ADEQ
Arizona Department of Environmental Quality

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Gila River

Reach 15040005-022: Yuma Wash to Bonita Creek
Reach 15040002-004: Bitter Creek to New Mexico State Line

Total Maximum Daily Loads

For

Suspended Sediment Concentration

Arizona Department of Environmental Quality

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Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

A.A.C.	Arizona Administrative Code
ADEQ	Arizona Department of Environmental Quality
ADWR	Arizona Department of Water Resources
AgI	Agriculture-Irrigation
AgL	Agriculture-Livestock watering
A.R.S.	Arizona Revised Statutes
AUM	Animal Unit Month
AZPDES	Arizona Pollution Discharge Elimination System
A-S NF	Apache-Sitgreaves National Forest
A&Ww	Aquatic and Wildlife-warmwater
BFR	Base Flow Recession
BFRC	Base Flow Recession Coefficient
BLM	Bureau of Land Management
BMP	Best Management Practice
CCF	Hundred cubic feet
cfs	cubic feet per second
EPA	Environmental Protection Agency
ft.	feet
FC	Fish consumption
FBC	Full Body Contact
FSN	Fixed Station Network
GIS	Geographic Information System
GNF	Gila National Forest
IBI	Index of Biotic Integrity
IQR	Interquartile Range
kg/day	kilograms per day
LA	Load Allocation
mg/l	milligrams per liter
mi.	miles
$mi.^2$	square miles
MOS	Margin of Safety
MSGP	Multi-Sector General Permit
NB	Natural Background
NEMO	Nonpoint Source Education for Municipal Officials
NEPA	National Environmental Policy Act
NM	New Mexico
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
NSD	Net Sediment Delivery
POR	Period of Record
PMP	Probable Maximum Precipitation
RNCA	Riparian National Conservation Area
RUSLE	Revised Universal Soil Loss Equation
SEDMOD	Spatially Explicit Delivery Model
SSC	Suspended sediment concentration
SWPPP	Storm Water Pollution Prevention Plan
TMDL	Total Maximum Daily Load

TSS	Total Suspended Solids
USDA	United States Department of Agriculture
USFS	United States Forest Service
USGS	United States Geological Survey
USLE	Universal Soil Loss Equation
WIP	Watershed Improvement Planning
WLA	Waste Load Allocation
WMSP	White Mountain Stewardship Project
WWTP	Waste Water Treatment Plant

1.0 EXECUTIVE SUMMARY

Reach 15040005-022 (Gila River – Yuma Wash to Bonita Creek) and Reach 15040002-004 (Gila River – Bitter Creek to New Mexico State Line) are listed on Arizona's 303(d) list of impaired waters for suspended sediment concentration exceedances. Reach 15040005-022 was originally listed for turbidity violations in 1990. With Arizona's repeal of its turbidity standard and the adoption of a suspended sediment concentration (SSC) standard in 2002, EPA overfiled on Reach 15040005-022 in 2004, asserting that violations of Arizona's narrative bottom deposits standard had occurred. Subsequently, EPA overfiled on Reach 15040005-022 specifically for suspended sediment concentration in 2009 based on data in Arizona's 2006/2008 305(b) report and additional USGS data that became available after the report was published. Reach 15040002-004 was listed in 2006 for violations of the SSC standard. This TMDL was undertaken in late 2006 for both reaches to establish allocations for attainment of Arizona's water quality standard.

Sampling undertaken in 2007, together with previous ADEQ ambient monitoring data and historic USGS flow history and sediment data, comprised the data set from which allocations were drafted and reductions were calculated. TMDL sampling covered all parts of the annual hydrograph at a number of sampling locations intended to isolate perennial tributary contributions and contributions from reach subwatersheds and the State of New Mexico. Base flow data and storm flow data for both winter storms and summer monsoons were sampled to obtain a comprehensive picture of the critical conditions affecting sediment loads in the watershed.

Because Arizona's water quality standard for SSC explicitly states that only data "*at or near baseflow*" and excluding data "*during or soon after a precipitation event*" could be used for consideration of impairments and load reductions, data was screened by flow history at USGS gauges for selection of sediment data that met the terms of the standard. Data was subsequently analyzed using flow and load duration curves paired with supplemental model runs of a GIS-based Revised Universal Soil Loss Equation (RUSLE) model. Allocations and load reductions were parsed out into five categories of flow conditions representing the entire range of flows from flood conditions to historic low flows and summarized in tabular form. Because the geometric mean as used in Arizona's standard is not a conservative value in a mass-balance analysis, data sets for subwatershed analyses of contributions were also calculated as arithmetic means and reductions. The arithmetic means, amenable to allocation and proration, are the numbers on which individual subwatershed reductions are presented. Cumulative geomean reductions are presented for each impaired watershed as a whole.

