL has been developed and approved or is in the process of being developed, watershed-based plans must be designed to achieve the load reductions called for in the TMDL.

Purpose and Scope

This watershed-based plan includes a watershed classification that has been developed for the Bill Williams Watershed. The classification supports the watershed-based plan and provides educational outreach material to stakeholders and watershed partnerships. It provides an inventory of natural resources and environmental conditions that affect primarily surface water quality.

In addition to the classification, this plan provides methods and tools to identify problem sources and locations for implementation of Best Management Practices to mitigate nonpoint source pollution. Although these chapters are written based on current information, the tools developed can be used to update this report and reevaluate water quality concerns as new information becomes available.

The watershed characterization includes physical, biological, and social data in a geographic information system (GIS) database format, as both mapped and tabulated data, as collected from available existing and published data sources. No additional data were collected.

The characterization also includes descriptions of environmental attributes and identification of water quality problems by incorporating water quality data reported in *The DRAFT Status of Water Quality in Arizona – 2004: Arizona's Integrated 305(b) Assessment and 303(d) Listing Report* (ADEQ, 2005), 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 site across the state can be found at: www.adeq.state.az.us/environ/water/assessment/assess.html.

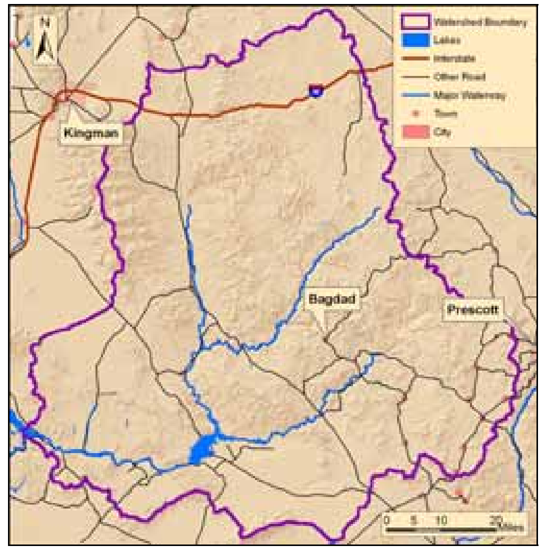
The watershed classification includes the identification of and mapping of important resources, and ranking of 10-digit HUC subwatersheds (defined later in this section) based on the likelihood of nonpoint source pollutant contribution to stream water quality degradation.

Following the classification, this watershed plan includes a management section with general discussions of recommended nonpoint source Best Management Practices that will need to be implemented to achieve the load reductions, as well as to achieve other watershed goals. 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.

Based on the watershed classification, a watershed-based plan is proposed that includes potential water quality improvement projects for subwatersheds that were determined to be most susceptible to known water quality concerns. The plan discusses the pollutant type and source, load reduction calculations, and sample management measures.

The Bill Williams Watershed is located in the west-central portion of the state of Arizona, bounded by the city of Prescott to the east, and Kingman to the northwest, as shown in Figure 1-1.

Figure 1-1: Bill Williams Watershed Location Map



<u>Methods</u>

GIS and hydrologic modeling were the major tools used to develop this watershed plan. In a GIS, two types of information represent geographic features: locational and descriptive data. Locational (spatial) data are stored using a vector or a raster 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, each of which is limited and defined by an equal amount of earth's surface. These units are of different shapes, i.e. triangular or hexagonal, but the most commonly used shape is the square, called a cell. Corresponding descriptive (attribute) data for each geographic feature are stored in a set of tables. The spatial and descriptive data are linked so that both sets of information are always available.

Planning and assessment in land and water resource management requires spatial modeling tools so as to incorporate complex watershed-scale attributes into the assessment process. Modeling tools applied to the Verde Watershed included AGWA, 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, and to simulate sediment load in the 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 Revised Universal Soil Loss Equation (RUSLE) was also used to estimate soil loss from different land use types (Renard et al., 1997).

The watershed classification 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, 2005), and simulate impacts due to mine sites (erosion and metals pollution) and grazing (erosion and pollutant nutrients).

The Bill Williams 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).

Within the six-digit HUC, subwatershed areas were delineated on the basis of the eight-digit cataloging HUC. The classifications and GIS modeling were conducted on the ten-digit HUC subwatershed areas.

Within this report, both HUC units and subwatershed names are used to clarify location. This watershed plan uses the following HUC watersheds:

- Bill Williams Watershed (H150302)
  - Big Sandy River (H15030201)
    - Markham Wash (1503020101)
    - Muddy Creek (1503020102)
    - Willow Creek (1503020103)
    - Trout Creek (1503020104)
    - Knight Creek (1503020105)
    - Upper Big Sandy River(1503020106)

Middle Big Sandy River (1503020107)
Lower Big Sandy River (1503020108)
Burro Creek (H15030202)
Francis Creek (1503020201)
Upper Burro Creek (1503020202)
Boulder Creek (1503020203)
Lower Burro Creek (1503020204)
Santa Maria River (H15030203)
Kirkland Creek (1503020301)
Sycamore Creek (1503020302)
Upper Santa Maria R. (1503020303)
Date Creek (1503020304)
Lower Santa Maria R. (1503020305)
Bill Williams River (H15030204)
Bullard Wash (1503020401)
Alamo Lake-Bill Williams River (1503020402)
Mohave Wash (1503020403)
Castaneda Wash-Bill Williams River (1503020404)

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 to be prioritized for the implementation of BMPs to assure nonpoint source pollution is managed.

Fuzzy logic is an approach to handle vagueness or uncertainty, and has been characterized 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. For example, one is either tall or short, 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 could not be considered ‘not-tall’. This is unsatisfactory, for example, if one has to describe or quantify 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 value 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. A user defines their membership functions to describe the relationship between an individual factor and the achievement of the stated goal. 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. Another 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.

Our general approach 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 1-2.

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 the watershed classification, the goal is to identify critical subwatersheds in which BMPs should be implemented to reduce nonpoint source pollution.

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 (For the Bill Williams, dissolved / total metals water quality impairment to streams due to mine activity);

2. Assemble GIS and other observation data; and

3. Define watershed characteristics through:
    a. water quality samples provided by ADEQ 's Integrated 305(b) Assessment and 303(d) Listing database;
    b. GIS mapping analysis; and
    c. Modeling / simulation of erosion vulnerability / potential for stream impairment (in this case, from soils in mine site areas and proximity to abandoned mine sites).

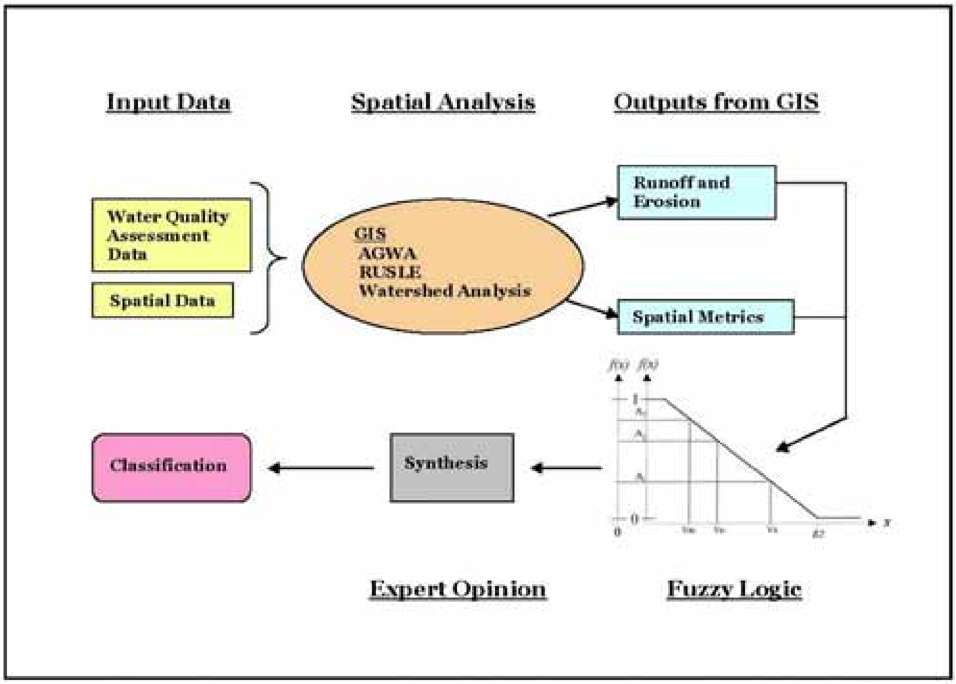
4. Use fuzzy membership functions to transform the vulnerability / impairment metrics into fuzzy membership values; and

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

Arizona's Integrated 305(b) Assessment and 303(d) Listing Report (ADEQ, 2005) was used to classify each monitored stream reach based on its relative risk of impairment for each of the chemical constituent groups. Four levels of risk where defined: extreme, high, moderate, and low. A water body is classified as 'extreme' risk if ADEQ has currently assessed it as being "Impaired" for a 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 an assessment.

Classifications were conducted at the 10-digit HUC watershed scale, resulting in the ranking of twenty-one subwatershed areas within the nearly 5,400 square mile area of the Bill Williams Watershed.

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



Structure of this Watershed Plan

Watershed characterizations, including physical, biological, and social characteristics, are discussed in Sections 2 through 4. Important environmental resources are discussed in Section 5, and 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, and the Watershed Plan is presented in Section 8. The full tabulation of the ADEQ water quality data and assessment status is provided in Appendix A.

Summary discussions of the modeling software, as well as suggested technical references of studies completed across the Verde Watershed are included in the remaining appendices.

References:

Arizona Department of Environmental Quality, ADEQ. 2005. The Status of Water Quality in Arizona – 2004: 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/2004.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.

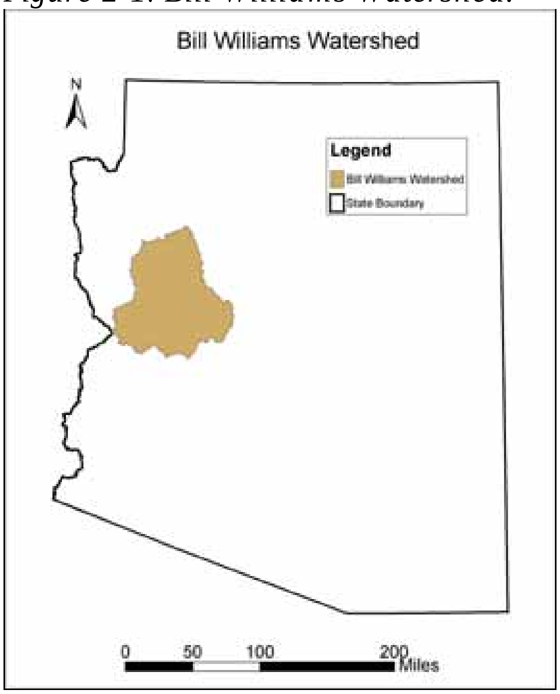
Reynolds, K.M. 2001. Fuzzy logic knowledge bases in integrated landscape assessment: Examples and possibilities. General Technical Report PNW-GTR-521. USDA Forest Service Pacific Northwest Research Station. 24 pp.

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

Section 2: Physical Features

The Bill Williams Watershed in Arizona is defined as the area drained by the Bill Williams River into the Colorado River at Lake Havasu, upstream from Parker Dam. The watershed is located in the northwestern part of the state, as shown in Figure 2-1.

Figure 2-1: Bill Williams Watershed.



Watershed Size

The Bill Williams Watershed covers approximately 5,393 square miles, representing 4.7% of the state of Arizona. At its widest point the watershed stretches roughly 100 miles north-south and 92 miles east-west.

The watershed was delineated by the U.S. Geological Survey and has been subdivided into subwatersheds or drainage areas. Each drainage area has a unique hydrologic unit code number, or HUC, and a name based on the primary surface water within the HUC. These drainage areas can be further subdivided as needed. This report will work with two levels: an eight-digit cataloging HUC, and a subdivision of these, a 10-digit HUC. The subwatershed areas were delineated on the basis of the eight-digit HUC, and the classifications and GIS modeling were conducted on the ten-digit HUC subwatershed areas.

The eight-digit subwatershed HUCs of the Bill Williams Watershed are listed in Table 2-1. The subwatershed areas are delineated in Figure 2-2. The four subwatersheds are identified with both the unique HUC digital classification and the subwatershed basin name in Table 2-1.

Table 2-1: Bill Williams Watershed HUCs, Subwatershed Areas.

HUC Designation and Subwatershed Name	Area (square miles)
H15030201 Big Sandy River	**2,157**
H15030202 Burro Creek	**712**
H15030203 Santa Maria River	**1,432**
H15030204 Bill Williams River	**1,092**
Bill Williams Watershed	***5,393***

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 Bill Williams Watershed ranges from 450 to 8,409 feet above mean sea level (msl). The tallest feature in the watershed is Hualapai Peak, in Hualapai Mountain Park, at 8,417 feet, within the Big Sandy River subwatershed. The lowest point within the watershed is at 450 feet near Parker Dam, where the Bill Williams discharges into Lake Havasu.

Figure 2-2: Bill Williams Watershed HUCs.

The Bill Williams River subwatershed is at a much lower average elevation than rest of the watershed, with a mean elevation of 1,964 feet. The other three subwatersheds have mean elevations of 3,724 feet or greater.

Approximately 47% of the Bill Williams Watershed has a slope of 15% or greater (Table 2-3 and Figure 2-4), and approximately 27% has a slope les than 5%. The Bill Williams River subwatershed is the only subwatershed that significantly deviates from this, with only 38% of its area over 15% slope, and 41% of its area having a slope less than 5%.

Table 2-2: Bill Williams Watershed Elevation Range.

Subwatershed Name	Min (feet)	Max (feet)	Mean (feet)
H15030201 Big Sandy River	**1,235**	***8,409**	**4,282**
H15030202 Burro Creek	**1,511**	**7,267**	**4,390**
H15030203 Santa Maria River	**1,235**	**7,207**	**3,724**
H15030204 Bill Williams River	**450**	**6,416**	**1,964**
Bill Williams Watershed	***450***	***8,409***	***3,679***

* Because of data resolution, this value is an average elevation within a 10 x 10 meter area around Hualapai Peak, elevation 8,417 feet.

Figure 2-3: Bill Williams Watershed Topography.

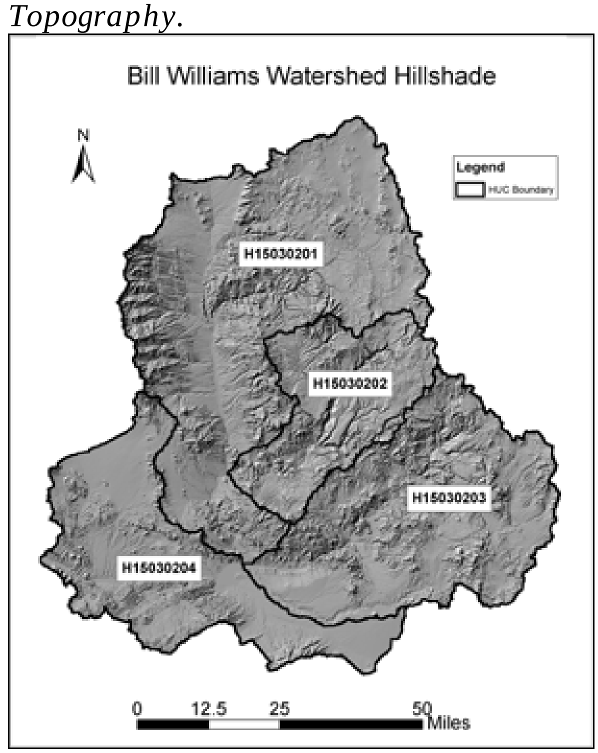
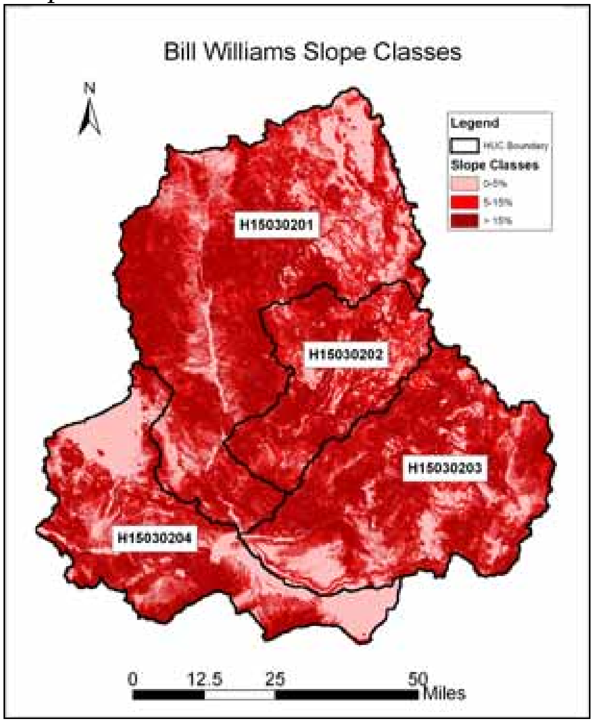


Table 2-3: Bill Williams Watershed Slope Classes

Subwatershed Name	Area (sq. miles)	0-5%	5-15%	>15%
H15030201 Big Sandy River	**2,157**	**24%**	**28%**	**48%**
H15030202 Burro Creek	**712**	**18%**	**32%**	**50%**
H15030203 Santa Maria River	**1,432**	**23%**	**28%**	**49%**
H15030204 Bill Williams River	**1,092**	**41%**	**21%**	**38%**
Bill Williams Watershed	***5,393***	***27%***	***27%***	***47%***

Figure 2-4: Bill Williams Watershed Slope Classes



<u>Water Resources</u>

Prior to discharging to Lake Havasu, the lower portion of the Bill Williams River meanders across a tree-lined valley, protected as a National Wildlife Sanctuary because of the many species of birds found there. The upper reaches tributaries and intermittent head streams flow through narrow, remote canyons and open terrain of Sonoran Desert scenery.

Several river segments within the Bill Williams have been designated as a Wild and Scenic River, and three segments are classified as Unique Waters of the State: Burro Creek, Francis Creek, and Peeples Canyon Creek.

Lakes and Reservoirs

There are 30 lakes and 2 reservoirs in the Bill Williams Watershed. Alamo Lake is the largest with about 13,400 acres of open water surface. Table 2-4 lists the major lakes within the watershed and their associated surface water area.

Rising waters behind Parker Dam (on the Colorado River) have created a shallow, marshy estuary where the Bill Williams enters Lake Havasu. Parker Dam moves water to the Colorado River Aqueduct for delivery to the Los Angeles area.

Stream Type

The Bill Williams Watershed contains a total of 6,388 miles of stream (Table 2-5). There are three different stream types: perennial, intermittent and ephemeral.

- Perennial stream means surface water that flows continuously throughout the year.

Table 2-4: Bill Williams Watershed Lakes and Reservoirs

Lake Name	Subwatershed	Surface Area (acre)	Elevation (feet above mean sea level)	Dam Name (if known)
Alamo Lake	Bill Williams River / Big Sandy River / Santa Maria River	13,402	1,237	Alamo Dam
Suicide Wash	Burro Creek	367	2,230	not known
Deer Mountain Wash	Burro Creek	102	2,391	not known
Mary Lake	Big Sandy River	40	5,576	not known
Red Lake	Big Sandy River	35	5,684	not known
Meadow Lake	Big Sandy River	22	4,874	not known

- Intermittent stream means a stream or reach of a stream that flows 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.

- An ephemeral stream is at all times above the ground water table, has no base flow, and flows only in direct response to precipitation.

Most of the streams in desert regions are intermittent or ephemeral. Some of these channels or washes are dry for years at a time, but are subject to flash flooding during high-intensity storms (Gordon et al., 1992).

Table 2-5: Bill Williams Watershed Stream Types Length.

Stream Type	Stream Length (miles)	% of Total Stream Length)
Intermittent	5	<1%
Perennial	185	3%
Ephemeral	6,198	97%
Total Length	***6,388***	***100.00%***

Table 2-6 lists the major streams in the Verde Watershed with their subwatershed name and length. Figure 2-5 shows the major lakes and streams.

Ninety seven percent of the streams in the Bill Williams Watershed are ephemeral streams with a total accumulated length of 6,198 miles. Only approximately 3% are perennial, mostly restricted to the main stem of the Bill Williams River.

Stream Density

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

Figure 2-5: Bill Williams Watershed Major Lakes and Streams

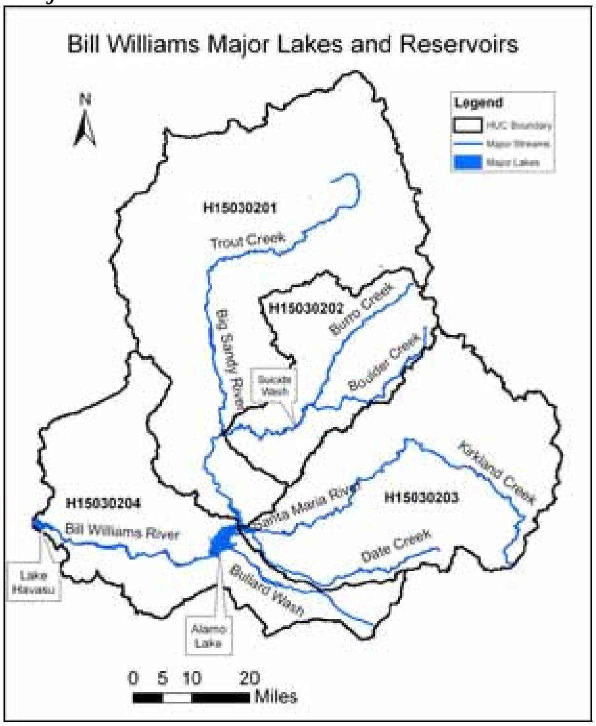


Figure 2-6: Bill Williams Watershed Stream Types

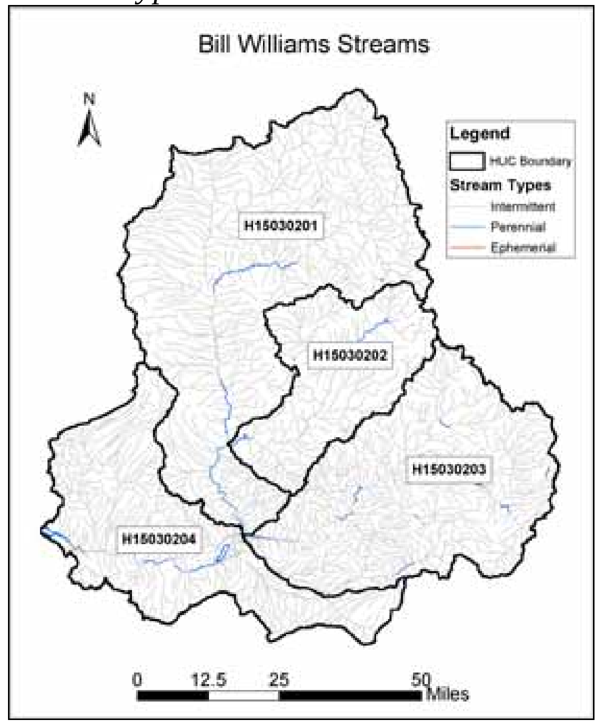


Table 2- 6: Bill Williams Watershed Major Streams.

Tributary Name	Subwatershed	Stream Length (miles)
Bill Williams River	**Bill Williams River**	**92**
Burro Creek	**Burro Creek**	**74**
Big Sandy River	**Big Sandy River**	**65**
Santa Maria River	**Santa Maria River**	**54**
Trout Creek	**Big Sandy River**	**54**
Date Creek	**Santa Maria River**	**49**
Kirkland Creek	**Santa Maria River**	**44**
Bullard Wash	**Bill Williams River**	**40**
Boulder Creek	**Burro Creek**	**37**

Increased erosion and sedimentation occur in a watershed with a high drainage density, and may reflect a geologically active erosion/ depositional setting. Drainage density may also indicate some degree of watershed degradation due to land-use, such as logging, grazing, and/or fire. The average stream density for the Bill Williams Watershed is 9.77 feet/acre (Table 2-7). Figure 2-7 shows drainage density in the Bill Williams Watershed.

The Santa Maria River subwatershed has the highest drainage density at 10.89 feet/acre while the high elevation, rugged Burro Creek subwatershed exhibits the lowest drainage density at 8.21 feet/acre.

Table 2-7: Bill Williams Watershed Stream Density

Sub Watershed	Area (acres)	Stream Length (feet)	Density (ft/acre)
H15030201 Big Sandy River	**1,380,246**	**12,634,854**	**9.15**
H15030202 Burro Creek	**455,940**	**3,741,957**	**8.21**
H15030203 Santa Maria River	**916,289**	**9,980,184**	**10.89**
H15030204 Bill Williams River	**698,836**	**7,372,521**	**10.55**
Bill Williams Watershed	***3,451,310***	***33,728,359***	***9.77***

Annual Stream Flow

Annual stream flows for nine gages were calculated for the Bill Williams watershed. These gages were selected based on their location, length of date record, and representativeness of watershed response. Figure 2-8 shows the location of these gages. The gage at the Bill Williams River below Alamo Dam has the highest measured annual mean stream flow with 113 cubic feet per second (cfs).

Figures 2-9 and 2-10 show typical hydrographs for the watershed. Figure 2-11 depicts the hydrograph of the Bill Williams River near Parker, Arizona, and shows the seasonal flow fluctuations and periods of no stream flow.

Figure 2-12 is a 5-year running average of stream flow for the Bill Williams River below Alamo Dam, showing the change in stream flow after the construction of the Alamo Dam in 1968. Figure 2-10 shows the same data on a log-scale.

Figure 2-7: Bill Williams Watershed Stream Density

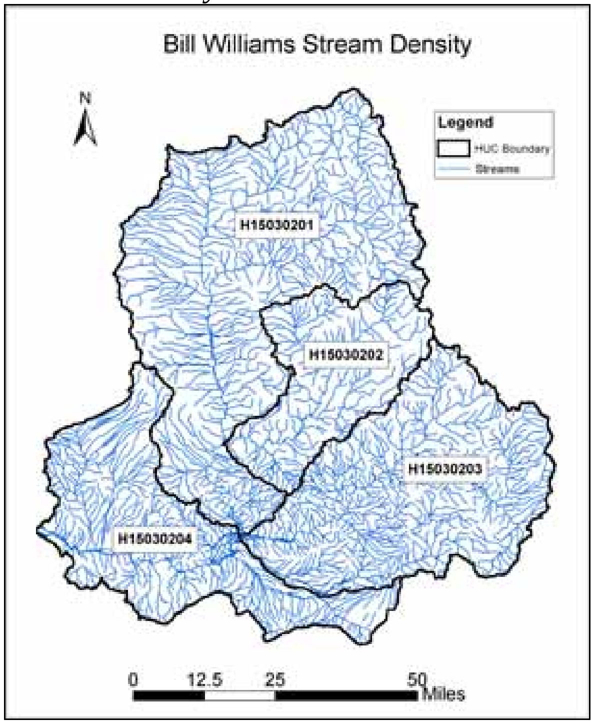


Figure 2-8: Bill Williams Watershed USGS Stream Gages.

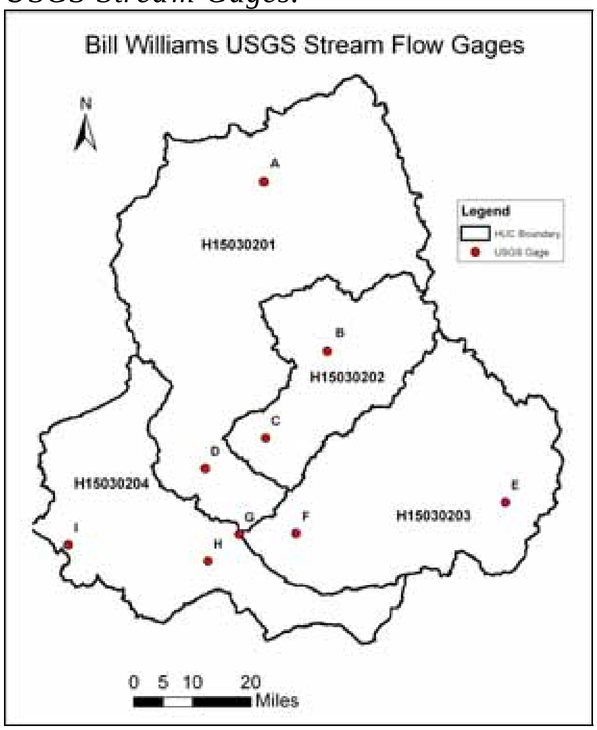


Table 2-8: Bill Williams Watershed USGS Gages.

ID	Site Name	Daily Flow Data Begin Date	Daily Flow Data End Date	Annual Mean Streamflow (cfs)
A	Cottonwood Wash Near Kingman	2/11/1964	9/30/1978	4.2
B	Francis Creek Near Bagdad	12/23/1984	9/30/1993	17.1
C	Burro Creek Old US 93 Bridge Near Bagdad	7/25/1980	9/30/1993	68.7
D	Big Sandy River Near Wikieup	3/29/1966	9/30/2003	81.3
E	Kirkland Creek Near Kirkland	4/12/1973	3/31/1983	11.0
F	Santa Maria River Near Bagdad	4/18/1966	9/30/2003	49.8
G	Santa Maria River Near Alamo	12/1/1939	4/30/1966	34.4
H	Bill Williams River Below Alamo Dam	12/1/1939	9/30/2003	113.0
I	Bill Williams River Near Parker	10/1/1988	9/30/2003	95.4

Figure 2-9: USGS Gage 09424450 (Big Sandy River near Wikieup) Hydrograph.

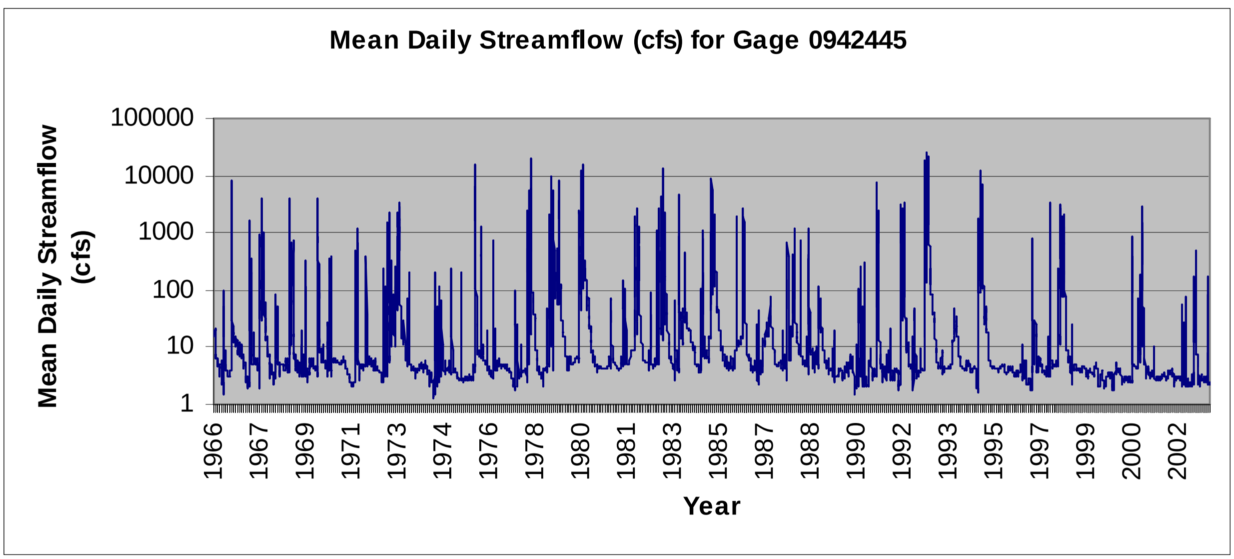


Figure 2-10: USGS Gage 09426000 (Bill Williams River Below Alamo Dam) Hydrograph.

