Boulder Creek Watershed Inventory & Characterization

Part I of the Boulder Creek Implementation Plan

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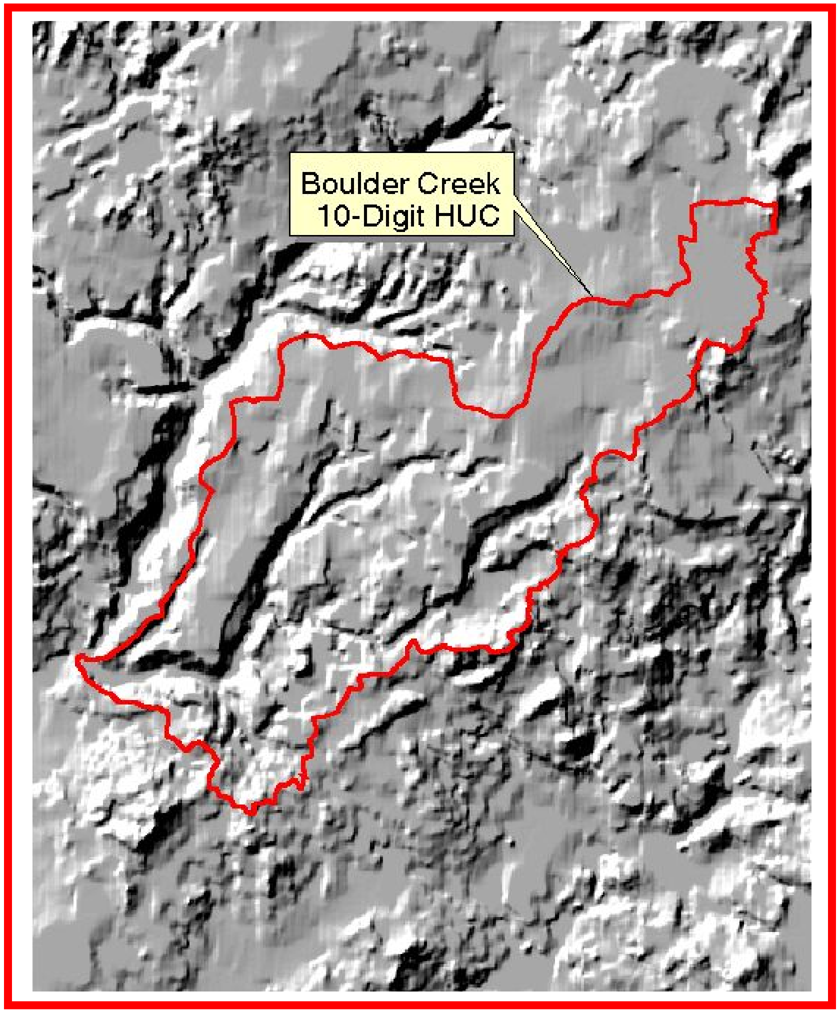

Satellite Map View of the Boulder Creek Watershed

Abstract

This Watershed Inventory and Characterization was prepared by Max Enterline, using Geographic Information Systems (GIS) at the Arizona Department of Environmental Quality (ADEQ) in 2003. The information was compiled from existing data sources available on ADEQ's GIS system and other agency sources that were available at the time of this report. ArcView 3.2 and ArcGIS 8.3 were also used to compile the maps. The "clipping method" was used with ESRI's ArcInfo software to quantify and qualify the basic environmental information needed to further understand the nature and "character" of the ecosystem in Boulder Creek.

ADEQ is required to prepare such a plan due to existing and historical impairments to the watershed based on state statutes, A.R.S. 49-231(3) (ADEQ, 2002-2003). The geographic scale of the watershed is considered a 10-digit Hydrologic Unit Code (HUC) watershed based on the latest information from the National Resource Conservation Service (NRCS), formerly known as the Soil Conservation Service (SCS).

The goal is that this report, parts I & II can fulfill ADEQ's mission of compiling comprehensive environmental information for an area of Arizona that is considered "impaired" due to heavy metal mining contamination in Boulder Creek. Boulder Creek has experienced problems for many years due to the abandoned "Hillside Mine," three large tailings piles and a perennial adit discharge from the toe of the middle pile. A Total Maximum Daily Load (TMDL) report was prepared to find and allocate the main pollution sources that are currently causing heavy metals to be present in Boulder Creek. This report focuses on the baseline information needed to startup the process of planning for cleanup, and Part II focuses on implementing the TMDL report recommendations; see Boulder Creek Implementation Plan – Part II.

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Glossary of Frequently used Terms and Acronyms

ADEQ	Arizona Department of Environmental Quality
ADWR	Arizona Department of Water Resources
AGFD	Arizona Game & Fish Department
ALRIS	Arizona State Land Information System Website
ASLD	Arizona State Land Department – Stakeholder
A.R.S.	Arizona Revised Statutes
AZPDES	Arizona Pollution Discharge Elimination System
BLM	Bureau of Land Management – Stakeholder
BMP	Best Management Practice – Same as MM
DOI	Department of the Interior
EPA	Environmental Protection Agency
FSN	Fixed Station Network – Sampling Program
GAP	Geographic Gap Analysis Program
GIS	Geographic Information Systems – Mapping Software
HUC	Hydrologic Unit Code – Numeric Watershed Code
LTP	Lower Tailings Pile
MDAS	Mining Data Analysis System – A Model
MLRU	Major Land Resource Unit – Land Use Cover
MM	Management Measure – Same as BMP
m.s.l.	Mean Sea Level
MTP	Middle Tailings Pile
NPDES	National Pollution Discharge Elimination System
NPS	nonpoint source pollution
NRCS	National Resource Conservation Service
PS	Point Source pollution
TIP	TMDL Implementation Plan
TMDL	Total Maximum Daily Load
UMTRA	Uranium Mine Tailings Reclamation Act
USFS	United States Forest Service
USGS	United States Geological Survey
UTP	Upper Tailings Pile
WBP	Watershed-based Plan

1.0 Historical Background

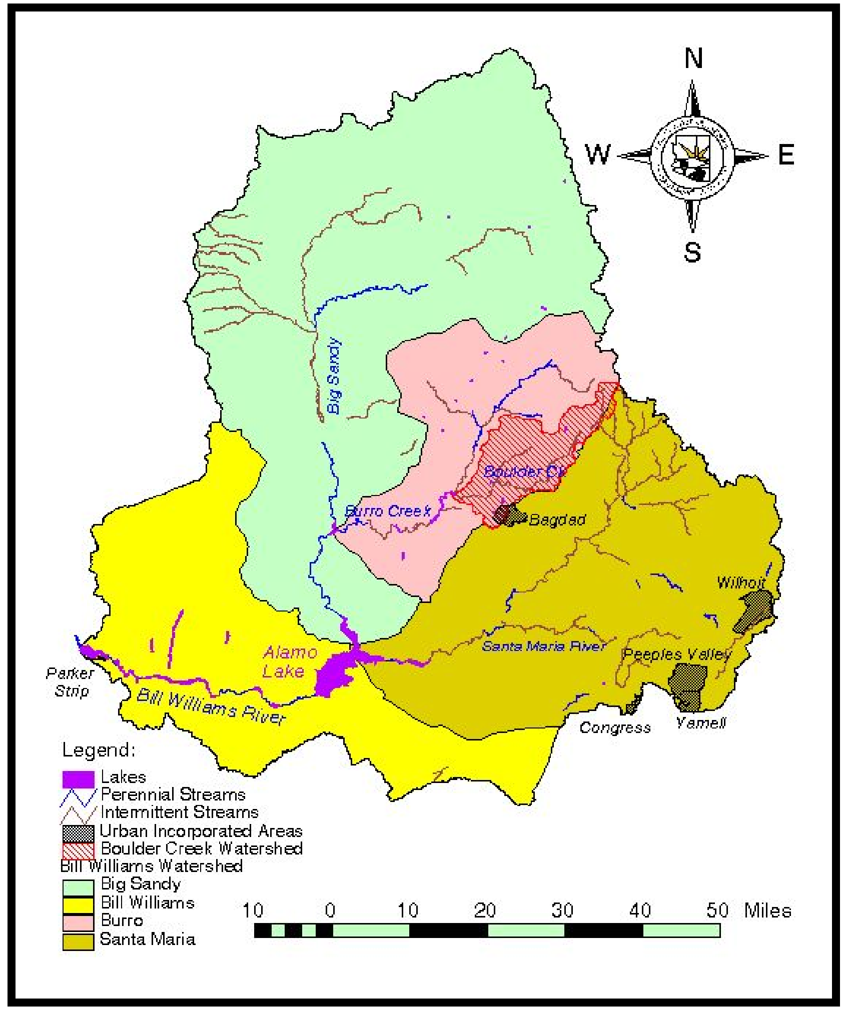
Understanding the basic environmental conditions of a given watershed provides the necessary background information to create an adequate implementation plan for a water body that needs restoration. Boulder Creek's size, main topographic features, surface water hydrology, climate, groundwater hydrology, geology, soil types, vegetation zones, land ownership, historical land uses and human activities on the landscape are provided in this inventory. This type of scientific information allows land managers to adjust and adaptively manage an area using a watershed approach, promoting a better watershed strategy. This information can also provide scientists a more accurate picture and help them predict with models what types of surface water flows can be achieved after storm events, assisting with future TMDL calculations based on highly variable flow conditions. Providing the baseline information of upland and downstream conditions is a crucial step towards finding feasible solutions and possible removal of pollution stressors, and can help clarify the means of doing so. This inventory and characterization is a starting point where stakeholders can share the knowledge about their watershed so they can find better ways to manage their land holdings and realize environmental improvements.

2.0 Geography/Topography

Boulder Creek is located in Western Yavapai County, near Bagdad Arizona. Boulder Creek is mostly an intermittent stream course, which flows approximately 37 linear miles from its headwaters near Camp Wood Mountain towards the confluence with Burro Creek. The Boulder Creek Watershed basin is considered a 10-digit hydrologic unit code (HUC) watershed, designated by the 10 digits 15030202-03 (NRCS, 2003). ADEQ utilized the new mapping delineation from the NRCS as a tool to help illustrate, define and characterize the Boulder Creek Watershed using GIS. Boulder Creek lies within the larger Burro Creek 8-digit HUC watershed designated as 15030202. Burro Creek lies completely within the larger Bill Williams Watershed area. Bill Williams is comprised of four of these larger 8-digit HUCs, including Burro Creek, the Santa Maria River, the Big Sandy River and the Bill Williams River below Alamo Lake. The Bill Williams Watershed is one of ten major watersheds that ADEQ uses to divide the state into "manageable regions" (See Map 1: Arizona's Ten Major Watersheds).

Map 1: Arizona's Ten Major Watersheds

The approximate size of the Boulder Creek Watershed is 150 square miles, and its uppermost elevation starts at Camp Wood Mountain, elevation 7,250 feet above mean sea level (m.s.l.). The lowest pour point of the watershed is 2,420 feet m.s.l. as it joins at the confluence with adjacent Burro Creek. The entire watershed drops in elevation from the northeast to the southwest over 4,800 feet from Camp Wood Mountain to Burro Creek (See Map 2: Bill Williams Watershed).