Results show that extensive reductions are called for in many locations and for many flow categories within the watershed. The Gila River at the New Mexico State Line is already in non-attainment with Arizona water quality standards, with needed mean reductions ranging from 74% to 84% (average 79 % reduction). Additional loading occurs in the Bitter Creek subwatershed below Duncan. Data points to heavy sediment loading in the Yuma Wash to Bitter Creek subwatershed, with needed reductions ranging from 90% to 98% (average 95.4 %). The San Francisco River is also a large sediment loading contributor, with reductions needed in three of five flow categories averaging 65.9 % for the three. Eagle Creek and Bonita Creek had limited data from which to calculate reductions and draw inferences, but where data existed, both tributaries were within their respective loading limits, though the RUSLE model showed erosion susceptibility of the Eagle Creek watershed. Cumulatively, Reach 15040005-022 meets loading requirements in the two lowest flow categories, and requires reductions for the three highest categories ranging from 45.9% to 95.1% in a geomean analysis. Reach 15040002-004, as a subwatershed nested within Reach 15040005-022's larger watershed, is required to meet a more stringent prorated load from

Reach 15040005-022’s requirements in four of the five flow categories. These more stringent requirements, not derived from a direct load duration application to Reach 15040002-004, were adopted to ensure that Reach 022 downstream would meet its TMDL. For the fifth (low flow) category, a more stringent number was required by using the direct load duration analysis for Reach 004 itself; this number was adopted as the load allocation for Reach 004. For Reach 15040002-004, implicit margins of safety were used for the four flow categories prorated from Reach 022, whereas an explicit MOS was adopted for the fifth flow category. Reach 004 cumulative reductions required in the geomean analysis range from 0.7% to 89.3% in the two categories where quantification of loads can be preformed with confidence. One category for dry conditions met its TMDL target. Two of the remaining categories had insufficient data to determine attainment.

2.0 PHYSICAL SETTING

2.1 Physiographic Setting

The Upper Gila River watershed as defined by ADEQ begins at Coolidge Dam at the San Carlos Reservoir east of Globe and includes all Arizona territory draining to this point exclusive of the San Pedro River watershed. The Gila River has its headwaters in the Gila Mountains of New Mexico and also drains a large area of west-central New Mexico. The watershed drains 12,900 square miles total, 7,354 square miles of which are in Arizona. The Central Highlands and Basin and Range physiographic provinces are both represented within watershed boundaries. Elevations range from 2,523 feet at Coolidge Dam to 10,720 feet at Mount Graham in the Pinaleno Mountains above Safford.

The reaches addressed by this TMDL are located in the Gila River Valley near Solomon, Arizona, the Gila Box Riparian National Conservation Area (RNCA) in the vicinity of Bonita Creek, and the Three Way area south of Clifton, Arizona. All may be characterized as being in the Basin and Range province. The Gila Box RNCA, administered by the Bureau of Land Management, is a popular recreational area for nearby residents with watercraft options, lush riparian corridors, and opportunities for wildlife observation.

The watershed is sparsely populated. Safford is the largest town in the area, with a population of 9,232 (2000). Clifton, county seat of Greenlee County, and Morenci, home of the Freeport-McMoRan (formerly Phelps-Dodge) Morenci copper mine are towns proximate to the study area. Agriculture is practiced in the Gila River Valley near Safford as well as in the Duncan Valley area near the New Mexico state line. Cotton is the principal crop grown in the area.

2.2 Climatic Setting

Hot summers and mild winters characterize the general climate of the Gila River watershed. Higher elevations of the watershed experience harsher winter conditions with winter-long snow cover in normal years. Increased precipitation falls in July through September as a result of high intensity, short duration storms associated with the summer monsoon season. A second rainy season occurs at lower elevations during the winter months (December through March). The winter events are less intense, but longer in duration and larger in extent.

2.3 Hydrology

The Gila River runs intermittently at the New Mexico state line, but portions become perennial between Duncan and Safford. The perennial segments occur where the Gila River takes a northward curve through the more varied topography and geology of the Gila Box area where subsurface water is forced to the surface. After exiting the Gila Box RNCA, the Gila River returns to intermittent status near the town of Solomon. The reaches addressed by this TMDL analysis are perennial reaches, though Reach 15040002-004 is impacted by agricultural diversions.

The Gila River is fed by three major perennial tributaries in the Gila Box area: the San Francisco River near the towns of Clifton and Morenci, Eagle Creek, and Bonita Creek (Figure 1). Approximate watershed areas for these three tributaries are 2,800, 665, and 315 square miles respectively. From USGS gauging station 09448500 on the Gila River near Solomon at the head of the Safford Valley to the state boundary with New Mexico, perennial streams and stream segments account for approximately 430 river miles.

Intermittent streams and stream segments (inclusive of the Gila River) comprise approximately 660 river miles. The remainder of stream mileage in the watershed above Solomon is ephemeral.

Two hot springs are located within the study area. The Eagle Creek Hot Springs is located downstream of Freeport-McMoRan's water pumping plant on Eagle Creek near an established ADEQ Ambient Monitoring site. The well-known Gillard Hot Springs on the Gila River upstream of the San Francisco River confluence has the hottest water temperature in the state.

The Gila River has an annual mean stream flow at Solomon, based on 84 years of records, of 463 cubic feet per second (cfs) (USGS Water Data for Arizona, 2007). USGS gauging station 09447800 on Bonita Creek near Morenci has a mean annual discharge of 12.2 cfs based on 26 years of records. The San Francisco River near Clifton has an annual mean flow of 221 cfs dating from 1911. Eagle Creek has an annual mean flow of 66 cfs at the pumping station near Morenci, based on data since 1943.

2.4 Land Use and Ownership

Land ownership in the Upper Gila Basin is split among federal, state, private and Native American reservation lands. The Bureau of Land Management administers approximately 23% of land in the basin. The U.S. Forest Service also administers 23% as the Apache-Sitgreaves National Forest. Native American reservation lands accounts for 29% of land. Arizona State Trust lands comprise 14%, while private ownership accounts for 10%. Military, National Park, and other land ownership classes each account for less than 1% within the watershed boundaries (Figure 2).

