Janet Napolitano, Governor
Stephen A. Owens, ADEQ Director

Turkey Creek

From a tributary at 34°19'28"/112°21'28"
to Poland Creek

Total Maximum Daily Loads
For
Copper and Lead
and Cadmium and Zinc De-Lists

Arizona Department of Environmental Quality
and PBS&J

September 22, 2006

Open File Report 06-06

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

A.A.C.	Arizona Administrative Code
A.A.R.	Arizona Administrative Register
ADEQ	Arizona Department of Environmental Quality
AFWS	Arizona Flood Warning System
AgI	Agriculture-Irrigation watering
AgL	Agriculture-Livestock watering
A&Wc	Aquatic and Wildlife-coldwater
A&Ww	Aquatic and Wildlife-warmwater
BASINS	Better Assessment Science Integrating Point and Nonpoint Sources
Cd(d)	Cadmium- dissolved
cfs	cubic feet per second
Cu(t)	Copper- total recoverable
Cu(d)	Copper- dissolved
EE/CA	Engineering Evaluation/Cost Analysis
EPA	United States Environmental Protection Agency
^{o}F	degrees Fahrenheit
ft.	feet
ft. msl	feet above mean sea level
FC	Fish consumption
FBC	Full Body Contact
FH1	Frigid Subhumid 1
FR	Forest Road
GIS	Geographic Information System
g/day	grams per day
HSPF	Hydrologic Simulation Program-Fortran Model
HUC	Hydrologic Unit Code
in.	inches
LAI	Labat-Anderson, Inc.
LA	Load Allocation
LR	Load Reduction
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MH2	Mesic Subhumid 2
mi.	miles

$mi.^2$	square miles
MOS	Margin Of Safety
NCDC	National Climate Data Center
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
Pb(t)	Lead- total recoverable
PMP	Prescott Mining Project
ppb	parts per billion
TMDL	Total Maximum Daily Load
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
USFS	United States Department of Agriculture- Forest Service
USGS	United States Geological Survey
WLA	Waste Load Allocation
WRCC	Western Region Climate Center
Zn(d)	Zinc- dissolved
µg/L	micrograms per liter

EXECUTIVE SUMMARY

Turkey Creek is an intermittent stream in the Middle Gila River watershed, central Arizona. The stream has been recognized as impaired by the Arizona Department of Environmental Quality (ADEQ) and the United States Environmental Protection Agency (EPA) since the 1992 water quality assessment. The most recent assessment in 2004 listed Turkey Creek as impaired due to cadmium, copper, lead, and zinc exceedances of the acute and chronic aquatic and wildlife- warmwater (A&Ww) designated use. The Total Maximum Daily Load (TMDL) study was initiated in 2000.

The Turkey Creek watershed lies within the Prescott Mining District. Historic mining in the area was extensive and the watershed contains many abandoned and inactive mine sites of various sizes. Numerous studies have been conducted on the mineral resources and water quality of the region. Several studies have identified the Golden Belt and Golden Turkey mines as sources of metal contamination to Turkey Creek. Both mines are located on land adjacent to the Creek and managed by the United States Forest Service (USFS). USFS recognizes the impacts of these mines sites, has designed reclamation plans and is set to begin on-the-ground improvements once funding has been secured.

Water quality sampling performed by ADEQ and hydrologic modeling by PBJ&S (2004) confirm that the Golden Belt and Golden Turkey mines do contribute to the degradation of water quality in Turkey Creek. Modeled scenarios included storm events of varying intensity, spatial extent, and discharge indicate that remediation of the sites will improve water quality. There is also a lead load entering the creek above the known mine sites causing exceedances. Current monitoring data cannot distinguish the lead load as anthropogenic or natural background. Water quality data and modeling results indicate that rain induced runoff is the critical loading condition to Turkey Creek. During large storm events, runoff from the land surface and tailings piles results in elevated flows containing large volumes of sediment and increased metal concentrations. Steady flows resulting from snow melt do not cause impairments.

Monitoring data and modeling results indicate that cadmium and zinc are not impairing Turkey Creek. Only one zinc and no cadmium exceedances were measured in in-stream samples. Samples collected from direct runoff from the tailings piles contain metal concentrations that are orders of magnitude higher than in-stream samples.

Efforts by the USFS to remediate the Golden Belt and Golden Turkey mines are supported by ADEQ. Additional public participation is encouraged and sought by both ADEQ and USFS. Once on-the-ground improvements have been implemented ADEQ will conduct monitoring to determine the effectiveness of remedial efforts in helping Turkey Creek attain water quality standards.

1.0 SETTING

1.1 Geography

Turkey Creek is located in the Middle Gila River watershed in south-central Yavapai County in central Arizona (Figure 1). The headwaters originate in the Bradshaw Mountains from the southeastern slope of Mount Union, approximately 9 miles (mi.) southeast of Prescott near the townsite of Goodwin. The area consists of broad ridges trending to the north or northwest which are cut by numerous valleys and washes draining generally to the south-southeast. From the headwaters, Turkey Creek flows to the southeast and then east, for approximately 30 mi. before joining with Poland Creek to form Black Canyon Creek which joins the Agua Fria River near the community of Rock Springs. The Agua Fria, which demarks a portion of the boundary between southern Yavapai and northern Maricopa counties, continues into Lake Pleasant. Turkey Creek drops approximately 4,680 feet (ft.) from the headwaters at about 7,520 feet above mean sea level (ft. msl) on Mount Union, to about 2,840 ft. msl at the confluence with Poland Creek.

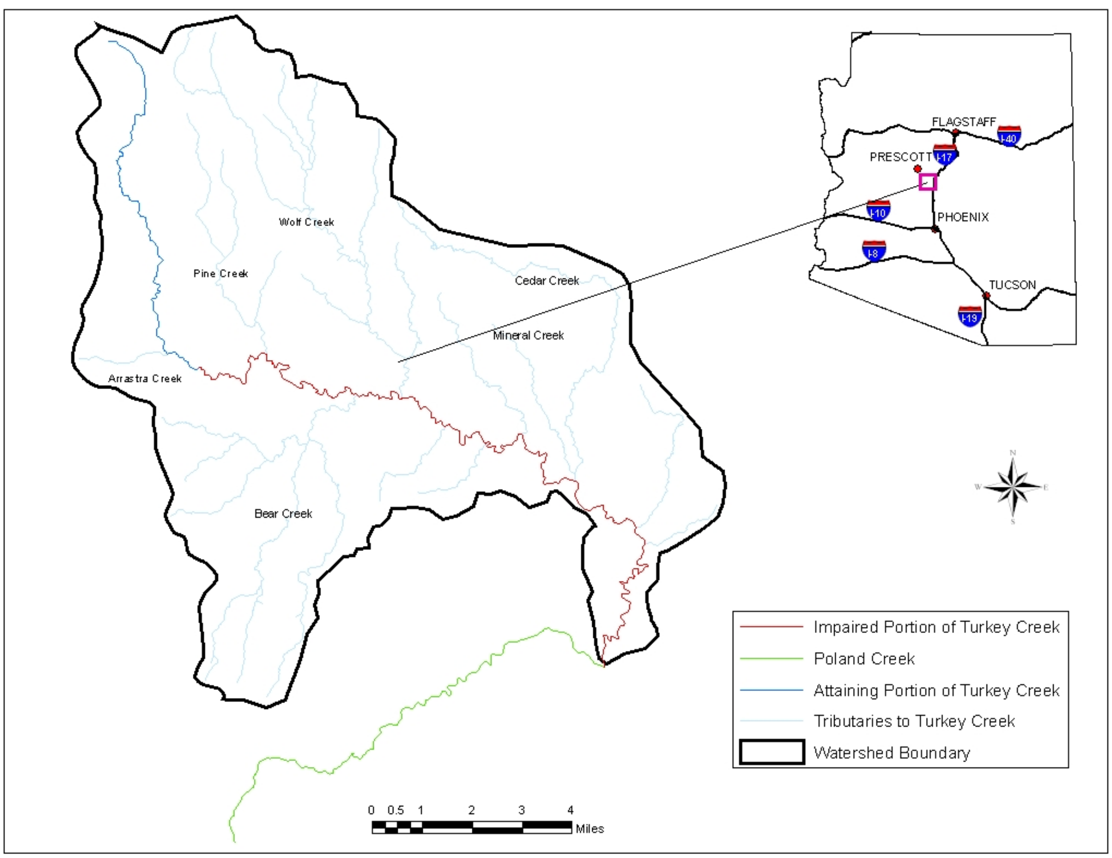

Figure 1. Location and major tributaries of the Turkey Creek Watershed

1.2 Climate

Temperatures throughout the watershed vary with season and elevation. In the Bradshaw Mountains, mean January air temperatures at 6,000 to 8,000 ft. msl have a range between 35 and 45 degrees Fahrenheit (^oF). In July at the same elevations, mean air temperatures range from 65 to 80°F. January air mean temperatures at 4,500 ft. msl have a range of 35 to 45°F and a July mean air temperature range of 70 to 85°F (Hendricks, 1985).

Annual precipitation totals vary primarily with elevation. The higher mountain elevations may receive 25 inches (in.) or more per year; the mid-elevation slopes and foothills may receive 20 to 25 in. per year; while the lower elevation valleys may get 15 to 20 in. per year. Annually, 50 to 60 percent of the rainfall is received during the winter storm period (Hendricks, 1985). In general, the winter rains tend to be of less intensity but of longer duration than summer storms, and are thus more likely to create sustained flow. Summer storms can be very intense, often creating flashy conditions, but do not typically create sustainable flow in the watershed.

There are numerous precipitation gages surrounding the Turkey Creek watershed that have long and consistent periods of record. These stations are listed in Table 1.

Table 1. Stations reporting precipitation data near the Turkey Creek watershed

Station Name (ID)	Latitude/Longitude	Operator*	Period of Record	Active?
Crown King 1NW (5712 / 022329)	34.214/ 112.354	AFWS/NWS NCDC/NWS	12/1914 to 1/1995	Yes
Mount Union (5380)	34.413/ 112.415	AFWS	Unknown	Yes
Mayer (5775)	34.391/ 112.128	AFWS	Unknown	Yes
Cordes (022109)	34.3/ 112.17	WRCC/NWS	12/1925 to 12/2002	No
Horsethief Basin (5697)	34.139/ 112.273	AFWS	Unknown	Yes
Bumble Bee (021059)	34.2/ 112.15	NWS	12/1952 to 9/1979	No
Aqua Fria near Rock Springs (09512800)	34.014/ 112.167	USGS	1/1970 to 9/2002	Yes
Sunset Point (5730)	34.187/ 112.134	AFWS	Unknown	No
Towers Mountain (5340)	34.24/ 112.363	AFWS	Unknown	No

*AFWS = Arizona Flood Warning System; NCDC = National Climate Data Center; NOAA = National Oceanic and Atmospheric Administration; NWS = National Weather Service; USGS = United States Geological Survey; WRCC = Western Region Climate Center

Local daily precipitation totals from March 2002 to March 2004 were collected for this project at a rain gage installed by ADEQ near the Golden Turkey/Golden Belt mine site; however, this data was not used in the model because it contained significant data gaps related to equipment malfunction.

1.3 Hydrology

The Turkey Creek watershed covers approximately 94 square miles ($mi.^2$). Turkey Creek is an intermittent stream, about 30 mi. in length. This investigation focuses on a 21 mi. segment of Turkey Creek from an unnamed tributary at 34°19' 28"/112°21' 28 to its confluence with Poland Creek. The top of the reach is approximately 1.25 mi. east of the confluence of Turkey Creek with Arrastra Creek, near the Senator Highway crossing of Arrastra Creek. Major tributaries of the listed segment include Pine Creek, Arrastra Creek, Bear Creek, Wolf Creek, Mineral Creek, and Cedar Creek (Figure 1). Field observations show that there are a few areas which have spring input and maintain flow throughout much of the year; one such spring is ¼ mi. downstream of the Golden Turkey Mine. USGS stream flow data for Turkey Creek indicate that sustained flow most often occurs from January to mid-June and that the stream is usually dry from September through December. Periodic flows occur during the summer monsoon season in response to an occasional storm. These summer storms are often short lived but typically of high intensity, sometimes dropping large amounts of precipitation in some regions while leaving adjacent areas dry. These storms create unpredictable conditions in the watershed, often causing flash flooding to occur.

Historically, the USGS maintained a gaging station on Turkey Creek near the town of Cleator; monitoring at this station was discontinued in 1992. The USGS “Turkey Creek near Cleator” gage was located just upstream of the Golden Belt and Golden Turkey mines. The period of record extends from October 1979 to September 1992, with the highest recorded flow being 5,230 cubic feet per second (ft^3/sec) on February 10, 1980 (USGS, 2002). There are two other notable USGS gages in the vicinity, one at “Aqua Fria near Rocks Springs”, which is southeast of the confluence of Black Canyon Creek with the Agua Fria, and one at “Aqua Fria near Mayer”, to the north. The “Agua Fria near Rock Springs” was operational from 1971 to 1973 and from 1975 to 1990, thus providing concurrent data with 1979 to1992 operation at the “Turkey Creek near Cleator” station. Table 2 summarizes the available stream gaging data.

Table 2. USGS stations reporting discharge in vicinity of Turkey Creek

Site Name	Station ID	Latitude/Longitude	Period of Record
Aqua Fria River near Rocks Springs	9512800	34°00'56"/ 112°10'02"	1/1970 to present
Aqua Fria River near Mayer	9512500	34°18'55"/ 112°03'48"	1/1940 to present
Turkey Creek near Cleator	9512600	34°16'56"/ 112°12'25"	10/1979 to 9/1992

For this investigation, ADEQ manually measured stream discharge and recorded stream stage by automated dataloggers. Two stream level loggers were installed in Turkey Creek in conjunction with the placement of automatic samplers upstream and downstream of the Golden Belt and Golden Turkey mines. An additional automatic sampler and level logger were installed on Turkey Creek at the confluence with Poland Creek. Channel cross sectional profiles were generated for these automated equipment sites as well as other sites to support the development of flow rating curves which were used during modeling.

1.4 Geology

The Bradshaw Mountains are located along the northeastern extent of the Basin and Range Province lying primarily within the physiographic province of the Transition Zone. This region is characterized by north to northwesterly trending short mountain ranges separated by narrow valleys. The rocks exposed in this region are predominantly of Precambrian and Tertiary age. The older Precambrian rocks of this area consist of metamorphosed volcanic and sedimentary rocks that have been intruded and deformed by plutons of granitic to gabbroic composition. The principal regional structures of these rocks are folds and normal and reverse faults of north to northeast trend (USFS, 2002).

Lindgren (1926) summarizes the mineralization at the Golden Belt and Golden Turkey mines as occurring in several quartz veins. The host rock is schist and with the veins cutting across the schist planes. These north-trending veins, which dip between 10 and 30 degrees to the east, range from a few inches wide to as much as six feet, and are formed primarily of quartz filling. The gold ore zone contains sulfide, primarily pyrite and galena, mineralization.

The topography in the area of the mine sites varies from steep to very steep bedrock controlled hill slopes to nearly level floodplains (USFS, 2002). Alluvium in Turkey Creek changes with each storm event as scour routinely moves the bed material; it can range from non-existent to a few feet in depth.

Soil types vary somewhat throughout the watershed, but are predominantly comprised of two major types, Mesic Subhumid 2 (MH2) (Lithic Haplustolls-Lithic Argiustolls-Rock Outcrop Association) found throughout the watershed and Frigid Subhumid 1 (FH1) (Mirabel-Dandrea-Brolliar Association) found primarily at the higher, mountain elevations. MH2 soils are characterized as shallow, gravelly and cobbly, moderately coarse to moderately fine-textured, gently sloping to very steep soils and rock outcrop on hills and mountains. FH1 soils are characterized as moderately deep to deep, gravelly and cobbly, moderately coarse and fine-textured, gently sloping to very steep mountain soils (Hendricks, 1985).

1.5 Vegetation and Wildlife

Turkey Creek is situated in the transitional Central Highlands Province and as a result, lies near the border of two biotic provinces, the Upper Sonoran and Navajonian. The vegetation encountered typifies the diversity that might be expected given the range in elevation and the associated precipitation. Soil moisture variation from north and south facing slopes also influence the plant cover able to grow successfully in many locales (Hendricks, 1985). Riparian corridors can be found along Turkey Creek and many of its tributaries. Some of these corridors are being degraded due to increasing growth of salt cedar, an invasive species. The USFS has identified the lowland leopard frog and Lucy's warbler as "species of concern" in some downstream reaches of Turkey Creek (USFS, 2002). No reported "Threatened" or "Endangered Species" are known to reside in the watershed.

Chaparral species predominate from approximately 2,500 ft. msl to 6,000 ft. msl. In the lowest elevations, saguaro, ocotillo, cholla, and prickly pear cactus are common, as are acacia and palo verde trees. At higher elevations, deep rooted evergreen shrubs and trees with sclerophyllous leaves (to retain moisture), are interspersed with annual and perennial grasses, forbs, and shrubs growing where the tree canopy is less dense. In this transition zone, manzanita, cliffrose, grama grasses, plains lovegrass, Texas and cane bluestem, tanglehead, galleta, oaks, junipers, and pinyon are common depending upon elevation and available moisture. Animal life found in this zone include occasional whitetail deer, mule deer, bighorn sheep, javelina, coyotes, quail, dove, pocket gopher, desert cottontail, kangaroo rat, Acorn Woodpecker, hummingbirds, and Vesper Sparrow (Hendricks, 1985).

Montane Conifer Forest extends from approximately 6,000 ft. msl to 7,500 ft. msl. Plants common in the upper elevations include Ponderosa and other pines, Douglas fir, aspen, and various oaks. The open canopy provides understory plants such as Arizona fescue, mountain muhly, mountain brome, squirreltail, forbs, shrubs, and broadleaf trees the opportunity for growth. Animal life in this zone include mountain lion, mule deer, turkey, coyotes, black bear, red squirrel, chipmunk, rabbit, porcupine, dove, Yellow-bellied Sapsucker, and Rocky Mountain Jay (Hendricks, 1985).

1.6 Land Ownership/Use

The majority of land in the watershed is owned and managed by the Bradshaw Ranger District, Prescott National Forest. This includes the property associated with the Golden Belt and Golden Turkey mines. There are, however, numerous privately owned ranches and mines (active, inactive and abandoned) in the watershed. Population density is sparse, with no large communities found in the watershed. The nearest communities are Bumble Bee, Mayer, Cleator, Crown King, Spring Valley, Cordes, and Cordes Junction. Their populations range in size from tens of people up to several hundred.

Ranching and mining are found throughout the watershed and appear to be the primary commercial activities of the region. Current mining appears to be small in scale and mostly recreational in nature. Large scale mining in the area was fairly active in the late 1800's and early to mid 1900's for a variety of metals including gold, silver, zinc, lead, and copper. Abandoned mines and adits are common throughout much of the region.

Land uses vary somewhat from lower to higher elevations; lower elevation land use consists of wildlife habitat, ranching, water supply, mining, and recreation; and, higher elevation land use consists of ranching, forest harvesting, wildlife habitat, recreation, water supply, and mining (Hendricks, 1985).

2.0 SOURCES OF WATER QUALITY DATA

The data set currently available has been developed from more than a decade of study with contributions by a number of participants. The complete data set reflects a variety of project goals based upon the end use requirements of the participating party. Some data, while not providing water quality information to aid the TMDL calculation, did provide background and guidance for this project. There are four primary sets of data available to this project.