Map 2: Bill Williams Watershed

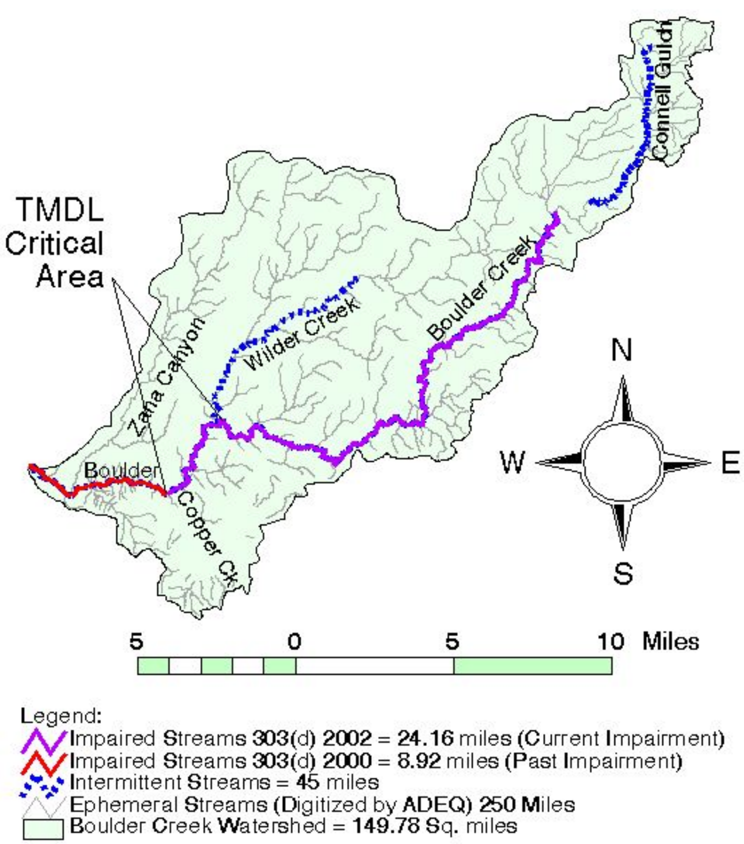
In a satellite photograph one can clearly see two deeply incised canyons, Boulder and Wilder Creek Canyons that dominate the middle and lower portions of the watershed. The upper northeast section appears to be more level terrain, comprised mostly of U.S. Forest land areas near Camp Wood Mountain (See Cover Page: Satellite Map).

3.0 Surface Hydrology

Starting in a forested area at the top of Camp Wood Mountain, at 7,250 m.s.l. numerous dry wash “arroyos” are formed and they flow generally to the south-southeast, forming a large wash known as Connell Gulch. Several side tributaries connect to Connell Gulch. The upland area also has several stock tanks, springs, seeps and ephemeral ponds along the drainage areas. Connell Gulch connects with Stubbs Gulch further downhill forming the headwaters of Boulder Creek at ~5480 m.s.l. Boulder Creek then trends to the south, flowing past Silent Basin, Wild Horse Basin, Behm Mesa and Contreras Wash. Boulder Creek also flows past the abandoned “Black Pearl” mine. Boulder Creek then joins with the 2nd largest stream in the watershed, Wilder Creek. Wilder Creek has numerous tributaries, stock tanks, pools, ponds and springs that originate from Strotjost Flat, Windy Ridge, Behm Mesa, Bozarth Mesa, Contreras Mesa and Long Point.

Steady flows are usually dependant on winter storms and spring snowmelt. Flows typically occur from late October to late May, with the highest flow rates from late January to early March. According to the TMDL report, during summer and extended drought conditions: Boulder Creek consists of a number of independent pools separated by long stretches of dry streambed.

Just downstream of the confluence with Wilder Creek and Boulder Creek, the “critical area” begins.

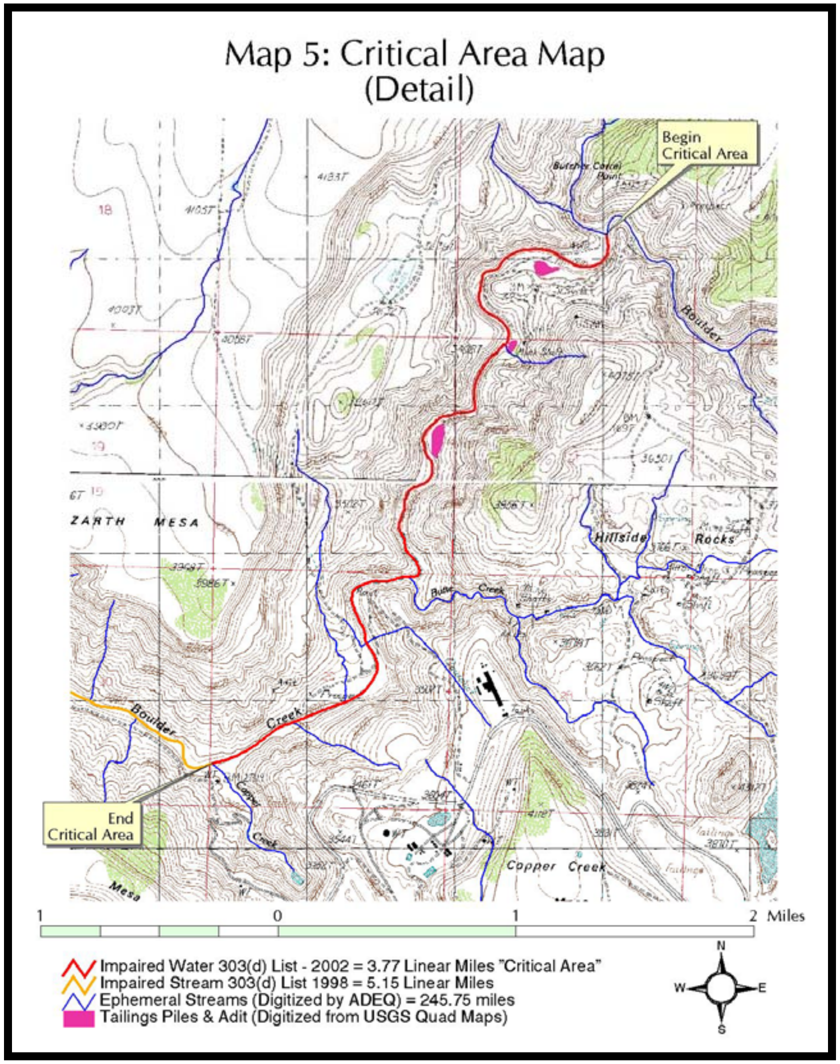


Map 4: TMDL Critical Area

The TMDL report defines the critical area where the pollution impairments are known to be located, and where the TMDL researchers concentrated their sampling efforts (ADEQ, 2003). Just west and south of the Wilder Creek confluence, remnants of the former Hillside Mine can be easily observed next to the Boulder Creek drainage. Three large tailings piles with eroded dam structures and the collapsed head frame entrance can still be seen next to the Boulder Creek main stem.

Erosion is evident on all three tailings piles and the dam structures need repair that lie next to Boulder Creek. At the Upper Tailings Pile the surface topography is very steep, creating a difficult access issue for the general area. Boulder Creek then bends back to the south passing by the other two large tailings piles. The middle and lower tailings piles are also located in very steep terrain further south. After passing the TMDL critical area for impairments Boulder Creek intersects Copper Creek, an aptly named drainage (See Critical Area Maps 4 & 5).

Copper Creek still has an active mining operation by Phelps Dodge located further east-southeast of Boulder Creek, next to the town of Bagdad Arizona. The Copper Creek area has been heavily modified, the natural hydrology has been disconnected due to copper mining. Copper Creek is completely modified from its natural state by tailings and aeration ponds, overburden piles, engineering controls and retention control structures.



Map 5: TMDL Critical Area Detail

These mine structures, erosion control structures and pollution controls limit and control surface water flows that may contain heavy metals. The TMDL report in 2003 determined that copper mining pollutants no longer contribute pollutant loadings to Boulder Creek from Copper Creek. Downstream of this confluence with Copper Creek, Boulder Creek is no longer listed for heavy metal impairments and was subsequently “de-listed” based on the TMDL sampling and analyses (ADEQ, 2003).

At this point on Boulder Creek below Copper Creek most of the heavy metals have naturally attenuated from the Hillside Mine due to the large distance; lack of flows and partially due to heavy metal precipitation within the water column. Heavy metals precipitate in the water column by dropping off and saturating within the stream sediments as the water flow rate slows down over distance. The TMDL model utilized this precipitation variable to more accurately predict the fate of transport of these heavy metal pollutants (See the Boulder Creek Implementation Plan, Part II for further discussion pp. 15-16).

Further downstream Boulder Creek turns to the west past Bozarth Mesa; Scorpion Mesa - a large re-vegetated tailings pile; one side tributary from Mulholland Basin; and past Zana Canyon located on the western fringe of the Boulder Creek Watershed. Finally Boulder Creek ends where it joins at the “pour point” with the *Unique Water* known as Burro Creek. Burro Creek and one of the tributaries Francis Creek were nominated as unique waters due to their recreational or ecological significance and offer critical habitat for threatened or endangered species (ADHS & BLM, 1985).

Digitized Stream Lengths in GIS

All streams in Boulder Creek = 296 miles

Intermittent streams = 45 miles

Ephemeral streams = 251 miles

Boulder Creek, headwaters to pour point = 39.72 miles

Wilder Creek, headwaters to pour point = 17.26 miles

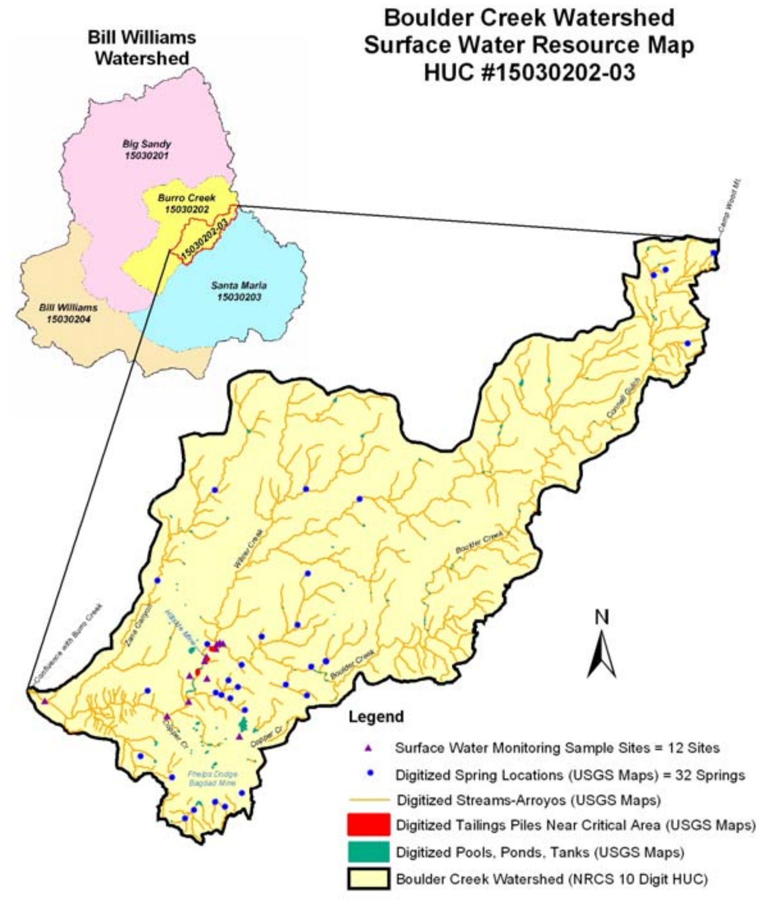
Zana Canyon, headwaters to pour point = 14.93 miles

Based on the GIS analysis conducted for this report, 32 springs, seeps or wells were identified for the entire Boulder Creek 10-digit HUC watershed. The original spring cover available on the State Land Department website known as ALRIS only identified 21 springs for the watershed after clipping. It should be noted that the Behm Mesa 7.5 minute USGS topographic quadrangle map did not have any springs, seeps or wells identified on the base map. Therefore this lack of information appears to be a data gap regarding this portion of the watershed and could be augmented with more accurate mapping information at a later date. ADEQ digitized all the drainages colored blue on the USGS maps in GIS to gain a more accurate estimate of the stream lengths by zooming in close on each water body. The stream lengths are listed in the text box at left.