2.5 Vegetation

Vegetation types within the watershed vary with elevation. The higher elevations are characterized by Ponderosa Pine, spruce, and montane species. The Central Highlands, located in the center of the watershed, are primarily mixed live oak, mixed Chaparral, and scrub brush. The interior portion of the watershed transitions into the Basin and Range province. Agricultural areas are located along the Gila River in areas suitable for this activity, primarily around Safford, Thatcher and near Duncan.

The vegetation communities within the study area reflect the Sonoran/Chihuahuan deserts plant community associations. Riparian corridors near the perennial waters consist of cottonwoods, Arizona sycamores, and other riparian vegetative communities.

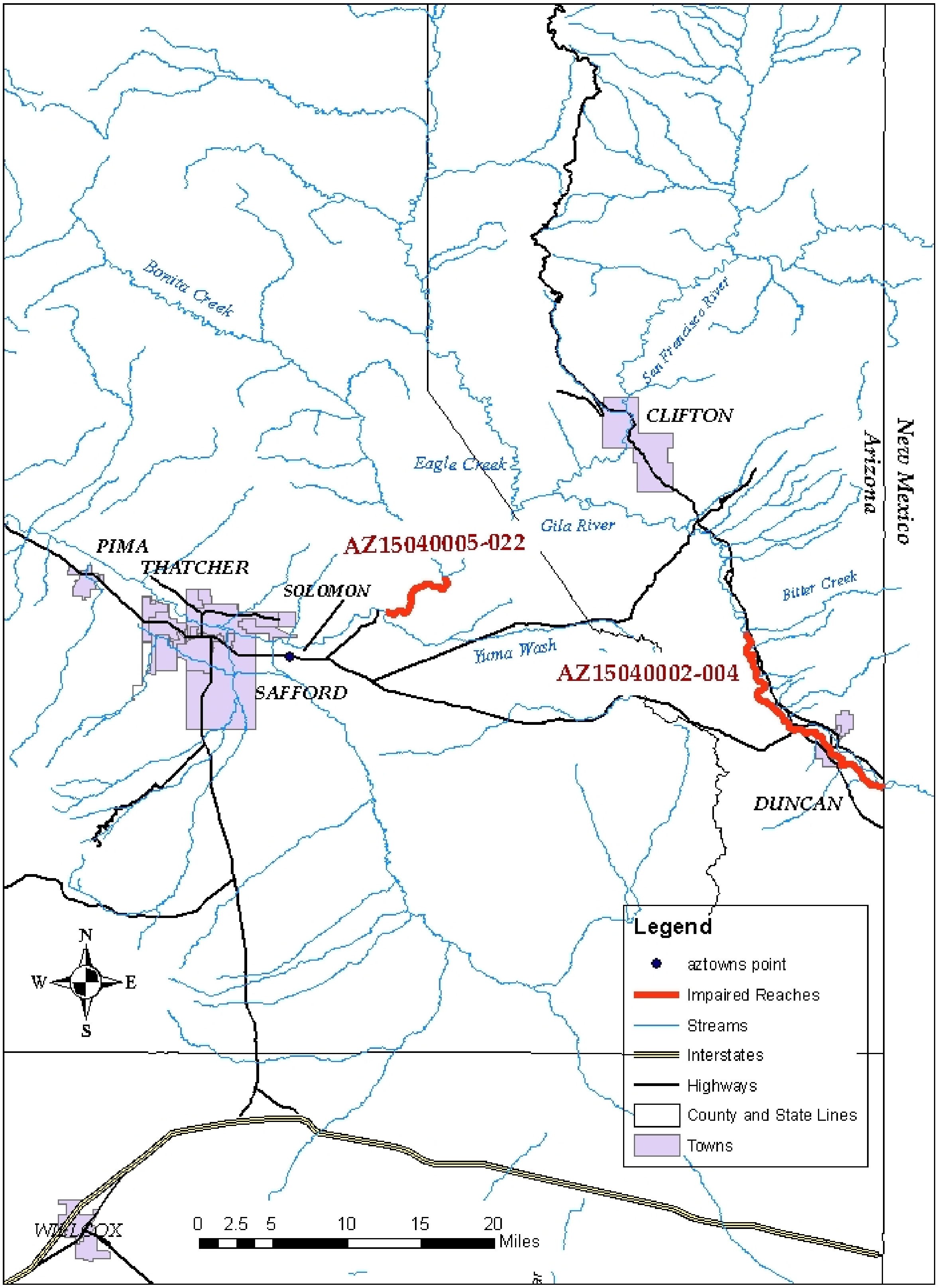

Figure 1. TMDL Project Area

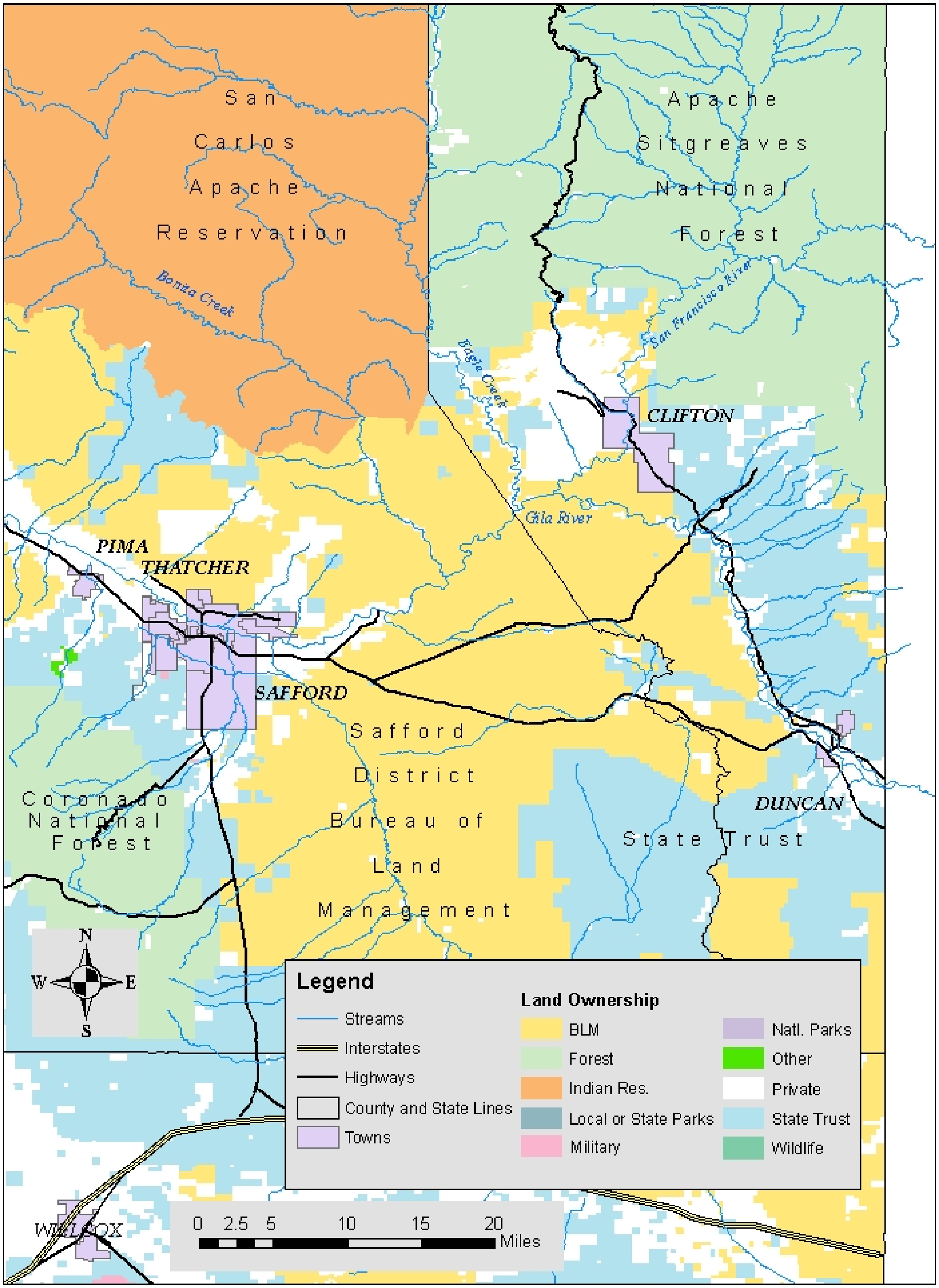

Figure 2. Land Ownership, Gila River Region, Eastern Arizona

3.0 NUMERIC TARGETS

The numeric target values of the TMDLs determined and presented in this document are based upon and calculated from the geomean concentrations (80 mg/l) of SSC for the Aquatic and Wildlife warm-water (AW&w) designated use expressed in Arizona's water quality standards. Concentrations of suspended sediment are expressed in terms of milligrams per liter (mg/l). Loads used in the load duration curve analyses are the product of concentrations and flows with an appropriate conversion factor applied. Loads are expressed in terms of kilograms per day (kg/day). The conversion factor used to convert from mg/l to kg/day is 2.446.