2.1 Labat- Anderson, Inc.

The first set of data is from a study by Labat-Anderson, Inc. (LAI) for the USFS in 1991. The study was conducted to evaluate the potential for the abandoned Golden Belt mine site to pose a risk to human health and/or the environment. Samples were collected on three dates in 1990 from surface runoff, Turkey Creek, soils, and drum contents. The laboratory analysis results showed elevated levels of arsenic, cadmium, copper, cyanide, lead, mercury, nickel, and zinc in the surface runoff. The study concluded that the tailings piles and contaminated soils appeared to be a contaminant source to Turkey Creek from surface runoff. Unfortunately only generalized sample site descriptions were recorded with no flow measurements. The conclusion of the study is, therefore, noted but the data were not further considered in the development of the Turkey Creek TMDL due to the lack of discharge measurements and generalized sample site locations.

2.2 Prescott Mining Project

The second set of data is from the Prescott Mining Project (PMP), published by ADEQ in April, 1997. The purpose of the PMP study was to characterize the impacts to surface and groundwater from inactive and abandoned mines within a 500 $mi.^2$ area located in the Bradshaw Mountains. A component of the PMP document is a study conducted in the Lower Turkey Creek Watershed. As part of this effort, surface water and groundwater samples were collected during three sampling events in 1994 and 1995. No rainfall had occurred in the watershed for at least two weeks prior to sampling. Samples were collected in sustained stream flow resulting from winter rainfall and snowmelt in higher elevations of the watershed. The results did not reveal elevated levels of heavy metals. The sampling sites are listed in Table 3 and shown in Figure 2. Sample results from the PMP were used in developing TMDLs for Turkey Creek.

2.3 ADEQ TMDL

The third set of data was collected by the ADEQ TMDL unit from 2000 to 2003 to assist with source and critical condition identification so that loads and allocations could be calculated for Turkey Creek. The majority of these samples were collected by an automatic sampler triggered by an increase in water level in the streambed. Therefore, the data includes multiple measurements at a single location during storm events. In addition to samples from the creek, samples were collected from springs and runoff from the tailings area. Some soil samples were also collected. The sampling sites are listed in Table 3 and shown in Figure 2.

Table 3. PMP and ADEQ sampling site locations

Station ID	Description	UTM Easting (m)	UTM Northing (m)
Prescott Mining Project sites			
BC-001	Black Canyon River below confluence of Turkey and Poland Creek	388095.84	3789337.37
LTC-001	Turkey Creek above confluence with Poland Creek	388090.55	3789357.40
LTC-002	Turkey Creek above Golden Belt Mine and Crown King Road	389083.52	3793794.09
LTC-003	Turkey Creek below confluence with Mineral Creek	387213.24	3795285.98
LTC-004	Cedar Canyon Creek 1 mile above confluence with Turkey Creek	387128.20	3796401.64
LTC-005	Turkey Creek below unnamed drainage by Jubilee Mine	385502.44	3796826.22
LTC-006	Unnamed drainage below Jubilee Mine & above conf. w/ Turkey Creek	385502.44	3796826.22
LTC-007	Turkey Creek below Golden Belt Mine	389482.88	3792684.73
LTC-008	Turkey Creek adjacent to lower tails of Golden Turkey Mine	389226.32	3792635.64
LTC-009	Turkey Creek adjacent to lower tails of Golden Belt Mine	389363.78	3793047.70
LTC-010	Turkey Creek 1-1/2 miles above confluence with Wolf Creek	379302.89	3798049.90
LTCW-001	Artesian well on Golden Belt Mine site	389482.88	3792684.73
PC-001	Poland Creek above confluence with Turkey Creek	388095.84	3789337.37
ADEQ sites			
GB drain	Drain below tailings piles at Golden Belt Mine	389390.28	3793030.75
GT ditch	Ditch below tailings piles at Golden Turkey Mine	389375.87	3792668.25
RainGage	ADEQ Rain Gage	389786.46	3792662.30
spring@TC	Artesian well (spring) downstream of mine	388993.70	3792429.88
Tailing pile	Tailing pile runoff samples	389390.28	3793030.75
TC B Min	Turkey Creek below mine, upstream of spring	389416.24	3792500.30
TC@261	Turkey Creek at 261	372285.81	3809487.75
TC@AgCmine	Turkey Creek at Silver Cord mine	388760.36	3790613.77
TC@bend	Turkey Creek at old bend	389529.90	3792612.09
TC@bottom	Turkey Creek upstream of spring	389077.21	3792484.35
TC@bridge	Turkey Creek at FR 259 bridge	389407.95	3793201.34
TC@Cleator	Turkey Creek north of Cleator at FR 93 crossing	386993.86	3795337.42
TC@Corral	Turkey Creek at Corral	379304.21	3798009.95
TC@FR706	Turkey Creek at FR 706	372893.12	3809063.50
TC@HW	Turkey Creek near Goodwin townsite	373834.56	3802482.20
TC@nb	Turkey Creek at new bend	389501.49	3792545.88
TC@PC	Turkey Creek at confluence with Poland Creek	388109.76	3789346.08
TC@senator weir	Turkey Creek at Senator weir	374485.49	3799091.56
TC@TR202	Turkey Creek at TR 202	379144.41	3798067.19
TC@trib	Turkey Creek downstream of tributary and of mines	389357.47	3792824.85
soil-bear ck	Sediment sampling - Bear Creek	379973.00	3798016.00
soil-cedar ck	Sediment sampling - Cedar Creek	387095.61	3795534.27
soil-mineral ck	Sediment sampling - Mineral Creek	386997.45	3795573.61
soil-pineck@pineflats	Sediment sampling - Pine Creek	375352.00	3803090.00
soil-tc,us/5000ft	Sediment sampling - Turkey Creek upstream of 5,000 MSL	374656.00	3798994.00
soil-tc,us/bear ck	Sediment sampling - Turkey Creek upstream of Bear Creek	379923.00	3798122.00
soil-tc@bridge	Sediment sampling - Turkey Creek at bridge	389376.97	3793289.45
soil-tc@fr93	Sediment sampling - Turkey Creek at FR 93	386829.61	3795394.02
soil-wolf ck	Sediment sampling - Wolf Creek	380596.38	3800081.81

2.4 USFS

The fourth major data source was an Engineering Evaluation/Cost Analysis (EE/CA) report prepared for the USFS by a contractor, Tetra Tech-EMI (2002). This study focused on the tailing and waste rock areas associated with the Golden Belt and Golden Turkey mines, shown in Figure 3. These mines had large ore processing areas where the ore was crushed and then ground before metal (typically gold) extraction was performed. These data include Total Metal and Synthetic Precipitation Leaching Procedure analyses of the tailing, waste rock, and stream sediments up and downstream of the ore processing areas. Also included are analyses of the particle size and pH – acidity characteristics of the tailing and waste rock in the two mine areas. Results from the EE/CA were used in developing TMDLs for Turkey Creek.

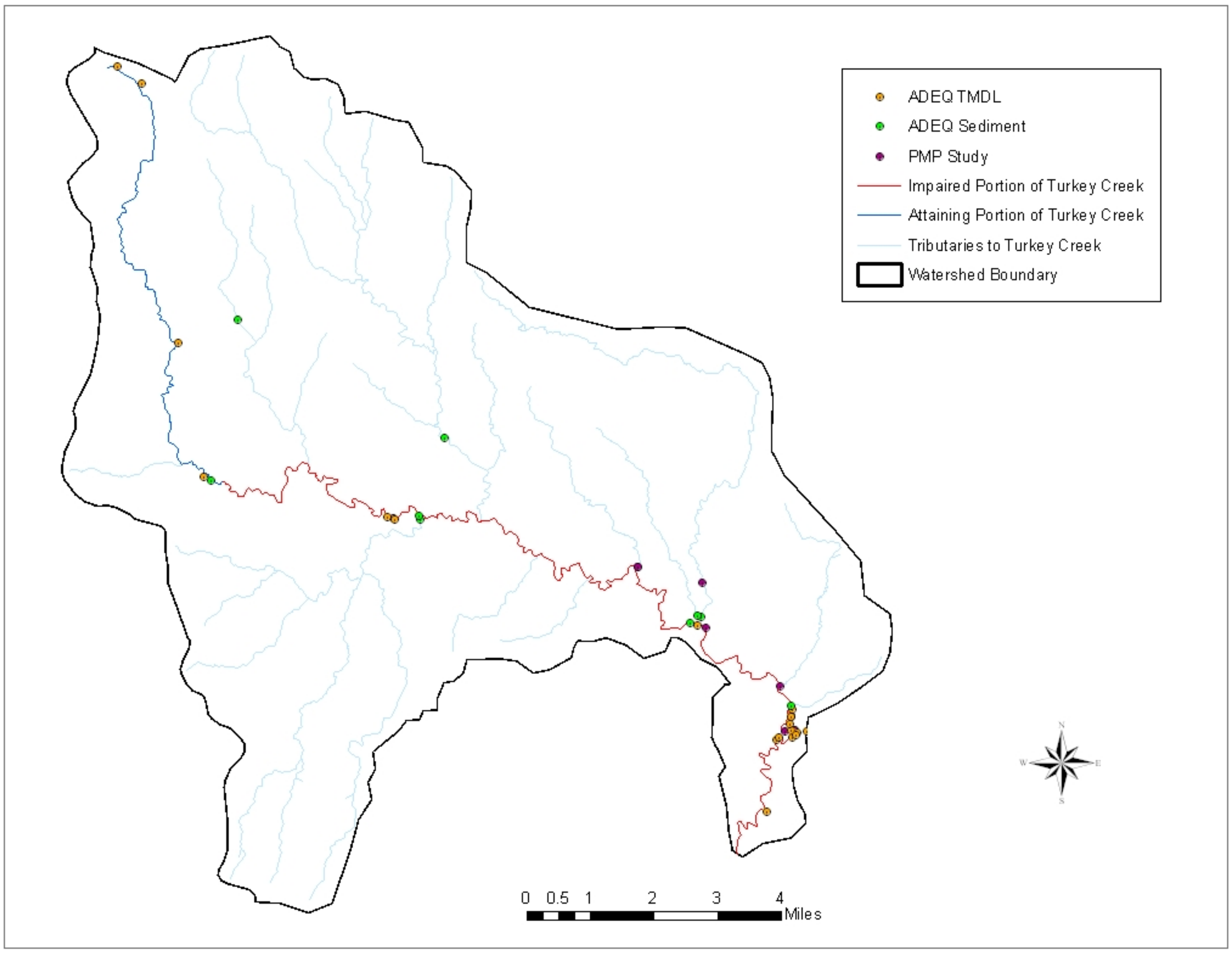

Figure 2. Sampling Locations in the Turkey Creek Watershed

Intensive sampling near the Golden Belt and Golden Turkey mines occurred during the ADEQ TMDL and PMP studies. Figure 3 shows the sample sites near the mines in greater detail.

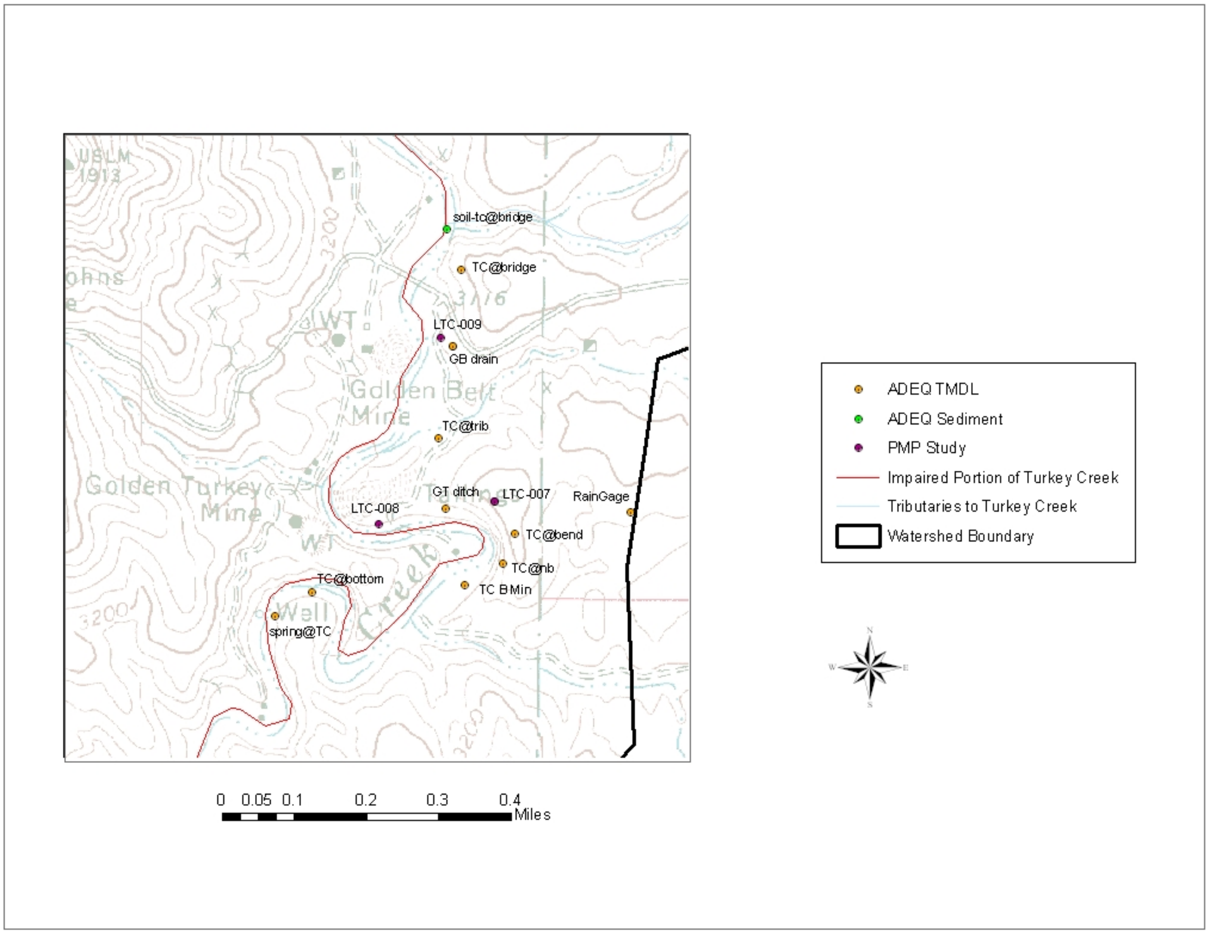

Figure 3. Sample sites near Golden Belt and Golden Turkey mines

3.0 LISTING HISTORY

Turkey Creek, Hydrologic Unit Code (HUC) #15070102-036, first appeared on the Arizona 303(d) assessment list of “water quality limited” waters in 1992 and has been listed continuously since then. The parameters and extent, for which the reach has been listed, have varied with available data, assessment criteria, and the changes in applicable standards which have occurred. The assessment and listing history is summarized in Table 4.

Table 4. Turkey Creek Assessment and Listing History

Year	Reach Length	Impaired Designated Uses [1]	Parameters [2]
1992	18 mi.	A&W, AgI, AgL	Arsenic$^{t\&d}$, cadmium^{t}, copper$^{t\&d}$, cyanide^{t}, lead^{t}, mercury^{t}, zinc^{d}
1994	18 mi.	A&Ww, AgI, AgL, FBC	Antimony^{t}, arsenic$^{t\&d}$, cadmium^{t}, copper$^{t\&d}$, cyanide^{t}, lead^{t}, and zinc^{d}
1996	18 mi.	A&Ww, AgI, AgL, FBC	Antimony^{t}, arsenic^{t}, cadmium^{t}, copper^{t}, cyanide^{t}, lead^{t}, TDS [3], zinc^{t}
1998	30 mi.	A&Ww, AgI, AgL, FBC, FC	Arsenic^{t}, cadmium^{t}, copper^{t}, cyanide^{t}, lead^{t}, mercury^{t}, nickel^{d}, zinc^{t} Antimony was delisted.
2002	30 mi.	A&Ww, AgI, AgL, FBC, FC	Cadmium^{d}, copper^{d}, zinc^{d} Arsenic, cyanide, and lead were delisted; arsenic and lead were placed on the “Planning List”.
2004	21 mi.	A&Ww, AgI, AgL, FBC, FC	Cadmium^{d}, copper^{d}, lead^{d}, zinc^{d}.

1. A&W =Aquatic & Wildlife; A&Ww =Aquatic & Wildlife (warm); AgI =Agriculture Use - Irrigation; AgL = Agriculture Use - Livestock FBC = Full Body Contact; FC = Fish Consumption
2. t = Total; d = Dissolved
3. TDS = Total Dissolved Solids

3.1 Data used for original Turkey Creek 1992 Listing on Arizona 303(d) List

The LAI results were the basis for the first 303(d) listing of Turkey Creek which occurred in the 1992 assessment. The reach, from headwaters to Poland Creek, was reported as 18 miles in length and identified as HUC #15070102-36. It was listed as in “nonsupport” due to exceedances for arsenic, cadmium, copper, cyanide, lead, mercury, and zinc. The set of nine samples included three surface water samples from Turkey Creek, three samples taken from surface pools or sheet flow from the mine site, and two samples collected at the artesian well described to be approximately 0.5 miles downstream of the mine. One additional surface water sample was collected, but was invalidated due to improper preservation.

3.2 Data used for Turkey Creek 1998 Listing on Arizona 303(d) List

Samples for soil, groundwater, and surface water were collected from twenty-five sites during three sample events, March, 1994; October, 1994; and March/April, 1995. The data for the PMP surface water samples collected along Turkey Creek were included in the assessment process by ADEQ for the 1998 303(d) List. The listing identified arsenic, cadmium, copper, cyanide, lead, mercury and zinc as exceeding Arizona Surface Water Quality Standards. Although the results of the PMP study showed no exceedances, the reach remained on the 303(d) list because the results did not provide sufficient weight for its removal in light of data obtained from the earlier LAI study.

3.3 Data used for Turkey Creek 2002 Listing on Arizona 303(d) List

Data collected by ADEQ's TMDL Unit were used in the 2002 assessment process. In the 2000-2001 period, nine samples were collected in five sampling events. Based on these nine samples taken during precipitation "runoff" events, the reach was determined to be "impaired" on the 303(d) List due to cadmium, copper, and zinc exceedances. Lead and arsenic were assessed as "inconclusive" due to insufficient data and placed on the "Planning List". Cyanide was delisted due to no exceedances observed in recent data. In addition, results for twelve samples taken on seven sampling events, but considered not to reflect "critical" conditions, were assessed as "inconclusive" due to a number of missing core parameters as defined by Table 4, Volume I of the ADEQ 2002 303(d) List.

3.4 Data used for Turkey Creek 2004 Listing on Arizona 303(d) List

It was determined for the 2004 Assessment that Turkey Creek would be divided into an upper and lower segment to allow application of the Aquatic and Wildlife coldwater (A&Wc) and warmwater (A&Ww) criteria. Throughout the state, this division was established at 5,000 ft .msl elevation. In Turkey Creek, this division occurs at 34°19'28"/112° 21'28". The uppermost segment, 15070102-36A, extends from the headwaters to 34°19'28"/112° 21'28" and the lower segment, 15070102-36B, continues from this point to the confluence with Poland Creek. The segment division occurs approximately 1.25 mi. downstream of the confluence with Arrastra Creek.

The evaluation of Turkey Creek for the 2004 assessment showed the uppermost segment was not impaired and that the lower portion was impaired for cadmium, copper, lead, and zinc due to exceedances of the acute and chronic A&Ww standards. Turkey Creek (both reaches) is included on the "Planning List" due to arsenic exceedances and missing core parameters including *Escherichia coli*, total boron, total manganese, and turbidity/suspended sediment concentration.