One caveat is that *some* of the intermittent stream miles shown in GIS may actually be perennial flowing stream segments depending on annual climate conditions, based on conversations with ADEQ's TMDL field personnel.

Year round perennial flows in Boulder Creek's watershed require on-the-ground verification. GIS digitizing with remote viewing is a method that usually has a built-in margin of error when there is no on-the-ground verification.

Another caveat is the GIS analysis is static in time based on the dates of existing GIS files and USGS maps. Due to the extreme drought conditions since the late 1990s, streams that were once perennial can change due to declining groundwater tables. The same is true for intermittent streams that can dry up so much they too change in character to being ephemeral, controlled strictly by rain events rather than rising groundwater tables. These changing hydrologic conditions are dynamic, can change periodically and are not static. (See

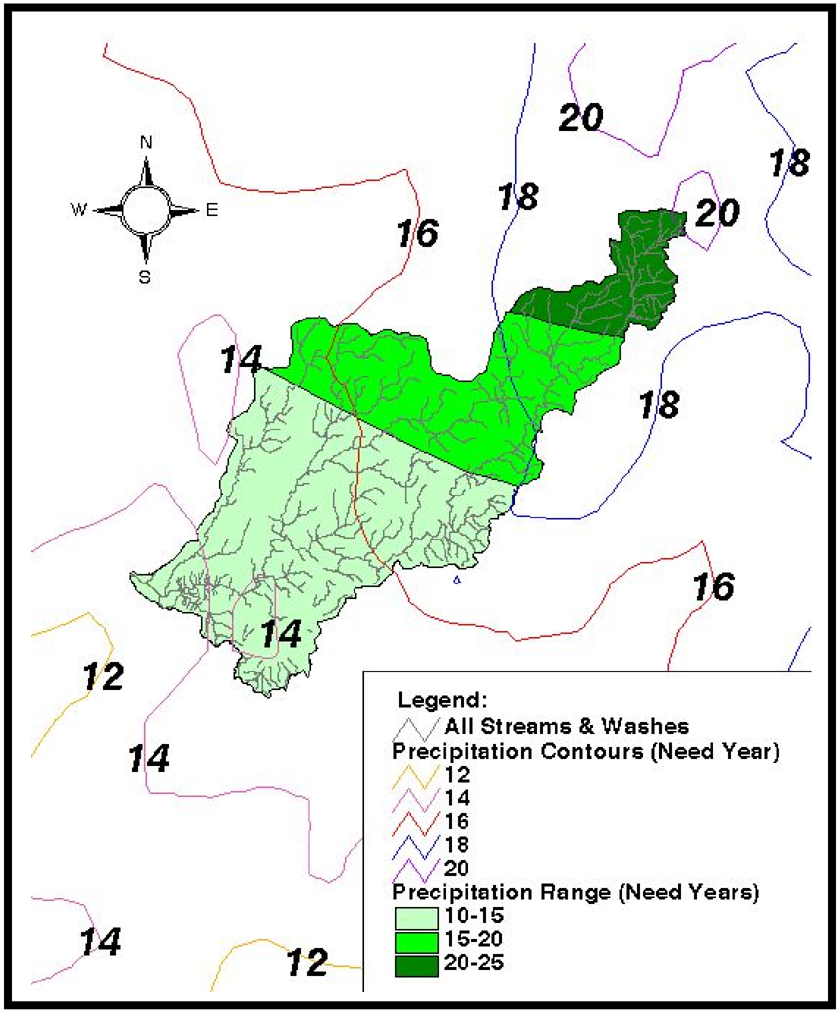


Map 6: Surface Water Resources Map

Map 6: Surface Water Resources Map & large fold out Surface Water Resources Map as a pocket part).

4.0 Climate

Typical for Arizona's watersheds, rain events vary in intensity from the short duration summer monsoon storms to the longer lasting winter rains. Winter rains are less intense and are more beneficial towards recharging the subsurface aquifers and vegetation. Less evaporation from surface waters and less evapotranspiration from plants typically occur in the winter as well.



Map 7: Precipitation Map

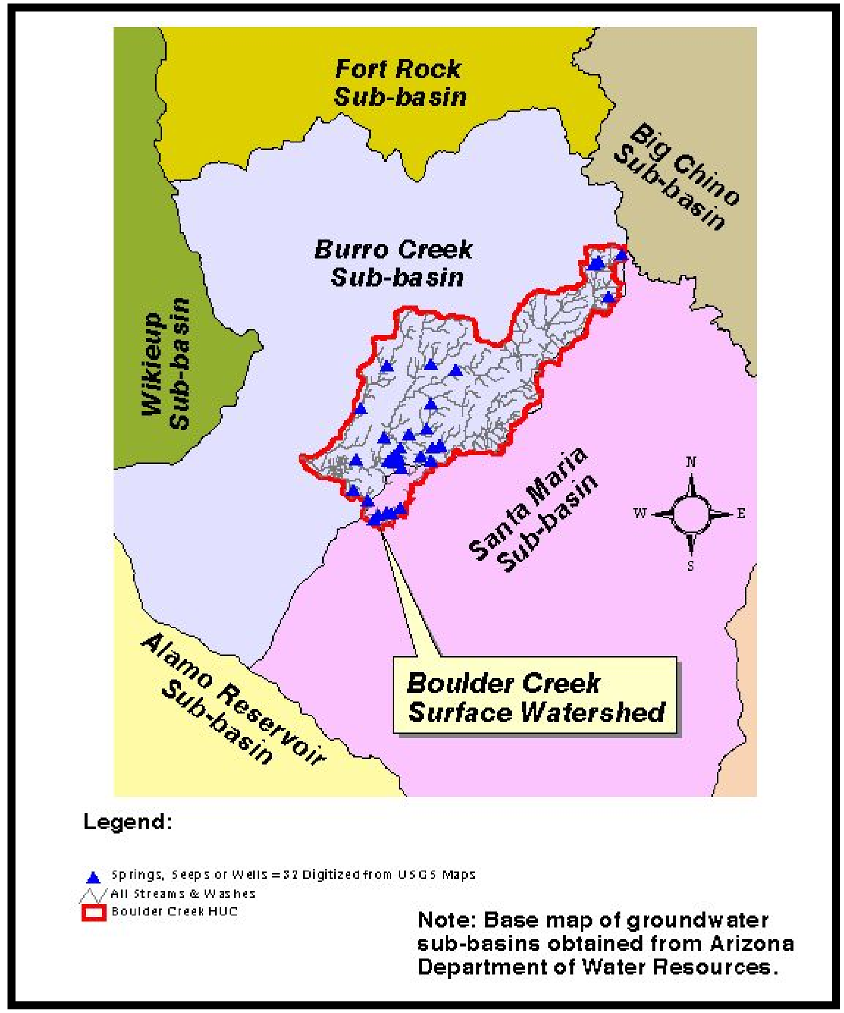
Summer monsoon events are flashier and can cause a great deal of erosion and flood damage. These high intensity storms are usually less beneficial in terms of groundwater and plant recharge. Higher rates of evaporation and evapotranspiration further limit the usefulness of summer rain events to the desert watersheds (See Map 7: Precipitation Map).

Precipitation in Boulder Creek ranges from 20-25 inches per year in the upland Prescott Forest area, especially near the peak of Camp Wood Mountain and elevations above 6000 feet m.s.l. From 4500 to 6000 feet the middle portions of the watershed typically have 15-20 inches of rain annually. Below 4500 feet one can expect 10-15 inches of rain per year in these dry desert portions of the watershed (See Map 7: Precipitation Map).

The nearest meteorological station in Bagdad has recorded precipitation data, providing representative conditions of the nearby Boulder Creek Watershed. The station is located at 3704 feet m.s.l. and has recorded continuous data since 1928. Average annual precipitation in Bagdad is 15 inches, with a low annual flow of 3 inches recorded in 1958 and a high of 29.2 inches in 1978. Daily temperature data since 1929 for Bagdad indicates an average annual temperature of 63.1 Fahrenheit (F). The temperature varied from average monthly readings of 45.7 F in January to 82.7 F in July (Tetra Tech, 2001).

5.0 Groundwater Hydrology

The connection between groundwater and surface water is very important. This relationship is especially important in drier desert regions like Boulder Creek, where groundwater is the only reliable source of potable water supply for drinking water and other commercial beneficial uses of water, such as mining. Two groundwater sub-basins lie underneath the Boulder Creek watershed. Groundwater “sub-basins” should not be confused with surface water "sub-basins". The most important groundwater sub-basin is the Burro Creek Sub-basin, which lies under most of the Boulder Creek surface watershed. The other groundwater sub-basin, which lies under the southern tip of the Boulder Creek Watershed, is the Santa Maria Sub-basin (ADWR, 2003).



Map 8: Groundwater Resources

This inventory identified 32 total springs, seeps or wells in the Boulder Creek watershed. These surface water features are controlled by groundwater level and pressure changes within the groundwater sub-basins (See Map 8: Groundwater Resources).

One spring-seep formed by a collapsed mining adit is located in the TMDL critical area where the Middle Tailings Pile (MTP) is located. This seep is considered one of the main loading sources of arsenic to the Boulder Creek river system. The TMDL report also quantifies the percentage of arsenic needing removal so the creek can meet applicable surface water standards (ADEQ, 2003).