All load target determinations and existing load calculations in the TMDL document are originally derived from SSC geomean concentration values, as expressed in the Arizona water quality standards and in data reporting. Consequently, attainment of the total maximum daily loads presented will result in waters that meet water quality standards for concentrations. Conversely, waters meeting the state's water quality standard-based concentration values will be meeting the required total maximum daily loads set forth in this document, except in cases where a prorated load value must be employed at an upstream reach to ensure attainment of the required load at a downstream reach. Additional discussion of this point is presented in Section 7.3. Suggested monitoring and effectiveness evaluation strategies pertaining to evaluations of loads and concentrations for the implementation of these TMDLs is addressed in Section 8.0.

3.1 Clean Water Act Section 303(d) List

ADEQ first listed AZ15040005-022 (Gila River, from Yuma Wash to Bonita Creek) for non-attainment of the Aquatic and Wildlife-warm water (A&Ww) designated use in 1990 due to turbidity exceedances. Arizona's turbidity standard was repealed in 2002, and the listing was subsequently dropped due to an insufficient number of samples in the reach with a new sediment parameter, suspended sediment concentration (SSC), resulting in an assessment of inconclusive in designated use support in 2004. Reach 15040005-022 was listed as impaired in 2004 by the Environmental Protection Agency (EPA) on the State of Arizona's 2004 303(d) list according to the provisions of the Clean Water Act Section 303(d) for violations of the State's narrative bottom deposits standard (ADEQ, 2004). EPA overfiled on Reach 15040005-022 specifically for suspended sediment concentration in 2009 based on data in Arizona's 2006/2008 305(b) report.