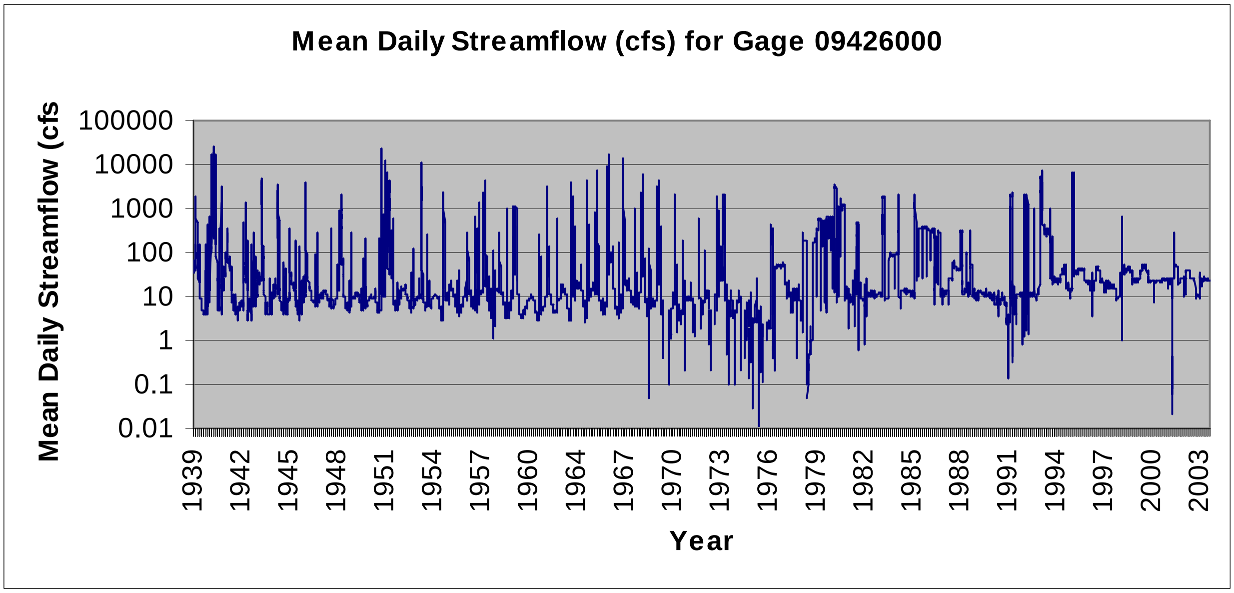


Figure 2-11: USGS Gage 09426620 (Bill Williams River Near Parker) Hydrograph.

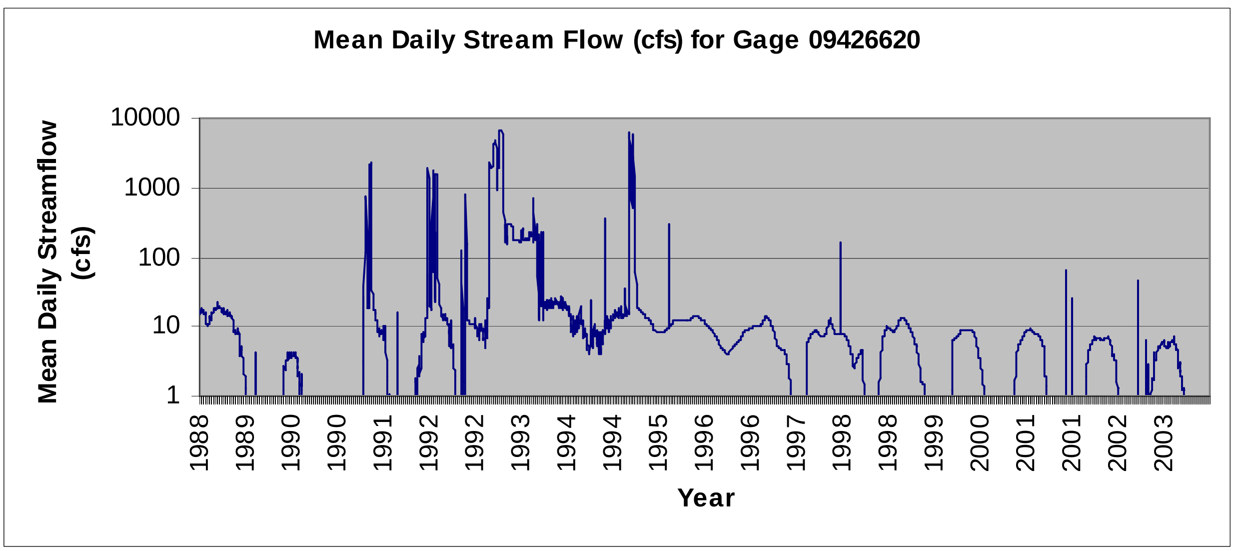
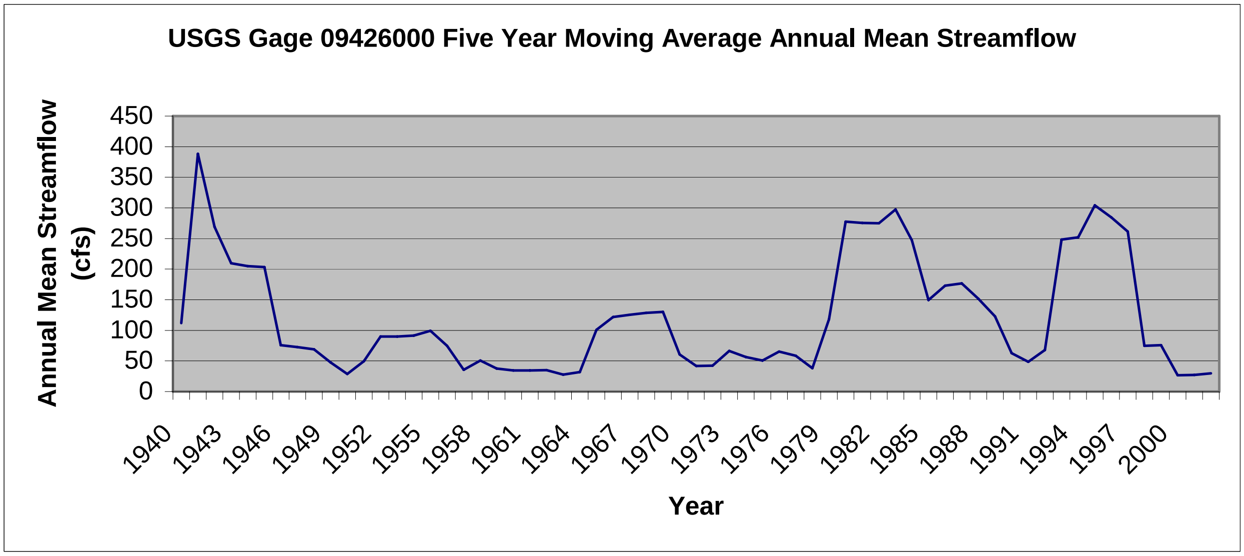


Figure 2-12: USGS Gage 09426000 (Bill Williams River below Alamo Dam) Five Year Annual Moving Average Streamflow (cfs).



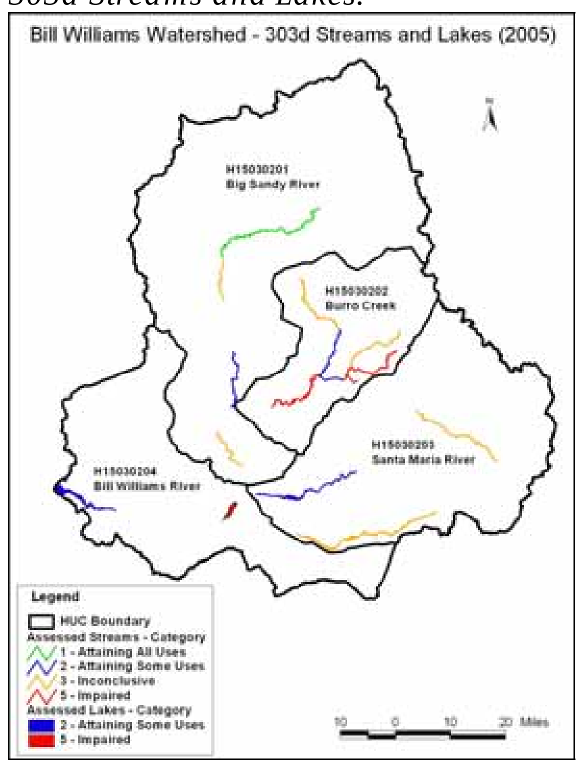
Water Quality

In the Bill Williams Watershed, two lakes and three stream reaches were listed as impaired in 2004 (ADEQ, 2005) (Figure 2-13):

- Alamo Lake (mercury, high pH, and ammonia);
- Coors Lake (mercury);
- Boulder Creek (mercury, arsenic, copper, and zinc); and
- Burro Creek (mercury).

An explanation of the 303d listing process is found in the Introduction (Section 1) of this text, and a tabulation of the water quality attributes can be found in the Classification section (Section 6). Only one stream reach was listed as "attaining all uses in the 2004 assessment report: Trout Creek, from Cow Creek to Knight Creek.

Figure 2-13: Bill Williams Watershed 303d Streams and Lakes.



Geology

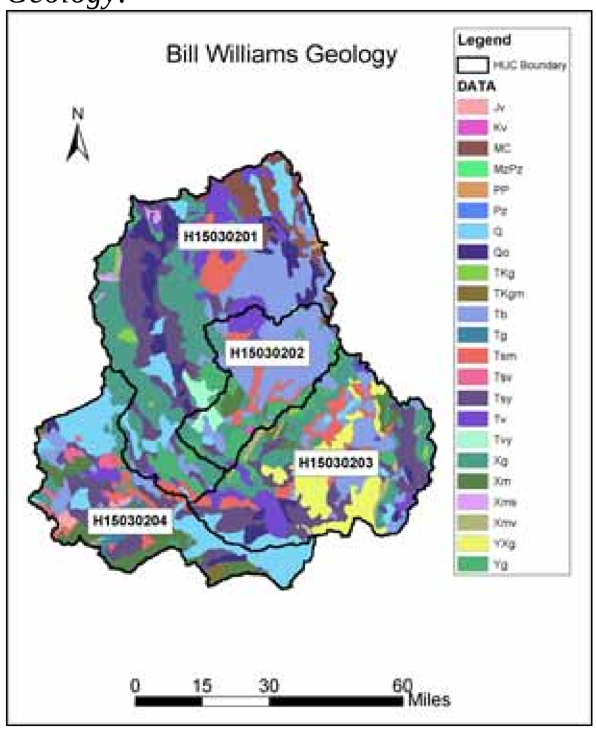
Beginning nearly 400 years ago when Spanish explorers shipped the gold and silver to Spain that they had mined from locations along the Santa Maria River, the Bill Williams Watershed has been a treasure of metallic resources. The Big Sandy, Burro Creek, and Santa Maria subwatersheds straddle the north-west trending belt of Precambrian-age ore-rich granitic and volcanic rocks within Arizona's Transition Zone physiographic province.

The Transition Zone is the highly eroded and rugged mountainous region between the Basin and Range Province and Colorado Plateau. Within the Bill Williams Watershed, the Weaver and Aquarius Mountains form the western-most extent of the Transition Zone. The land forms and elongate block-faulted mountain ranges and wide, alluvium-filled valleys of the Basin and Range Province are found to the west, within the Bill Williams subwatershed (H15030204) and the western portion of the Big Sandy subwatershed (H15030201). Figure 2-14 depicts the geology in the Bill Williams Watershed.

The Hualapai Mountains are examples of the Basin and Range landform, and consist of volcanic and plutonic intrusive rocks, block-faulted along the Big Sandy River channel. The intermontaine depressions have subsided thousands of feel and are filled with volcanics, alluvium, and fluvial and lacustrine sediments. The extensive valley fill within the Big Sandy River channel has concealed what must be extensive north-west trending faults. Tertiary age river deposits are observed as shear vertical cliffs as the Big Sandy erodes and down cuts into the alluvium.

At the land surface, Precambrian granites within the Santa Maria subwatershed erode into large rounded boulders that disintegrated gradually into coarse sand, and the barn-size boulders form distinctive landforms across the Weaver Mountain and in the area of Skull Valley and Yarnell.

Figure 2-14: Bill Williams Watershed Geology.



Until the Pliocene-age tectonic uplift of the region (2 to 5 million years before present), the Gulf of California extended north to Parker, and as much as 2,000 feet of sediment had been deposited. The Tertiary age (63 to 5 million years before present) sediments within the Big Sandy, the Santa Maria, and Bill Williams have been deeply dissected as the drainage has kept pace with the tectonic uplift and associated

Colorado River downcutting. As head-cutting progresses upstream, even the small intermittent steam tributaries at the outer edge of the arid watershed are observed to be severely downcut.

Extensive porphyritic copper deposits are found in the area around Bagdad, and elevated uranium concentrations have been measured in the granite of Lawler Peak, near Bagdad. Volcanic lake deposit sediments have been mined near Alamo Lake, with estimated reserves of uranium oxide in excess of 50,000 tons. Mineralization across the district is extensive, with oxide and sulfide copper ores, manganese oxides, gold, silver, molybdenum, cobalt, and titanium. Near Bagdad, the proposed Twin Peaks Mine contains one of the largest undeveloped gold deposits in North America.

Table 2- 9: Bill Williams Watershed Geology.

Name	Geologic Code	Big Sandy River H15030201	Burro Creek H15030202	Santa Maria River H15030203	Bill Williams River H15030204	*Bill Williams Watershed*
VOLCANIC ROCKS (Jurassic; locally latest Triassic)	Jv	-	-	-	2.24%	*<1%*
VOLCANIC ROCKS (late Cretaceous, early Tertiary near Safford)	Kv	-	0.48%	0.02%	-	*<1%*
SEDIMENTARY ROCKS (Mississippian to Cambrian)	MC	7.39%	0.39%	-	-	*3%*
MESOZOIC AND PALEOZOIC ROCKS (structurally complex Jurassic, Triassic, and Paleozoic rocks in west-central Arizona)	MzPz	-	-	-	0.15%	*<1%*
SEDIMENTARY ROCKS (Permian and Pennsylvanian)	PP	0.36%	-	-	-	*<1%*
PALEOZOIC ROCKS (undifferentiated)	Pz	-	-	-	1.32%	*<1%*
SURFICIAL DEPOSITS (Holocene to middle Pleistocene)	Q	7.93%	0.88%	5.82%	29.39%	*11%*
OLDER SURFICIAL DEPOSITS (middle Pleistocene to latest Pliocene)	Qo	9.28%	0.27%	2.98%	1.81%	*5%*
GRANITOID ROCKS (early Tertiary to late Cretaceous; 55 to 85 Ma.)	TKg	0.85%	0.25%	0.53%	0.06%	*<1%*
GRANITIC ROCKS (early Tertiary to late Cretaceous; 45 to 75 Ma.)	TKgm	-	-	-	1.49%	*<1%*
BASALTIC ROCKS (late to middle Miocene; 8 to 16 Ma.)	Tb	13.24%	47.25%	13.60%	6.95%	*17%*
GRANITOID ROCKS (early Miocene to Oligocene; 18 to 38 Ma.)	Tg	-	-	-	3.89%	*<1%*
SEDIMENTARY ROCKS (middle Miocene to Oligocene; 15 to 38 Ma.)	Tsm	4.47%	10.31%	7.95%	6.85%	*7%*
VOLCANIC AND SEDIMENTARY ROCKS (middle Miocene to Oligocene)	Tsv	-	-	-	2.67%	*<1%*
SEDIMENTARY ROCKS (Pliocene to middle Miocene)	Tsy	15.44%	1.59%	18.24%	12.63%	*14%*
VOLCANIC ROCKS (middle Miocene to Oligocene; 15 to 38 Ma.)	Tv	9.26%	7.53%	6.79%	2.54%	*7%*
VOLCANIC ROCKS (Pliocene to middle Miocene; 4 to 15 Ma.)	Tvy	1.35%	3.46%	-	-	*1%*
GRANITOID ROCKS (early Proterozoic; 1400 Ma. or 1650 to 1750 Ma.)	Xg	22.86%	10.51%	15.63%	9.63%	*17%*

Name	Geologic Code	Big Sandy River H15030201	Burro Creek H15030202	Santa Maria River H15030203	Bill Williams River H15030204	*Bill Williams Watershed*
METAMORPHIC ROCKS (early Proterozoic; 1650 to 1800 Ma.)	**Xm**	**0.15%**	**3.65%**	**2.71%**	**18.25%**	***5%***
METASEDIMENTARY ROCKS (early Proterozoic; 1650 to 1800 Ma.)	**Xms**	**0.90%**	**-**	**-**	**-**	***<1%***
METAVOLCANIC ROCKS (early Proterozoic; 1650 to 1800 Ma.)	**Xmv**	**-**	**0.35%**	**2.48%**	**-**	***<1%***
GRANITOID ROCKS (middle or early Proterozoic; 1400 Ma or 1650 to 1750 Ma.)	**YXg**	**-**	**-**	**18.69%**	**0.01%**	***5%***
GRANITOID ROCKS (middle Proterozoic; 1400 Ma.)	**Yg**	**6.51%**	**13.08%**	**4.57%**	**0.12%**	***6%***
Area (square miles)		***2,157***	***712***	***1,432***	***1,092***	***5,393***

Table 2-10: Bill Williams Watershed Rock Type (Percent by Subwatershed).

Name	Big Sandy River H15030201	Burro Creek H15030202	Santa Maria River H15030203	Bill Williams River H15030204	*Bill Williams Watershed*
Alluvium	**17.21%**	**1.15%**	**8.80%**	**31.20%**	***16%***
Igneous Rocks	**54.07%**	**82.91%**	**62.29%**	**29.60%**	***55%***
Metamorphic Rocks	**1.05%**	**3.65%**	**2.71%**	**18.25%**	***5%***
Sedimentary Rocks	**27.67%**	**12.28%**	**26.19%**	**19.48%**	***24%***
Undifferentiated	**-**	**-**	**-**	**1.47%**	***<1%***
Area (square Miles)	***2,157***	***712***	***1,432***	***1,092***	***5,393***

Soils

Based on the soil characteristics for the Bill Williams Watershed two types of maps were created: a soil texture map (Table 2-11 and Figure 2-15), and a soil erodibility factor map (Table 2-12 and Figure 2-16). Soil erodibility is generated from the soil texture characteristics.
There are 23 different soil textures within the watershed. The ‘unweathered bedrock textured zone’ comprises 28% of the Bill Williams watershed and the ‘clay’ texture zone covers approximately 13% of the area (Table 2-11).

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. 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. Within the equation, the Soil Erodibility Factor (K), is estimated in the units of mass/unit area, and is based on soil texture, with a range of values between 0.0 (no erosion potential) to 1.0 (USDA, 1997). Table 2-12 shows these values for each subwatershed.

Table 2-11: Bill Williams Watershed Soil Texture.

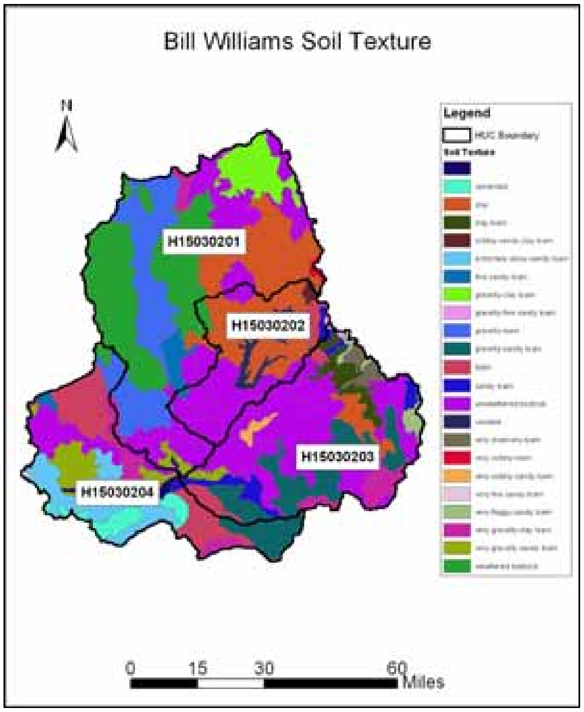
Soil Texture	Big Sandy River H15030201	Burro Creek H15030202	Santa Maria River H15030203	Bill Williams River H15030204	*Bill Williams Watershed*
cemented	0	0	0	7.98%	*2%*
clay	16.29%	42.30%	4.41%	0	*13%*
clay loam	0.00%	0.24%	6.15%	0	*2%*
cobbly-sandy clay loam	0.16%	1.60%	0	0	*<1%*
extremely stony-sandy loam	0	0	0	24.21%	*5%*
fine sandy loam	2.35%	0.69%	0	1.09%	*1%*
gravelly-clay loam	7.55%	0	0	0	*3%*
gravelly-fine sandy loam	0	0.34%	0.37%	0	*<1%*
gravelly-loam	19.91%	0.26%	0	3.00%	*9%*
gravelly-sandy loam	0	0	21.65%	9.04%	*8%*
loam	0	4.70%	3.11%	20.69%	*6%*
sandy loam	0	1.48%	5.73%	0.47%	*2%*
unweathered bedrock	21.45%	36.19%	44.73%	11.74%	*28%*
variable	0	9.93%	0	0	*1%*
very channery-loam	0	0	2.89%	0	*1%*
very cobbly-loam	0.43%	0	0	0	*<1%*
very cobbly-sandy loam	0	0	1.39%	0	*<1%*
very fine sandy loam	0	0	0	0.21%	*<1%*
very flaggy-sandy loam	0	0	2.65%	0	*1%*
very gravelly-clay loam	1.75%	0	5.68%	8.41%	*4%*
very gravelly-sandy loam	1.05%	0	1.23%	11.72%	*3%*
weathered bedrock	29.06%	2.29%	0	1.44%	*12%*

The Santa Maria River subwatershed exhibits the highest weighted mean for Soil Erodibility Factor, with K = 0.14, while the Burro Creek subwatershed has the lowest weighted mean for K at 0.06. The weighted mean K for the whole Bill Williams Watershed is 0.11 (Table 2-12).

Table 2-12: Bill Williams Watershed Soil Erodibility Factor.

Subwatershed Name	Min	Max	Weighted Average
H15030201 Big Sandy River	**0.00**	**0.31**	**0.10**
H15030202 Burro Creek	**0.00**	**0.27**	**0.06**
H15030203 Santa Maria River	**0.00**	**0.28**	**0.14**
H15030204 Bill Williams River	**0.00**	**0.32**	**0.11**
Bill Williams Watershed	**0.00**	**0.32**	**0.11**

Figure 2-15: Bill Williams Watershed Soil Texture.



Climate

Precipitation

For the 30 years (1961-1990) of precipitation data used in this report, the average annual precipitation for the Bill Williams Watershed is 12.9 inches per year. The Santa Maria subwatershed had the highest average rainfall per year at15.5 inches/year, while the Bill Williams River subwatershed exhibited the lowest at less than 9 inches/year (Figure 2-17 and Table 2-13).

Figure 2-16: Bill Williams Watershed Soil Erodibility Factor.

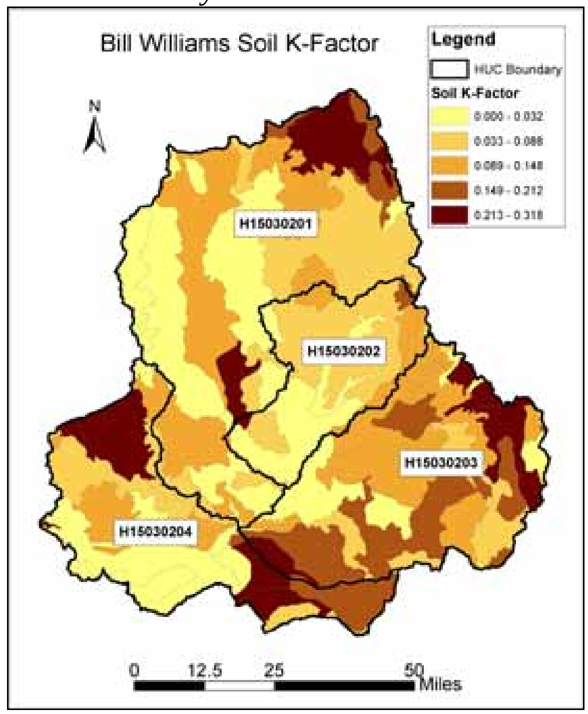


Table 2-13: Bill Williams Watershed Precipitation (in/yr).

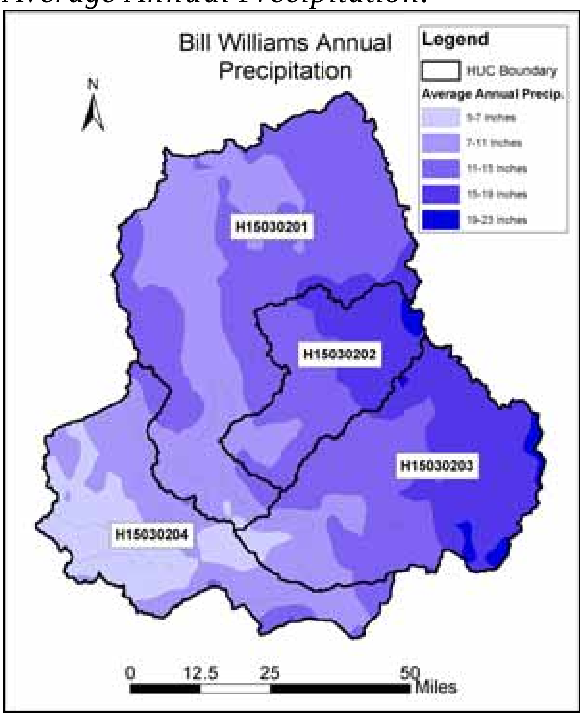
Subwatershed Name	Min	Max	Mean
H15030201 Big Sandy River	**7.00**	**21.00**	**12.41**
H15030202 Burro Creek	**9.00**	**21.00**	**15.50**
H15030203 Santa Maria River	**7.00**	**23.00**	**15.29**
H15030204 Bill Williams River	**5.00**	**17.00**	**8.79**
Bill Williams Watershed	***5.00***	***23.00***	***12.85***

Temperature

Four weather stations in the Bill Williams Watershed are shown in Figure 2-18. Data from these locations were used for watershed modeling. Although there are additional weather stations in the watershed, these stations were selected for modeling because of consistency and duration of the data.

Table 2-14 shows a summary of temperature data for the eight weather stations for which summary data were available for the 1971-2000 period (WRCC, 2004).

Figure 2-17: Bill Williams Watershed Average Annual Precipitation.



For the 30 years of temperature data, the average annual temperature for the Bill Williams Watershed is 61.8° Fahrenheit. The Bill Williams River subwatershed has the highest daily average temperature at 69.7°F. Table 2-15 shows the average annual values for the other subwatersheds, and Figure 2-19 shows the average annual watershed temperatures.

Table 2-14: Summary of Temperature Data for Four Temperature Gages in the Bill Williams Watershed.

Gage	Annual Mean Max. (ºF)	Annual Mean Min. (ºF)	Annual Mean Temperature (ºF)
Alamo Dam	**86.8**	**54.8**	**70.8**
Bagdad	**77.0**	**49.0**	**63.0**
Hillside 4NNE	**77.4**	**40.4**	**58.9**
Wikieup	**83.8**	**48.2**	**66.0**

Figure 2-18: Bill William Watershed Weather Stations.

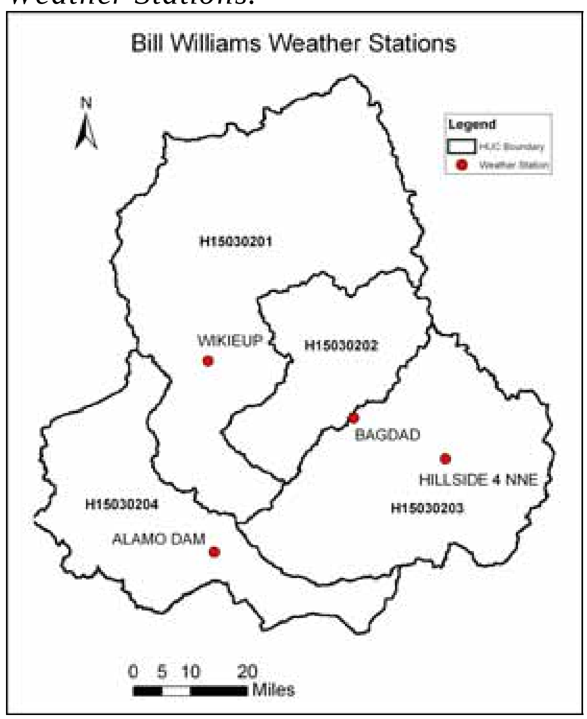


Figure 2-19: Bill Williams Watershed Average Annual Temperature.

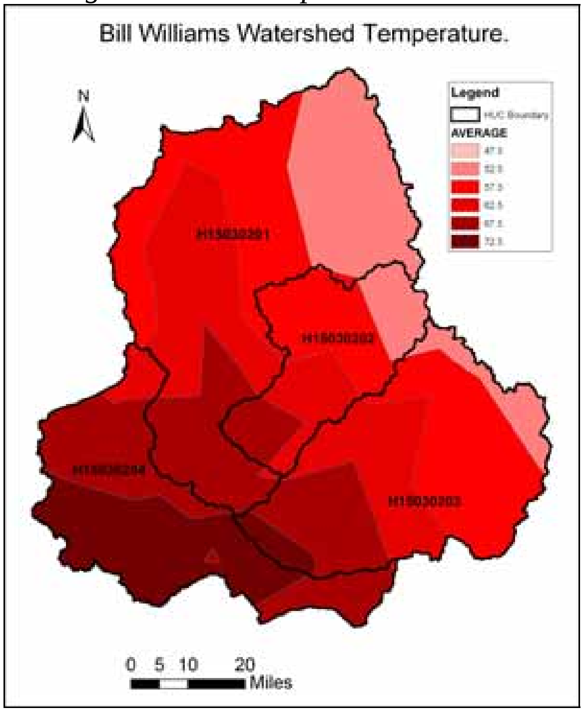


Table 2-15: Bill Williams Watershed Average Annual Temperature.

Subwatershed Name	Average Annual Temperature (ºF)
H15030201 Big Sandy River	**59.1**
H15030202 Burro Creek	**59.3**
H15030203 Santa Maria River	**60.6**
H15030204 Bill Williams River	**69.7**
Bill Williams Watershed	***61.8***

References

Arizona Department of Environmental Quality, ADEQ. 2005. The Status of Water Quality in Arizona – 2004: Arizona's Integrated 305(b) Assessment and 303(d) Listing Report, 1110 West Washington Ave., Phoenix, Arizona, 85007. EQR0501. http://www.azdeq.gov/environ/water/assessment/2004.html.

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, Betsy, M.E. Flynn, J.T.C. Parker, and J.P. Hoffmann. 2002. Investigation of the Geology and Hydrology of the Upper and Middle Verde 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.

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

U.S. 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.

U.S. 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, it's geographic projection and scale, the name(s) of the contact person and/or organization, and general description of the data.*

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 an ecosystem region or ecoregion. 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.

In Bailey's classification system, there are four *Domain* groups. Three of the groups are humid, thermally differentiated, and are named polar, humid temperate and humid tropical. The dry domain, which is defined on the basis of moisture alone, is the fourth domain. 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 Bill Williams Watershed in the dry domain. There are two different divisions of the 'dry domain' within the watershed: Tropical/Subtropical Desert Division and Tropical/Subtropical Steppe Division. These divisions each cover approximately 50% of the watershed. The watershed can also be further subdivided into Provinces and Sections using the Bailey's ecological classification, as shown in Figures 3-1, 3-2 and 3-3.