6.0 Geology

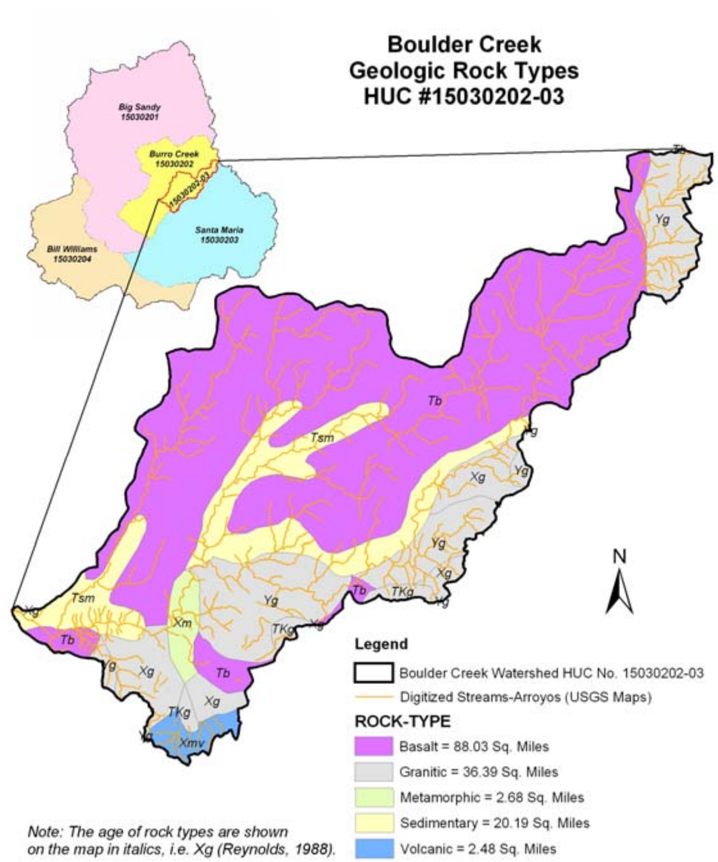
The geology of Boulder Creek consists of five major rock type categories: basalt, granitic, metamorphic, sedimentary and volcanic. Grouping the geologic zones into five basic rock type categories helps simplify our understanding of Boulder Creek's geology. Each rock type can exhibit different levels of groundwater saturation and storage potential.

For instance, alluvial rock types would be expected to have the most groundwater saturation and storage potential than other rock types. However, alluvial rock types were not identified in this watershed, re-affirming the dry "character" of the Boulder Creek watershed. Sedimentary rock types, somewhat similar to alluvium, also exhibit higher saturation and storage potential than the remaining rock types.

Rock Types	Square Miles	Percentage
Basalt	88	58.6%
Granitic	36.4	24.2%
Sedimentary	20	13.3%
Metamorphic	2.7	1.8%
Volcanic	2.5	1.6%

With this basic understanding, we can posit that this watershed has more limited groundwater resource potential when compared to other alluvial-dominated watersheds. Also, one would not expect to find as much groundwater stored in granitic or basalt formations unless there are subsurface fissures, pore spaces and/or voids that have the potential to store more groundwater reserves. Based on the GIS analysis of this watershed the Boulder Creek area is underlain by the following geologic rock types. The magnitudes of these rock types are also quantified by percentage of Boulder Creek's total area in the table above.

Based on the geologic findings one would not expect large amounts of groundwater reserves in the Boulder Creek area. Largest in magnitude, basalt underlies more than half of the watershed. Granitic rocks underlie another ¼ of the watershed. Sedimentary rock types represent only 13% of the entire watershed. Metamorphic rock types appear to underlie the critical area of the Hillside Mine, colored light-green. (See Map 9: Geologic Rock Types).



Map 9: Geologic Rock Types

Map Unit	Age	Rock Type
Tb	Late to middle Miocene; 8 to 16 Ma	Basalt
TKg	Early Tertiary to Late Cretaceous; 55 to 85 Ma	Granitic
Tsm	Middle Miocene to Oligocene; 15 to 38 Ma	Sedimentary
Xg	Early Proterozoic; 1650 to 1750 Ma	Granitic
Xm	Early Proterozoic; 1650 to 1800 Ma	Metamorphic
Xmv	Early Proterozoic; 1650 to 1800 Ma	Volcanic
Yg	Middle Proterozoic; 14000 Ma	Granitic

(Source: Stephen J. Reynolds, 1988)

Sedimentary areas of the watershed would be expected to have more groundwater potential, more springs, seeps or wells that are borne from sedimentary rock types in general. These sedimentary areas (colored yellow) are extremely important towards further development and/or applying for the beneficial uses of potential groundwater reserves. The different ages that these rock types were formed are also shown on adjacent table (Reynolds, 1988).

A more detailed analysis of Boulder Creek reveals the area's geologic complexity. Exposed rocks in this area are predominately Precambrian and Tertiary in age. Older Precambrian rocks consist of metamorphosed volcanic and sedimentary rocks that have been intruded and deformed by granitic and gabbroic rocks. These were subsequently covered by Cretaceous or early Tertiary rhyolite tuffs, intruded rhyolite dikes and quartz monzonite. Quaternary lava flows later carved into the present day mesas (Andersen et al, 1955). In the TMDL critical area Boulder Creek cuts through very steep canyons and mesas capped with Quaternary basalt flows and underlying basement rock. Near the Hillside Mine the creek cuts through a section of mica schist, metamorphosed sandstone and shale complex. Near the lower tailings pile the creek flows over Butte Falls tuff, a bedded, water saturated and metamorphosed tuff that grades upward into the mica schist near the Hillside Mine. Downstream a short distance from Butte Falls the creek gradient decreases and the canyons walls become less constrictive. Boulder Creek then flows over outcrops of gabbro, Gila conglomerate and Quaternary gravels (Andersen et al, 1955).

Another report from EPA indicates that Lawler Peak, a nearby mountaintop composed mainly of granite strikes underneath the Hillside Mine. The granite derived from Lawler Peak reportedly has higher levels of uranium naturally in the ore body than in other copper-mined regions of Arizona (EPA, 1999). Therefore, one would expect to see some higher background levels of uranium from the Lawler Peak granite than the background levels in other copper mined regions of the state.

Since the natural geology of Lawler Peak and the subsurface under the Hillside Mine have recorded higher background levels of uranium in the granite ore body one would also expect to see some higher uranium-radon readings from the Hillside Mine tailings piles than in other copper tailings across the state. Several surface water and soil analytical measurements were taken from the upper and middle tailings piles in 1993 by ADEQ that do indicate some higher levels than background for the Lawler Peak granites (ADEQ 1993 & EPA, 1999).

However, it should be noted that none of the readings taken in 1993 exceeded today's "applicable surface water quality standards" based on Boulder Creek's assigned designated uses (ADEQ, 2003). The adit discharge was also measured and was found to have high readings of "Gross Alpha", a by-product of uranium decay in rocks that would have violated 1993 drinking water standards, but currently there are no Domestic Water Source (DWS) designated uses are assigned to this remote area of Boulder Creek (ADEQ, 1993 & 2003).

7.0 Soils

Soils in the Boulder Creek Watershed are extremely important to understand. Aldo Leopold, a famous naturalist known as the father of wildlife ecology (1887-1948), observed that there is a strong relationship between soils and wildlife populations. Today watershed scientists have observed similarly that topsoil conditions have a strong correlation with water quality conditions in general.

This is true in the Boulder Creek region where soil sediment transport due to erosive soils can have an impact on the movement of heavy metal pollutants. Also, clay-dominated soils tend to absorb, store and potentially transport pollutants, though slow leaching and percolation the heavy metal mercury. Since there is a strong relationship between stream health and sediment erosion in a given watershed, gaining a basic understanding of soil types along the surface, their erosive capacity, slope and saturation potential are useful variables to consider for this Plan. Based on a clipping procedure used in ArcInfo GIS, surface soil textures were identified along with their magnitudes by percentage of the total watershed in the table below:

Soil Texture Types	Square Miles	Percentage
Cobbly-Clay	71.3	47.5%
Cobbly-Sandy Loam	21	14%
Very Gravelly-Sandy Loam	20.4	13.6%
Unweathered Bedrock	17.4	11.6%
Loam	10	6.6%
Gravelly-Loam	7	4.6%
Very Cobbly-Fine Sandy Loam	1.7	1.1%
Sandy Loam	1	0.6%

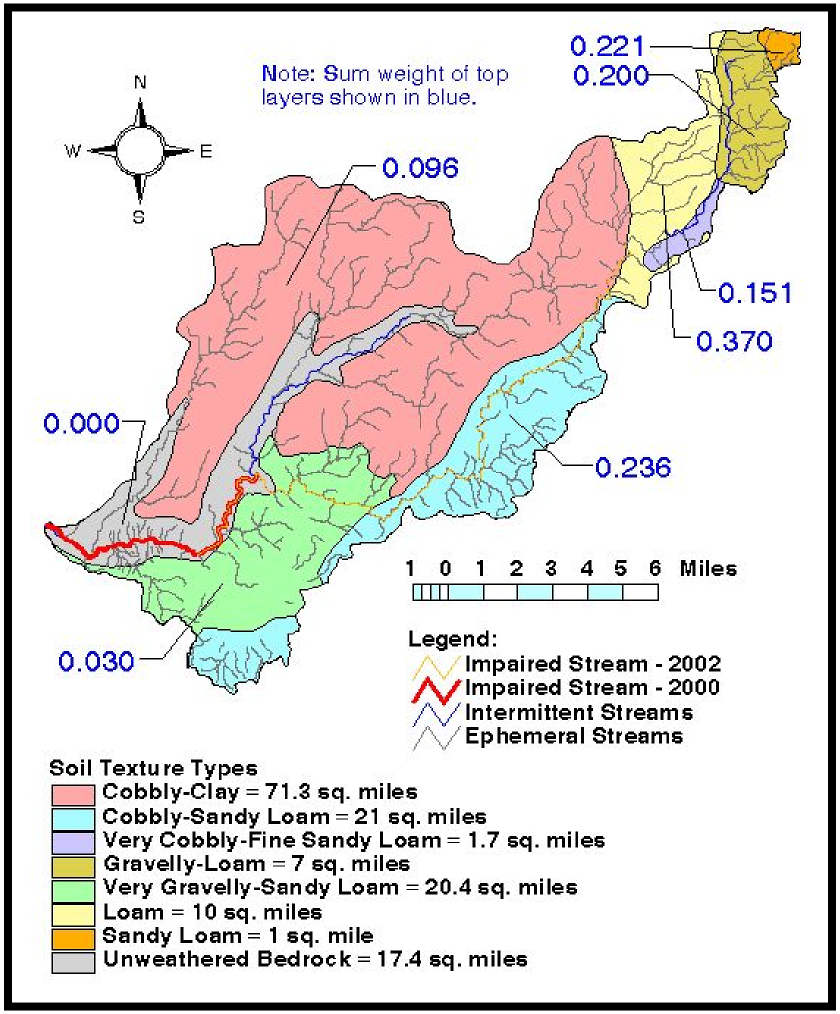
One interesting finding from the GIS soil cover file is that Wilder Creek and Boulder Creek's main stem is underlain by unweathered bedrock. This unweathered bedrock area extends through the TMDL critical area where the impairments are located. Clearly unweathered bedrock would be expected to be less erosive. Scoured bedrock areas would normally withstand erosional forces and allow water to transport farther and with greater speed down unweathered bedrock drainage areas. The erosive capacity information is measured in specific weights of each soil cover type, including the sum weight of the surface soils only, and another measurement showing the sum weight of the entire soil layer, expressed in average numbers.

The higher the recorded sum weight "K" factor number, the greater the erosive capacity of that soil type. For example, the "unweathered bedrock" in Wilder and Boulder Creek has the assigned soil weight value of 0.000, meaning this type of soil cover has a very low or almost "zero" erosive capacity. Therefore, the higher the sum weight average number, the more concerns we may have over erosion. See the soil type average sum weight numbers in the table below:

Soil Texture Types	Sum Weight All-K Factors	Sum Weight Top-K Factors
Cobbly-Clay	0.1755	0.0960
Cobbly-Sandy Loam	0.1416	**0.2360**
Very Gravelly-Sandy Loam	0.0233	0.0300
Unweathered Bedrock	0.0000	0.0000
Loam	0.2155	**0.3700**
Gravelly-Loam	0.2502	0.2000
Very Cobbly-Fine Sandy Loam	0.1399	0.1510
Sandy Loam	0.2118	**0.2210**

ADEQ's FSN Unit recently released a report that tested the statistical significance of these sum weighted average numbers for soils, and whether these values impact Total Suspended Solids (TSS), field turbidity and lab turbidity. These are typical monitoring measures of in-stream water quality health related to sediment transport. The FSN Unit determined that the sum weight of **top** layers had a statistically stronger confidence level than the sum weight of **all** layers. See table at right again that includes both the sum weights of **top** layers and **all** layers for clarity. The FSN unit stated, overall, as might be intuitively expected, the upper layer's soil erodibility was a better indicator of water quality problems than the average soil erodibility of all layers.