3.5 FINAL DETERMINATION OF IMPAIRMENT

Data collected during this study have confirmed the impairment of Turkey Creek due to copper and lead during storm run-off events. Data indicate that arsenic, cadmium and zinc do not impair Turkey Creek. Therefore, loads and reductions for copper and lead are calculated in Section 8.0 and delisting rationale are discussed in Section 9.0.

4.0 NUMERIC TARGETS

4.1 Clean Water Act Section 303(d) List

Section 303(d) of the Clean Water Act requires states to compile a list, the 303(d) List, of surface waterbodies that do not meet applicable water quality standards. TMDLs must be developed for waterbodies on the 303(d) List. TMDLs set the amount of the given pollutant(s) that the waterbody can withstand without creating an impairment of that surface water's designated beneficial use(s).

4.2 Beneficial Use Designations

ADEQ codifies water quality standards in the Arizona Administrative Code (A.A.C.), Title 18, Chapter 11. Designated beneficial uses, such as fish consumption, recreation, agricultural uses, and support of aquatic and wildlife, are described in A.A.C. R18-11-104 and are listed for specific surface waters in Appendix B of A.A.C. R18-11. Turkey Creek is currently protected along reach HUC#15070102-36B for the following designated uses: A&Ww; Fish Consumption (FC); Full Body Contact (FBC); Agricultural Livestock Watering (AgL); and Agricultural Irrigation (AgI).

4.3 Current Water Quality Standards

The State of Arizona's surface water quality standards are listed in A.A.C. R18-11, Article 1. For the currently listed segment of Turkey Creek, the most stringent surface water quality standards for dissolved copper, cadmium, lead, and zinc are related to protecting A&Ww from chronic exposure. The water quality standards for these dissolved metals are hardness-based and thus vary with the observed hardness at the time of sampling. Applicable hardness values range from 25-400 milligrams per liter (mg/L) and are calculated from total calcium and magnesium concentrations. The most stringent surface water quality standard for total lead is based upon the FBC standard of 15 micrograms per liter (µg/L). The lowest total copper standards applies to the AgL beneficial use and equals 500 µg/L. Applicable water quality standards are summarized in Table 5.

Table 5. Water quality standards for target analytes

ANALYTE	A&WW ACUTE [1, 2] (µg/L)	A&WW CHRONIC (µg/L)	FBC (µg/L)	FC (µg/L)	AgI (µg/L)	AgL (µg/L)
Cadmium, Dissolved	$(e^{(1.128[\ln(Hardness)] - 3.6867)}) \times (1.136672 - \ln(Hardness) \times (0.041838)$	$(e^{(0.7852[\ln(Hardness)] - 2.715)}) \times (1.101672 - \ln(Hardness) \times (0.041838)$	NNS	NNS	NNS	NNS
Copper, Dissolved	$(e^{(0.9422[\ln(Hardness)] - 1.7)})(0.96)$	$(e^{(0.8545[\ln(Hardness)] - 1.702)})(0.96)$	NNS	NNS	NNS	NNS
Copper, Total	NNS	NNS	1,300	NNS	5,000	500
Lead, Total	NNS	NNS	15	NNS	10,000	100
Lead, Dissolved	$(e^{(1.2730[\ln(Hardness)] - 1.460)}) \times (1.46203 - \ln(Hardness) \times (0.145712)$	$(e^{(1.2730[\ln(Hardness)] - 4.705)}) \times (1.46203 - \ln(Hardness) \times (0.145712)$	NNS	NNS	NNS	NNS
Zinc, Dissolved	$(e^{(0.8473[\ln(Hardness)] + 0.884)})(0.978)$	$(e^{(0.8473[\ln(Hardness)] + 0.884)})(0.978)$	NNS	NNS	NNS	NNS

1. Hardness is expressed as mg/L $CaCO_3$ as calculated by the laboratory

2. NNS = No Numerical Standard

5.0 SOURCE ASSESSMENT

5.1 Watershed Information Resources

Numerous data sets were analyzed in an effort to understand the origins and nature of the pollutants in Turkey Creek. In addition to water quality and sediment sample results, field observations, physiographic data, hydrologic data, and meteorologic data were evaluated. The physiographic, hydrologic, and meteorologic information were taken primarily from published references and websites, as listed in the bibliography.

5.2 Nonpoint Source Loadings

Nonpoint source loadings represent a diffuse form of water pollution from various natural and anthropogenic sources that accumulate in a watershed and are most often transported to the waterbody via runoff from rainfall. Examples of nonpoint sources include agricultural practices, atmospheric deposition, weathering and erosion of susceptible materials (including mine tailings and waste rock), animal wastes, and, street and urban debris.

Water quality samples were collected at locations throughout the reach as frequently as possible, during different flow events including summer monsoons, winter storms, and snow melt. Sites were chosen so that conclusions could be drawn regarding sub-watershed contributions to Turkey Creek and pollutant attenuation. It is difficult to allocate loads to the various nonpoint sources in the Turkey Creek watershed as the situation is confounded by over one hundred years of anthropogenic influence. A more practical approach to estimating loads and allocations is to consider the loads within Turkey Creek at prime locations in the segment.

5.2.1 Natural Background

Because this project began before Turkey Creek was segmented, when the entire length of the creek was listed as impaired, samples were taken at four locations in the upper portion of the watershed. The uppermost water sample was taken where Turkey Creek is crossed by Forest Road (FR) 261 (TC@261). This lies near the base of Mt. Union and reasonably represents the headwaters of the stream. Three additional sampling sites were established above the 5,000 ft. msl segmentation, see figure 3. In the Turkey Creek watershed, sample results from the upper segment suggest that natural background pollutant levels are negligible.

5.2.2 Weathering and/or Erosion

The weathering and erosion of terrestrial sediments can introduce pollutants into a stream system once a mechanism for transport has been established. Natural erosion rates and overall sediment delivery to a water body are increased by increasing the surface area exposed at the surface. Natural processes such as forest fires and wildlife disturbances together with anthropogenic activities (mining and livestock grazing) can greatly increase rates.

5.2.3 Mining

Numerous hard-rock mining efforts have created waste rock and tailings piles throughout the entire region. The weathering of the exposed waste rock can mobilize metals, which can find their way into the stream. Smaller adits and exploratory digs ranging in depth from a few inches to several feet are found throughout the watershed.

These may be seen on the hillsides, in stream channels, or virtually anywhere the prospector may have suspected valuable ores might lie. Where significant ore deposits were mined larger tailings and waste piles resulted, such as those of the Golden Belt and Golden Turkey mines. These represent two of the largest mines in the watershed covering approximately twelve acres. A little over eight acres of this is in the form of fine tailings, which are subject to wind and water erosion (USFS, 2002). They are located below FR 259 adjacent to Turkey Creek and each other. While numerous smaller operations and prospects exist, their individual contribution to the degradation of Turkey Creek is negligible.

5.2.3a Golden Belt Mine

Golden Belt mine is currently inactive, but during the late 1800's and early 1900's was mined extensively for lead, gold, silver, zinc, and copper. The ore was associated largely with sulfide mineralization, primarily pyrite and galena, and contains a correspondingly higher sulfide concentration than the Golden Turkey mine (USFS, 2002). The tailings and waste rock from the operation extend well up slope from the channel of Turkey Creek and cover about 4.36 acres. Beginning approximately 80 to 100 yards downstream of the FR 259 Bridge crossing on Turkey Creek, the tailings from Golden Belt mine, covering about 3.25 acres, extend into the active floodplain of the stream, forming the western bank for approximately 250 to 300 yards. The toe of the tailings has eroded to the extent that it is currently susceptible to further erosion by the stream primarily during moderate to higher flow events. The waste rock pile covers approximately 1.12 acres and is located on the southwest edge of the tailings pile. Based upon the in-stream indicators observed by ADEQ staff, such as tailings deposits in the streambed, it would appear that tailings materials readily migrate into Turkey Creek during those local precipitation events sufficient to cause surface flow from the tailings.

5.2.3b Golden Turkey Mine

Golden Turkey mine is currently inactive, but during the late 1800's and early 1900's was mined extensively for lead, gold, silver, zinc, and copper. The Golden Turkey mine ore was quartz rich and was reported to have high recovery (90%) which resulted in relatively low sulfide content (USFS, 2002). It is located immediately below the Golden Belt mine, and approximately a quarter of a mile downstream of the FR 259 Bridge.

The tailings and waste rock from the operation extend well away from both the eastern and western sides of the stream, covering a total of about 6.35 acres. Both tailings piles extend into the active floodplain of the stream and are susceptible to further erosion by the stream primarily during moderate to higher flow events. The eastern pile covers about 4.31 acres and is located on a horseshoe bend surrounded on three sides by the stream. The tailings at the apex of the bend have eroded to the extent that they form a steep wall, approximately 45 to 50 feet high. Based upon observed tailings deposits in the streambed, it appears that tailings material readily migrate into Turkey Creek during local precipitation events sufficient to cause surface flow from the tailings. On the western bank, two waste rock and one tailings pile cover a total of about 2.05 acres and are directly opposite the eastern tailings pile. The upstream waste rock pile covers approximately 1.15 acres, and is located at the beginning of the bend. The lower waste rock pile covers about 0.66 acres and is approximately 125 yards downstream of the upper pile, near the apex of the bend. The western tailings pile covers approximately 0.23 acres. It is bordered on the north by an unnamed tributary and on the south by the large waste-rock pile. Its eastern extent lies at the edge of Turkey Creek on the outside of the horseshoe bend (USFS, 2002).

5.2.4 Runoff

Runoff of precipitation from the land surface (overland flow) is an important source of loading to Turkey Creek. Storm events and snow melt sufficient to produce runoff and transport of sediment to the stream may cause impairments. Loading can occur from both disturbed and undisturbed land. Samples collected from direct runoff from mine tailing and waste piles have metal concentrations that are orders of magnitude higher than those measured in the stream. The effects of runoff can be seen in comparing the results of storm induced runoff samples during the TMDL investigation and those from the PMP study which sampled winter baseflow conditions.

5.2.5 Stream Sediment

Samples were collected targeting lead and copper in sediments as a result of a mid to late term data review. The sediments were analyzed for total lead and copper, for which, as revealed by the data review, water samples occasionally yielded exceedances at the FR 259 Bridge. The intent of the in-channel sediment sampling, although limited in extent, was to determine the background levels, extent of contamination, and isolate potential sources of these parameters within the watershed. The sediment sample approach was chosen as the possibilities for water sample collection were very limited due to the low frequency of significant rainfall and flow events experienced at this point in the investigation.

Turkey Creek was sampled for in-channel sediment at four locations ranging from just above the 5000 ft. msl near Arrastra Creek, down to just above the FR 259 Bridge. In addition, in-channel sediment samples were taken from Pine Creek, Bear Creek, Wolf Creek, Mineral Creek, and Cedar Creek which are the largest tributaries to Turkey Creek. The results indicate that these metals may be present as bed-load in much of the watershed. Copper was detected in all samples indicating that copper is prevalent throughout the drainage. Lead was not detected in Turkey Creek above the confluence with Bear Creek, and is below detection limits in three of the five major tributaries. All of the results were orders of magnitude lower than the Arizona Non-Residential Remediation Standards of 63,000 milligrams per kilogram (mg/kg) for copper and 2,000 mg/kg for lead (ADEQ, 2001). Table 6 summarizes the sediment sample site locations and analytical results.

Table 6: ADEQ Sediment sample sites in upstream to downstream order

Sediment Sample site	Total Copper recovery (mg/kg)	Total Lead recovery (mg/kg)
Turkey Creek (above of 5000 ft.)	38	<10
Pine Creek (tributary)	680	<10
Turkey Creek (above of Bear Creek)	44	<10
Bear Creek (tributary)	48	13.2
Wolf Creek (tributary)	31	<10
Turkey Creek@ FR93	57	15.6
Mineral Creek (tributary)	210	16
Cedar Creek (tributary)	48	<10
Turkey Creek@ FR259 Bridge	42	11.6

The USFS EE/CA 2002 sample results from three sites above the FR 259 Bridge correspond well with the results listed in Table 6. The average lead concentration was 15 mg/kg with copper averaging 44 mg/kg in the USFS EE/CA.

5.2.6 Groundwater

An artesian well is located approximately 0.25 miles downstream of the Golden Turkey and Golden Belt mines. It is reported, as far back as 1936, to have been used as the drinking water supply for the mines when they were operational. No records as to its development are known to exist. The well significantly contributes to the flow of Turkey Creek throughout much of the year. This is especially true during the times of low flow common to the stream. ADEQ TMDL unit study records for May 29, 2003 indicate that observable flow started at the spring (measured at 0.11 cubic feet per second (cfs)), continued past Silver Cord Mine (0.06 cfs), and reached the confluence with Poland Creek (0.02 cfs). The well output varies with apparent seasonal changes in the water table, but has been observed to flow at some level throughout much of the duration of the ADEQ TMDL study. Its output has been measured on two occasions as a part of the TMDL study. On May 29, 2003, the flow, measured approximately 25 yards downstream, was 0.12 cfs. The second measurement was on July 29, 2003, when the flow was measured directly from the spring outfall at 0.03 cfs. There was no evidence of channel flow upstream of the spring at the time of either measurement. Data obtained from the analysis of the three water samples collected by ADEQ, offered no indication of actual or potential exceedances of any applicable water quality standard.

5.2.7 Grazing

Agricultural use may contribute to increased erosion either from the working of the soil or by the presence of livestock. Livestock often move in and out of the stream channel in search of shade, water, or food. Their movement disturbs the banks and often creates trails into the stream channel which may act as waterways during precipitation events causing erosion and increasing the sediment load reaching the stream. Overgrazing, when it occurs, removes groundcover plants which aid in soil retention.

5.2.8 Foresting

Forest harvesting also includes heavy motorized travel in and out of the region as the operators drag or haul the material out of the forest. The tracks that are established can act as watercourses into the stream channel which may contribute to loading.

5.2.9 Recreation

Recreational activities common to the area, such as hiking, horseback riding, all terrain vehicle or other motorized travel can cause disturbance of the soils in or near the stream, to make them more susceptible to erosion. Placer miners often work directly in the stream channel, disturbing the alluvium and digging into the rock formations suitable to their pursuits. Evidence of placer mining is commonly observed in and around Turkey Creek.

5.3 Point Source Loadings

Point source loadings represent a discharge entering directly to the waterbody via a discrete conduit such as a pipe which impacts the overall pollution loading of the waterbody. The discharge may be characterized as having a positive or negative impact, depending upon whether the inflow decreases or increases the concentration of the pollutants in the waterbody. To date, no permitted point source discharges are known to exist in the Turkey Creek watershed.

6.0 MODEL FRAMEWORK

A TMDL is the total amount of a pollutant that can be assimilated by the receiving water while still achieving water quality standards. TMDLs can be expressed in terms of mass per time or by other appropriate measures (i.e. pounds per day or grams per day). TMDLs are comprised of the sum of individual wasteload allocations (WLAs) for point sources, and load allocations (LAs) for nonpoint sources and natural background. In addition, the TMDL must include a margin of safety (MOS), either implicitly or explicitly, that accounts for the uncertainty in the relationship between pollutant loads and the quality of the receiving water body. This definition is expressed as:

$$TMDL = \sum WLA + \sum LA + MOS$$

To develop TMDLs for Turkey Creek, the following approach was taken.

1. Collect and review recent and historic data
2. Select model(s) and associated inputs
3. Define TMDL endpoints
4. Simulate existing conditions through range of seasons and flows
5. Assess source loading alternatives
6. Determine the TMDL and source allocations

Water quality data for the model were taken from nineteen ADEQ monitoring locations to determine the extent, frequency, and conditions under which stream impairment occurs, as well as to define background water quality. Additional data from LAI study, ADEQ-PMP, Bureau of Land Management, and USGS were also used to support the water quality analysis.

6.1 Model Development

This section describes the process of developing, calibrating, and validating the selected model, Hydrologic Simulation Program-Fortran – Better Assessment Science Integrating Point and Nonpoint Sources (HSPF-BASINS), to represent the Turkey Creek watershed. HSPF is a component of the BASINS program which integrates Geographic information System (GIS), data analysis, and modeling to support watershed based analysis and TMDL development.

6.1.1 Model Framework

The HSPF-BASINS model, a public domain software program distributed by EPA, was chosen for use on the Turkey Creek TMDL. HSPF is a comprehensive, conceptual, continuous model designed to simulate all the water quantity and water quality processes that occur in a watershed, including sediment transport and movement of contaminants. Although it is usually classified as a lumped model, it can reproduce spatial variability by dividing the basin in hydrologically homogeneous land segments and simulating runoff for each land segment independently, using different meteorological input data and watershed parameters. The model includes fitted parameters as well as parameters that can be measured in the watershed.

HSPF simulates the hydrologic and water quality processes that occur on pervious and impervious land surfaces together with in-stream processes in discrete time steps. It uses continuous rainfall and other meteorological records to compute stream flow hydrographs and pollutant concentrations. It has been deemed appropriate to assess the effects of point and nonpoint source treatment alternatives as well as various other uses. HSPF has been applied to applications of as small as a few acres to as large as several thousand square miles. Programs available separately, support data preprocessing and post processing for statistical and graphical analysis of data saved to the Watershed Data Management file.

Data requirements include meteorological records of precipitation and estimates of potential evapotranspiration for watershed simulation. Air temperature, dew point temperature, wind, and solar radiation are required for snowmelt. Air temperature, wind, solar radiation, humidity, cloud cover, and tillage practices may be required for water-quality simulation. Physical measurements and related parameters are required to describe the land area, channels, and reservoirs.

6.1.2 Subwatershed Definition

The Turkey Creek watershed was divided into subwatersheds shown in Figure 4. The segment numbering starts with #2 because BASINS uses #1 for all areas outside the watershed. The subwatershed delineation was based on the National Hydrographic Dataset stream network, and the topographic data downloaded from WebGIS (WebGIS, 2004).

HSPF allows land segments of different characteristics (e.g. based on land use, soil) in each subwatershed. The areas of the tailings and waste rock on the USFS survey map were used to delineate individual land segments for the tailing and waste rock areas.

A unique feature of HSPF is that only one flow and concentration value is produced for each subwatershed. One goal in setting up the subwatersheds is to have appropriate boundaries from which comparison can be made with field data. This requires greater detail in the area of the mine waste sites.

6.1.3 Meteorological Data

HSPF requires precipitation and potential evapotranspiration data. Precipitation data at Crown King (Coopid 022329) were obtained from the National Climatic Data Center. Additional precipitation data were obtained from the Flood Control District of Maricopa County. The rain gages are Mt. Union (#5380), Crown King (#5715), Sunset Point (#5730) and Arizona Hunt Club (#5775). These five rain gages are shown in Figure 4.