Figure 3-1: Bill Williams Watershed Ecoregions – Divisions.

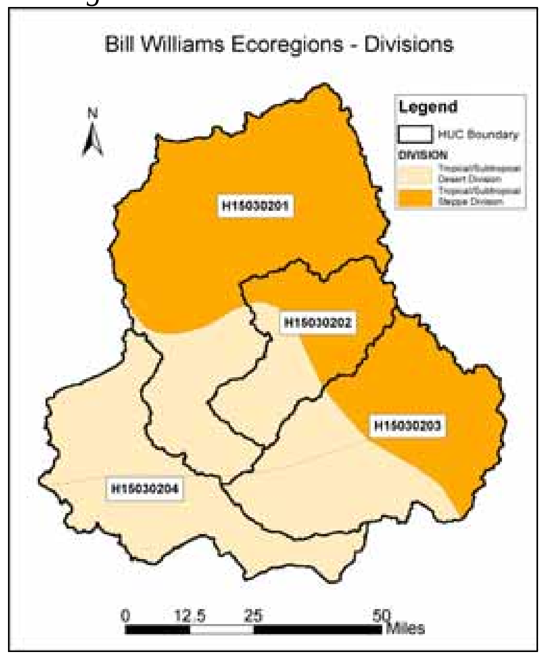
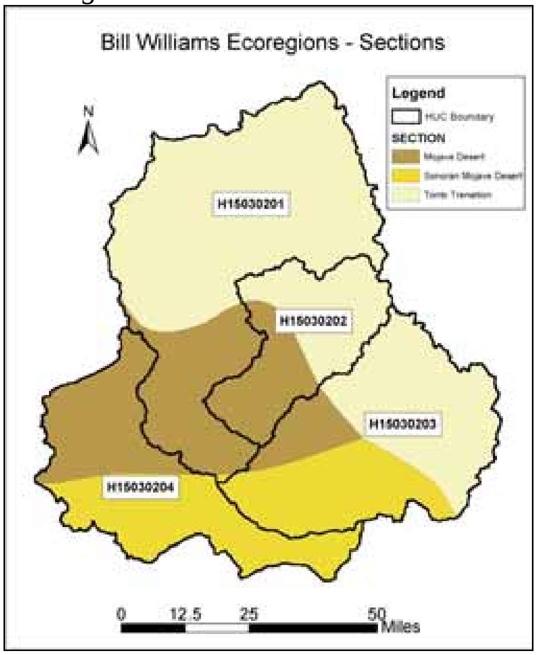


Figure 3-2: Bill Williams Watershed Ecoregions – Provinces.

Figure 3-3: Bill Williams Watershed Ecoregions – Sections.



The subwatersheds are identified using the USGS Hydrologic Unit Codes (HUC). Subwatershed areas were delineated on the basis of the eight-digit cataloging HUC, and the classifications and GIS modeling were conducted on the ten-digit HUC subwatershed areas.

The essential feature of a dry climate is that annual losses of water through evaporation at the earth's surface exceed annual water gain from precipitation. Dry climates occupy one-forth or more of the earth's land surface.

Commonly two divisions of dry climates are recognized: the arid desert and the semi arid steppe. Generally, the steppe is a transitional belt surrounding the desert and separating it from the humid climates beyond.

The boundary between arid and semi arid climates is arbitrary but is commonly defined as one-half the amount of precipitation separating steppe from humid climates. Steppes typically are grasslands of short grasses and other herbs, with locally developed shrub and woodland. Soils are commonly Mollisols and Aridisols containing some humus (Bailey, 1995).

In desert areas xerophytic plants provide negligible ground cover. In dry periods, visible vegetation is limited to small hard-leaved or spiny shrubs, cacti, or hard grasses. Many species of small annuals may be present, but they appear only after the rare but heavy rains have saturated the soil. Soils are mostly Aridisols and dry Entisols. The dominant pedogenic process is salinization which produces areas of salt crust where only salt-loving plants can survive. Calcification is conspicuous on well drained uplands (Bailey, 1995).

Table 3-1: Bill Williams Ecoregions – Divisions.

Subwatershed Name	Area (square miles)	Tropical/Subtropical Steppe	Tropical/Subtropical Desert
H15030201 Big Sandy River	**2,157**	**76%**	**24%**
H15030202 Burro Creek	**712**	**57%**	**43%**
H15030203 Santa Maria River	**1,432**	**51%**	**49%**
H15030204 Bill Williams River	**1,092**	**-0-**	**100%**
Bill Williams River Watershed	***5,393***	***52%***	***48%***

Table 3-2: Bill Williams Ecoregions – Provinces.

Subwatershed Name	Area (square miles)	Colorado Plateau Semi-Desert	American Semi-Desert and Desert Province
H15030201 Big Sandy River	**2,157**	**76%**	**24%**
H15030202 Burro Creek	**712**	**57%**	**43%**
H15030203 Santa Maria River	**1,432**	**51%**	**49%**
H15030204 Bill Williams River	**1,092**	**-0-**	**100%**
Bill Williams River Watershed	***5,393***	***52%***	***48%***

Table 3-3: Bill Williams Ecoregions – Sections.

Subwatershed Name	Area (square miles)	Tonto Transition	Mojave Desert	Sonoran Mojave Desert
H15030201 Big Sandy River	**2,157**	**76%**	**24%**	**<1%**
H15030202 Burro Creek	**712**	**57%**	**43%**	**-0-**
H15030203 Santa Maria River	**1,432**	**51%**	**12%**	**37%**
H15030204 Bill Williams River	**1,092**		**42%**	**58%**
Bill Williams River Watershed	***5,393***	***52%***	***27%***	***21%***

<u>Vegetation</u>

Two different vegetation maps were created for the Bill Williams Watershed, one based on biotic (vegetation) communities (Figure 3-4) and the other based on vegetative cover (Figure 3-5).

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. Under this classification there are eight different biotic communities in the watershed. Arizona Upland Sonoran Desertscrub covers 36% of the watershed, and Great Basin Conifer Woodland and Interior Chaparral each cover slightly more than 20% of the watershed area.

The second vegetation map was created based on the GAP Vegetation cover, which shows vegetation communities on a finer scale. Based on this map, eighteen different vegetation types are found within the watershed, including urban landscape, surface water features, and agriculture. Sonoran Desertscrub was the most common vegetation type, covering 41% of the watershed, with Great Basin Conifer Woodland (29%) and Mogollon Chaparral Scrubland (20%) also prevalent.

Figure 3-4: Bill Williams Watershed Brown, Lowe and Pace Vegetation.

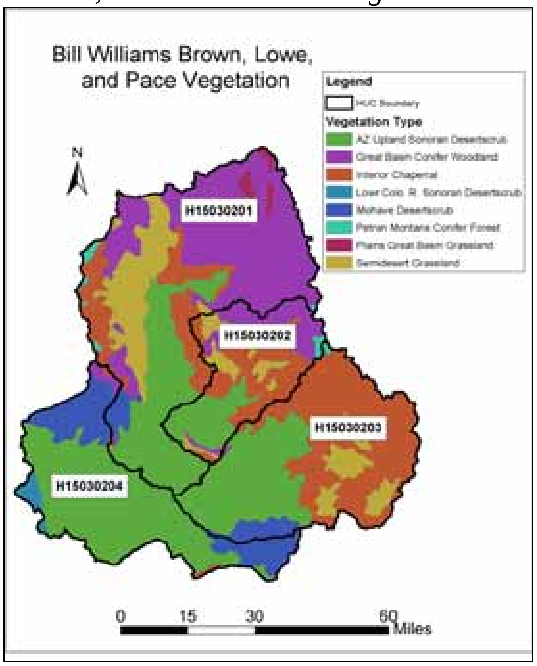


Figure 3-5: Bill Williams Watershed GAP Vegetation.

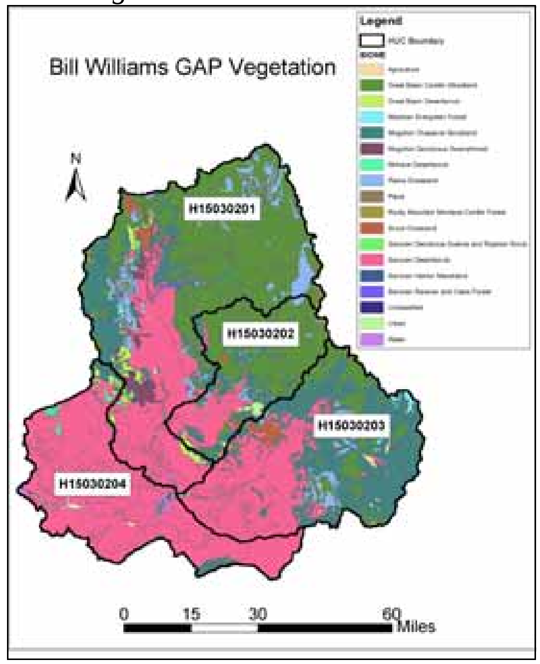


Table 3-4: Bill Williams Watershed - Brown, Lowe and Pace Vegetation.

Biotic Community	Big Sandy River H15030201	Burro Creek H15030202	Santa Maria River H15030203	Bill Williams River H15030204	*Bill Williams Watershed*
AZ Upland Sonoran Desertscrub	**24%**	**23%**	**35%**	**70%**	***36%***
Great Basin Conifer Woodland	**43%**	**26%**	**<1%**	**2%**	***21%***
Interior Chaparral	**14%**	**37%**	**50%**	**1%**	***24%***
Lower Colorado River Sonoran Desertscrub	**-0-**	**-0-**	**-0-**	**3%**	***<1%***
Mohave Desertscrub	**2%**	**-0-**	**5%**	**24%**	***7%***
Petran Montane Conifer Forest	**1%**	**14%**	**<1%**	**-0-**	***<1%***
Plains & Great Basin Grassland	**2%**	**-0-**	**-0-**	**-0-**	***<1%***
Semidesert Grassland	**15%**	**12%**	**9%**	**-0-**	***10%***
square miles	***2,157***	***712***	***1,432***	***1,092***	***5,393***

Table 3-5: Bill Williams Watershed- GAP Vegetation.

Vegetation Cover	Big Sandy River H15030201	Burro Creek H15030202	Santa Maria River H15030203	Bill Williams River H15030204	*Bill Williams Watershed*
Agriculture	<1%	<1%	1%	1%	*<1%*
Great Basin Conifer Woodland	45%	57%	13%	<1%	*29%*
Great Basin Desertscrub	2%	1%	<1%	1%	*1%*
Madrean Evergreen Forest	<1%	-0-	1%	-0-	*<1%*
Mogollon Chaparral Scrubland	14%	17%	42%	4%	*20%*
Mogollon Deciduous Swamp forest	3%	<1%	<1%	<1%	*1%*
Mohave Desertscrub	<1%	-0-	-0-	1%	*<1%*
Plains Grassland	6%	3%	4%		*4%*
Playa	-0-	-0-	-0-	0.19%	*<1%*
Rocky Mountain Montane Conifer Forest	<1%	1%	<1%	-0-	*<1%*
Scrub Grassland	1%	1%	2%	-0-	*1%*
Sonoran Deciduous Swamp and Riparian Scrub	<1%	<1%	<1%	<1%	*<1%*
Sonoran Desertscrub	25%	19%	37%	91%	*41%*
Sonoran Interior Marshland	-0-	-0-	-0-	<1%	*<1%*
Sonoran Riparian and Oasis Forest	<1%	<1%	<1%	<1%	*<1%*
Unclassified	-0-	-0-	-0-	<1%	*<1%*
Urban	-0-	<1%	<1%	-0-	*<1%*
Water	<1%	<1%	<1%	1%	*<1%*
Area (square miles)	*2,157*	*712*	*1,432*	*1,092*	*5,393*

Habitats (Riparian and Wetland Areas)

The Arizona Game & Fish Department has identified riparian vegetation associated with perennial waters and has mapped the data in response to the state Riparian Protection Program. This map was used to identify riparian areas in the Bill Williams Watershed (Figure 3-6).

There are nine different types of riparian areas within the watershed, totaling almost eleven thousand acres (Table 3-6). Cottonwood Willow and Mesquite are the largest categories of riparian area, with both comprising over three thousand acres.

Major Land Resource Areas (MLRA's)

There are five different MLRA's in the Bill Williams Watershed. The two dominant MLRA's in the watershed are Arizona Interior Chaparral and Sonoran Basin and Range, covering 39% and 43%, respectively, of the total watershed area (Figure 3-7 and Table 3-7).

Figure 3-6: Bill Williams Watershed Riparian and Wetland Areas.

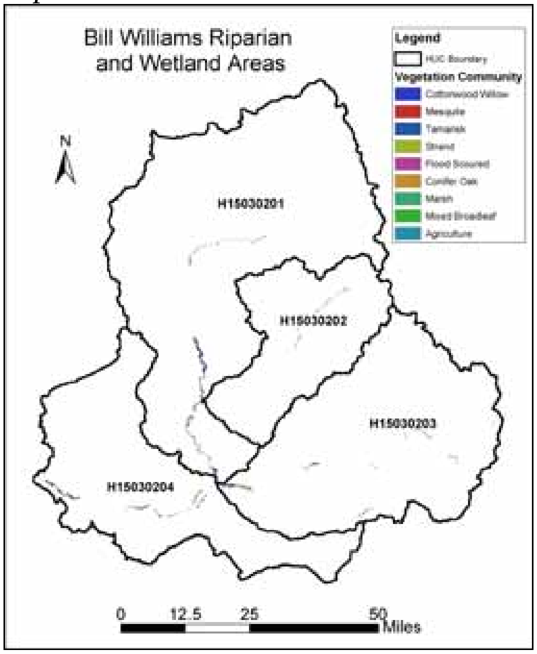


Figure 3-7: Bill Williams Watershed Major Land Resource Areas.

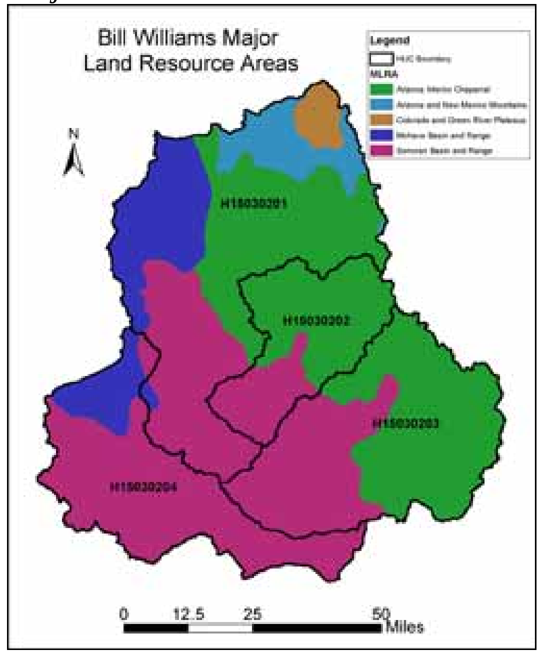


Table 3-6: Bill Williams Watershed Riparian and Wetland Areas (acres).

Vegetation Community	Big Sandy River H15030201	Burro Creek H15030202	Santa Maria River H15030203	Bill Williams River H15030204	***Bill Williams Watershed***
Cottonwood Willow	**1,906**	**-0-**	**638**	**635**	***3,178***
Mesquite	**1,957**	**159**	**759**	**276**	***3,150***
Tamarisk	**443**	**-0-**	**459**	**935**	***1,837***
Strand	**120**	**9**	**24**	**7**	***160***
Flood Scoured	**718**	**4**	**93**	**478**	***1,293***
Conifer Oak	**-0-**	**-0-**	**6**	**-0-**	***6***
Marsh	**-0-**	**-0-**	**-0-**	**333**	***333***
Mixed Broadleaf	**243**	**505**	**207**	**-0-**	***955***
Agriculture	**25**	**-0-**	**8**	**-0-**	***33***
Total Riparian Acres	***5,411***	***677***	***2,194***	***2,663***	***10,946***

Table 3-7: Bill Williams Watershed Major Land Resource Areas.

Major Land Resource Area	**Big Sandy River H15030201**	**Burro Creek H15030202**	**Santa Maria River H15030203**	**Bill Williams River H15030204**	***Bill Williams Watershed***
Arizona Interior Chaparral	**36%**	**69%**	**59%**	**-0-**	***39%***
Arizona and New Mexico Mountains	**12%**	**-0-**	**-0-**	**-0-**	***5%***
Colorado and Green River Plateaus	**4%**	**-0-**	**-0-**	**-0-**	***2%***
Mohave Basin and Range	**20%**	**-0-**	**-0-**	**16%**	***11%***
Sonoran Basin and Range	**27%**	**31%**	**41%**	**84%**	***43%***
Area (square miles)	***2,157***	***712***	***1,432***	***1,092***	***5,393***

References:

Bailey, R.G. 1976. “Ecoregions of the United States” map, Aug. 17, 2001, unnumbered publication. Intermountain Region, USDA Forest Service, Ogden, Utah, from 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

Bailey, R.G. 1996. Ecosystem Geography. Springer-Verlag. New York. 204 p.

Bailey, R.G. 2002. Ecoregion-Based Design for Sustainability. Springer-Verlag. New York. 222 p.

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

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
Arizona Gap Analysis Project Vegetation Map. April, 11 2003.
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'. http://sdfsnet.srnr.arizona.edu/index.php

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.

**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, it's 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 occupy the land in a given watershed helps a partnership understand the significance of each stakeholders influence on the watershed. The Bill Williams Watershed is comprised of three Counties: Yavapai, Mohave and La Paz (Figure 4-1 and Table 4-1). Yavapai and Mohave each cover 46% of the watershed.

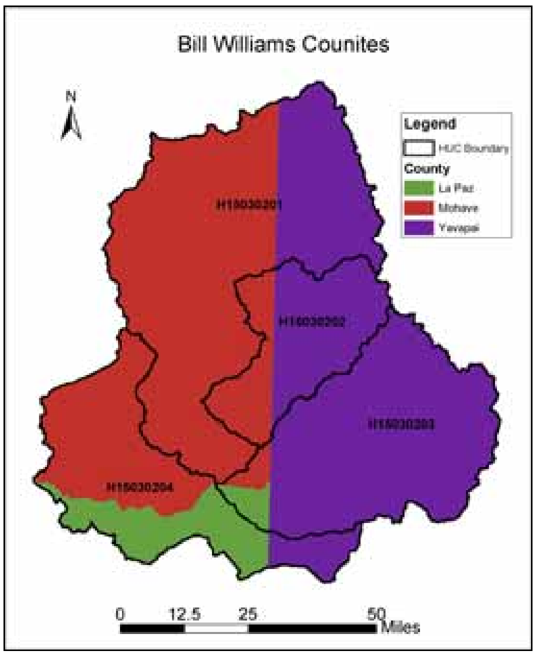


Figure 4-1: Bill Williams Watershed Counties.

Council of Governments (COGs)

Two Councils of Governments are present in the Bill Williams Watershed. They are the Northern Arizona Council of Governments (NACOG) and the Western Arizona Council of Governments (WACOG). NACOG covers approximately the eastern half of the watershed, while WACOG covers approximately the western half.

Table 4-1: Bill Williams Watershed Counties.

Sub watershed	Area (sq. miles)	Yavapai	Mohave	La Paz
H15030201 Big Sandy River	**2,157**	**26%**	**73%**	**-0-**
H15030202 Burro Creek	**712**	**67%**	**33%**	**-0-**
H15030203 Santa Maria River	**1,432**	**93%**	**3%**	**4%**
H15030204 Bill Williams River	**1,092**	**11%**	**57%**	**32%**
Bill Williams Watershed	***5,393***	***46%***	***46%***	***7%***

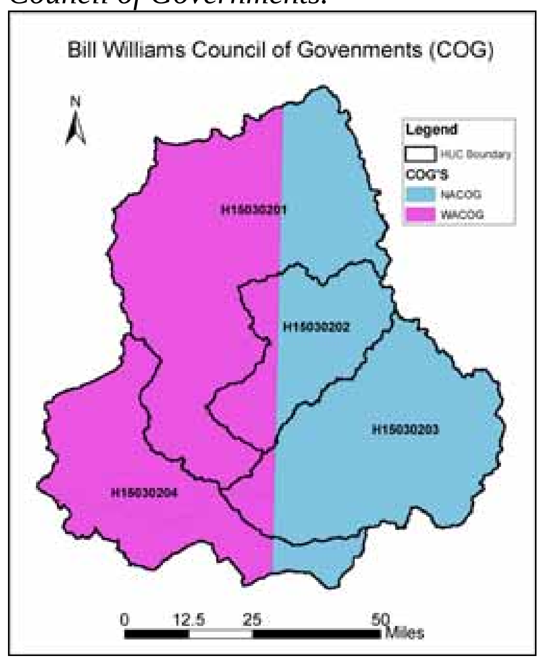


Figure 4-2: Bill Williams Watershed Council of Governments.

Table 4-2: Bill Williams Watershed Council of Governments.

Subwatershed Area	Area (square miles)	NACOG	WACOG
H15030201 Big Sandy River	**2,157**	**26%**	**73%**
H15030202 Burro Creek	**712**	**67%**	**33%**
H15030203 Santa Maria River	**1,432**	**93%**	**7%**
H15030204 Bill Williams River	**1,092**	**11%**	**89%**
Bill Williams Watershed	***5,393***	***46%***	***54%***

Urban Areas

A population density map was created for the Bill Williams Watershed based on the 2000 Census block group population data. From this map, areas with a population density greater than 1,000 persons per square mile were designated as urban. The classification yielded one urban area: a portion of the incorporated town of Prescott. This 669 acre urban area is located on the far eastern edge of the watershed, in the Santa Maria River subwatershed (Figure 4-3).

Roads

The total road length in the Bill Williams Watershed is 582 miles, representing approximately 3.4% of all roads in Arizona. The predominant road type is 'neighborhood roads' with nearly 51% of the total roads length (Table 4-3). The Santa Maria River subwatershed has the greatest accumulated length of roads with 212 miles (Figure 4-4).

Figure 4-3: Bill Williams Watershed Urban Areas (1,000 Persons / square mile).

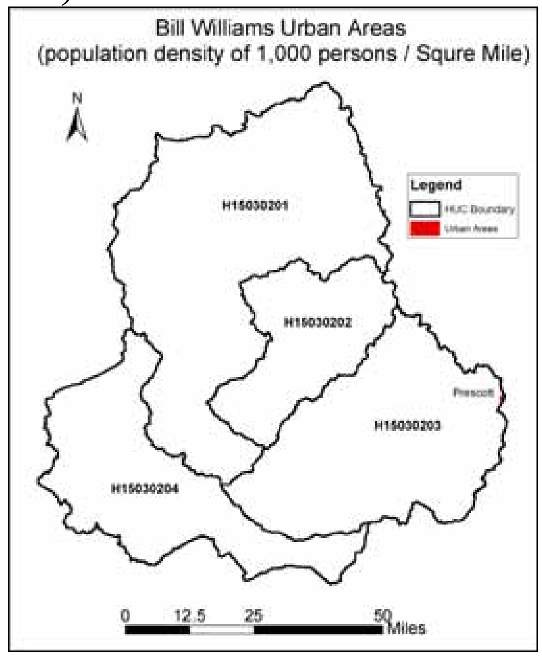


Table 4-3: Bill Williams Watershed Road Types.

Census Classification Code	Road Length (miles)	Percent of Total Length
Road	**18**	**3%**
Primary Road	**44**	**8%**
Secondary Road	**171**	**29%**
Connecting Road	**49**	**8%**
Neighborhood Road	**295**	**51%**
Special Feature Road	**5**	**<1%**
All roads (total miles)	***582***	***100%***

Primary roads include Interstate Route 40. Secondary roads are usually undivided with single lane characteristics, such as US Highway 93. Connecting roads are similar to secondary roads, and neighborhood roads are used for local traffic.

Figure 4-4: Bill Williams Watershed Road Types.

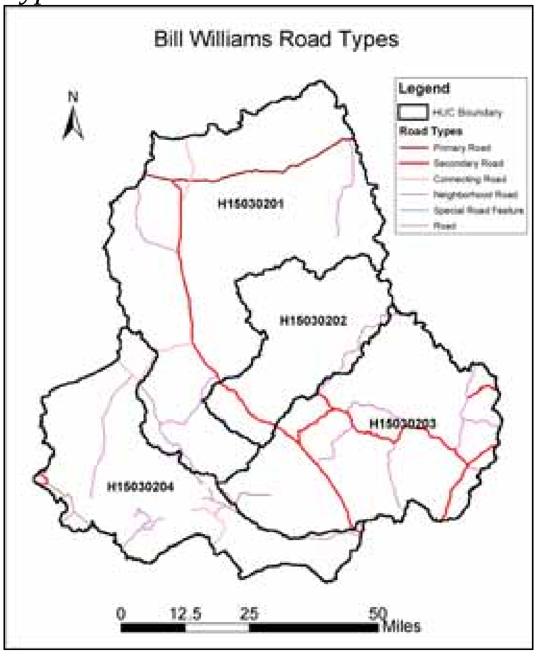


Table 4-4: Bill Williams Watershed Roads (by HUC).

Subwatershed Area	Road Length (miles)	Percent of Total Length
H15030201 Big Sandy River	**196**	**34%**
H15030202 Burro Creek	**37**	**6%**
H15030203 Santa Maria River	**212**	**36%**
H15030204 Bill Williams River	**139**	**24%**
Bill Williams Watershed	***582***	***100%***

Population

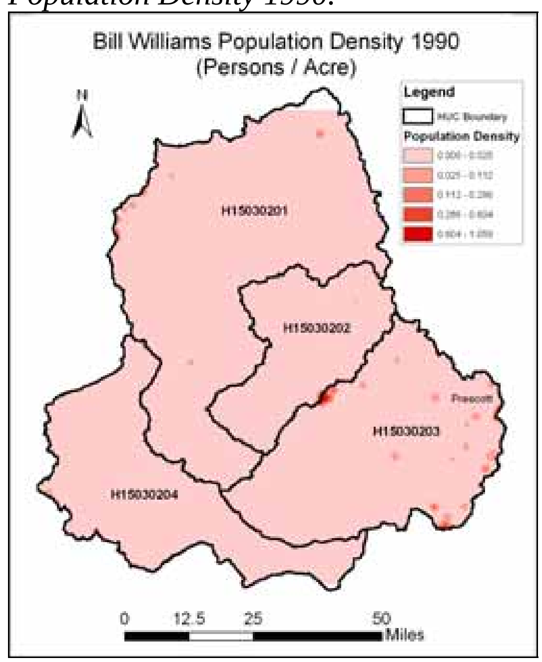
Census Population Densities in 1990

Census block statistics for 1990 were compiled from the Census 1990 CD (Geo-Lytics, 1998). These data were linked with census block data and used to create a density map, which shows the number of individuals per acre (Figure 4-5). Table 4-5 tabulates the population density for 1990 in persons per acre.

Table 4-5: Bill Williams Watershed Population Density 1990 (persons / acre).

Subwatershed Area	Area (square miles)	Min	Max	Mean
H15030201 Big Sandy River	**2,157**	**-0-**	**<1**	**<1**
H15030202 Burro Creek	**712**	**-0-**	**1**	**<1**
H15030203 Santa Maria River	**1,432**	**-0-**	**1**	**<1**
H15030204 Bill Williams River	**1,092**	**-0-**	**<1**	**-0-**
Bill Williams Watershed	***5,393***	***-0-***	***1***	***<1***

Figure 4-5: Bill Williams Watershed Population Density 1990.



Note: the northern and southern tips of the watershed do not have 1990 population density information. This was a limitation of the dataset used.

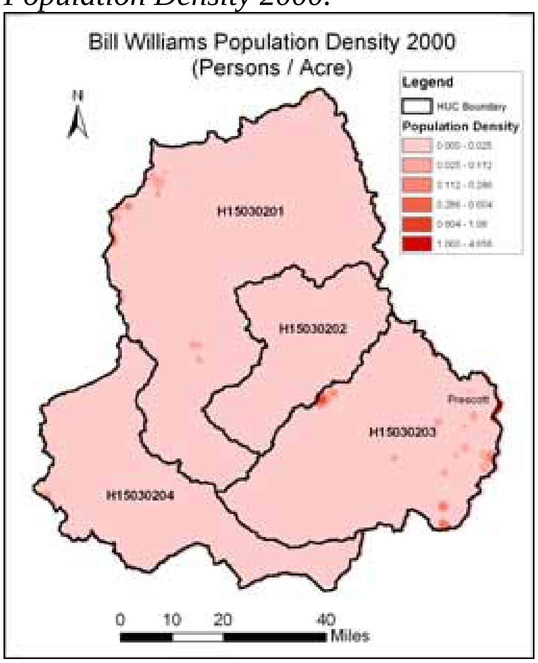
Census Population Densities in 2000

The census block statistics shapefile and table for 2000 were downloaded from the ESRI website (ESRI Data Products, 2003), and a density map was created (Figure 4-6).

Table 4-6: Bill Williams Watershed Population Density 2000 (persons / acre).

Subwatershed Area	Area (square miles)	Min	Max	Mean
H15030201 Big Sandy River	**2,157**	**-0-**	**<1**	**<1**
H15030202 Burro Creek	**712**	**-0-**	**1**	**<1**
H15030203 Santa Maria River	**1,432**	**-0-**	**5**	**<1**
H15030204 Bill Williams River	**1,092**	**-0-**	**<1**	**-0-**
Bill Williams Watershed	***5,393***	***-0-***	***4.658***	***<1***

Figure 4-6: Bill Williams Watershed Population Density 2000.



Population Change

The 1990 and 2000 population density maps were used to create a population density change map. The resulting map shows population increase or decrease over the ten year time frame (Figure 4-7). Table 4-7 tabulates the population density change for each subwatershed.

Table 4-7: Bill Williams Watershed Population Density Change 1990-2000 (persons / acre).

Subwatershed Area	Area (square miles)	Min	Max	Mean
H15030201 Big Sandy River	**2,157**	**- <1**	**<1**	**<1**
H15030202 Burro Creek	**712**	**- <1**	**<1**	**-0-**
H15030203 Santa Maria River	**1,432**	**- <1**	**5**	**<1**
H15030204 Bill Williams River	**1,092**	**- <1**	**<1**	**-0-**
Bill Williams Watershed	***5,393***	***-<1***	***5***	***<1***

Figure 4-7: Bill Williams Watershed Population Density Change 1990-2000.

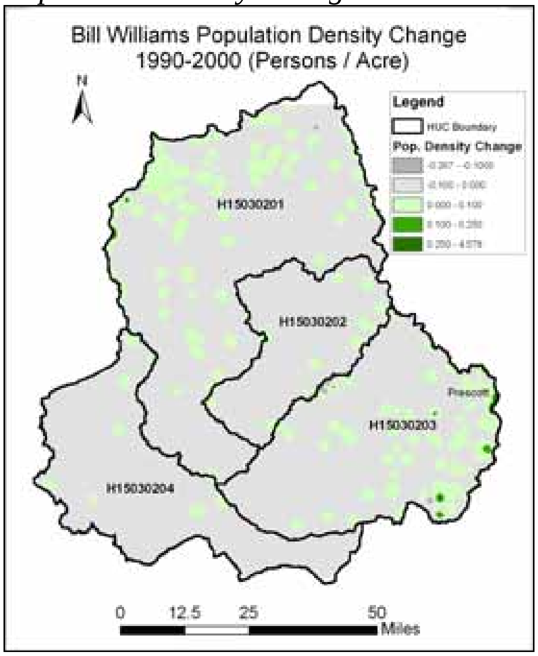
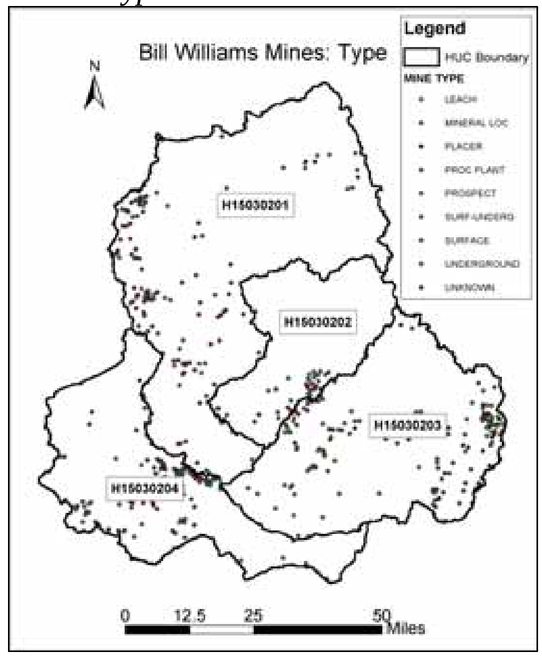


Figure 4-8: Bill Williams Watershed Mines: Type.