The average sum weight numbers of top layers highlighted **in bold** in the above table indicate the three most erosive areas in the watershed. Loam was the most highly erosive soil with a sum weight of top layers being 0.3700, located west of Camp Wood Mountain. Cobbly-Sandy Loam was 0.2360 and Sandy Loam 0.2210.



Map 10: Soil Surface Texture Map

Based on the GIS mapping and assigned specific weights of the top layers only, one can clearly see that the upper reaches have higher erodibility factors, and the downstream reaches exhibit lower erodibility factors (See Map 10: Soil Surface Texture Map).

Therefore, one would expect during a major rainstorm to see some of these loamy soils from the upper reaches, moving downhill to the lower reaches and sometimes depositing, and possibly transporting pollutants along with the erosive soils on top of Boulder Creek's unweathered bedrock areas. The motility (movement) of erosive sediments across hard landscapes like unweathered bedrock should be expected during major storm events. This basic understanding of soil characteristics in Boulder Creek near the Hillside Mine provides us with additional knowledge about the geomorphology of the critical area of impairments. Additional clues can be gleaned from this soil characterization information, such as where Cobbly-Clay soils are located above Wilder Creek. Knowledge of local soil conditions can possibly assist engineers, planners and water quality specialists to find better solutions for improving water quality in Boulder Creek.

For instance, determining where clay dominated soils located nearby could potentially assist in the use of capping materials for encapsulation of tailings piles

8.0 Vegetation

Few would argue that the relationships between plant life, wildlife, soil, groundwater, surface water, climate, agriculture and ranching are potential variables that can affect watershed health. In the field begin to understand whether a watershed is suffering based on visual indications of plant species stress.

Sometimes variables such as limited groundwater supplies; drought conditions, pollution and/or mismanagement of land are causally linked to vegetation health. The recruitment of native species and invasive species can be directly measured in the field by biologists to help develop short and/or long-term plans for land management.

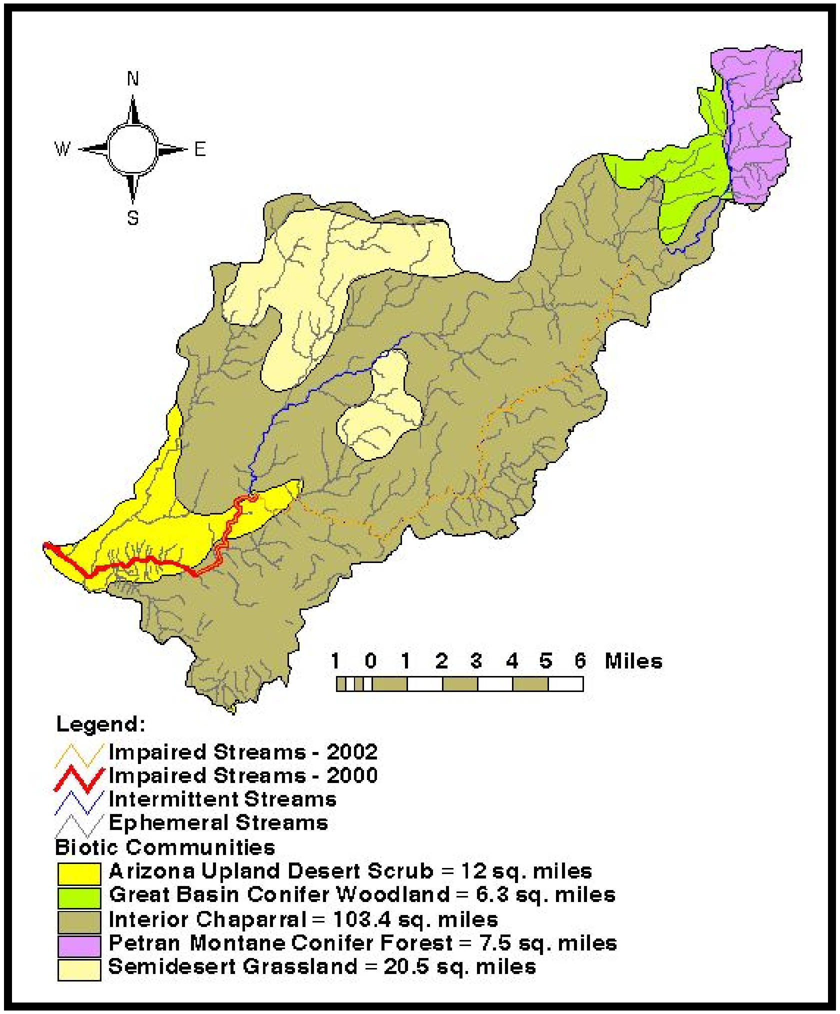
8.1 Biomes/Biotic Communities

Arizona researchers Brown, Lowe and Pace (BLP) helped create the first classification scheme for native vegetation types in this southwestern region, using biomes. “Use of the biome concept by BLP is its strength: Biomes are natural communities characterized by distinctive vegetation physiognomy and evolutionary history within a formation, i.e. forest, grassland, and swamp, persisting through time and space” (Halvorson et al, 2002).

The BLP classification system uses generalizations, or broad categories that are designated as biotic communities of each region. The purpose of the mapping effort was to “tie wildlife to recognized biomes to meet local assessment needs and for use by management at the regional level” (Halvorson et al, 2002). After clipping in ArcInfo GIS the following biotic communities or biomes were identified in the Boulder Creek Watershed showing the magnitude of each biome in descending order in the table below:

Biomes, Biotic Communities	Square Miles	Percentage
Interior Chaparral	103.4	68.9%
Semidesert Grassland	36.4	24.2%
AZ Upland Desert Scrub	12	8%
Petran Montane Conifer Forest	7.5	5%
Great Basin Conifer Woodland	6.3	4.2%

The table indicates the significance of the Interior Chaparral biome. Almost 70% of the watershed is classified in this biotic community. Also, the wide variation from Upland Desert, Semi-desert Grasslands, Interior Chaparral, Conifer Forest and Conifer Woodland shows the distinctive differences and climate changes from top to bottom (See Map 11: Biotic Communities).



Map 11: Biotic Communities

8.2 GAP Vegetation Classes

The University of Arizona in Tucson and Northern Arizona University in Flagstaff helped compile the GAP vegetation classification system in 2001. The GAP was formed to identify conservation priorities and “gaps” in the protection of biodiversity at a landscape scale (Halvorson et al, 2002). The researchers used satellite images taken from 1991 through 1993. Then they digitized around those areas that exhibited similar spectral rates, infra red light and other light-band frequencies (Halvorson et al., 2002).

The college researchers noted that this remote-viewing method was particularly effective in accurately identifying forest, woodlands, shrub and desert scrub communities. They also observed through caveat that grassland biomes were much harder to digitize with accuracy and differentiate using remote sensing satellite photo interpretation (Halvorson et al, 2002). The GAP project recently created an additional mapping research effort that directly correlates to this vegetation cover, showing animal species richness on a landscape scale. This species richness cover was not readily available at the time of this report.

An accuracy assessment was conducted for each vegetation classification in the final GAP report. "The purpose of the accuracy assessment is to allow potential users to determine the map's fitness for use in their applications." (Halvorson et al, 2002) Two of the zones "industrial" and "agricultural" were also considered to have a high accuracy rate for spectral interpretation. It is intuitive that these human-made zones would be more discernible from satellite images because they typically are easy to identify from surrounding more natural

GAP Vegetation Zones	**Square Miles**	**Percentage**
1. PJ (Mixed)/Mixed Chaparral-Scrub	52.2	34.7%
2. Interior Chaparral (Mixed)/ Mixed Grass-Scrub Complex	23.9	15.9%
3. Semidesert Grassland	20.5	13.6%
4. Pinyon-Juniper (Mixed)	19.2	12.7%
5. PJ/Sagebrush/Mixed Grass Scrub	10.4	6.9%
6. Industrial	8.3	5.5%
7. PJ-Shrub/Ponderosa Pine-Gambel Oak-Juniper	8.4	5.5%
8. Interior Chaparral (Mixed)/ Sonoran Paloverde-Mixed Cacti	6.6	4.4%
9. Interior Chaparral-Shrub Live Oak-Pointleaf Manzanita	5.3	3.5%
10. Agriculture	0.4	0.26%

landscape areas.

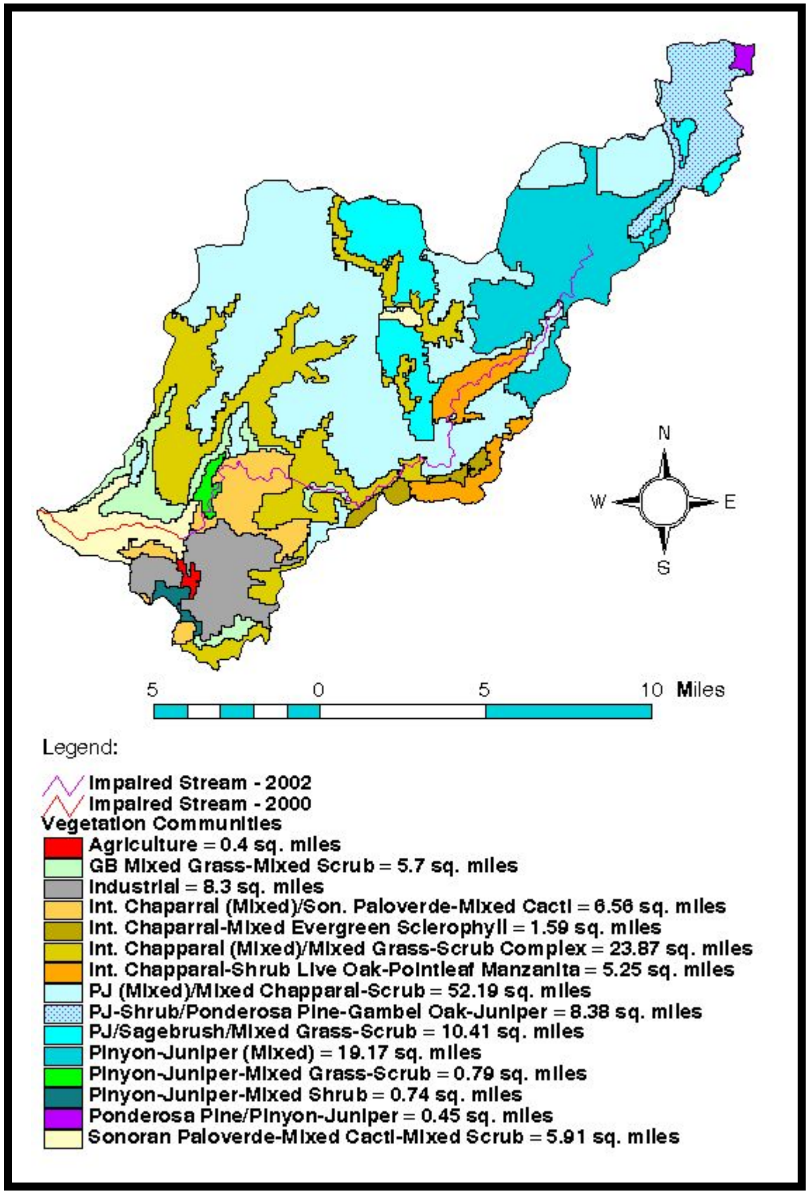
ADEQ found it useful to query these biome classifications to determine the extent of acreage of each type of land cover in the Boulder Creek Watershed. Based on the clipping procedure in GIS, fifteen different vegetation classifications were identified, and the ten most important types are listed in descending order in the table on page 24.