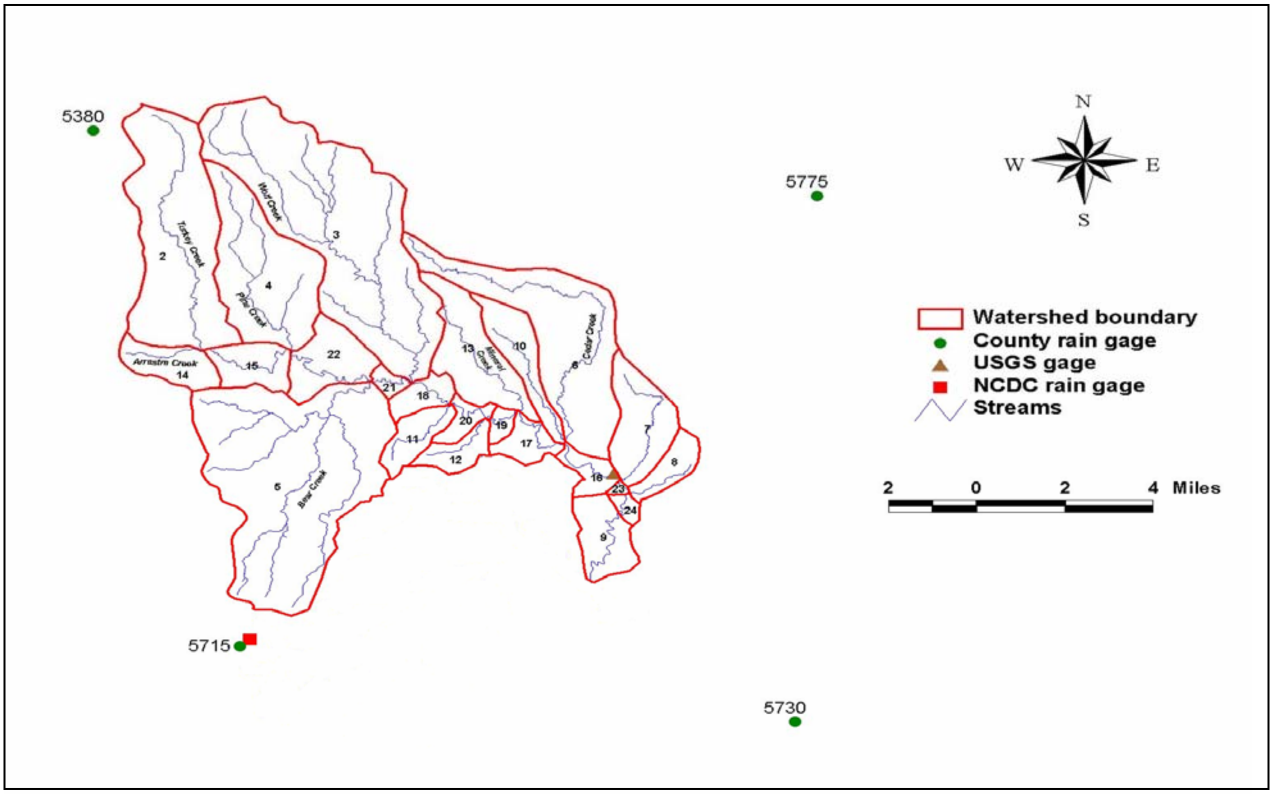

Figure 4. Subwatershed delineations and gage locations

Potential evapotranspiration data at the Phoenix International Airport and the Flagstaff Airport were obtained from the EPA BASINS website (EPA, 2004). Both the mean elevation and latitude of the Turkey Creek watershed are intermediate between the weather stations at Phoenix and Flagstaff. Therefore, the potential evapotranspiration data from these two stations were averaged to determine the potential for the Turkey Creek watershed. Note that the potential evapotranspiration reflects the meteorological conditions of the weather station. The effect of the type of vegetation is accounted for with the parameters in the model.

The potential evapotranspiration data were only available up to 1995. For simulation of recent years, the dates of the time series were shifted such that data of earlier years were repeated for later years. For example, the 1991 data were used for 2003. It was found that model results were not very sensitive to which particular year was used.

6.1.4 Land Use/Land Cover

Land use/land cover data were also downloaded from WebGIS (WebGIS, 2004). There are four types of land use/land cover in the watershed:

- Evergreen forest land
- Shrub and brush rangeland
- Strip mines, quarries, and gravel pits
- Reservoirs

Based on the land use/land cover data, all the subwatersheds were classified as pervious segments in the model. There is only a small reservoir at the upstream end of the Cedar Creek subwatershed. It is considered to have an insignificant effect on the hydrology and therefore not modeled.

6.1.5 Soils

Soil Survey Geographic Database data were downloaded from the Soil Data Mart of the National Resources Conservation Service (NRCS, 2004). The soil data indicate which areas belong to which hydrologic soil groups. The soil infiltration rates of the subwatersheds were estimated based on the hydrologic soil groups and the recommended values in BASINS Technical Note 6 (EPA, 2000).

6.1.6 Flows

Flow observations are needed for model calibration. There was only one USGS flow gage in the watershed, Turkey Creek near Cleator (09512600). Daily flow data were available from 10/1/79 to 9/30/92.

Table 7 presents a summary of the daily flow data by month. There was flow reported on 56% of the days of record, but the percentage of days with flow, and the magnitude of the flows, is highest in the January-May period. It is expected that snowmelt plays a significant role in this pattern. The peak flow record at the gage equaled 5,230 cfs on February 19, 1980.

6.1.7 Stream Routing

Routing of the flow requires rating curves of the stream reaches relating depth and discharge. The model also requires rating curves relating depth and surface area and volume of the reach.

Table 7. Summary of Daily Flow Characteristics of Flow at USGS Gage 09512600

Month	Number of days with flow	% of days with flow	Average daily flow (cfs)	
			Based on number of days in period	Based on number of days with flow
January	22.7	73%	9.1	13.2
February	21.5	77%	51.3	59.1
March	27.5	89%	33.2	37.2
April	27.7	92%	9.9	10.8
May	22.9	74%	3.1	3.3
June	9.7	32%	0.9	2.6
July	7.8	25%	3.7	15.7
August	13.5	44%	6.8	13.3
September	10.6	35%	2.1	4.5
October	9.9	32%	1.0	2.7
November	13.4	45%	2.0	7.2
December	16.5	53%	13.5	24.5
Year	203.6	56%	11.1	20.0

BASINS generated the rating curves based on channel slope, Manning's roughness coefficient, and typical stream dimensions. However, during the calibration process the transport of sediment, which depends on flow, appeared to be too fast. Therefore, the flow rates in the rating curves were halved to better match the data. For Reach 24, downstream of the FR 259 Bridge, a simple U.S. Army Corp of Engineers Hydrologic Engineering Center- River Analysis System model was set up based on the topographic information on the USFS survey map and used to generate the rating curves. These rating curves were also applied to Reach 23.

6.2 Model Calibration

This section describes the process of hydraulic and water quality calibration. It describes the data and limitations along with the choices made to simulate the system.

6.2.1 Flow Calibration to the USGS gage at Cleator

The first part of the process is to calibrate the HSPF model to represent the measured flows at the Cleator gage. Theissen polygons were initially employed to allocate rain records to subbasins. Early on in the process it was found that the model results were very sensitive to the particular rain gage records employed, and to snowmelt conditions. For example, the two rain records on the southwest side of the basin, the NCDC # 022329 and Maricopa County #5715, are close geographically, but have very different data, such that the model results were substantially different. Figure 5 shows that there are considerable variations in the annual rainfall amounts recorded at the five rain gages.

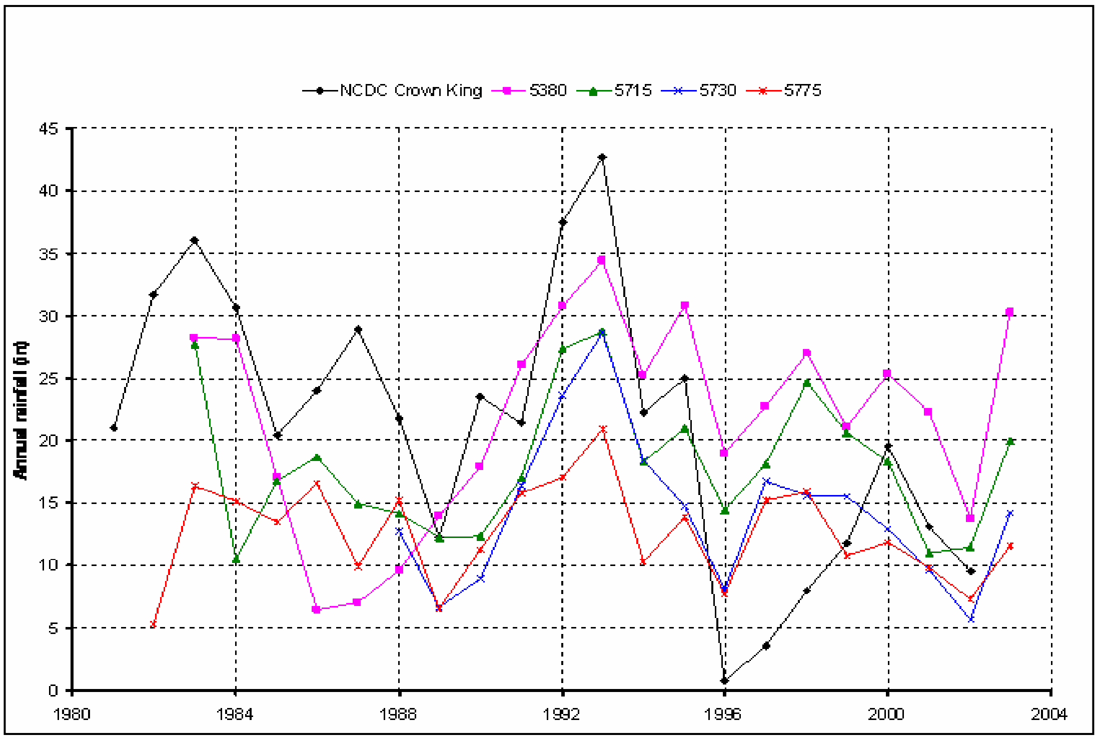

Figure 5. Annual precipitation totals for various gages

A major decision faced was whether to attempt to simulate snowmelt. Referring to Table 7, flows during March and April were more frequent than other months and the magnitude of the flows was greatest in February and March. It was judged that snowmelt played an important part in the winter and spring flows. While it would be possible to represent that process, without specific data on the snowmelt process in the watershed the representation would be approximate at best. Accordingly, the decision was made to not simulate snowmelt and concentrate on the months when this was not a factor—June through December. Although snowmelt contributes significantly to the flow in Turkey Creek it does not contribute to the impairment as shown by the PMP study results.

Using data from those months for the period of record, experiments were made with several combinations of rain gages. During these runs, the total runoff for each year was the primary comparison variable. With the rain records removed from the watershed, a comparison with individual rain/runoff events was not possible. Using coefficients for storage and infiltration that are within recommended ranges, it was ultimately determined that simply using the records from station 5775 to the northeast of the watershed produced a year-to-year pattern that was closest to the measured flows at Cleator. This is illustrated in Figure 6.

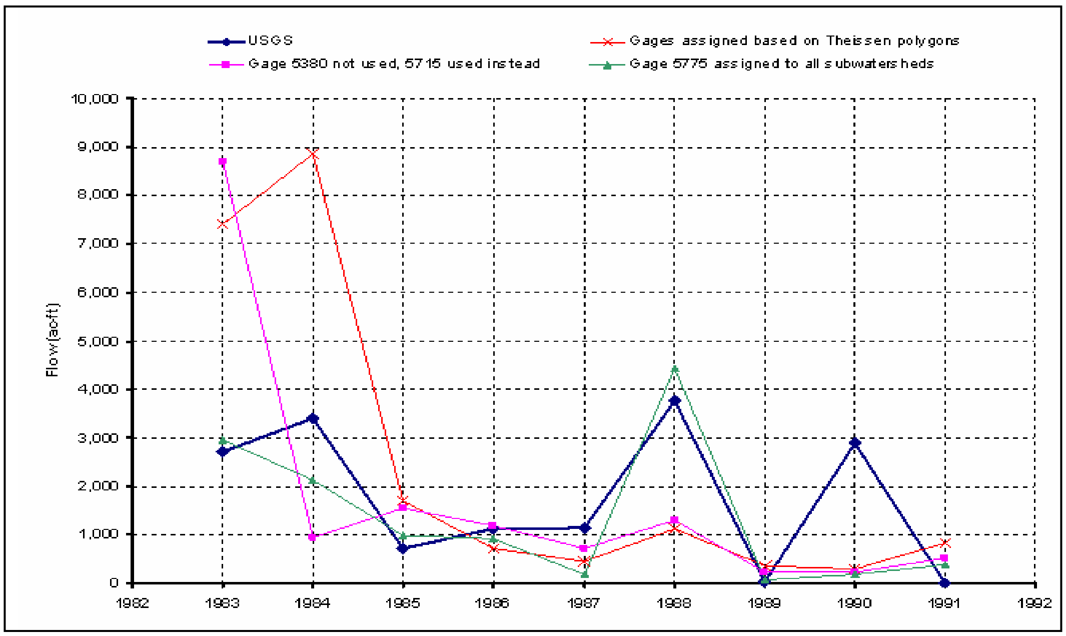

Figure 6. Comparison between observed and modeled flows (sum of June to December flows)

6.2.2 Flow calibration to local flow measurements

Once annual flows were calibrated, event driven flow calibration was attempted. In most cases these flows are smaller and may not represent the effects of rain events over the entire watershed. Again, a limitation is that there are no available rain records within the watershed and there are substantial variations among the records of the rain gages surrounding the watershed. Therefore, there is significant uncertainty in the rain distribution within the watershed. In the calibration process, using the model coefficients that had worked to represent average annual flows over the larger watershed, the available rain records were used as a reference and the distribution within the watershed was adjusted so that a reasonable match between modeled and observed flows was obtained.

Two types of flow records are available. One is flow estimation based on level logger data at the FR 259 Bridge, immediately upstream of the tailings area. The level logger data were converted to flows using a rating curve developed from channel cross-section survey and discharge measurements. It is noted that there is a short distance between the level logger and the cross section at which the rating curve was derived. It was assumed that the level logger measurements were the same as water depths at the cross section of the rating curve. Negative values of the level logger record were assumed to correspond to zero flow. The second type of flow record is the field measurements by ADEQ at selected times and locations during sampling events.

Two events were selected for calibration and validation. The first event occurred in September 2002 with the second in mid August 2003. Both events included water quality and discharge measurements.

Figure 7 illustrates the results of the process for the period of mid-August, 2003. During this time flows were measured on several occasions and a level-logger record was obtained. Figure 8 shows that the modeled flow matches the level logger flow reasonably well. Although limited, manual discharge measurements generally correlate with the modeled flows.

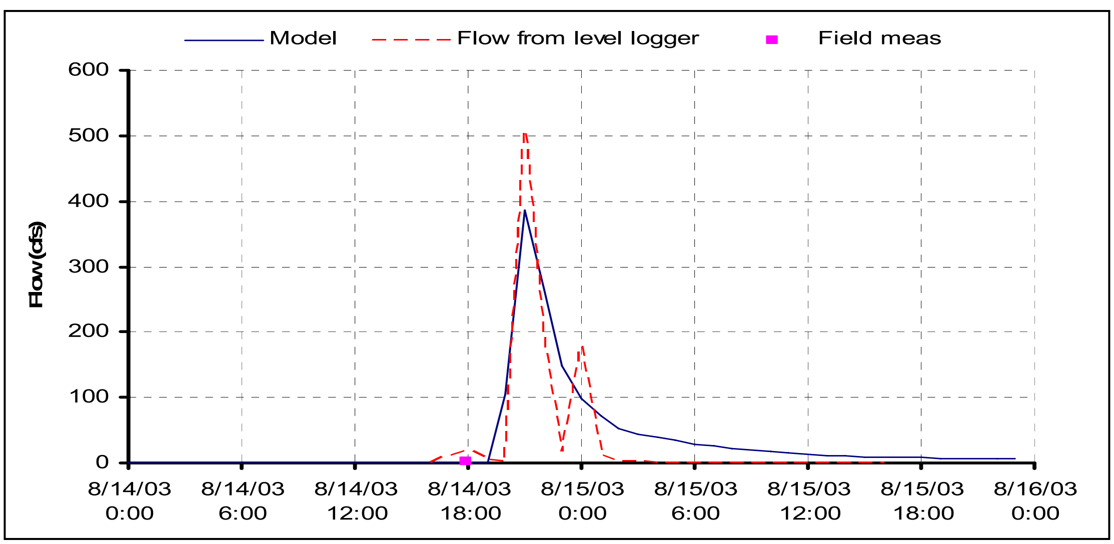

Figure 7. Measured and modeled flows for August 2003 event, Reach 23

6.2.3 Water Quality Calibration

After calibration to available flow data, water quality calibration was performed. The process involved running the model, comparing output time series of various constituents with observed data, and adjusting model parameters to improve agreement between observations and model results.

The model simulates the removal of sediment and associated metals from the watershed as well as scour and settling in the stream. The materials removed from the watershed enter into the stream and the model simulates the transport, deposition, and scouring of sediment and associated metals in the stream, and partitioning between dissolved and particulate metals. The tailing and waste rock piles are a small part of the watershed where runoff and scour occur. The tailings are unconsolidated material with a sand content of approximately 50% with the rest split between silt and clay (USFS, 2002). These tailings are believed to behave somewhat like a sponge, soaking up some of the rain and gradually discharging the water to the creek after acquiring some dissolved metals. The process of dissolved metals gradually leaching from the tailing piles was modeled by assigning a dissolved metal concentration in the interflow for the model segment with the tailings. Interflow is the amount of water that enters the ground and discharges into the stream at a later time than the direct overland flow.

There are a large number of parameters in the HSPF model. The technical notes (EPA, 2000) and literature on the BASINS website provide typical ranges for some of the parameters. These were used as guidance in the model development. It should be recognized that the model is an approximation of reality. Due to the inherent variability of the natural system, the model can only be expected to capture the main features relevant to the study.

The first step in the model calibration process was working with the data from upstream of the tailing site; FR 259 Bridge (bottom of Reach 23) and above. There were two data sets collected at the bridge site that had both flow observations and water quality samples, August 2003 and September 2002. The samples for the August 2003 event were collected before the main runoff event. A few observations were available at the Cleator site for the September 2002 event. In general, the concentrations tend to be fairly low and the model results appear to be in reasonable agreement. However, higher concentrations almost assuredly occurred during the runoff event in August 2003.

With the model reproducing background results in the right order, the next step was to simulate the effects of the mine waste sites where considerably more data are available. The area of each tailing and waste rock site was added to Reach 24. The model results of total suspended solids (TSS), total lead (Pb(t)) and copper (Cu(t)) and dissolved copper (Cu(d)) for the August 2003 event are compared with the data at the New Bend site in Figure 8.

Note that Cu(d) concentrations of 0.005 mg/L correspond to data below the reporting limit and half the reporting limit was used to represent such data. With Cu(t), the data show a second peak in the afternoon of August 15, 2003 that is not in the TSS and Pb(t) data. An isolated incident might have caused the rise in Cu(t) level. With Cu(d) the model matches the increasing concentrations in the declining limb of the runoff event, but continues to higher values when the flow is near zero. This reflects the elevated interflow concentration used in calibration and may not be reflective of actual conditions.

The next step was to apply the coefficients developed for the August 2003 data with the runoff data from September 2002. This is the model validation step. Data and model results for Reach 24 for the September 2002 event are shown in Figure 9. The data were collected at stations TC@bottom, TC@trib, and TC@bend. There is again reasonable agreement between model results and the data on September 10, 2002, but some aspects are hard to resolve. For example, the measured flows on September 9th were very low, only about 1 to 2 cfs, but the TSS values were over 500 mg/L. Other data indicate that there were times that the measured flows were similar or higher but with much lower TSS or metals concentrations. In this case, a very local rainfall that did not contribute significantly to flow could have washed enough sediment to the stream to raise the TSS and total metal levels (i.e. localized event near tailings piles). Focusing only on data from September 11th, the model results are generally similar to the data.