The draft 2006/2008 Arizona Water Quality Assessment lists the Gila River from Bitter Creek to the New Mexico state line (AZ15040002-004) as impaired for sediment exceedances. The 2006 listing of AZ15040002-004 constituted the first listing for this reach for sediment-related impairments. Total Maximum Daily Load (TMDL) allocations must be developed for those waters listed on the 303(d) list. TMDLs determine the amount of given pollutant(s) that the water body can withstand without creating an impairment of that surface water's designated use(s).

3.2 Beneficial Use Designations

ADEQ codifies water quality regulations in AAC Title 18, Chapter 11 (ADEQ, 1996). Designated beneficial uses, such as fish consumption, recreation, agriculture, and aquatic biota, are described in AAC R18-11-104 and are listed for specific surface waters in Appendix B of AAC R18-11. The Gila River is currently protected for the following designated uses: Aquatic and Wildlife-warm water (A&Ww); Fish Consumption (FC); Full Body Contact (FBC); Agriculture Irrigation (AgI); and Agriculture Livestock (AgL).

3.3 Applicable Water Quality Standards

The applicable water quality standard considered by this TMDL is a numeric suspended sediment concentration standard for both Reaches 15040005-022 and 15040002-004.

Arizona's previous (2003) suspended sediment water quality standard stated:

The following water quality standard for suspended sediment concentration, expressed as a geometric mean (four sample minimum) shall not be exceeded. The standard applies to a surface water that is at or near base flow and does not apply to a surface water during or soon after a precipitation event: A&Wc, A&Ww 80 mg/l. (A.A.C. R18-11-108A, 2003)

Arizona adopted a revised suspended sediment water quality standard based on a median sediment value of 80 mg/l with a minimum of four samples collected at least seven days apart and an exclusion of data within 48 hours of a local storm event in January 2009, late in the review period for this TMDL. This TMDL was calculated by and written to attain the provisions of the 2003 standard cited above. For reasons addressed subsequently, writing the TMDL based on the 2003 standard is as protective as or more so than if it had been written under the revised 2009 standard.

The 2003 water quality standard for suspended sediment concentration does not apply during a storm event or soon after a storm event, or to flows not at or near baseflow. To determine whether samples were collected under the influence of a storm flow regime, base flow recession coefficients and flow magnitude changes in site-specific flow histories using USGS mean daily flows were examined and employed as screening devices. The methodology is extensively outlined in Appendix A.

The decision to write the TMDL on the basis of the geometric mean standard as opposed to the median standard recently adopted adds an additional implicit margin of safety to the calculations. In all cases considered, the geometric mean value for existing data sets was higher than the median value for each category of flow analyzed in the impaired reaches. Requiring this higher value to conform to the same numeric total maximum daily load target ensures that the 2009 standard recently adopted will be attained with an MOS greater than those explicitly called out in this document. It should be noted that while geometric mean targets were used to determine whether the impaired reaches were attaining the TMDL value for each flow category, a conversion from geometric means to arithmetic means was carried out for the purposes of allocation of loads by subwatersheds in this mass-balance analysis. The use of arithmetic means allows for a mathematically valid and defensible conservation of mass for loads considered in this analysis; geometric means cannot validly be prorated or allocated in such a way as to give reliable and unbiased numbers (Parkhurst, 1998). Percentage reductions are calculated from the arithmetic means for each flow category where the geomean and arithmetic mean agree in determining attainment or non-attainment status by category. While unfortunate, the necessity of considering all three of these disparate metrics is thus evident. The median represents the standard to be in effect upon approval of the TMDL. The geometric mean represents the standard in effect at the time the TMDL was written and samples collected and assessed. The arithmetic mean is necessary to permit valid subwatershed allocations and calculate meaningful percentage reductions required. The linkages between these metrics consist of the evaluation of the median relative to the geomean in all categories for the impaired reaches, and the ratios of the logarithms between geometric means and arithmetic means by category for the load allocations. Sections 7.2 and 7.3 discuss target values and analytical approaches more comprehensively.

4.0 SOURCE ASSESSMENT

The Gila River and its tributaries flow through largely uninhabited areas of western New Mexico and eastern Arizona. The watershed is large, comprising 7874 square miles above the USGS Solomon gauge. Major perennial tributaries of the Gila River in Arizona include the San Francisco River, Eagle Creek, and Bonita Creek. Coniferous forested lands, range or shrub land, and grasslands total 97% of the watershed area. Table 1 breaks down the various land use classifications according the 1992 National Land Cover Data set.