The GAP vegetation classes indicate more subtle variations between areas than the biotic communities established by BLP. The largest class, Pinyon Juniper (Mixed)/Mixed Chaparral-Scrub covers 34.7% of the entire watershed. This shows that the Interior Chaparral areas have a scattering of Pinyon Juniper trees in the unit, where the previous BLP information does not make this distinction. The industrial area identified is of special interest because it clearly shows the aerial extent of the Phelps Dodge's Bagdad mining operation.

The industrial classification covers over 8 square miles of the watershed. A very small area of agriculture was identified in the middle of the mined industrial area. Other small vegetation area classifications were not included in the table above for brevity. (See Map 12: GAP Vegetation Communities).

9.0 Fauna

A multi-agency research effort is currently underway to define critical habitat areas in Yavapai and Mohave Counties for large ungulates (hoofed animals), such as elk, desert bighorn, mule deer, pronghorn antelope and



Map 12: GAP Vegetation Communities

white-tailed deer. Arizona Game & Fish Department (AGFD) identified the need for this effort and the USGS and Northern Arizona University are collaborating on this thematic mapping project.

The Boulder Creek Watershed lies entirely within Yavapai County, and their hoofed animal research will help identify those critical habitats that are in need of restoration and improved connectivity. Also, their research will use satellite images to document temporal changes across the landscape to identify trends of habitat loss. Their research when completed can be used to augment the inventory when the information becomes readily available. Other animals observed in the watershed are mountain lions, javelina, small mammals, and various bird species. Several mountain lions sitings with new cubs were made by local area miners from Phelps Dodge. One group apparently lives in the Butte Creek subwatershed, a tributary to Boulder Creek near the critical area (Karl Ford, Interview, 2003).

Boulder Creek is also home to a variety of fish, most notably *Gila robusta* (Roundtail Chub) and *Catostomus insignis* (Sonoran Sucker). No federally threatened or endangered (T&E) fish species have been sighted in Boulder Creek (Peter Unmack, Interview, 2002).

10.0 Human Disturbances

This section will cover the baseline information regarding human-caused disturbances to the watershed. Since this Plan is iterative in nature, this section may be expanded at a later date.

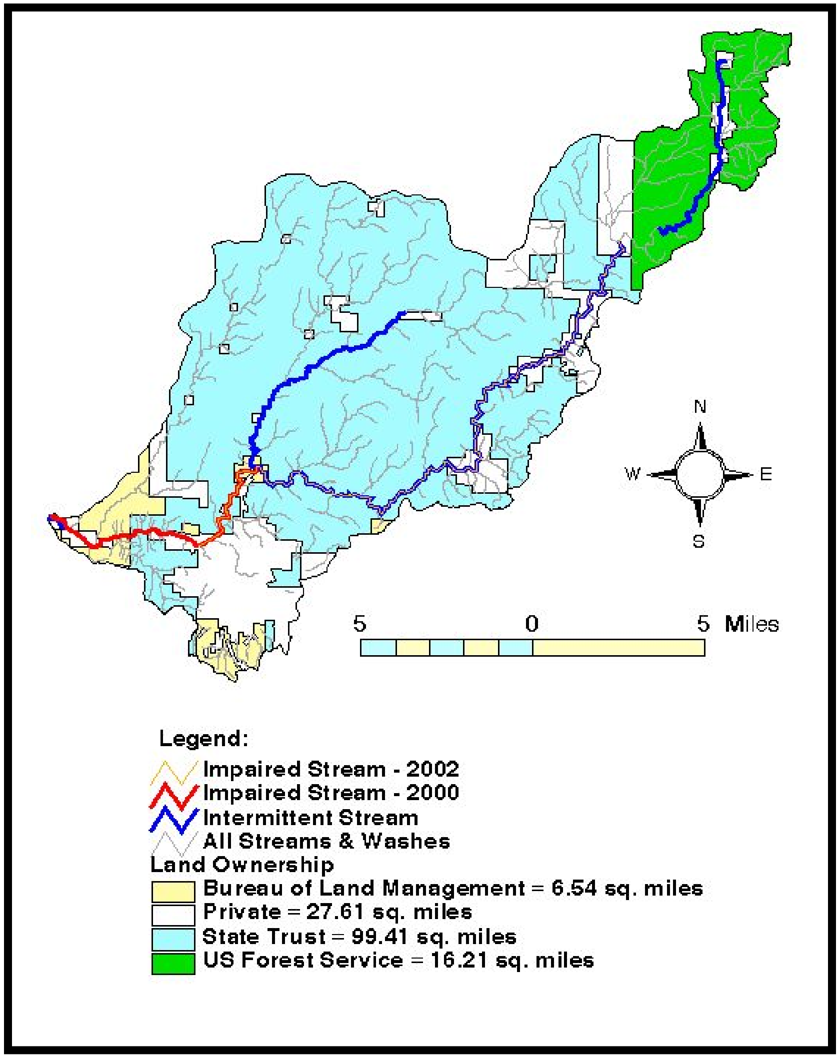
10.1 Land Ownership

The shape, complexity and arrangement of land ownership boundaries can directly affect the way in which a watershed can be effectively managed. Ownership is one of the main drivers for forming partnerships, coordinating and managing various stakeholder interests.

Successful partnerships work towards common goals, common interests and help to prioritize the watershed issues in a given area. Mutual understanding and collaboration through forming partnerships is an educational process that requires everyone’s help, coordination and information sharing. The inventory and Implementation Plan Part II should help in this regard.

State Trust lands managed by the Arizona State Land Department (ASLD) comprise roughly 2/3rds of the entire watershed. The critical area of impairment at the Hillside Mine involves three of the four landowners in the Boulder Creek Watershed: 1) the BLM owns the upper tailings pile (LTP), 2) a private company KFX owns the middle tailings pile (MTP), and, 3) the ASLD owns the lower tailings pile (LTP) (See Map 13: Land Ownership and the Cover Page of the Implementation Plan Part II for detail). After clipping in GIS, the following land ownership patterns are revealed for the Boulder Creek Watershed:

Land Ownership	Square Miles	Percentage
State Trust	99.4	66.3%
Private	27.6	18.4%
U.S. Forest Service	16.2	10.8%
Bureau of Land Management	6.5	4.4%



Map 13: Land Ownership

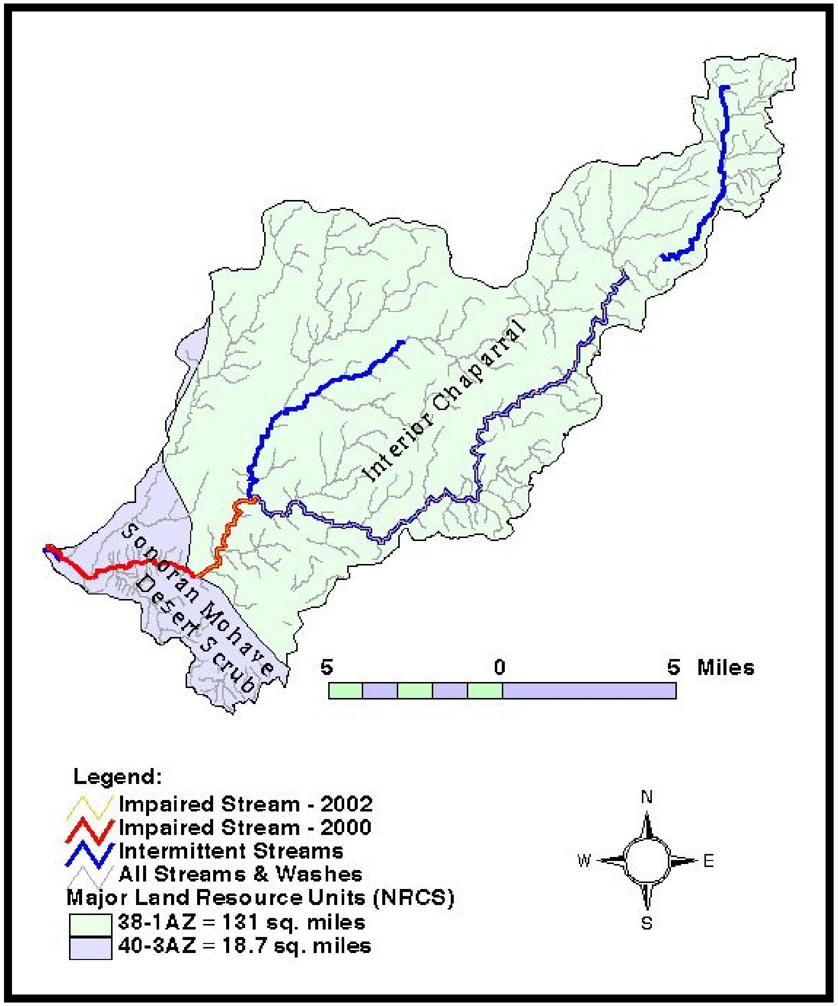
10.2 Land Use

Sometimes understanding land ownership boundaries by themselves can be misleading towards how a given landscape is actually managed. Gaining a basic understanding of land uses on the surface can provide researchers a better picture of actual land management strategies and concerns on the ground. The National Resource Conservation Service (NRCS) compiled a land use cover in GIS that combines the following variables: vegetation, soils, elevation, topography, climate and water resources into Major Land Resource Units (MLRUs). (See Map 14: Land Use Map).

Multivariate MLRU's further explain what one might expect to find on the land surface in each defined area. The NRCS provides a website that includes a narrative explanation of each MLRU, describing the dominant characteristics located in each unit, and the typical concerns each unit is known to exhibit. This combined-variable tool in GIS reveals the following land use trends for the Boulder Creek Watershed:

Major Land Resource Units	Square Miles	Percentage
38-1AZ Interior Chaparral	131	87%
40-1AZ Upper Sonoron Desert Shrub	18.7	13%

The dominant MLRU is the Interior Chaparral Unit #38-1AZ. This unit comprises roughly 87% of the watershed. The Interior Chaparral Unit is used mostly for livestock grazing. Small areas are cultivated for hay, alfalfa, corn and sorghum. Mining is an important land use with large commercial copper mines in operation. Recreational uses of land are also increasing in importance. The following



Map 14: Major Land Resources Units

concerns over land use were listed for the Interior Chaparral Unit: 1) livestock predation, 2) woody fuel buildup due to fire suppression of naturally occurring wildfires, 3) sedimentation of water storage reservoirs, 4) conflicts between recreational uses, livestock grazing and mining, 5) spread of noxious plants onto grassland sites, and, 6) limited groundwater supplies are deep and not very abundant (NRCS Website, 2003).