Mines

There are 534 mines in the Bill Williams Watershed recorded with the Arizona State Mine Inspector. Eight different mine types are represented, with the bulk of the mines registered as underground (shaft) mines (Figure 4-8 and Table 4-8). Many of the mines are no longer producing (Figure 4-9 and Table 4-9)). Gold is the most commonly mined ore, with copper and silver being second and third (Figure 4-10 and Table 4-10). However, copper mining produces the largest volume of ore.

Figure 4-9: Bill Williams Watershed Mines: Status.

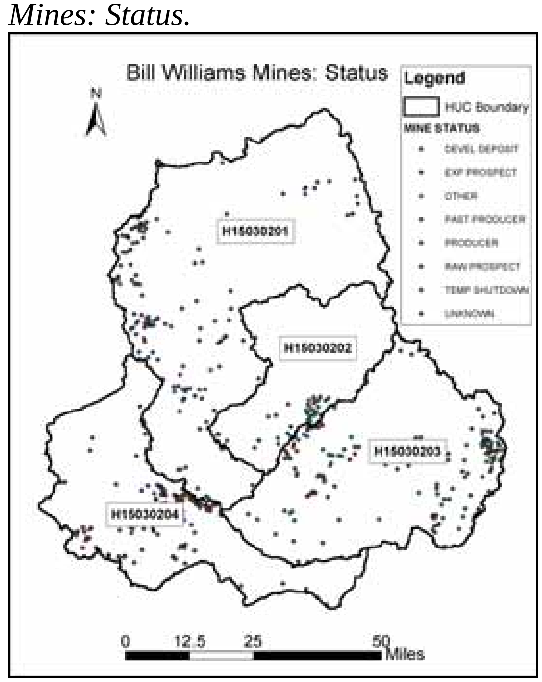


Figure 4-10: Bill Williams Watershed Mines: Primary Ore.

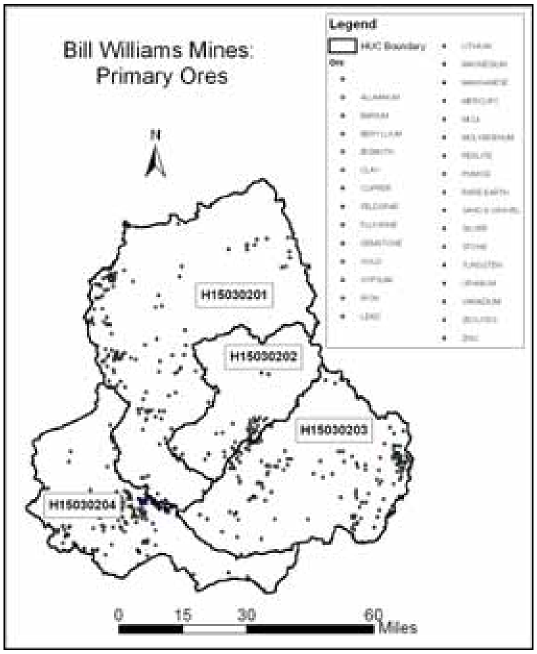


Table 4-8: Bill Williams Watershed Mines: Type.

Type	**Big Sandy River H15030201**	**Burro Creek H15030202**	**Santa Maria River H15030203**	**Bill Williams River H15030204**	***Bill Williams Watershed***
Leach	**1**	**-0-**	**1**	**-0-**	***2***
Mineral Locatable	**-0-**	**2**	**11**	**4**	***17***
Placer	**2**	**-0-**	**7**	**-0-**	***9***
Processing Plant	**6**	**3**	**-0-**	**-0-**	***9***
Prospect	**10**	**8**	**24**	**13**	***55***
Surface / Underground	**12**	**7**	**33**	**31**	***83***
Surface	**19**	**5**	**26**	**29**	***79***
Underground	**30**	**15**	**48**	**32**	***125***
Unknown	**75**	**10**	**13**	**57**	***155***
Total Mines	***155***	***50***	***163***	***166***	***534***

Table 4-9: Bill Williams Watershed Mines: Status.

Status	Big Sandy River H15030201	Burro Creek H15030202	Santa Maria River H15030203	Bill Williams River H15030204	*Bill Williams Watershed*
Developed Prospect	**17**	**8**	**29**	**9**	***63***
Explored Prospect	**10**	**14**	**47**	**9**	***80***
Past Producer	**35**	**6**	**34**	**85**	***160***
Producer	**-0-**	**5**	**6**	**-0-**	***11***
Raw Prospect	**3**	**2**	**14**	**7**	***26***
Temp. Shutdown	**-0-**	**-0-**	**-0-**	**1**	***1***
Other	**1**	**-0-**	**-0-**	**-0-**	***1***
Unknown	**89**	**15**	**33**	**55**	***192***
Total Mines	***155***	***50***	***163***	***166***	***534***

Table 4-10: Bill Williams Watershed Mines: Ore Type.

Ore	Total Number of Mines	Ore	Total Number of Mines
Gold	**187**	**Quartz Crystal**	**7**
Copper	**157**	**Bismuth**	**6**
Silver	**148**	**Vanadium**	**6**
Manganese	**72**	**Zeolites**	**5**
Lead	**51**	**Aluminum**	**5**
Iron	**41**	**Mercury**	**4**
Molybdenum	**31**	**Pumice**	**4**
Zinc	**31**	**Arsenic**	**3**
Uranium	**31**	**Columbium**	**3**
Tungsten	**29**	**Thorium**	**3**
Calcium	**17**	**Gypsum**	**3**
Stone	**14**	**Lithium**	**3**
Fluorine	**13**	**Cadmium**	**2**
Clay	**13**	**Bismuth**	**2**
Beryllium	**12**	**Perlite**	**2**
Sand & Gravel	**11**	**Rare Earth**	**2**
Gemstone	**11**	**Tantalum**	**2**
Barium	**10**	**Kyanite Group**	**1**
Silicon	**8**	**Selenium**	**1**
Mica	**8**	**Sulfur**	**1**
Feldspar	**8**	**Tellurium**	**1**

Land Cover

The land cover condition in the early 1990's was determined using the National Land Cover Dataset (NLCD). The NLCD classification contains 21 different land cover categories from which 19 classes are represented within the Bill Williams watershed (Figure 4-11 and Table 4-11). The most common land cover in the Bill Williams watershed is Shrubland which makes up 71% of the area. Evergreen Forest is the other major land-cover type, comprising 20% of the watershed.

Figure 4-11: Bill Williams Watershed Land Cover.

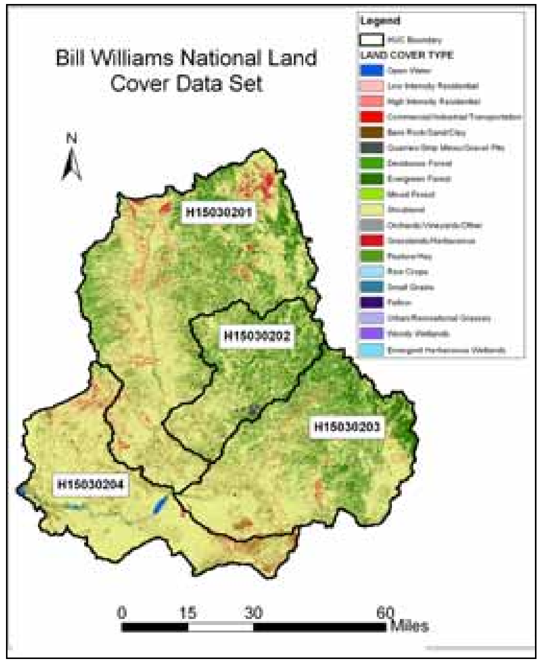


Table 4-11: Bill Williams Watershed Land Cover.

Land Cover	Big Sandy River H15030201	Burro Creek H15030202	Santa Maria River H15030203	Bill Williams River H15030204	*Bill Williams Watershed*
Open Water	**<1%**	**<1%**	**<1%**	**<1%**	***<1%***
Low Intensity Residential	**<1%**	**<1%**	**<1%**	**<1%**	***<1%***
High Intensity Residential	**-0-**	**-0-**	**<1%**	**-0-**	***<1%***
Commercial/Industrial/ Transportation	**<1%**	**<1%**	**<1%**	**<1%**	***<1%***
Bare Rock/Sand/Clay	**3%**	**3%**	**3%**	**8%**	***4%***
Quarries/ Strip Mines /Gravel Pits	**0.0**	**1%**	**<1%**	**-0-**	***<1%***
Deciduous Forest	**1%**	**1%**	**1%**	**<1%**	***<1%***
Evergreen Forest	**21%**	**34%**	**26%**	**2%**	***20%***
Mixed Forest	**<1%**	**<1%**	**<1%**	**<1%**	***<1%***
Shrubland	**70%**	**60%**	**67%**	**85%**	***71%***
Orchards/Vineyards/ Other	**-0-**	**<1%**	**<1%**	**<1%**	***<1%***
Grasslands/Herbaceous	**5%**	**1%**	**3%**	**4%**	***4%***
Pasture/Hay	**<1%**	**<1%**	**<1%**	**<1%**	***<1%***
Row Crops	**<1%**	**<1%**	**<1%**	**<1%**	***<1%***
Small Grains	**<1%**	**<1%**	**<1%**	**<1%**	***<1%***
Fallow	**<1%**	**-0-**	**-0-**	**-0-**	***<1%***
Urban/Recreational Grasses	**-0-**	**-0-**	**<1%**	**-0-**	***<1%***

Land Cover	Big Sandy River H15030201	Burro Creek H15030202	Santa Maria River H15030203	Bill Williams River H15030204	*Bill Williams Watershed*
Woody Wetlands	**<1%**	**<1%**	**<1%**	**<1%**	***<1%***
Emergent Herbaceous Wetlands	**<1%**	**-0-**	**<1%**	**<1%**	***<1%***

Land Ownership

In the Bill Williams watershed there are 10 different land ownership entities (Figure 4-12 and Table 4-12). The Bureau of Land Management (BLM), Arizona State Trust Land, and private land owners hold 40%, 28%, and 26% of the watershed area, respectively. Over 80% of the land in the Bill Williams River subwatershed is BLM land. Private land ownership is greatest in the Big Sandy River and Burro Creek subwatersheds with 33% and 41% of the watershed area, respectively.

Figure 4-12: Bill Williams Watershed Land Ownership.

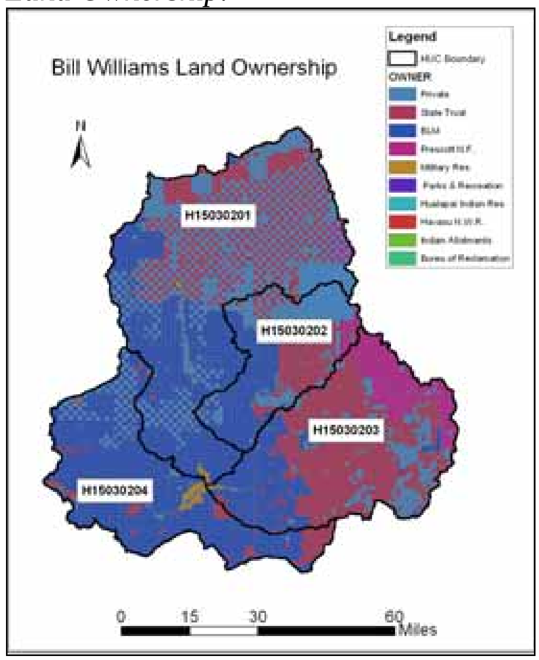


Table 4-12: Bill Williams Watershed Land Ownership.

Owner	Big Sandy River H15030201	Burro Creek H15030202	Santa Maria River H15030203	Bill Williams River H15030204	*Bill Williams Watershed*
Private	**41%**	**33%**	**14%**	**9%**	***26%***
State Trust	**25%**	**27%**	**49%**	**8%**	***28%***
BLM	**32%**	**36%**	**21%**	**80%**	***40%***
Prescott N.F.	**1%**	**4%**	**16%**	**2%**	***5%***
Military Reservation	**<1%**	**-0-**	**<1%**	**<1%**	***<1%***
Parks and Recreation	**<1%**	**-0-**	**-0-**	**-0-**	***<1%***
Hualapai Indian Res.	**<1%**	**-0-**	**-0-**	**-0-**	***<1%***
Havasu N.W.R.	**-0-**	**-0-**	**-0-**	**<1%**	***<1%***
Indian Allotments	**<1%**	**-0-**	**<1%**	**-0-**	***<1%***
Bureau of Reclamation	**-0-**	**-0-**	**-0-**	**<1%**	***<1%***
Area (square miles)	***2,157***	***712***	***1,432***	***1,092***	***5,393***

Special Areas

Preserves:

There are no wildlife preserves within the Bill Williams Watershed.

Golf Courses:

There are no known golf courses in the Bill Williams Watershed.

Wilderness:

There are 11 different wilderness areas within the Bill Williams Watershed, comprising a total of 234,772 acres (Figure 4-13 and Table 4-13). The Arrastra Mountain Wilderness Area is the largest at nearly 130,000 acres.

Figure 4-13: Bill Williams Watershed Wilderness Areas.

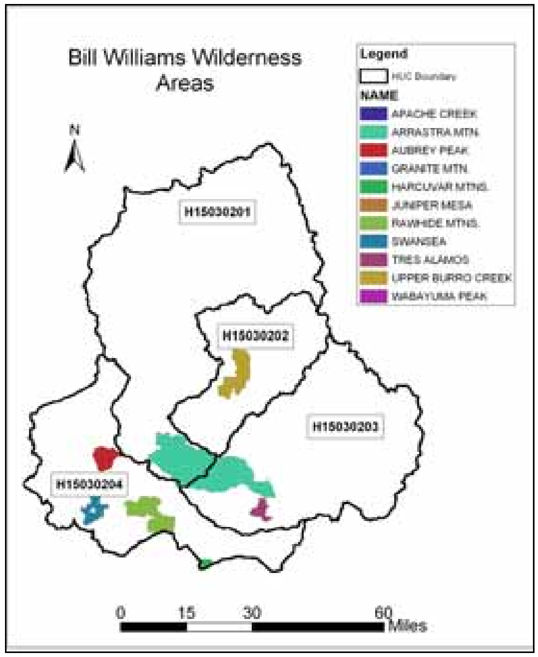


Table 4-13: Bill Williams Watershed Wilderness Areas (acres).

Wilderness Area	Big Sandy River H15030201	Burro Creek H15030202	Santa Maria River H15030203	Bill Williams River H15030204	*Bill Williams Watershed*
Apache Creek	-	50	-	-	*50*
Arrastra Mtn.	69,116	144	59,856	695	*129,812*
Aubrey Peak	-	-	-	15,387	*15,387*
Granite Mtn.	-	-	298	-	*298*
Harcuvar Mtns.	-	-	-	3,400	*3,400*
Juniper Mesa	185	-	-	-	*185*
Rawhide Mtns.	-	-	-	33,129	*33,129*
Swansea	-	-	-	16,332	*16,332*
Tres Alamos	-	-	8,265	-	*8,265*
Upper Burro Creek	-	27,511	-	-	*27,511*
Wabayuma Peak	403	-	-	-	*403*

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
Landuse. 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, it's 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 Bill Williams Watershed has extensive and important natural resources, with national, regional and local significance. The watershed contains critical riparian habitat for several rare and endangered species, including the southwestern willow flycatcher. The watershed also contains important recreational resources including extensive wilderness areas with hiking, bird watching and fishing being important outdoor activities. Seven natural resource areas (NRA's) have been identified for protection based on the combination of natural resource values. Factors that were considered in delineating these natural resource areas include: legal status (Unique Waters, critical habitat for threatened and endangered species, and wilderness); the presence of perennial waters and riparian areas; recreational resources; and local values.

The seven identified NRA's (Figure 5-1) are:

- Lower Bill Williams River
- Upper Burro Creek
- Trout Creek
- Kirkland Creek
- Middle Big Sandy
- Date Creek
- Bullard Wash

The NRA's have been categorized within the 10-digit HUC subwatershed area where they are located, and the significance of each area is discussed below.

Lower Bill Williams River NRA

The Lower Bill Williams River NRA (LBW-NRA) is one of the most significant natural resource areas in Arizona. The NRA includes four 10-digit HUC subwatersheds: Lower Big Sandy River; Lower Santa Maria River; Castaneda Wash-Bill Williams River; and Alamo Lake. The LBW-NRA contains several wilderness areas, extensive riparian forests, important recreation areas, and critical wildlife habitat. Many of the important resource values in the LBW-NRA are water dependent.

The Bill Williams River National Wildlife Refuge is located at the mouth of the Bill Williams River as it enters the Colorado River at Parker Dam, between Lake Havasu City and Parker. The refuge holds one of the last stands of natural cottonwood-willow forest along the lower Colorado River, creating a unique ecosystem that provides good habitat for resident and migratory wildlife. The riparian habitat of the refuge draws a variety of neotropical migratory birds on migration from Central and South America to their breeding grounds in the north. About a dozen endangered Yuma clapper rails spend the summer months in the cattails of the marsh and may over-winter on the refuge.

Another endangered bird, the southwestern willow flycatcher, nests on the refuge in the willow trees lining the river. The refuge also provides habitat for other wildlife including rattlesnakes, cottontails, javelina and deer, as well as predatory coyotes, bobcats, and the less common cougars. The refuge is an important recreation resource providing bird watching, hunting and fishing opportunities.

There are several wilderness areas in the LBW-NRA administered by the Bureau of Land Management (BLM). The 129,800-acre Arrastra Mountain Wilderness is located in Mohave, Yavapai, and La Paz counties, 100 miles northwest of Phoenix and 70 miles southeast of Kingman. This sprawling wildland encompasses imposing landscapes and unique natural features. The Poachie Range, which trends northwest-southeast through the north-central portion of the wilderness, rises to almost 5,000 feet (Wilderness Institute, et al., 2005).

The western and southern portions of the Arrastra Mountain Wilderness encompass more than 20 miles of the Big Sandy and Santa Maria rivers. West of the Big Sandy River, the Artillery Mountains are dominated by the striking red Artillery Peak, a 1,200-foot tall volcanic plug. The east side of the wilderness contains the uniquely pristine Peoples Canyon. Peoples Canyon has been classified as a Unique Water in Arizona. Several springs here maintain a two-mile-long chain of deep, interconnecting pools densely shaded by hundreds of sycamores, willows and cottonwoods (Wilderness Institute, et al., 2005).

The 38,470-acre Rawhide Mountains Wilderness is located in Mohave and La Paz Counties, 80 miles south of Kingman and 50 miles southeast of Lake Havasu City. The wilderness includes portions of two mountain ranges, the Rawhide Mountains to the north and the Buckskins to the south, separated by eight miles of the Bill Williams River. More than five miles of this perennial stream meanders through a 600-foot-deep gorge, and several rocky side canyons with small waterfalls enter the main canyon within the wilderness. The riparian environment here supports a variety of plants and animals, including a cottonwood-willow riparian forest, beavers, raptors, amphibians and reptiles. This area also provides habitat for a pair of nesting bald eagles (Wilderness Institute, et al., 2005). The large size of this wilderness, the varied and colorful terrain, and the presence of year-round water enhance wilderness opportunities for hikers, backpackers, river-runners, birdwatchers and photographers.

The 16,400-acre Swansea Wilderness is about 25 miles northeast of Parker in La Paz and Mohave counties. The wilderness includes the eastern end of the Buckskin Mountains, the Black Mesa extension to the north, and six miles of the Bill Williams River. The northern portion is a series of eroded volcanic dikes and plugs with precipitous cliffs. The Buckskin Mountain portion is a more subtle and rounded topography with a complex drainage system leading to the river (Wilderness Institute, et al., 2005). Recreation such as sightseeing, backpacking, day hiking, horseback riding, wildlife viewing, rock climbing, and photography are enhanced by the varying topography and the riparian corridor along the Bill Williams River.

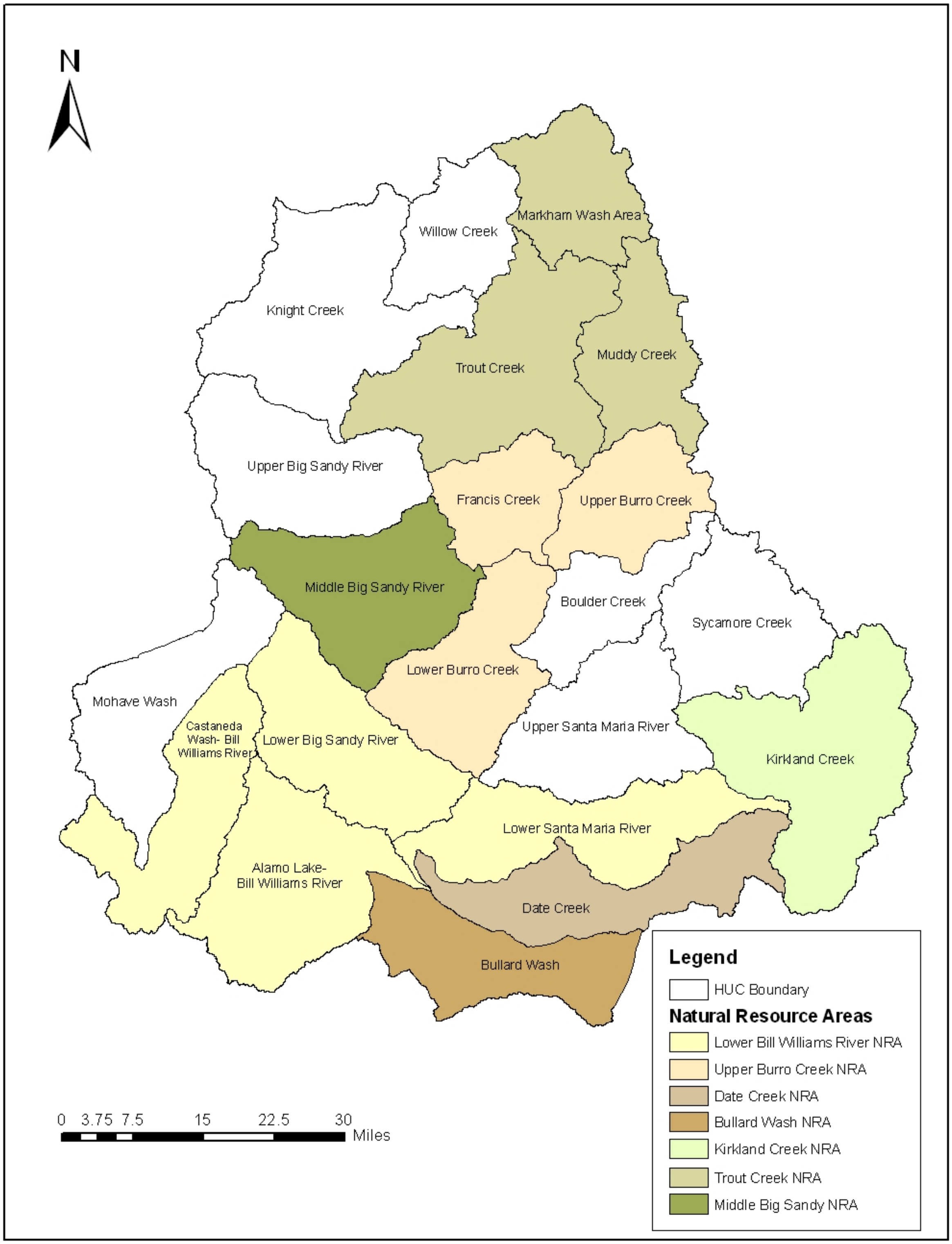


Figure 5-1: Natural Resource Areas in the Bill Williams River Watershed.

The 15,400-acre Aubrey Peak Wilderness is located in Mohave County, 70 miles south of Kingman and 40 miles east of Lake Havasu City. The wilderness contains imposing landforms carved into a variety of brightly colored volcanic rhyolites, tuffs, and basalt. Aubrey Peak, a large cliff-encircled mesa, dominates the eastern portion of the wilderness, along with numerous other large mesas, buttes and volcanic plugs. The Aubrey Peak Wilderness encompasses a portion of a Mohave/Sonoran Desert transition zone. Stands of large saguaro, palo verde, ironwood and smoke trees, typical Sonoran Desert species, often merge with Joshua and other species more typical of the Mohave Desert, creating a visually intriguing, quilt-like mosaic of plants throughout the area (Wilderness Institute, et al., 2005). This wilderness offers excellent opportunities for primitive types of recreation. Hiking, backpacking, and photography have become increasingly more popular in recent years.

Alamo Lake, located on the Bill Williams River where the Big Sandy River and Santa Maria River converge, was created in 1968 with the completion of Alamo Dam. The Army Corps of Engineers designed the earthen dam primarily for flood control. Alamo Lake State Park is located on Alamo Lake's southwest shore. Nestled in the Bill Williams River Valley, Alamo Lake State Park offers fishing, boating, camping, swimming, and bird watching opportunities. Spring rains bring an abundance of wild flowers and the lake environment attracts a variety of wildlife year round, including bald and golden eagles, waterfowl, foxes, coyotes, mule deer and wild burros. Fishing is an important recreation activity, with excellent opportunity to catch bluegill, largemouth bass, channel catfish and black crappie (Wilderness Institute, et al., 2005).

Lower Bill Williams River NRA Protection Needs

Most of the resource values in the LBW-NRA depend on the protection and restoration of the Lower Bill Williams riparian forest. The riparian forest provides critical habitat for several protected wildlife species, as well as recreation opportunities, as discussed above. It is important to note that three BLM wildernesses contain a portion of the Bill Williams River and that the riparian forest and river are important components of the wilderness experience. Nonpoint source pollutant management measures should be taken to protect and restore the channel and riparian systems.

Alamo Lake is an important recreation resource for fishing and boating. However, ADEQ has designated it as an impaired water body due to high levels of ammonia and pH. The high concentrations of ammonia and pH, and low levels of dissolved oxygen, indicate potential contamination from organics, with livestock waste being the probable primary source. Also, in 2004, a fish consumption advisory was issued due to elevated mercury concentrations found in fish tissue. To address the protection needs of the LBW-NRA, non-point source pollutant management measures should be taken to control the import of heavy metals and organic material into Alamo Lake.

Upper Burro Creek NRA

The Upper Burro Creek NRA (UBC-NRA) is a pristine environment that contains the Upper Burro Creek Wilderness. Burro Creek from Francis Creek to Boulder Creek is classified as a Unique Waters. The NRA includes three 10-digit HUC subwatersheds: Francis Creek, Lower Burro Creek and Upper Burro Creek.

The 27,440-acre Upper Burro Creek Wilderness lies along the upper reaches of Burro Creek, a perennial stream and one of the few streams in Arizona to flow relatively undisturbed into the lower desert. Nine miles of Burro Creek lie within the wilderness. In this area, Burro Creek passes through incised bedrock where it runs deep, creating clear blue pools connected by small waterfalls. In other areas, the creek has backed up into long, marshy pools ringed with young trees and other riparian vegetation (Wilderness Institute, et al., 2005). Upper Burro Creek Wilderness offers outstanding recreational opportunities for hiking, backpacking, camping, sightseeing, hunting, rock collecting, and horseback riding. Swimming, bird watching and photography are special attractions all along the stream corridor. Upstream from the wilderness area, Upper Burro Creek contains several additional miles of perennial stream. This area is administered by Bureau of Land Management.

Upper Burro Creek NRA Protection Needs

Based on current water quality monitoring information, Burro Creek from Francis Creek to Black Canyon classified as impaired for mercury (see Appendix A). Based on watershed classification results (section 6), this area should be specifically monitored for metals and sediment concentrations. Water quality monitoring should be continued and NPS pollutant management measures should be implemented when appropriate. Livestock grazing is the primary land use in the watershed and special attention should be given to protecting and restoring the riparian areas that may be impacted by this activity.

Trout Creek NRA

The Trout Creek NRA (TC-NRA) contains three 10-digit HUC subwatersheds: Trout Creek, Muddy Creek, and Markham Wash Area. Trout Creek is the only water in the Bill Williams that has been assessed as Attaining All Uses as reported in Arizona's Integrated 305(b) Assessment and 303(d) listing report (ADEQ, 2005), and represents the reference site for a pristine stream system for the region. The NRA contains several miles of perennial stream that supports an intact riparian area.

Trout Creek NRA Protection Needs

Based on current water quality monitoring information there is currently no indication of impairment within the TC-NRA. Based on the watershed classification results, this area should be monitored for organics and sediment concentrations (see Section 6). Water quality monitoring should be continued and NPS management measures should be implemented when appropriate.

Livestock grazing is currently the primary land use in the watershed and special attention should be given to protecting the riparian areas. The TC-NRA has a relatively higher percentage of private land compared to the rest of the watershed. Although there is currently little indication of development pressure within the TC-NRA this trend should be monitored. If development pressures increase in the future, actions should be taken to mitigate the potential impacts, as discussed in Section 7, Watershed Management where applicable best management practices are discussed.

<u>Kirkland Creek NRA</u>

The Kirkland Creek NRA (KC-NRA) consists of only one 10-digit HUC subwatershed, Kirkland Creek. The KC-NRA was designated as a NRA as a result of local concern regarding Kirkland Creek riparian and stream environments. The KC-NRA is the fastest growing area in the watershed due to development pressures from Prescott, Arizona. Kirkland Creek has several miles of perennial stream and is an important local resource for recreation and aesthetics.

Kirkland Creek NRA Protection Needs

Water quality and quantity is a concern within the KC-NRA. E. coli has been found to exceed surface water quality standards and is considered a potential health issue. Residents have also expressed concern over diminished stream flows within the system, with sections of the stream going dry during low flow conditions. Inadequate septic systems have been identified as a potential source of E. coli, and increased groundwater pumping for both water supply and irrigation is having an impact on stream flow. Both issues can be associated with increased development. Livestock grazing is also an important land use in the KC-NRA and special attention should be given to protecting and restoring the riparian areas. Based on watershed classification results (see Section 6), this area should be closely monitored for metals, sediment, organics and selenium concentrations since it is classified as high risk.

<u>Middle Big Sandy NRA</u>

The Middle Big Sandy NRA (MBS-NRA) contains one 10-digit HUC subwatershed, Middle Big Sandy River. The MBS-NRA includes a long stretch of riparian areas.

Middle Big Sandy NRA Protection Needs

Based on watershed classification results, this area should be closely monitored for metals, and selenium concentrations (See Section 6).

<u>Date Creek NRA</u>

The Date Creek NRA (DC-NRA) consists of only one 10-digit HUC subwatershed, Date Creek. The DC-NRA includes Tres Alamos Wilderness Area, administered by the BLM.

The Tres Alamos Wilderness has a total of 8,300 acres and is located in the southern Black Mountains. Columns of colorful stone are the most striking landscape features of this wilderness area. The landscape tops out at Sawyer Peak (4,293 feet), the highest point in the Black Mountains. The eastern portion of the area contains the Blacks' scenic ridgelines, canyons, and washes, while the western side consists of lower desert bajadas (slopes) and plains. On the bajadas and hills you'll find saguaro and palo verde trees. Joshua trees and creosote bushes dot the plains, and mesquite and acacia line the washes. The Gila monster lives here in seclusion, and prairie falcons and golden eagles rule the skies (Wilderness Institute, et al., 2005).