Land Use	Total Area, sq meters	Total area, sq mi	Percentage
Scrubland	9,033,092,100	3487.696	44.29%
Evergreen Forest	8,534,533,500	3295.202	41.85%
Grasslands/herbaceous	2,451,675,600	946.597	12.02%
Mixed Forest	174,973,500	67.558	0.86%
Quarries/strip mines/gravel pits	52,778,700	20.378	0.26%
Pasture/Hay	41,634,900	16.075	0.20%
Bare Rock/sand/clay	38,474,100	14.855	0.19%
Open Water	17,133,300	6.615	0.08%
Row Crops	15,523,200	5.994	0.08%
Deciduous Forest	12,757,500	4.926	0.06%
Small grains	8,098,200	3.127	0.04%
Low Intensity residential	4,181,400	1.614	0.02%
Commercial/Industrial/transport.	3,379,500	1.305	0.02%
Woody wetlands	2,671,200	1.031	0.01%
Orchards/vineyards	1,745,100	0.674	0.01%
Emergent herbaceous wetlands	942,300	0.364	<0.01%
Urban/recreational grasses	690,300	0.267	<0.01%
Total:		7874.277	100.00%

Table 1. Land Use Classification, Gila River watershed above Reach 15040005-022

4.1 Summary of Point Sources

4.1.1 NPDES/AZPDES Existing Permitted Sources

An AZPDES permit for the Alpine wastewater treatment plant (WWTP) near Alpine, Arizona in Apache County sets a monthly limit of 13.04 kg/day and a weekly limit of 18.84 kg/day for total suspended solids. This allocation was not factored into TMDL waste load allocation calculations because of the existence of a dam at Luna Lake immediately downstream, which effectively disrupts hydrologic continuity and prevents TSS loads from being assimilated with loads from the rest of the San Francisco River.

The Tyrone copper mine, a large mine southwest of Silver City, New Mexico owned by Freeport-McMoRan (FMI), is managed as a “no-discharge” facility (Matush, 2008). Two additional NPDES permits are reported within the watershed in New Mexico: the Reserve WWTP (Permit ID NM0024163), with monthly TSS mass limits of 19 lbs per day (monthly limit) and 28 lbs per day (seven day limit), and the New Mexico Game and Fish Hatchery at Glenwood, New Mexico (Permit ID NM0030163), with a daily TSS mass average of 166 lbs per day and a daily TSS maximum of 249 lbs per day (Menzie, 2008). As they are beyond the scope of Arizona's jurisdiction, all New Mexico point source contributions will be subsumed into a general load allocation for the state of New Mexico.

There are no other AZPDES permits addressing discharges where TSS or SSC are constituents of concern in Graham or Greenlee counties above the Yuma Wash-Gila River confluence, no municipal separate storm sewer systems, and no Superfund sites within the delineated watershed in Arizona. See Section 7.2 for further information on how TMDL allocations were determined.

4.1.2 General Permit, Current and Future Permittees

The purpose of Arizona's multi-sector general permit (MSGP) and construction general permit (CGP) is to protect the quality and beneficial uses of Arizona's surface water resources from pollution in stormwater runoff resulting from mining, non-mining, and construction operations and activities. Under the Clean Water Act and Arizona Revised Statutes, it is illegal to have a point source discharge of pollutants that is not authorized by a permit, including stormwater runoff from industrial or construction sites to a water of the United States. To protect water quality, general permits require operators to plan and implement appropriate pollution prevention and control practices for stormwater runoff, including the implementation and maintenance of stormwater control measures that directly result in loading reductions of sediment.

Under Arizona's general stormwater permits, permittees are required to control discharges from the facility as necessary to not cause or contribute to an exceedance of an applicable water quality standard. This requirement forms the basis for the WLA explained below for existing and future permittees covered under the Non-Mining MSGP, Mining MSGP and Construction General Permits.

Permittees may meet the terms of the WLA in one of the following ways:

- The SSC numeric standard (80 mg/l) may be met as a concentration-based wasteload allocation for discharges occurring more than 48 hours after the latest local storm event from each of the individual stormwater outfalls or other points of discharge as identified in the permittee's approved SWPPP or

- Permittees can demonstrate through implementation of erosion best management practices (BMPs) and monitoring that discharges of sediment from the permitted outfalls occurring more than 48 hours after the latest local storm event either do not reach or are not causing or contributing to exceedances of the SSC water quality standard in a downstream receiving water with an A&W designated use or the impaired reaches of the Gila River addressed in this TMDL.

The permitting agency may impose additional monitoring or BMP requirements to determine compliance with the WLA established above. Specific monitoring requirements and BMP requirements will be addressed in SWPPPs to be reviewed by the ADEQ Stormwater and General Permits Unit, as required in Sections 2.2.2 and 3.1.1 of the 2010 ADEQ Mineral Industry and Industrial MSGPs.

4.2 Summary of Nonpoint Sources

4.2.1 Agriculture

Two primary areas of agriculture are identified in the project area; one area northwest of Silver City, New Mexico along the Gila River near the small communities of Gila and Cliff, and the Duncan Valley area extending from Canador Peak, New Mexico to a point east of Duncan, Arizona. Smaller-scale agricultural acreage appears intermittently in the Sheldon-York-Guthrie corridor of Arizona south of Clifton. Isolated small areas of pasture and hay are found near the San Francisco River near Alpine, Arizona, south of Reserve, New Mexico, along the U.S. Highway 180 corridor in New Mexico, and near Redrock, New Mexico on the Gila River. In terms of total watershed area, all agricultural areas comprise 0.33% of total watershed area, or approximately 26 square miles of the 7,874 square mile watershed. The Arizona Department of Water Resources reports:

> *Duncan Valley Basin agricultural irrigation is located southeast of the Town of Duncan in the Duncan Valley and northwest of Duncan in the York Valley area. Principal crops include alfalfa, cotton, corn and wheat and there is some commercial vegetable production. The Franklin Irrigation District, also known as the Duncan Valley Irrigation District, serves farmers in the Duncan Valley. The district boundaries extend into New Mexico and irrigation wells in Arizona and New Mexico are used to irrigate lands in both states (Upper Gila Watershed Partnership, 2004). The District was formed in 1922 and encompasses about 4,700 acres of Gila River bottom land* (ADWR Water Atlas, 2008).

