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Ambient Surface Water Quality for Rivers and Streams of the Upper Gila River Basin: Water Year 2000

Ambient Surface Water Quality of Rivers and Streams in the Upper Gila Basin Water Year 2000

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ABSTRACT:

Ambient Surface Water Quality of Rivers and Streams in the Upper Gila Basin, Water Year 2000

By Doug McCarty, Steve Pawlowski, and Patti Spindler

Abstract

A regional study of the ambient surface water quality of the Upper Gila River Basin was conducted by the Arizona Department of Environmental Quality (ADEQ) to characterize chemical and biological surface water quality to appraise current (Water Year 2000) baseline conditions. The Upper Gila River Basin is located in southeastern Arizona and includes Greenlee, Graham, and parts of Cochise and Gila counties. Sampling was conducted at 22 sites by ADEQ personnel; USGS data was included from two additional sites. Surface water samples were collected for general inorganics, nutrients, total and dissolved metals as well as a standard set of physical parameters. Bioassessments consisting of aquatic macroinvertebrate samples were collected and analyzed in the spring of 2000.

The vast majority (99.5%) of samples either met applicable state-adopted acute water quality standards or were reported as non-detects for the few analytes where detection limits were above water quality standards. For the pool of analytes sampled during the year, there was a total of 19 acute exceedances. The 19 exceedances included turbidity (7), dissolved oxygen (11) and total beryllium (1). The beryllium exceedance (full body contact and fish consumption designated uses) was collected at the San Francisco River below Clifton in the fall quarter. Throughout the basin over the entire water year from a pool of 1251 individual analyses for total and dissolved metals, only 41 returned with detectable results representing 3.28% of the samples. Water chemistry types were largely comprised of calcium-bicarbonate (5%), mixed cation (calcium predominating)-bicarbonate (59%), or mixed cation - mixed anion waters (18%). Three sites (14%) had sodium-dominated chemistry with a bicarbonate anion. One site (5%) exhibited a calcium-sulfate chemistry.

Bioassessment data indicated that the macroinvertebrate communities from warm water streams were generally in good condition. Only two warm water samples were impaired due to sediment from grazing and roads. In contrast, the majority of cold water samples were impaired due to sediment and intermittency from primarily natural conditions. The cold water macroinvertebrate community was significantly altered in the sediment impaired samples, with a loss in the number of intolerant taxa, percent stoneflies, and percent scrapers. There was also loss of taxa richness, diptera taxa, scraper taxa, and an increase in the community tolerance in the sediment impaired samples.

Soil erodibility, characterized by a measure called K factor from the USDA State Soil Geographic Data Base (STATSGO), was found to have limited predictive ability for the susceptibility of Upper Gila waters to turbidity and total suspended solids problems. Soil attribute data aggregated to provide upper soil layer erodibility factors was shown to be significantly associated ($p \leq 0.05$) with total suspended solids, field turbidity, and lab turbidity in a Kruskal-Wallis non-parametric test. Bonferroni post-hoc testing showed significant differences ($p \leq 0.10$) for TSS between high and moderate classes and between moderate and low soil erodibility classes. Field and lab turbidity were shown to have significant ($p \leq 0.10$) differences between classes of soil erodibility between high and moderate classes. STATSGO soil attribute data aggregated to provide average soil erodibility factors was not significantly associated with TSS, field, or lab turbidity. No significant associations were found between soil hydrologic group present at the sites

and TSS or turbidity.

Geologic source materials were found to influence water chemical composition in the Upper Gila Basin. This influence was not consistent over the spectrum of major ions and the ion response at each site indicated varying degrees of sensitivity dependent upon the geologic source material present at the site. Magnesium and bicarbonate were highly sensitive to the geologic class of the site, exhibiting significant differences among a number of rock types. Sodium and potassium were moderately sensitive, while other major ions exhibited little or no sensitivity to geologic class. Sedimentary clastic rock types were most likely to show differences from other rock types. Pairings of sedimentary clastic types with each of the other major types (volcanic, sedimentary sandstone, metamorphic, alluvium, and undifferentiated sedimentary) consistently showed the highest number of major ions that exhibited significant differences based on rock type.

Forested watersheds subject to multiple-use management resulted in better water quality in general than lands devoted to range or pasture grazing, agriculture, or mining. Such a finding suggests a critical role played by the forests in suppressing active erosion, providing protection and cover to the land surface subject to run-off, possible filtration effects for groundwater recharge that eventually surfaces in streams, and the maintenance of a relatively undisturbed area serving as the feeding watershed. Kruskal-Wallis testing showed strong ($p \leq 0.01$) significant differences between land use classes for conductivity, dissolved oxygen and oxygen saturation, total suspended sediments, Kjeldahl nitrogen, field turbidity and pH, and both field and lab total dissolved solids. Bonferroni post-hoc testing at the 95% confidence level revealed that forest management uses exhibited a consistently higher level of water quality for the parameters tested and exhibited the most significant differences with other land use classes.

1.0 ADEQ SURFACE WATER MONITORING PROGRAM

1.1 Purpose and Scope

The Arizona Department of Environmental Quality [ADEQ] Surface Water Monitoring and Standards Unit [SWMSU] is responsible for monitoring water quality of Arizona's rivers and streams. SWMSU staff obtain water quality data to assess the biological, chemical, and physical integrity of Arizona's surface waters.

Arizona law mandates that ADEQ conduct ongoing monitoring of Arizona surface waters to detect the presence of new and existing pollutants; determine compliance with applicable water quality standards; determine the effectiveness of best management practices, agricultural best management practices and best available demonstrated control technologies; evaluate the effects of pollutants on public health and the environment; and determine water quality trends [*See* Arizona Revised Statutes § 49-225(A)]. SWMSU staff collect water quality data for these purposes. §106(e)(1) of the Clean Water Act also mandates that ADEQ collect water quality data on Arizona's surface waters. §106(e)(1) requires that ADEQ establish and operate a program to monitor, compile, and analyze data on the quality of the "waters of the United States." The SWMSU implements this federally-mandated monitoring program. §106(e)(1) of the Clean Water Act further requires that ADEQ provide water quality data for annual and biennial updates of Arizona's water quality assessment reports required by §§ 205(j) and 305(b) of the Clean Water Act. A primary objective of the SWMSU monitoring program is to obtain credible and scientifically defensible data for use in water quality assessments required by the Clean Water Act. The most recent § 305(b) report prepared by ADEQ is entitled The Status of Water Quality in Arizona - 2002.

Figure 1. San Francisco River near Martinez Ranch north of Clifton.

This report includes a summary of the water quality data used to assess water quality conditions in the Upper Gila River Basin.

The objectives of SWMSU's surface water quality monitoring program are:

- To collect data to characterize baseline water quality conditions of streams in the selected watershed;
- To determine compliance with applicable surface water quality standards;
- To provide data to determine water quality trends;
- To provide data to support water quality assessments; and
- To support the development of new water quality standards addressing biological and physical integrity.

1.2 SWMSU Monitoring Programs

One of the core monitoring programs of the Surface Water Monitoring and Standards Unit is the Fixed Station Network [FSN] Monitoring Program. The FSN Monitoring Program is a statewide data collection program whose primary purposes are to: 1) characterize baseline water quality in perennial, wadeable streams, and 2) monitor changes in water quality over time, and 3) provide long-term data to determine water quality trends. SWMSU staff conduct quarterly monitoring at FSN sites each year. In WY 2000, the FSN monitoring network consisted of 27 monitoring stations. Four stations were established on rivers and streams in the Upper Gila Basin.

Another important SWMSU program is the rotational basin monitoring program. SWMSU staff conduct monitoring to characterize baseline water quality conditions of wadeable, perennial streams in selected basins on a 5-year rotating schedule. ADEQ has identified 10 major basins for purposes of this data collection effort. SWMSU targets its monitoring effort in 2 major watersheds each year and all 10 major watersheds are monitored over a 5-year cycle. The Upper Gila Basin was one of first watersheds selected for monitoring at the inception of the rotational watershed monitoring program in Water Year 2000. This report presents the findings from water quality data obtained at 24 Upper Gila River Basin sites that were sampled between October 1, 1999 and September 30, 2000.

SWMSU staff also collect water quality data to determine whether water quality is being maintained and protected in Arizona's outstanding state resource waters or "unique waters." The primary purpose of this monitoring program is to characterize baseline water quality in the state's unique waters. A long-term goal of the program is to collect a sufficient amount of water quality data to do trend analysis to determine whether state antidegradation requirements applicable to unique waters are being met. Currently, there are 18 unique waters in Arizona. Three unique waters are found in the Upper Gila River Basin. They are: Bonita Creek, Cave Creek, and the South Fork of Cave Creek.

1.3 Sampling Sites

SWMSU selected 22 sampling sites for monitoring in the Upper Gila River basin **(Appendix A; Figure 4)**. Sample sites in the Upper Gila River Basin were selected using the following criteria:

- Sites were located on wadeable, perennial streams.
- Sites were located to provide broad geographic coverage of wadeable, perennial streams located in the Upper Gila River basin.
- Sites were established to monitor water quality in each of the three "Unique Waters" found in the Upper Gila River basin.

- Sites were established to be representative of surface waters with both cold water and warm water aquatic life designated uses.
- Sites were established to characterize water quality conditions in rivers and streams that crossed the Arizona-New Mexico border.
- Biocriteria reference sites were included to further characterize reference conditions in Arizona.
- Sites were selected in locations with reasonable road access that required a minimum of hiking to reach the sampling site.
- If possible, sites were located at or near U.S. Geological Survey or other agency discharge gaging stations.
- In some cases, sites were established to measure impacts from nonpoint source discharges of pollutants, including discharges from mining and agricultural activities.
- Sites were established in a straight length of the stream channel with a smooth, uniform bottom, free of obstructions, where flows were well-mixed.

1.4 Monitoring Duration and Frequency

Water Year 2000 began on October 1, 1999 and ended on September 30, 2000. SWMSU staff performed quarterly monitoring at each sampling site.

Figure 2. Site Establishment on the Blue River

1.5 Sample Collection

In general, water quality samples were collected using sampling protocols designed to obtain representative samples. All SWMSU sampling protocols are documented in Fixed Station Network Procedures Manual for Surface Water Quality Monitoring (2).

Either grab samples or composite samples were collected depending upon the width, depth, and velocity of the stream. Grab samples were collected from small, shallow, low flow streams. SWMSU staff used depth-integrated and equal-width-increment sampling methods to obtain samples from larger, deeper, and faster streams. Samples were composited in churn splitters.

Field measurements of water temperature, pH, dissolved oxygen, total dissolved solids, and specific conductivity were made using a Hydrolab multi-parameter monitoring instrument. Turbidity measurements were made using a Hach 2100P portable turbidimeter. Discharge measurements were made at sampling site cross-sections using Marsh-McBirney flow meters and top-setting wading rods. Samples for dissolved metals analytes were filtered in the field using Geopump peristaltic pumps and 0.45 Fm membrane filters.

1.6 Sample Analysis and Target Analytes

All water chemistry analyses for inorganic chemicals, total and dissolved metals, and nutrients were performed by the Arizona Department of Health Services State Laboratory. Method reporting limits may be found for laboratory analytes in **Appendices C1, C2,** and **C3**. Field parameters including fecal coliform, E. coli, dissolved oxygen, specific conductivity, and others were sampled and recorded by SWMSU personnel on-site. Water quality data included the following target analytes:

Field Measurements
Air Temperature
Water Temperature
Dissolved Oxygen
Percent Saturation
Conductivity
pH
Total Dissolved Solids
Turbidity
Discharge
Flow Velocity
Stream Width
Stream Depth

General Inorganics
Alkalinity, Total
Alkalinity, Phenophthalein
Hardness, Measured
Hardness, Calculated
Calcium
Magnesium
Potassium
Sodium
Chloride
Fluoride
Sulfate
Nitrate+Nitrite
Conductivity
Total Dissolved Solids
pH
Bicarbonate
Carbonate
Total Suspended Solids

Bacteria
Fecal Coliform
Escherichia Coli

Total Metals
Mercury
Arsenic
Barium
Beryllium
Boron
Cadmium
Chromium
Copper
Iron
Lead
Manganese
Thallium
Nickel
Silver
Zinc
Antimony
Selenium

Dissolved Metals
Arsenic
Mercury
Barium
Beryllium
Cadmium
Copper
Lead
Thallium
Nickel
Silver
Zinc
Antimony
Selenium

Nutrients
Phosphorus
Kjeldahl Nitrogen
Ammonia

1.7 Quality Assurance

Obtaining high quality data requires following appropriate techniques for obtaining water quality samples and analyzing them for their constituents. SWMSU has implemented a quality assurance program to assure the reliability of its monitoring and measurement data. Specifics are outlined in the ADEQ Quality Assurance Program Plan for the Surface Water Monitoring and Standards Unit (9).

Field quality control measures were applied to all Upper Gila River Basin sites in keeping with general SWMSU protocols (2). Quality control measures included the collection of field blanks (churn and filter blanks) and the collection of splits / duplicates to comprise a total of 10% of all samples collected. The breakdown between blanks and splits was two-to-one. Two split samples were collected in the Upper Gila Basin during WY2000. The Blue River at the Juan Miller Road Crossing (UGBLR005.68) fall visit and the Gila River above the Old Safford Bridge (UGGLR197.26) fall visit were the two site visits selected in a random assignment of split samples during the planning for WY2000. All total and dissolved metals, nutrients, and major ions sampled met the criteria of less than 10% relative percent difference between the sample and its split for these two site visits.

Office quality assurance measures applied to field data included the application of five ratios / balances to assess the adherence of the sample to general chemistry norms **(Appendix B)**. These measures include Field / Lab pH ratio, Field / Lab conductivity ratio, TDS / EC ratio, TDS / calculated sum ratio, and cation / anion balance. Ratios, methods of calculation, and ratio acceptable ranges are discussed in the ADEQ Fixed Station Network Procedures Manual (2). The pH ratio was uniformly in range (0.9 to 1.1) for each of the 71 sample visits. Nine of 71 conductivity ratios were out of the normal range (0.9 to 1.1). The TDS / EC ratio showed four of the 71 sample visits out of range (0.55 to 0.75), while the TDS / Sum ratio showed eighteen of the 71 site visits out of the normal ranges (1.0 to 1.2). Twenty-nine of the 71 sample visits did not meet the required percent or absolute difference as outlined by Standard Methods for the cation/anion balance.

Investigations were undertaken to determine the reasons for the poor performance of both the cation/anion balance and the TDS /Sum ratio. Discussions with the ADHS State Laboratory throughout 2000 and 2001 led to a modification of their methods for testing and calculating this balance in June 2001. Prior to this date, parameters used for these calculations had been analyzed from a nitric acid-preserved sample bottle. After consultations, the State Laboratory began measuring these analytes from an unpreserved sample bottle. Subsequent cation / anion balances show better adherence to expected values. All departures from norms on the cation / anion balance for the Upper Gila basin in WY 2000 can be attributed to the employment of the improper method of testing and calculation previously used by the State Lab (26).

The TDS / Sum ratio was also affected by the improper measurement methods employed by the lab. The State Laboratory confirmed that major cations (Ca, Mg, K, Na) were tested from a nitric acid-preserved bottle during the year. Such testing led to values reported and used for the ratio that were higher than might be expected if sampled from an unpreserved sample bottle (26). Consequently, some of the calculated ratios affected by this consideration would be lower than they would be under the modified procedures. Two low TDS / Sum ratios resulted from the improper method.

Three factors were at work that can account for TDS / Sum ratios higher than the acceptable range put forth by Standard Methods. Sulfate testing by the State Laboratory during the year was done with a relatively coarse detection limit of 10.0 mg/l. The sulfate detection limit has since improved to 1.0 mg/l, but levels of sulfate appearing in the waters of single-digit magnitude would not be detected and would cause under-reporting of the anion balance and the sum of constituents in the ratio. This problem would lend itself to higher than normal ratios. Secondly, ADEQ field personnel have observed that in streams with low specific conductivity and low total dissolved solids, the TDS / Sum ratio is consistently high. The ratio does not appear to hold for relatively pure natural waters that are largely free of solute loads. USGS confirms this observation (23). Lastly, silica (SiO_2) was not tested for as a major constituent. Silicon is one of the more prevalent elements on earth, and silica concentrations in the world's rivers are estimated to range from 10.4 mg/l to 13 mg/l (23). Lack of this constituent in the ratio would again lend itself to suppression of the sum of constituents in the denominator of the ratio, leading to a higher than expected ratio.

Refinement of the meaning of QA ratios and their relation to data validity led to the acceptance of anomalous ratios as indicative of characteristics of the matrix and non-indicative of a problem with particular analytes not involved in the calculations. An anomalous ratio without corroborating evidence of a problem on other fronts was deemed insufficient to censor data from entering the data repository or being subject to use in analysis. None of these measures were intended nor used to exclude data from ADEQ acceptance or use for further analysis (9). Instead, the measures are used as meta-data indicating the characteristics of the matrix from which analytes are subsequently analyzed.

2.0 THE REGION: UPPER GILA RIVER BASIN

The Upper Gila River Basin **(Figure 4)** is located in southwestern New Mexico and in southeastern Arizona. The Arizona portion of the Upper Gila River Basin extends from the Arizona border with New Mexico to Coolidge Dam at the San Carlos Reservoir near Globe, Arizona. The Upper Gila watershed in Arizona encompasses 7,354 square miles or approximately 6% of the state's land area (8).

Elevations in the Upper Gila Basin range from 10,717 ft in the Pinaleno Mountains at Mt. Graham to 2,523 ft at the Coolidge Dam on the Gila River. Major mountain ranges in the basin include the Chiricahuas, Pinalenos, Gila Mountains, and the White Mountains.

The Arizona Department of Water Resources has identified a total of 389 miles of perennial streams in the Upper Gila River Basin (10). Further discussion of these streams follows in Section 2.2.

Figure 3. Bonita Creek riparian corridor.

2.1 Physiographic Provinces and Ecoregions

The Upper Gila River Basin lies within the boundaries of two major physiographic provinces: the Central Highlands province, which forms the northern portion of the basin, and the Basin and Range province, which forms the southern and western portions of the basin (14).

The Central Highlands province is an area of transition between the Colorado Plateau in the northern part of the state and the Basin and Range hydrologic province to the south and west (8). The northern boundary of the Central Highlands province is defined by the Mogollon Rim, a 2,000-foot escarpment that forms the surface water drainage divide between the Central Highlands and the Plateau Uplands. The province is characterized by rugged mountainous terrain with shallow intermontane basins. Elevations in the province range from approximately 2,000 feet near the confluence of the Salt and Verde Rivers to 11,400 feet at Mt. Baldy in the White Mountains (14). Most of the perennial streams in the state are found here. These streams typically flow from the Mogollon Rim and White Mountains south and west toward the Basin and Range Lowlands. The headwaters of a number of streams that were sampled in WY 2000 are located in the Central Highlands Province, including the San Francisco River, Campbell Blue Creek, Blue River, Eagle Creek, Bonita Creek, and KP Creek.

The Basin and Range province is in the southern and southwestern part of Arizona. The province consists of generally north to northwestward-trending mountain ranges ("sky islands") separated by broad alluvial valleys. Altitudes range from 800 ft. above sea level west of Phoenix to 10,720 feet at Mt. Graham near Safford, Arizona (14). Intermittent and ephemeral streams are common in the Basin and Range province. Frye Creek, Ash Creek, the lower portions of Eagle Creek and Bonita Creek, and the main stem of the Gila River are located within the Basin and Range hydrologic province.

Most of the Upper Gila River Basin falls within the Southern Deserts ecoregion. The northern portion of the basin is within the Arizona / New Mexico Mountains ecoregion. A small portion of the western part of the basin falls within the Southern Basin and Range ecoregion (8).

2.2 Hydrography

The principal river of the Upper Gila River Basin is the Gila River **(Figure 6)**. The headwaters of the Gila River are found on the western slopes of the Continental Divide in the Mogollon and Black mountains of west-central New Mexico. The Gila River is perennial as it flows through the towns of Gila, Cliff, Redrock and Virden in New Mexico. Much of the upper Gila River in New Mexico lies within the Gila National Forest where a large part of the forest is a designated wilderness area relatively free of human impacts. The Gila River becomes intermittent as it enters Arizona from New Mexico through the Duncan-Virden Valley near the town of Duncan, Arizona. During periods of low flow, all surface water in the Gila River may be diverted for irrigation in New Mexico. Immediately below Duncan, additional diversions for irrigation occur. Approximately 15 to 20 miles below the town of Duncan, the Gila River traverses a perennial reach for approximately 35 miles. This stretch of the Gila River is maintained by inflows from three major tributaries: the San Francisco River, Bonita Creek, and Eagle Creek (8). A portion of this perennial reach and its riparian corridor was designated as the Gila Box Riparian National Conservation Area by the Arizona Desert Wilderness Act of 1990.

The San Francisco River is the largest tributary to the Gila River in the Upper Gila Basin. The headwaters of the San Francisco River are located in the mountains immediately northwest of the small community of Alpine, Arizona. The San Francisco River flows eastward to Luna Lake and then across the Arizona-New Mexico state line. In New Mexico, the river bends to the south for a run of approximately 40 miles, where it turns again to the west and re-enters Arizona and flowing to the southwest through the town of Clifton to its confluence with the Gila River. By the time the San Francisco River reaches the main stem of the Gila River at Clifton, it adds 50,000 to 60,000 acre feet annually to the perennial flow of the Gila River (34). The San Francisco River also picks up flow from the Clifton Hot Springs as it passes through the town of Clifton, thus undergoing a basic water-chemistry change from a calcium-bicarbonate water type to a sodium-chloride water type due to the input of high levels of salts from the Clifton Hot Springs (11).

The headwaters of Eagle Creek are located near the boundary between the Apache-Sitgreaves National Forest and the San Carlos Apache Reservation in the Central Highlands Province. Eagle Creek flows southward along the reservation boundary and empties into the Gila River about two miles downstream from the confluence of the San Francisco River and Gila River (8). Most of the Eagle Creek watershed is used only for grazing and national forest management uses. Mining practices have potential effects where Eagle Creek flows east of the Phelps-Dodge mine near Morenci, Arizona. Flow in Eagle Creek is supplemented by a water transfer from the Upper Salt River Basin. In 1944, the Phelps Dodge Corporation entered into an agreement with the Salt River Valley Water Users Association to divert up to 14,000 acre-feet annually of water from the Black River, a tributary to the Salt River. Surface water is pumped from the Black River over the watershed divide into Willow Creek, a tributary of Eagle Creek. The water is subsequently pumped from Eagle Creek to Morenci and Clifton, Arizona where it is used for mining purposes and municipal supply (21).

Bonita Creek, the third major perennial tributary to the Gila, enters the Gila River about five miles below the mouth of Eagle Creek and two miles above the head of the Safford Valley. The headwaters of Bonita Creek are located on the San Carlos Apache Indian Reservation. The stream flows for approximately 33 miles on the reservation before crossing the reservation boundary, then another 15 miles before joining the Gila River. The lower segment of Bonita Creek serves as a municipal water supply for the City of

Safford and surrounding communities in the Gila River Valley, including Thatcher, San Jose, Central, and Solomon. Infiltration galleries for the public water system that serves these communities are located in Bonita Creek approximately 4 miles above its confluence with the Gila River (21). Bonita Creek is recognized as one of the state's outstanding resource waters and it is designated as a "Unique Water."

Other important perennial streams selected for sampling in the Upper Gila Basin consist of the Blue River, a major tributary to the San Francisco draining the east-central region of Arizona; Frye and Ash Creeks on the flanks of the Pinaleno Mountains; KP Creek and Campbell Blue Creek, tributaries to the Blue River; and Cave Creek and South Fork of Cave Creek in the Chiricahuas Mountains of southeastern Arizona. Frye Creek comprises an additional part of the Town of Safford's water supply. Cave Creek and the South Fork of Cave Creek have been designated as "Unique Waters."

Specific sites selected and sampled in WY2000 are mapped and labeled with site codes in **Figure 4.**

2.3 Climate

The climate in the Upper Gila River Basin is characterized by its variability due largely to elevation changes and large differences in precipitation from one year to the next. Mean annual precipitation ranges from less than 10 inches in the lowland deserts of the Basin and Range Province to more than 25 inches in the mountains of the Central Highlands province (17). Mean annual precipitation rates can be highly variable from year to year. Precipitation amounts can be three times greater in wet years than in dry years.

Altitude is one of the most important controlling factors of climate in Arizona. In general, precipitation increases and temperature decreases with increasing elevation during all seasons of the year. The large topographic relief within Arizona's physiographic provinces contributes to the variability of precipitation and temperature within the state.

The climate of the Upper Gila River Basin is characterized by two rainy periods separated by two dry periods during the year. The best defined of the two rainy periods, the summer "monsoon," normally occurs during July and August. Summer monsoon rains typically result from the northeastward flow of moist air from the Gulf of Mexico across Mexico into Arizona. The summer monsoon season is characterized by afternoon or evening thunderstorms. Summer monsoon storms are often highly localized, of short duration, and frequently intense. The other rainy period occurs in the winter, typically from December to mid-March. Winter storms in Arizona result from moist air moving eastward from the Pacific Ocean into Arizona. Winter storms are typically more widespread and of lower intensity. Arizona's winter storms produce snow at higher elevations in the Central Highlands province. The winter snowpack is very important to central Arizona because the melting snow during spring runoff supplies most of the water to perennial and intermittent streams flowing out of the Central Highlands to the Basin and Range province to the south and west.

2.4 Geologic Characterization

The geology of the Upper Gila Basin **(Figure 5)** is determined by the physiographic provinces it inhabits. The Gila River valley west of the Gila Box area (northeast of Safford) and the San Simon drainage are largely Quaternary alluvium in constitution. The river valley overlays extensive deposits of sediments that comprise major aquifers tapped by the agricultural practices in the vicinity. Unconsolidated sediments are thought to be up to 3000 feet thick in the Gila River valley. The mountainous regions south of Arizona's White Mountains in the northern part of the basin are largely volcanic in origin dating from the Tertiary era. The mountains of the Basin and Range lowlands are composed chiefly of granite, gneiss, schist, and quartzite. Some mountains are capped by volcanic rocks that range from Precambrian to Tertiary in age (14). The two principal mountain ranges in the southern part of the basin illustrate the general character of the basin: the Chiricahua Mountains in the southeastern corner of the state have a volcanic origin, while the Pinaleno Mountains are metamorphic in nature. Extensive discussion of the more detailed geologic character and analyses relating geologic character of source materials and water chemistry types is addressed in Section 5.0.