From these results it appears that the model is calibrated to the runoff process. It represents with reasonable accuracy both dissolved and particulate water quality parameters for two different events at stations above and below the tailings piles. This is essentially all the data that are available with both the necessary concentration and flow data.

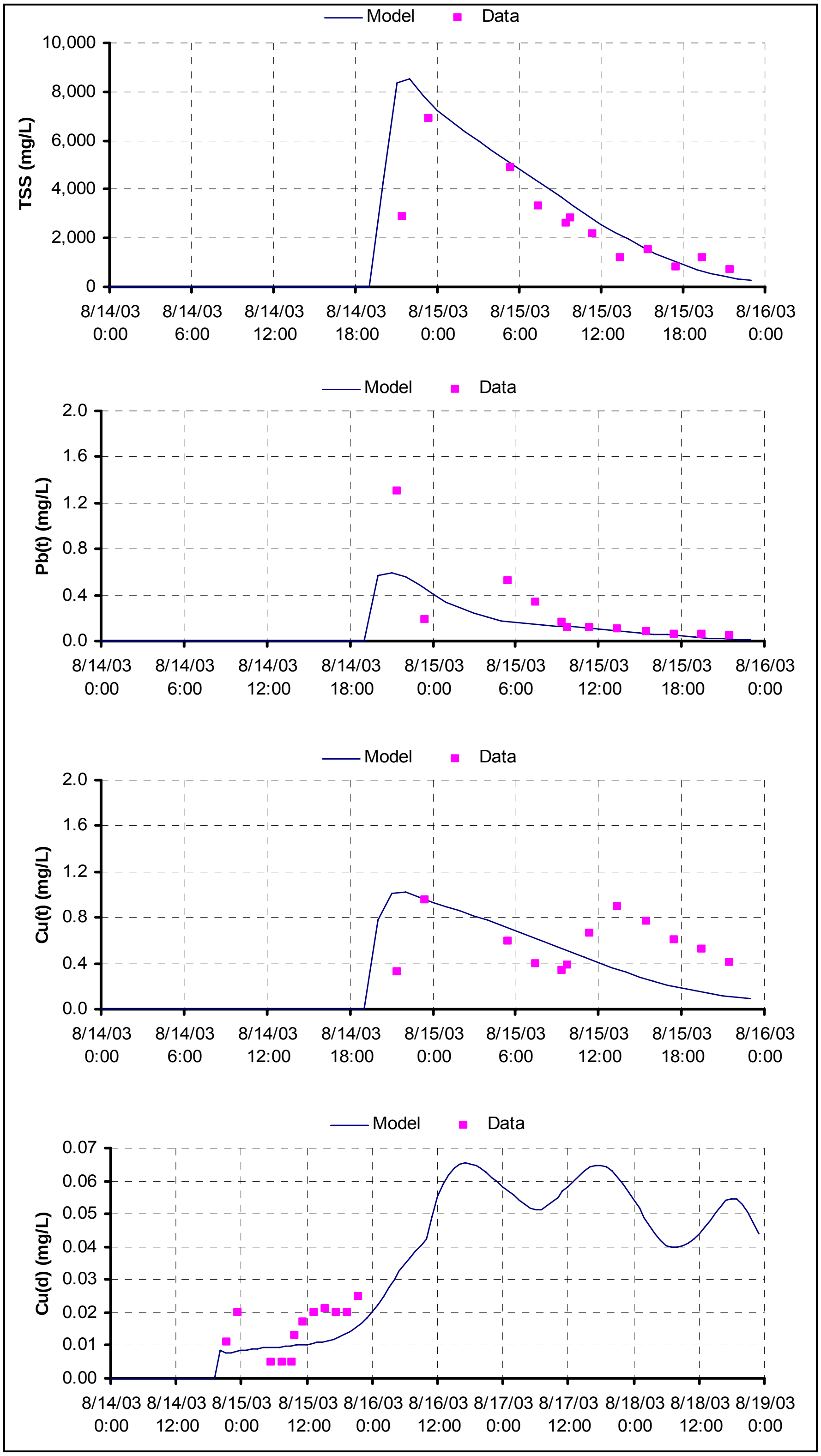

Figure 8. TSS, Pb(t), Cu(t) and Cu(d) model results and field data for August 2003 event

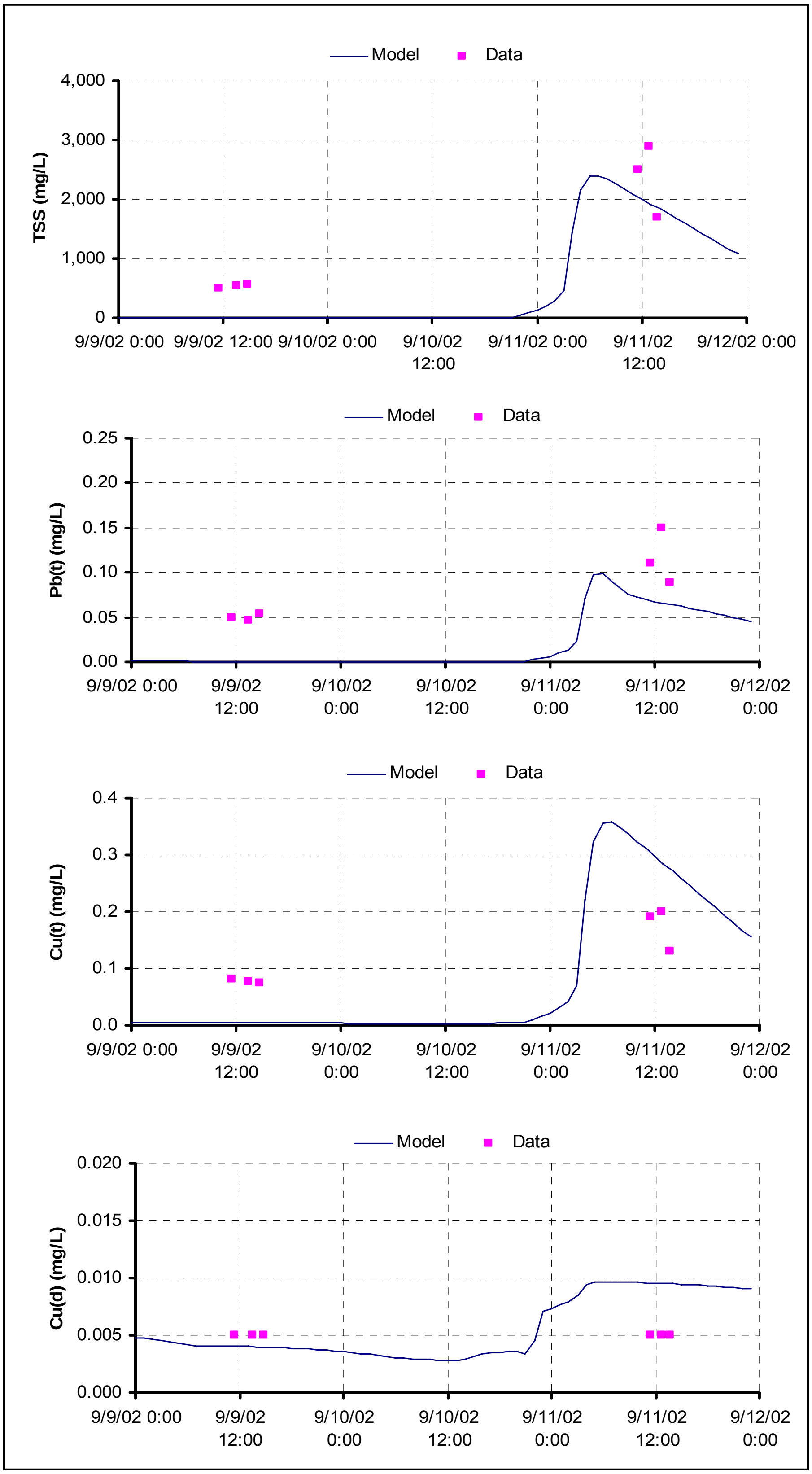

Figure 9. TSS, Pb(t), Cu(t) and Cu(d) model results and field data for August 2002 event

6.2.4 Other Data Calibration

In addition to the creek data modeled above, a few samples with very high concentrations of cadmium (Cd) and zinc (Zn) have caused Turkey Creek to be listed for these parameters. These concentrations are orders of magnitude different from the other stream samples. Though they are assessed as in-stream samples, they were probably collected at locations at which the flows were predominantly direct runoff from the tailings piles.

In order to represent these high concentrations of Cd and Zn in the model, an attempt was made to model a tributary through a tailings area draining to Turkey Creek. All the flow in the tributary came from the tailings area and the tributary output was expected to reflect the high concentrations in the direct runoff from the tailings. However, the attempt was not successful. Probably because the model segment was so much smaller than the other model segments, the model results were unstable.

6.2.5 Snowmelt Comparison

As discussed earlier, flows during the January to May period are frequently larger and more sustained than during the rest of the year. A major factor in this difference is the melting of snow accumulated in the upper elevations of the watershed. While such flows are a major part of the total flow of Turkey Creek, they are not runoff producing events and may have a relatively mild effect on contaminant levels.

To assess the snowmelt effect, ADEQ data obtained during winter flows without known local heavy rains were compiled and summarized in Table 8. Data are grouped upstream and within the tailings pile area. While the flows include some fairly high values, the TSS concentrations are all in the low hundreds, in contrast to the runoff events where values over 5,000 mg/L were common. Metals are low in these data with higher detections in the area influenced by the tailings, but no criteria exceedances. These data are similar to those found in the PMP data (ADEQ, 1997) that were collected under non-runoff conditions.

Table 8. Measured concentrations of TSS, copper, and lead in winter flow

Site	Sample date	Discharge (cfs)	TSS (mg/L)	Cu(t) (mg/L)	Cu(d) (mg/L)	Pb(t) (mg/L)
Upstream of tailings area						
TC@Cleator	02/15/03	17.3	13	<.01	<.01	<.005
TC@Bridge	02/09/01	3.9	1	<0.015	<0.015	<.005
TC@Bridge	02/14/01	6.5	24	<0.015	<0.015	<.005
TC@Bridge	03/07/01	26.3	277	<0.015	<0.015	<.005
TC@Bridge	02/15/03	17.3	25	<.01	<.01	<.005
TC@Bridge	02/26/03	18.3	27	<.01	<.01	<.005
TC@Bridge	03/18/03	71.1	75	0.012	<.01	<.005
Between FR 259 and spring						
TC@Trib	03/07/01	0.1	286	0.021	<0.015	0.01
TC@Trib	02/15/03	14.2	19	<.01	<.01	<.005
TC@Trib	02/26/03	20.8	32	<.01	<.01	<.005
TC@Trib	03/17/03	112.2	240	0.027	<.01	0.0082
TC@bend	02/15/03	13.4	20	<.01	<.01	<.005
TC@bend	02/26/03	16.1	37	<.01	<.01	<.005
TC@bend	03/17/03	114.6	220	0.025	<.01	0.0091
TC@bottom	02/15/03	10.1	21	<.01	<.01	<.005
TC@bottom	02/26/03	16.2	34	<.01	<.01	<.005

6.2.6 Calibration Discussion

The model appears to represent the major factors and processes in the watershed with reasonable accuracy. For low and moderate flows not associated with local rain, the model characterizes the data well. When rains occur, sediment is washed from the watershed and high TSS levels in the stream are produced. The model represents this process with reasonable agreement to available data. In the calibration events, the rain records indicate that the rain fell on an area substantially larger than the tailings areas. Thus the contribution of sediments and metals from the tailings piles was relatively small compared with the rest of the watershed. However, the application of the model will involve a local rain event in which the contribution from the tailings piles would be much more significant.

While the model is calibrated to the system, the limitations must be recognized. Most of the exceedances of water quality criteria are associated with runoff events, and it is the nature of such events to be highly variable in time and space. Information on the details of the rain events had to be estimated, so the model predictions must be considered to be approximations rather than precise values. With those limitations recognized, the model is a useful tool for water quality planning purposes.

7.0 TMDL MODELING

The objective of using mathematical models is to apply the modeled metal concentrations and flows to determine load reductions necessary by using the TMDL equation:

$$TMDL = \sum WLA + \sum LA + MOS$$

where the TMDL is the loading capacity, WLA is the waste load allocation for point sources, LA is the load allocation considering background and non-point sources, and MOS is the margin of safety. There are no point sources in the watershed so there will be no WLA term. The modeling presented in this section is an initial application of the calibrated model that attempts to address some of the complex issues of the project.

The TMDL, WLA, LA and MOS are all expressed in terms of loads, a product of flow and concentration. Typically a load has units of mass per time, e.g. lbs/day of parameter of concern. The original language in the Clean Water Act referred to the situation of multiple point sources of oxygen demanding waste that exceeded the assimilative capacity of the river even when the waste was treated to the typical technology-based treatment level. A TMDL, in that context, would determine the reduction in waste oxygen demanding load needed to achieve water quality criteria.

In Turkey Creek itself there are three chemical constituents, Pb(t), Cu(t), and Cu(d) that are the subject of the TMDL analysis. These appear to have background or LA concentrations that are related to flow in different ways. In addition, there have been very elevated concentrations of dissolved cadmium (Cd(d)) and dissolved zinc (Zn(d)) found on an unnamed tributary to Turkey Creek emanating from the tailings pile, causing Turkey Creek to be listed for these parameters. However, modeling results confirm sampling data that indicate dissolved cadmium and zinc do not impair Turkey Creek under modeled and observed flows.

7.1 Application of Model to Turkey Creek

All of the loads that will be considered here are related to flows in intermittent streams that are typically dry except in response to snow melt or precipitation events. The flows result from precipitation somewhere in the watershed and do not involve wastewater dischargers. There are a number of different sources of runoff flow and the chemical constituents—upstream watershed, tailings piles and waste rock piles associated with two known mine and ore processing areas. In addition there may be mining wastes in the upper watershed. The main actions that can be taken at this time to address the listed parameters are to remove or isolate the known mine waste sources.

A consideration is that attainment of numerical criteria is defined in terms of concentrations for each parameter rather than load. An important part of this TMDL modeling analysis will be determining for each of the sources the flow that appears to be typically associated with these concentrations that will allow use of the TMDL load equation. The values selected in this report are estimates of what might ultimately be required. In the case of Pb(t) and Cu(t), the concentration appears to be related to the TSS and both are related to the flow. The higher the flow, the higher the TSS and the higher the Pb(t) and Cu(t).

With Cu(d) the lower flows offer more contact with the land and opportunity for copper to enter solution and thus have higher concentrations. But at the same time, lower flows offer more of an opportunity for calcium and magnesium to enter solution, increasing the hardness of the water. A higher hardness concentration raises the criteria levels (that are a function of hardness), resulting in a lower chance of criteria exceedance. Figure 10 presents the hardness data with a regression curve that relates Turkey Creek hardness to flow. This equation will be used to define the specific numerical criteria values for Cu(d).

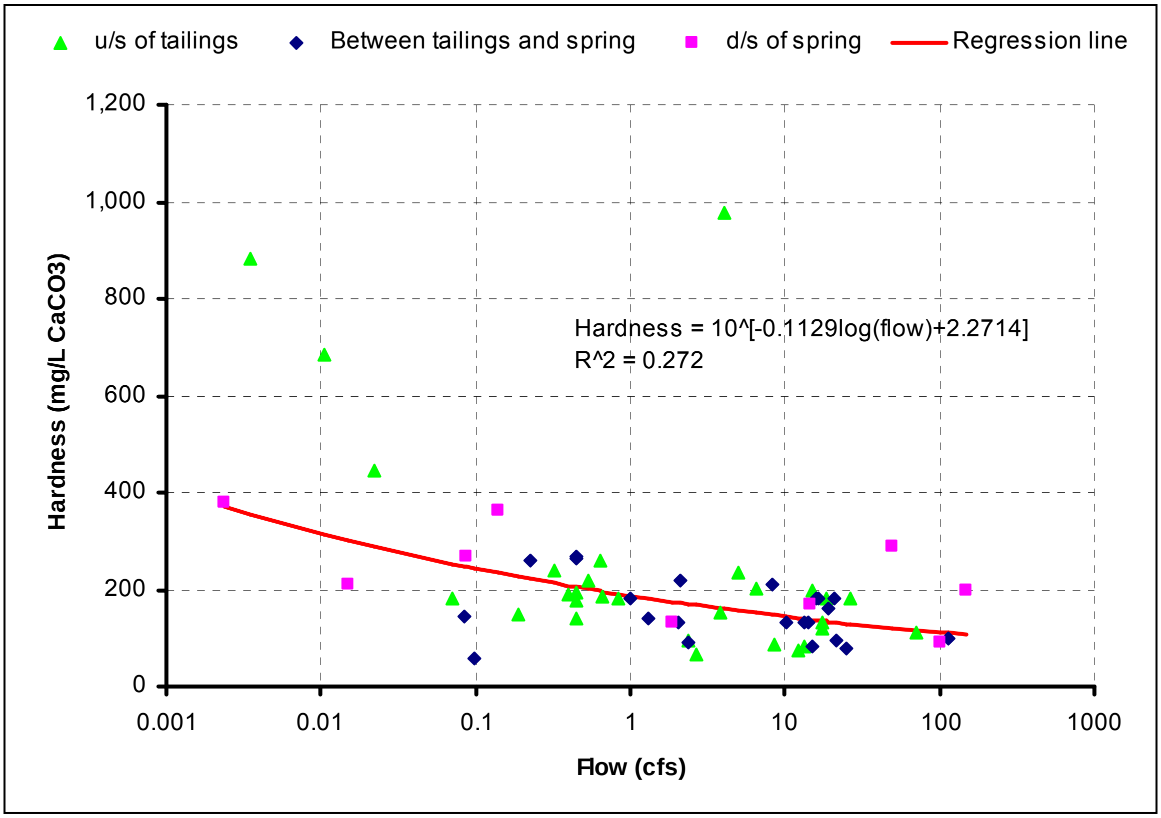

Figure 10. Hardness versus flow in Turkey Creek

7.2 Model Scenarios

This section develops the basic information for the TMDL process. The procedure followed is to first employ the calibrated model on a series of runs, starting with the flows from a 24-hr rain typically used to generate a 100-yr runoff event, and stepping down to small events typical of the area and conditions for which the model was calibrated. Since smaller, more localized rains would appear to be the more common situation, a series of model runs was performed first for rain occurring on Reaches 16 (Mineral Creek confluence to the old USGS gage near Cleator), 23 (gage to FR 259 Bridge), and 24 (FR 259 Bridge to end of mine tailings area), see Figure 4. The incremental effect of the tailings and waste rock piles are likely to be more significant with the smaller rain. To achieve a runoff flow typically used in flood studies, it was necessary to add antecedent soil moisture. The soil moisture was achieved by simulating a separate rain the day before the event in question.

With each rain event the maximum, arithmetic mean, flow-weighted average, and median concentrations are computed. For these concentration determinations, a 1-day averaging period is employed, starting when the hydrograph first shows significant flow and ending 24 hours later. The 1-day period is a judgment call as to when the event is over. A longer period could be employed because at least on larger rain events the trailing edge of the hydrograph extends for many days. However, these flows tend to be low with characteristics very different from the runoff event. The 1-day window appears to capture most of the runoff volume associated with a 24-hr rain event.