Agriculture in the area can broadly be broken down into two classes: irrigated seasonal cropland, and pasture or forage land. Agricultural areas are generally found within the floodplains of the streams and rivers of the Gila River watershed and thus are considered possible nonpoint source contributors to sediment pollution. These areas have the potential to add to sediment loading rates for stream networks depending upon the practices used in tilling, the crops planted, and the general slope of agricultural acreage.

4.2.2 Forest/Rangeland

Forest areas and rangelands comprise by far the highest percentage of watershed lands, totaling more than 87% of watershed area. Much of this land is under the management of the U.S. Forest Service and the Department of the Interior's Bureau of Land Management. USFS Region Three Forests within the watershed boundary include the Apache-Sitgreaves National Forest (A-S NF) and the Gila National Forest (GNF). BLM lands within the watershed are administered by the BLM's Las Cruces and Safford Field Offices.

Generally, forest lands protect against excessive erosion of soils by a higher organic content binding the soil together, and by providing a floor layer of litter and duff covers to shield soils from separation and transport due to rainfall. Logging practices and grazing on public lands are examples of sanctioned public land uses that have a potential for contributing to increased sediment loading of streams and rivers. Each of these activities will be addressed. Forest and range lands that are largely unaffected by human activities serve as conditions for natural background determinations of sediment loading rates. Wilderness areas as designated by Congress are areas where the multiple-use mandate in effect elsewhere on Forest lands is set aside. No motorized travel, no roads, and no permanent human habitation or influence is allowed in a designated wilderness area. The Gila National Forest is home to the 558,000 acre Gila Wilderness, the first designated wilderness in the United States, and the 1,200 acre Blue Range Wilderness adjacent to the Arizona border. Both areas lie within the watershed of the Gila River. Arizona's Apache-Sitgreaves National Forest is home to the Blue Range Primitive Area, a 28,100 acre parcel adjacent to the Blue Range

Wilderness Area in New Mexico. Total area of these regions largely unaffected by anthropogenic influence is approximately 918 square miles, or 11.7% of the Gila's watershed above the lowest impaired reach.

4.2.3 Roads

Unpaved roads have the potential to add to sediment loading rates for stream networks in at least two substantive ways. Improper siting and design of unimproved roads, particularly in rugged terrain, has the potential to create channelizing of runoff, greater runoff velocities, and greater erosive potential, which could eventually find its way into streams and natural waterways. Associated activities with road construction, such as cut-and-fill activities leave exposed to the elements greater portions of disturbed soils, which represent an ongoing possibility of future erosive potential. Additionally, the potential is amplified by the removal of native cover necessary to construct the road. Unimproved road crossings over intermittent or perennial stream waters also carry a higher possibility of adding to the sediment load of natural waterways.

Road density is limited in the Arizona portion of the delineated watershed and thus is considered to be a minor contributor to sediment loading. Road density is lessened by the presence of two federal wilderness areas and one federal primitive area within the watershed. Much of the sediment loading attributable to the presence, use, and design of roads ends up as channel storage, as the lower velocities and stream power available for much of the year at baseflow stream discharge is not sufficient to carry liberated sediments downstream and out of the watershed until a precipitation event of sufficient power and intensity provides enough transport capacity to flush the system out. The Gila River main stem has only two road crossings between the impaired reaches and the New Mexico state line. One occurs at Duncan where paved Highway 191 crosses the Gila; the other occurs south of Clifton on the Black Canyon Scenic Byway, an unpaved road with a concrete bridge crossing known locally as the "Old Safford Bridge." Both road crossings are bridged.

4.2.4 Erosion and Sedimentation

Many desert streams exhibit sand-dominated substrates and habitats as a natural condition, and the Gila River watershed is no exception in this regard. Friable soils and sparse vegetative cover in open desert areas contribute to relatively high natural levels of sediment loading. The San Francisco River subwatershed, with its tributary Blue River in particular, has already been identified by studies and research as having unique soil characteristics that tend towards a higher susceptibility for mass wasting and landslide events (References, ADEQ, 2002a). RUSLE modeling determined averages on a per square mile basis ranging from 38,189 kg/mi^2/day for the Eagle Creek watershed to 11,757 kg/mi^2/day for the Bitter Creek subwatershed (Additional details about RUSLE modeling may be found in Section 5.2.). While subpar land management practices can aggravate and accelerate erosive processes, erosion in natural systems is a part of the natural order and cannot be eliminated entirely, nor would it be desirable to do so. Unfortunately, as much of the Gila River watershed is overlaid with active land management practices of one type or another in the form of grazing allotments, multiple-use National Forest Lands, agriculture, logging, mining, or light development, it is not possible to strictly partition and segregate loading of natural origin from the loading attributable to anthropogenic influence. The matter is further complicated by the long recorded human history of over 100 years in the Gila River watershed. There is no baseline data available from times when land management practices or human influence on the landscape was not occurring.