2.5 Land Ownership

Land ownership within the Upper Gila River Basin is distributed between state, federal, private, and tribal entities **(Figure 6)**. Twenty-nine (29) percent of the land area of the Upper Gila River Basin is within the San Carlos Apache Reservation. Public lands in the Apache-Sitgreaves and the Coronado National Forests account for another 23% of the land area in the basin. The Bureau of Land Management manages 23% of the land area within the basin. State trust lands account for 14% of the land area. Privately-held lands comprise only 10% of the acreage in the Upper Gila River Basin (8).

2.6 Land Uses

Much of the northern part of the watershed is within the Apache-Sitgreaves National Forest and is managed by the U.S. Forest Service. A large portion of these public lands are within the Blue Range Primitive Area. U.S. Forest Service management of the Blue Range Primitive Area is similar to the management of a wilderness area: no grazing currently occurs nor is logging permitted (24). However, roads and road crossings are still present and actively used. Several areas of private in-holdings, including the small community of Blue, occupy this area, and unpaved roads provide access to these areas. At least one FSN long-term site, the Blue River at the Juan Miller Road Crossing, is affected by a road crossing.

Outside of the Blue Range Primitive Area, grazing and logging are the principal land use activities on the national forest. The entire Apache Sitgreaves National Forest is partitioned for various grazing allotments. Grazing, logging, and recreation occur under the U. S. Forest Service multiple use management philosophy.

The southern forests of the Upper Gila River Basin, in particular the Chiricahua and Pinaleno mountains, are administered by the Coronado National Forest. These mountainous areas are the renowned “sky islands” of southeastern Arizona. The Pinalenos are home to the Mt. Graham International Observatory run by the University of Arizona. Impoundments of streams draining the Pinalenos provide part of the water supply for the City of Safford. The Chiricahua Mountains are largely undeveloped, but they are the home of the Southwestern Research Station, a facility funded by the Smithsonian Museum of Natural History. Grazing occurs in the Cave Creek watershed, but not within Cave Creek Canyon proper (25). In general, SWMSU sampling sites would only minimally, if at all, be affected by these land use activities, due to the extreme ruggedness of the Pinalenos and the remoteness of the Chiricahuas.

With most of the population centers of the Upper Gila Basin in the Basin and Range lowlands, it follows that the principal economic activities occurring in the basin would be present near the Gila River or in the lower reaches of its tributaries outside of national forest boundaries. The principal economic activities in the basin are agriculture, mining, and ranching.

Farming occurs in the Gila River Valley near the towns of Safford, Thatcher, and Pima. Cotton and alfalfa are the primary crops grown in the area. Agriculture also is an important land use near the Town of Duncan near the Arizona-New Mexico border where one of the sites for Water Year 2000 was located. In general, agricultural impacts on surface water quality typically include higher levels of turbidity, total dissolved solids, boron, and selected inorganic chemicals.

Mining uses also factor into the land use patterns of the Upper Gila River Basin. The Phelps-Dodge copper mine at Morenci is a large and active mining operation with the potential to significantly impact local water quality. Two WY 2000 sites were selected to monitor potential mining runoff from this mining area. The two sites were Eagle Creek below Gold Gulch and the San Francisco River below Clifton. SWMSU staff carefully monitored these sites for total and dissolved metals, pH, and turbidity.

Grazing constitutes the fourth major land use of the Upper Gila River Basin. Much of the open desert range land surrounding Safford, Arizona and extending southeasterly towards I-10 is administered by the Bureau of Land Management and used for cattle grazing. The Gila Box area northeast of Safford also falls into this land-use category. Selected areas in the Apache-Sitgreaves National Forest, particularly the area east of Alpine above Luna Lake are used for pasture and subject to grazing impacts.

2.7 Cities and Towns

The Upper Gila River Basin is sparsely populated. The larger towns in the basin are found along the main stem Gila River and the San Francisco River. Principal cities and towns include Duncan, Safford, Pima, Thatcher, Clifton and Morenci. According to 2000 Census information, the largest town in the Upper Gila River Basin is Safford with a population of 9,232 .

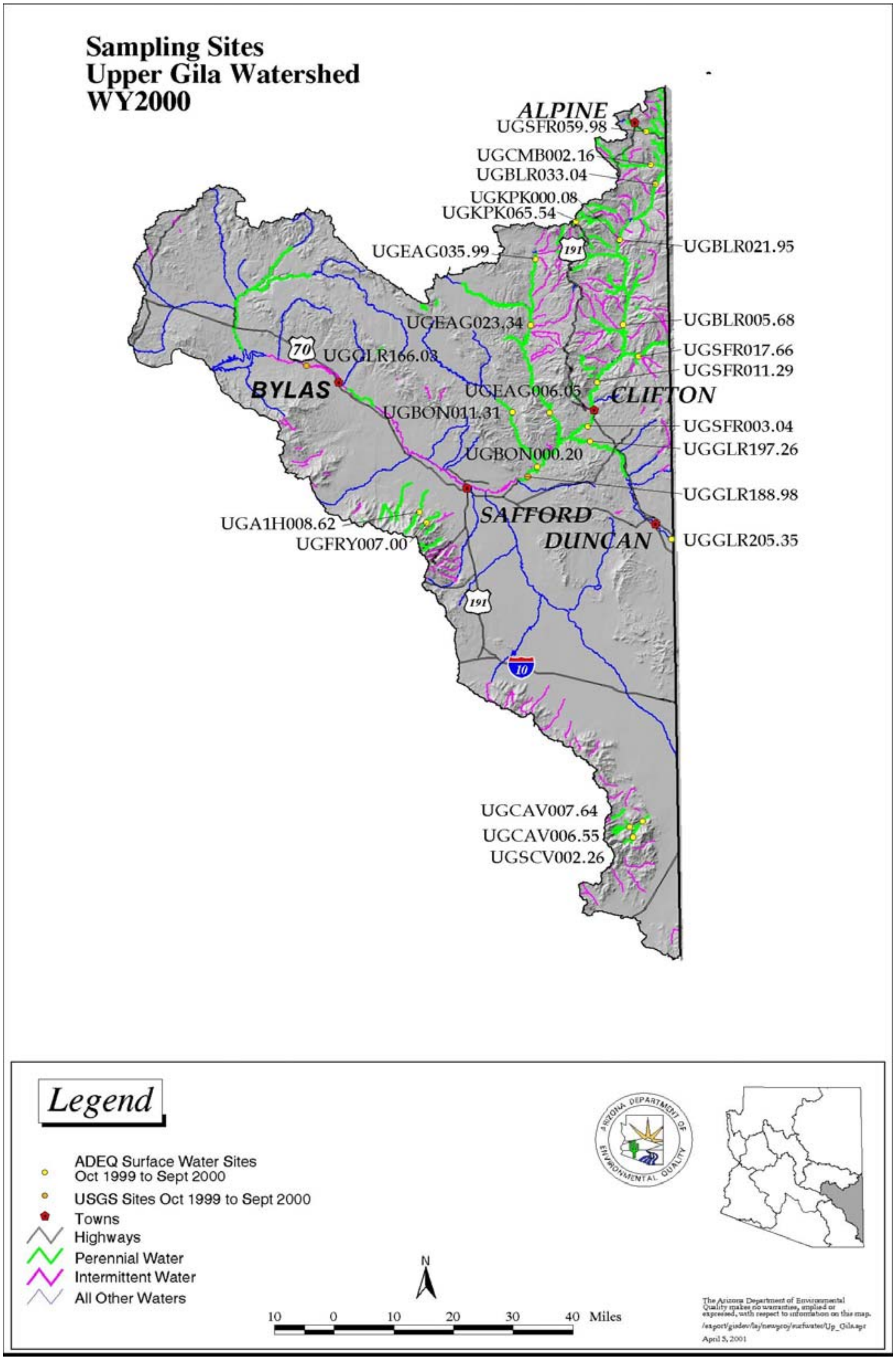


Figure 4. Water Quality Monitoring Sites, Upper Gila Basin WY 2000

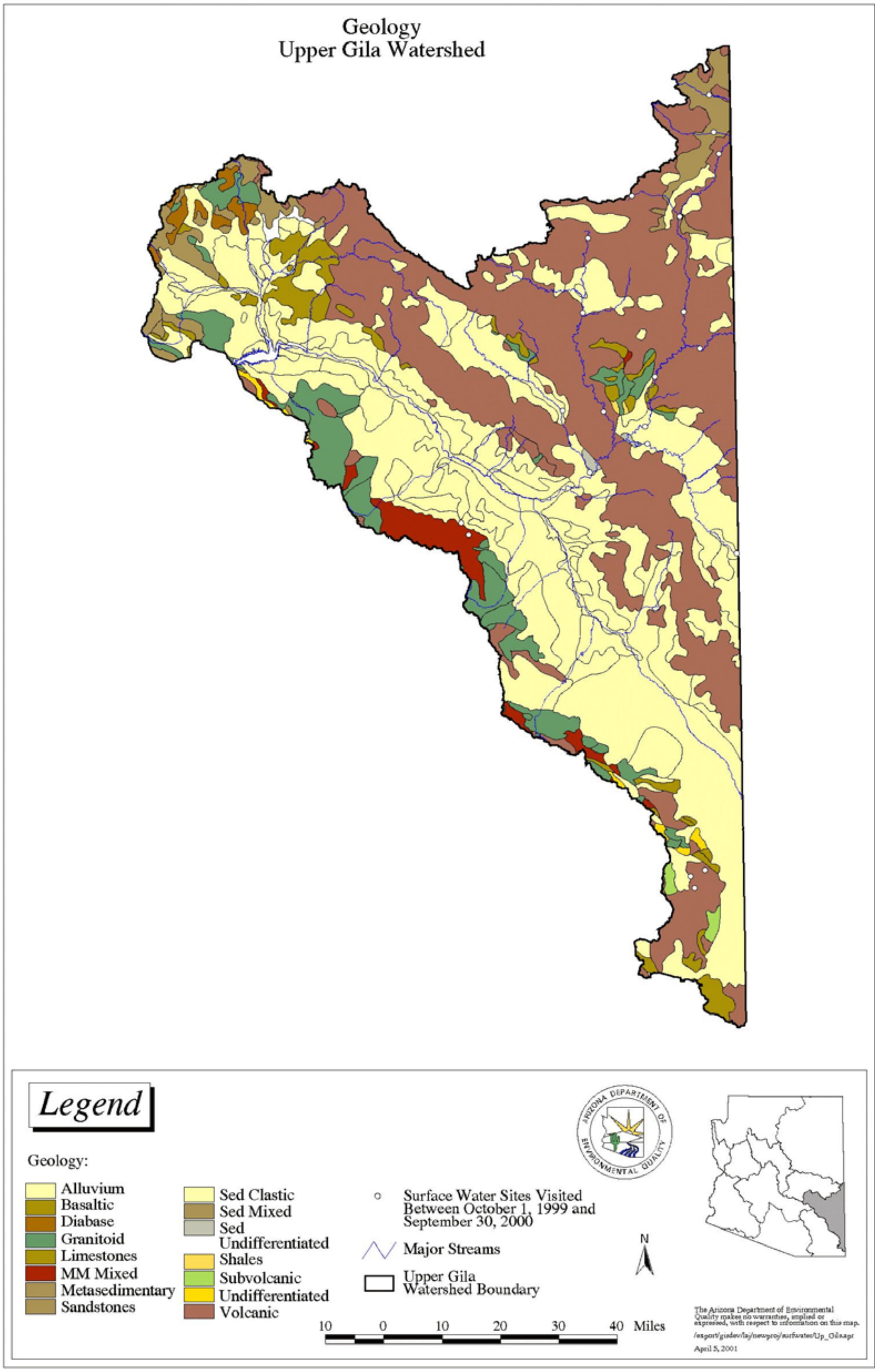


Figure 5. Geologic map of Upper Gila Watershed.

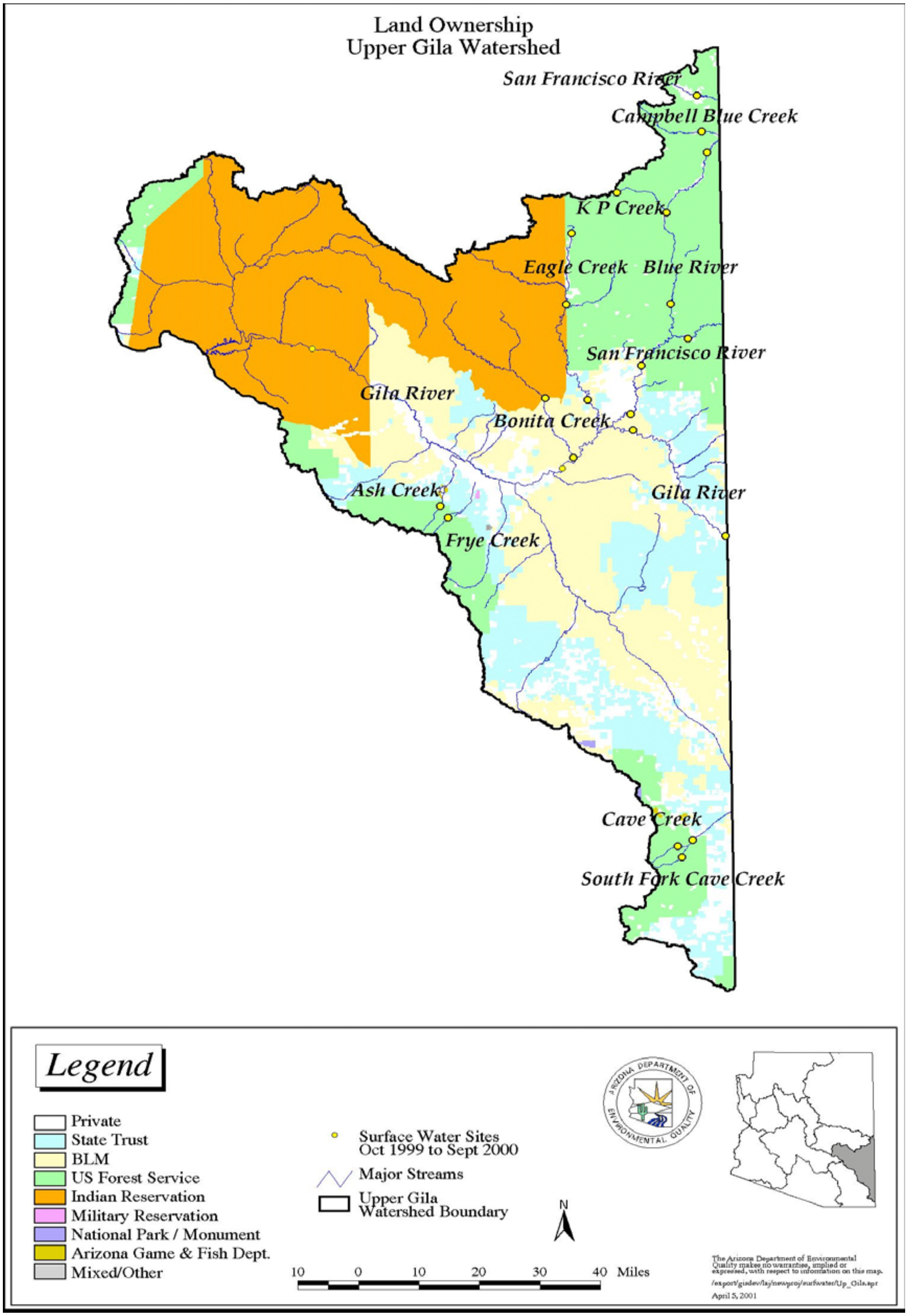


Figure 6. Land Ownership in the Upper Gila River Basin

3.0 PREVIOUS WATER QUALITY STUDIES

Only a few studies have been done on the quality of surface water in the Upper Gila River Basin. Hem (21) studied the water quality characteristics of the Gila River basin above Coolidge Dam.

The Arizona Department of Water Resources [ADWR] reported that the chemical water quality of the Gila River changes considerably from its headwaters in New Mexico to the terminus of the Upper Gila Basin at the San Carlos Reservoir (10). ADWR noted that there is a progressive degradation of water quality in the Gila River caused by irrigation return flows and fault-generated springs and seeps having their origin in the evaporite beds underlying the Gila River Valley floor. Citing Hem (21), ADWR states that the concentration of total dissolved solids in the Gila River at the Arizona-New Mexico state line averaged 305 mg / L . ADWR further states in their water quality assessment that inflows from the San Francisco River cause large increases in sodium and chloride concentrations in the Gila River between the bridge at Highway 666 (now Hwy. 191) and the mouth of Bonita Creek. ADWR hypothesized that this increase may have been caused by inputs of mineralized water from Clifton Hot Springs which has been found to have as much as 9,790 mg / L of total dissolved solids (21). ADWR also notes that large amounts of surface water are diverted from the Gila River below the USGS gaging station at the head of the Safford Valley near Solomon, Arizona for agricultural irrigation. The Gila River receives considerable inflows from groundwater and agricultural return flows in the Safford Valley area. Consequently, there are large increases in the concentration of dissolved solids as the Gila River flows downstream to the San Carlos Reservoir. Hem (21) reported that the average concentration of total dissolved solids in the Gila River near Bylas, Arizona was 1,397 mg / L. This is corroborated by high dissolved solids concentrations in the Gila River near Calva, Arizona have been found by the U.S. Geological Survey [USGS]. The average concentration of dissolved solids at the Calva sample site at the head of the San Carlos Reservoir as reported by the USGS for Water Year 2000 was 1,446 mg / L (34).

In a USGS study led by Baldys (14), summary statistics and temporal trends for 19 water chemistry constituents and for turbidity were computed for 13 study sites in the Gila River basin from data collected as early as October, 1972 through September, 1987. Two of the 13 study sites are located in the Upper Gila River Basin: 1) the Gila River at Calva, and 2) the San Francisco River near Clifton. An additional study site, the Gila River near Redrock, is located in the Upper Gila River Basin in the State of New Mexico. The authors used a nonparametric statistical technique, the seasonal Kendall tau test for flow-adjusted data, to analyze changes in water chemistry data. Decreasing trends were found for 49 data sets at the 13 study sites. Increasing trends for the 19 water chemistry constituents and turbidity were found for 24 data sets at the 13 study sites.

Water quality data for the Gila River at Calva indicated decreasing trends in the values of hardness, dissolved chloride, dissolved sodium, dissolved sulfate, dissolved solids, dissolved barium, dissolved lead, and total manganese. The Gila River at Calva site tied with another USGS study site for the most decreasing trends (eight trends total) at an individual site. An increasing trend of values for pH were reported at the Gila River at Calva site. The highest median (40 NTU) and highest maximum (21,000 NTU) values for turbidity in the USGS study were measured at the Gila River at Calva site. The maximum concentrations of dissolved sodium (1,200 mg/L), dissolved chloride (2,200 mg/L), total ammonia (74.0 mg/L), and barium (600 mg / L) in the study also were recorded for the Gila River at Calva site. The USGS found that the median concentrations of hardness, dissolved solids, dissolved sodium, dissolved sulfate, and dissolved chloride were larger at sites located above reservoirs, especially the Gila River at Calva site at the head of the San Carlos Reservoir. The USGS concluded that the water quality of the Gila River near Calva was influenced by irrigation return flows.

Denise L. Baker and Kirke A. King of the U.S. Fish And Wildlife Service [USFWS] Contaminants

Program conducted a study in the Upper Gila River Basin in July, 1994 (13). The study involved the collection of water, sediment, and lizard, avian, and fish tissue samples from June to August, 1990 from 10 locations in the Upper Gila River basin. The objective of this study was to survey the Upper Gila River Basin to determine if surface waters from mining and agricultural drainages had the potential to cause significant harmful effects on fish and wildlife resources. Based on avian, lizard, and fish tissue concentrations for cadmium and mercury that approached critical reproductive effect threshold levels, the USFWS recommended regular monitoring of fish tissue for those parameters. Based on selenium concentrations in one fish sample that exceeded the dietary level for protection of avian predators, the USFWS recommended fish tissue monitoring for selenium in conjunction with the tissue monitoring for cadmium and mercury.

The U.S. Fish & Wildlife Service conducted limited water quality monitoring as part of this study. Sampling sites within the Upper Gila River Basin included the San Francisco River (two sites), the Gila River (7 sites), and the San Carlos River (1 site). Water samples were analyzed for alkalinity, arsenic, barium, calcium, cadmium, chloride, chromium, copper, hardness, iron, lead, manganese, magnesium, mercury, nitrate (as N), pH, selenium, silver, sulfate, total dissolved solids, and zinc. The limited water quality data indicated that the surface water in the Gila River, San Francisco River, and San Carlos River should be classified as hard water as determined by total alkalinity as calcium carbonate results. Total alkalinity results ranged from 151 to 257 mg / L.

4.0 WATER DISCHARGE AND QUALITY CHARACTERIZATION

4.1 Flow Conditions in the Upper Gila Basin, Water Year 2000

Streamflow in Arizona depends upon a number of factors, including precipitation, elevation, geographic location in the state and exposure to prevalent monsoon flows, geology, and snowmelt releases. The Upper Gila Basin has two factors that contribute strongly to perennial streamflow. The basin's location at the eastern edge of the state places it more strongly into monsoonal flows during the monsoon season of July to September when afternoon thunderstorms routinely build. Additionally, the high elevations of the White Mountains north of Clifton-Morenci and the isolated ranges to the south, including the Pinalenos and the Chiricahuas, draw precipitation in the winter months in the form of snow. Steady snowmelts in the spring months allow recharge of local aquifers and the consistent feeding of perennial streams in the area through springs and seeps.

Arizona stream discharge is highly variable from season to season and year to year. Stream courses that are generally perennial have been known to go dry during drought; conversely, ephemeral drainages can flow in flood events during the monsoon season. A water quality program that makes episodic visits to selected stream sites must rely upon outside records for a full accounting of flow and other conditions during the periods of the water year between visits. The United States Geological Survey (USGS) maintains a network of flow and gauge monitoring stations placed in strategic locations in streams around the state. Data for the periods of record for these sites are available over the Internet (www.usgs.gov), and are useful for determining flow conditions throughout the year. USGS also publishes Water Resources Data for each water year, where daily records, maximums, minimums, long-term averages, and monthly averages are all available for review. Discharge graphs shown in this section all derive from USGS data.

Four USGS monitoring stations were selected for the purposes of characterizing flow in the basin: San Francisco River at Clifton, Arizona (09444500), Gila River at the head of Safford Valley near Solomon, Arizona (09448500), Gila River near Clifton, Arizona (09442000), and Blue River near Clifton, Arizona (09444200). All of the sites except for the USGS Solomon site were co-located with ADEQ Fixed Station Network sites during the water year. The USGS Solomon site has the added benefit of being located downstream of the confluences of the San Francisco River, Eagle Creek, and Bonita Creek, thus reflecting the hydrologic inputs of these streams into the system.

Flows at these four major stations on perennial rivers and streams in the Upper Gila basin for WY2000 reflect a sub-par year for precipitation and water run-off. Generally, Water Year (WY) 2000 is acknowledged as the second year of a gathering drought, and the figures show below-average cumulative run-offs and instantaneous discharges. The spreads between WY2000 upper decile thresholds and corresponding historic thresholds were wider than the spreads between lowest decile thresholds for WY2000 and historic values, suggesting that for much of the year, discharges did not deviate much from baseflow conditions. **Figures 9-12** tend to support this assertion. Furthermore, all four graphs show a substantial decline in discharge values over the last six months of the water year. Median flows for these four sites ranged from 66% to 83% of the historic median values for the periods of respective record. Total run-offs for the year for the four sites ranged from 16% to 29% of historic averages for cumulative run-off (34).

The Blue River near Clifton **(Figure 9)** had a total average annual flow of 50,230 acre-feet for the historic period of record covering years 1968-2000 (34). The median flow for the period of record is 21 cfs. The upper decile (10% exceeds flows) for the period of record is 164 cfs, while the lowest decile (90% exceeds flows) is 5.0 cfs. For water year 2000, total annual flow for the Blue at this site was 8480 acre-feet, approximately 16% of average. Median flow for WY2000 was 14 cfs (67% of median value). The upper decile of flows for WY 2000 was 21 cfs, while the lower decile discharge value was 2.4 cfs. Monthly summary statistics of the Blue for WY2000 when compared to the monthly statistics for the period of record show a range from 6.1 % to 44.0 % of the mean monthly flows for the period of record. The average monthly flow for WY2000 was 17.3% of the mean monthly flow (34).

The San Francisco River below Clifton **(Figure 10)** had a period of record encompassing years 1914-2000 (34). Mean annual total for the period of record is 161,400 acre-feet. Median flow for this site over the period of record is 75 cfs. The upper decile (10% exceeds flows) is 442 cfs, while the lowest decile (90% exceeds flows) is 35 cfs. For Water Year 2000, annual total discharge was 40,650 acre-feet (25.2% of average). Median flow in WY 2000 was 59 cfs (78.7% of historic median). The “10% exceeds” flow value for WY 2000 was 79 cfs (17.9% of historic value), and the “90% exceeds” flow value was 23 cfs (65.7% of historic flow value). Monthly summary means for the San Francisco at Clifton in WY 2000 ranged from 14.4% to 58.4% of historic monthly means, with an average of 29.2% (34).

The Gila River near Clifton **(Figure 11)** had a total average annual flow of 147,600 acre-feet for the historic period of record covering years 1911-2000 (34). The median flow for the period of record is 77 cfs. The upper decile (10% exceeds flows) for the period of record is 434 cfs, while the lowest decile (90% exceeds flows) is 18 cfs. For water year 2000, total annual flow for the Gila at this site was 42,990 acre-feet, approximately 29% of average. Median flow for WY2000 was 51 cfs (66.2% of median value). The upper decile of flows for WY 2000 was 100 cfs (23% of corresponding historic value), while the lower decile discharge value was 25 cfs (139% of corresponding historic value). Monthly summary statistics of the Gila near Clifton for WY2000 when compared to the monthly statistics for the period of record show a range from 14.1 % to 116.8 % of the mean monthly flows for the period of record. The average monthly flow for WY2000 was 38.5% of the mean monthly flow (34).

The Gila River at the head of the Safford Valley near Solomon **(Figure 12)** has a period of record encompassing years 1921-2000 (34). Mean annual total for the period of record is 338,500 acre-feet, reflecting the added flows of Eagle and Bonita Creeks and the San Francisco River. Median flow for this site over the period of record is 178 cfs. The upper decile (10% exceeds flows) threshold is 988 cfs, while the lowest decile (90% exceeds flows) threshold is 64 cfs. For Water Year 2000, annual total discharge was 96,360 acre-feet (28.5% of average). Median flow in WY 2000 was 148 cfs (83.1% of historic median). The “10% exceeds” flow value for WY 2000 was 202 cfs (20.4% of corresponding historic value), and the “90% exceeds” flows was 57 cfs (89% of corresponding historic flow value). Monthly summary means for the San Francisco at Clifton in WY 2000 ranged from 18.1% to 69.4% of historic monthly means, with an average of 34.0% (34).