Table 9 presents the results of this series of model runs with the rain over the nearby watershed. Results are shown for three locations, Reaches 23, 24, and 9 (confluence with Poland Creek). In each case the rainfall amount employed is noted, as well as the peak runoff flow rate, the average flow over the day, and the event runoff coefficient (sum runoff volume/sum rain volume). The concentration values shown include the 1-day median, arithmetic average, flow-weighted average, and maximum hourly. At Reach 23, the Pb(t) shows a pattern of increasing maximum concentration as the rain event gets larger, but the median, arithmetic and flow-weighted averages do not change a great deal for events larger than the 2-year rain. Cu(t) shows a generally similar pattern, while Cu(d) shows little change in any of the concentration values with rain event size. With smaller rain events, 3-month up to 2-year, concentrations of Pb(t) and Cu(t) get smaller as the rain size gets smaller.

As noted in the calibration section, steady flows do not produce high concentrations while the runoff events, particularly those with intense rain, tend to produce high TSS and associated metals. A runoff event will produce a short spike of high flows followed by a trailing limb where flows and concentrations subside.

Based on the model results for a localized intense rain, it appears that the 0.015 mg/L (15 parts per billion (ppb)) concentration is exceeded by all concentration values at a flow lower than 100 cfs. For example, the 2-year event has a peak flow of 68 cfs and all concentrations greater than 0.015 mg/L. Only at the 0.25 year event are the arithmetic and flow-weighted averages less than 0.015 mg/L.

Table 9. Model results with local rain on Reaches 16, 23, and 24

Return period (yr)		0.25	0.5	1	2	5	10	25	50	100
Rainfall (in)		1.66	1.9	2.19	2.43	3.07	3.57	4.26	4.80	5.36
Reach 23										
Runoff coefficient		7%	10%	14%	17%	25%	31%	38%	42%	47%
Peak hourly flow		8.0	19.3	39.2	68.1	218.0	338.0	497.0	620.0	743.0
Average flow (cfs)		2.3	4.4	7.9	11.1	22.2	32.4	47.6	60.7	75.0
Pb(t)	Median	0.001	0.004	0.011	0.021	0.000	0.000	0.000	0.000	0.000
(mg/L)	Mean	0.005	0.016	0.047	0.092	0.197	0.151	0.138	0.134	0.137
	Flow-weighted	0.009	0.038	0.133	0.284	0.776	0.699	0.693	0.724	0.776
	Maximum	0.025	0.107	0.317	0.543	1.160	1.306	1.569	1.672	1.750
Cu(t)	Median	0.008	0.028	0.080	0.157	0.259	0.162	0.119	0.055	0.047
(mg/L)	Mean	0.028	0.077	0.175	0.290	0.489	0.351	0.291	0.265	0.259
	Flow-weighted	0.057	0.168	0.386	0.639	1.328	1.146	1.106	1.140	1.208
	Maximum	0.134	0.316	0.618	0.930	1.806	2.004	2.384	2.532	2.658
Cu(d)	Median	0.001	0.002	0.005	0.008	0.009	0.009	0.008	0.008	0.008
(mg/L)	Mean	0.003	0.004	0.006	0.006	0.006	0.007	0.007	0.007	0.006
	Maximum	0.009	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Reach 24										
Peak hourly flow		9.3	25.2	52.9	88.9	268.0	422.0	637.0	810.0	982.0
Average flow (cfs)		3.1	5.9	10.4	14.7	29.4	43.0	63.1	80.5	99.3
Pb(t)	Median	0.003	0.015	0.037	0.068	0.112	0.058	0.043	0.034	0.031
(mg/L)	Mean	0.012	0.034	0.084	0.147	0.283	0.237	0.218	0.216	0.218
	Flow-weighted	0.022	0.074	0.210	0.397	0.975	0.952	0.954	1.007	1.083
	Maximum	0.051	0.183	0.485	0.783	1.515	2.150	2.585	2.774	2.932
Cu(t)	Median	0.454	0.429	0.553	0.664	0.856	0.689	0.629	0.654	0.652
(mg/L)	Mean	0.455	0.476	0.552	0.673	0.959	0.804	0.734	0.731	0.722
	Flow-weighted	0.373	0.410	0.573	0.804	1.464	1.291	1.240	1.279	1.350
	Maximum	0.672	0.686	0.693	1.015	1.888	2.234	2.591	2.781	2.945
Cu(d)	Median	0.427	0.110	0.044	0.037	0.029	0.038	0.059	0.079	0.100
(mg/L)	Mean	0.346	0.264	0.213	0.192	0.151	0.121	0.136	0.163	0.185
	Maximum	0.671	0.683	0.684	0.685	0.688	0.631	0.484	0.533	0.568
Hardness	For median Cu(d)	169	162	156	156	154	150	147	144	141
(mg/L)	For maximum	188	183	178	175	169	165	160	156	153
Criteria	Cu(d) chronic	0.014	0.014	0.013	0.013	0.013	0.013	0.012	0.012	0.012
(mg/L)	Cu(d) acute	0.024	0.024	0.023	0.023	0.022	0.022	0.021	0.020	0.020
Reach 9										
Peak hourly flow		5.5	12.6	26.9	44.8	185.0	294.0	437.0	578.0	744.0
Average flow (cfs)		3.0	5.7	10.2	14.4	29.0	42.5	62.5	79.8	98.5
Pb(t)	Median	0.008	0.016	0.038	0.072	0.121	0.063	0.038	0.034	0.030
(mg/L)	Mean	0.012	0.023	0.064	0.135	0.320	0.277	0.268	0.277	0.289
	Flow-weighted	0.015	0.031	0.099	0.241	0.846	0.874	0.900	0.956	1.036
	Maximum	0.050	0.112	0.305	0.614	1.486	1.656	1.991	2.397	2.674
Cu(t)	Median	0.399	0.384	0.544	0.695	0.977	0.716	0.607	0.593	0.594
(mg/L)	Mean	0.405	0.430	0.538	0.710	1.063	0.856	0.767	0.747	0.744
	Flow-weighted	0.361	0.397	0.567	0.809	1.475	1.308	1.253	1.284	1.354
	Maximum	0.665	0.658	0.659	0.956	1.891	1.948	2.114	2.476	2.732
Cu(d)	Median	0.266	0.071	0.021	0.016	0.014	0.018	0.024	0.029	0.035
(mg/L)	Mean	0.274	0.182	0.129	0.111	0.080	0.056	0.051	0.056	0.067
	Maximum	0.656	0.620	0.568	0.546	0.494	0.358	0.277	0.219	0.263
Hardness	For median Cu(d)	165	158	150	148	146	143	141	138	136
(mg/L)	For maximum	185	178	174	171	166	162	157	153	150
Criteria	Cu(d) chronic	0.014	0.013	0.013	0.013	0.012	0.012	0.012	0.012	0.012
(mg/L)	Cu(d) acute	0.024	0.023	0.023	0.022	0.022	0.021	0.021	0.020	0.020

Cu(t) has higher concentrations overall than Pb(t) in Reach 23 and behaves in a similar fashion. The most stringent criterion that applies to Cu(t) is for AgL where the level is 0.5 mg/L (500 ppb). For the 2-year event this criterion is exceeded by the maximum and flow-weighted averages, but not the arithmetic average and median values. Smaller rain events do not exceed the criterion while larger rain events show a similar pattern to the 2-year event. With Cu(d) in Reach 23 the copper concentrations show little change with event size except at the very lowest flows.

Comparing results at Reach 24 with Reach 23 in Table 9, the effect of the tailings can be seen. Concentrations of all parameters and all values are higher in Reach 24, with the biggest increase showing up at the smaller rain event sizes. At Reach 9, the Poland Creek confluence, all concentration values are lower reflecting the effect of smoothing of the flow. For this set of simulation, no rain was applied on Reach 9. The effect of including rain on Reach 9 is discussed below.

Concentrations of Cu(d) in Reach 24 are much higher than in Reach 23. One of the reasons is that the Cu(d) is introduced in the model through a combination of interflow and partitioning from sediment associated copper in the runoff from the tailings and waste rock areas. The interflow is flow through the soil and in the tailings areas it has ample contact time to absorb Cu(d). There are also contributions in the model from direct runoff from the tailing and waste rock sites in Reach 24. The net result for this series of simulations is that all the Cu(d) values in Reach 23 are lower than the current reporting limit for ADEQ analyses (10 ppb), but those in Reach 24 and 9 are markedly higher.

The results in Table 9 are intended to be worst-case, with an intense rain pattern concentrated near the tailings area. The model simulations shown in Table 10 were done with the same rain applied uniformly over the entire watershed. Intense, widespread rains are unlikely to occur, but need to be addressed. Again, the goal was to start out with a flow that was representative of a large and rare event, the 100-yr return interval or 0.01 annual probability event. To get agreement between the model flow and the flow that would be predicted by flood modeling, the antecedent moisture was used. This was implemented with a rain two days before the event in question, and this antecedent moisture rain was maintained for all subsequent smaller rain events. The absolute size of the rain events is smaller (e.g. for the 100-yr events it was 5.36 in. but was reduced to 4.59 in. on the full watershed) reflecting the effect of the drainage area reduction factor for the larger watershed. The flows in Table 10 are larger because of the larger watershed area involved. However, the relative contribution of runoff flows from the tailings and waste rock is smaller.

Table 10. Model results with rain over the entire watershed

Return period (yr)		0.25	0.5	1	2	5	10	100
Rainfall (in)		1.42	1.63	1.88	2.08	2.63	3.06	4.59
Reach 23								
Runoff coefficient		1%	2%	3%	5%	10%	15%	32%
Peak hourly flow (cfs)		36.3	81.7	262.0	538.0	1770.0	4190.0	19600.0
Average flow (cfs)		28.6	52.1	105.7	177.6	539.3	1009.4	3370.4
Pb(t)	Median	0.001	0.002	0.005	0.010	0.056	0.148	0.264
(mg/L)	Mean	0.002	0.005	0.016	0.034	0.132	0.230	0.405
	Flow-weighted avg	0.002	0.006	0.024	0.061	0.247	0.421	0.810
	Maximum	0.004	0.015	0.078	0.171	0.539	0.828	1.401
Cu(t)	Median	0.005	0.010	0.022	0.050	0.281	0.499	0.614
(mg/L)	Mean	0.009	0.027	0.062	0.107	0.338	0.531	0.762
	Flow-weighted avg	0.009	0.033	0.090	0.166	0.510	0.785	1.328
	Maximum	0.027	0.091	0.221	0.356	0.899	1.345	2.161
Cu(d)	Median	0.003	0.004	0.005	0.006	0.008	0.008	0.008
(mg/L)	Mean	0.003	0.004	0.005	0.006	0.008	0.008	0.008
	Maximum	0.007	0.008	0.008	0.008	0.009	0.009	0.008
Reach 24								
Peak hourly flow (cfs)		36.5	81.2	235.0	517.0	1770.0	4100.0	19900.0
Average flow (cfs)		28.3	51.8	105.4	177.5	541.0	1012.5	3388.5
Pb(t)	Median	0.002	0.006	0.011	0.019	0.065	0.161	0.284
(mg/L)	Mean	0.004	0.010	0.022	0.042	0.150	0.255	0.433
	Flow-weighted avg	0.004	0.012	0.030	0.067	0.254	0.430	0.839
	Maximum	0.010	0.026	0.080	0.179	0.559	0.886	1.721
Cu(t)	Median	0.016	0.024	0.037	0.063	0.298	0.519	0.647
(mg/L)	Mean	0.024	0.041	0.076	0.121	0.356	0.554	0.783
	Flow-weighted avg	0.023	0.046	0.103	0.177	0.518	0.792	1.358
	Maximum	0.051	0.104	0.222	0.367	0.873	1.364	2.077
Cu(d)	Median	0.010	0.009	0.008	0.008	0.008	0.009	0.008
(mg/L)	Mean	0.011	0.010	0.009	0.008	0.008	0.008	0.008
	Maximum	0.025	0.016	0.010	0.009	0.009	0.009	0.010
Hardness	For median Cu(d)	133	121	114	105	99	98	94
(mg/L)	For maximum Cu(d)	149	139	120	104	129	78	88
Criteria	Cu(d) chronic	0.011	0.011	0.010	0.009	0.009	0.009	0.008
(mg/L)	Cu(d) acute	0.020	0.018	0.016	0.014	0.017	0.011	0.012
Reach 9								
Peak hourly flow (cfs)		37.3	81.1	236.0	475.0	1640.0	3760.0	20300.0
Average flow (cfs)		28.6	53.4	111.4	187.6	567.2	1055.6	3496.1
Pb(t)	Median	0.002	0.005	0.010	0.016	0.072	0.183	0.344
(mg/L)	Mean	0.002	0.009	0.027	0.055	0.182	0.285	0.440
	Flow-weighted avg	0.002	0.008	0.031	0.075	0.279	0.433	0.796
	Maximum	0.007	0.038	0.158	0.291	0.706	1.045	1.456
Cu(t)	Median	0.021	0.039	0.057	0.087	0.323	0.558	0.730
(mg/L)	Mean	0.025	0.052	0.099	0.154	0.419	0.617	0.813
	Flow-weighted avg	0.022	0.052	0.119	0.204	0.564	0.799	1.292
	Maximum	0.052	0.145	0.329	0.510	1.097	1.590	2.144
Cu(d)	Median	0.009	0.009	0.008	0.008	0.008	0.008	0.008
(mg/L)	Mean	0.009	0.009	0.008	0.008	0.008	0.008	0.008
	Maximum	0.012	0.010	0.010	0.010	0.009	0.009	0.010
Hardness	For median Cu(d)	140	122	109	105	99	99	94
(mg/L)	For maximum Cu(d)	134	128	114	103	89	81	87
Criteria	Cu(d) chronic	0.012	0.011	0.010	0.009	0.009	0.009	0.008
(mg/L)	Cu(d) acute	0.018	0.017	0.015	0.014	0.012	0.011	0.012

The simulations in Table 10 show more uniform values for Pb(t) and Cu(t), with smaller differences between the maximum and median values. Another important difference between the full basin and local rain results in the two tables is with Cu(d). Results in Reach 23 are quite low in both tables, but in Reach 24 they jump markedly with the local rain but not with the rain over the entire watershed. Another difference is in the Reach 9 results. In the local rain simulations (Table 9) no rain was applied to this watershed while it is included in the entire watershed simulations. The effect is that for some parameters, Reach 9 values are higher than those in Reach 24.

The bottom part of Tables 9 and 10 (Reaches 24 and 9) contains hardness values estimated from the regression equation in Figure 9 corresponding to the median and maximum Cu(d) concentrations, and the associated Cu(d) criteria. It can be seen that the modeled values for Reach 24 and 9 are well in excess of the criteria for the local rain but not the rain over the entire watershed. Values upstream are well below the criteria for both rain patterns.

To explore further the effect of including runoff from Reach 9 in local simulations, a set of the smaller rain events were simulated to include rain over Reach 9. Comparing the Reach 9 results in Table 11 with those in Table 9 (Reaches 16, 23, and 24 were not affected by rain in Reach 9), the flow values are markedly higher reflecting the larger size of Reach 9 and the fact that it has lower soil permeability than the more upstream reaches. The average concentrations of Pb(t) are higher while the Cu(t) and Cu(d) values are lower. The main reason for the higher Pb(t) is that the same lead fraction in sediment is used throughout the model and Reach 9 has a larger area with a higher runoff contribution. The same factor also applies for Cu(t). However, another factor is that the Cu(d) load in the interflow of the tailings area is diluted by the runoff from Reach 9. At the smaller rain events, the dilution effect appears to more than offset the contribution of particulate copper from Reach 9 such that the Cu(t) concentrations are lower in Reach 9 than in Reach 24.

All of the simulations shown have been performed using a rainfall pattern used in flood studies. It is an intense rain that generates relatively high peak flows and also has the effect of mobilizing or eroding sediment from the watershed. This is the kind of event that was recorded in some ADEQ monitoring where high TSS and metal concentrations were recorded. But not all rains are this intense. To assess the effect of rain distribution on the local watershed, the 2-year 24-hr rain of 2.43 in. along with the 100-yr rain, were simulated with an even distribution over the period (0.1 in./hour and 0.22 in./hour). Model results show that a slow even rain produces much less runoff volume and much lower concentrations.

A final model simulation is steady flows from the upstream part of the watershed that might be generated by snow melt. Simulations were run at 20, 70 and 110 cfs, with all flow originating well upstream and all having zero background concentrations. With higher flows there is an increase in the Pb(t) and Cu(t) levels, but they are well below criteria.

Table 11. Model results with local rain on Reaches 9, 16, 23, and 24

Reach 9							
Peak hourly flow (cfs)		68.9	164.0	290.0	406.0	1110.0	2350.0
Average flow (cfs)		13.5	22.6	35.5	47.8	122.5	269.6
Pb(t) (mg/L)	Median	0.007	0.015	0.029	0.047	0.037	0.011
	Mean	0.027	0.055	0.103	0.155	0.181	0.167
	Flow-weighted avg	0.071	0.183	0.363	0.544	0.716	0.837
	Maximum	0.188	0.381	0.642	0.877	1.374	1.650
Cu(t) (mg/L)	Median	0.224	0.264	0.309	0.460	0.412	0.271
	Mean	0.236	0.308	0.418	0.545	0.534	0.428
	Flow-weighted avg	0.279	0.450	0.712	0.969	1.082	1.198
	Maximum	0.388	0.657	1.016	1.339	2.055	2.362
Cu(d) (mg/L)	Median	0.033	0.023	0.017	0.015	0.017	0.033
	Mean	0.080	0.061	0.039	0.028	0.029	0.057
	Maximum	0.263	0.256	0.206	0.157	0.102	0.180
Hardness	For median Cu(d)	148	143	139	138	134	126
(mg/L)	For maximum Cu(d)	168	163	159	157	148	137
Criteria (mg/L)	Cu(d) chronic	0.013	0.012	0.012	0.012	0.012	0.011
	Cu(d) acute	0.022	0.021	0.021	0.021	0.019	0.018

8.0 TMDL CALCULATION

The TMDL calculations are based on rain, flow, and concentration simulations developed using the BASINS-HSPF model. The worst case scenario shown by the model occurred when localized rain fell on the tailings piles and immediately upstream of the Golden Turkey and Golden Belt mines (summarized in Table 9). Under this condition, loads from the piles to Turkey Creek were maximized without contributing flow from higher portions of the watershed.

The TMDL or loading capacity and the resulting load reductions necessary to meet the TMDL will be calculated from modeled results using the TMDL equation:

$$TMDL = \sum WLA + \sum LA + MOS$$

Loading capacity, existing loads, and reductions needed will be calculated at the end of three stream reaches, namely Reaches 23 (at FR 259 Bridge), 24 (end of Golden Belt and Turkey mining area), and 9 (confluence with Poland Creek). These three sites are used to represent the loads from the upper watershed, known mining influences, and loads exiting the watershed.

A complicating factor is the concentrations and loads upstream of the main mine waste sites consist of both true background and other residual mining activity. At this point it is not known how much of the metals in runoff are natural and how much are a result of anthropogenic activities. More research on this topic is planned by ADEQ. In the meantime it is assumed that for Pb(t) and Cu(t) the natural background concentrations are the reporting levels, and for Cu(d) the concentrations in Reach 23 reflect the natural background.

8.1 Margin of Safety

The purpose of a MOS is to provide for uncertainty in the calculations. Dilks and Freedman (2004) reviewed the subject of MOS determination. They cite the National Research Council's (2001) review of the TMDL program that concluded that there was a lack of consistency and rigor in current approaches and noted the need for explicit uncertainty analysis in the MOS determination.

Analysis of uncertainty is an essential step. In this case there is a substantial pool of data collected by the ADEQ, and the model appears to provide a reasonably accurate representation of the processes and agreement with field data. The basic information and source of the problem (the tailings piles) is also known with a reasonable degree of certainty. There still is substantial uncertainty in:

- the events themselves—rains are variable in timing and location that can make big differences in stream concentrations,
- how selected events are to be related to specific criteria,
- how the flows are to be related to loads with short-term runoff events,
- the time required for tailings-related particulate lead to get out of the system.