Although there are no established trails, the area is suitable for hiking, camping and horseback riding.

Date Creek NRA Protection Needs

Based on watershed classification results this area classified as low risk due to limited data (see Section 6). Water quality monitoring should be continued in this area.

Bullard Wash NRA

The Bullard Wash NRA (BW-NRA) consists of only one 10-digit HUC subwatershed, Bullard Wash. The DC-NRA includes the Harcuvar Mountains Wilderness Area, administered by the BLM.

The Harcuvar Mountains Wilderness has a total of 25050 acres. This desert encompasses over 10 miles of the Harcuvar Mountains' ridgeline, from an elevation of 2,400 feet on the bajadas to more than 5,100 feet on the mountainous crest. Plant and animal communities thrive on diverse landforms, including a 3,500-acre "island" of interior chaparral habitat on the northern ridgeline that hides a few species of wildlife cut off from their parent populations: rosy boas, Gilbert's skinks, and desert night lizards. Desert bighorn sheep live alongside mountain lions, desert tortoises, golden eagles, and several species of hawks. Isolated from the rest of the world, the Harcuvar Mountains offer splendid and lonely backpacking in the canyons and on the ridges (Wilderness Institute, et al., 2005).

Bullard Wash NRA Protection Needs

Based on current water quality data, Bullard Wash assessed as “impaired” for mercury, Organics and PH (see Appendix A). Based on watershed classification results, this area is classified as high risk for metals and organics concentrations (See Section 6). Water quality monitoring should be continued in this area.

References:

Arizona Department of Environmental Quality, ADEQ. 2005. The Status of Water Quality in Arizona – 2004: 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/2004.html.

Wilderness Institute, Arthur Carhart National Wilderness Training Center, and the Aldo Leopold Wilderness Research Institute. 2005. Wilderness.net website www.wilderness.net

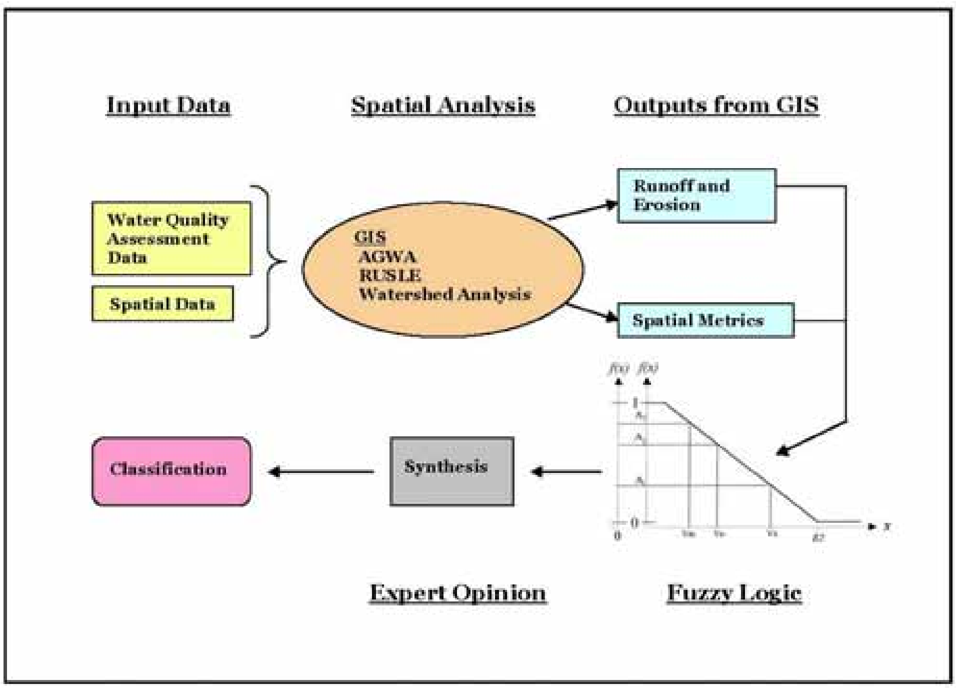
Section 6: Watershed Classification

In this section, each 10-digit subwatershed in the Bill Williams Watershed is classified or ranked based on susceptibility to water quality problems and pollution sources in the watershed 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.

Methods

The general approach to classifying 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.

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



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

- 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;

- Assemble GIS data and other observational data;

- Define watershed characteristics through:

  - ✓ Water quality assessment data provided by Arizona's Integrated 305(b) Assessment and 303(d) Listing Report (ADEQ, 2005);
  - ✓ GIS mapping analysis; and
  - ✓ Modeling / simulation of erosion vulnerability and potential for stream impairment (in this case, from soils in mine site areas and proximity to abandoned mine sites).

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

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

Fuzzy Logic

The "fuzzy logic" method is used to integrate different types of data (Guertin et al., 2000; Reynolds, 2001). Using fuzzy logic, a watershed tool was developed that can be updated as new water quality information becomes available. In this tool, the "weight" or priority given a specific factor used in the classification can be changed or adjusted, making the tool more valuable because underlying bias in interpreting the data can be uncovered and evaluated.

Fuzzy logic is an approach to handle vagueness or uncertainty, and has been characterized 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. For example, one is either tall or short, 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 considered in the tall class, although he could not be considered 'not-tall'. This is not satisfactory, for example, if one has to describe or quantify 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.

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 case above, the degree of tallness was iteratively added in intervals of 0.2. An example of a continuous data set would be graphing heights of all individuals and correlating 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.

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 HUC numerical identification and subwatershed name.

Classifications were conducted for 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 evaluated for the Bill Williams Watershed are:

- Metals (mercury, copper, zinc, lead, arsenic), with mercury used as an index since it is the most common parameter sampled in the subwatershed;
- Sediment (turbidity is used as an index since it was the previous standard and represents most of the sampling data);
- Organics (Escherichia coli, nutrients, high pH factors, and dissolved oxygen are concerns 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.

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

HUC 10	Subwatershed Name
1503020101	Markham Wash
1503020103	Willow Creek
1503020105	Knight Creek
1503020104	Trout Creek
1503020102	Muddy Creek
1503020106	Upper Big Sandy River
1503020202	Upper Burro Creek
1503020201	Francis Creek
1503020107	Middle Big Sandy River
1503020203	Boulder Creek
1503020302	Sycamore Creek
1503020204	Lower Burro Creek
1503020403	Mohave Wash
1503020303	Upper Santa Maria River
1503020108	Lower Big Sandy River
1503020301	Kirkland Creek
1503020404	Castaneda Wash-Bill Williams River
1503020402	Alamo Lake-Bill Williams River
1503020305	Lower Santa Maria River
1503020304	Date Creek
1503020401	Bullard Wash

Water Quality Assessment Data

Data collected and used for Arizona's 2004 Integrated 305(b) Assessment and 303(d) Listing Report (ADEQ, 2005) was used to define the current level of impairment based on water quality sampling results from several entities and volunteer groups in Arizona. In assigning fuzzy membership values, the location of a subwatershed relative to an impaired water was considered. Appendix A Table 1 is a summary of the water quality monitoring and assessment data collected on the Bill Williams Watershed.

ADEQ's assessment criteria and assessment definitions are found in Arizona's Integrated 305(b) Assessment and 303(d) Listing Report (ADEQ, 2005). Surface waters assessed as "impaired" are included in Arizona's 303(d) List of Impaired Waters and 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, 2004).

The water quality data were used to classify each monitored stream reach based on its relative risk of impairment for the constituent groups described above.

To classify each 10-digit subwatershed, based on its relative risk of impairment for the constituent groups described above, four levels of risk were defined: Extreme, High, Moderate, and Low.

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

- High risk – If a surface water 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 within the subwatershed is assessed as "inconclusive" or "attaining," but there are still a low number of samples exceeding standards for a constituent group; 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.

For more information on ADEQ's Bill Williams Watershed Water Quality Assessment, see the ADEQ Website: http://www.adeq.state.az.us/environ/water/assessment/assess.html

Each 10-digit HUC subwatershed is assigned a fuzzy membership value (FMV) based on the water quality parameters and assessment results. Table 6-2 contains the FMVs used for different watershed conditions based on the water quality classification results. It should be noted that not every 10-digit HUC subwatershed contained a water quality measurement site.

The FMVs are based on two considerations: 1) relative risk of impairment (described above), and 2) assessed water quality status of downstream surface waters if the subwatershed has either “high” or “moderate” condition.

The status of downstream surface waters provides a way to evaluate the potential 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.

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

Reach Condition	Downstream Condition	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

Reaches classified as either extreme or low risk were given precedence over high or moderate classified reaches in determining downstream water quality condition because of their ambiguity. For example, if a downstream water body was classified as extreme risk, it was used to define the downstream water quality condition. However, if a reach along the pathway was classified as low risk, then the low risk reach was used to define the downstream water quality condition.

Table 1 in Appendix A provides more clarification on the ADEQ Water Quality Assessment results, and defines the basis for classification as extreme, high, moderate, and low risk.

Metals

Metals are the most severe water quality problem in the Bill Williams Watershed because of the potential toxicity to aquatic life.

Lower Big Sandy River; Alamo Lake, Lower Burro Creek, Lower Santa Maria River and Bullard Wash subwatersheds are impaired due to high mercury exceedances. Boulder Creek subwatershed has been found to be impaired due to mercury, arsenic and copper, and metals were found to exceed standards in several other reaches. However, some stream reaches have not been sampled for metals.

The primary sources for metals in the Bill Williams Watershed are probably runoff and erosion from active and abandoned mines. Developed urban areas should also be considered a nonpoint source for metals pollutants; however, the Bill Williams Watershed is mostly rural and has little industry besides mining. Because of the sparse population density, urban development is not foreseen as a major source of metals, and “development” was not used as a classification factor.

The factors used for the metals classification were:

- ADEQ water quality assessment results;

- Presence of mines within a subwatershed;
- Presence of mines within the riparian zone; and
- Potential contribution of mines to sediment yield.

Water Quality Assessment Data – Metals

Arizona's Integrated 305(b) Assessment and 303(d) Listing Report (ADEQ, 2005) was used to define the current level of impairment for metals. The location of a subwatershed relative to an impaired water was considered when assigning fuzzy membership values. Table 6-2 contains the fuzzy membership values used for different subwatershed conditions based on the water quality assessment results. Table 6-3 contains the fuzzy membership values for metals assigned to each 10-digit HUC subwatershed, based on the criteria defined in Table 6-2.

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

Subwatershed Name	FMV	Justification
Markham Wash	**0.3**	**Classified as moderate risk (no data) and drains into Trout Creek that is classified as low risk.**
Muddy Creek	**0.3**	**Classified as moderate risk (no data) and drains into Trout Creek that is classified as low risk.**
Willow Creek	**0.7**	**Classified as moderate risk (no data) and drains into Lake Alamo that is classified as extreme risk.**
Trout Creek	**0.0**	**Classified as low risk.**
Knight Creek	**0.7**	**Classified as moderate risk (no data) and drains into Lake Alamo that is classified as extreme risk.**
Upper Big Sandy River	**0.7**	**Classified as moderate risk (no data) and drains into Lake Alamo that is classified as extreme risk.**
Middle Big Sandy River	**0.7**	**Classified as moderate risk and drains into Lake Alamo that is classified as extreme risk**
Lower Big Sandy River	**1.0**	**Classified as extreme risk.**
Francis Creek	**0.7**	**Classified as moderate risk and drains into Alamo Lake that is classified as extreme risk.**
Upper Burro Creek	**0.7**	**Classified as moderate risk (no data) and drains into Alamo Lake is classified as extreme risk.**
Boulder Creek	**1.0**	**Classified as extreme risk**
Lower Burro Creek	**1.0**	**Classified as extreme risk**
Kirkland Creek	**0.7**	**Classified as moderate risk (lack of data) and drains into Lower Santa Maria River that is classified as extreme risk.**
Sycamore Creek	**0.7**	**Classified as moderate risk (no data) and drains into Lower Santa Maria River that is classified as extreme risk.**
Upper Santa Maria River	**0.7**	**Classified as moderate risk (no data) and drains into Lower Santa Maria River that is classified as extreme risk.**
Date Creek	**0.7**	**Classified as moderate risk (lack of data) and drains into Lower Santa Maria River that is classified as extreme risk.**
Lower Santa Maria River	**1.0**	**Classified as extreme risk.**
Bullard Wash	**1.0**	**Classified as extreme risk.**

Subwatershed Name	FMV	Justification
Alamo Lake-Bill Williams River	**1.0**	**Classified as extreme risk.**
Mohave Wash	**0.5**	**Classified as moderate risk (no data) and drains into Castaneda Wash-Bill Williams River that is classified as moderate risk.**
Castaneda Wash-Bill Williams River	**0.5**	**Classified as moderate risk.**

Note: This table is cross-referenced to Table 1 of Appendix A where the 10-digit HUC names are tabulated with the subwatershed name.

Location of Mining Activities

Section 2, Physical Characteristics and Section 4, Social Characteristics of the Bill Williams Watershed contain a more thorough discussion of the geologic conditions and location of mine sites and mine types across the watershed.

The subwatersheds were classified using the fuzzy logic methodology by incorporating the spatial data from Sections 2 and 4 with the tabulated ADEQ water quality assessment data.

The number of mines in a subwatershed and within the riparian zone (< = 250 m from a stream) were used to assess the relative impact of mining on the concentration of dissolved and total metals in the subwatershed. The fuzzy membership functions for both conditions are:

Number of mines/subwatershed:

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

Number of mines/riparian:

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 subwatersheds based on the number of and location of mines.

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

Subwatershed	FMV # mines /watershed	FMV # mines /riparian
Markham Wash	**0.625**	**0.000**
Muddy Creek	**0.375**	**0.000**
Willow Creek	**0.000**	**0.200**
Trout Creek	**0.000**	**0.000**
Knight Creek	**1.000**	**1.000**
Upper Big Sandy River	**1.000**	**1.000**
Middle Big Sandy River	**1.000**	**0.800**
Lower Big Sandy River	**1.000**	**0.400**
Francis Creek	**0.000**	**0.000**
Upper Burro Creek	**0.000**	**0.200**
Boulder Creek	**1.000**	**1.000**
Lower Burro Creek	**1.000**	**1.000**
Kirkland Creek	**1.000**	**1.000**
Sycamore Creek	**0.120**	**0.000**
Upper Santa Maria River	**1.000**	**1.000**
Date Creek	**0.875**	**0.200**
Lower Santa Maria River	**1.000**	**0.400**
Bullard Wash	**0.750**	**0.800**
Alamo Lake-Bill Williams River	**1.000**	**1.000**
Mohave Wash	**0.375**	**0.000**
Castaneda Wash-Bill Williams River	**1.000**	**0.200**

Potential Contribution of Mines to Sediment Yield

Based on RUSLE modeling (Renard et al., 1997; see Appendix C) the potential for erosion from mines to contribute to the sediment yield for a subwatershed was evaluated. The modeling results were reclassified into 6 categories. The first category represented zero potential for contribution (i.e. no mines) and was given a fuzzy membership value of 0.0. The fuzzy membership values were increased by increments of 0.2 for each higher erosion category. Table 6-5 contains the results.

Table 6-5: FMV Per Erosion Category.

Subwatershed	Category	FMV
Markham Wash	3	0.4
Muddy Creek	3	0.4
Willow Creek	2	0.2
Trout Creek	2	0.2
Knight Creek	5	0.8
Upper Big Sandy River	6	1
Middle Big Sandy River	5	0.8
Lower Big Sandy River	5	0.8
Francis Creek	2	0.2
Upper Burro Creek	2	0.2
Boulder Creek	5	0.8
Lower Burro Creek	4	0.6
Kirkland Creek	6	1
Sycamore Creek	2	0.2
Upper Santa Maria River	6	1
Date Creek	3	0.4
Lower Santa Maria River	4	0.6
Bullard Wash	3	0.4
Alamo Lake-Bill Williams River	6	1
Mohave Wash	2	0.4
Castaneda Wash-Bill Williams River	4	0.6

Metals Results

The fuzzy membership values were used to create a combined fuzzy score for each subwatershed and were incorporated into the weighted combination method. The results are found in Table 6-6, and the weights are listed at the bottom of the table.

Weights were developed in cooperation with ADEQ and were ranked to emphasis the proximity of mines to the riparian 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. Therefore, the weight assigned to those mines was 0.1, as opposed to 0.3 for the other categories.

Each of the assigned weights were multiplied with the FMV, and then added to result in the weighted ranking. Subwatershed areas were classified into two groups, ‘high’ or ‘low’, based on the natural breaks of the FMV results. Figure 6-2 shows the results of the weighted combination method classified into high and low priority for metals.

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

Subwatershed	WQA[1]	# Mines / HUC	# Mines / Riparian	Erosion Category	Weighted
Markham Wash	**0.3**	**0.625**	**0.000**	**0.4**	**0.273**
Muddy Creek	**0.3**	**0.375**	**0.000**	**0.4**	**0.248**
Willow Creek	**0.7**	**0.000**	**0.200**	**0.2**	**0.330**
Trout Creek	**0.0**	**0.000**	**0.000**	**0.2**	**0.060**
Knight Creek	**0.7**	**1.000**	**1.000**	**0.8**	**0.850**
Upper Big Sandy River	**0.7**	**1.000**	**1.000**	**1**	**0.910**
Middle Big Sandy River	**0.7**	**1.000**	**0.800**	**0.8**	**0.790**
Lower Big Sandy River	**1.0**	**1.000**	**0.400**	**0.8**	**0.760**
Francis Creek	**0.7**	**0.000**	**0.000**	**0.2**	**0.270**
Upper Burro Creek	**0.7**	**0.000**	**0.200**	**0.2**	**0.330**
Boulder Creek	**1.0**	**1.000**	**1.000**	**0.8**	**0.940**
Lower Burro Creek	**1.0**	**1.000**	**1.000**	**0.6**	**0.880**
Kirkland Creek	**0.7**	**1.000**	**1.000**	**1**	**0.910**
Sycamore Creek	**0.7**	**0.120**	**0.000**	**0.2**	**0.282**
Upper Santa Maria River	**0.7**	**1.000**	**1.000**	**1**	**0.910**
Date Creek	**0.7**	**0.875**	**0.200**	**0.4**	**0.478**
Lower Santa Maria River	**1.0**	**1.000**	**0.400**	**0.6**	**0.700**
Bullard Wash	**1.0**	**0.750**	**0.800**	**0.4**	**0.735**
Alamo Lake-Bill Williams River	**1.0**	**1.000**	**1.000**	**1**	**1.000**
Mohave Wash	**0.5**	**0.375**	**0.000**	**0.4**	**0.308**
Castaneda Wash-Bill Williams River	**0.5**	**1.000**	**0.200**	**0.6**	**0.490**
Weights	**0.300**	**0.100**	**0.300**	**0.300**	

[1] WQA = Water Quality Assessment results

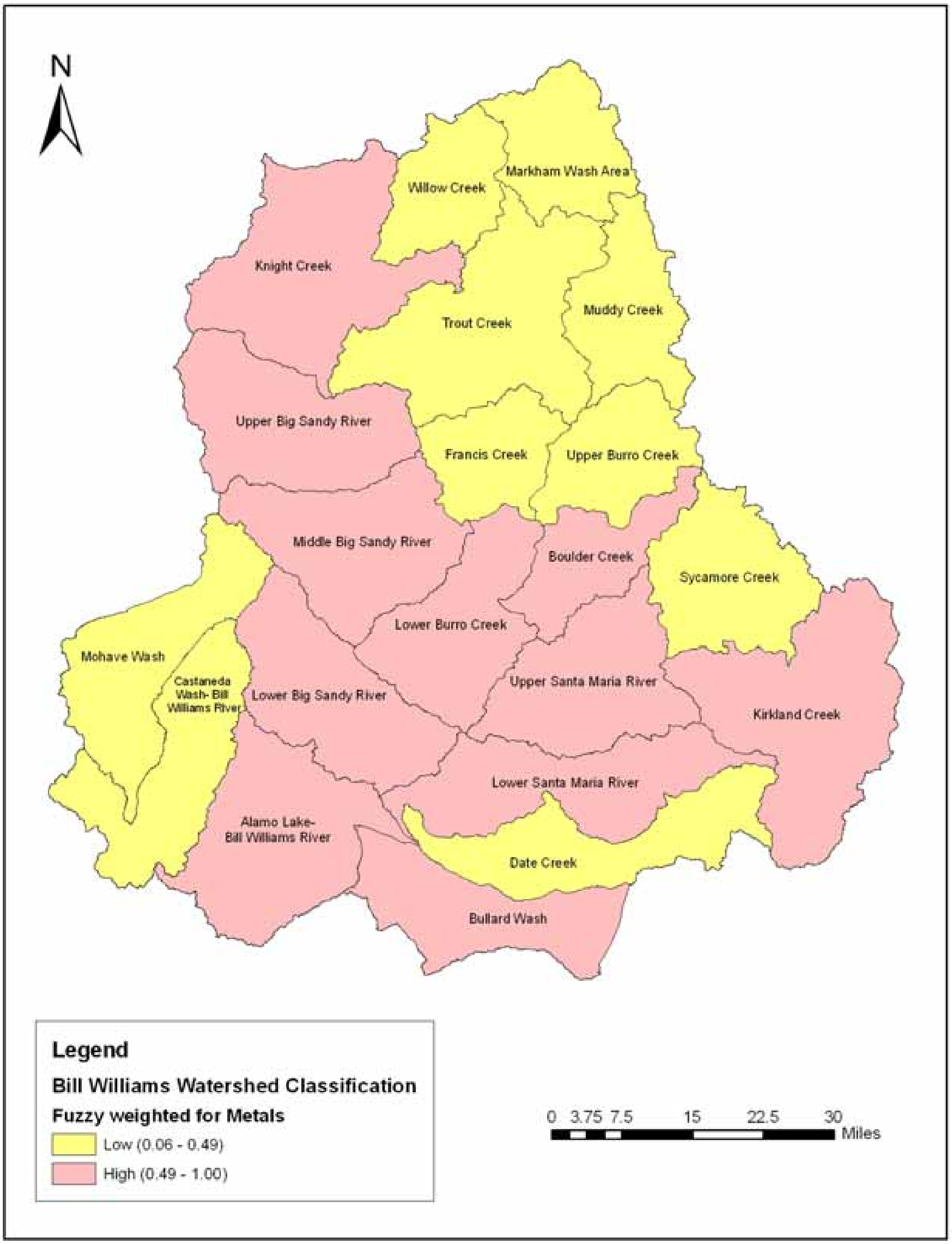


Figure 6-2: Results for the Fuzzy Logic Classification for Metals, Based on the Weighted Combination Approach.

Sediment

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

The factors used for the sediment classification are:

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

Since the available water quality data is limited, more weight was placed on subwatershed characteristics and modeling results when doing the classification.

Water Quality Assessment Data - Sediment

Arizona's Integrated 305(b) Assessment and 303(d) Listing Report (ADEQ, 2005), 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 assessment results. Table 6-7 contains the fuzzy membership values assigned to each 10-digit HUC subwatershed based on turbidity data.

Table 6-7: Fuzzy Membership Values for Sediment Assigned to each 10-Digit HUC Subwatershed, Based on Water Quality Assessment Results.

Subwatershed Name	FMV	Justification
Markham Wash	**0.3**	**Classified as moderate risk (no data) and drains into Trout Creek that is classified as low risk.**
Muddy Creek	**0.3**	**Classified as moderate risk (no data) and drains into Trout Creek that is classified as low risk.**
Willow Creek	**0.6**	**Classified as moderate risk (no data) and drains into Upper Big Sandy River subwatershed that is classified as high risk.**
Trout Creek	**0.0**	**Classified as low risk.**
Knight Creek	**0.6**	**Classified as moderate risk and drains into Upper Big Sandy River subwatershed that is classified as high risk.**
Upper Big Sandy River	**0.7**	**Classified as high risk and drains into Middle Big Sandy River subwatershed that is classified as moderate risk.**
Middle Big Sandy River	**0.5**	**Classified as moderate risk and drains into Lower Big Sandy River subwatershed that is classified as moderate risk.**
Lower Big Sandy River	**0.5**	**Classified as moderate risk and drains into Alamo Lake that is classified as moderate risk.**
Francis Creek	**0.5**	**Classified as moderate risk and drains into Lower Burro Creek that is classified as moderate risk.**

Subwatershed Name	FMV	Justification
Upper Burro Creek	**0.5**	**Classified as moderate risk and drains into Lower Burro Creek that is classified as moderate risk.**
Boulder Creek	**0.5**	**Classified as moderate risk and drains into Lower Burro Creek that is classified as moderate risk.**
Lower Burro Creek	**0.5**	**Classified as moderate risk and drains into Lower Big Sandy River that is classified as moderate risk.**
Kirkland Creek	**0.5**	**Classified as moderate risk and drains into Upper Santa Maria River that is classified as moderate risk.**
Sycamore Creek	**0.3**	**Classified as moderate risk and drains into Upper Santa Maria River that is classified as moderate risk.**
Upper Santa Maria River	**0.3**	**Classified as moderate risk and drains into Lower Santa Maria River that is classified as moderate risk.**
Date Creek	**0.5**	**Classified as moderate risk and drains into Alamo Lake that is classified as moderate risk.**
Lower Santa Maria River	**0.5**	**Classified as moderate risk and drains into Alamo Lake that is classified as moderate risk.**
Bullard Wash	**0.6**	**Classified as moderate risk and drains into Castaneda Wash-Bill Williams River that is classified as high risk.**
Alamo Lake-Bill Williams River	**0.6**	**Classified as moderate risk and drains into Castaneda Wash-Bill Williams River that is classified as high risk.**
Mohave Wash	**0.6**	**Classified as moderate risk and drains into Castaneda Wash-Bill Williams River that is classified as high risk.**
Castaneda Wash-Bill Williams River	**0.7**	**Classified as high risk.**

Land Ownership

The principal land use in the Bill Williams 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)) and comprises approximately 45% of the total watershed area. The remaining lands where grazing occurs are primarily Arizona State Trust Lands (approximately 28%), and privately owned land (approximately 26%). 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 below.

State and Private ownership over the subwatershed area:

FMV = 0 if (%State + private < = 10)
FMV = (%State + private – 10) / 15
FMV = 1 if (%State + private > = 25)

Table 6-8 contains the fuzzy membership values assigned to each 10-digit HUC subwatershed in the Bill Williams Watershed based on land ownership.

Table 6-8: Fuzzy Membership Values Based on Land Ownership.

Subwatershed	**% State + Private**	**FMV**
Markham Wash	**100**	**1.00**
Muddy Creek	**90.14**	**1.00**
Willow Creek	**97.66**	**1.00**
Trout Creek	**99.95**	**1.00**
Knight Creek	**80.19**	**1.00**
Upper Big Sandy River	**48.75**	**1.00**
Middle Big Sandy River	**15.64**	**0.38**
Lower Big Sandy River	**15.35**	**0.36**
Francis Creek	**72.21**	**1.00**
Upper Burro Creek	**83.13**	**1.00**
Boulder Creek	**84.82**	**1.00**
Lower Burro Creek	**19.2**	**0.61**
Kirkland Creek	**78.34**	**1.00**
Sycamore Creek	**35.68**	**1.00**
Upper Santa Maria River	**77.27**	**1.00**
Date Creek	**59.87**	**1.00**
Lower Santa Maria River	**51.75**	**1.00**
Bullard Wash	**23.05**	**0.87**
Alamo Lake-Bill Williams River	**6.88**	**0.00**
Mohave Wash	**22.01**	**0.80**
Castaneda Wash-Bill Williams River	**15.93**	**0.40**

Human Use Index - Sediment Load

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 Bill Williams Watershed, human use consists of developed areas as defined by National Land Cover Data as residential land use, mining, agricultural lands and roads (USGS, 2003). 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)/subwatershed:

$$FMV = 0 \text{ if } (HUI <= 5\%)$$
$$FMV = (HUI - 5) / 15$$
$$FMV = 1 \text{ if } (HUI >= 20\%)$$

Human Use Index (HUI)/riparian:

$$FMV = 0 \text{ if } (HUI <= 1\%)$$
$$FMV = (HUI - 1) / 4$$
$$FMV = \text{ if } (HUI >= 5\%)$$

Table 6-9 contains the fuzzy membership values assigned to each 10-digit HUC subwatershed in the Bill Williams Watershed based on the Human Use Index.

Runoff

Based on SWAT modeling (see Appendix D) the potential runoff for a subwatershed area was evaluated. The modeling results were reclassified into 5 categories, with the first category given a fuzzy membership value of 0.2. The fuzzy membership values were increased by 0.2 for each higher erosion category, as shown in Table 6-10.

Erosion

Sediment yield is a measure of the rate of erosion, and depends on a combination of soil properties, topography, climate and land cover.

SWAT was used to evaluate the potential sediment yield for each subwatershed (see Appendix D). The modeling results were reclassified into 5 categories, with the first category given a fuzzy membership value of 0.2. The fuzzy membership values were increased incrementally by 0.2 for each higher erosion category based on modeled sediment yield, as shown on Table 6-11.

Table 6-9: Fuzzy Membership Values Based on the Human Use Index.

Subwatershed	FMV HU Index /watershed	FMV HU Index /riparian
Markham Wash	0.00	0.73
Muddy Creek	0.00	0.75
Willow Creek	0.00	1.00
Trout Creek	0.00	0.47
Knight Creek	0.00	1.00
Upper Big Sandy River	0.00	0.47
Middle Big Sandy River	0.00	0.32
Lower Big Sandy River	0.00	0.10
Francis Creek	0.00	0.29
Upper Burro Creek	0.00	0.34
Boulder Creek	0.06	1.00
Lower Burro Creek	0.00	0.51
Kirkland Creek	0.00	0.98
Sycamore Creek	0.00	0.28
Upper Santa Maria River	0.00	0.76
Date Creek	0.00	0.26
Lower Santa Maria River	0.00	0.29
Bullard Wash	0.00	0.33
Alamo Lake-Bill Williams River	0.00	0.54
Mohave Wash	0.00	0.22
Castaneda Wash-Bill Williams River	0.00	0.30

Table 6-10: Fuzzy Membership Values and Runoff Categories.

Subwatershed	Runoff Category	FMV
Markham Wash	2	0.4
Muddy Creek	5	1.0
Willow Creek	2	0.4
Trout Creek	3	0.6
Knight Creek	2	0.4
Upper Big Sandy River	2	0.4
Middle Big Sandy River	2	0.4
Lower Big Sandy River	1	0.2
Francis Creek	4	0.8
Upper Burro Creek	5	1.0
Boulder Creek	5	1.0
Lower Burro Creek	5	1.0
Kirkland Creek	5	1.0
Sycamore Creek	5	1.0
Upper Santa Maria River	4	0.8
Date Creek	3	0.6
Lower Santa Maria River	4	0.8
Bullard Wash	1	0.2
Alamo Lake-Bill Williams River	1	0.2
Mohave Wash	2	0.4
Castaneda Wash-Bill Williams River	1	0.2

Sediment Results

The weighted combination approach was used to create combined fuzzy scores to rank sediment results, as shown in Table 6-12. The weights used in the classification are found at the bottom of Table 6-12.

Table 6-11: Fuzzy Membership Values and Erosion Categories.

Subwatershed	Erosion Category	FMV
Markham Wash	1	0.2
Muddy Creek	2	0.4
Willow Creek	3	0.6
Trout Creek	3	0.6
Knight Creek	2	0.4
Upper Big Sandy River	3	0.6
Middle Big Sandy River	3	0.6
Lower Big Sandy River	2	0.4
Francis Creek	3	0.6
Upper Burro Creek	4	0.8
Boulder Creek	3	0.6
Lower Burro Creek	3	0.6
Kirkland Creek	4	0.8
Sycamore Creek	5	1.0
Upper Santa Maria River	3	0.6
Date Creek	1	0.2
Lower Santa Maria River	3	0.6
Bullard Wash	1	0.2
Alamo Lake-Bill Williams River	3	0.6
Mohave Wash	2	0.4
Castaneda Wash-Bill Williams River	4	0.8

Table 6-12: Summary Results for Sediment Based on the Fuzzy Logic Approach - Weighted Combination Approach.