Figure 7. Gila River near Duncan, March 2000.

Figure 8. Gila River near Duncan, September 2000.

Even well-established major watercourses in Arizona can exhibit intermittent behavior through the course of a water year, as the Gila River near the New Mexico border shows in this pair of photos before and after a Sonoran desert summer.

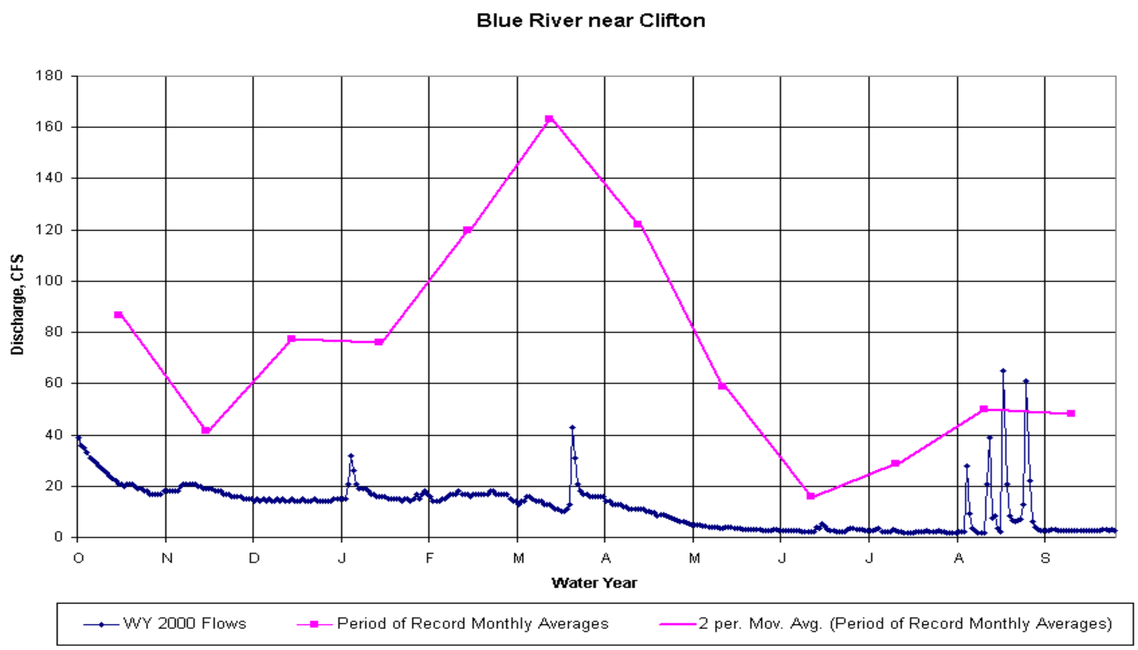


Figure 9. Monthly flow averages versus WY2000 flow for the Blue River near Clifton.

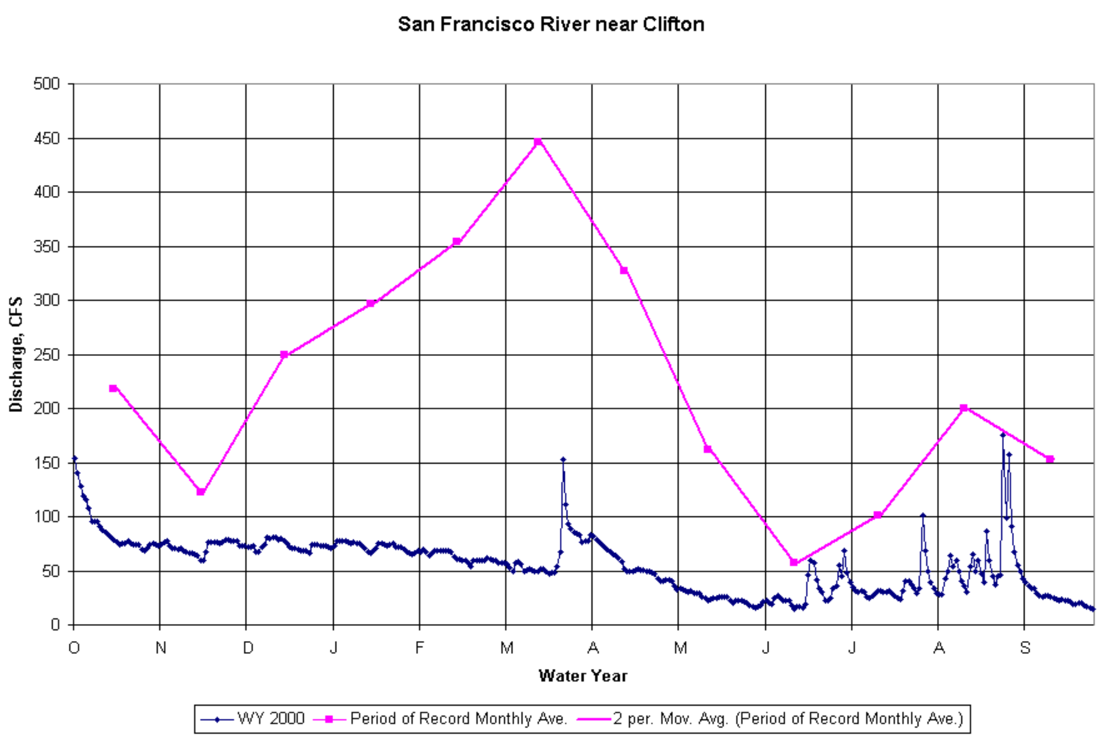


Figure 10. Monthly flow averages versus WY2000 flow for the San Francisco River near Clifton .

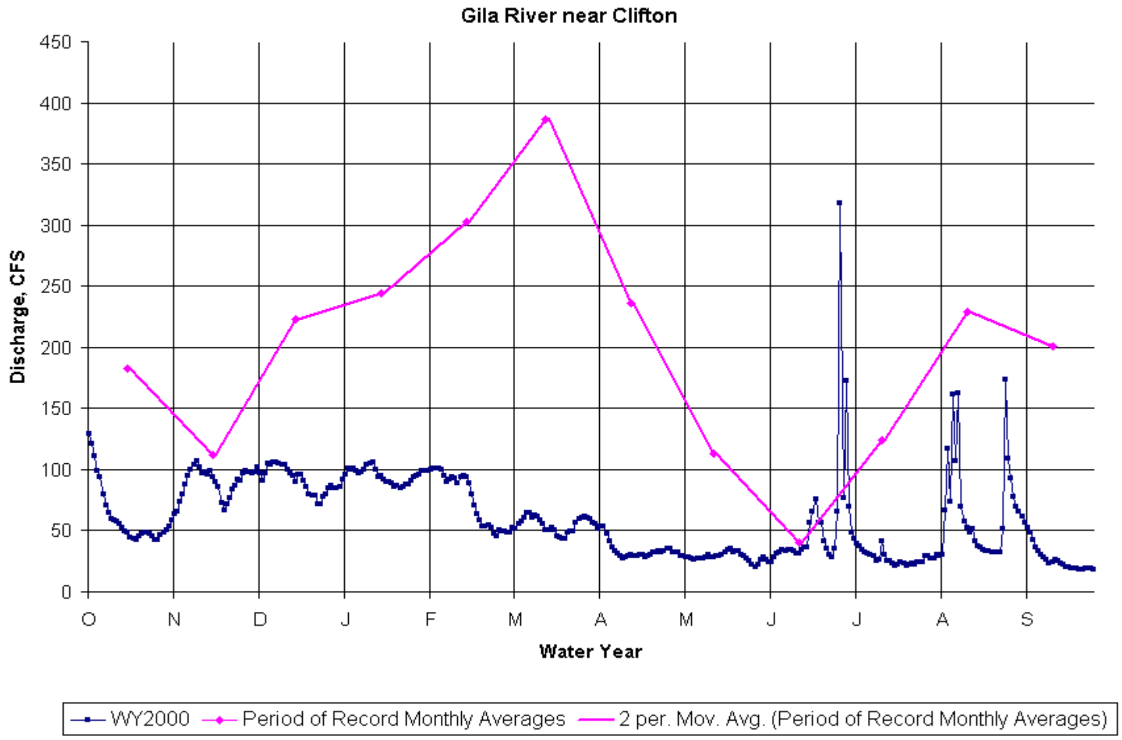


Figure 11. Monthly flow averages vs. WY2000 flow for the Gila River near Clifton.

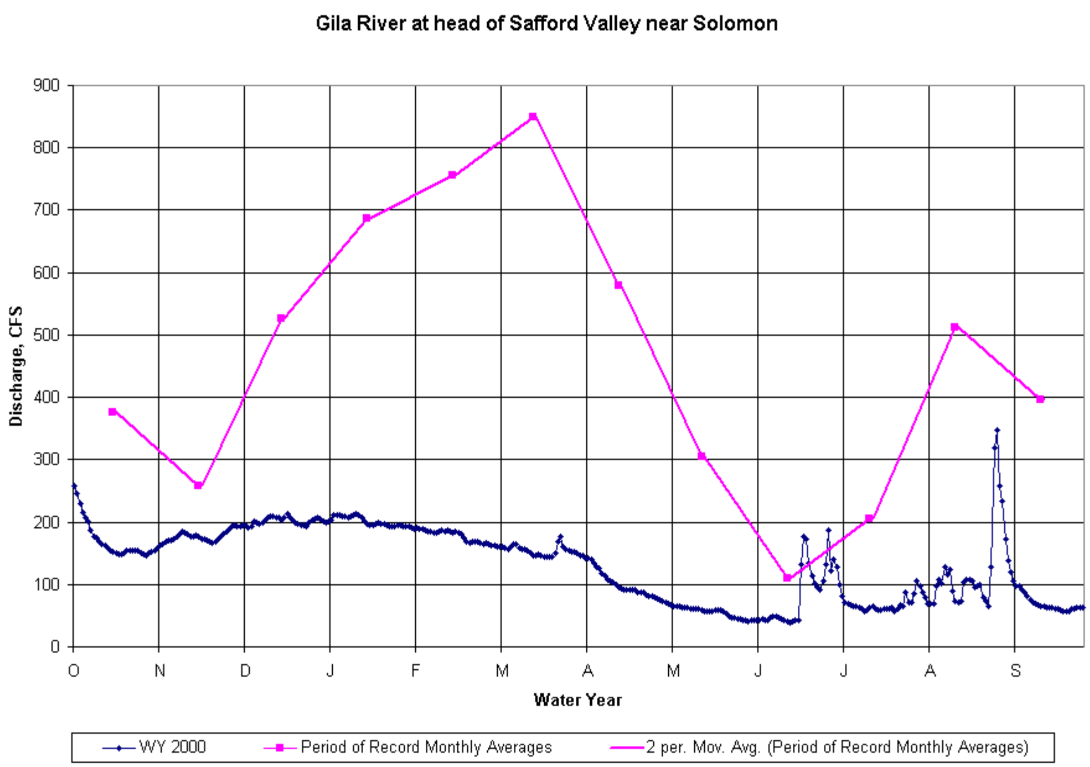


Figure 12. Monthly flow averages vs. WY 2000 flow for the Gila River near Solomon.

4.2 General Water Chemistry

Generally, the surface water in the Upper Gila River Basin may be categorized as fresh, hard, and slightly alkaline (22). Hardness values averaged 163 mg/l across the basin, with only 12 site visits returning a hardness value exceeding 200 mg/l **(Figure 15)**. Total dissolved solids concentrations averaged 257 mg/l, well below the category threshold of 1000 mg/l for a slightly saline characterization. pH values averaged 8.01 for field readings and showed a slight drift to an average of 8.10 for lab-measured values. Four site visits showed slightly acidic readings below 7.00; no field measurements exceeding the state standard of 9.00 for pH were observed.

Water chemistry in the Upper Gila River Basin is illustrated by the accompanying Piper trilinear diagram **(Figure 13)**. Median values from 23 sites visited in the Upper Gila watershed in WY 2000 were plotted on the diagram. Cation axes were developed independently for calcium (Ca), magnesium (Mg), and sodium with potassium (Na+K). Anion axes were developed for three major constituent groupings including sulfate (SO_4), chloride (Cl), and bicarbonate with carbonate (HCO_3+CO_3).

The cation triangle (lower left, **Figure 13**) shows that calcium is the dominant cation (>50%) at 10 sites, while sodium and potassium comprised the dominant cations at two sites. It may safely be assumed that the sodium ion constitutes the major portion of this combination. At nine sites, no predominant cation existed, though of these nine, six tended towards calcium predominance.

The anion triangle (lower right, **Figure 13**) illustrates that bicarbonate coupled with carbonate comprised the dominant anion at 21 of the 23 sites. Sulfate was the major anion at one site, and chloride was the dominant anion at the other site. No sites exhibited a mix in which there was no dominant anion.

The cation-anion diamond shows the projected values from each of the triangle diagrams. Calcium-bicarbonate chemistry predominates at 19 of the sites. Calcium sulfate/chloride chemistry characterized one site. Sodium chloride/sulfate chemistry characterizes two of the sites. One site was intermediate between calcium bicarbonate and sodium bicarbonate chemistry. **Table 1** lists the water chemistry types by site. **Figure 14** illustrates the distribution of water chemistry types across the basin for sites sampled in WY2000.

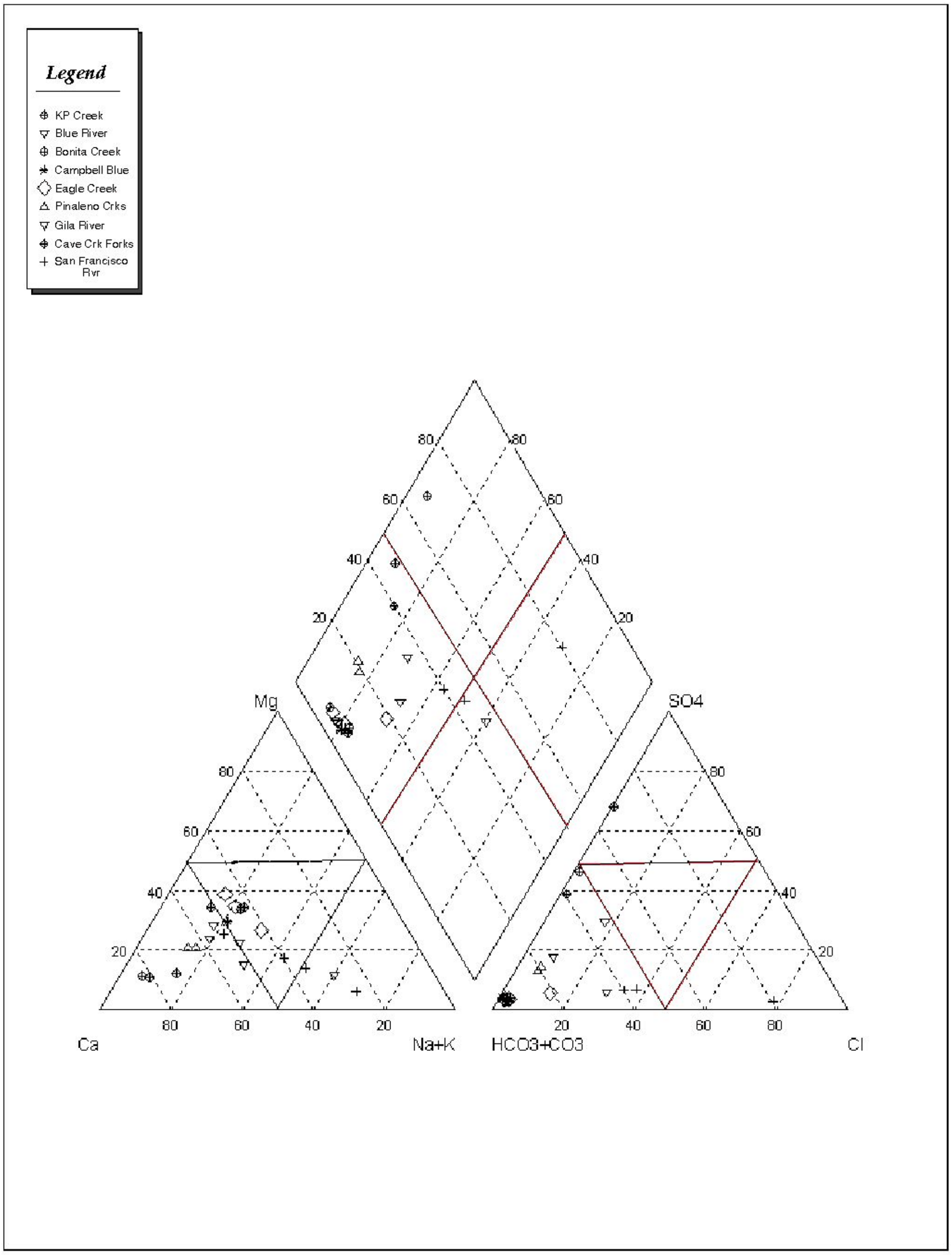


Figure 13. Piper trilinear diagram of water chemistry for the Upper Gila watershed, WY 2000.

Table 1. Water chemistry types for Upper Gila sampling sites.

Site	Site ID	Water Chemistry Type
Ash Creek at FSR #307	UGA1H008.62	Calcium Mixed-Bicarb
Blue River at Juan Miller Road Crossing	UGBLR005.68	Calcium Mixed-Bicarb Mixed
Blue River below Jackson Box	UGBLR033.04	Calcium Mixed-Bicarb
Blue River below KP Creek confluence	UGBLR021.95	Calcium Mixed-Bicarb
Bonita Creek above Gila River	UGBON000.20	Calcium Mixed-Bicarb
Bonita Creek at Reservation Boundary	UGBON011.31	Calcium Mixed-Bicarb
Campbell Blue Creek above K. E. Canyon	UGCMB002.16	Calcium Mixed-Bicarb
Cave Creek below Coronado Ranger Station	UGCAV006.55	Calcium-Bicarb Mixed
Cave Creek below North Fork Confluence	UGCAV007.64	Calcium-Sulfate Mixed
Eagle Creek above Honeymoon Campground	UGEAG035.99	Calcium Mixed-Bicarb
Eagle Creek below Gold Gulch	UGEAG006.05	Calcium Mixed-Bicarb
Eagle Creek above Sheep’s Wash	UGEAG023.34	Calcium Mixed-Bicarb
Fry Creek at FS Trail #36	UGFRY007.00	Calcium Mixed-Bicarb
Gila River at New Mexico Border nr Duncan	UGGLR205.35	Calcium Mixed-Bicarb
Gila River above Old Safford Bridge	UGGLR197.26	Sodium Mixed-Bicarb Mixed
KP Creek above confluence with Blue River	UGKPK000.08	Calcium Mixed-Bicarb
KP Creek below KP Cienega	UGKPK065.54	Calcium-Bicarb
San Francisco River above Clifton	UGSFR011.29	Sodium Mixed-Bicarb Mixed
San Francisco River below Clifton	UGSFR003.04	Sodium Mixed-Chloride
San Francisco River above Luna Lake	UGSFR059.98	Calcium Mixed-Bicarb
San Francisco River near Martinez Ranch	UGSFR017.66	Sodium Mixed-Bicarb Mixed
South Fork Cave Creek above South Fork Campground	UGSCV002.26	Calcium-Bicarb Mixed

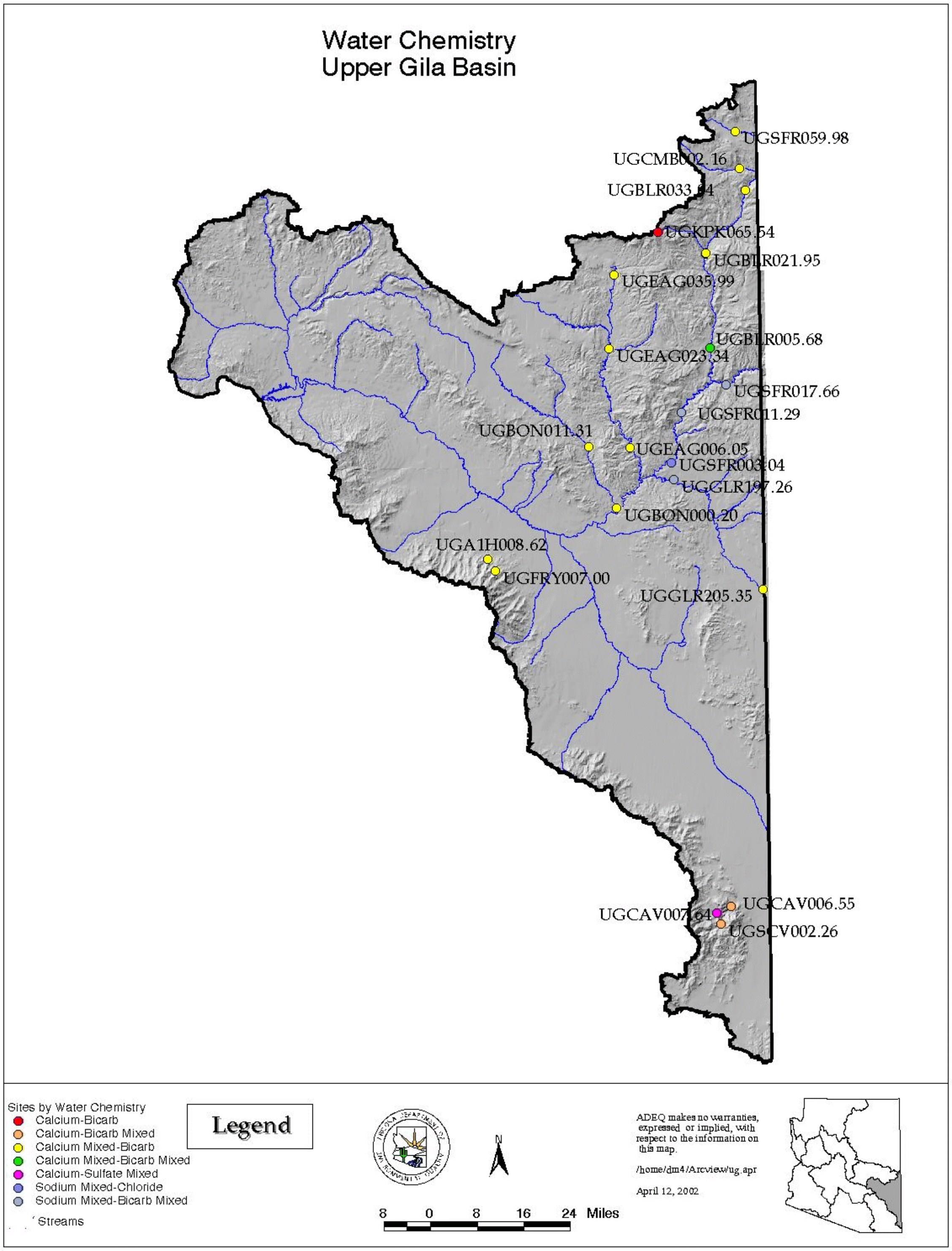


Figure 14. Water Chemistry Types, Upper Gila Basin sampling sites.

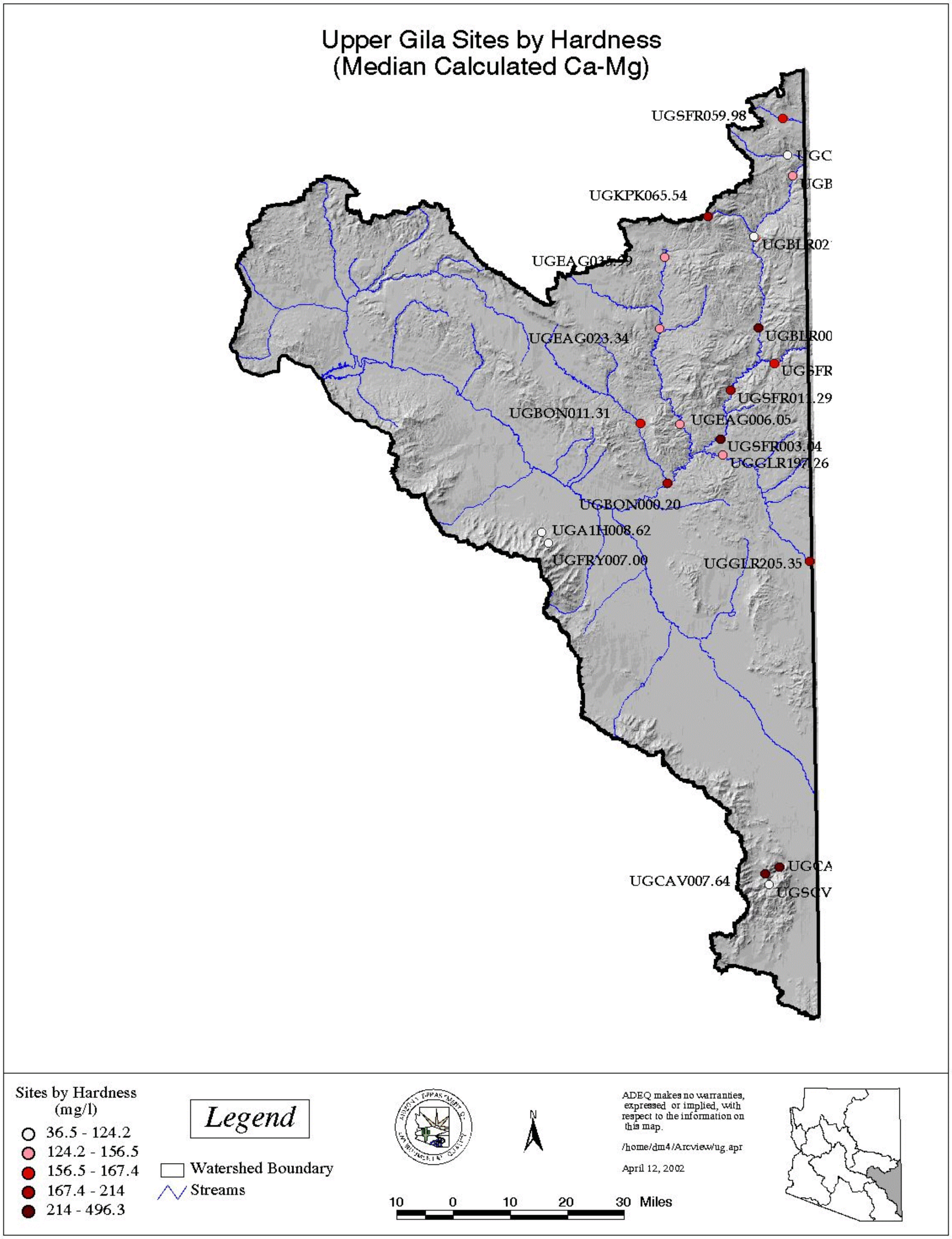


Figure 15. Median Water Hardness by site, Upper Gila basin WY 2000.