The Arizona Department of Health Services has confirmed the precision of their measurements to be plus or minus 5%. An additional 15% MOS will be applied to account for variable field conditions and model decisions. Variability in field conditions include sampling occurring under drought conditions, the use of autosamplers, grab sample techniques and manual discharge measurements. Modeling decisions that necessitate using a MOS include lack of rain records in the watershed that relate to flow measurements, use of default values, and inability to directly model the chemical and hydrologic processes taking place in and on the tailings piles. Therefore, an explicit MOS of 20% will be applied to the TMDL calculations.

8.2 Waste Load Allocations

As stated previously, there are no known permitted discharges (point sources) located within the Turkey Creek watershed. Therefore the WLA variable will be assigned a value of zero in the TMDL equation.

8.3 Load Allocations

Nonpoint source contributions from the watershed may come from either natural background conditions or anthropogenic sources (i.e. mining). LAs will be calculated for these sources; however, not enough data is available to determine the difference between natural background concentrations and anthropogenic sources above and below the known mining area. The two known mining sources within the watershed that have been identified are the Golden Turkey and Golden Belt mines. There are likely many smaller operations located throughout the watershed that potentially contribute to the loading of metals to Turkey Creek but simply have not been located. It should be noted that, if in the future, LAs are determined to result from point sources they will become WLAs.

8.4 Load Reductions

Load Reductions (LR) are needed when the existing load is larger than the LA calculated using the TMDL equation. The LR can be calculated by:

$$LR = \text{Existing load} - LA$$

The percent reduction needed is calculated by using:

$$\% \text{ Reduction} = (LR/\text{Existing Load}) * 100$$

In cases where the LR is negative, no reduction is necessary. In instances where the inclusion of the margin MOS causes existing loads to exceed the loading capacity a reduction in the existing load will still be required.

8.5 Turkey Creek TMDLs

TMDLs identify the amount of pollutant that can be assimilated by the waterbody and still meet water quality standards. The pollutants of concern requiring TMDLs for Turkey Creek are copper and lead. Tables 12 through 15 summarize the TMDL calculations for Reaches 23, 24, and 9, respectively. Tables 12 and 13 were calculated using the average flow and mean concentration for each flow event using the data in Table 9. Cu(d) limits where calculated using the chronic A&Ww standard with an average hardness of 141 mg/L. In order to calculate the load in grams per day (g/day) from discharge in ft^3/sec (cfs) and concentrations in mg/L a conversion factor needed to be calculated:

$$ft^3/sec * 28.32 L/ft^3 * 86400 sec/day * mg/L * g/1000mg = 2447 g/day$$

The conversion factor of 2447 g/day was used in the following equation:

$$\text{Existing Load} = cfs * [metal] * 2447 g/day$$

Table 12 shows that loading of Pb(t) is occurring in the watershed above the FR 259 bridge. Above the three month return interval flow (2.3 cfs), the FBC standard of 0.015 mg/L is expected to be exceeded. Lead has a high specific gravity and readily settles out of the water column in flows that do not have enough energy to keep particles suspended. Sampling results indicate that exceedances of the Pb(t) standard occur at the sample site located above FR 93 but not at the next upstream sample site located above Bear Creek. Tributaries located between these two sites include several unnamed streams and Wolf and Bear Creeks.

Unidentified mining sources may be contributing lead to Turkey Creek during runoff events. The watershed contains many historic mining districts that are known to have contained lead bearing accessory minerals. Insufficient data has been collected to determine what percentage of the lead load observed above FR 259 is naturally occurring or resulting from anthropogenic activities. Further, targeted sampling, will be needed to determine the source of lead to Turkey Creek above the FR 259 bridge. Both total and dissolved copper results indicate that surface water standards are being met under all flow regimes above FR 259.

Table 12. TMDLs for Reach 23 with rainfall over Reaches 16, 23, and 24

Metal	Return Interval (yr)	Avg Flow (cfs)	Existing load (g/day)	LA (g/day)	MOS (g/day)	TMDL (g/day)	% Reduction
Total Pb	0.25	2.3	28	67	17	84	0
	0.5	4.4	172	129	32	161	25
	1	7.9	909	231	58	289	75
	2	11.1	2499	325	81	406	87
	5	22.2	10702	650	163	813	94
	10	32.4	11972	949	237	1186	92
	25	47.6	16074	1394	348	1742	91
	50	60.7	19903	1777	444	2222	91
	100	75	25143	2196	549	2745	91
Total Cu	0.25	2.3	158	2245	561	2806	0
	0.5	4.4	829	4294	1074	5368	0
	1	7.9	3383	7710	1928	9638	0
	2	11.1	7877	10834	2708	13542	0
	5	22.2	26564	21667	5417	27084	0
	10	32.4	27828	31622	7906	39528	0
	25	47.6	33895	46458	11614	58072	0
	50	60.7	39361	59243	14811	74054	0
	100	75	47533	73200	18300	91500	0
Dissolved Cu	0.25	2.3	17	54	13	67	0
	0.5	4.4	43	103	26	129	0
	1	7.9	116	185	46	231	0
	2	11.1	163	260	65	325	0
	5	22.2	326	520	130	650	0
	10	32.4	555	759	190	948	0
	25	47.6	815	1115	279	1393	0
	50	60.7	1040	1422	355	1777	0
	100	75	1101	1757	439	2196	0

The effects of rain on tailings piles of the Golden Belt and Golden Turkey mines can be seen when loads are calculated for Reach 24 (Table 13). Loads for both copper and lead increase significantly, exceeding water quality standards during all modeled flows. The only exception is lead at the three month return (3.1 cfs) interval meeting standards.

Table 13. TMDLs for Reach 24 with rainfall over Reaches 16, 23, and 24

Metal	Return Interval (yr)	Avg Flow (cfs)	Existing load (g/day)	LA (g/day)	MOS (g/day)	TMDL (g/day)	% Reduction
Total Pb	0.25	3.1	91	91	23	113	0
	0.5	5.9	491	173	43	216	65
	1	10.4	2138	305	76	381	86
	2	14.7	5288	430	108	538	92
	5	29.4	20360	861	215	1076	96
	10	43	24937	1259	315	1574	95
	25	63.1	33660	1848	462	2309	95
	50	80.5	42548	2357	589	2946	94
	100	99.3	52971	2908	727	3634	95
Total Cu	0.25	3.1	3451	3026	756	3782	12
	0.5	5.9	6872	5758	1440	7198	16
	1	10.4	14048	10150	2538	12688	28
	2	14.7	24208	14347	3587	17934	41
	5	29.4	68992	28694	7174	35868	58
	10	43	84598	41968	10492	52460	50
	25	63.1	113334	61586	15396	76982	46
	50	80.5	143995	78568	19642	98210	45
	100	99.3	175437	96917	24229	121146	45
Dissolved Cu	0.25	3.1	2625	85	21	106	97
	0.5	5.9	3811	161	40	202	96
	1	10.4	5421	264	66	330	95
	2	14.7	6906	373	93	466	95
	5	29.4	10863	746	187	933	93
	10	43	12732	1091	273	1364	91
	25	63.1	20999	1478	370	1848	93
	50	80.5	32108	1886	471	2357	94
	100	99.3	44953	2326	582	2908	95

Tables 12 and 13 show the effects of localized rain occurring over Reaches 16, 23, and 24, under this scenario, flow in Turkey Creek continues to the confluence with Poland Creek without any contributions from Reach 9. The loads calculated for the mouth of Turkey Creek are, therefore, the loads coming from Reach 24 and the small changes in the modeled numbers are due to natural attenuation, see table 14.

Table 14. TMDLs for Reach 9 with rainfall over Reaches 16, 23, 24

Metal	Return Interval (yr)	Avg Flow (cfs)	Existing load (g/day)	LA (g/day)	MOS (g/day)	TMDL (g/day)	% Reduction
Total Pb	0.25	3	88	88	22	110	0
	0.5	5.7	321	167	42	209	48
	1	10.2	1597	299	75	374	81
	2	14.7	4856	432	108	540	91
	10	42.5	28807	1248	312	1560	96
	100	98.5	69658	2892	723	3615	96
Total Cu	0.25	3	2973	2937	734	3671	1
	0.5	5.7	5998	5579	1395	6974	7
	1	10.2	13428	9984	2496	12480	26
	2	14.7	25539	14389	3597	17986	44
	10	42.5	89022	41600	10400	52000	53
	100	98.5	179326	96412	24103	120515	46
Dissolved Cu	0.25	3	2011	82	21	103	96
	0.5	5.7	2538	145	36	181	94
	1	10.2	3220	260	65	325	92
	2	14.7	3993	374	94	468	91
	10	42.5	5824	998	250	1248	83
	100	98.5	16149	2314	578	2892	86

Although the total lead loads are significantly higher under the scenario of Reach 9 receiving direct rain (Table 11 compared to Table 9), the concentrations and load reductions are less than when the reach receives no rain. This is a result of the higher flows expected with rain falling over a larger area. Under the scenario where Reach 9 does not receive any rain the load from Reach 24 is simply transported downstream with no additional loads being added from the local watershed.

Table 15 summarizes the TMDLs for Reach 9 when rain falls over Reaches 9, 13, 23, and 24. Rainfall on Reach 9 results in higher flows and decreased load reductions necessary for total and dissolved copper. However, the increased flows do not result in a lowering of the reduction needed for total lead. The conclusion drawn from this is that the watershed of Reach 9 is contributing a total lead load to Turkey Creek.

Table 15. TMDLs for Reach 9 with rainfall over Reaches 9, 16, 23, and 24

Metal	Return Interval (yr)	Avg Flow (cfs)	Existing load (g/day)	LA (g/day)	MOS (g/day)	TMDL (g/day)	% Reduction
Total Pb	0.25	13.5	892	395	99	494	56
	0.5	22.6	3042	662	165	827	78
	1	35.5	8947	1039	260	1299	88
	2	47.8	18130	1400	350	1749	92
	10	122.5	54256	3587	897	4484	93
	100	269.6	110172	7894	1973	9867	93
Total Cu	0.25	13.5	7796	13176	3294	16470	0
	0.5	22.6	17033	22058	5514	27572	0
	1	35.5	36311	34648	8662	43310	5
	2	47.8	63747	46653	11663	58316	27
	10	122.5	160071	119560	29890	149450	25
	100	269.6	282356	263130	65782	328912	7
Dissolved Cu	0.25	13.5	2643	369	92	461	86
	0.5	22.6	3373	573	143	717	83
	1	35.5	3388	901	225	1126	73
	2	47.8	3275	1213	303	1516	63
	10	122.5	8693	2869	717	3587	67
	100	269.6	37604	6315	1579	7894	83

To evaluate the effect of completely removing the tailings piles from the system, the small area rain results were repeated with the separate contribution from tailings removed. This results in a major reduction in the concentrations of Cu(t) and Cu(d), but the reduction amount is much less for Pb(t). The reduction in Cu(t) is largely due to the removal of the Cu(d) load from the tailings. Note that the Cu(d) load from the tailings may be overestimated due to limitation of the model. It was found from the data analysis and model calibration that much of the TSS and associated particulate lead and copper in Reach 24 apparently came from the upstream watershed. While the Golden Belt and Golden Turkey mines are identified sources, there are probably many other unidentified sources in the watershed that contribute significant amounts of particulate lead and copper. Further monitoring and investigation are needed to identify these sources.

8.6 Critical Conditions

Critical conditions refer to the set of circumstances that lead to loading to the waterbody sufficient enough to cause exceedances. Critical conditions for loading to Turkey Creek are directly related to storm induced runoff. Sustained, steady baseflow conditions resulting from spring snowmelt (when it occurs) do not lead to impairments. The distinction between these two events is evident when LAI and ADEQ TMDL results are compared to the PMP results.

The PMP study was conducted during sustained flow in Turkey Creek related to snowmelt with no precipitation falling in the watershed during the two weeks prior to sampling. No elevated metal concentrations were measured in the PMP study. In contrast, the ADEQ TMDL study sampled during summer and winter storm induced runoff events that lead to increased stream flow and sediment transport. The LAI study collected runoff samples from the tailings at the Golden Belt and Turkey Belt mines to determine impacts to Turkey Creek. During these events elevated concentrations of copper and lead were observed.

A mean monthly TMDL can be calculated using the data in Table 13 for the typical three month (July to September) Arizona monsoon season. The historic USGS gage data indicate that the average flows for these months equals 4.2 cfs, approximately the 0.5-yr return interval in Table 13. Assuming an average of 30 days per month the mean monthly TMDLs for Pb (t), Cu(t), and Cu(d) are 6480 g, 215,940 g, and 6060 g, respectively.

8.7 Linkage Analysis

BASINS-HSPF provided the framework to analyze the relationship between the sources of metal contamination to Turkey Creek and the conditions under which loading of pollutants occurs. The observed metal concentrations, hydrological, and meteorological data were used to calibrate and validate a hydrologic model that links watershed and stream components. The calibrated model was used to determine loads at different flow regimes under varying meteorological conditions. The model was run under different scenarios (flows, precipitation, and remedial efforts) to determine the relationship between various parameters. The loads provided by the models runs are the basis for the TMDL calculations.

Data clearly indicate that the tailings material of the Golden Belt and Golden Turkey mines, when sufficient rainfall causes runoff, degrades the water quality of Turkey Creek. Removing or preventing runoff from the tailings would improve water quality in Turkey Creek. However, modeling results show that a total lead load from above these mines causes water quality exceedances. Although a potential source area appears to be located between a sample site with all non-detects (above Bear Creek) for total lead and one with exceedances (above Mineral Creek), the lead load cannot be differentiated between natural background and anthropogenic sources.

9.0 Delist rationale for Cadmium and Zinc

Based on the ADEQ 2004 303(d) List, Turkey Creek was assessed as impaired for both dissolved cadmium and zinc, in addition to copper and lead. However, in-stream samples collected during the ADEQ TMDL study indicate that cadmium and zinc do not impair Turkey Creek. Samples collected directly from tailings pile runoff were several orders of magnitude higher than in-stream samples—in some cases hundreds of mg/L instead of the much smaller values typically observed in Turkey Creek. Only one in-stream sample, for dissolved zinc, has exceeded water quality standards. Table 16 summarizes the data for cadmium and zinc.

Table 16. Cadmium and Zinc Data Summary

Metal	Number of in-stream samples	Number of exceedances	Number of tailings runoff samples	Number of exceedances
Cd (t)	165	0	8	6
Cd (d)	167	0	8	5
Zn (t)	167	0	8	5
Zn (d)	169	1	8	5

The data used in the original listing was collected as direct runoff from the tailings and misinterpreted as in-stream samples. In-stream sample results did not approach the levels seen in the tailings pile runoff. While the load of these metals from the tailings does not appear to be sufficient to produce criteria exceedances in the creek, they are clearly an indication of a water quality concern. These delist recommendations are also contained in the draft 2006 ADEQ Integrated Assessment Report.

10.0 IMPLEMENTATION PLAN

TMDL implementation plans are required by A.R.S 49-234, paragraphs G, H, & J requiring TMDL implementation plans to be written for those navigable waters listed as impaired and for which a TMDL has been completed pursuant to Section 303(d) of the Clean Water Act. Implementation plans provide a strategy that explains "how the allocations in the TMDL and any reductions in existing pollutant loadings will be achieved and the time frame in which compliance with applicable surface quality standards is expected to be achieved." Due to the nonpoint source of pollutants within Turkey Creek, the voluntary implementation of this plan lies on the responsibilities of stakeholders to achieve necessary load reductions to maintain water quality standards within the described reach.

Congress amended the Clean Water Act in 1987 to establish the Section 319 Nonpoint Source Management Program. As a result of this federal guidance, states have an improved partnership in their efforts to reduce nonpoint source pollution. The ADEQ Water Quality Improvement Grant Program allocates 319 grant funds from the EPA to interested parties for implementation of nonpoint source management and watershed protection. Under Section 319, state, private/public entities, and Indian tribes receive grant money which support restoration projects to implement on-the-ground water quality improvement projects to control nonpoint source pollution

When a given grantee applies for 319 funding, a watershed based plan or implementation plan submitted with the proposal demonstrates that the project has been carefully planned, reveals technical-economic feasibility, and illustrates the milestones that need to be implemented within a clear timeline. Watershed-based plans, such as TMDL implementation plans, help 319 proposals gain the highest priority for funding.

Watershed-based or implementation plans define nine essential elements to help provide reasonable assurance to EPA, stakeholders, and the state of Arizona that load allocations identified in the TMDL will be achieved. Waterbodies that have a completed TMDL and watershed-based plan or implementation plan receive high priority for 319 grant funds. These nine essential elements clearly define: causes and sources of pollutant(s), an estimate of load reductions, management measures that will need to be implemented, an estimate of technical and financial assistance needed, an information and education component, reasonable schedule of implementation, measurable milestones and events to determine if whether the management measures are being implemented, a set of criteria to evaluate pollutant reduction, as well as, a set of methods to monitor project effectiveness.

Stakeholder input is requested to promote collaboration and acceptance of the strategies proposed in this TMDL implementation plan. After the plan is adopted through a public participation process, then ADEQ is required to revisit and review the TMDL every five years to determine if the TMDL implementation plan was successful.

The USFS, as current owner of the mine properties, is developing a plan for implementation of remedial actions at the Golden Belt, Golden Turkey and French Lily mines which is reported to be at the 90% development stage (USFS, 2004). An EE/CA was completed in 2002 by Tetra Tech EM, Inc. The French Lily mine is nearby in an adjacent watershed. The USFS plan for the two mines on Turkey Creek calls for among other things, control of local surface flow by incorporating run-on/runoff diversion structures around the mines, regrading and relocating of tailings to improve stability, and construction of protective barriers (gabions) at critical points to reduce erosion of the piles by the stream. The foot of each tailings pile is to be moved back from the flood plain to the level consistent with a projected 100 year flood event to reduce scour during flood events. All tailings piles are to be regraded to a 3:1 slope, capped, and revegetated to aid in control of surface erosion. The activities cited are expected to significantly reduce the impact of these mine wastes on the Turkey Creek watershed. Implementation of the USFS plan is dependent upon funding approval by the U.S. Congress.

10.1 Management Measures

Consolidating and capping the tailings onsite, along with establishing surface control measures, were alternatives that were chosen as the implementation measures according to the Turkey Creek EE/CA for Golden Belt, Golden Turkey, and French Lilly Mines. The decision to select and implement these remedial efforts was a result of a thorough analysis of effectiveness, ability to implement, and cost. Projected remediation activities contracted out by USFS include the removal of mill tailings from the floodplain and the onsite consolidation of the tailings. After stabilization of the tailings with surface control measures, a construction of an earthen cap will provide source control. The proposed remedial efforts include the mitigation of shafts and adits.

To reduce the mobility of contaminants and potential for environmental dispersion, engineering controls will be instituted as remedial alternatives for the mine cleanup. Engineering controls do not reduce the concentration of metals in the tailings piles; rather the controls curtail direct exposure and transportation of contaminants. The engineering controls chosen by Tetra Tech and USFS as alternatives for the cleanup include containment (capping) and surface controls such as revegetation and drainage management, summarized in Table 17.