Similar to the Interior Chaparral Unit, the Sonoran Mohave Desert Scrub MLRU #40-1AZ, which comprises 13% of the watershed, is primarily used for wildlife and livestock grazing. The number of livestock fluctuates significantly between seasons of favorable moisture and drought years. Groundwater is deep, not abundant, and occurs only in local areas. Mining has been and continues to be an important land use. Copper and gold are the main minerals. Locally important materials include sand, gravel, and river cobble (NRCS Website, 2003).

10.3 Agriculture

According to the GAP vegetation cover digitized from 1991-1993 satellite photos, only 0.25% of the watershed is used for active cultivation (See 8.2 GAP Vegetation Classes). Since the GAP report indicated agricultural lands exhibited a high degree of fitness for satellite interpretation, this reported land area of 0.4 square miles is considered to be fairly accurate for the date of this photograph. However, because this land use area appeared to be so small in 1991-1993 when compared to the rest of the watershed, agricultural crops are not considered to be a major contributing factor to nonpoint source pollution in 2003.

10.4 Range Cattle Grazing

Based on research and readily available information there are two main cattle ranches in the Boulder Creek 10-digit HUC watershed, the Byner Ranch has a large grazing allotment that allows the ranch to graze all the way from Wikieup, through portions of Burro and Boulder Creek areas. They currently have over 80-head of cattle on the allotment in 2003.

The Yolo Ranch is also located in the Boulder Creek Watershed. However, the number of animals on this ranch was not known (Jeff Campbell, Interview, 2003). There are also a couple of smaller private ranch holdings that have a limited amount of livestock on them. Since the Boulder Creek area is experiencing the negative affects of an extended drought, the reported animal numbers on the Byner Ranch have most likely been reduced when compared to earlier, wetter years.

10.5 Active and Inactive Mining Operations

The historical mining GIS file shows 30 historical mines formerly located in the Boulder Creek Watershed and these include the Hillside, Tungstona and Black Pearl Mines. There is only one active operation located in the watershed at the Phelps Dodge Bagdad Mine near the Copper Creek watershed. Another GIS file indicates polygon areas where certain ore bodies exhibit a high potential for finding certain heavy metals and groups of heavy metals. This polygon GIS file indicates three different areas where certain metals of geologic potential can be found below the ground. The mine potential areas are listed in the following table:

Mine Potential Areas	Further Description
Copper	Porphryry w/or w/out molybdenum, manganese, gold & peripheral lead-zinc-silver
Copper, gold, silver with or without zinc	Stratabound volcanogene massive sulfide
Tungsten	Skarn & veins or pegmatites w/or w/out beryllium or lithium

(Source: "Mine Potential" GIS shape file from ALRIS)

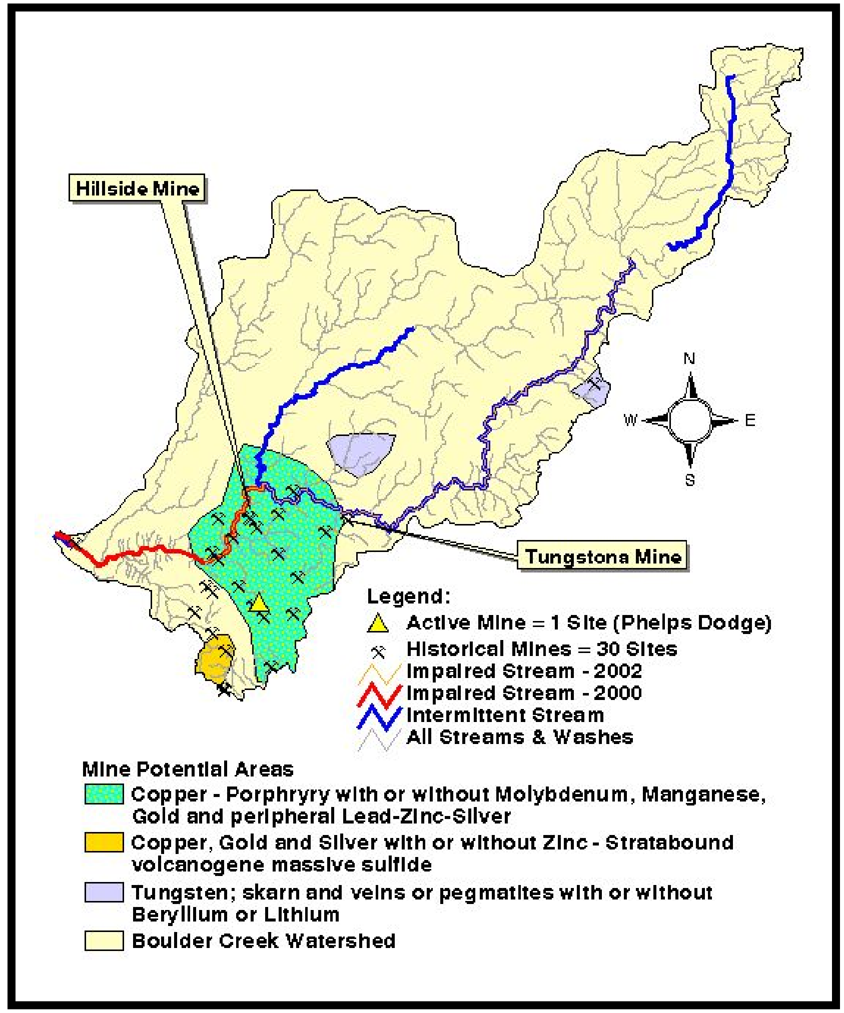
A large active mining operation is located along Copper Creek, a sub-watershed of Boulder Creek 10 digit HUC watershed, which flows into Boulder Creek below the critical area of impairment, below the old Hillside Mine. Large open strip-mining pits, active areas of placer mining, lakes, ponds and other mining works are located in this heavily-mined area. Phelps Dodge is the active mine operator at the aptly named Bagdad Mine next to Bagdad Arizona.

According to an interview with Jeff Campbell from the Phelps Dodge Bagdad Mine, two tailings piles are currently being processed for copper and one pond receives the tailings surface water flows in the Copper Creek sub-watershed. Two additional seepage collection return ponds gather seepage from the mining operation and residual storm water flows from the face of the tailings piles and natural hillside. The seepage collection return ponds provide temporary storage of the seepage and storm water. Then the mine pumps the water back up the hill to the mill facility where the grinding lines are located (Jeff Campbell, Interview, 2003).

The northern extent of the Phelps Dodge property is located near the Butte Creek drainage where several overburden stockpiles have been placed. Overburden piles are not expected to contain large amounts of heavy metals; rather they usually contain less contaminated soils that were removed to get to the ore bodies below for mining (See Map 15: Mining Map). A large tailings pile can be observed on the USGS Topographic quad map just below the Copper Boulder Creek confluence along the southern edge of Boulder Creek, near Scorpion Mesa. This tailings pile was capped and re-seeded many years ago (Jeff Campbell, 2003).

According to the GAP vegetation cover, the “industrial” area extent in Boulder Creek was determined to be 8.3 square miles in size. Since the GAP report indicated a high fitness rating for satellite interpretation, this reported "industrial" land area is considered to be fairly accurate for the date of the satellite photos, 1991-1993. Therefore the estimated size of the active Phelps Dodge Bagdad Mine is 8.3 square miles (See 8.2 GAP Vegetation Classes).

The Hillside, Tungstona and Black Pearl Mines are three former mining operations in the Boulder Creek Watershed. The abandoned Black Pearl Mine is located south of Boulder Creek's headwaters, further east and uphill of Wilder Creek and the Urie Basin area. The abandoned Tungstona Mine is located above the confluence of Wilder Creek with Boulder Creek. The abandoned Hillside Mine is located downstream of the

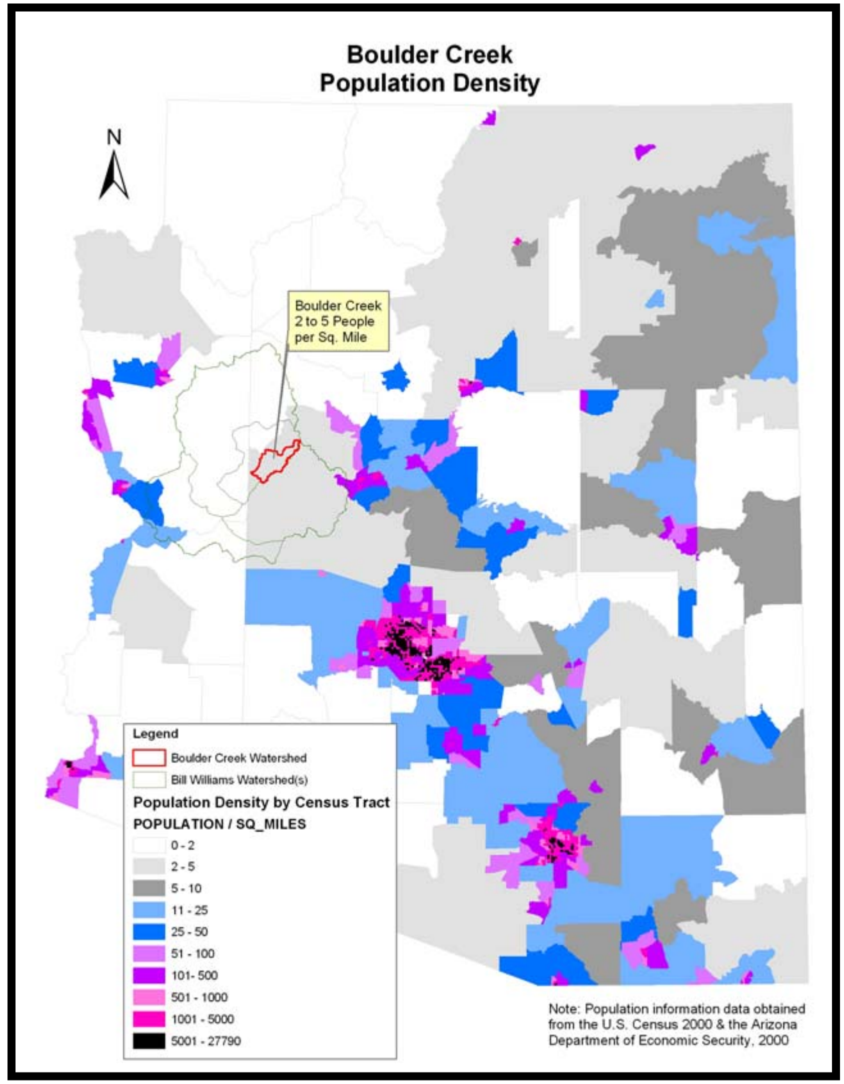


Map 15: Mining

Wilder Creek confluence. This north and upstream of the critical area of impairment where the Hillside Mine tailings piles are located. Three large tailings piles and eroded dam structures along the stream. The Hillside Mine is considered a problem area for water quality impairments, defined as the "critical area" for the TMDL report in section 3 of this Plan.