4.3 General Water Quality of the Main Stem Gila River

Two sites were contracted from ADEQ to USGS for the characterization of water quality on the Gila River. These sites were the Gila River at Calva, Arizona (USGS ID 09466500, ADEQ Site ID UGGLR166.03) and the Gila River at the head of the Safford Valley near Solomon, Arizona (USGS ID 09448500, ADEQ Site ID UGGLR188.98). Sites were sampled on a quarterly basis for a range of constituents that were more extensive than ADEQ’s normal suite.

The Calva site is located in Graham county at latitude 33E 11' 08" longitude 110E 13' 10". The site is on the San Carlos Indian Reservation and has a watershed area of 11, 470 square miles. USGS has been monitoring this site since 1929 (34). The Solomon site is located 8 miles northeast of Solomon and 17 miles downstream from the San Francisco River. It is in Graham county as well, with a location of latitude 32E 52' 06" and longitude 109E 30' 38". The Solomon site has a drainage area of 7896 square miles. The period of record is continuous from 1914 (34).

The water in the main-stem of the Gila River may be characterized as fresh (median TDS 693.5 mg/l), very hard (calculated median value 396 mg/l), and slightly alkaline (median pH 8.15) (23). **Table 2** compares median values for primary cations, anions, TDS, and hardness values for the two sites. A clear difference exists between Calva (the downstream site) and Solomon for most of the major ions, total dissolved solids, and hardness values. In most cases, these differences show an increase for the downstream data values when compared to the upstream values.

Water chemistry analysis shows a Ca-Na-Cl-HCO_3 water type (classified as calcium mixed - chloride mixed for the purposes of this report) for the Solomon site and a Na-Cl-HCO_3 water type (sodium - chloride mixed) for the Calva site. The Solomon site reflects the inflow from the San Francisco River, which is a sodium-chloride water type at its mouth, mixing with the Gila water chemistry (sodium mixed - bicarbonate mixed) prevailing upstream of the San Francisco River. The Calva site reflects the increasing impacts of agricultural-return flows throughout the Gila River valley, which typically show higher total dissolved solids and higher values of salts in solution.

Both median hardness and total dissolved solids values were elevated over the values from the rest of the basin, as would be expected for a river of a higher Strahler classification receiving and concentrating the solute loads of tributary waters and one that also serves as the watercourse for irrigation-return flows. PH values were not appreciably different from pH values elsewhere in the basin.

4.3.1 Chemical Differences Between Solomon and Calva

The non-parametric Mann-Whitney Rank Sum statistical test was run on all analytes for the Calva and Solomon sites to determine whether any significant statistical differences existed between upstream and downstream sites on the Gila. USGS data was split into two groups dependent upon site and tested by analyte.

Results show that total and dissolved boron were significantly different at the 95% confidence level between the upstream Solomon site and the downstream Calva site. Stream stage, dissolved bicarbonate, total ammonia, and nitrate + nitrite all showed significant differences at the 90% confidence level. No

Table 2. Comparison of Median Values of Major Ionic Species and Selected Other Parameters for USGS Calva and Solomon Sites.

Analyte	Gila River near Solomon (Median values in mg/l)	Gila River at Calva (Median values in mg/l)
Hardness	358	390
TDS	580	1590
Ca	117.75	105
Mg	15.5	31
K	6.3	7.75
Na	115	440
HCO_3	163	349.5
CO_3	**ND**	**ND**
Cl	160	560
F	**ND**	**ND**
SO_4	66	250
NO_3	**ND**	**ND**

ND denotes "Not Detected."

other analyte achieved a difference significant at the 90% confidence level. Though a difference between medians of TDS is apparent in **Table 2**, differences in total dissolved solids with a p-value of 0.149 were not strong enough to achieve 90% confidence.

The findings of the analysis for the analytes identified as being significantly different suggest a link to known agricultural land-use practices in the Gila River Valley that are likely responsible for the change of the character of the water. Ammonia and nitrate+nitrite are both suggestive of the use of fertilizers for crops and the potential impacts of one concentrated animal feeding operation in the Gila River Valley. Boron in both total and dissolved forms is indicative of repeated cycles of watering and evaporation as found in irrigation practices. As a fairly common element in various forms of boron salts that are constituents of geologic units, boron may be leached out of the soils in irrigation ditches and trenches, then precipitated as excess irrigation water evaporates. Repeated cycles of this process will increase the level of salts that irrigation waters take into solution. Irrigation water eventually returned to the Gila would subsequently carry the higher loads of boron and various other salts. Boron is a water quality analyte of particular interest to the agricultural community; high boron levels can prove to be toxic for many types of crops and orchards, particularly citrus. (14, 23).

4.4 Selected Physical Parameter Ranges by Stream

Data for selected constituents, including discharge, dissolved oxygen, pH, total dissolved solids, specific conductivity, and field turbidity, were grouped by stream and examined for ranges, outlier events, and the relative rank ordering of median values.

Pearson correlation tests grouped by streams were run for the group of six analytes. In addition, Bonferroni post-hoc tests were run to determine whether results were significant at the 95% confidence level ($p \leq 0.05$). For the majority of stream systems, sufficient data cases were not present to allow for statistically valid results. In the handful of stream systems with enough data to allow for statistically valid results (San Francisco River [14]; Blue River[10]; Bonita Creek [8]; Eagle Creek[12]), the only statistically significant results were expected correlations between field conductivity and lab total dissolved solids. In none of the comparisons did streamflow correlate with any of the five other variables at a statistically significant level.

4.5 Nutrients

Nutrients are defined by U.S. Geological Survey as elements or compounds essential for animal or plant growth. Common nutrients in fertilizer include nitrogen, phosphorus, and potassium (17). Unfortunately, high concentrations of nutrients in surface waters can create problems, including nuisance algal blooms and excessive aquatic vegetation growth, depletion of dissolved oxygen, and potential human and aquatic life health effects.

The SWMSU monitoring program sampled for ammonia, total phosphorus, nitrate-nitrite, and total Kjeldahl nitrogen (TKN) at the 22 sites in the Upper Gila River Basin. Detection limits for ammonia and phosphorus from the ADHS State Lab analysis were 0.020 mg/l. Detection limits for nitrate-nitrite and TKN were 0.050 mg/l. State surface water quality standards for nutrients are set out in Title 18, Chapter 11, Article 1 of the Arizona Administrative Code. Generally, these water quality standards relate to total phosphorus and total nitrogen and they are site-specific, i.e. they do not apply across the state. Numeric water quality criteria for ammonia to protect aquatic life are pH-dependent and apply at all sites. Generally speaking, the most stringent surface water quality standard to prevent acute ammonia toxicity for the A&Wc use is 0.885 mg N/l (at 9.0 pH). The acute threshold for the A&Ww use is 1.32 mg N/l (also at 9.0 pH). Higher values are permitted by the surface water quality standards at lower pH values.

The sample results from sites sampled in the Upper Gila River Basin in Water Year 2000 indicate that there are no nutrient problems **(Figure 16)**. Only 6 of 71 site visits showed results for ammonia over the minimum reporting level. The mean for all site visits was 0.003 mg/l, and the 95% confidence interval for the range was well below the minimum reporting level (*See* accompanying table). None of the detected values exceeded even the minimum threshold for a water quality standards violation.

Nitrate-nitrite standards apply statewide for domestic water sources at 10,000 micrograms / liter. No samples were reported at levels approaching this value. Of the 71 site visits, only 32 sites reported results above the minimum reporting level. The mean for all values for all sites in the Upper Gila River Basin in WY 2000 was 0.10 mg/l (100 Fg / L) with the 95% confidence interval stretching from 0.05 to 0.14 mg N / L (i.e., 50 to 140 Fg / L).

Phosphorus was detected in 60 of the 71 site visits. The mean of all phosphorus sampling in the basin was

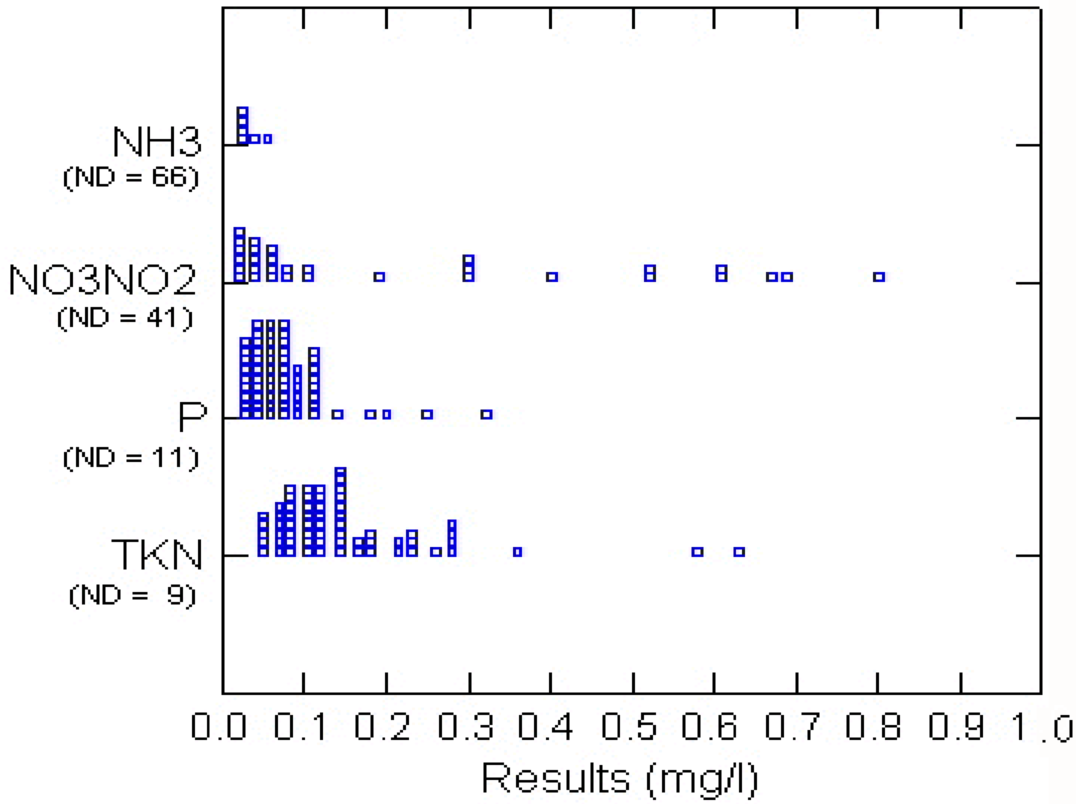


Figure 16. Upper Gila Nutrient Dot Density Diagram.

Displayed is the distribution for ammonia (NH3), nitrate-nitrite (NO_3+NO_2), phosphorus (P), and total Kjeldahl nitrogen (TKN). Number of non-detects are indicated by 'ND' in the axis label.

0.067 mg P/l with a 95% confidence interval from 0.054 to 0.080 mg P/l.

Total Kjeldahl nitrogen showed a mean of 0.13 mg N/l with a 95% confidence interval of the range from 0.11 to 0.16 mg N/l.

4.6 Water Quality Standards Violations

Overview

In general, the water quality in the Upper Gila Basin is good. For the 22 sites in the basin with a total of 75 site visits through the water year, and a general collection of 65 analytes per visit, there were a total of 19 acute exceedances of surface water quality standards in Water Year 2000 **(Figure 17)**. Of these 19 exceedances, seven were for turbidity and 11 were for dissolved oxygen. The single water quality standard acute exceedance for a metal occurred in the fourth quarter of the water year at the San Francisco River below Clifton. Total beryllium in this case was measured at 12.5 ug/l, which exceeds the full body contact recreation standard of 4 ug/l for and the fish consumption standard of 0.21 ug/l..

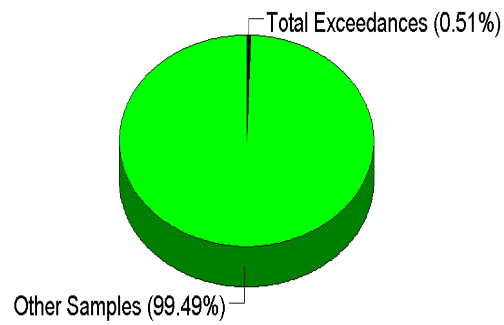


Figure 17. Exceedances as a percentage of total samples

Total mercury, arsenic, cadmium, lead, thallium, nickel, silver, zinc, and antimony were not detected at any site in Water Year 2000. Total iron was detected on 17 site visits; boron followed with seven results reported above the minimum reporting level [MRL], and manganese showed four measureable results. Other total metals detected included selenium (2), copper (2), barium (2), chromium (1), and beryllium (1) **(Figure 19)**.

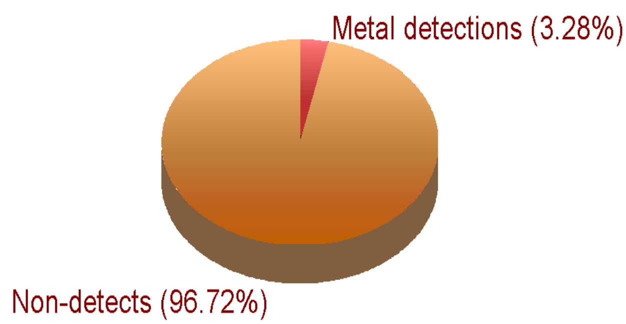


Figure 18. Metal Detections as percentage of all metals sampled, Upper Gila WY 2000

Dissolved metals were less likely to be detected than total metals at sample sites in the Upper Gila basin. In Water Year 2000, dissolved mercury, arsenic, beryllium, cadmium, lead, thallium, nickel, silver, zinc, and antimony were not detected at any sample site. Dissolved selenium was detected on two occasions; dissolved barium returned two measurable results, and dissolved copper was detected once.

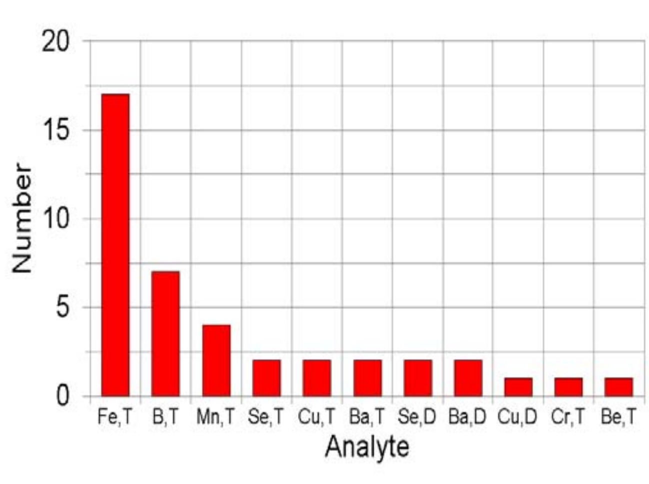


Figure 19. Number of Metal Detections by Analyte

Overall, for 1251 metal analyte results reported for the water year, 41 measurable results were reported. The remaining 1210 results were below laboratory detection limits. 41 detections out of 1251 results yields a detection rate of 3.28%, indicating water of exceptional chemical quality **(Figure 18)**. The single water quality standards exceedance for a metal out of 1251 sample results represents an exceedance rate of 0.08% **(Figure 20)**. For more information on state water quality standards and exceedances in the Upper Gila, please refer to The Status of Water Quality in Arizona: Clean Water Act Section 305(b) Report 2002.

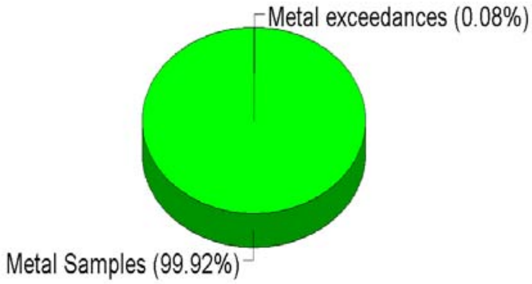


Figure 20.Metals Exceedances as Percentage of All Metals Sampled, Upper Gila WY 2000

Statistical Results

Several notes about statistics presented in this report related to standards exceedances: 1) the exceedance statistics for WY2000 relate only to *acute* water quality standards; 2) the statistics are based on laboratory detection levels achievable by the state laboratory; these detection levels were not always sufficiently low to allow direct comparison of a result to the water quality standards; and 3) these statistics are based only on results for WY2002 and do not supplant assessment findings in the 2002 Arizona 305(b) report (8).

Several of the analytes have chronic water quality standards that are below the laboratory detection limits and isolated analytes (dissolved copper and dissolved cadmium) have acute standards less than the laboratory detection limit in effect at the time of sampling. For some analytes, there are specific conditions where the standards are particularly low and make comparison difficult or impossible. For example, the acute water quality standards for dissolved copper and dissolved cadmium standards are extremely low at very low hardness values (below 73 mg/l and 26 mg/l respectively). However, few locations throughout the watershed support these very low hardness values, making the chance of exceedance relatively low.

The same is true for the chronic water quality standards. For a handful of analytes at limited hardness values, the chronic standards are extremely low. For example, dissolved cadmium and zinc chronic exceedances would be logged at very low hardness levels (33 and 37 mg/l, respectively) and, as noted above, few locations within the watershed have these very low hardness levels. The possibility of dissolved copper and lead exceedances are somewhat more likely, given hardness thresholds of 114 and 189 mg/l, respectively.

Mercury is a special case of a metal that is not hardness dependent but does have very stringent surface water quality standards due to its toxicity to humans, aquatic species and wildlife. The laboratory detection limit for mercury is 0.5 µg/l, while the chronic water quality standard for aquatic and wildlife uses is 0.01 µg/l. Clean sampling techniques have recently been adopted by SWMSU to address this issue.One objective of this report entailed employing a distance-trend analysis to determine if multiple sites on the same river in Water Year 2000 had detectable trends of increasing or decreasing constituents, particularly metals, throughout their runs. The overall water quality in the Upper Gila, with so few detectable results in the watershed, did not permit a meaningful application of this test.

Appendices C1, C2, and C3 summarize results in the basin for inorganic constituents, total metals, nutrients, and dissolved metals.

5.0 ANALYSES

5.1 Parameter Level Covariation

Analyte concentrations were compared with one another using the Pearson Correlation Coefficient test. Each analyte was run against all other analytes without stratification or grouping. Results were examined for statistically-significant positive and negative correlations.

Among the expected results:

- Streamflow was significantly ($p \leq 0.05$) and positively correlated with stream width, depth, and flow velocity.
- Lab and field pH, turbidity, and conductivity were significantly and positively correlated amongst their respective pairs.
- Total suspended solids (TSS) was positively correlated with both field and lab turbidity.
- Field and lab measurements of total dissolved solids and conductivity were positively and significantly correlated with levels of calcium, magnesium, potassium, sodium, bicarbonate, fluoride, and chloride.
- Total hardness was correlated with levels of calcium, magnesium, potassium, sodium, bicarbonate, and chloride.
- Total alkalinity was correlated with calcium, magnesium, bicarbonate, and carbonate.
- Dissolved oxygen concentration and percentage saturation were correlated.

Negative correlations were revealed as follows:

- Stream depth was negatively correlated with sulfate levels.
- Phosphorus was negatively correlated with calcium, sulfate, and total hardness.
- Magnesium was negatively correlated with *Escherichia Coli* levels and nitrate-nitrite levels.
- Other than magnesium, *Escherichia Coli* was negatively correlated with bicarbonate and total alkalinity levels.
- Water temperature was negatively correlated with dissolved oxygen.

All of these correlations were significant at the 95 percent confidence level ($p \leq 0.05$).

Some surprising and remarkable associations were found:

- Sodium, potassium, chloride, fluoride, and nitrate-nitrite were positively correlated with streamflow; other major ions did not show this association. Sodium and potassium were also strongly correlated to one another.
- Among the nutrients, ammonia, nitrate-nitrite, phosphorus, and Kjeldahl nitrogen all showed positive and significant correlations with flow velocity, but only Kjeldahl nitrogen and nitrate-nitrite were correlated with streamflow. All nutrients were positively and significantly correlated with field and lab turbidity as well as TSS.
- Fecal coliform and *Escherichia Coli* showed strong positive correlations with flow velocity, but as with nutrients, did not show correlation with streamflow. These two analytes also showed the same pattern as the nutrients in correlating to field and lab turbidity and total suspended solids.
- Magnesium, bicarbonate, and carbonate were the only major ions to show a correlation with lab and field pH.

The correlation of nutrients and bacteria with flow velocity and to a lesser degree streamflow suggests an entraining effect of flow on sinks of nutrient deposits that may be immersed in sediment beds. These results were surprising and led to a rerun of the Pearson Correlation test examining only these parameters. Results were confirmed in large part, but the rerun did discover that ammonia did not confirm its inclusion in the group from the larger Pearson run.

5.2 Statistical Analysis of Turbidity and Total Suspended Solids Data

An ongoing problem in all Arizona watersheds is excessive sedimentation. The Fixed Station Network program monitors for this problem in part by measuring indicator parameters such as total suspended solids and turbidity. Results from WY2000 in the Upper Gila indicate a total of seven exceedances for turbidity **(Figure 26)**. Data from Water Year 2000 for the Upper Gila River Basin was classified according to the State Soil Geographic (STATSGO) Database *(USDA National Resources Conservation Service)* attributes soil hydrologic group and soil erodibility factor (also called *K* factor), then subsequently statistically analyzed by non-parametric methods.

5.2.1 Soil Hydrologic Groups

Soil hydrologic groups represent differing classes of runoff potential. Group A soils have a low runoff potential; B soils have moderate infiltration potential, with moderately deep and moderately well-drained soils. Group C soils possess slow infiltration properties, usually including a layer that impedes water movement. Group D soils have a high runoff potential with much rock, clay, or high water tables.

Data from the STATSGO database for soil hydrologic group were attributed to a component (sub unit) of the map unit with no spatial boundaries given for the limitations and location of the component within the larger map unit. Soil hydrologic group class could and often did vary within the map unit as the component varied, necessitating the aggregation and weighting of the group by the relative percentage of the map unit occupied by the component. Letter values were converted to numeric values (A=1; B=2; C=3; D=4), multiplied by the percentage of component spatial extent in the map unit, then summed for the larger map unit. The summed values were then rounded to the nearest ordinal value and reconverted to the letter scheme. These weighted hydrologic group classifications were then applied to the sites that resided within the host map unit.

Figure 22 displays the graphic results of this data processing.

Figure 21. Bonita Creek downcutting near Gila confluence. Downcutting, is one geomorphic indicator of possible land-use problems and can be reflected in turbidity and total suspended solids data from a water quality sampling location. It can also occur as a result of flood events.

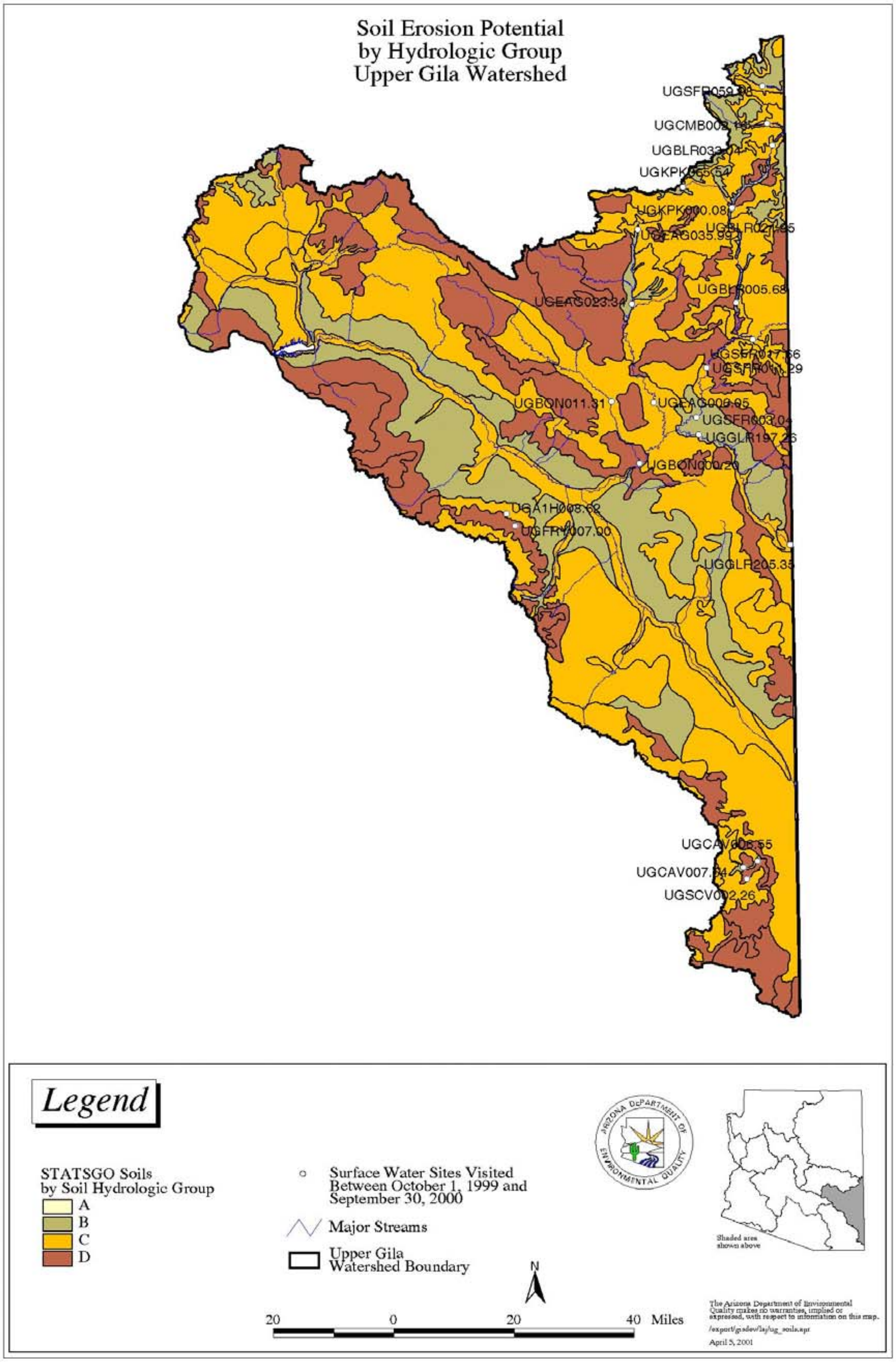


Figure 22. State Soils Geographic Database Soils by Hydrologic Group

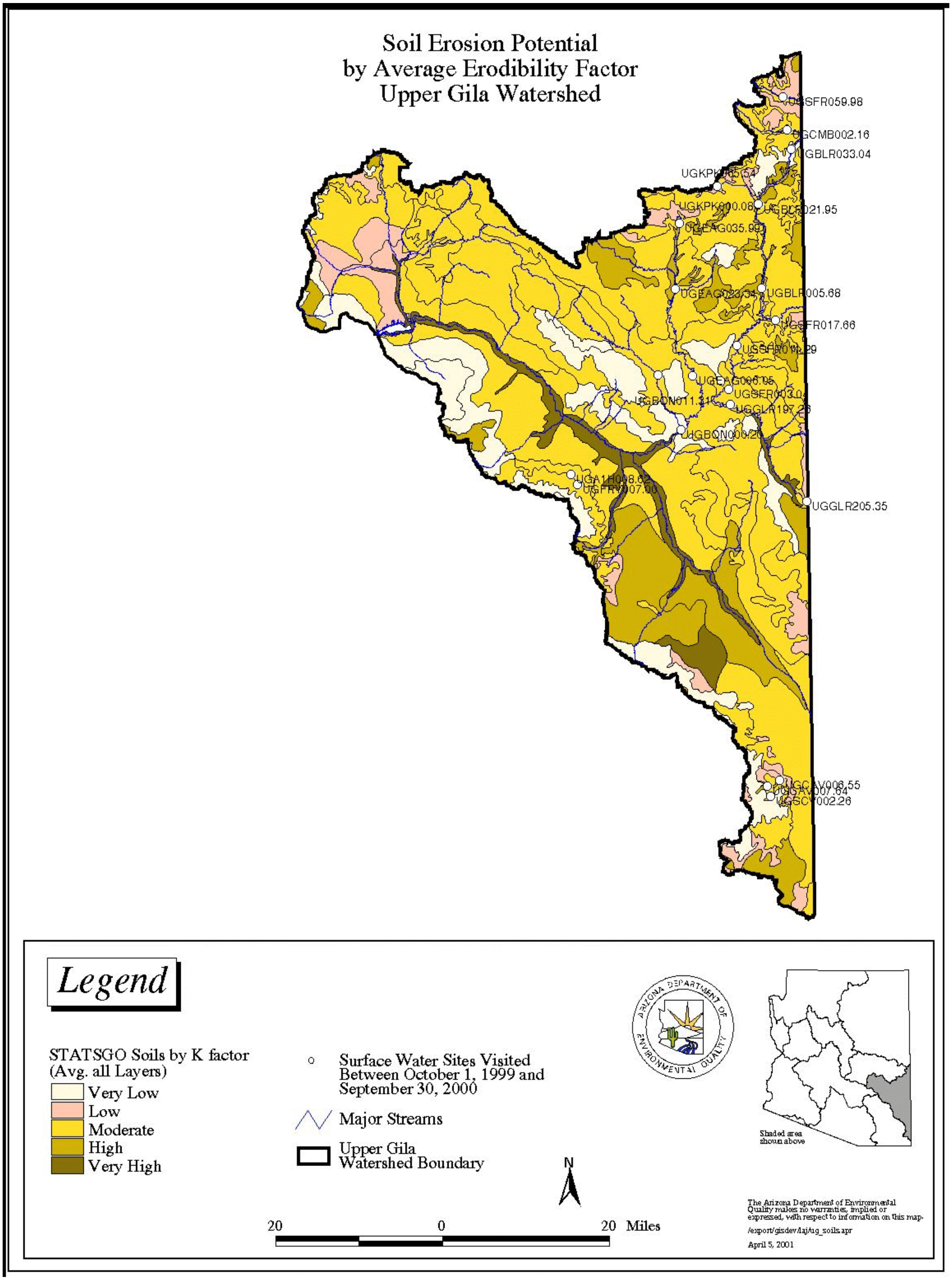


Figure 23. State Soil Geographic Database Soils by K (Soil Erodibility) Factor.