Subwatershed	WQA[1]	Owner	HU Index /watershed	HU Index /riparian	Runoff	Erosion	FMV Weighted
Markham Wash Area	0.3	1.00	0.00	0.73	0.4	0.2	0.39
Muddy Creek	0.3	1.00	0.00	0.75	1.0	0.4	0.64
Willow Creek	0.6	1.00	0.00	1.00	0.4	0.6	0.58
Trout Creek	0.0	1.00	0.00	0.47	0.6	0.6	0.50
Knight Creek	0.6	1.00	0.00	1.00	0.4	0.4	0.52
Upper Big Sandy River	0.7	1.00	0.00	0.47	0.4	0.6	0.48
Middle Big Sandy River	0.5	0.38	0.00	0.32	0.4	0.6	0.41
Lower Big Sandy River	0.5	0.36	0.00	0.10	0.2	0.4	0.24
Francis Creek	0.5	1.00	0.00	0.29	0.8	0.6	0.55
Upper Burro Creek	0.5	1.00	0.00	0.34	1.0	0.8	0.68
Boulder Creek	0.5	1.00	0.06	1.00	1.0	0.6	0.76
Lower Burro Creek	0.5	0.61	0.00	0.51	1.0	0.6	0.64
Kirkland Creek	0.5	1.00	0.00	0.98	1.0	0.8	0.81
Sycamore Creek	0.3	1.00	0.00	0.28	1.0	1.0	0.72
Upper Santa Maria River	0.3	1.00	0.00	0.76	0.8	0.6	0.64
Date Creek	0.5	1.00	0.00	0.26	0.6	0.2	0.37
Lower Santa Maria River	0.5	1.00	0.00	0.29	0.8	0.6	0.55
Bullard Wash	0.6	0.87	0.00	0.33	0.2	0.2	0.26
Alamo Lake-Bill Williams River	0.6	0.00	0.00	0.54	0.2	0.6	0.38
Mohave Wash	0.6	0.80	0.00	0.22	0.4	0.4	0.35
Castaneda Wash-Bill Williams River	0.7	0.40	0.00	0.30	0.2	0.8	0.42
Weights	0.05	0.05	0.1	0.2	0.3	0.3	

[1]WQA = Water Quality Assessment results

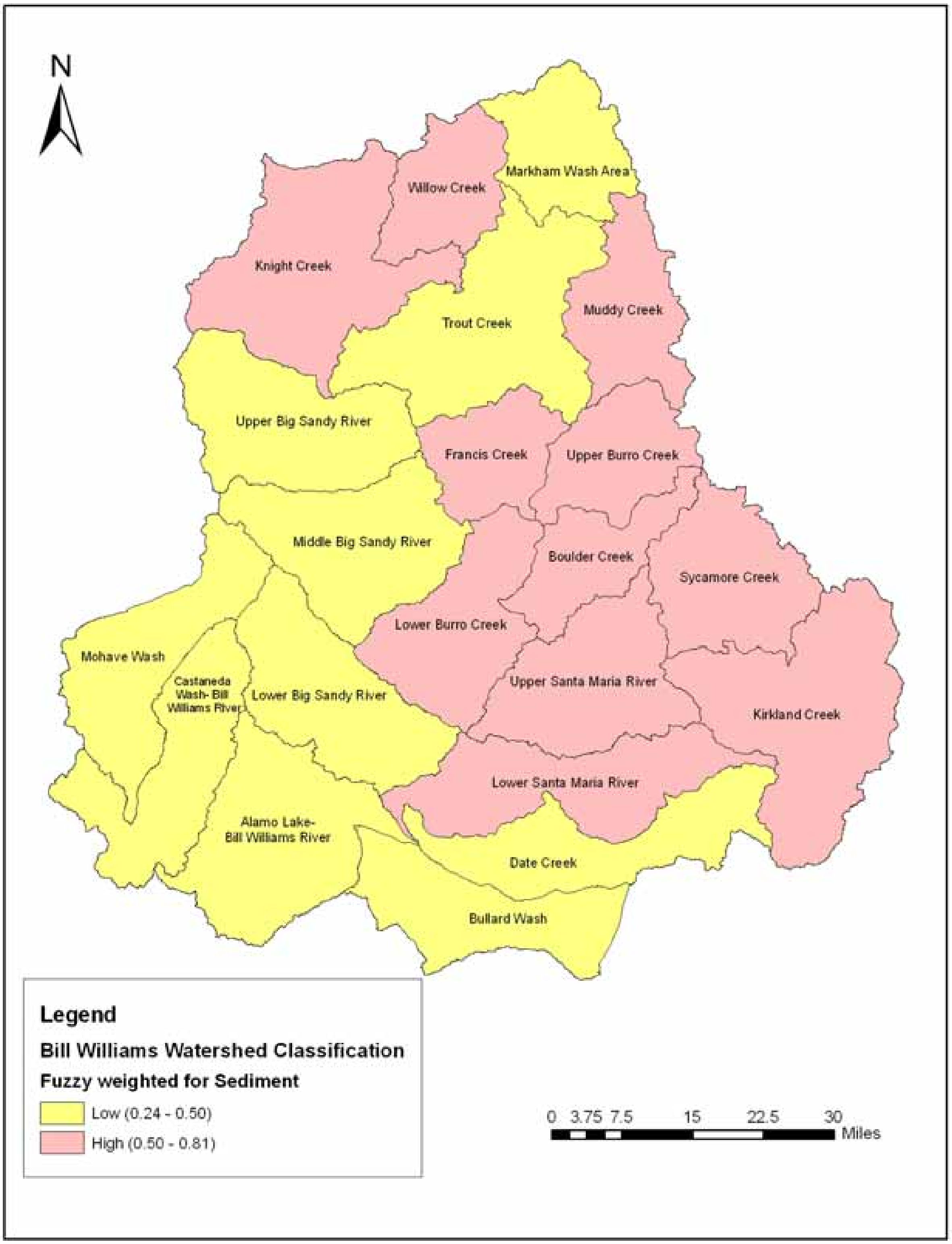


Figure 6-3: Results for the Fuzzy Logic Classification for Sediment Based on the Weighted Combination Approach.

Organics

Several water quality parameters that have been identified as concerns in the Bill Williams Watershed are related to the introduction of organic material to a water body. Lower Big Sandy River, Lower Santa Maria River, Bullard Wash and Alamo Lake subwatersheds assess as impaired for organics due to pH exceedances. Alamo Lake is also assessed as impaired for ammonia, most likely related to the decomposition of organic material.

The factors that were used for the organic material classification are:

- ADEQ water quality assessment results for organic parameters, including dissolved oxygen, E. coli, nutrients, 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 Data - Organics

Arizona's Integrated 305(b) Assessment and 303(d) Listing Report (ADEQ, 2005) 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 6-13 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 Bill Williams Watershed, human use consists of developed areas as defined by National Land Cover Data as residential land use, mining, agriculture and roads (USGS, 2003).

Human activity can introduce organic material to a water body through disposal of organic compounds and sewage. Most of the residential development in the Bill Williams Watershed utilizes 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 6-13: Fuzzy Membership Values Assigned to each 10-Digit HUC Subwatershed, Based on Water Quality Assessment Results for Organics.

Subwatershed	FMV	Justification
Markham Wash	0.3	Classified as moderate risk (no data) and drains into Trout Creek that is classified as low risk.
Muddy Creek	0.3	Classified as moderate risk (no data) and drains into Trout Creek that is classified as low risk.
Willow Creek	0.7	Classified as moderate risk (no data) and drains into Lower Big Sandy River subwatershed that is classified as extreme risk.
Trout Creek	0	Classified as low risk.
Knight Creek	0.7	Classified as moderate risk and drains into Lower Big Sandy River subwatershed that is classified as extreme risk.
Upper Big Sandy River	0.7	Classified as moderate risk and drains into Lower Big Sandy River subwatershed that is classified as extreme risk.
Middle Big Sandy River	0.7	Classified as moderate risk and drains into Lower Big Sandy River subwatershed that is classified as extreme risk.
Lower Big Sandy River	1.0	Classified as extreme risk.
Francis Creek	0.7	Classified as moderate risk and drains into Lower Big Sandy River that is classified as extreme risk.
Upper Burro Creek	0.7	Classified as moderate risk and drains into Lower Big Sandy River that is classified as extreme risk.
Boulder Creek	0.7	Classified as moderate risk and drains into Lower Big Sandy River that is classified as extreme risk.
Lower Burro Creek	0.7	Classified as moderate risk and drains into Lower Big Sandy River that is classified as extreme risk.
Kirkland Creek	1.0	Classified as high risk and drains into Lower Santa Maria River that is classified as extreme risk.
Sycamore Creek	0.7	Classified as moderate risk and drains into the Lower Santa Maria River that is classified as extreme risk.
Upper Santa Maria River	0.7	Classified as moderate risk and drains into the Lower Santa Maria River that is classified as extreme risk.
Date Creek	0.7	Classified as moderate risk and drains into Alamo Lake that is classified as extreme risk.
Lower Santa Maria River	1.0	Classified as extreme risk
Bullard Wash	1.0	Classified as extreme risk.
Alamo Lake-Bill Williams River	1.0	Classified as extreme risk.
Mohave Wash	0.5	Classified as moderate risk and drains into Castaneda Wash-Bill Williams River that is classified as moderate risk.
Castaneda Wash-Bill Williams River	0.5	Classified as moderate risk.

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 subwatershed:

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 6-14 contains the fuzzy membership values assigned to each 10-digit HUC subwatershed in the Bill Williams Watershed based on the Human Use Index.

Land Use - Organics

The principal land use in the Bill Williams Watershed is livestock grazing. Livestock grazing occurs primarily on land owned by the federal government (BLM and the U.S. F.S.), on Arizona State Trust land and private land.

Each 10-digit HUC subwatershed was assigned a fuzzy membership value based on its primary land use relative to livestock grazing. Boulder Creek and Lower Burro Creek subwatersheds were assigned a fuzzy membership value of 0.0 since their primary use was from mining. Castaneda Wash - Bill Williams subwatershed was assigned a fuzzy membership value of 0.0 because the principal landowner near the river is the Bill Williams Wildlife Refuge, and the BLM has several wilderness areas along the river, which suggests that the land is managed and nonpoint source pollution is controlled. All remaining subwatersheds were initially assigned a value of 1.0 as the land was assumed to primarily be used for livestock grazing.

Table 6-14: Fuzzy Membership Values for Organics, Based on the Human Use Index.

Subwatershed	FMV HUI/ subwatershed	FMV HUI/ Riparian
Markham Wash	**0.594**	**0.975**
Muddy Creek	**0.310**	**1.000**
Willow Creek	**0.683**	**1.000**
Trout Creek	**0.206**	**0.720**
Knight Creek	**0.886**	**1.000**
Upper Big Sandy River	**0.253**	**0.724**
Middle Big Sandy River	**0.209**	**0.572**
Lower Big Sandy River	**0.066**	**0.355**
Francis Creek	**0.217**	**0.542**
Upper Burro Creek	**0.153**	**0.594**
Boulder Creek	**1.000**	**1.000**
Lower Burro Creek	**0.299**	**0.759**
Kirkland Creek	**0.822**	**1.000**
Sycamore Creek	**0.192**	**0.526**
Upper Santa Maria River	**0.621**	**1.000**
Date Creek	**0.304**	**0.505**
Lower Santa Maria River	**0.332**	**0.539**
Bullard Wash	**0.285**	**0.582**
Alamo Lake-Bill Williams River	**0.290**	**0.793**
Mohave Wash	**0.064**	**0.470**
Castaneda Wash-Bill Williams River	**0.092**	**0.548**

Nutrients

According to Arizona's Integrated 305(b) Assessment and 303(d) Listing Report (ADEQ, 2005), Lake Alamo has been reported to be in exceedance for ammonia. This condition is most likely caused by decomposition of organic material under anaerobic conditions, and is not likely to be the result of a direct flush of ammonia into the system. Ammonia is highly volatile and typically does not persist in a water body. Coupled with the observation of reported low levels of dissolved oxygen found at the Lake Alamo, the likely explanation is due to organic material decomposition.

Nutrients, specifically nitrogen and phosphorus, do not appear to be a problem within the Bill Williams Watershed. This analysis is supported by the lack of potential sources for nutrients within the system. The application of commercial fertilizers to support agriculture is the most common source of introduced nutrients, but this is largely absent in the Bill Williams Watershed.

Another source of introduced nutrients is runoff from residential areas where landscapes are fertilized. The Bill Williams Watershed not only has a low density of urban development, but most of the home sites in the area are likely to use natural landscaping due to the lack of water resources available for irrigation. There are also no known commercial activities within the watershed that would introduce nutrients into the system.

pH

Lake Alamo is reported to be impaired for high pH (caustic) levels. Caustic pH measurements can be an indication of lake eutrophication. Typical, unpolluted flowing water will have pH values ranging from 6.5 to 8.5; 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 land lakes such as Lake Alamo.

Organics Results

The weighted combination approach was used to create the combined fuzzy score, and the results are found in Table 6-15. The weights used in the classification are found at the bottom of the table. Figure 6-4 shows the results of the weighted combination method classified into high and low priority for organics.

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

Subwatershed	WQA[1]	Land Use	HUI/ HUC	HUI/ Riparian	FMV Weighted
Markham Wash	0.300	1.000	0.594	0.975	0.701
Muddy Creek	0.300	1.000	0.310	1.000	0.652
Willow Creek	0.700	1.000	0.683	1.000	0.847
Trout Creek	0.000	1.000	0.206	0.720	0.457
Knight Creek	0.700	1.000	0.886	1.000	0.887
Upper Big Sandy River	0.700	1.000	0.253	0.724	0.678
Middle Big Sandy River	0.700	1.000	0.209	0.572	0.623
Lower Big Sandy River	1.000	1.000	0.066	0.355	0.620
Francis Creek	0.700	1.000	0.217	0.542	0.616
Upper Burro Creek	0.700	1.000	0.153	0.594	0.619
Boulder Creek	0.700	0.000	1.000	1.000	0.710
Lower Burro Creek	0.700	0.000	0.299	0.759	0.498
Kirkland Creek	1.0	1.000	0.822	1.000	0.964
Sycamore Creek	0.700	1.000	0.192	0.526	0.606
Upper Santa Maria River	0.700	1.000	0.621	1.000	0.834
Date Creek	0.700	1.000	0.304	0.505	0.622
Lower Santa Maria River	1.000	1.000	0.332	0.539	0.728
Bullard Wash	1.000	1.000	0.285	0.582	0.732
Alamo Lake-Bill Williams River	1.000	1.000	0.290	0.793	0.796
Mohave Wash	0.500	1.000	0.064	0.470	0.504
Castaneda Wash-Bill Williams River	0.500	0.000	0.092	0.548	0.333
Weights	0.300	0.200	0.200	0.300	

[1]WQA = Water Quality Assessment results

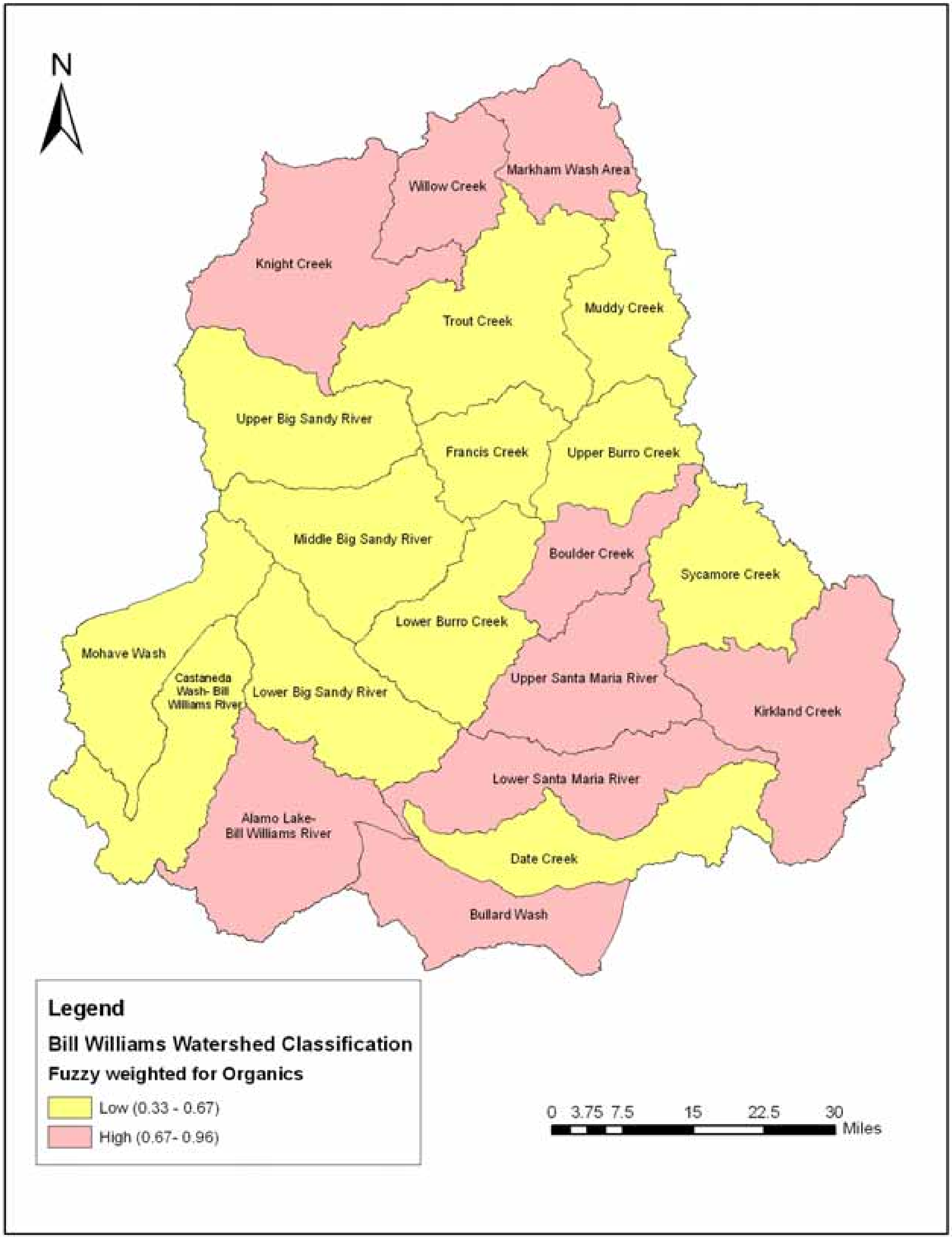


Figure 6-4: Results for the Fuzzy Logic Classification for Organics, Based on the Weighted Combination Approach.

Selenium

According to Arizona's Integrated 305(b) Assessment and 303(d) Listing Report (ADEQ, 2005), the Middle Big Sandy River and Boulder Creek subwatersheds exceed the standards for selenium. High values for selenium are associated with high values for metals in both reaches, and is likely to be naturally occurring in the highly mineralized soils of the region. In addition, the high selenium values may be associated with mining evaporation or tailings ponds, where evaporation would increase the relative concentration of selenium, as well as other constituents.

Water Quality Assessment Data - Selenium

The ADEQ Water Quality Assessment 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 6-16 contains the fuzzy membership values for selenium for each subwatershed based on the water quality assessment results.

Agricultural lands

The percentage of the agricultural lands in each 10-digit HUC subwatershed was calculated and a fuzzy membership function was defined as follows:

FMV = 0 if (% of Agricultural land = 0)
FMV = (% of Agricultural land / 1)
FMV = 1 if (% of Agric. land > = 1)

Selenium Results

Table 6-17 shows the fuzzy membership values for selenium for agricultural lands. The fuzzy membership values were used to create a combined fuzzy score for each subwatershed and were incorporated into the weighted combination method. These results are found in Table 6-18, and the weights are listed at the bottom of the table.

High values for selenium are most likely naturally occurring in the highly mineralized soils of the region. In addition, the high selenium 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 drainage water from seleniferous irrigated soils (Hem 1970). Figure 6-5 shows the results of the weighted fuzzy logic classification for selenium, and Figure 6-6 shows the results in relation to agricultural lands.

Table 6-16: Fuzzy Membership Values for Selenium Assigned to each Subwatershed, Based on Water Quality Assessment Results.

Subwatershed Name	FMV	Justification
Markham Wash	0.3	Classified as moderate risk (no data) and drains into Trout Creek that is classified as low risk.
Muddy Creek	0.3	Classified as moderate risk (no data) and drains into Trout Creek that is classified as low risk.
Willow Creek	0.6	Classified as moderate risk (no data) and drains into Middle Big Sandy River subwatershed that is classified as high risk.
Trout Creek	0.0	Classified as low risk.
Knight Creek	0.6	Classified as moderate risk and drains into Middle Big Sandy River subwatershed that is classified as high risk.
Upper Big Sandy River	0.6	Classified as moderate risk and drains into Middle Big Sandy River subwatershed that is classified as high risk.
Middle Big Sandy River	0.7	Classified as high risk and drains into Lower Big Sandy River subwatershed that is classified as moderate risk.
Lower Big Sandy River	0.3	Classified as moderate risk and drains into Alamo Lake that is classified as low risk.
Francis Creek	0.3	Classified as moderate risk and drains into Lower Burro Creek that is classified as low risk.
Upper Burro Creek	0.3	Classified as moderate risk and drains into Lower Burro Creek that is classified as low risk.
Boulder Creek	0.7	Classified as high risk and drains into Lower Burro Creek that is classified as low risk.
Lower Burro Creek	0.0	Classified as low risk.
Kirkland Creek	0.3	Classified as moderate risk and drains into Lower Santa Maria River that is classified as low risk.
Sycamore Creek	0.5	Classified as moderate risk and drains into Upper Santa Maria River that is classified as moderate risk.
Upper Santa Maria River	0.3	Classified as moderate risk and drains into Lower Santa Maria River that is classified as low risk.
Date Creek	0.3	Classified as moderate risk and drains into Alamo Lake that is classified as low risk.
Lower Santa Maria River	0.0	Classified as low risk.
Bullard Wash	0.0	Classified as low risk.
Alamo Lake-Bill Williams River	0.0	Classified as low risk.
Mohave Wash	0.5	Classified as moderate risk and drains into Castaneda Wash-Bill Williams River that is classified as moderate risk.
Castaneda Wash-Bill Williams River	0.5	Classified as moderate risk.

Table 6-17: Fuzzy Membership Values for Selenium Assigned to each Subwatershed, Based on the Percentage of Agricultural Lands.

Subwatershed Name	Percentage of Agricultural Lands	FMV for Agricultural Lands
Markham Wash	0.01%	0.01
Muddy Creek	0.00%	0.00
Willow Creek	0.16%	0.16
Trout Creek	0.01%	0.01
Knight Creek	0.03%	0.03
Upper Big Sandy River	0.35%	0.35
Middle Big Sandy River	0.41%	0.41
Lower Big Sandy River	0.02%	0.02
Francis Creek	0.00%	0.00
Upper Burro Creek	0.00%	0.00
Boulder Creek	0.04%	0.04
Lower Burro Creek	0.01%	0.01
Kirkland Creek	1.02%	1.00
Sycamore Creek	0.01%	0.01
Upper Santa Maria River	0.01%	0.01
Date Creek	0.33%	0.33
Lower Santa Maria River	0.09%	0.09
Bullard Wash	0.01%	0.01
Alamo Lake-Bill Williams River	0.35%	0.35
Mohave Wash	0.00%	0.00
Castaneda Wash-Bill Williams River	1.50%	1.00

Table 6-18: Weighted Combination Method Results for Selenium based on the Fuzzy Logic Approach.

Subwatershed Name	WQA[1]	FMV for Agricultural lands	FMV Weighted
Markham Wash	0.30	0.01	0.16
Muddy Creek	0.30	0.00	0.15
Willow Creek	0.60	0.16	0.38
Trout Creek	0.00	0.01	0.01
Knight Creek	0.60	0.03	0.32
Upper Big Sandy River	0.60	0.35	0.48
Middle Big Sandy River	0.70	0.41	0.56
Lower Big Sandy River	0.30	0.02	0.16
Francis Creek	0.30	0.00	0.15
Upper Burro Creek	0.30	0.00	0.15
Boulder Creek	0.70	0.04	0.37
Lower Burro Creek	0.00	0.01	0.01
Kirkland Creek	0.30	1.00	0.65
Sycamore Creek	0.50	0.01	0.26
Upper Santa Maria River	0.30	0.01	0.16
Date Creek	0.30	0.33	0.32
Lower Santa Maria River	0.00	0.09	0.05
Bullard Wash	0.00	0.01	0.01
Alamo Lake-Bill Williams River	0.00	0.35	0.18
Mohave Wash	0.50	0.00	0.25
Castaneda Wash-Bill Williams River	0.50	1.00	0.75
Weights	0.5	0.5	

[1]WQA = Water Quality Assessment results

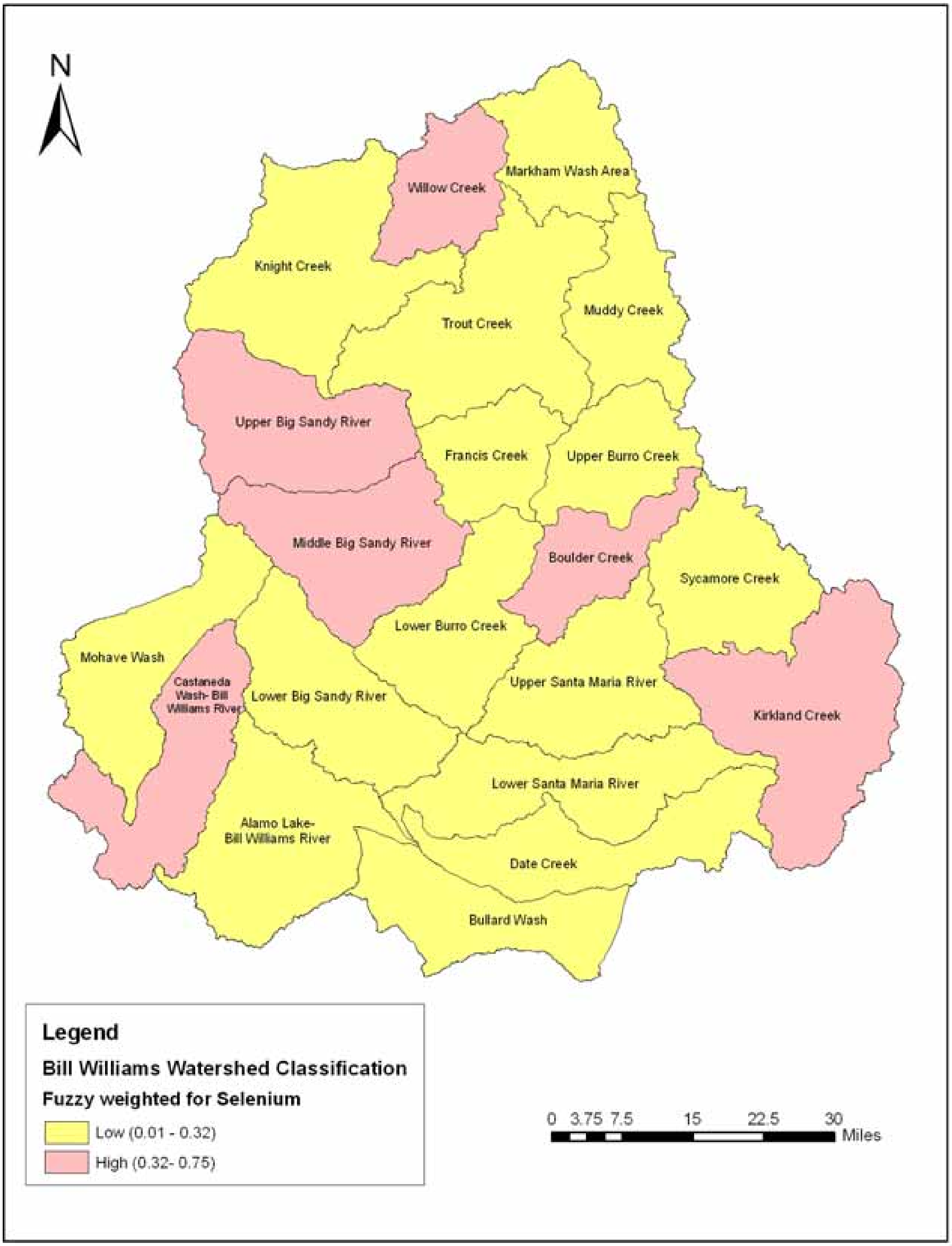


Figure 6-5: Results for the Fuzzy Logic Classification for Selenium Based on the Weighted Combination Approach.

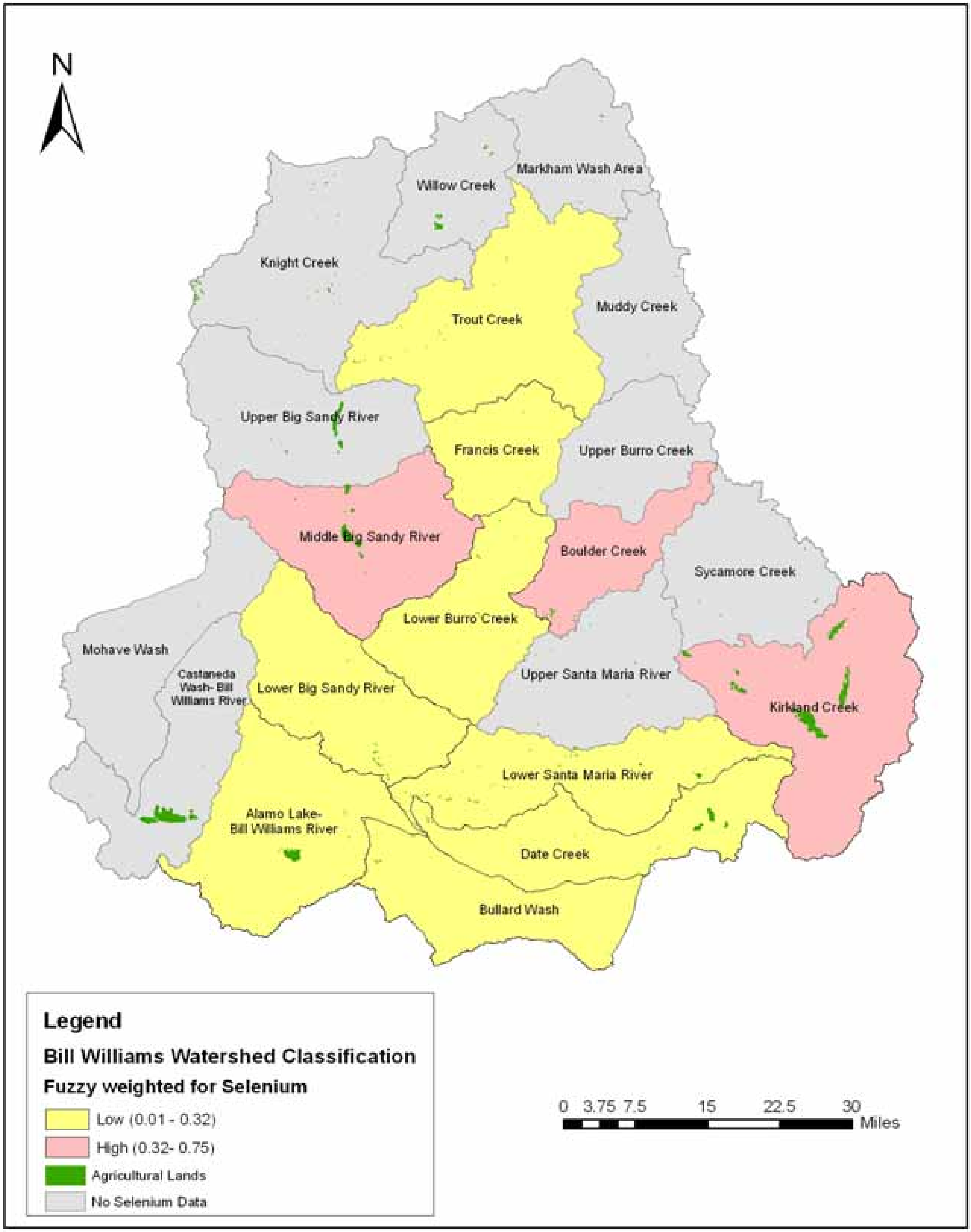


Figure 6-6: Results for the Fuzzy Logic Classification for Selenium, Based on the Weighted Combination Approach, Showing the Distribution of Agricultural Lands in each 10-digit HUC Subwatershed.