Table 17. Reclamation Technology Screening Summary for the Mine Cleanup at the Golden Belt and Golden Turkey Mine Sites

Reclamation Technology	Process Options	Description	Screening Containment
Surface Controls	Consolidation Grading Revegetation Erosion Protection	1. Combine similar waste types in a common area 2. Level out waste piles to reduce slopes for managing surface water infiltration, runoff, and erosion 3. Seed with appropriate vegetative species to establish an erosion-resistant ground surface	1. Potentially effective in conjunction with other process options assuming waste does not contain high concentrations of phytotoxic chemicals 2. Limits direct exposure 3. Readily implementable
Containment	Earthen Cap	1. Apply soil and establish vegetative cover to stabilize surface 2. Waste materials are left in place	1. Surface infiltration and runoff potential would be reduced, but not prevented 2. Limits direct exposure 3. Readily implementable

10.2 Technical and Financial Assistance

The proposed containment practices and surface control measures are consistent with actions taken at many abandoned mines. Many factors have been considered in the cost analysis of remediation including, but not limited to, cost estimates of management measures, planning and characterizing, design and engineering, labor, available resources, and maintenance.

The cost estimates of the forthcoming management measures to remediate the abandoned mine sites were based on that of similar mine cleanups in Arizona and New Mexico. Moreover, the estimates considered were third-party contracts under a competitive bidding process. Cost estimates presented in this section represent total costs of projected implementation efforts at the Golden Turkey and Golden Belt mine sites. Furthermore, the total cost estimate includes forecasts for capital costs and an estimated value of 30 years of annual maintenance.

The USFS has indicated the estimated allotted funding available for the mine cleanup totals $2.1 million dollars. The funding will be phased in two parts, $600 thousand dollars allotted in 2006 and $1.5 million dollars funded in 2007. These estimated total dollar amounts and funding dates are subject to change.

Tables 18 and 19 provide remedial cost estimates for the Golden Belt and Golden Turkey reclamation project and are calculated in the USFS EE/CA. Exact cost estimates are subject to change, as well as contingent upon, a borrow pit assessment to determine the availability of cover material for earthen cap.

Additional funding for Turkey Creek remediation projects can be obtained through competitive grant application processes. Many stakeholders and public/environmental interest groups would like to apply for grant money but lack the proper resources to do so. There are resources available to those who seek technical assistance with organizing grant materials and drafting grant proposals.

ADEQ's Water Quality Improvement Grant program provides annual grant workshops that act as "fact finding" and "information gathering" sessions for potential applicants. Attendance at these grant workshops will provide the most up-to-date information pertinent to the year's grant cycle. The Water Quality Improvement Grant program provides customer service and technical assistance if further explanation of 319 grant policies and procedures is necessary. ADEQ's Water Quality Improvement Grant program's Web address is:

www.azdeq.gov/environ/water/watershed/fin.html.

The following Web sites are organizations designed to consult and provide tools that will help interested parties complete grant applications successfully and effectively, as well as, find additional funding for environmental restoration projects.

www.earthwrites.com/index.html
www.ericfacility.net/ericdigests/ed359067.html
www.fundsnetservices.com/environ.htm

Table 18. Cost Estimate Analysis: Golden Belt Mine

Cost Item	Quantity	Unit	Unit Cost	Cost ($)
Capital Costs				
Mobilization, Bonding, and Insurance	1	LS	13,000.00	13,000.00
Site Preparation and Interim Stormwater Control	4.5	AC	1,000.00	4,500.00
Waste Relocation and Consolidation	49,729	CY	2.50	124, 322.50
Waste Grading	4.5	AC	5,000.00	22,500.00
Run-on Diversions	620	LF	25.00	15,500.00
Riprap Toe along Turkey Creek	650	LF	50.00	32,500.00
Coversoil (24 inch)*	14,000	CY	2.50	35,000
Seed and Mulch	4.5	AC	1,500.00	6,750.00
Farm Fence	2,100	LF	3.00	6,300.00
Berms, Road Barriers	1	LS	1,000.00	1,000.00
Road Decommissioning	1,080	LF	1.25	1,350.00
Stream Rehabilitation	1,000	LF	15.00	15,000.00
Cleanup and Demobilization	1	LS	6,500.00	6,500.00
Subtotal Construction Costs				**$284,222.50**
Construction Contingencies	15% of Construction Cost			42,633.38
Engineering Design and Construction Oversight	15% of Construction Cost			42,633.38
Total Capital Costs				**$369,489.25**
Annual Operation and Maintenance (O&M) Costs				
Site Inspection	4	EA	500	2,000.00
Site Maintenance	1% of Construction Cost			2,842.23
Subtotal Annual O&M Costs				**$4,842.23**
O&M Contingencies	15%			726.33
Total Annual O&M Cost				**$5,568.56**
Present Worth of O&M Costs Based on 30 Year Life @ 7.00%	PF Factor = 12.41			69,105.81
Total Present Worth				**$438,595.06**

Table 19. Cost Estimate Analysis: Golden Turkey Mine

Cost Item	Quantity	Unit	Unit Cost	Cost ($)
Capital Costs				
Mobilization, Bonding, and Insurance	1	LS	25,000.00	25,000.00
Site Preparation and Interim Stormwater Control	6.5	AC	1,000.00	6,500.00
Waste Relocation and Consolidation	133,852	CY	2.50	334,630.00
Waste Grading	6.5	AC	5,000.00	32,500.00
Run-on Diversions	670	LF	25.00	16,750.00
Riprap Toe along Turkey Creek	650	LF	50.00	33,500.00
Coversoil (24 inch)*	20,500	CY	2.50	51,250.00
Seed and Mulch	6.5	AC	1,500.00	9,750.00
Farm Fence	2,100	LF	3.00	6,300.00
Berms, Road Barriers	4	LS	1,000.00	4,000.00
Road Decommissioning	11,735	LF	1.25	14,668.75
Stream Rehabilitation	1,200	LF	15.00	18,000.00
Cleanup and Demobilization	1	LS	12,500.00	12,500.00
Subtotal Construction Costs				**$565,348.75**
Construction Contingencies	15% of Construction Cost			84,802.31
Engineering Design and Construction Oversight	15% of Construction Cost			84,802.31
Total Capital Costs				**$734,953.38**
Annual Operation and Maintenance (O&M) Costs				
Site Inspection	4	EA	500	2,000.00
Site Maintenance	1% of Construction Cost			5,653.49
Subtotal Annual O&M Costs				**$7,653.49**
O&M Contingencies	15%			1,148.02
Total Annual O&M Cost				**$8,801.51**
Present Worth of O&M Costs Based on 30 Year Life @ 7.00%	PF Factor = 12.41			109,226.75
Total Present Worth				**$844,180.12**

10.3 Information and Outreach

The information, education, and outreach component of this implementation plan is an integral part of public relations, understanding, and community involvement for the future of Turkey Creek. Outreach goals will be to provide an information/education component that will be used to enhance public understanding of the project and encourage their participation in selecting, designing, and implementing nonpoint source management measures.

A public relations effort and press release by USFS and ADEQ is intended to be developed as on-the-ground projects commence. The intent would be to notify the nearby communities of the cleanup actions prior to construction. Communication with the nearby community will help answer questions about the impact a cleanup project such as this will bring to the surrounding lands. A public outreach effort, incorporating a press release would celebrate project completion and prospective water quality improvements.

10.4 Schedule

The implementation schedule for the proposed management measures will function on dynamic timelines due to funding cycles, communication protocol timelines, conceptual engineering design, contractual negotiations and temporal patterns.

There are not any established regulatory deadlines applied to the implementation efforts in the Turkey Creek watershed. Efforts of the USFS to initiate a cleanup of nonpoint source pollution are strictly voluntary. The projected timeline for implementation is as follows:

1. Implement first phase of removal action – 2006
2. Implement second phase of removal action – 2007
3. If necessary, implement third phase of removal action – 2008
4. Operation and Maintenance of cap and mine sites – FY 2006-2009

10.5 Milestones

In order to evaluate the effectiveness of TMDL implementation at Turkey Creek, measurable milestones must be tracked. As selected management measures take effect in the Turkey Creek watershed, a routine assessment of the project status and achievements is needed to determine reasonable assurance of successful implementation.

Milestones are interim and contingent on certain measures like funding, coordination, organization, schedules of stakeholders, timelines, communication, staffing/personnel, and temporal patterns. Initiations of some actions are dependent on the delivery of others. Therefore, milestones used to evaluate Turkey Creek implementation will adapt as the project matures and deliverables are processed.

Measurable milestones will track the progress of the management measures, schedules, and evaluation of this project. The stakeholders and land owners at Turkey Creek will be responsible for tracking milestones and schedule for evaluation. Water quality monitoring can be an important factor in gauging water quality milestones versus implementation milestones that may not be contingent on monitoring. If the water quality calculations found in the Turkey Creek TMDL are used as a baseline; the future progress of pollutant reduction in Turkey Creek can be measured.

Predetermined course of actions should be established in the event milestones are not met. Criteria to establish new milestones that did not meet expectations set forth in the chart below should be based on:

- proximity (time) to achieving milestone;
- sum of efforts equal total goal (how many tasks were achieved in process of meeting goal);
- is milestone beneficial to completion of project; and
- changes in plans or goals that will adversely effect milestone

Upon review of the above criteria, new milestones will be established for Turkey Creek implementation that will give reasonable assurance whether nonpoint source management measures are being implemented and effective. Progress toward many of the TMDL goals can be measured using Table 20.

10.6 Evaluation Criteria

It is necessary to evaluate the progress of the plan to measure the effectiveness of project goals, best management practices, and management measures. The ultimate goal of TMDL implementation is the attainment of water quality standards for Turkey Creek.

The estimated schedule for the mine cleanup outlined in the Schedule section will be a guideline for evaluation criteria. Completion in a reasonable timeframe of the major objectives in the mine cleanup will provide significant criteria to evaluate the implementation goals of Turkey Creek. Failure to meet the timelines within a reasonable timeframe will provide justification to modify the schedule.

Table 20. Implementation Milestones

Description		Measurement Method	Goal	When Attained
Secure funding cycle		Signed and completed contracts	Initiation of project and contract bidding	2007
Conceptual engineering design	15%	Completion	Project management measures depend on completion of accurate and sound engineering design	2007
	65%	Completion		
	100%	Completion		
Surface Controls	Stabilize area, which includes selective regrading and revegetation of the cap	Completion	Establish run-on/runoff controls to minimize soil erosion of waste piles, reduce runoff into Turkey Creek, and establish self perpetuating plant communities	2008-2009
	Remove tailings from floodplain	Movement of tailings location visual Engineering design approved	Drainage channels protected from all flows	2008
	Consolidate tailings onsite	Piles grouped condensed: visual Engineering design approved	Minimize waste square footage, protect drainage areas, and reduce potential risk to human health and environment	2008
Containment	Construct a cap	Completion	Reduction of metal loadings in Turkey Creek due to runoff, erosion, and groundwater contamination	2009
Mitigate adits and shafts		Map and chart designated adits and shafts to mitigate	Remediation for public safety and environmental hazards	2008

The Turkey Creek TMDL is a water quality study based on water quality data from sampling and modeling. In order to track effectiveness of implementation, water quality sampling must be used as evaluation criteria for the sake of consistency and accuracy. Data used to determine the TMDL load reductions can be used as a baseline for effectiveness criteria. Conjointly, data used to establish TMDL load reductions necessary to meet Arizona water quality standards can be used as criteria to evaluate water quality progress. If compliance with surface water quality standards has not been achieved, the Turkey Creek implementation project objectives need to be reviewed and modified.

The results of the evaluation will be tracked and compared with project status, schedules, milestones, and water quality restoration. Cleanup projects and mine reclamations such as Turkey Creek's involve extensive cleanup tasks and rely on an abundance of resources. Often progress and milestones may not be readily visible for many years. Using the results from evaluations to track implementation efforts offer reasonable assurance that projects are progressing towards goals. Using the aforementioned criteria to evaluate the project progression will provide confirmation of the need to revise components of the Turkey Creek TMDL Implementation Plan such as schedules, milestones, and/or management measures if the goals are not met.

10.7 Monitoring Component

Establishing a monitoring component to evaluate the effectiveness of the implementation efforts at Turkey Creek will be vital to provide assurance of a successful project. Two types of monitoring should be included in the monitoring plan. Implementation monitoring and effectiveness monitoring provide a comprehensive approach to monitoring and tracking the effectiveness of implementation efforts.

Implementation monitoring is used to determine whether activities and management measures were carried out as planned and how effective the activities have been. Implementation monitoring will also evaluate implementation progression of management goals, milestones and schedules, amongst others factors.

Effectiveness monitoring should be used to evaluate the success of the Turkey Creek implementation project in restoring metal concentrations to acceptable levels that comply with state water quality standards. Effectiveness monitoring involves in-stream monitoring to evaluate water quality changes that occur due to implementation of management measures. Effectiveness monitoring will assist in determining the effectiveness of management measures applied as a result of a TMDL and evaluate the status of the waters toward achieving load reductions and improving water quality. ADEQ is required to revisit waters in which a TMDL study has been performed within five years (A.R.S. § 49-234 paragraph J) to measure the effectiveness of water quality implementation and to gather additional data for Arizona's 305(b) Water Quality Assessment Report and 303(d) List of Impaired Waters. Assessing water quality data for Turkey Creek will determine whether Turkey Creek is attaining its designated uses and meeting applicable water quality standards. ADEQ will perform additional water quality and sediment sampling to provide monitoring data before and after remediation efforts. This data will provide ADEQ and USFS with the necessary water quality data to determine the success of these implementation initiatives. Monitoring points to measure the effectiveness should include the FR 259 Bridge, below the Golden Belt and Golden Turkey mines and at the confluence of Turkey and Poland Creeks. These sampling sites correspond to the bottom of Reaches 23, 24 and 9, respectively.

11.0 PUBLIC PARTICIPATION

Stakeholder and public participation for the Turkey Creek TMDL Project has been encouraged and received throughout the development of the TMDL. ADEQ has extended a request for input from the watershed groups, local residents, governmental agencies, and other interested parties related to their opinions and suggestions regarding the TMDL study and findings, current and future implementation plans, model selection and use, data collection, and the level of involvement that they might contribute to the decision process.

In addition to informal meetings in the field with stakeholders, two formal public meetings were conducted during the Turkey Creek TMDL project. The public meetings were arranged with the assistance of the local stakeholders and watershed groups. The first was held on March 23, 2004 at the Bumble Bee Ranch, near Bumble Bee, Arizona, with approximately twenty attendees representing local ranchers and landowners, residents, and miners, in addition to staff from USFS, ADEQ and PBS&J, the ADEQ modeling contractor. Discussion at this meeting included introduction of the TMDL process to the attendees; a preliminary reporting on the ADEQ investigation and the modeling status at that time; and the announcement by USFS outlining anticipated remediation plans for three of the larger mines in the area. Notice regarding guidance available to parties interested in pursuing development of other remediation projects, as well as the availability of federal (319) grants for that purpose, was provided. A question and answer period followed. The second meeting at Bumble Bee Ranch occurred on September 9, 2004. The draft TMDL report and the associated model were the main topics of discussion.

The draft TMDL report was made available for a 30-day public comment period beginning on April 13, 2006 and ending on May 12, 2006. Public notice of the availability of the draft document was made via a posting in a newspaper of general circulation -*The Prescott Daily Courier*; via email notifications; via phone calls; and via webpage postings. Responses to questions and comments received during the 30-day public comment period were addressed in a public notice posted in the Arizona Administrative Register (A.A.R.). The only written comments received by ADEQ were from the Arizona Game and Fish Department (AGFD). AGFD primary concerns related to the proposed surface controls to reduce soil erosion and ground surface stabilization. They suggested limited access to the remediated areas, especially to off-highway vehicles and livestock. They also expressed the desire to have any revegetation activities utilize native species. ADEQ agreed with their concerns and suggestions and added language to the implementation section of the TMDL. ADEQ also forwarded the AGFD comments to the USFS which is the lead agency for remediation efforts at the Golden Belt and Golden Turkey mines. A 45-day review period, June 30 to August 14, 2006, followed the A.A.R. notice. Responses to questions and comments received during the public notice phase will be submitted to the EPA with this report.

REFERENCES

Arizona Administrative Code, Title 18, Chapter 11. Water Quality Standards.

Arizona Department of Environmental Quality. 1992. Arizona's 1992 Water Quality Assessment

Arizona Department of Environmental Quality. 1994. Arizona's 1994 Water Quality Assessment, EQR 94-3

Arizona Department of Environmental Quality. 1996. Arizona's 1996 Water Quality Assessment, EQR 96-33

Arizona Department of Environmental Quality. 1997. Prescott Mining Project Final Report, Vol. I & II. OFR-97-9

Arizona Department of Environmental Quality. 1998. Arizona's 1998 Water Quality Limited Waters List EQR-98-8.

Arizona Department of Environmental Quality. 2001. Soil Remediation Standards. Arizona Administrative Code, Title 18, Chapter 7, Article 2.

Arizona Department of Environmental Quality. 2002. The Status of Water Quality in Arizona-2002, Arizona's Integrated 305(b) And 303(d) Listing Report 2002.

Arizona Department of Environmental Quality. 2004. The Status of Water Quality in Arizona-2004, Arizona's Integrated 305(b) and 303(d) Listing Report 2004. EQR-05-01.

Arizona Department of Environmental Quality. 2006. 2006 Status of Ambient Surface Water Quality in Arizona- Arizona's Integrated 305(b) Assessment and 303(d) Listing Report (August 2006 Draft)

Dilks, D.W. and P. L. Freedman. 2004. Improved Consideration of the Margin of Safety in Total Maximum Daily Load Development. J ASCE, Env. Eng. Div. June, 2004.

Hendricks, David M., 1985. Arizona Soils. College of Agriculture, University of Arizona, Tucson, Arizona

Lindgren, W., 1926. Ore deposits of the Jerome and Bradshaw Mountains quadrangles, Arizona, U.S. Geological Survey Bulletin 782, 192p.

National Research Council. 2001. Assessing the TMDL approach to water quality management, Water Science and Technology Board, Division of Earth and Life Sciences, Washington DC

National Resources Conservation Service. 2004. Soil Data Mart

http://soildatamart.nrcs.usda.gov/

PBS&J. 2004. Turkey Creek Model Development Report, Yavapai County, Arizona. Prepared for Arizona Department of Environmental Quality.

U.S. Environmental Protection Agency. (2004). BASINS: Better Assessment Science Integrating Point and Nonpoint Sources. http://www.epa.gov/waterscience/ftp/basins/wdm_data/

U.S. Environmental Protection Agency (2000) BASINS Technical Note 6: Estimating Hydrology and Hydrologic Parameters for HSPF. Office of Water, EPA 823-R00-012

U.S. Forest Service, Dept. of Agriculture. 1991. Site Assessment for the Golden Belt Mine, Bradshaw Ranger District, Prescott National Forest. Prepared by Labat-Anderson, Inc., Arlington, Va.

U.S. Forest Service, Dept. of Agriculture. 2002. Engineering Evaluation and Cost Analysis, Golden Belt, Golden Turkey, and French Lily Mines. Prescott National Forest, Arizona. Prepared by Tetra Tech EM, Inc., Albuquerque, NM.

U.S. Forest Service, Dept. of Agriculture. 2004. Maps of Golden Belt, Golden Turkey, and French Lily mines, 90% Design Submittal, Turkey Creek Mines Removal Action, Prescott National Forest, Prescott, AZ. Prepared by Ecology and Environment, Inc., Seattle, WA.

U.S. Geological Survey. 2002. Daily Streamflow for Arizona

http://nwis.waterdata.usgs.gov/az/nwis/discharge

WebGIS (2004) Yavapai- Arizona Terrain Data

(http://www.webgis.com/terr_pages/AZ/dem1/yavapai.html)