Figure 24. Stream turbidity and the role of soils.
Soils and the geologic composition of source origin play a substantial role in determining the chemical makeup of Arizona's surface waters to problems like total suspended sediments, turbidity, and bank erosion potential. At times, such problems are evident simply from an observation of the sample site, as this photo demonstrates at KP Creek.

Total Suspended Solids (TSS) and field and laboratory turbidity data from 22 sites and 90 separate sampling events were grouped according to the aggregated soil hydrologic group at the site, then analyzed for statistically-significant ($p \leq 0.05$) differences in total suspended solids and field turbidity using the Kruskal-Wallis test with the Tukey option. With all constituents, no statistically significant difference between the soil hydrologic groups was found, indicating most broadly that soil hydrologic group as a classification variable did not accurately predict the levels of measured turbidity and total suspended solids at the sites. A more conservative conclusion would be that the aggregation and weighting scheme is an ineffective and insensitive application of soil hydrologic group classification to the soils predominating at the site and as such, does not predict TSS or turbidity levels.

5.2.2 Average Soil Erodibility Factor

Another measure of soil erodibility is *K factor*, also called a soil erodibility factor, which quantifies the susceptibility of soil detachment by water. These erodibility factors predict the long-term average soil loss which results from sheet and rill erosion (33). They are empirically derived and separated into 14 classes ranging from 0.02 to 0.69. STATSGO attributes for K factor by layer were processed in two ways and statistically analyzed by each.

The first method consists of multiplying the k factor by the thickness of the layer as a weighting measure, summing the weighted layers and dividing by the total thickness of layers in a sequence for an average

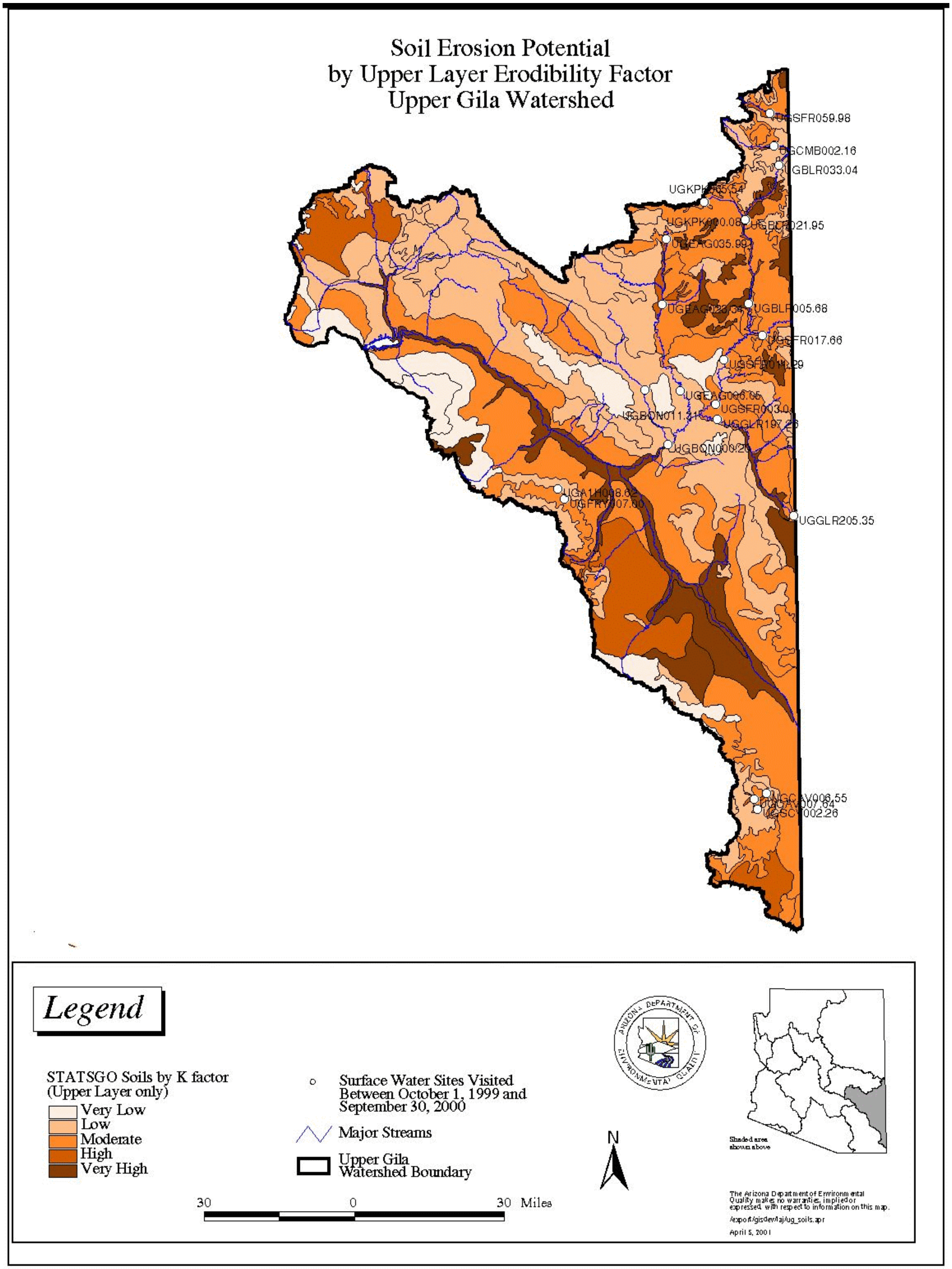


Figure 25. State Soils Geographic Database by Upper Layer K (Soil Erodibility) Factor.

weighted K-factor for a map component; multiplying the weighted k-factor by the percentage of area covered by the component in the map unit; and summing the weighted percentages for an aggregate K-factor for the map unit. Results were mapped in ArcView **(Figure 23)** and classified by natural breaks into 5 groups, and the group classification (Very Low, Low, Moderate, High, Very High) served as the grouping classification for a Kruskal-Wallis test with the Bonferroni post-hoc test option. Significant relationships ($p \leq 0.05$) were found with the Kruskal Wallis test for both lab turbidity (p=0.017) and field turbidity (p=0.048) when run against the average K factor for all soil layers.

When the Bonferonni post-hoc test was run on these data, the significant results found by the Kruskal-Wallis test did not hold up. No significant differences between groups (classifications within the Upper Gila included High, Moderate, Low, and Very Low) were found using this more stringent test with the average K factor as the variable tested against.

5.2.3 Upper Layer Soil Erodibility Factor

The second method consisted of examining only the upper layer (layer 1) of the soil component. Layer 1 K-factors were extracted, joined to map components, multiplied by their percentage of coverage within the map unit; and summed across the map unit. Results were mapped in ArcView **(Figure 25)** and again classified by the natural breaks in the data into the categories as previously listed. These grouping classifications were then run across turbidity and TSS data to check for associations. Statistical significance was found with the Kruskal Wallis test for TSS (p=0.004), Field turbidity (p=0.019) and lab turbidity (p=0.004).

Bonferroni post-hoc testing of the differences between groupings (High, Medium, and Low were represented in the Upper Gila Basin) found associations that were weaker than the Kruskal Wallis test indicated. Using the more stringent Bonferroni measures, TSS was found to have a significant difference at the 90% confidence level between the High and Moderate groups. A significant difference at the 90% confidence level was also found between the Moderate and Low groups for this test. Data were insufficiently strong to show any significance between High and Low groupings. Probability for the test on the whole was significant at the 95% confidence level (p=0.048).

Weaker results characterized the field and lab turbidity values tested against the top layer K factor, though both were significant at a lower 90% confidence level. Field turbidity showed an overall p value = 0.076. Difference between group testing revealed a significant difference between High and Moderate groups at the 90% confidence level (p=0.087) for field turbidity. Lab turbidity was also significant at the 90% confidence interval (p=0.062), with a significant difference shown between High and Moderate groups at the 90% confidence interval (p=0.081).

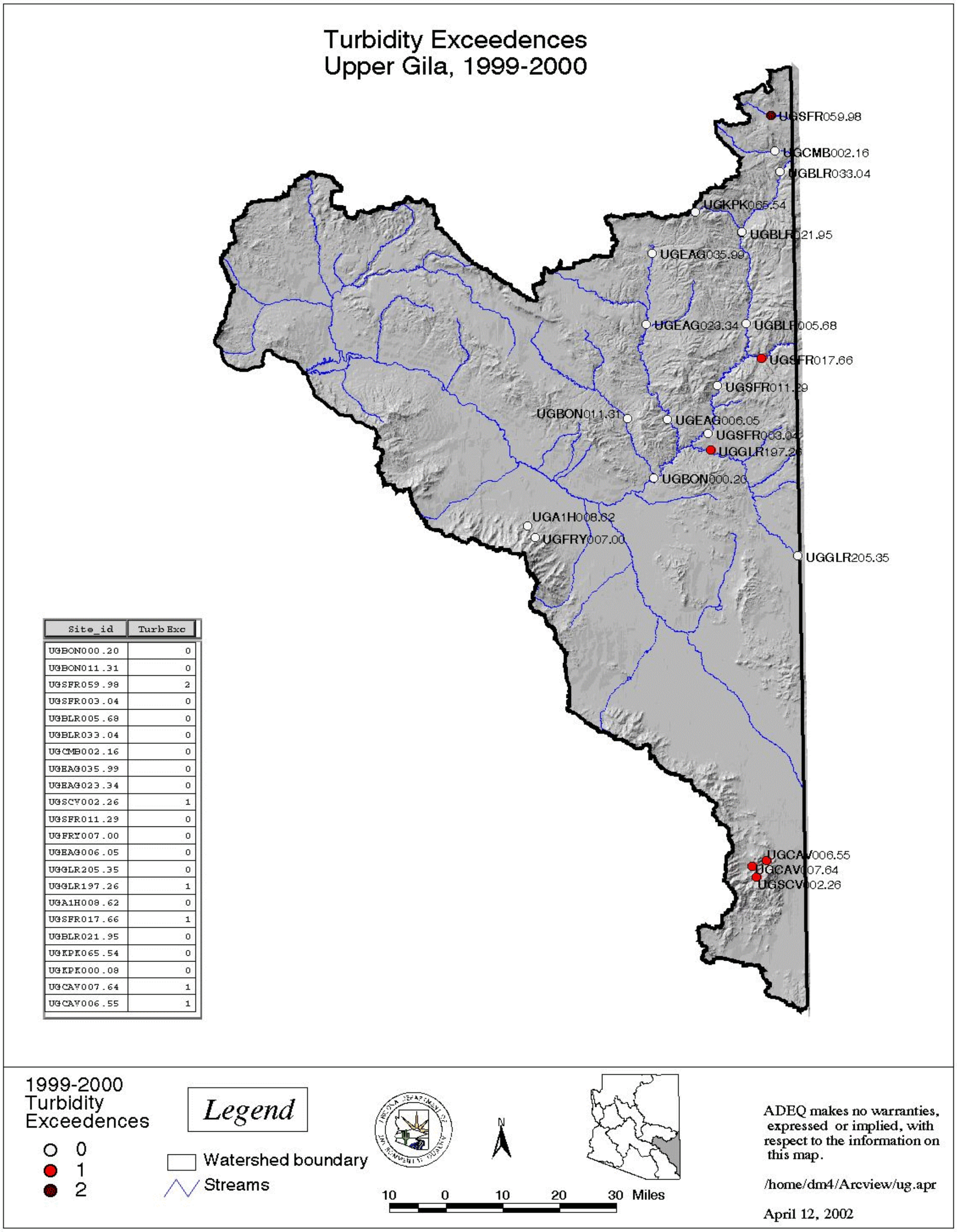
See **Appendix D** for a summary of the larger Kruskal Wallis testing and the Bonferroni testing between groups for both upper layer and average erodibilities of all layers.

5.2.4 Conclusions

These methods were employed on a trial basis to determine if relationships between turbidity or TSS problems and soil hydrologic group or soil erodibility factors could be established. All three analytes were insensitive to soil hydrologic group. Overall, as might be intuitively suspected, the upper layer's soil erodibility was a better indicator of water quality problems than the average soil erodibility of all layers. All three problem analytes showed an association with soil erodibility factor, with Total Suspended Solids and Lab Turbidity showing the strongest relationship in non-parametric testing. Both showed a 99% confidence level. Subsequent testing among groups using the parametric Bonferronni post-hoc test, showed that associations were not as strong as the Kruskal-Wallis results indicated. Significant differences, though weak (90% confidence level, or $p \leq 0.1$), were present, generally between high and moderate classes. Total

Suspended Solids yielded the highest joint probability of significance, with confidence lower when analyzed between groups or classes.

Further testing of these measures will be necessary in additional watersheds before a conclusive statement about their utility can definitively be made. It is possible that these measures in concert with as-yet undetermined factors may lead to a stronger predictive relationship.



Site_id	Turb Exc
UGBON000.20	0
UGBON011.31	0
UGSFR059.98	2
UGSFR003.04	0
UGBLR005.68	0
UGBLR033.04	0
UGCMB002.16	0
UGEAG035.99	0
UGEAG023.34	0
UGSCV002.26	1
UGSFR011.29	0
UGFRY007.00	0
UGEAG006.05	0
UGGLR205.35	0
UGGLR197.26	1
UGA1H008.62	0
UGSFR017.66	1
UGBLR021.95	0
UGKPK065.54	0
UGKPK000.08	0
UGCAV007.64	1
UGCAV006.55	1

Figure 26. Upper Gila turbidity exceedances, WY 2000

5.3 Statistical Analysis of Geologic Setting and General Water Chemistry

Not all ions that appear in water quality analysis can be attributed to the dissolution of geologic parent material into the surface water matrix. Chemical reactions in soil material, inputs from the atmosphere and biochemical processes all play a role (23). For example, bicarbonate in substantial quantities is derived from carbon dioxide extracted from the air and liberated from soil biochemical reactions (23). Furthermore, surface water chemical equilibria is generally a much more complex system that groundwater chemistry, due to the number of possible inputs (23). Additionally, geologic source material have differing resistance to or affinities for contribution of ions to solution. Igneous rocks like granite and rhyolite are less likely to add ions to natural waters than are limestones and dolomites (23). The picture is further complicated by the distance that water travels in a surface water system and the cumulative effect of all geologic units that the water travels over as it drains the watershed.

Even so, influences of parent material on water chemistry can be expected to reveal themselves in an analysis. It is expected that the geologic setting influences the composition of waters at the water quality sites selected for sampling. Geology also was thought to have possibly influenced physical parameters like turbidity and total suspended solids. To investigate this hypothesis, sites were characterized according to dominate chemical composition and then statistically analyzed by major ion for differences among primary geologic composition.

Major cation and anion data from the Upper Gila Basin for Water Year 2000 were tested for statistical differences between general categories of geologic origin at the site collected. A geologic GIS coverage from the State Lands Department was further augmented by classifying the rock types of the geologic layers as alluvium, metamorphic, sedimentary clastic, sedimentary sandstone, sedimentary undifferentiated, and volcanic. These six categories were not the only ones for the state of Arizona, but they represent the totality of sites in the Upper Gila Basin. The results of testing are presented in **Table 3**. The Kruskal-Wallis statistical test was evaluated assuming five degrees of freedom. The null hypothesis of no significant difference amongst rock types was rejected if the p-value was less than or equal to 0.05.

Significant results were further tested using the Tukey Post-Hoc test to determine which rock types showed the differences for each cation and anion deemed significant. The results of the testing are shown in **Appendix E**. Summarized results include the following:

< Magnesium and bicarbonate were highly sensitive to the geologic class of the site, exhibiting significant differences in concentrations among a number of different rock types (10 and 8 respectively). Sodium (5) and potassium (4) were moderately sensitive to geologic class. Fluoride (2), chloride (2), and nitrate-nitrite (3) were slightly sensitive in exhibiting significant differences. Calcium, sulfate, and carbonate were insensitive to any difference of concentration based on the rock class at the site, all showing no significant differences amongst the geologic classes.

< Of the rock classes, sedimentary clastic rock types were by far the most likely to show contrasting differences with other rock types among the major ions (21), followed respectively by volcanic (11), metamorphic (10), sedimentary undifferentiated (10), sedimentary sandstone (8), and alluvium (8).

< The rock types most consistently contrasting differences among themselves in concentrations of major ions were sedimentary clastic - sedimentary sandstone (5), sedimentary clastic - volcanic (5),

Table 3. **Kruskal-Wallis Test Result for Geologic Significance**

Cation/Anion	# Cases	K-W Test Statistic	Probability	Significance
Ca	73	22.103	0.001	Significant
Mg	73	28.424	0.000	Significant
Na	73	31.744	0.000	Significant
K	73	32.228	0.000	Significant
HCO_3	72	27.712	0.000	Significant
CO_3	72	12.362	0.030	Significant
$NO_3 + NO_2$	72	18.828	0.002	Significant
Cl	72	22.357	0.000	Significant
SO_4	72	16.664	0.005	Significant
F	72	24.444	0.000	Significant

sedimentary clastic - metamorphic (3), sedimentary clastic - alluvium (4), and sedimentary clastic - sedimentary undifferentiated (3). No other permutation of rock classes exhibited more than two significant differences.

Results explicitly bear out one of the hypotheses in that the sedimentary clastic rock types, including limestones and dolomites, are more prone to contribute ions to natural surface waters in the Upper Gila Basin. Magnesium, the most sensitive analyte to rock class, is a component of dolomite ($CaMg(CO_3)$**),** and tends to precipitate into solution much more readily than it can be precipitated out of solution., unlike its frequent companion calcium. Consequently, in a cumulative flow path, the ratio of calcium to magnesium will approach 1.0 over distance and number of chemical processes entered (23) after beginning heavily in favor of calcium.

Bicarbonate, as one product of the carbonate species dissolution from geologic units, also plays a role as a middle station in equilibria processes between carbon dioxide and carbonate. Thus, while the mere presence of bicarbonate in Upper Gila natural waters cannot strictly be attributed to contribution from geologic units, this analysis showed that bicarbonate concentrations did vary in a statistically significant way among the rock classes tested. Carbonate, however, was insensitive to rock geologic class.

5.4 Statistical Analysis of Land Use and Water Quality Data

Assignment of land uses to various sites was hampered by the lack of definitive criteria, the mix of uses, particularly on federal Forest lands, and the non-existence of adequate GIS coverages that would aid in making the determinations. Ultimately, uses were assigned to each of the sampling sites based on activities apparent at and upstream of the site. A large dose of common sense and collaborative discussion and agreement among ADEQ Surface Water Monitoring personnel were employed along with several rules of thumb:

- One use was assigned per site. An attempt was made to characterize the site based on the apparent predominant activities occurring in the immediate area.

- Consideration was always given to the directionality of stream flow along the water course when assigning uses. Thus, an activity that was occurring nearby in the area would not dictate the assignment of a particular use if the activity was occurring downstream of the sampling site. A classic example of this applied to the San Francisco River site above Clifton; though tailings piles from the Phelps-Dodge Mine were filling the upper reaches of the ephemeral drainages tributary to the San Francisco, these drainages were downstream of the selected sampling site and thus did not warrant consideration for the assignment of the use for the site. They did, however, become the predominant use for the site on the San Francisco River below Clifton, even though this site was several miles further away.

- Greater weight was given to activities occurring upstream of a site rather than at the site; impacts could be expected to take some distance to become fully cumulative and well-mixed in the stream channel.

Use classes include the following:

- Sites located within a few miles downstream of major active mining operations were assigned a *Mining* use. Inactive mines and small-scale mining claims, which pepper the state, were not considered sufficient impacts to require an assignment of the *Mining* use to the sites in the vicinity. For the purposes of this study, two sites (San Francisco River below Clifton; Eagle Creek below Gold Gulch) below the Phelps-Dodge Mine in Morenci were assigned this use.

- *Agricultural* uses were assigned to sites affected by irrigation diversions and agricultural return flows. The sites were restricted to the Gila River Valley bottom at the New Mexico state line near Duncan.

- Sites located within the boundary of National Forests (Coronado or Apache-Sitgreaves) were assigned a *Forest Management* use, which could theoretically encompass a wide range of impacts from nearly undisturbed (wilderness areas would be expected to be completely undisturbed, but none exist in the study area) to moderate-to-heavy impacts by recreation, logging or grazing. The ambiguity of this class is freely acknowledged; land management activities can be mixed in nature and intensity on National Forest lands, and some of these activities (e.g. grazing) are not exclusive to Forest lands, but also appear on rangeland administered by the BLM. It was not possible to more finely distinguish actual grazing occurring in the Apache-Sitgreaves, as the entire Forest has been partitioned into grazing allotments, and all are potentially active, with the exception of those in the Blue Range Primitive Area. Fortunately in these cases, such weaknesses do not appear to affect the results of the subsequent statistical analysis, as *Forest Management* uses were consistently the one class of land uses that stood apart from others with significantly better water quality. Two exceptions were made for sites within National Forest boundaries. The San Francisco River above Luna Lake near Alpine and Eagle Creek above Sheep's Wash were both assigned *Pasture /Range Land* designations based on the lack of canopy cover at the sites and their locations in the lower reaches of extensive meadows or grasslands.

- *Range Land/Pasture* uses were assigned to sites not fitting other classes. Generally *Range Land/Pasture* sites are administered by the BLM, or privately-held. Though this class served as the de-facto default category, implicit criteria accompany this land use:
  1) Lack or paucity of canopy cover, i.e. grasslands, meadows, or open desert. This criterion is not applied to the riparian corridor, where healthy deciduous communities often exist. Rather it is intended to characterize the uplands away from the water courses. Canopy cover would be expected to make a difference in watershed storm responses, grazing utility, and be reflected indirectly in various measurable water quality parameters including temperature, nutrient levels, turbidity, total suspended solids and dissolved oxygen.
  2) Elevations generally below 5000 feet, where state-designated aquatic and wildlife cold water uses (not to be confused with land uses) change to aquatic and wildlife warm water uses. The San Francisco at Luna Lake was an exception to this criteria.
  3) Predominant activity, where it exists, generally limited to grazing as the principal use of the land.
  4) Pronounced erosional problems may be present, due to the sensitivity of the soils where not sufficiently vegetated, the exposure of the watersheds to the full unbuffered effects of storm events and overland sheet flows, the rapid downcutting of streams from rapid fluctuations in discharge ("flashiness" or flash flood susceptibility), or to improper grazing practices.

Figure 27. Forest uses land-use classification.

The land use classification for Forest uses can encompass streams that fall just short of completely undisturbed wilderness. KP Creek, shown in this photo, is a classic example.

Other land uses not applied in this study include *Urban* impacts, *Construction and Development* activities, and *Groundwater Recharge Zones* to name a few. *Rural Property/Rural Community* impacts for small communities found throughout Arizona (including the towns of Alpine, Safford, Clifton, Morenci, and Thatcher in the Upper Gila basin) is a valid land use class for consideration. For sites in proximity to these communities, each was subjected to a judgment as to whether such rural community impacts were the predominant impact on the water quality sampled at the site. In each instance in this study, the determination was made that other land use classes more accurately represented the impacts occurring.