10.6 Census Population

The western edges of the Town of Bagdad are situated inside the Boulder Creek Watershed. The largest portions of Bagdad lie outside of the watershed boundary. However, due to its close proximity to Boulder Creek the population in Bagdad can affect the environmental condition of Boulder Creek through recreational land uses, wildcat dumping, hunting, and off road vehicle usage. According to the Year 2000 Census, 1,578 people



Map 16: Population Density per Square Mile

live in the Town of Bagdad, Arizona. The 1990 Census figures were higher when 1,858 people lived in Bagdad. The Year 2000 Census lists Bagdad as a Census Data Place (CDP), a place not large enough to be considered an incorporated town. The Year 2000 Census also lists that 813 housing units are located in Bagdad. It is no coincidence that population declines mirror the downturn of the copper industry in the 1990s and can be seen in the 1990 through 2000 population trends. Projected population growth estimates show a very slow growth trend for Bagdad with 1,860 people in 1997 and a projected population of 1,879 in 2050, a gain of only 19 people in over 50 years (U.S. Census, 2000).

However, recent copper prices in late 2003 have surged upwards, over 90 cents a pound, which could cause an upward trend to the population base in Bagdad. Based on the GIS system, the population density for the vicinity of Boulder Creek is approximately 2-5 people per square mile by the 2000 census (See Map 16: Census Population Density per Square Mile).

10.7 Point Sources

Point source discharges are typically described as end-of-pipe discharges to a water body, rather than discharges that originate from sheet-flow across the landscape such as Non-point source discharges. An example of a point source discharge in Boulder Creek would be the former mining adit that seeps pollution into Boulder Creek from near the Middle Tailings pile at the former Hillside Mine. According to the Clean Water Act the following definition of a point source discharge is listed on EPA's website: *"any discernable, confined, and* *discrete conveyance including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged"* (http://www.epa.gov/owow/nps/qa.html).

An adit, in mining terminology, is described as a horizontal mineshaft usually used for dewatering. The TMDL report identified this point source adit, which currently appears to be a seep/spring as one of the main sources contributing arsenic, zinc and low pH water to Boulder Creek's main stem. Low pH is problematic in that this overly acidic water can continue to extract heavy metals from abandoned tailings piles, from existing geologic formations, and can cause continued leaching problems with heavy metals to the stream. The potential exists that the Middle Tailings Pile is providing sub-flow contaminated waters to the adit through percolation of the abandoned tailings pile, and/or the former subsurface workings of the Hillside Mine below the head frame entrance (Karl Ford, BLM, 2003).

Other types of point sources of pollution were searched in the Boulder Creek Watershed using the GIS system. ADEQ assembled the following GIS files to determine if other point sources are located in the watershed area: AZPDES/NPDES permitted sites, underground storage tanks (USTs), leaking underground storage tanks (LUSTs) and the "Places" database that lists all *potential* point sources in Arizona. No current AZPDES permitted sites were found on the GIS database. ADEQ also searched a GIS file known as the Source Water Assessment Program (SWAP). This drinking water protection program identifies drinking water wells that may have potential contamination issues within a specified radius of a given wellhead. The following potential point sources were identified in the Boulder Creek Watershed:

4) Bagdad Open Pit Mine;
5) Bagdad Smelter;
6) Bagdad Townsite WWTP – Waste Water Treatment Plant;
7) Green Valley Power Corporation; and,
8) Hillside Mine (This is the adit seep site location previously discussed above).

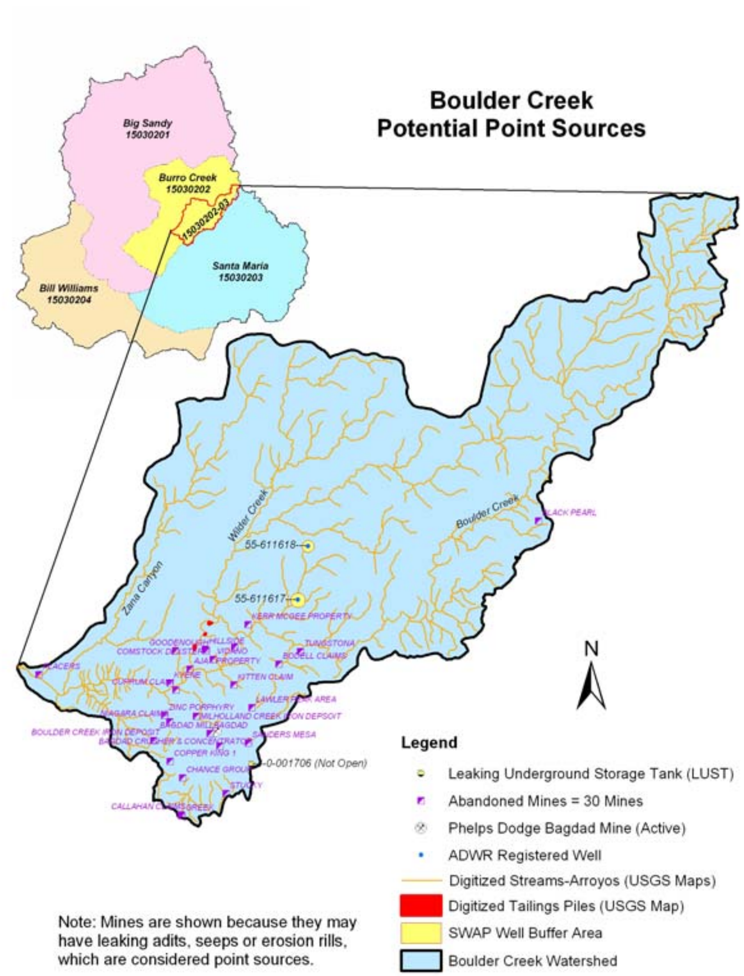
One leaking underground storage tank (LUST), no longer considered open as of December 31, 2002: facility I.D. 0-001706; and, eight “Places” identified as *potential* point sources that may or may not require further AZPDES permitting:

1) Bagdad – Concentrator Copper Filter;
2) Bagdad Mine;
3) Bagdad New Mill;

In addition two Source Water Assessment Program (SWAP) well buffers were identified around two existing wells identified on ADWR’s well registry list. They are located above the Urie Basin area in Contreras Wash, a small tributary of Boulder Creek just upstream and east of the Wilder Creek confluence and the TMDL “critical area.” These buffer zones are delineated to ascertain whether nearby sources of pollution have the *potential* for negatively impacting the nearby wells (See Map 17: Potential Point Sources Map).

10.8 Existing Non-point Sources

The three abandoned tailings piles located at the Hillside Mine along Boulder Creek are considered non-point sources (NPS) of pollution. Unlike pollution from industrial and sewage treatment plants, NPS comes from many diffuse sources. NPS pollution is caused by rainfall or snowmelt moving over and through the ground. As the runoff moves, it picks up and carries away natural and human-made pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters, and even our underground sources of drinking water. Controlling NPS from impacting downstream water bodies is one of Arizona's biggest water quality challenges.



Map 17: Potential Point Sources

NPS can originate from many areas and the most obvious in the Boulder Creek Watershed can be described as follows; 1) natural background due to heavy storm events, 2) natural air deposition due to wind erosion and dust, or, 3) anthroprogenic (human-caused) pollution from a variety of land use activities such as the abandoned tailings piles at the Hillside Mine.

The most common human-caused NPS in Arizona is agricultural land use. Ranching and livestock grazing is an example of this land use activity in the Boulder Creek Watershed. Naturally occurring NPS pollution or human-caused NPS pollution can wash downstream from either natural geologic formations or heavily mined and scoured areas. The TMDL report takes natural background sources into account in its equilibrium calculations, modeling and subsequent assignment of load allocations (See the Boulder Creek Implementation Plan, Part II) for further discussion.

11.0 Conclusion

This inventory and characterization is focused on a larger scale watershed, the Boulder Creek 10-digit HUC watershed, which includes upland areas. The subsequent Boulder Creek Implementation Plan, Part II focuses on a smaller area where the critical area of impairment is located with some upstream areas added as “natural background” flow areas. In short, Part II zooms in on the Hillside Mine area and the three tailings piles (See Cover Page of the Boulder Creek Implementation Project, Part II for illustration).

It is clear that cooperation among stakeholders and information sharing are crucial steps towards the successful cleanup of the critical area defined in the TMDL report. Much needed information has already been exchanged among stakeholders in 2003, including “outside” stakeholders such as the Phelps Dodge Bagdad Mine and AMEC Engineering, Inc. hired by BLM for this project.

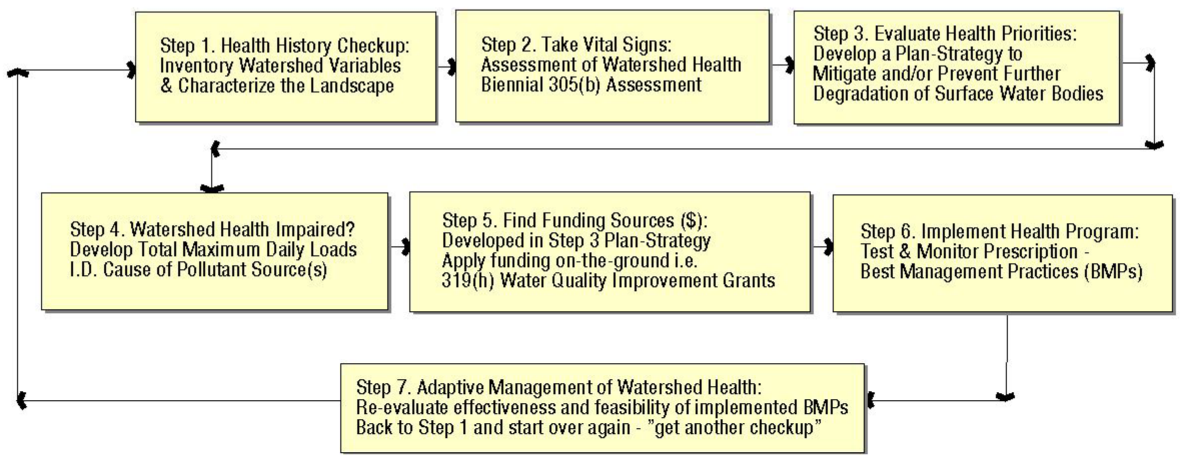
Based on the iterative nature of this document, it can be revisited and the “prescriptions” for improving Boulder Creek’s ecological health should remain holistic, economically feasible and evolve as the Plan matures. Much like human health, a watershed must be managed with a health care “process” plan in mind. Visits to the “doctor” should continue for Boulder Creek and the water quality should be revisited and monitored for the long term. (See Flow Chart on next page).

Lastly, the entire Bill Williams Watershed region could benefit greatly from the future cleanup of Boulder Creek and the Hillside Mine tailings piles. Alamo Lake is downstream and has been used for recreation and fishing for many years. A TMDL is currently underway to define potential mercury and methyl-mercury sources to Alamo Lake. The overall health of the region, including those who choose to recreate in the area is clearly at stake with this plan.

ADEQ's Water Quality Division
The Watershed Management Unit

The Holistic Process of Watershed Health

Improving the health of people through medicine is as much an art as it is a science. The same is true for watersheds, the process must be holistic, it must be iterative. (Karen Smith, ADEQ's Water Quality Division Director, National TMDL Science & Policy 2002 - Keynote Address).



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End note: Most of the GIS files were clipped using the ArcInfo Software, much like a cookie-cutter to ascertain the quantities of a given variable "inside" of the Boulder Creek Watershed. This inventory is intended to promote watershed awareness to the key stakeholders and the public at large (Enterline, 2003).