References:

Arizona Department of Environmental Quality, ADEQ. 2005. The Status of Water Quality in Arizona – 2004: 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/2004.html.

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.

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.

Data Sources:*

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.

USGS (U.S. Department of the Interior, U.S. Geological Survey), 2003. 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, it's 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 Bill Williams 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.

The Boulder Creek TMDL Implementation Plan is also summarized within this section. A TMDL plan is a study for an impaired water body that defines the maximum amount of a specified water quality parameter or pollutant that can be carried by a waterbody without causing an exceedance of water quality standards.

Management Methods

This 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 pollutant categories – metals, organics, and nutrients.

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 Bill Williams Watershed include the mining industry, new housing developments and increased urbanization, and new road construction. The Trout and Kirkland Creek Natural Resource Areas are particularly at risk from 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 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 Bill Williams Watershed's waters.

- Promote septic tank inspections and certification of septic systems by local government entities.
- Promote construction site inspection and enforcement actions 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 Bill Williams waters are elevated concentrations of dissolved and particulate metals, sediment and organics. The high priority 10-digit HUC watersheds 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 the impairment for each constituent group. The management measures discussed herein are brief and are 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 additional nonpoint source Best Management Practices (BMPs), can be found at the NEMO website, www.srnr.arizona.edu/nemo.

Metals

The primary nonpoint source of anthropogenic metals in the Bill Williams Watershed is abandoned 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 insignificant in this rural area, however, the watershed has a long history of mining with many abandoned and several active mines. 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 Bill Williams Watershed, including federal, state and private lands, with the majority of the mines found on land administered by the Bureau of Land Management (BLM) 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 are found in Table 7-1.

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 dependant 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.

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.

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. Once located, an onsite inventory should be conducted to clarify the degree of risk the site exhibits towards discharging elevated concentrations of metals to a water body.

Risk factors, such as: area of 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, should be assessed. 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 semiarid environments, revegetation of a disturbed site is relatively difficult even under optimal conditions. The amount of effort that is 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.

Erosion Control:

If revegetation 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 erosion treatments that are usually applied in combination with revegetation.

Reclaimed Mine Site
(Dept. of the Interior, Office of Surface Mining, http://www.osmre.gov/awardwy.htm)

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.

Rock Rip-Rap Sediment Control
(Dept. of the Interior, Office of Surface Mining, http://www.osmre.gov/ocphoto.htm)

A long-term treatment includes 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.

Rock Structure for Runoff Control
(Dept. of the Interior, Office of Surface Mining, http://www.osmre.gov/ocphoto.htm)

Removal:

The mine waste/tailing material can be excavated and removed. This treatment is very expensive and infeasible for some sites due to lack of accessibility.

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, the 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, Tribal entities).

Figure 7-1 identifies land ownership across the 10-digit HUCs. Table 7-2 provides a listing of percentage of land ownership as distributed across the subwatershed areas. This table provides a basis from which to identify stakeholders pertinent to each subwatershed area, and is repeated here in more detail than the brief discussion of land ownership in Section 4, Social and Economic Characteristics of the watershed.

Note that recommendations for those subwatersheds owned by tribal groups are not provided in this document.

Subwatershed areas prioritized for educational outreach on problems associated with abandoned mines include Alamo Lake, Boulder Creek, Upper Big Sand River, Lower Burro Creek, Upper Santa Maria River, and Kirkland Creek.

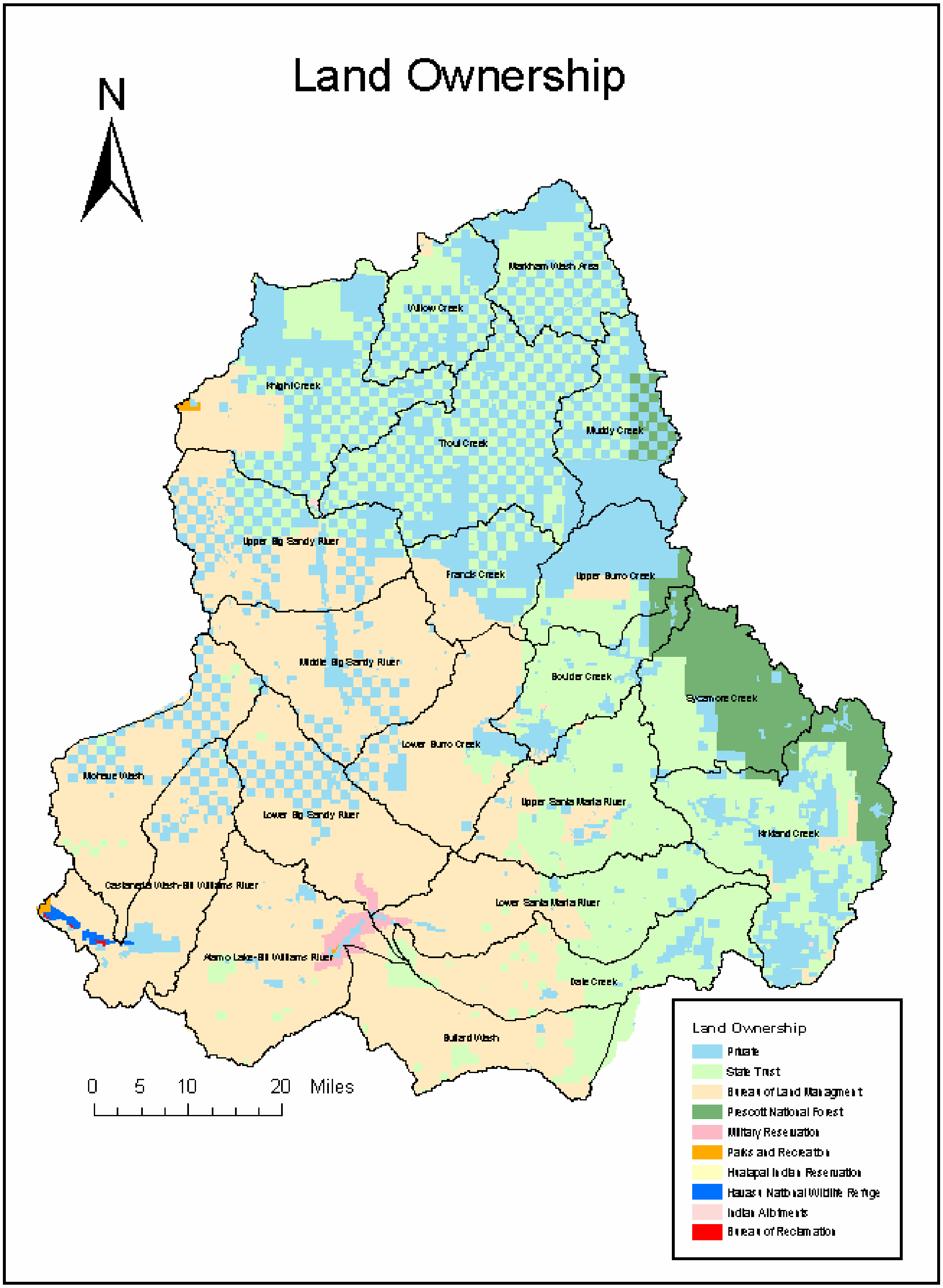


Figure 7-1: Bill Williams Watershed Land Ownership by Subwatershed

Table 7-2: Percentage Land Ownership by Subwatershed in the Bill Williams Watershed.

Sub-watershed	Private	State Trust Lands	U.S. Bureau of Land Mngmt	U.S. Forest Service	Military Reserv.	Nat'l Park Service	U.S. Fish & Wildlife Service	Indian Allot(1)
Markham Wash	**50.65**	**49.35**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Willow Creek	**48.89**	**48.77**	**2.34**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Knight Creek	**45.50**	**34.69**	**18.99**	**0.00**	**0.00**	**0.61**	**0.00**	**0.21**
Trout Creek	**56.42**	**43.52**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.05**
Muddy Creek	**69.04**	**21.10**	**0.00**	**9.86**	**0.00**	**0.00**	**0.00**	**0.00**
(2) Upper Big Sandy River	**37.12**	**11.64**	**51.21**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Upper Burro Creek	**55.61**	**27.52**	**9.16**	**7.71**	**0.00**	**0.00**	**0.00**	**0.00**
Francis Creek	**51.34**	**20.87**	**27.79**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Middle Big Sandy River	**15.64**	**0.00**	**84.36**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Boulder Creek	**19.29**	**65.52**	**4.37**	**10.82**	**0.00**	**0.00**	**0.00**	**0.00**
Sycamore Creek	**7.67**	**28.01**	**0.00**	**64.32**	**0.00**	**0.00**	**0.00**	**0.00**
Lower Burro Creek	**13.47**	**5.73**	**80.80**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Mohave Wash	**17.95**	**4.04**	**77.97**	**0.00**	**0.00**	**0.00**	**0.04**	**0.00**
Upper Santa Maria River	**5.88**	**71.40**	**22.72**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Lower Big Sandy River	**14.94**	**0.41**	**82.98**	**0.00**	**1.68**	**0.00**	**0.00**	**0.00**
Kirkland Creek	**32.46**	**45.89**	**3.30**	**18.29**	**0.00**	**0.00**	**0.00**	**0.06**
(3) Castaneda Wash	**15.75**	**0.18**	**80.27**	**0.00**	**0.00**	**0.62**	**2.90**	**0.00**
Alamo Lake	**3.32**	**3.57**	**88.09**	**0.00**	**4.93**	**0.09**	**0.00**	**0.00**
Lower Santa Maria River	**4.14**	**47.61**	**47.01**	**0.00**	**1.24**	**0.00**	**0.00**	**0.00**
Date Creek	**8.02**	**51.85**	**40.11**	**0.00**	**0.02**	**0.00**	**0.00**	**0.00**
Bullard Wash	**0.45**	**22.60**	**76.23**	**0.00**	**0.72**	**0.00**	**0.00**	**0.00**
Percentage of Bill Williams	**26.32**	**28.07**	**39.77**	**5.10**	**0.48**	**0.08**	**0.14**	**0.02**

(1) Non-Federally designated Indian Tribal land allotments.

(2) Federally designated Indian Tribal lands (Reservations) comprise 0.03% of the Upper Big Sandy River subwatershed, representing less than 0.001% of the overall Bill Williams Watershed.

(3) Bureau of Reclamation owns 0.28 % of the Castaneda Wash – Bill Williams River, for a total of 0.01% of the Bill Williams Watershed area.

Boulder Creek TMDL Implementation Plan:

Boulder Creek is a 37 mile intermittent waterway that drains seasonal precipitation from its headwaters near Camp Wood Mountain, 7,000 feet above mean sea level, to its confluence with Burro Creek at 2,460 feet. It is delineated within the 10-digit HUC Boulder Creek subwatershed.

Boulder Creek appeared on the 1998 List of Water Quality Limited Waters (303d List) for exceedences of surface water quality standards for arsenic, beryllium, copper, lead, manganese and zinc (ADEQ, 1998). In 2004, ADEQ completed its Boulder Creek TMDL Implementation Plan (ADEQ, 2004) to meet the State of Arizona's TMDL implementation plan requirements based on Arizona Revised Statutes (A.R.S. § 231-4).

ADEQ has concluded that historic mining within Boulder Creek's watershed has impaired the intermittent waterway from Wilder to Burro Creek. The plan defines an action strategy to implement cleanup of the four main sources of pollution defined by ADEQ's TMDL report: three tailing piles and an adit discharge from the Hillside Mine.

A TMDL is comprised of the sum of individual waste load allocations within the receiving water body for point sources, load allocations for nonpoint sources, and natural background levels. An adit is a horizontal mine shaft that usually is used for mine dewatering. The three tailings piles are located on land owned by the Bureau of Land management (BLM), a private owner, and the State of Arizona.

Using TMDL endpoints calculated specifically for the impaired reach, Boulder Creek has been identified as an impaired surface water due to excessive amounts of arsenic, copper, and zinc due to historic metal mining from the Hillside Mine. TMDL endpoints are precise values calculated as a reasonable goal for the surface water. TMDL endpoints represent the in-stream water quality targets, and different TMDL endpoints are necessary for each parameter.

The Boulder Creek TMDL implementation plan makes recommendations for the cleanup of the identified source areas. Daily load allocations for arsenic, copper, and zinc have been reported by ADEQ (ADEQ, 2004).

The process of selecting management measures for Boulder Creek was a collaborative effort among stakeholders, including state agencies, local land owners, and Phelps Dodge (the active mining company near the Bagdad area). BLM conducted their own research and hired an engineering consultant to identify and design solutions towards restoring surface water quality located on BLM land. Proposed management measures, anticipated load reductions, measurable milestones, and costs of implementation of selected measures are included in the TMDL Implementation Plan (ADEQ, 2004).

Sediment

Erosion and sedimentation are major environment problems in the western United States, including the Bill Williams Watershed. In semiarid regions, the primary source of sediment is from channel scour. Excessive channel scour and down-cutting can lead to deterioration of the extent and condition of a riparian system. Increases in channel scour are caused by increased surface runoff produced by changing watershed conditions. Restoration of impaired channel riparian systems can also mitigate erosion damage.

The primary land uses in the Bill Williams Watershed that can contribute to sediment erosion are livestock grazing and mining. Development is also increasing in some areas, notably the Kirkland Watershed. The increase in impervious land surface associated with development accelerates surface runoff, increases flow velocity, and exacerbates channel scour. Dirt roads, a common feature in the watershed, can also be an important source of sediment. The recommended sediment management actions (see Table 7-3) are:

- Grazing Management
- Filter Strips
- Fencing
- Watering Facilities
- Rock Riprap
- Erosion Control Fabrics
- Toe Rock
- Water Bars
- Erosion Control on Dirt Roads
- Channel and Riparian Restoration
- Education

Grazing Management:

Livestock grazing is currently the primary land use in the Bill Williams 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 the land 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:

Creating a filter strip along a waterbody will retard the movement of sediment into the waterbody, and may remove pollutants from runoff before the material enters the body of water. Filter strips will reduce sedimentation of streams, lakes and other bodies of water, and 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.

Table 7-3. Proposed Treatments for Addressing Erosion and Sedimentation.

Action	Load Reduction Potential	Estimated Time 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.

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 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 Livestock Watering Facility
(EC Bar Ranch http://www.ecbarranch.com)

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.

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.

Toe Rock:

Placement of rock and riprap along the toe of soil slopes reduces erosion and increases slope stability.

Rock Riprap and Jute Matting Erosion Control along a stream.
(Photo: Lainie Levick)

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 (tailings piles, 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. If a road is adjacent to a stream, engineered road stabilization treatments may be necessary.

The stabilization of roads and other embankments reduces sediment inputs from erosion and protects the related infrastructure. Traditional stabilization relied on expensive rock (riprap) treatments. Other options are available including the use of erosion control fabric, toe rock, and revegetation to stabilize banks.

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 it 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:

Education programs should be developed to address the impact of livestock grazing and promote the implementation of erosion control treatments. In the Kirkland Creek Watershed, education programs should address stormwater management from land development and target citizen groups, developers, and watershed partnerships.

Subwatershed areas prioritized for educational outreach to address erosion control include Kirkland Creek, Boulder Creek and Sycamore Creek.

<u>Organics</u>

At several locations within the Bill Williams Watershed, water quality problems associated with the introduction of animal waste were observed. The two primary sources of animal waste in the Bill Williams Watershed are livestock grazing in riparian areas and failing septic systems. The failure of residential septic systems is an issue in both the Kirkland Creek and Burro Creek Watersheds. Livestock grazing is common across the entire watershed. The recommended actions (Table 7-4) 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 livestock are present.

Table 7-4. Proposed Treatments for Addressing Organics.

Action	Load Reduction Potential	Estimated Time 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 fencing slows runoff and traps organics from sheet flow or channelized flow in areas of soil disturbance.

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 status 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 http://www.azdeq.gov/environ/water/permits/wastewater.html contains more information on permitting septic systems.

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 education programs to address the impact of livestock grazing and promote the implementation of filter strips and alternative watering facilities.

Education programs should also be developed on residential septic system maintenance. These programs should promote septic tank inspections and certification of septic systems by local municipalities or government entities.

Subwatershed areas that are prioritized for educational outreach to address organics include Knight Creek, Upper Santa Maria River and Kirkland Creek.

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, wheelline 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 wheelline is $805 per acre.

Education:

Develop educational programs that explain the sources of selenium, and illustrate the various alternative irrigation systems.

Strategy for Channel and Riparian Protection and Restoration

Riparian areas are one of the most critical resources in the Bill Williams 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 Bill Williams Watershed are managed by federal agencies, principally the Bureau of Land Management and U.S. Fish and Wildlife 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 four natural resource areas, including: the extensive riparian forests of the Lower Bill Williams Natural Resource Area; the perennial stream of the Upper Burro Creek Wilderness; the Trout Creek perennial stream that support an intact riparian area; and the Kirkland Creek riparian environment. 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 may be necessary. Treatments may involve engineered channel re-alignment, grade control and bank stabilization structures and a variety of revegetation and other bioengineering 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 classifications 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 upstream watershed conditions, onsite restoration efforts are likely to fail unless the overall watershed conditions are also improved. This requires an integrated approach that crosses 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* (erosion control, grazing management)
- *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)

Targeted Audiences:

The target audiences will include developers, private land owners, livestock growers, home owners and citizen groups. Several programs, including those addressing septic systems, stormwater management, and water conservation, will target the Kirkland Watershed, the fastest growing area in the Bill Williams Watershed. Development of an 'Adopt a Stream' Program will be considered.

References:

ADEQ, Arizona Department of Environmental Quality, November 1998. Arizona Water Quality Assessment 1998 Volume II – Assessment Data and Standards, EQR 98-14, Phoenix, Arizona.

ADEQ, Arizona Department of Environmental Quality, August 2004. The Boulder Creek TMDL Implementation Plan. Publication # OFR 04-03. Water Quality and Grants Unit, 1110 W. Washington St., Phoenix, AZ 85007.

Baker, L.A., and L. Farnsworth. 1995. Feasibility of management options to improve water quality in Rainbow Lake. Prepared for Arizona Department of Environmental Quality. 53 pp.

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, it's 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 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 watershed-based planning 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 6-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 most susceptible to 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. This methodology ranked 31 subwatersheds for four key nonpoint source water quality concerns:

- metals originating from abandoned mine sites;
- stream sedimentation due to land use activities;
- organic and nutrient pollution due to land use activities; and
- selenium due to agricultural practices.

Table 8-1 shows all 21 subwatersheds and their final weighted fuzzy membership value for each of these four constituents. Values highlighted in bold and 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 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.

Summary of Weighted Fuzzy Membership Values for each Subwatershed				
Subwatershed Name	**Metals WFMV[1]**	**Sediment WFMV[2]**	**Organics WFMV[3]**	**Selenium WFMV[4]**
Markham Wash	**0.273**	**0.390**	**0.701**	**0.160**
Muddy Creek	**0.248**	**0.640**	**0.652**	**0.150**
Willow Creek	**0.330**	**0.580**	**0.847**	**0.380**
Trout Creek	**0.060**	**0.500**	**0.457**	**0.010**
Knight Creek	**0.850**	**0.520**	**0.887**	**0.320**
Upper Big Sandy River	**0.910**	**0.480**	**0.678**	**0.480**
Middle Big Sandy River	**0.790**	**0.410**	**0.623**	**0.560**
Lower Big Sandy River	**0.760**	**0.240**	**0.620**	**0.160**
Francis Creek	**0.270**	**0.550**	**0.616**	**0.150**
Upper Burro Creek	**0.330**	**0.680**	**0.619**	**0.150**
Boulder Creek	**0.940 [5]**	**0.760**	**0.710**	**0.150**
Lower Burro Creek	**0.880**	**0.640**	**0.498**	**0.370**
Kirkland Creek	**0.910**	**0.810**	**0.964**	**0.010**
Sycamore Creek	**0.282**	**0.720**	**0.606**	**0.650**
Upper Santa Maria River	**0.910**	**0.640**	**0.834**	**0.160**
Date Creek	**0.478**	**0.370**	**0.622**	**0.320**
Lower Santa Maria River	**0.700**	**0.550**	**0.728**	**0.050**
Bullard Wash	**0.735**	**0.260**	**0.732**	**0.010**
Alamo Lake – Bill Williams River	**1.000 [6]**	**0.380**	**0.796**	**0.180**
Mohave Wash	**0.308**	**0.350**	**0.504**	**0.250**
Castaneda Wash – Bill Williams River	**0.490**	**0.420**	**0.333**	**0.750**

Notes:

1 Values greater than 0.49 indicate High Priority for Metals (shaded boxes), Table 6-6, Figure 6-2.
2 Values greater than 0.50 indicate High Priority for Sediment (shaded boxes), Table 6-12, Figure 6-3.
3 Values greater than 0.68 indicate High Priority for Organics (shaded boxes), Table 6-15, Figure 6-4.
4 Values greater than 0.32 indicate High Priority for Selenium (shaded boxes), Table 6-18, Figure 6-5.
5 Boulder Creek has a TMDL plan in place with recommended projects to address metals so the Upper Big Sandy River Subwatershed is selected for example project implementation.
6 Alamo Lake is heavily influenced by upstream conditions; Upper Big Sandy River Subwatershed is selected for example project implementation.

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 four example subwatershed projects that will be discussed here are:

1. Upper Big Sandy River, for metals pollution;

2. Kirkland Creek, for sediment pollution;

3. Kirkland Creek, for pollutants due to organics and nutrients derived from land use; and

4. Castaneda Wash – Bill Williams River, for selenium due to agricultural practices.

Example projects with best management practices to reduce sediment, metals, 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. Upper Big Sandy River – 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 Upper Big Sandy River subwatershed ranked as one of the most critical areas in the Bill Williams Watershed impacted by metals related to an abandoned mine site (i.e. third highest fuzzy membership value for metals; Alamo Lake (first) is heavily influence by upstream conditions and Boulder Creek (second) already has a TMDL plan), and a project to control the movement of metal-laden sediment is recommended. The land owners within this subwatershed include the U.S. Bureau of Land Management (51.21%), State Trust Lands of Arizona (11.64%), and private owners (37.12%, Table 7-2). 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:
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 an abandoned 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 - 3. Kirkland Creek Example Projects

Pollutant Type and Source:
(1) Sediment pollution due to grazing, and (2) organic pollutants, specifically *E. coli*, assumed to originate from cattle watering in the stream channel.

The Kirkland Creek subwatershed of the Bill Williams River watershed ranked as the most critical area impacted by land use activities. It had the highest fuzzy membership values for both sediment and organics, both of which are highly correlated to land use activities (Table 8-1).

For this example project it will be assumed that grazing within the riparian area has exacerbated erosion (sediment pollution) and introduced fecal matter into the stream (organic pollution in the form of *E. coli*). The land owners within this subwatershed (Table 7-2) include the U.S. Forest Service (18.29%), U.S. Bureau of Land Management (3.3%), private owners (32.46%), and State Trust lands (45.89%). 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 project is to reduce both sediment and bacterial (organic) pollution to the Kirkland Creek subwatershed. Sediment load reductions can be calculated and documented using the Michigan DEQ (1999) methodology, available at the NEMO website, under BMP Manual, Links (www.ArizonaNEMO.org).

Prior to initiating a project to reduce *E. coli* bacteria pollution, it may benefit the watershed partnership to determine the source of the bacterial contamination. 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). For example, implementation of DNA fingerprinting technology will identify the actual sources of bacterial and clarify how best to target an implementation plan and project.

The results of a study funded from Section 319 Nonpoint Source Grant funds for Oak Creek Canyon within the Verde Watershed found that most of the fecal pollution came from natural animal populations in the canyon with sporadic and seasonal impacts from human, dog, cattle, house and llama sources (NAU, 2000). The Oak Creek Task Force (a locally led watershed group) suggested implementing locally approved grazing modifications to decrease the inflow of sediment carrying fecal material, as well as public education and increased toilet facilities within the canyon to reduce nonpoint source bacterial pollutants.

In Kirkland Creek, pathogens and sediment are assumed to most likely originate from grazing practices because livestock grazing is one of the primary land uses. However, recent development in the Peeples Valley - Yarnell area has increased the number of septic systems in the area which may also contribute to the presence of pathogens. For this project example it is assumed that load reduction should concentrate on grazing management.

Management Measures:
Implementing grazing management practices to improve or maintain riparian health will help reduce excess surface runoff and accelerated erosion, and reduce the amount of bacterial pollution to the stream. Sustainable livestock grazing can be achieved in all plant communities by changing the duration, frequency and intensity of grazing.

In addition, livestock 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. Section 7 discusses these management measures. Tables 7-3 and 7-4 present load reduction potential, required maintenance and anticipated costs associated with various management options. 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 or the installation of an alternative water source may necessitate project design by a licensed engineer.

4. Castaneda Wash – Bill Williams River Subwatershed Example Project

Pollutant Type and Source: Selenium pollution due to flood irrigation practices.

The Castaneda Wash – Bill Williams River subwatershed of the Bill Williams River ranked as the most critical area impacted by agricultural land use practices that exacerbate the concentration of naturally occurring selenium (i.e. highest fuzzy membership values for Selenium, Table 8-1). 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 this subwatershed (Table 7-2) include the U.S. Bureau of Land Management (80.27%), private owners (15.75%), State Trust lands (<1%), National Park Service (<1%) and U.S. Fish and Wildlife Service (2.9%). 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:
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.

In some watersheds in California, agricultural drainage water contains 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 may be beyond the scope of a proposed best management practices project, and technologies are still in the research stage.

Section 7 outlines load reduction potential, maintenance, and anticipated costs associated with the installation of mechanized irrigation systems. 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. Mechanized irrigation, however, allows for improved water conservation and improved management of limited water resources.

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 Upper Bill Williams Partnership is currently the only partnership that has formed within the Bill Williams River Watershed. The Upper Bill Williams Partnership concentrates on the Kirkland Creek subwatershed and meetings have been held in Skull Valley.

To increase stakeholder participation, outreach and public education activities need to be initiated within the watershed, such as sponsoring a booth at the County Fair. Working with other Cooperative Extension programs, such as Project WET (Water Education for Teachers, K-12 classroom education), the booth provided displays, posters, and fact sheets on important water topics in addition to individual water quality improvement projects.

The NEMO program offers each watershed partnership the opportunity to post 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 Castaneda Wash – Bill Williams River, the Kirkland Creek and Upper Big Sandy River 10-digit HUC subwatershed areas have been prioritized 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 specific 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.

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

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.

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, and 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.**

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 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
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 8-2, 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.

Monitoring

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) Assessment Report (ADEQ, 2002), but the overall stakeholder group watershed plan will identify additional data collection activities that are tied to stakeholder concerns and goals. For the Castaneda Wash – Bill Williams River, Kirkland Creek and Upper Big Sandy River subwatersheds are identified as vulnerable to water quality impairment due to metals, organics and nutrients, and selenium. Monitoring of stream reaches within the Bill Williams River (Castaneda Wash – Bill Williams River), Santa Maria River (Kirkland Creek) and Big Sandy River (Upper Big Sandy River) 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 8-2, 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 all twenty-one 10-digit HUC subwatersheds within the Bill Williams River 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 Bill Williams River Watershed (ADEQ, 2002).

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 21 subwatersheds included in this assessment, the three watersheds with the highest risk of water quality degradation are:

1. Upper Big Sandy River Subwatershed, for metals pollution;

2. Kirkland Creek Subwatershed, for sediment pollution and for pollutants due to organics and nutrients derived from land use; and,

3. Castaneda Wash – Bill Williams River, 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. 2002. Arizona's Integrated 305(b) Water Quality Assessment and 303(d) Listing Report, Bill Williams Watershed Assessment. http://www.azdeq.gov/environ/water/assessment/download/305-02/9billwil.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

Northern Arizona University (NAU). November 8, 2000. The Oak Creek Canyon *Escherichia coli* Genotyping Project. Submitted to Arizona Department of Environmental Quality, Nonpoint Source Unit, Phoenix, Arizona.

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

Table 1: Water Quality Data and Assessment Status, Bill Williams Watershed.

<table>
<tr><th>Reach
Sites</th><th>Results</th><th>Available Water Quality Data and Assessment Status[1,2,3]</th></tr>
<tr><td colspan="3">Markham Wash Area Subwatershed
HUC 1503020101
No data collected.
Classification:
Moderate risk for all constituent categories due to lack of monitoring data.</td></tr>
<tr><td colspan="3">Muddy Creek Subwatershed
HUC 1503020102
No data collected.
Classification:
Moderate risk for all constituent categories due to lack of monitoring data.</td></tr>
<tr><td colspan="3">Willow Creek Subwatershed
HUC 1503020103
No data collected.
Classification:
Moderate risk for all constituent categories due to lack of monitoring data.</td></tr>
<tr><td colspan="3">Trout Creek Subwatershed
HUC 1503020104
Combined classification:
Low risk for metals;
Low risk for sediment;
Low risk for organics; and
Low risk for selenium.</td></tr>
<tr><td rowspan="2">Trout Creek
Cow Creek- Knight Creek
15030201-014

Two Sites:
BWTRT006.15
BWTRT001.79</td><td>Sampling</td><td>E. coli; temperature; pH; dissolved oxygen; total dissolved solids; turbidity; arsenic; barium; beryllium; antimony; thallium; boron; cadmium (t) (d); chromium (t) (d); copper (t) (d); lead (t) (d); manganese (t); mercury (t) (d); selenium (t) (d); silver (t) (d); zinc (t) (d); nickel (t) (d); Uranium; nitrogen as ammonia; n-kjeldahl; nitrite/nitrate; phosphorus; and hardness.</td></tr>
<tr><td>Status</td><td>Parameters exceeding standards: None.
Currently assessed as “Attaining All Uses.”

Subwatershed risk classification:
Low risk for metals;
Low risk for sediment;
Low risk for organics and other constituent groups; and
Low risk for selenium.</td></tr>
</table>

<table>
<tr><th>Reach
Sites</th><th>Results</th><th>Available Water Quality Data and Assessment Status[1,2,3]</th></tr>
<tr><td colspan="3">Knight Creek Subwatershed
HUC 1503020105
No data collected.
Classification:
Moderate risk for all constituent categories due to lack of monitoring data.</td></tr>
<tr><td colspan="3">Upper Big Sandy River Subwatershed
HUC 1503020106
Combined classification:
Moderate risk for metals;
High risk for sediment;
Moderate risk for organics; and
Moderate risk for selenium.</td></tr>
<tr><td rowspan="2">Big Sandy River
Deluge Wash - Tule Wash
15030201-011

One Site:
BWBSR041.02</td><td>Sampling</td><td>temperature; pH; dissolved oxygen; total dissolved solids; turbidity.</td></tr>
<tr><td>Status</td><td>Parameters exceeding standards: Former turbidity standard (1/4) assessed as “Inconclusive”. On the planning list due to lack of data for E. coli, dissolved metals (cadmium, copper, and zinc) and total metals (copper, lead, and mercury).