Sites were considered and assigned to one of these four land-use categories (agriculture, mining, forest management/undisturbed, and Range Land/Pasture) according to their spatial distribution and locations. **Appendix A** summarizes the land use category assigned to each.

A Kruskal-Wallis non-parametric test was run on the data using the assigned categories to check for statistically significant differences amongst the land uses for various parameters. Parameters tested included water temperature, field conductivity, dissolved oxygen, percentage saturation,total suspended solids,ammonia, Kjehldahl Nitrogen, Nitrite-nitrate, phosphorus, fecal coliform, Escherichia coli, field turbidity, field and lab total dissolved solids, and field pH. The null hypothesis of no significant differences between land uses categories was rejected if the probability of exceedance was greater than 95% (p-value $\leq$ 0.05). Three degrees of freedom were assumed in the testing.

Table 4 summarizes the findings of the Kruskal-Wallis test. Post hoc tests of the significant results using the Bonferroni adjustment was then performed to determine the significant differences ($p \leq 0.05$) amongst the four land uses. **Appendix F** list the matrices of significance for these comparisons.
In summary of sample results tested for differences among land uses, the following results were observed:

< Field readings of conductivity, pH, turbidity, total dissolved solids, turbidity, dissolved oxygen, and percent saturation, and lab readings of Kjeldahl nitrogen and total dissolved solids all showed similar degrees of difference amongst the land uses, with two significant differences noted for each of these analytes. Total suspended solids were slightly less sensitive to change in land use class, showing only one significant difference between classes.

< Of the land use classes, forest land uses (17) exhibited the most differences with other land use classes. Pasture/range uses exhibited 9 differences, while mining uses exhibited 8 differences. The agriculture use class showed no significant differences with any of the other three land classes; this was due in large measure to the paucity of sites and site visits that could be classified as agriculturally affected, requiring a larger cumulative difference from other classes to register as significantly ($p <= 0.05$) different. It is likely that augmenting the number of site visits to sites in this land-use class would reveal that agricultural uses would exhibit a number of significant differences with forest uses, but probably few to no differences with either the mining use or the range use class among the group of analytes tested.

< The land-use classes most consistently exhibiting differences amongst themselves in this grouping of field analytes and selected nutrients were forest-uses - pasture/range (9), and forest-uses – mining (8). Agriculture - Forest uses (0), Agriculture - Range (0), Agriculture - Mining (0), and Mining- Range (0) comparisons were uniformly non-indicative of differences.

In summary, forested watersheds subject to multiple-use management resulted in better water quality in general than lands devoted to range or pasture grazing, agriculture, or mining. Such a finding suggests a critical role played by the forests in suppressing active erosion, providing protection and cover to the land surface subject to run-off, possible filtration effects for groundwater recharge that eventually surfaces in streams, and the maintenance of a relatively undisturbed area serving as the feeding watershed. Kruskal-Wallis testing showed strong ($p \leq 0.01$) significant differences between land use classes for conductivity, dissolve oxygen and oxygen saturation, total suspended sediments, Kjeldahl nitrogen, field turbidity and pH, and both field and lab total dissolved solids. Bonferroni post-hoc testing at the 95% confidence level revealed that forest management uses exhibited a consistently higher level of water quality for the parameters tested and exhibited the most significant differences with other land use classes.

Table 4. Kruskal-Wallis Statistical Test Results for Land Use Classifications

Analyte	# Cases	KW Test Statistic	Probability	Significance
Field Conductivity	75	23.833	0.000	Significant
Water Temp	75	4.289	0.232	Not Significant
Dissolved Oxygen	75	23.651	0.000	Significant
Percentage O2 Saturation	75	28.104	0.000	Significant
Total Suspended Solids	72	16.672	0.001	Significant
Ammonia	72	2.988	0.394	Not Significant
Kjeldahl Nitrogen	72	19.062	0.000	Significant
Nitrite-Nitrate	72	4.232	0.237	Not Significant
Phosphorus	72	0.118	0.990	Not Significant
Fecal Coliform	60	3.585	0.310	Not Significant
Escherichia coli	60	0.150	0.985	Not Significant
Field Turbidity	77	31.069	0.000	Significant
Field TDS	76	21.864	0.000	Significant
Lab TDS	73	21.042	0.000	Significant
Field pH	75	19.634	0.000	Significant

6.0 BIOASSESSMENTS IN THE UPPER GILA RIVER BASIN

6.1 Introduction

ADEQ is presenting macroinvertebrate based bioassessments to address the condition of the aquatic resource, as part of the Upper Gila River Basin water quality report. Bioassessments provide an empirically based assessment and are a better measure of the condition of the aquatic resource than chemical based standards. ADEQ is in the process of creating biocriteria, but these criteria have not yet been incorporated into the surface water quality standards. As such, these data are provided for informational purposes only.

During water year 2000, ADEQ collected 13 macroinvertebrate samples and habitat data during the spring index period (April to June) from riffle habitats in streams of the Upper Gila River Basin. These data are assessed along with an additional 70 spring samples collected in 1992-99 and 16 fall samples collected in 1996-98 in the Upper Gila. Samples were collected using ADEQ Biocriteria Program standard protocols for macroinvertebrate sample collection (9) and analyzed using empirically derived warm water and cold water indexes of biological integrity to assess biological integrity in perennial, wadeable streams.

Each index of biological integrity was developed with macroinvertebrate data from approximately 100 reference samples collected statewide, various metrics were tested for their ability to detect impaired samples, then the metrics which best discriminated impairment in four structural and functional categories (richness, composition, tolerance, and trophic group) were assigned to the index. Each metric for a study sample is compared to a reference threshold value to calculate a percentage, then the percentages for each metric are averaged for a 0-100 index of biological integrity score, with higher values indicating better conditions. The nine metrics in the warm water index and seven metrics in the cold water index, as well as the scoring categories for each index follow **(Table 5)**. This watershed report exhibits the number and percent of impaired sites during the various study periods, the causes and sources of impairment, and how the macroinvertebrate community has responded to impairment from sediment, the dominant cause in the Upper Gila River Basin streams.

Warm Water Index - metrics	**Cold Water Index - metrics**
Total taxa richness	Total taxa richness
Ephemeroptera taxa richness (mayflies)	Diptera taxa richness
Trichoptera taxa richness (caddisflies)	Intolerant taxa richness
Diptera taxa richness (true flies)	Hilsenhoff Biotic Index
Percent Ephemeroptera	Percent Plecoptera (stoneflies)
Percent dominance by one taxon	Percent Scrapers
Hilsenhoff Biotic Index (tolerance idex)	Scraper taxa richness
Scraper taxa richness (diatom grazers)	
Percent scrapers	

Table 5. Scoring categories for warm water and cold water IBI scores in Arizona.

Waterbody type	Exceptional	Good	Impaired	Very Impaired
Warm water	73 - 100	53 - 72	27 - 52	0 - 26
Cold water	97 - 100	88 - 96	44 - 87	0 - 43

6.2 Results

6.2.1 Spring Bioassessments

All of the warm water macroinvertebrate communities collected during spring 2000 were in good to exceptional condition, with IBI scores ranging from 68-82. In contrast, 66% (n=4/6) of the cold water samples were in impaired condition, with IBI scores ranging from 53-100 as shown in **Table 6**. Excess sediment was the primary cause of impairment at the four cold water reaches during spring 2000. The sediment came from natural sources at two of the sites, and from roads in/near the streambed and grazing at the other two sites (Appendix H1).

The percentages were similar when data for the whole nine-year period, from 1992-2000, were considered. Only 10% (n=2/21) of warm water stream samples were impaired **(Figure 28)**, with IBI scores ranging from 30-82. Excess sediment was the primary cause of impairment at both sites, with grazing and roads as sources of sediment at the two sites, Bonita Creek and Emigrant Canyon **(Appendix G2)**.

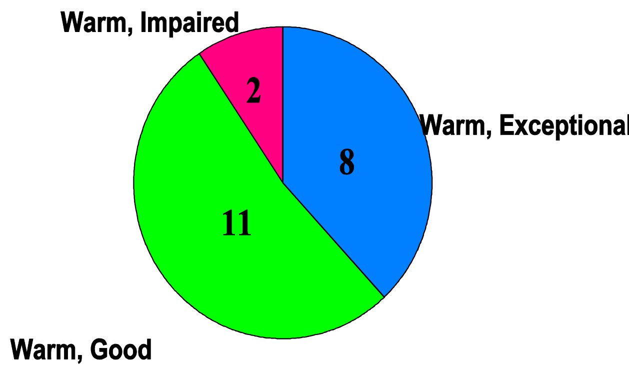


Figure 28. Number and percent of warm water IBI scores in each scoring category for Upper Gila River Basin sites, spring 1992-2000.

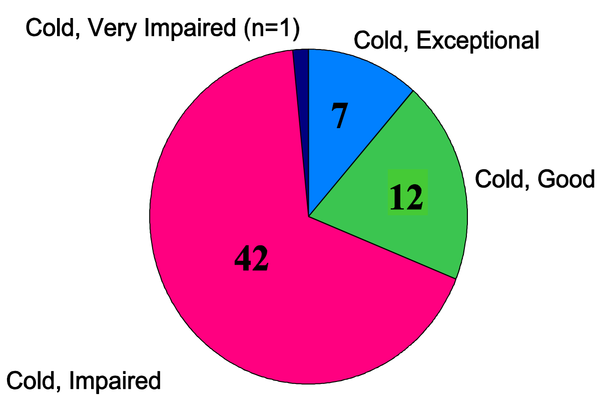


Figure 29. Number and percent of cold water IBI scores in each scoring category for Upper Gila Basin sites, spring 1992-2000.

For cold water samples, 68% were impaired during the nine year period, with IBI scores ranging from 23-100 (**Figure 29).** Sediment was the primary cause of impairment for 20 of the 43 sites. Intermittency, poor habitat, crayfish and low dissolved oxygen comprised the remainder of the causes, in ranked order. There were four sources responsible; natural, intermittency, grazing, and roads **(Appendix G1).**

6.2.1.1 Geographic analysis of spring samples, 1992-2000

Streams in the Blue River drainage were impaired by naturally high sedimentation rates, crayfish, 1993 flood impacts, intermittency, and sediment due to primarily natural sources and due to grazing. Campbell Blue, Coleman, and the Upper Blue River contained macroinvertebrate communities that were in the best condition of all sites in the Upper Gila River and probably should be retained as reference sites. Grant Creek is intermittent and Lanphier and the Lower Blue River were sediment impacted due to grazing and naturally high sedimentation rates (27), respectively. Pigeon Creek, a warm water tributary to the Blue River was in good condition **(Figure 30 and 31).**

All five Eagle Creek samples were impaired due to sediment and crayfish due primarily to a road in the streambed and floodplain and biotic interactions with exotic species. The single cold water San Francisco River samples at Martinez Ranch was impaired due to sediment from grazing.

Only one of six Bonita Creek samples was impaired by either scouring winter flows or sediment from road crossings.

The macroinvertebrate communities from streams draining Mt. Graham, Frye and Marijilda Creeks, were both impaired due primarily to intermittency and bedrock habitat.

Almost all the samples from Cave Creek and South Fork Cave Creek stream reaches draining the east side of the Chiricahua Mountains were impacted primarily due to intermittency, but also due to sediment, bedrock habitat, and low dissolved oxygen. Cave Creek above Herb Martyr Campground was impaired in 1997 due to low dissolved oxygen, was in exceptional condition in 1998 then in marginally poor condition in 1999 also due to low dissolved oxygen. These changes could be due to ecosystem recovery from the debris flows of the Rattlesnake Fire of 1995. Four of five South Fork Cave Creek above South Fork Campground samples were impaired due to sediment and groundwater upwelling zone effects; this site was in good condition only after the 1993 flood. Three of five East Turkey Creek samples were impaired probably due to a combination of bedrock dominated habitat and debris flows from the fire. Emigrant Canyon was impaired by sediment due to grazing and natural conditions **(Appendix H1 and H2).**

Table 6. Ranges and means of index of biological integrity scores for warm and cold water macroinvertebrate samples collected from the Upper Gila River Basin across various seasons and years, 1992-2000. The IBI scoring threshold between good and impaired is 53 for warm water streams and 88 for cold water streams.

	Spring 2000		Spring 1992-2000		Fall 1996-98	
	Coldwater	Warmwater	Coldwater	Warmwater	Coldwater	Warmwater
Range	53-100	68-82	23-100	30-82	62-94	63-81
Mean	75	76	75	66	73	72
N	6	7	62	21	6	10
Number exceeding	4	0	43	2	5	0

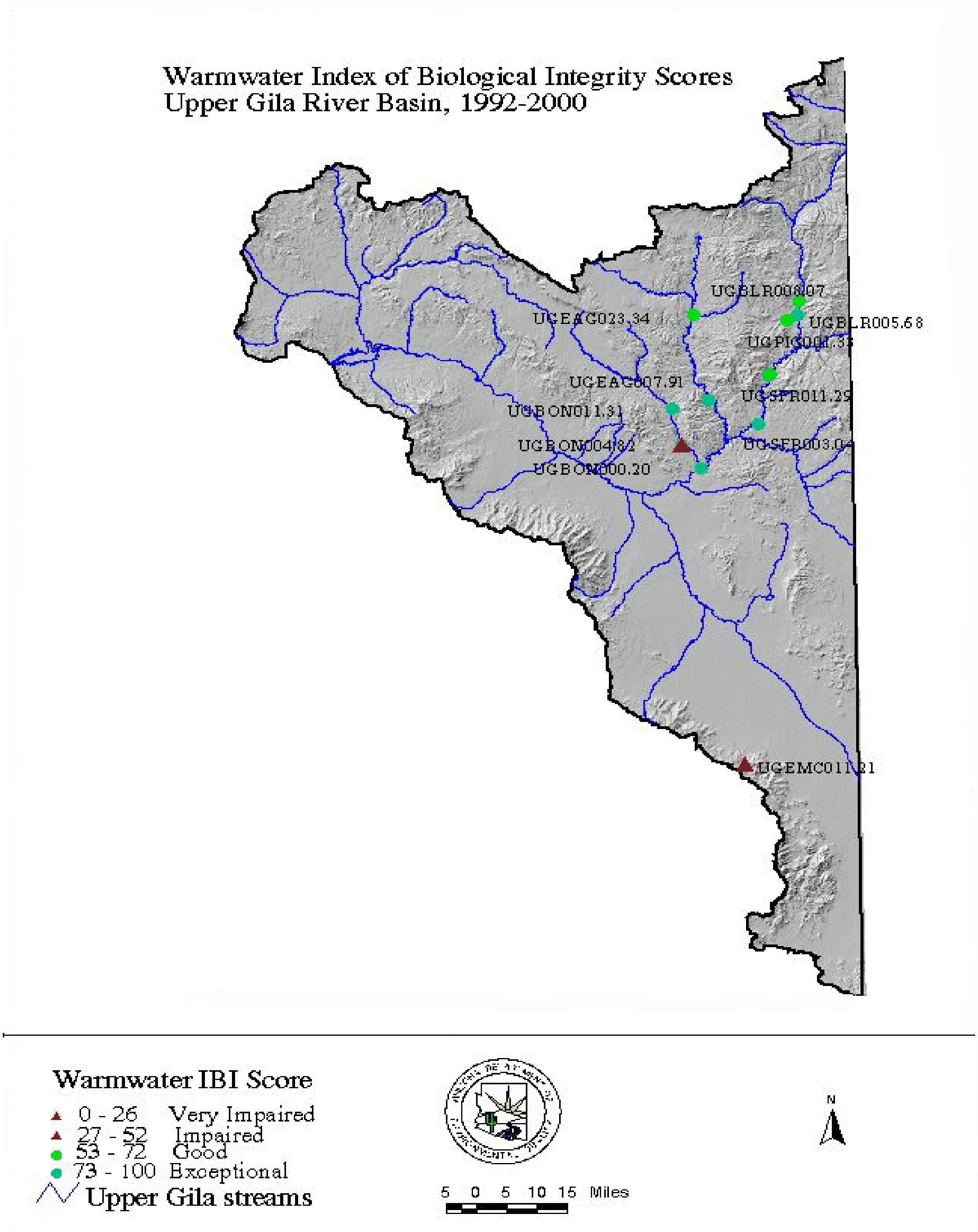


Figure 30. Index of Biological Integrity (IBI) scoring categories for macroinvertebrate samples collected from warm water perennial streams in the Upper Gila River Basin during the spring index period, 1992-2000.

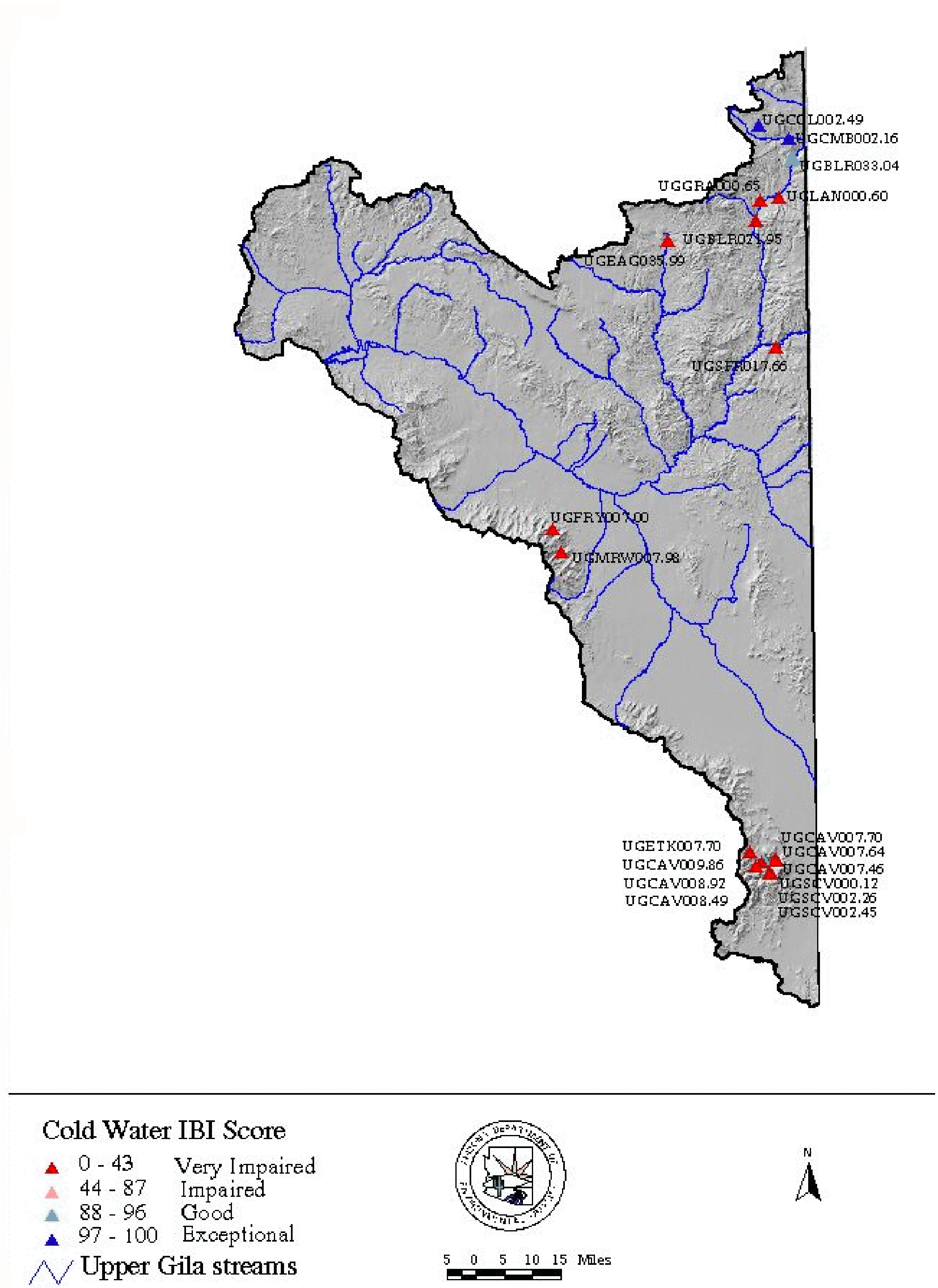


Figure 31. Index of Biological Integrity (IBI) scoring categories for macroinvertebrate samples collected from cold water perennial streams in the Upper Gila River Basin during the spring index period, 1992-2000.

6.2.2 Fall Bioassessments

There were 16 fall samples collected during 1996-98 as part of three other monitoring projects: Bonita Creek Stream Ecosystem Monitoring Intensive survey, Cave Creek and South Fork Cave Creek Unique Waters surveys in the Chiricahua Mountains, and an Intensive survey on the Gila and San Francisco Rivers.

The Indexes of Biological Integrity were derived from spring samples and are applied to fall samples in this analysis, as we have not developed an IBI for a fall index period. As a result, there is less confidence in the fall sample results using these indexes.

The percent impaired reaches in the 1996-98 fall samples were similar to spring percentages: 0% (n=0/10) of warm water **(Figure 32)** and 83% (n=5/6) of cold water samples were impaired **(Figure 33).** Temporal intermittency was the primary cause of impairment at 5/6 sites. Sediment from a debris flow that followed the 1995 Rattlesnake fire was the secondary cause of impairment at the Cave Creek at 8.49 site **(Appendix G3)**.

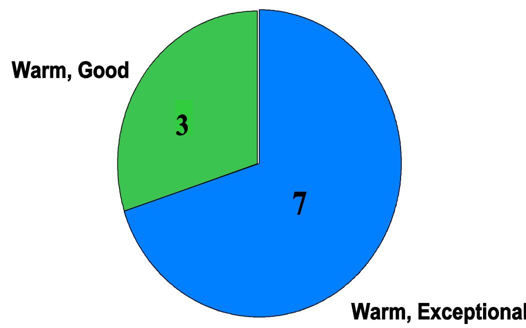


Figure 32. Number and percent of warm water IBI scores in each category for Upper Gila River Basin sites collected Fall, 1996-98.

In the Bonita Creek samples, all five of the warm water samples were in good to exceptional condition despite land use problems in the watershed, such as intensive grazing in the upper watershed and multiple road crossings over the creek.

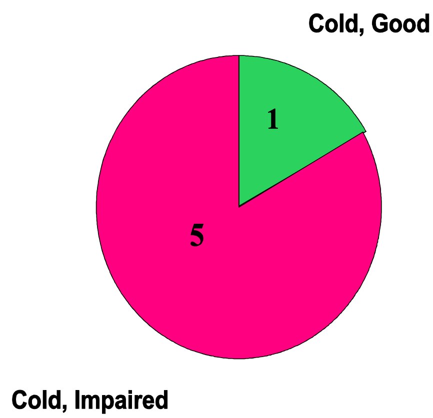


Figure 33. Number and percent of cold water IBI scores in each category for Upper Gila River Basin streams, collected Fall 1996-98.

Five of the six Chiricahua Mountain cold water samples were impaired due to temporally intermittent reaches which dry out during the summer. Cave Creek and South Fork Cave Creek were affected by widespread scouring and deposition due to debris flows from the 1995 Rattlesnake Fire. Temporally intermittent streams are only able to support species with short life cycles, those which survive dry periods as diapausing nymphs in the substrate, have delayed hatching of eggs, diapause as prepupae or are able to move to damp areas. Intermittent streams do not support some caddisflies like Hydropsyche or stoneflies like Acroneuria which are univoltine to semi-voltine, and do not diapause (35). Community structure shifts away from taxa with aerial adults, such as mayflies, stoneflies, caddisflies, to one dominated by snails, beetles and hemipterans (39).

All five of the Gila River and San Francisco River warm water samples were in good to exceptional condition, despite grazing and mining in their watersheds, respectively.

6.3 Causes and Sources

The causes and sources of impairment to macroinvertebrate communities were determined through the analysis of habitat data, field notes, and physico-chemical data collected on the sample date. Extensive quantitative and qualitative habitat data are recorded on ADEQ stream ecosystem monitoring field forms, which enable an evaluation of habitat quality, biotic interferences, sediment, riparian condition and overall stream condition. Causes and sources were identified by listing potential causes and sources reported in the field forms, then deducing the most probable cause and source in discussions with the field sampling staff.

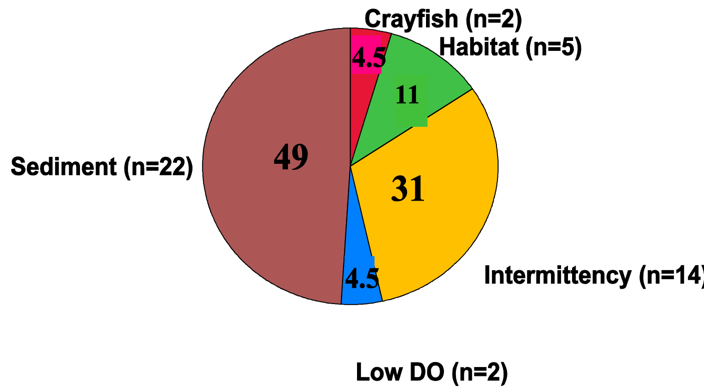


Figure 34. Causes of impairment of Upper Gila macroinvertebrate samples collected during spring 1992-2000.

Sediment was the most prevalent cause of impairment in both warm water and cold water streams (49%), sampled in the spring index period during the study period of 1992-2000 **(Figure 34).** Intermittency accounted for 31% of impaired sites. Poor habitat, crayfish predation, and low dissolved oxygen accounted for the remainder of impaired sites.

The primary source of impairment at 38% of cold water and warm water sites was "natural." Natural sources include debris flows from burned areas, naturally erodible soils, and groundwater upwelling zones. Intermittency accounted for another 31% of impairment and is shown separately from "natural" in **Figure 35.** Grazing and roads in or near the stream accounted for the remainder of sources of impairment to macroinvertebrate communities of Upper Gila River Basin streams.

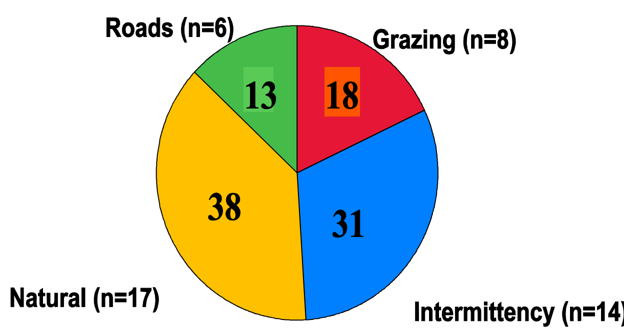


Figure 35. Sources of impairment to Upper Gila macroinvertebrate samples collected during spring 1992-2000.

6.4 Sediment impacts to cold water macroinvertebrate community structure

Further research into effects of sediment on macroinvertebrate communities of the Upper Gila are presented, since sediment was the dominant cause of impairment. Changes in cold water macroinvertebrate community structure due to sediment are presented in Figure 36. Six of the cold water metrics are presented with average metric scores from unimpacted sites compared to average metric scores of sediment impacted sites to determine how community metrics varied with sediment impacts. The metrics most affected by sediment in this dataset are number of intolerant taxa, % Plecoptera (stoneflies), and %scrapers, though all the metrics were affected to some degree **(Table 7).**

Stoneflies, in addition to mayflies and caddisflies (EPT), are affected by increased embeddedness of cobbles by fine sediments, which fill the interstitial spaces, thereby reducing habitable area for the EPT and resulting in either changes in invertebrate density or a taxonomic alteration from a complex community of EPT to a simple community of small, burrowing chironomid larvae and oligochaetes (36, 37). It is hypothesized that scrapers, which feed on periphyton (single celled and filamentous algae attached to the substrate) would be affected by a loss of food source due to shading and smothering of periphyton by sediment, as well as by suffocation.

Table 7. Mean metric scores for seven cold water metrics at sediment impaired and at unimpaired sites in the Upper Gila River Basin, 1992-2000.

	Total taxa	Diptera taxa	Intolerant taxa	HBI	Plecoptera %	Scraper %	Scraper taxa	CW-IBI
Sediment Impaired	25.8	8.3	1.3	5.95	0.55	5.145	4.15	63.7
Good/ Exceptional	32.2	9.9	3.7	5.1	4.4	25.7	7.4	95.9
Percent difference	20	16	65	14	87	80	45	34

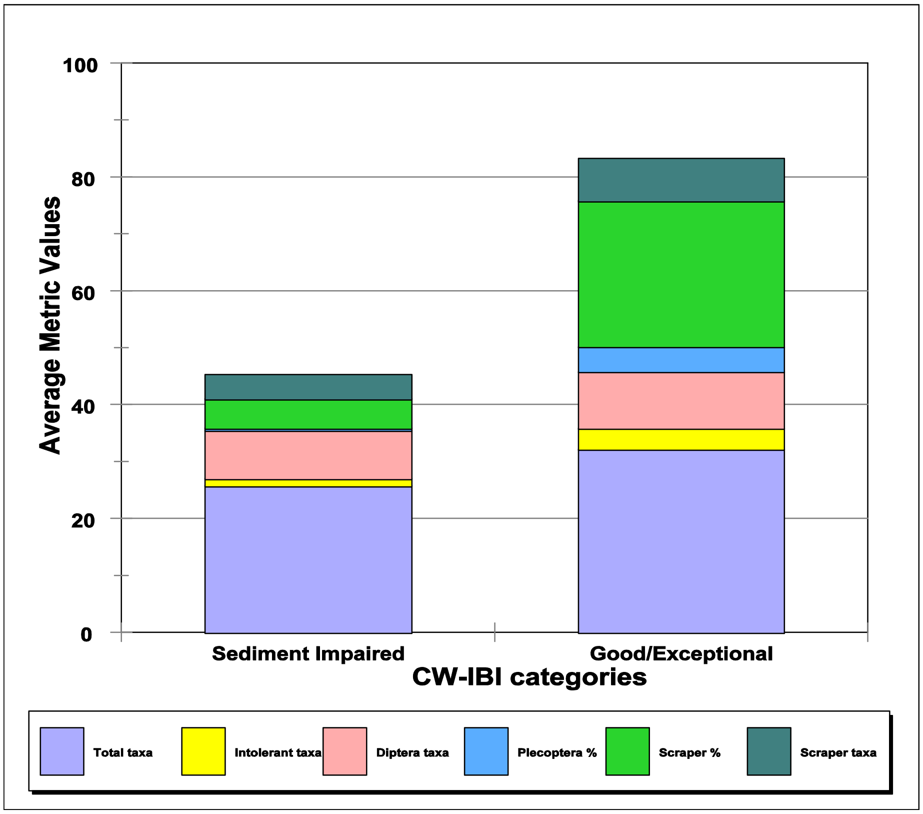


Figure 36. Comparison of macroinvertebrate community structure in cold water, unimpacted versus sediment impacted streams from the Upper Gila, spring 1992-2000.

Discussion

The majority of warm water macroinvertebrate samples from 1992-2000 were in good to exceptional condition, compared with the statewide warm water reference condition (19). Only two warm water samples were impaired due to sediment from grazing and roads. In contrast, the majority of cold water samples were impaired due to sediment and intermittency from primarily natural conditions. The macroinvertebrate community was significantly altered in the sediment impaired samples, with a loss in the number of intolerant taxa, percent stoneflies, and percent scrapers. There was also loss of taxa richness, diptera taxa, scraper taxa, and an increase in the community tolerance in the sediment impaired samples.

Geographically, the macroinvertebrates of cold water streams located in the upper part of the Upper Gila watershed and most of the warm water streams are in the best condition. However the majority of cold water sites in the Upper Gila River Basin are impaired. Streams in the Blue River drainage are particularly susceptible to natural sediment problems. The geology of the Blue River Watershed is extremely unstable as evidenced by the large number of landslides which vary in size from a few acres to over 5000 acres in size (27). As a result, the watershed has a high to extreme potential to produce sediment from natural conditions. This may explain the impaired condition of the Blue River, Lanphier Creek, and Grant Creek. Despite the landslides that occur over geologic time, Coleman Creek, Campbell Blue Creek and the Upper Blue River supported diverse, healthy communities of invertebrates during the study period and should be retained as reference sites for further monitoring.

Many of the streams in the Chiricahua Mountains were determined to be temporally intermittent after several site visits. These so called “impaired” samples are the result of natural conditions, unknown at the time of sampling. In addition, streams draining the eastern side of the Chiricahuas were affected by debris flows from the 1995 Rattlesnake fire, which scoured and laid deep sediment deposits in the streambeds, possibly contributing to the intermittent condition of many streams. As a result, only the perennial sites at Cave Creek above Herb Martyr Campground and East Turkey Creek should be retained as monitoring sites in the next five-year monitoring cycle.

7.0 SUMMARY OF UPPER GILA RIVER BASIN WATER QUALITY

Overall, water quality in the Upper Gila Basin is very good. This conclusion is supported by a number of measures. When compared to state water quality standards, ADEQ data showed a total of 19 exceedances in a pool of 3840 analytes (0.05%) sampled and analyzed in WY2000. Of these 19 exceedances, eleven were attributed to dissolved oxygen deficiencies, seven to turbidity violations, and one to total beryllium. Nine of the eleven dissolved oxygen deficiencies were associated with low-discharge values of less than one cubic foot per second, a naturally-occurring condition warranting little concern. The beryllium exceedance was an anomalous result for the San Francisco River below Clifton in WY2000; all other values measured during the year were reported as not detectable. Turbidity exceedances, total suspended solids, and macroinvertebrate bioassessment results indicate that sedimentation is the greatest contributor to water quality degradation in the Upper Gila.

Metal loads in the Upper Gila, both total and dissolved, were almost non-existent for the sites sampled. Total and dissolved metal results from the Upper Gila Basin were reported so infrequently that the monitoring program was led to examine and revise the sampling protocol for subsequent years of the targeted watershed monitoring program. Forty-one detectable results above the State lab minimum reporting level were recorded from a pool of 1251 metal analyte results (3.28%). The metals exceedance rate with one beryllium value represented 0.08%. In the history of ADEQ sampling dating to 1988 at the site where the beryllium exceedance was logged, there have been four detections and three exceedances of the total beryllium standard. The cause of these infrequent appearances of beryllium is unknown.

No nutrient exceedances and consistently low levels of total phosphorus, Kjehldahl nitrogren, and ammonia were recorded in the basin for WY2000. The mean value of nitrate for all sites was 0.10 mg/l. Total phosphorus results had a mean of 0.067 mg/l. Ammonia was detected at low levels (< 0.1 mg/l) on six of 71 site visits; all other visits result in non-detects. No pH values exceeded or fell short of state standards; water basin-wide was of a slightly alkaline character with an average pH value of 8.1 standard units.

Biocriteria assessment results indicated the majority of warm water macroinvertebrate samples from 1992-2000 were in good to exceptional condition, compared with the statewide warm water reference condition (19). Only two warm water samples were impaired due to sediment from grazing and roads. In contrast, the majority of cold water samples were impaired due to sediment and intermittency from primarily natural conditions. The macroinvertebrate community was significantly altered in the sediment impaired samples, with a loss in the number of intolerant taxa, percent stoneflies, and percent scrapers. There was also loss of taxa richness, diptera taxa, scraper taxa, and an increase in the community tolerance in the sediment impaired samples.

Geographically, the macroinvertebrates of cold water streams located in the upper part of the Upper Gila watershed and most of the warm water streams are in the best condition. However the majority of macroinvertebrate samples from cold water streams in the Upper Gila River Basin indicate impairment. Streams in the Blue River drainage are particularly susceptible to natural sediment problems. The geology of the Blue River Watershed is unstable as evidenced by the large number of landslides which vary in size from a few acres to over 5000 acres in size (27). As a result, the watershed has a high to extreme potential to produce sediment from natural conditions. This may explain the impaired condition of the Blue River, Lanphier Creek, and Grant Creek.

Turbidity and total suspended solids concentrations varied similarly in WY2000 for the Upper Gila. Turbidity exceedances were usually accompanied by elevated levels of total suspended solids when compared to the historic values recorded at the site. Additionally, both of these parameters appeared to be sensitive to flow levels; at base flow or low flow values, there were three turbidity problems (San Francisco River near Martinez Ranch and two at the San Francisco above Luna Lake). Only when flows were elevated did the majority of turbidity and TSS problems manifest. Three exceedances of the turbidity standard occurred shortly after a monsoon storm in the Cave Creek watershed of the Chiricahuas. Two USGS measurements showed turbidity exceedances at Calva and Solomon with very high flows. These results suggest that latent water quality problems attributable to sediment may only become evident at the higher flows. When turbidity problems are apparent even in low-flow conditions, a suggestion of contributing land-use factors is made.

Figure 25 in this report illustrates that all turbidity exceedances occurred in areas with moderate, high, or very high upper layer soil erodibility (*K*) factors. With the distribution of turbidity problems being basin-wide, this was the only ascertainable geographic pattern apparent for turbidity/TSS issues in the watershed. However, *K* factors in and of themselves do not predict water quality problems. Ash, Frye, and Eagle Creeks, as well as the Blue River, all occupy areas of moderate or above soil erodibility; none of these creeks showed turbidity problems. These results suggest that while soil erodibility may create the conditions for excessive sedimentation of waterways, catalyzing forces are likely necessary to actually cause problems. Likely catalyzing forces for turbidity and TSS problems in the Upper Gila include grazing, roads, natural events, and bank erosion. Minor impacts from rural communities (Alpine) can contribute; further south, the Gila River is influenced by agriculture and irrigation practices.

While macroinvertebrate impairments, turbidity exceedances, and total suspended solids data all indicated sediment effects in the watershed, these three measures did not identify the same places within the watershed as having a problem. In part, this can be attributed to the different time scales being examined; turbidity and TSS will catch only transient degradation problems whereas bioassessments characterize conditions for longer spans of time. There are also implications to be considered in the differences of the scope of the measures: bioassessments tend to integrate multiple stressors, including habitat, flow levels, metals, nutrients and sediment-related factors over time, while turbidity and total suspended solids are direct measures of sediment or sediment-related properties in the water column at the time of sampling. The consideration of results is further complicated by the fact that at some sites, only water chemistry and physical parameters were collected, so there is no verification of sediment impairment by the biota. This occurred on sites such as the Gila River near the old Safford bridge, where a turbidity exceedance was logged, and at the San Francisco River above Luna Lake (2 turbidity exceedances). At these sites, bioassessments were not done due to the presence of sand-dominated habitat or a lack of riffle habitat.

It will benefit interested parties to be mindful that these measures do not necessarily characterize the same problems, nor will they necessarily dovetail in their agreement that sediment-related issues exist at any given site or that impairments and elevations can be traced to common sources. Some turbidity elevations stem from natural causes or events, and the aquatic community does tolerate short-lived turbidity pulses. In other cases, aquatic insect communities can show impairments where causes of the impairment may not be supported or further illuminated by the current (at the time of sampling or assessment) water quality parameters. For the Upper Gila in WY2000, turbidity problems occurred where bioassessments indicated no problems with the aquatic insect community (Cave Creek watershed, SFR at Martinez Ranch), while other areas such as the Blue River showed macroinvertebrate impairments though no turbidity or TSS problems were shown. This could be due to a movement of sediment and substrates during high flow events which were not sampled, or it could suggest impairment due to other factors such as habitat, metals, nutrients or flows. Cases such as these suggest the advisablity of being cautious about the evaluation of water quality degradation attributable to sediment.

Considerable care should be exercised in extrapolating from a position of asserting that sediment impairments or sediment-related parameter elevations are present to a position of asserting that such impairments or elevations are by definition problems. Even less tenable are extensions of conclusions pertaining to land-use practices: in such cases, additional information is needed to evaluate these impairments and to tease out naturally-induced causes from human-induced aggravations of the river systems. Where human impacts are notable and substantial, further conclusions about land-use practices may be justified with additional information or analysis. Turbidity, TSS, and bioassessments are best viewed as complementary samples for the purposes of assessing the existence, degree and nature of sediment impairments and elevations, with each illustrating or suggesting a particular facet or aspect of potential causes or sources.

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Appendix A. Upper Gila Water Quality Sampling Sites

Site ID	HUC	Reach	Latitude	Longitude	Elevation	Agency	Program
UGA1H008.62	15040005	040	32 46 25.0	109 51 37.0	4240	ADEQ	FSN
UGBLR005.68	15040004	025	33 17 31.6	109 11 40.8	4160	ADEQ	FSN
UGBLR021.95	15040004	025	33 31 39.6	109 12 06.8	5160	ADEQ	FSN
UGBLR033.04	15040004	026	33 41 03.967	109 04 56.78	6110	ADEQ	FSN
UGBON000.20	15040005	030	32 53 45	109 28 45	3150	ADEQ	FSN
UGBON011.31	15040005	030	33 03 03.6	109 33 24.1	3940	ADEQ	FSN
UGCAV006.55	15040006	852A	31 53 51.895	109 09 40.48	4920	ADEQ	FSN
UGCAV007.64	15040006	852A	31 52 57.05	109 12 11.82	5360	ADEQ	FSN
UGCMB002.16	15040004	028	33 44 19.500	109 05 47.50	6670	ADEQ	FSN
UGEAG006.05	15040005	025	33 02 47.7	109 26 11.9	3600	ADEQ	FSN
UGEAG023.34	15040005	027	33 17 39.500	109 29 38.50	4645	ADEQ	FSN
UGEAG035.99	15040005	028	33 28 46.049	109 28 30.19	5435	ADEQ	FSN
UGFRY007.00	15040005	988	32 44 36.500	109 50 18.50	5800	ADEQ	FSN
UGGLR197.26	15040002	001	32 57 54.11	109 18 29.31	3336	ADEQ	FSN
UGGLR205.35	15040002	004	32 41 12.65	109 03 07.77	3680	ADEQ	FSN
UGKPK000.08	15040004	029	33 31 48	109 12 08	5160	ADEQ	FSN
UGKPK065.54	15040004	029	33 35 01	109 20 33	8760	ADEQ	FSN
UGSCV002.26	15040006	849	31 51 13.500	109 11 32.50	5520	ADEQ	FSN
UGSFR003.04	15040004	001	33 00 28.3	109 18 54.2	3435	ADEQ	FSN
UGSFR011.29	15040004	003	33 07 56	109 16 58	3600	ADEQ	FSN
UGSFR017.66	15040004	004	33 12 03.2	109 08 54.7	3980	ADEQ	FSN
UGSFR059.98	15040004	023	33 49 55.2	109 06 30.7	7960	ADEQ	FSN
UGGLR166.03	15040005	011	33 11 08	110 13 10	2515	USGS	
UGGLR188.98	15040005	022	32 52 06	109 30 38	3065	USGS	

Appendix A. Upper Gila Water Quality Sampling Sites - Continued

Site ID	Flow Regime	Water Type	Dominant Geology	Soil Hydrologic Group
UGA1H008.62	Perennial	Calcium Mixed - Bicarbonate	Metamorphic	C
UGBLR005.68	Perennial	Calcium Mixed - Bicarb Mixed	Volcanic	B
UGBLR021.95	Perennial	Calcium Mixed - Bicarbonate	Volcanic	B
UGBLR033.04	Perennial	Calcium Mixed - Bicarbonate	Volcanic	C
UGBON000.20	Perennial	Calcium Mixed - Bicarbonate	Sedimentary Undifferentiated	D
UGBON011.31	Perennial	Calcium Mixed - Bicarbonate	Sedimentary Clastic	C
UGCAV006.55	Intermittent	Calcium - Bicarbonate Mixed	Volcanic	B
UGCAV007.64	Perennial	Calcium - Sulfate Mixed	Volcanic	B
UGCMB002.16	Perennial	Calcium Mixed - Bicarbonate	Sedimentary Sandstone	C
UGEAG006.05	Perennial	Calcium Mixed - Bicarbonate	Volcanic	C
UGEAG023.34	Perennial	Calcium Mixed - Bicarbonate	Volcanic	B
UGEAG035.99	Perennial	Calcium Mixed - Bicarbonate	Volcanic	B
UGFRY007.00	Perennial	Calcium Mixed - Bicarbonate	Metamorphic	D
UGGLR197.26	Perennial	Sodium Mixed - Bicarb Mixed	Sedimentary Clastic	B
UGGLR205.35	Perennial	Calcium Mixed - Bicarbonate	Alluvial	D
UGKPK000.08	Perennial	Calcium Mixed - Bicarbonate	Volcanic	B
UGKPK065.54	Perennial	Calcium - Bicarbonate	Volcanic	C
UGSCV002.26	Perennial	Calcium - Bicarbonate Mixed	Volcanic	D
UGSFR003.04	Perennial	Sodium Mixed - Chloride	Sedimentary Clastic	B
UGSFR011.29	Perennial	Sodium Mixed - Bicarb Mixed	Volcanic	C
UGSFR017.66	Perennial	Sodium Mixed - Bicarb Mixed	Volcanic	C
UGSFR059.98	Perennial	Calcium Mixed - Bicarbonate	Sedimentary Sandstone	B
UGGLR166.03	Perennial	Sodium - Chloride Mixed	Alluvium	N/A
UGGLR188.98	Perennial	Calcium Mixed - Chloride Mixed	Alluvium	N/A

Appendix A. Upper Gila Water Quality Sampling Sites - Continued

Site ID	K Factor, Upper Layer	Average K Factor, All Layers	Land Use
UGA1H008.62	Low	Moderate	Forest Mgmt.
UGBLR005.68	High	High	Forest Mgmt.
UGBLR021.95	High	High	Forest Mgmt.
UGBLR033.04	Low	Very Low	Forest Mgmt.
UGBON000.20	Low	Very Low	Range/Pasture
UGBON011.31	Low	Moderate	Range/Pasture
UGCAV006.55	High	High	Forest Mgmt.
UGCAV007.64	High	High	Forest Mgmt.
UGCMB002.16	High	Moderate	Forest Mgmt.
UGEAG006.05	Low	Moderate	Mining
UGEAG023.34	High	High	Range/Pasture
UGEAG035.99	High	High	Forest Mgmt.
UGFRY007.00	Moderate	Moderate	Forest Mgmt.
UGGLR197.26	Moderate	Moderate	Range/Pasture
UGGLR205.35	Moderate	Low	Agriculture
UGKPK000.08	High	High	Forest Mgmt.
UGKPK065.54	Moderate	Moderate	Forest Mgmt.
UGSCV002.26	Moderate	Moderate	Forest Mgmt.
UGSFR003.04	Moderate	Moderate	Mining
UGSFR011.29	Low	Moderate	Range/Pasture
UGSFR017.66	Moderate	Moderate	Range/Pasture
UGSFR059.98	Moderate	Low	Range/Pasture
UGGLR166.03	N/A	N/A	Range/Pasture
UGGLR188.98	N/A	N/A	Range/Pasture

Appendix B. QC Data Validation by Site and Date

SITE_ID	Sample Date	Sample Type	EC Ratio (0.9-1.1)	pH Ratio (0.9-1.1)	TDS/EC Ratio (0.55-0.75)	TDS/Sum Ratio (1.0-1.2)	PERCENT DIFFERENCE	ABSOLUTE DIFFERENCE	Cation Sum	Anion Sum	C/A Balance Met?
UGA1H008.62	10-NOV-1999	GRAB	0.8	1.1	0.69	2.0	0.38	0.00	0.589	0.585	Yes
	16-MAR-2000	GRAB	0.8	1.1	0.71	1.4	32.73	0.57	1.161	0.588	No
	26-SEP-2000	GRAB	0.9	1.0	0.65	1.2	-0.64	-0.02	1.320	1.337	Yes
UGBLR005.68	09-MAY-2000	MEWI	0.9	1.0	0.59	1.1	-0.26	-0.03	5.914	5.944	Yes
	16-NOV-1999	MEWI	0.9	1.0	0.56	1.1	0.87	0.10	5.517	5.421	Yes
	20-SEP-2000	MEWI	0.9	1.0	0.62	1.1	0.94	0.12	6.355	6.236	Yes
	28-MAR-2000	GRAB	0.9	1.0	0.61	1.1	2.68	0.32	6.070	5.754	No
UGBLR021.95	17-NOV-1999	GRAB	0.9	1.0	0.58	1.1	5.05	0.41	4.275	3.864	No
	19-SEP-2000	GRAB	0.9	1.0	0.64	1.2	3.46	0.27	4.029	3.760	No
UGBLR033.04	17-NOV-1999	GRAB	0.8	1.0	0.58	1.1	4.86	0.38	4.071	3.694	No
	19-SEP-2000	GRAB	0.9	1.0	0.66	1.2	1.13	0.09	3.913	3.826	Yes
UGBON000.20	09-NOV-1999	GRAB	0.9	1.0	0.61	1.0	6.07	0.59	5.155	4.565	No
	15-MAR-2000	GRAB	0.9	1.0	0.63	1.2	12.84	1.22	5.372	4.149	No
	22-MAY-2000	GRAB	1.0	1.0	0.59	1.1	1.30	0.13	4.895	4.770	Yes
	28-SEP-2000	GRAB	0.9	1.0	0.63	1.2	-1.24	-0.12	4.655	4.772	Yes
UGBON011.31	11-JAN-2000	MEWI	0.9	1.0	0.66	1.3	5.05	0.39	4.025	3.638	No
	16-MAY-2000	GRAB	0.9	1.0	0.63	1.1	-1.02	-0.08	3.877	3.957	Yes
	26-JUL-2000	GRAB	0.9	1.0	0.62	1.2	-1.63	-0.11	3.415	3.528	Yes
	30-NOV-1999	GRAB	0.9	1.0	0.59	1.1	2.45	0.20	4.185	3.985	No
UGCAV006.55	11-JUL-2000	GRAB	1.0	1.1	0.88	1.5	4.91	0.18	1.901	1.723	Yes
	16-NOV-1999	MEWI	0.9	1.0	0.64	1.1	1.64	0.18	5.580	5.400	Yes
	25-JAN-2000	GRAB	0.8	1.0	0.67	1.0	-2.48	-0.34	6.714	7.056	No
UGCAV007.64	11-JUL-2000	GRAB	1.0	1.1	0.81	1.6	3.70	0.11	1.599	1.484	Yes
	15-NOV-1999	MEWI	0.9	1.0	0.72	1.0	-0.64	-0.13	10.296	10.427	Yes
	24-JAN-2000	MEWI	0.9	1.0	0.74	1.1	-0.03	-0.01	10.875	10.881	Yes
	31-MAY-2000	GRAB	1.0	1.0	0.77	1.1	-1.59	-0.47	14.633	15.105	Yes
UGCMB002.16	13-OCT-1999	GRAB	0.9	1.0	0.55	1.1	4.85	0.26	2.770	2.513	No
	16-AUG-2000	GRAB	0.9	1.0	0.68	1.3	-1.68	-0.09	2.705	2.797	Yes
	27-JUN-2000	GRAB	0.9	1.0	0.67	1.2	2.08	0.11	2.746	2.633	Yes
	28-MAR-2000	MEWI	0.9	1.0	0.62	1.2	6.23	0.29	2.473	2.183	No
UGEAG006.05	11-JAN-2000	GRAB	0.9	1.0	0.63	1.2	2.22	0.19	4.363	4.173	No
	17-MAY-2000	GRAB	1.0	1.0	0.60	1.1	1.87	0.17	4.744	4.570	Yes
	26-JUL-2000	GRAB	0.9	1.0	0.66	1.3	0.71	0.06	4.144	4.086	Yes
	30-NOV-1999		0.9	1.0	0.59	1.1	4.04	0.37	4.770	4.400	No
UGEAG023.34	01-DEC-1999		0.9	1.0	0.59	1.0	4.74	0.33	3.606	3.279	No
	09-MAY-2000	GRAB	1.0	1.0	0.67	1.2	-0.15	-0.01	3.353	3.363	Yes
	12-JAN-2000	GRAB	0.9	1.0	0.67	1.3	5.15	0.30	3.067	2.766	No
	25-JUL-2000	GRAB	0.9	1.0	0.69	1.3	3.52	0.25	3.727	3.474	No