Subwatershed risk classification:
Moderate risk for metals because of no data;
High risk for sediment;
Moderate risk for organics and other constituent groups due to lack of data; and
Moderate risk for selenium due to lack of data.</td></tr>
<tr><td colspan="3">Middle Big Sandy River Subwatershed
HUC 1503020107
Classification:
Moderate risk for metals;
Moderate risk for sediment;
Moderate risk for organics; and
High risk for selenium.</td></tr>
<tr><td>Big Sandy River
Sycamore-Burro Creek
15030201-004

One Site:
BWBSR024.50</td><td>Sampling</td><td>E. coli; temperature; pH; dissolved oxygen; total dissolved solids; turbidity; suspended sediment concentration; arsenic; barium; beryllium; antimony; thallium; boron; cadmium (t) (d); chromium (t) (d); copper (t) (d); lead (t) (d); mercury (t); selenium ; silver (t) (d); zinc (t) (d); nickel (t) (d); nitrogen as ammonia; n-kjeldahl; nitrite/nitrate; phosphorus; fluoride; and hardness.</td></tr>
</table>

Reach Sites	Results	Available Water Quality Data and Assessment Status[1,2,3]
	Status	Parameters exceeding standards: Mercury (1/17) assessed as "Attaining"; former turbidity standard (2/19) assessed as "Attaining"; dissolved oxygen (3/19) assessed as "Attaining"; and Selenium (1/1) assessed as "Inconclusive". Subwatershed risk classification: • Moderate risk for metals; • Moderate risk for sediment; • Moderate risk for organics and other constituent groups; and • High risk for selenium.
Lower Big Sandy River Subwatershed **HUC 1503020108** **Combined classification:** • Extreme risk for metals; • Moderate risk for sediment; • Extreme risk for organics; and • Moderate risk for selenium.		
Big Sandy River Rupley - Alamo Lake North 15030201-001 One Site: BWBSR011.20	Sampling	*E. coli* (2); temperature; pH; dissolved oxygen; total dissolved solids (2); turbidity; suspended sediment concentration (2); arsenic (2); barium (2); beryllium (2); antimony (2); selenium (2); boron (2); cadmium (t 2) (d 2); chromium (t 2) (d 2); copper (t 2) (d 2); lead (t 2) (d 2); manganese (t 2); mercury (t 2) (d 2); selenium (t 2) (d 2); zinc (t 2) (d 2); nitrogen as ammonia (2); nitrite/nitrate (2); phosphorus (2); fluoride (2); and hardness (2).
	Status	Parameters exceeding standards: Dissolved oxygen (2/7) assessed as "Inconclusive". Subwatershed risk classification: • Moderate risk for metals due to limited data; • Low risk for sediment; • High risk for organics due to dissolved oxygen exceedances; and moderate risk for other constituent groups and • Moderate risk for selenium because of limited data.

Reach Sites	Results	Available Water Quality Data and Assessment Status[1,2,3]
Alamo Lake 15030204-0040 Six Sites: BWALA-1 BWALA-2 BWALA-3 BWALA-4 BWALA-A BWALA-B	Sampling	temperature; pH; dissolved oxygen; total dissolved solids; turbidity; arsenic; barium; boron; cadmium (t) (d); chromium (t) (d); copper (t) (d); lead (t) (d); manganese (t); mercury (t) (d) ; selenium ; silver (t) (d); zinc (t) (d); nickel (t) (d); uranium; nitrogen as ammonia; n-kjeldahl; phosphorus; sulfate; chloride; fluoride; hardness; TS; and TSS.
	Status	Parameters exceeding standards: Mercury assessed as "Impaired"; Ammonia (6/144) assessed as "Impaired"; pH (46/189) assessed as "Impaired"; dissolved oxygen (11/190) assessed as "Attaining". Subwatershed risk classification: • Extreme risk for metals; • Moderate risk for sediment due to limited data; • Extreme risk for organics and low for other constituent groups; and • Low risk for selenium.
Francis Creek Subwatershed **HUC 1503020201** **Combined classification:** • Moderate risk for metals; • Moderate risk for sediment; • Moderate risk for organics; and • Moderate risk for selenium.		
Francis Creek headwaters-Burro Creek 15030202-012 One Site: BWFRA001.73	Sampling	*E. coli* (2); temperature (2); pH (2); dissolved oxygen (2); total dissolved solids (2); turbidity (2); suspended sediment concentration (2); arsenic (2); barium (2); beryllium (2); antimony (2); selenium (2); Thallium (2); boron (2); cadmium (t 2) (d 2); chromium (t 2) (d 2); copper (t 2) (d 2); lead (t 2) (d2); manganese (t 2); mercury (t 2) (d 2); selenium (t 2) (d 2); silver (t 2) (d 2); zinc (t 2) (d 2); Nickel (t2) (d 2); Uranium (2); nitrogen as ammonia (2); n-kjeldahl (2); nitrite/nitrate (2); phosphorus (2); and hardness (2).

Reach Sites	Results	Available Water Quality Data and Assessment Status[1,2,3]
	Status	Parameters exceeding standards: None. Subwatershed risk classification: • Moderate risk for metals due to limited data; • Moderate risk for sediment due to limited data ; • Moderate risk for organics and other constituent groups due to limited data; and • Moderate risk for selenium due to limited data.
Upper Burro Creek Subwatershed **HUC 1503020202** **No data collected.** **Classification:** • Moderate risk for all constituent categories due to lack of monitoring data.		
Boulder Creek Subwatershed **HUC 1503020203** **Combined classification:** • Extreme risk for metals; • Moderate risk for sediment; • Moderate risk for organics; and • High risk for selenium.		
Butte Creek headwaters-Boulder Creek 15030202-163 One Site: BWBUT	Sampling	total dissolved solids; turbidity; arsenic; barium; selenium; cadmium (t) (d); chromium (t) (d); copper (t) (d); lead (t); manganese (t); mercury (t) (d); selenium (t) (d); silver (t) (d); zinc (t) (d); sulfate; and hardness (2).
	Status	Parameters exceeding standards: Mercury dissolved (2/2) assessed as “Impaired” and Mercury (total) (1/7) assessed as “Inconclusive”; Selenium (1/4) assessed as “Inconclusive”. Subwatershed risk classification: • Extreme risk for metals; • Moderate risk for sediment due to limited data; • Moderate risk for organics and other constituents groups due to lack of data; and • High risk for selenium.

Reach Sites	Results	Available Water Quality Data and Assessment Status[1,2,3]
Boulder Creek Wilder Creek-Copper Creek 15030202-005A Eight Sites: BWBOU002.78 BWBOU003.15 BWBOU003.31 BWBOU003.42 BWBOU003.72 BWBOU003.81 BWBOU003.90 BWBOU004.10	Sampling	temperature ; pH; dissolved oxygen; total dissolved solids; turbidity; arsenic; barium; beryllium; selenium; cadmium (t) (d); chromium (t) (d); copper (t) (d); lead (t) (d); manganese (t); mercury (t) (d); selenium (t) (d); silver (t) (d); zinc (t) (d); sulfate; and hardness (2).
	Status	Parameters exceeding standards: Arsenic (dissolved) (4/30) assessed as “Impaired”; Arsenic (total) (FBC - 26/45) ; Arsenic (total) (AgL - 8/42) assessed as “Impaired”; Copper (dissolved) (2/30) assessed as “Impaired” ; Copper (total) (1/58) assessed as “Attaining”; Lead (total) (1/13) assessed as “Attaining”; Manganese (total) (3/33) assessed as “Attaining”; Mercury (dissolved) (A&Ww chronic - 3/3) assessed as “Impaired”; Mercury (dissolved) (A&Ww acute – 1/17) assessed as “Inconclusive”; Mercury (dissolved) (FC - total- 1/6) assessed as “Inconclusive”; Zinc (dissolved) (A&Ww acute - 2/30) and (A&Ww chronic - 2/30) assessed as “Impaired” ; Zinc (total) (1/33) assessed as “Attaining”; pH (1/70) assessed as “Attaining”; Selenium (total) (1/4) assessed as “Inconclusive”. Subwatershed risk classification: • Extreme risk for metals; • Moderate risk for sediment due to limited data; • Moderate risk for organics and other constituents groups due to limited data; and • High risk for selenium.
Boulder Creek Copper Creek-Burro Creek 15030202-005B Four Sites: BWBOU000.95	Sampling	temperature; pH; dissolved oxygen; total dissolved solids; turbidity; arsenic; barium; beryllium; selenium; cadmium (t) (d); chromium (t) (d); copper (t) (d); lead (t) (d); manganese (t); mercury (t) (d); selenium (t) (d); silver (t) (d); zinc (t) (d); sulfate; and hardness.

Reach Sites	Results	Available Water Quality Data and Assessment Status[1,2,3]
BWBOU002.00 BWBOU002.68 BWBOU002.70 3 sites in pdf, 4 sites in Excel	Status	Parameters exceeding standards: Mercury (dissolved) (A&Ww chronic - 1/1) assessed as "Inconclusive"; Mercury (dissolved) (A&Ww acute - 1/13) assessed as "Inconclusive"; Mercury (dissolved) (FC-total - 1/14) assessed as "Attaining"; Lead (1/13) assessed as "Attaining"; Arsenic (1/21) assessed as "Attaining"; and selenium (1/4) assessed as "Inconclusive". Subwatershed risk classification: • High risk for metals; • Moderate risk for sediment due to limited data; • Moderate risk for organics and other constituent groups due to lack of data; and • High risk for selenium.
Boulder Creek Unnamed wash at 34◦ 41' 14"/113◦ 48' 00"-Wilder Creek 15030202-006B Four Sites: BWBOU004.15 BWBOU004.30 BWBOU005.86 BWBOU006.27	Sampling	temperature; pH; dissolved oxygen; total dissolved solids; turbidity; arsenic; barium; beryllium; selenium; cadmium (t) (d); chromium (t) (d); copper (t) (d); lead (t) (d); manganese (t); mercury (t) (d); selenium (t) (d); silver (t) (d); zinc (t) (d); Sulfate; and hardness.
	Status	Parameters exceeding standards: Mercury (dissolved) (A&Ww chronic 6/6) assessed as "Impaired"; Mercury (dissolved) (A&Ww acute 1/17) assessed as "Inconclusive"; Mercury (dissolved) (FC-total- 2/9) assessed as "Inconclusive"; Copper (dissolved) (A&Ww chronic 1/19) assessed as "Inconclusive"; Copper (dissolved) (A&Ww acute 1/18) assessed as "Inconclusive"; Zinc (dissolved) (A&Ww chronic 1/19) assessed as "Inconclusive"; Zinc (dissolved) (A&Ww acute 1/19) assessed as "Attaining". Subwatershed risk classification: • Extreme risk for metals; • Moderate risk for sediment due to limited data; • Moderate risk for organics and other constituents groups due to lack of data; and • Low risk for selenium.
Coors Lake 15030202-5000	Sampling	No water quality data.

Reach Sites	Results	Available Water Quality Data and Assessment Status[1,2,3]
	Status	Parameters exceeding standards: None. Lake assessed as "Impaired" due to mercury in fish tissue. Subwatershed risk classification: • Extreme risk for metals; • Moderate risk for sediment due to lack of data; • Moderate risk for organics and other constituents groups due to lack of data; and • Moderate risk for selenium.
Wilder Creek headwaters-Boulder Creek 15030202-007 One site: BWWLD000.27	Sampling	total dissolved solids; turbidity; arsenic; barium; selenium; cadmium (t) (d); chromium (t) (d); copper (t 1) (d); lead (t); manganese (t); mercury (t) (d); selenium (t) (d); silver (t) (d); zinc (t) (d); Sulfate; and hardness.
	Status	Parameters exceeding standards: None. Currently assessed as "Inconclusive" due to lack of data for core parameters. Subwatershed risk classification: • Moderate risk for metals due to limited data; • Moderate risk for sediment due to limited data; • Moderate risk for organics and other constituents groups due to lack of data; and • Low risk for selenium.
Lower Burro Creek Subwatershed **HUC 1503020204** **Combined classification:** • Extreme risk for metals; • Moderate risk for sediment; • Moderate risk for organics; and • Low risk for selenium.		
Burro Creek Francis Creek- Boulder Creek 15030202-008 Unique Water	Sampling	total dissolved solids; turbidity; arsenic; barium; selenium; cadmium (t) (d); chromium (t) (d); copper (t) (d); lead (t); manganese (t); mercury (t) (d); selenium (t) (d); silver (t) (d); zinc (t) (d); Sulfate; and hardness.

Reach Sites	Results	Available Water Quality Data and Assessment Status[1,2,3]
One Site: BWBRO0011.54	Status	Parameters exceeding standards: Copper (dissolved) (A&Ww-chronic) (1/17) assessed as "Inconclusive"; Copper (dissolved) (A&Ww-acute) (1/17) assessed as "Inconclusive"; Mercury (dissolved) (1/1) assessed as "Inconclusive" due to mercury in fish tissue. Subwatershed risk classification: • Extreme risk for metals; • Moderate risk for sediment due to limited data; • Moderate risk for organics and other constituents groups due to lack of data; and • Low risk for selenium.
Burro Creek Boulder Creek- Black Canyon 15030202-004 Four Sites: BWBRO011.53 BWBOR009.67 BWBOR008.75 BWBRO008.56	Sampling	*E. coli;* temperature; pH; dissolved oxygen; total dissolved solids; turbidity; suspended sediment concentration (2); arsenic; barium; beryllium; antimony; selenium; Thallium; boron; cadmium (t) (d); chromium (t) (d); copper (t) (d); lead (t) (d); manganese (t); mercury (t) (d); selenium (t) (d); silver (t) (d); zinc (t) (d); Nickel (t) (d); Uranium; nitrogen as ammonia; n-kjeldahl; nitrite/nitrate; phosphorus; sulfate; and hardness.
	Status	Parameters exceeding standards: Mercury (dissolved) (A&Ww-chronic) (3/3) assessed as "Impaired"; Mercury (dissolved) (FC-total) (2/26) assessed as "Attaining"; turbidity (1/19) assessed as "Attaining". Subwatershed risk classification: • Extreme risk for metals; • Low risk for sediment; • Low risk for organics and other constituents groups; and • Low risk for selenium.
Kirkland Creek Subwatershed **HUC 1503020301** **Combined classification:** • Moderate risk for metals; • Moderate risk for sediment; • High risk for organics; and • Moderate risk for selenium.		

Reach Sites	Results	Available Water Quality Data and Assessment Status[1,2,3]
Kirkland Creek Skull Valley-Santa Maria River 15030203-015 One Site: BWKRK009.77	Sampling	*E. coli* (2); temperature (2); pH (2); dissolved oxygen (2); total dissolved solids (2); turbidity (2); suspended sediment concentration (2); arsenic (2); barium (2); beryllium (2); antimony (2); selenium (2); Thallium (2); boron (2); cadmium (t 2) (d 2); chromium (t 2) (d 2); copper (t 2) (d 2); lead (t 2) (d 2); manganese (t 2); mercury (t 2) (d 2); selenium (t 2) (d 2); silver (t 2) (d 2); zinc (t 2) (d 2); Nickel (t 2) (d 2); Uranium (2); nitrogen as ammonia (2); ; n-kjeldahl (2); nitrite/nitrate (2); phosphorus (2); and hardness (2).
	Status	Parameters exceeding standards: *E. coli* (1/2) assessed as "Inconclusive". Subwatershed risk classification: • Moderate risk for metals due to limited data; • Moderate risk for sediment due to limited data; • High risk for organics and moderate for other constituents groups; and • Moderate risk for selenium due to limited data.
Sycamore Creek Subwatershed **HUC 1503020302** **No data collected.** **Classification:** • Moderate risk for all constituent categories due to lack of monitoring data.		
Upper Santa Maria River Subwatershed **HUC 1503020303** **No data collected.** **Classification:** • Moderate risk for all constituent categories due to lack of monitoring data.		
Date Creek Subwatershed **HUC 1503020304** **Classification:** • Moderate risk for all constituent categories due to limited monitoring data.		

Reach Sites	Results	Available Water Quality Data and Assessment Status[1,2,3]
Date Creek Cottonwood Creek-unnamed reach 15030203-008 15030203-003 One Site: BWDAT019.44	Sampling	*E. coli* (1); temperature (2); pH (2); dissolved oxygen (2); total dissolved solids (2); turbidity (2); suspended sediment concentration (2); arsenic (2); barium (2); beryllium (2); antimony (2); selenium (2); Thallium (2); boron (2); cadmium (t 2) (d 2); chromium (t 2) (d 2); copper (t 2) (d 2); lead (t 2) (d 2); manganese (t 2); mercury (t 2) (d 2); selenium (t 2) (d 2); silver (t 2) (d 2); zinc (t 2) (d 2); Nickel (t 2) (d 2); Uranium (2); nitrogen as ammonia (2); ; n-kjeldahl (2); nitrite/nitrate (2); phosphorus (2); and hardness (2).
	Status	Parameters exceeding standards: None. Subwatershed risk classification: • Moderate risk for metals due to limited data; • Moderate risk for sediment due to limited data; • Moderate risk for organics and other constituents groups due to limited data; and • Moderate risk for selenium due to limited data.
Lower Santa Maria River Subwatershed **HUC 1503020305** **Combined classification:** • Extreme risk for metals; • Moderate risk for sediment; • Extreme risk for organics; and • Low risk for selenium.		
Alamo Lake 15030204-0040 Six Sites: BWALA-1 BWALA-2 BWALA-3 BWALA-4	Sampling	temperature; pH; dissolved oxygen; total dissolved solids; turbidity; arsenic; barium; boron; cadmium (t) (d); chromium (t) (d); copper (t) (d); lead (t) (d); manganese (t); mercury (t)(d) ; selenium ; silver (t) (d); zinc (t) (d); nickel (t) (d); uranium; nitrogen as ammonia; n-kjeldahl; phosphorus; sulfate; chloride; fluoride; hardness; TS; and TSS.

Reach Sites	Results	Available Water Quality Data and Assessment Status[1,2,3]
BWALA-A BWALA-B	Status	Parameters exceeding standards: Mercury assessed as “Impaired”, Ammonia (6/144) assessed as “Impaired”; pH (46/189) assessed as “Impaired”; dissolved oxygen (11/190) assessed as “Attaining”. Subwatershed risk classification: • Extreme risk for metals; • Moderate risk for sediment due to limited data; • Extreme risk for organics and low for other constituents groups; and • Low risk for selenium.
Santa Maria River Bridle Wash-Date Creek 15030203-009 One Site: BWSMR013.57	Sampling	*E. coli;* temperature; pH; dissolved oxygen; total dissolved solids; turbidity; suspended sediment concentration (2); arsenic; barium; beryllium; antimony; selenium; Thallium; boron; cadmium (t) (d); chromium (t) (d); copper (t) (d); lead (t) (d); manganese (t); mercury (t) (d); selenium (t) (d); silver (t) (d); zinc (t) (d); Nickel (t) (d); Uranium; nitrogen as ammonia; n-kjeldahl; nitrite/nitrate; phosphorus; sulfate; and hardness.
	Status	Parameters exceeding standards: *E. coli* (1/14) assessed as “Inconclusive”. Subwatershed risk classification: • Low risk for metals; • Low risk for sediment; • Low risk for organics and low for other constituents groups; and • Low risk for selenium.
Bullard Wash Subwatershed **HUC 1503020401** **Combined classification:** • Extreme risk for metals; • Moderate risk for sediment; • Extreme risk for organics; and • Low risk for selenium.		

Reach Sites	Results	Available Water Quality Data and Assessment Status[1,2,3]
Alamo Lake 15030204-0040 Six Sites: BWALA-1 BWALA-2 BWALA-3 BWALA-4 BWALA-A BWALA-B	Sampling	temperature; pH; dissolved oxygen; total dissolved solids; turbidity; arsenic; barium; boron; cadmium (t) (d); chromium (t) (d); copper (t) (d); lead (t) (d); manganese (t); mercury (t)(d) ; selenium ; silver (t) (d); zinc (t) (d); nickel (t) (d); uranium; nitrogen as ammonia; n-kjeldahl; phosphorus; sulfate; chloride; fluoride; hardness; TS; and TSS.
	Status	Parameters exceeding standards: Mercury assessed as "Impaired", Ammonia (6/144) assessed as "Impaired"; pH (46/189) assessed as "Impaired"; dissolved oxygen (11/190) assessed as "Attaining". Subwatershed risk classification: • Extreme risk for metals; • Moderate risk for sediment due to limited data; • Extreme risk for organics and low for other constituents groups; and • Low risk for selenium.
Alamo Lake-Bill Williams River Subwatershed **HUC 1503020402** **Combined classification:** • Extreme risk for metals; • Moderate risk for sediment; • Extreme risk for organics; and • Low risk for selenium.		
Alamo Lake 15030204-0040 Six Sites: BWALA-1 BWALA-2 BWALA-3 BWALA-4 BWALA-A BWALA-B	Sampling	temperature; pH; dissolved oxygen; total dissolved solids; turbidity; arsenic; barium; boron; cadmium (t) (d); chromium (t) (d); copper (t) (d); lead (t) (d); manganese (t); mercury (t)(d) ; selenium ; silver (t) (d); zinc (t) (d); nickel (t) (d); uranium; nitrogen as ammonia; n-kjeldahl; phosphorus; sulfate; chloride; fluoride; hardness; TS; and TSS.
	Status	Parameters exceeding standards: Mercury assessed as "Impaired", Ammonia (6/144) assessed as "Impaired"; pH (46/189) assessed as "Impaired"; dissolved oxygen (11/190) assessed as "Attaining". Subwatershed risk classification: • Extreme risk for metals; • Moderate risk for sediment due to limited data; • Extreme risk for organics and low for other constituents groups; and • Low risk for selenium.

Reach Sites	Results	Available Water Quality Data and Assessment Status[1,2,3]
Mohave Wash Subwatershed **HUC 1503020403** **No data collected.** **Classification:** • Moderate risk for all constituent categories due to lack of monitoring data.		
Castaneda Wash-Bill Williams River Subwatershed **HUC 1503020404** **Combined classification:** • Moderate risk for metals; • High risk for sediment; • Moderate risk for organics; and • Moderate risk for selenium.		
Bill Williams River Point B-Colorado River 15030204-001 One Site: BWBWR005.88	Sampling	*E. coli;* temperature; pH; dissolved oxygen; total dissolved solids; turbidity; suspended sediment concentration; boron; cadmium (d); chromium (d); copper (d); lead (d);mercury (d); silver (d); zinc (d); Nickel (d); n-kjeldahl; nitrite/nitrate; phosphorus; fluoride; hardness ;TS; and TSS.
	Status	Parameters exceeding standards: Turbidity (1/8) assessed as “Inconclusive”; and dissolve oxygen (1/11) assessed as “Attaining”. Subwatershed risk classification: • Moderate risk for metals due to limited data; • High risk for sediment; • Moderate risk for organics and low for other constituents groups; and • Moderate risk for selenium due to lack of 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:

(t) = (t) metal or metalloid (before filtration)
(d) = dissolved fraction of the metal or metalloid (after filtration)
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: dissolved Oxygen
E. coli: Escherichia coli bacteria
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: total dissolved solids
total solids: (t) Solids
total suspended solids: (t) Suspended Solids
turbidity: Measurement of suspended matter in water sample.
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.

AgI: Agricultural Irrigation. Surface water is used for the irrigation of crops.

AgL: Agricultural Livestock Watering (AgL). 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.

Appendix B: Suggested Readings
Bill Williams Watershed

U.S. Geological Survey (USGS)

Pierce, H.A. 2001. Structural controls on ground-water conditions and estimated aquifer properties near Bill Williams Mountain, Williams, Arizona. U.S. Dept. of the Interior, U.S. Geological Survey.

Senger, H.W., Littin, G.R. 1981. Maps Showing Ground-Water Conditions in the Bill Williams Area, Mohave, Yavapai, and Yuma Counties, Arizona. 1980. Geological Survey Open File Report 82-87 (WRI) 2 Sheets, 16 Ref.

Bedinger, M.S., Sargent, K.A., Langer, W.H. (Eds.). 1990. Studies of Geology and Hydrology in the Basin and Range Province, Southwestern United States for Isolation of High-Level Radioactive Waste Characterization of the Sonoran Region, Arizona. USGS Professional Paper 1370-D.

Wilson, R.P., and Owen, J.S.J. 2002. Hydrologic conditions in the Bill Williams River National Wildlife Refuge and Planet Valley, Arizona. Water Resources Investigations – U.S. Geological Survey.

U.S. Bureau of Land Management Yuma District Office

Final, Yuma District (Bill Williams) Resource Management Plan Amendment. 1994. U.S. Dept. of the Interior, Bureau of Land Management, Arizona State Office.

U.S. Bureau of Reclamation

U.S. Bureau of Reclamation & U.S. Fish & Wildlife Service. Lower Colorado River National Wildlife Refuges Comprehensive Management Plan, 1994-2014 Final Environmental Assessment: Havasu National Wildlife Refuge, Bill Williams National Wildlife Refuge, Cibola National Wildlife Refuge, Imperial National Wildlife Refuge. http://purl.access.gpo.gov/GPO/LPS32950

U.S. Fish & Wildlife Service

U.S. Fish & Wildlife Service. Bill Williams River National Wildlife Refuge. 1999. http://purl.access.gpo.gov/GPO/LPS37560

Other References:

Busch, D.E., and Smith, S.D. 1995. Mechanisms associated with decline of woody species in riparian ecosystems of the southwestern U.S. Ecological Monographs 65:(3) 347-370.

Horton, J.L., 2000. Relationships between depth to ground water and southwestern riparian tree physiological condition. Doctoral Thesis. Northern Arizona University. 171 p.

Horton, J.L., Kolb, T.E., Hart, S.C. 2001. Physiological response to groundwater depth varies among species and with river flow regulation. Ecological Applications 11(4): 1046-1059.

Rodrigues, L., Vionnet, C., Maddock, T., Wheater H., Kirby C., 1998. Appropriate representation of rapidly varying processes in the hydrology of riparian areas**.** In: Hydrology in a Changing Environment. Volume II. Proceedings of the British Hydrological Society International Conference, Exeter, UK. John Wiley & Sons Ltd. pp 307-317.

Shafroth, P.B. Auble, G.T., Stromberg, J.C., Patten, D.T. 1998. Establishment of woody riparian vegetation in relation to annual patterns of streamflow, Bill Williams River, Arizona. Wetlands 18(4): 577-590.

Shafroth, P.B., Stromberg, J.C., Patten, D.T., 2000. Woody riparian vegetation response to different alluvial water table regimes. Western North American Naturalist 60(1): 66-76.

Shafroth, P.B., Stromberg, J.C., Patten, D.T., 2002. Riparian vegetation response to altered disturbances and stress regimes. Ecological Applications 12(1): 107-123.

Vionnet, L.B., 1995. Investigation of stream-aquifer interactions using a coupled surface water and groundwater flow model. Doctoral Thesis. University of Arizona. 195 p.

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 Van Remortel's (2004) 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 come 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 a user specified threshold for contributing area. A threshold of 500 30x30 meter cells was specified as the contributing area for stream delineation. This number was chosen based on consultation with the program author. The AML also created 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 Upper Gila watershed was done as a single unit.

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. 2004. Soil & Landform Metrics: Programs and U.S. Geodatasets Version 1.1. Environmental Protection Agency. 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 versions 3.x, a widely used and relatively inexpensive geographic information system (GIS) software package.

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 Upper Gila 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 National Elevation Dataset, 30-Meter Digital Elevation Models (DEMs). April 8, 2003. http://gisdata.usgs.net/NED/default.asp
- Soils: USDA Natural Resource Conservation Service, STATSGO Soils. April 17, 2003. http://www.ncgc.nrcs.usda.gov/branch/ssb/products/statsgo/
- Land cover: United States Geological Survey. July 21, 2003. http://landcover.usgs.gov/natllandcover.asp

- 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 is 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.

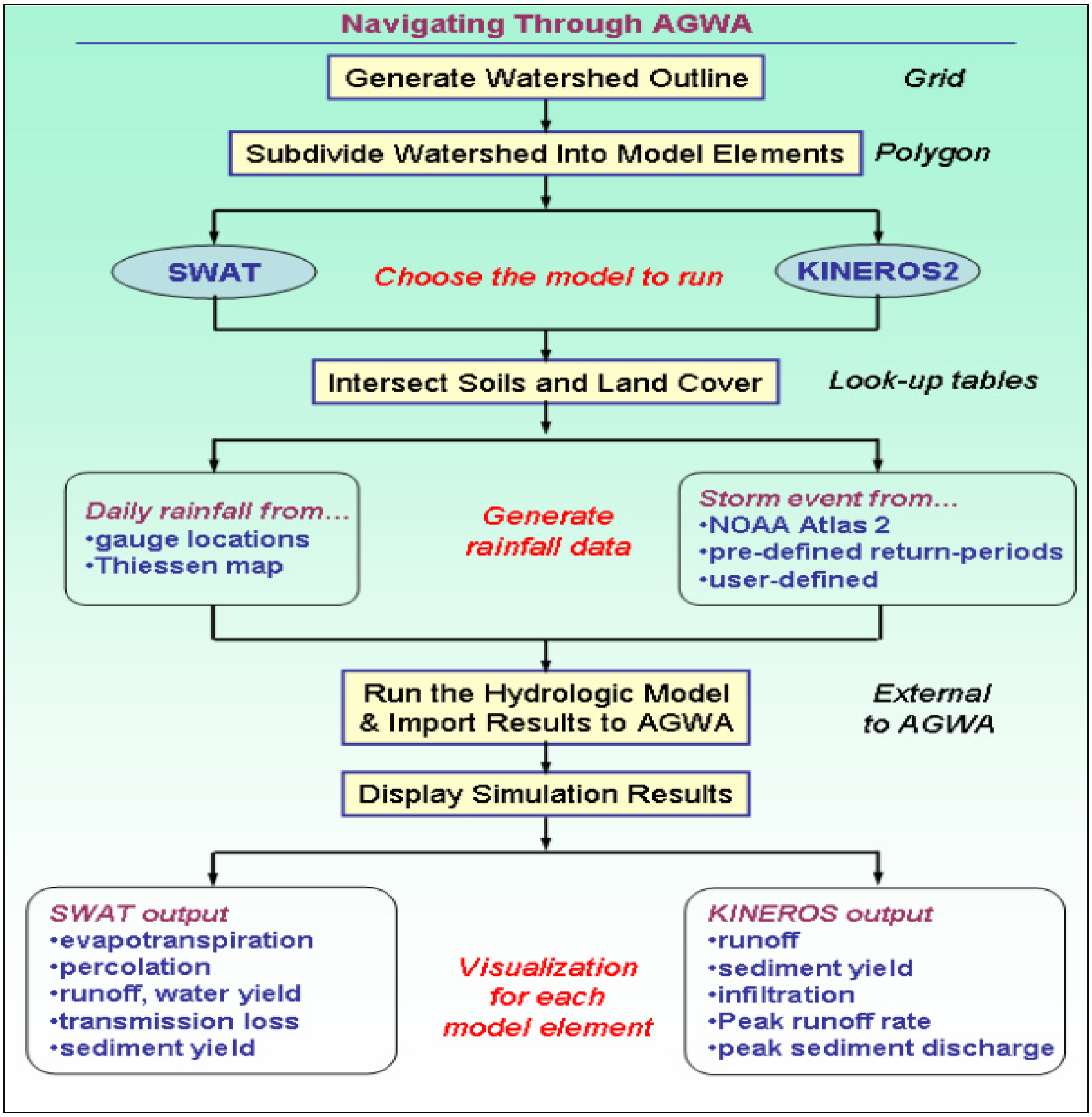


Figure D-1: Flow chart showing the general framework for using KINEROS2 and SWAT in AGWA.

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/

Williams, J.R. 1969. Flood routing with variable travel time or variable storage coefficients. Trans. ASAE 12(1):100-103.