Appendix B. QC Data Validation by Site and Date - Continued

SITE_ID	Sample Date	Sample Type	EC Ratio (0.9-1.1)	pH Ratio (0.9-1.1)	TDS/EC Ratio (0.55-0.75)	TDS/Sum Ratio (1.0-1.2)	PERCENT DIFFERENCE	ABSOLUTE DIFFERENCE	Cation Sum	Anion Sum	C/A Balance Met?
UGEAG035.99	01-DEC-1999	GRAB	0.9	1.0	0.64	1.2	6.05	0.37	3.231	2.862	No
	10-MAY-2000	GRAB	1.0	1.0	0.68	1.3	1.57	0.09	3.016	2.923	Yes
	12-JAN-2000	GRAB	0.9	1.0	0.64	1.3	3.67	0.22	3.080	2.862	No
	25-JUL-2000	GRAB	0.9	1.0	0.68	1.3	2.74	0.17	3.233	3.060	No
UGFRY007.00	08-NOV-1999	GRAB	0.7	1.1	0.75	2.0	6.93	0.10	0.748	0.651	Yes
	27-SEP-2000	GRAB	0.9	1.0	0.67	1.2	-5.74	-0.12	0.995	1.116	Yes
UGGLR197.26	09-NOV-1999				0.65	1.0	7.67	1.04	7.300	6.261	No
	15-MAR-2000		0.9	1.0	0.64	0.9	-1.41	-0.22	7.576	7.793	Yes
	23-MAY-2000	MEWI	0.9	1.0	0.58	1.0	-0.12	-0.02	6.849	6.865	Yes
	27-SEP-2000	GRAB	0.8	1.0	0.64	1.1	-0.72	-0.09	6.426	6.520	Yes
	27-SEP-2000	SPLIT	0.8	1.0	0.65	1.1	-0.13	-0.02	6.367	6.383	Yes
UGGLR205.35	09-NOV-1999	MEWI	0.9	1.0	0.57	1.0	4.47	0.44	5.194	4.749	No
	15-MAR-2000		0.9	1.0	0.64	1.0	6.08	0.63	5.454	4.829	No
UGKPK000.08	19-SEP-2000	GRAB	0.9	1.0	0.70	1.3	1.06	0.08	3.773	3.693	Yes
UGKPK065.54	16-NOV-1999	GRAB	0.7	1.1	0.64	1.6	4.55	0.06	0.708	0.646	Yes
UGSCV002.26	11-JUL-2000	GRAB	1.0	1.1	1.10	2.0	5.69	0.12	1.076	0.960	Yes
	16-NOV-1999	GRAB	0.9	1.0	0.63	1.2	0.65	0.02	1.912	1.888	Yes
	24-JAN-2000	GRAB	0.8	1.0	0.70	1.2	7.44	0.31	2.220	1.912	No
	30-MAY-2000	GRAB	1.0	1.0	0.68	1.2	-1.83	-0.09	2.367	2.455	Yes
UGSFR003.04	10-JAN-2000	EWDI	0.9	1.0	0.57	1.1	0.77	0.17	11.261	11.090	Yes
	15-MAY-2000	EWDI	1.0	1.0	0.55	1.1	-0.40	-0.17	21.173	21.342	Yes
	24-JUL-2000	EWDI	0.9	1.0	0.58	1.2	-2.51	-1.07	20.712	21.778	Yes
	30-NOV-1999	EWDI	0.9	1.0	0.54	1.0	2.91	0.66	11.659	10.999	Yes
UGSFR011.29	10-JAN-2000	EWDI	0.9	1.0	0.60	1.1	3.16	0.35	5.787	5.432	No
	17-MAY-2000	EWDI	0.9	1.0	0.60	1.1	-0.21	-0.03	6.094	6.119	Yes
	24-JUL-2000	EWDI	0.9	1.0	0.61	1.2	-0.61	-0.07	5.854	5.926	Yes
	29-NOV-1999	EWDI	0.9	1.0	0.58	1.1	5.14	0.57	5.877	5.303	No
UGSFR017.66	08-MAY-2000	MEWI	0.9	1.0	0.59	1.1	0.87	0.11	6.405	6.294	Yes
	12-SEP-2000	MEWI	0.9	1.0	0.56	0.8	-13.84	-2.10	6.544	8.646	No
	18-NOV-1999	MEWI	0.9	1.0	0.57	1.0	-0.08	-0.01	5.652	5.661	Yes
UGSFR059.98	13-OCT-1999	GRAB	1.0	1.0	0.61	1.1	4.75	0.39	4.282	3.894	No
	28-MAR-2000	GRAB	1.0	1.0	0.66	1.2	8.95	0.68	4.111	3.436	No

Appendix C1. Summary Results of Inorganics and Physical Parameters

Constituent	MRL (mg/l)	Number of Site Visits over MRL	Lower 95% Confidence Level	Mean	Upper 95% Confidence Level
Calcium	5.0	71	38.2	45.3	52.4
Magnesium	1.0	71	10.6	11.8	12.9
Sodium	5.0	67	25.0	38.0	51.1
Potassium	0.5	71	2.4	3.2	4.0
Bicarbonate	2.0	71	159.2	173.3	187.3
Carbonate	2.0	30	2.1	3.4	4.7
Chloride	1.0	68	16.0	42.7	69.5
Sulfate	10.0	40	12.9	27.9	43.0
Fluoride	0.20	68	0.48	0.60	0.73
Nitrate-Nitrite	0.05	32	0.05	0.10	0.14
Total Alkalinity	2.0	71	135.5	147.6	159.6
Phenolphthalein Alkalinity	2.0	30	1.7	2.8	3.9
Total Dissolved Solids	--	N/A	202.1	256.2	310.3
Total Suspended Solids	4.0	35	5.5	10.0	14.5
Conductivity	--	N/A	324	409	495
Dissolved Oxygen	--	N/A	7.6	7.9	8.2
Turbidity, Field	--	N/A	4.6	8.0	11.4
pH, Field	--	N/A	8.0	8.1	8.2

Appendix C2. Summary Results of Total Metals for Upper Gila Basin

Constituent (Total Recoverable)	MRL (ug/l)	Number of SiteVisits over MRL	Lower 95% Confidence Level	Mean	Upper 95% Confidence Level
Antimony	5.0	0		> 90% of data below MRL	
Arsenic	10	0		> 90% of data below MRL	
Barium	100	2		> 90% of data below MRL	
Beryllium	0.5	1		> 90% of data below MRL	
Boron	100	7	6.5	24.2	41.9
Cadmium	1.0	0		> 90% of data below MRL	
Chromium	10	1		> 90% of data below MRL	
Copper	10	2		> 90% of data below MRL	
Iron	100	19	76.6	228.6	380.6
Lead	5.0	0		> 90% of data below MRL	
Manganese	50	4	0.0	11.2	23.0
Mercury	0.5	0		> 90% of data below MRL	
Nickel	100	0		> 90% of data below MRL	
Selenium	5.0	2		> 90% of data below MRL	
Silver	1.0	0		> 90% of data below MRL	
Thallium	2.0	0		> 90% of data below MRL	
Zinc	50	0		> 90% of data below MRL	

Appendix C3. Summary Results of Dissolved Metals and Nutrients for Upper Gila Basin

Dissolved Metals

Constituent (Dissolved)	MRL (ug/l)	Number of SiteVisits over MRL	Lower 95% Confidence Level	Mean	Upper 95% Confidence Level
Antimony	5.0	0	> 90% of data below MRL		
Arsenic	10	0	> 90% of data below MRL		
Barium	100	2	> 90% of data below MRL		
Beryllium	0.5	0	> 90% of data below MRL		
Cadmium	1.0	0	> 90% of data below MRL		
Copper	10	1	> 90% of data below MRL		
Lead	5.0	0	> 90% of data below MRL		
Mercury	0.5	0	> 90% of data below MRL		
Nickel	100	0	> 90% of data below MRL		
Selenium	5.0	2	> 90% of data below MRL		
Silver	1.0	0	> 90% of data below MRL		
Thallium	2.0	0	> 90% of data below MRL		
Zinc	50	0	> 90% of data below MRL		

Nutrients

Constituent	MRL (mg/l)	Number of Site Visits over MRL	Lower 95% Confidence Level	Mean	Upper 95% Confidence Level
Nitrate-Nitrite	0.05	32	0.05	0.10	0.14
TKN	0.05	62	0.11	0.13	0.16
Ammonia	0.02	6	0.000	0.003	0.005
Phosphorus	0.02	60	0.054	0.067	0.080

Appendix D. Statistical Results for Testing of Soil Erodibility Factors Against TSS, Field and Lab Turbidity

ANALYTE	Total Suspended Solids	Field Turbidity	Lab Turbidity
Average K Factor, All Layers			
Kruskal-Wallis	NS	$p \leq 0.05$	$p \leq 0.05$
Bonferroni	NS	NS	NS
Upper Layer K Factor			
Kruskal-Wallis	$p \leq 0.01$	$p \leq 0.05$	$p \leq 0.01$
Bonferroni	$p \leq 0.05$	$p \leq 0.1$	$p \leq 0.1$

Bonferroni Probabilities of Significant Differences between Classes

TSS vs. Upper Layer Soil K factor

Classes	High	Moderate	Low
High	1.000		
Moderate	0.079	1.000	
Low	ns	0.077	1.000

Field Turbidity vs. Upper Layer Soil K Factor

Classes	High	Moderate	Low
High	1.000		
Moderate	0.087	1.000	
Low	ns	ns	1.000

Lab Turbidity vs. Upper Layer Soil K Factor

Classes	High	Moderate	Low
High	1.000		
Moderate	0.081	1.000	
Low	ns	ns	1.000

Appendix E. Tukey Post-Hoc Testing of Major Ions vs. Geologic Composition

	Alluvium	Meta-morphic	Sedimentary Clastic	Sedimentary Sandstone	Sedimentary Undiffer-entiated	Volcanic
Calcium						
Alluvium	1.0000					
Metamorphic	ns	1.0000				
Sedimentary Clastic	ns	ns	1.0000			
Sedimentary Sandstone	ns	ns	ns	1.0000		
Sedimentary Undifferentiated	ns	ns	ns	ns	1.0000	
Volcanic	ns	ns	ns	ns	ns	1.0000
Magnesium						
Alluvium	1.000					
Metamorphic	ns	1.000				
Sedimentary Clastic	0.002	0.000	1.000			
Sedimentary Sandstone	ns	0.024	ns	1.000		
Sedimentary Undifferentiated	0.000	0.000	0.020	0.002	1.000	
Volcanic	0.004	0.000	ns	ns	0.001	1.000
Sodium						
Alluvium	1.000					
Metamorphic	ns	1.000				
Sedimentary Clastic	0.003	0.006	1.000			
Sedimentary Sandstone	ns	ns	0.001	1.000		
Sedimentary Undifferentiated	ns	ns	0.021	ns	1.000	
Volcanic	ns	ns	0.000	ns	ns	1.000
Potassium						
Alluvium	1.000					
Metamorphic	ns	1.000				
Sedimentary Clastic	0.008	0.031	1.000			
Sedimentary Sandstone	ns	ns	0.001	1.000		
Sedimentary Undifferentiated	ns	ns	ns	ns	1.000	
Volcanic	ns	ns	0.000	ns	ns	1.000
Carbonate						
Alluvium	1.000					
Metamorphic	ns	1.000				
Sedimentary Clastic	ns	ns	1.000			
Sedimentary Sandstone	ns	ns	ns	1.000		
Sedimentary Undifferentiated	ns	ns	ns	ns	1.000	
Volcanic	ns	ns	ns	ns	ns	1.000

Appendix E Cont. - Tukey Post-Hoc Testing of Major Ions vs. Geologic Composition

	Alluvium	Meta-morphic	Sedimentary Clastic	Sedimentary Sandstone	Sedimentary Undiffer-entiated	Volcanic
<u>Bicarbonate</u>						
Alluvium	1.000					
Metamorphic	ns	1.000				
Sedimentary Clastic	0.010	0.000	1.000			
Sedimentary Sandstone	ns	0.002	ns	1.000		
Sedimentary Undifferentiated	0.000	0.000	ns	ns	1.000	
Volcanic	0.039	0.000	ns	ns	0.033	1.000
<u>Nitrate-Nitrite</u>						
Alluvium	1.000					
Metamorphic	ns	1.000				
Sedimentary Clastic	ns	ns	1.000			
Sedimentary Sandstone	ns	ns	0.013	1.000		
Sedimentary Undifferentiated	ns	ns	0.050	ns	1.000	
Volcanic	ns	ns	0.001	ns	ns	1.000
<u>Chloride</u>						
Alluvium	1.000					
Metamorphic	ns	1.000				
Sedimentary Clastic	ns	ns	1.000			
Sedimentary Sandstone	ns	ns	0.030	1.000		
Sedimentary Undifferentiated	ns	ns	ns	ns	1.000	
Volcanic	ns	ns	0.002	ns	ns	1.000
<u>Sulfate</u>						
Alluvium	1.000					
Metamorphic	ns	1.000				
Sedimentary Clastic	ns	ns	1.000			
Sedimentary Sandstone	ns	ns	ns	1.000		
Sedimentary Undifferentiated	ns	ns	ns	ns	1.000	
Volcanic	ns	ns	ns	ns	ns	1.000
<u>Fluoride</u>						
Alluvium	1.000					
Metamorphic	ns	1.000				
Sedimentary Clastic	ns	ns	1.000			
Sedimentary Sandstone	ns	ns	0.008	1.000		
Sedimentary Undifferentiated	ns	ns	ns	ns	1.000	

Appendix F. Bonferonni Post-Hoc Results for Differences Among Land Use Classes

Field Conductivity, Significant Differences

Land Use	Agriculture	Forest Uses	Mining	Pasture/Range
Agriculture	1.000			
Forest Uses	ns	1.000		
Mining	ns	0.000	1.000	
Pasture/Range	ns	0.000	ns	1.000

Dissolved Oxygen, Significant Differences

Land Use	Agriculture	Forest Uses	Mining	Pasture/Range
Agriculture	1.000			
Forest Uses	ns	1.000		
Mining	ns	0.000	1.000	
Pasture/Range	ns	0.000	ns	1.000

Field Turbidity, Significant Differences

Land Use	Agriculture	Forest Uses	Mining	Pasture/Range
Agriculture	1.000			
Forest Uses	ns	1.000		
Mining	ns	0.005	1.000	
Pasture/Range	ns	0.000	ns	1.000

Total Suspended Solids, Significant Differences

Land Use	Agriculture	Forest Uses	Mining	Pasture/Range
Agriculture	1.000			
Forest Uses	ns	1.000		
Mining	ns	ns	1.000	
Pasture/Range	ns	0.000	ns	1.000

Percent O_2 Saturation, Significant Differences

Land Use	Agriculture	Forest Uses	Mining	Pasture/Range
Agriculture	1.000			
Forest Uses	ns	1.000		
Mining	ns	0.000	1.000	
Pasture/Range	ns	0.000	ns	1.000

Kjeldahl Nitrogen, Significant Differences

Land Use	Agriculture	Forest Uses	Mining	Pasture/Range
Agriculture	1.000			
Forest Uses	ns	1.000		
Mining	ns	0.011	1.000	
Pasture/Range	ns	0.000	ns	1.000

Field pH, Significant Differences

Land Use	Agriculture	Forest Uses	Mining	Pasture/Range
Agriculture	1.000			
Forest Uses	ns	1.000		
Mining	ns	0.016	1.000	

Lab Total Dissolved Solids, Significant Differences

Land Use	Agriculture	Forest Uses	Mining	Pasture/Range
Agriculture	1.000			
Forest Uses	ns	1.000		
Mining	ns	0.000	1.000	
Pasture/Range	ns	0.001	ns	1.000

Field Total Dissolved Solids, Significant Differences

Land Use	Agriculture	Forest Uses	Mining	Pasture/Range
Agriculture	1.000			
Forest Uses	ns	1.000		
Mining	ns	0.000	1.000	
Pasture/Range	ns	0.002	ns	1.000

Appendix G1. Coldwater IBI scores, causes and sources for Upper Gila River Basin samples, Spring 1992-2000

Station ID	Year	Index Period	Stream Type	IBI Score	Narrative Rating	Most Probable Cause	Secondary Cause(s)	Most Probable Source	Secondary Sources
UGBLR021.95	2000	Spring	cold	74.7	Impaired	Sediment		Naturally erodible soils	Pasture, upland grazing
UGBLR033.04	1992	Spring	cold	89.1	Good				
UGBLR033.04	1993	Spring	cold	66.5	Impaired	Sediment		Naturally erodible soils	Pasture, upland grazing
UGBLR033.04	1994	Spring	cold	84.8	Impaired	Sediment		Naturally erodible soils	Pasture, upland grazing
UGBLR033.04	1996	Spring	cold	99.5	Exceptional				
UGBLR033.04	2000	Spring	cold	92.9	Good				
UGCAV007.46	1997	Spring	cold	48.4	Impaired	Intermittency		Intermittency	
UGCAV007.46	1998	Spring	cold	67.0	Impaired	Intermittency		Intermittency	
UGCAV007.64	1997	Spring	cold	49.1	Impaired	Sediment	Thermal	Natural	
UGCAV007.64	1999	Spring	cold	45.8	Impaired	Sediment	Thermal	Natural	
UGCAV007.64	2000	Spring	cold	53.3	Impaired	Sediment	Thermal	Natural	
UGCAV007.70	1997	Spring	cold	47.0	Impaired	Intermittency	Sediment	Intermittency	
UGCAV007.70	1998	Spring	cold	74.0	Impaired	Intermittency	Sediment	Intermittency	
UGCAV008.49	1997	Spring	cold	54.8	Impaired	Intermittency	Sediment	Intermittency	
UGCAV008.49	1998	Spring	cold	89.6	Good				
UGCAV008.92	1997	Spring	cold	56.7	Impaired	Habitat	Bedrock,	Grazing	Upwelling,
UGCAV008.92	1999	Spring	cold	70.4	Impaired	Habitat	Bedrock,	Grazing	Upwelling,

Station ID	Year	Index Period	Stream Type	IBI Score	Narrative Rating	Most Probable Cause	Secondary Cause(s)	Most Probable Source	Secondary Sources
UGCAV009.86	1997	Spring	cold	55.4	Impaired	Low DO	Sediment	Natural	Upwelling, debris flows,
UGCAV009.86	1998	Spring	cold	100.0	Exceptional				
UGCAV009.86	1999	Spring	cold	83.5	Impaired	Low DO	Sediment	Natural	Upwelling, debris flows, grazing
UGCMB002.16	1992	Spring	cold	86.4	Impaired	Crayfish	Low DO	Natural	Crayfish, upwelling zone,
UGCMB002.16	1993	Spring	cold	96.4	Good				
UGCMB002.16	1994	Spring	cold	82.4	Impaired	Crayfish	Low DO	Natural	Crayfish, upwelling zone,
UGCMB002.16	1996	Spring	cold	96.3	Good				
UGCMB002.16	2000	Spring	cold	100.0	Exceptional				
UGCOL002.49	1992	Spring	cold	90.0	Good				
UGCOL002.49	1993	Spring	cold	84.7	Impaired	Habitat		Natural	Grazing, road
UGCOL002.49	1994	Spring	cold	97.1	Good				
UGCOL002.49	1996	Spring	cold	100.0	Exceptional				
UGEAG035.99	1992	Spring	cold	59.3	Impaired	Sediment	Crayfish	Roads	Predation
UGEAG035.99	1993	Spring	cold	52.1	Impaired	Sediment	Crayfish	Roads	Predation
UGEAG035.99	1994	Spring	cold	54.7	Impaired	Sediment	Crayfish	Roads	Predation
UGEAG035.99	1996	Spring	cold	63.6	Impaired	Sediment	Crayfish	Roads	Predation
UGEAG035.99	2000	Spring	cold	55.3	Impaired	Sediment	Crayfish	Roads	Predation

Station ID	Year	Index Period	Stream Type	IBI Score	Narrative Rating	Most Probable Cause	Secondary Cause(s)	Most Probable Source	Secondary Sources
UGETK007.70	1992	Spring	cold	100.0	Exceptional				
UGETK007.70	1993	Spring	cold	100.0	Exceptional				
UGETK007.70	1994	Spring	cold	89.7	Good				
UGETK007.70	1995	Spring	cold	51.6	Impaired	Habitat	Bedrock	Natural	
UGETK007.70	1998	Spring	cold	76.3	Impaired	Habitat	Bedrock	Natural	
UGFRY007.00	1992	Spring	cold	86.5	Impaired	Intermittency	Bedrock	Intermittency	Bedrock
UGFRY007.00	1993	Spring	cold	96.4	Good				
UGFRY007.00	1994	Spring	cold	91.8	Good				
UGFRY007.00	1996	Spring	cold	80.7	Impaired	Intermittency	Bedrock	Intermittency	Bedrock
UGGRA000.65	1992	Spring	cold	100.0	Exceptional				
UGGRA000.65	1993	Spring	cold	75.8	Impaired	Intermittency	1993 floods	Intermittency	
UGGRA000.65	1994	Spring	cold	44.6	Impaired	Intermittency		Intermittency	
UGLAN000.60	1992	Spring	cold	73.8	Impaired	Sediment	Nutrients	Grazing	Natural
UGLAN000.60	1993	Spring	cold	69.5	Impaired	Sediment	Nutrients	Grazing	Natural
UGLAN000.60	1994	Spring	cold	80.7	Impaired	Sediment	Nutrients	Grazing	Natural
UGLAN000.60	1996	Spring	cold	70.4	Impaired	Sediment	Nutrients	Grazing	Natural
UGMRW007.98	1992	Spring	cold	87.5	Impaired	Intermittency		Intermittency	
UGMRW007.98	1993	Spring	cold	96.4	Good				
UGMRW007.98	1994	Spring	cold	79.9	Impaired	Intermittency		Intermittency	
UGSCV000.12	1997	Spring	cold	62.9	Impaired	Intermittency		Intermittency	Debris flows,
UGSCV000.12	1998	Spring	cold	62.4	Impaired	Intermittency		Intermittency	Debris flows,

Station ID	Year	Index Period	Stream Type	IBI Score	Narrative Rating	Most Probable Cause	Secondary Cause(s)	Most Probable Source	Secondary Sources
UGSCV002.45	1992	Spring	cold	78.7	Impaired	Sediment	GW	Natural	Debris flows,
UGSCV002.45	1993	Spring	cold	96.4	Good				
UGSCV002.45	1994	Spring	cold	79.6	Impaired	Sediment	GW Upwelling	Natural	Debris flows, GW upwelling
UGSCV002.45	1995	Spring	cold	23.2	Very Impaired	Sediment	GW Upwelling	Natural	Debris flows, GW upwelling
UGSCV002.45	1998	Spring	cold	64.7	Impaired	Sediment	GW Upwelling	Natural	Debris flows, GW upwelling
UGSCV2.26	1997	Spring	cold	61.1	Impaired	Intermittency		Intermittency	
UGSFNM	2000	Spring	cold	73.73	Impaired	Sediment		Grazing	
UGBLR005.68	2000	Spring	warm	82.2	Exceptional				
UGBLR008.07	1992	Spring	warm	59.3	Good				
UGBLR008.07	1993	Spring	warm	53.3	Good				
UGBLR008.07	1994	Spring	warm	58.8	Good				
UGBLR008.07	1996	Spring	warm	78.4	Exceptional				
UGBON000.20	2000	Spring	warm	77.9	Exceptional				
UGBON004.82	1993	Spring	warm	54.2	Good				
UGBON004.82	1994	Spring	warm	63.1	Good				
UGBON004.82	1995	Spring	warm	46.2	Impaired	Sediment		Roads	Grazing
UGBON004.82	1996	Spring	warm	73.5	Exceptional				
UGBON011.31	2000	Spring	warm	78.2	Exceptional				
UGEAG007.78	2000	Spring	warm	74.2	Exceptional				
UGEAG023.34	1992	Spring	warm	69.8	Good				

Station ID	Year	Index Period	Stream Type	IBI Score	Narrative Rating	Most Probable Cause	Secondary Cause(s)	Most Probable Source	Secondary Sources
UGEAG023.34	1993	Spring	warm	54.6	Good				
UGEAG023.34	1994	Spring	warm	70.5	Good				
UGEAG023.34	2000	Spring	warm	68.4	Good				
UGEMC011.21	1995	Spring	warm	30.4	Impaired	Sediment		Grazing	Natural
UGPIG001.33	1993	Spring	warm	65.8	Good				
UGSFR003.04	2000	Spring	warm	73.5	Exceptional				
UGSFR011.29	2000	Spring	warm	78.0	Exceptional				
UGSFR011.68	1992	Spring	warm	71.6	Good				

Appendix G2. Warmwater IBI scores, causes, and sources for Upper Gila River Basin samples, Spring 1992-2000.

Station ID	Year	Index Period	Stream Type	IBI Score	Narrative Rating	Most Probable Cause	Secondary cause(s)	Most Probable source	Secondary sources
UGBLR005.68	2000	Spring	warm	82.2	Exceptional				
UGBLR008.07	1992	Spring	warm	59.3	Good				
UGBLR008.07	1993	Spring	warm	53.3	Good				
UGBLR008.07	1994	Spring	warm	58.8	Good				
UGBLR008.07	1996	Spring	warm	78.4	Exceptional				
UGBON000.20	2000	Spring	warm	77.9	Exceptional				
UGBON004.82	1993	Spring	warm	54.2	Good				
UGBON004.82	1994	Spring	warm	63.1	Good				
UGBON004.82	1995	Spring	warm	46.2	Impaired	Sediment		Roads	Grazing
UGBON004.82	1996	Spring	warm	73.5	Exceptional				
UGBON011.31	2000	Spring	warm	78.2	Exceptional				
UGEAG007.78	2000	Spring	warm	74.2	Exceptional				
UGEAG023.34	1992	Spring	warm	69.8	Good				
UGEAG023.34	1993	Spring	warm	54.6	Good				
UGEAG023.34	1994	Spring	warm	70.5	Good				
UGEAG023.34	2000	Spring	warm	68.4	Good				
UGEMC011.21	1995	Spring	warm	30.4	Impaired	Sediment		Grazing	Natural
UGPIG001.33	1993	Spring	warm	65.8	Good				
UGSFR003.04	2000	Spring	warm	73.5	Exceptional				
UGSFR011.29	2000	Spring	warm	78.0	Exceptional				
UGSFR011.68	1992	Spring	warm	71.6	Good				

Appendix G3. IBI scores, causes and sources for Upper Gila River Basin samples, Fall 1996-1998.

Station ID	Year	Index Period	Stream Type	IBI Score	Narrative Rating	Most Probable Cause	Secondary cause(s)	Most Probable source	Secondary sources
UGBON000.20	1996	Fall	warm	73.4	Exceptional				
UGBON000.20	1997	Fall	warm	74.7	Exceptional				
UGBON003.17	1996	Fall	warm	73.1	Exceptional				
UGBON007.87	1996	Fall	warm	65.4	Good				
UGBON011.31	1996	Fall	warm	62.5	Good				
UGGLR190.39	1997	Fall	warm	73.1	Exceptional				
UGGLR190.45	1997	Fall	warm	73.3	Exceptional				
UGGLR194.91	1997	Fall	warm	68.2	Good				
UGSFR000.04	1997	Fall	warm	78.8	Exceptional				
UGSFR011.29	1997	Fall	warm	80.5	Exceptional				
UGCAV007.46	1998	Fall	cold	61.7	Impaired	Intermittency		Intermittency	
UGCAV007.70	1998	Fall	cold	62.9	Impaired	Intermittency		Intermittency	
UGCAV008.49	1998	Fall	cold	65.2	Impaired	Intermittency		Intermittency	
UGCAV009.86	1998	Fall	cold	94.3	Good				
UGCAV009.86	1998	Fall	cold	94.3	Good				
UGSCV000.12	1998	Fall	cold	71.0	Impaired	Intermittency		Intermittency	
UGSCV002.26	1998	Fall	cold	84.0	Impaired	Intermittency		Intermittency	