As in all river systems, natural erosive processes contribute nonpoint source sediment loads in the Gila River watershed. Detachment of soil particles from uplands by wind or precipitation events, transport of detached particles overland into watercourses, and the conveyance of sediment within the watercourse are all integral parts of and closely partnered with processes of the hydrologic cycle. A stream's hydrologic function consists not only of conveying water through the hydrologic network, but also of transporting sediment loads. Excessive sediment loads can create aggradation or deposition within the stream channel network. Additionally, excessively exposed and vulnerable soils provide excessive loads through natural processes of erosion on the uplands, and sediments within the hydrologic system coupled with the hydraulic force of water in the system contribute to erosion along stream banks and down-cutting within the stream channel proper.

4.2.5 Channel Storage

A significant percentage of in-stream sediment loads results from prior deposition of sediments in the river network upstream. This channel storage is entrained and moved through the stream network in high-intensity precipitation events, as is apparent in observing the distribution of data points in the load duration curve used to analyze sediment loads. Cleland (EPA, 2007a) noted in a load duration analysis that the category consisting of the highest ten percent of flows recorded in the flow distribution is largely comprised of data points where sediment or other pollutants are being mobilized from in-channel storage. Additional sediment loads in the moist conditions category of the flow distribution can likely be attributed to the same process. A measure of the amount of sediment exiting the watershed from a pour point compared to the amount of sediment modeled as entering the hydrologic cycle off the land surface is termed the sediment delivery rate, and is used as a standard part of engineering sedimentation analysis. Sediment delivery rates for the watershed being analyzed were determined by the RUSLE model used in this study to be uniformly low for all subwatersheds modeled, ranging from 12.1% for the Gila from the New Mexico state line to its headwaters to 16% for the Bonita Creek watershed. In part, these low sediment delivery rates are attributable to the large watershed areas for most subwatersheds in the project area and the sheer volume of sediment entering the system in more than 7800 square miles, but an additional factor is the energy available to move sediment through the hydrologic network. The amount of energy available to the hydrologic system outside of storm events for its transport functions is determined by the gradient of the stream relative to the watercourse length. In large watersheds, the gradient flattens as the river reaches lower elevations. Sediment loads that may have been mobilized for a period of time higher in the watershed can be dropped within the watershed in an aggradation/deposition process until enough energy is available in the system to re-mobilize the sediment and carry it further towards the watershed pour point.

Given the low sediment delivery rates and the long distances the streams in the project study are traveling, it is concluded that a significant portion of sediment loading in the Gila River system is initially stored in-channel in the impaired reaches and upstream of them elsewhere in the hydrologic network and is only episodically entrained and flushed out of the network. These sediment reservoirs reflect contributions from natural sediment loading relatively unaffected by anthropogenic impacts and nonpoint source loadings aggravated by anthropogenic impacts. The relative percentages of each in the river’s total sediment loading will reflect the degree of impairment of the hydrologic system when state water quality standards are exceeded. The purpose of a natural background determination (Section 6.2) is to ascertain loading and expected concentrations attributable to natural sources and conditions, such as native soil erosion potential and levels of in-channel storage appropriate for natural loading. Loading and concentrations in excess of these amounts are ascribed to nonpoint source loading, by definition adversely influenced by human activity and subject to measures for improvement of water quality.

In a watershed the size of the Gila River system, it will take a considerable period of time for in-channel sediment reservoirs to move downstream through the impaired reaches. In-stream channel storage greatly retards the appearance of improvements made in uplands sediment loading as measured in water quality suspended sediment concentrations. Watershed and land management practice improvements over a large area of the Gila River watershed will likely not result in immediate water quality improvement, particularly in high-intensity hydrologic events, due to the backlog of sediment already stored in the system which will require flushing out before improvements will be seen.

4.2.6 Urban/Developed

Minimal impact from lightly developed areas in the Gila River watershed is observed. Three towns in eastern Arizona have the potential to add to sediment problems in the Gila River ecosystem: Alpine, on the upper reaches of the San Francisco River, Clifton/Morenci, situated on the lower reaches of the San Francisco River, and the town of Duncan, on the Gila River near the New Mexico state line. Smaller communities in New Mexico include Gila, Cliff and Reserve. Development is considered a minor contributor to sediment issues in the project area, given the size of the watershed (7800+ square miles), the relative small footprint of each community, and the low density of structures and infrastructure in the communities. Developed areas comprise 0.04% of watershed total area.

4.2.7 Mining

Surface mining activities, improperly managed and regulated, have the potential to add to sediment loading of waterways. Two large commercial and active mines within the watershed, the Tyrone copper mine and the Morenci operation, both owned by Freeport-McMoRan, are regulated by the states of Arizona and New Mexico as point source discharges. In addition, there are a number of small-scale prospects and mining claims in the area, both active and historic, which add to the possibility of sediment loads delivered to watercourses from waste rock and tailing pile erosion in storm events. Mining activities include small exploratory digs, identified prospects, adits, and shafts, both active and inactive, of a variety of sizes and depths. A number of mining districts line the San Francisco River north of Clifton where historic mining activities have taken place. There is additionally a small mining district along the Arizona-New Mexico border in a region of ephemeral drainages leading to the Gila River north of Duncan. All of these areas are potential nonpoint source loading zones for sediment and other water quality limiting analytes.

4.2.8 Grazing

A-S NF and GNF comprise a large part of watershed acreage and have active grazing programs. Additionally, the Bureau of Land Management has grazing allotments on the Safford District and the Las Cruces District in New Mexico, both of which exist within the Gila River watershed. Information supplied by the national forests is of a comprehensive character and not restricted only to acreage within the Gila River watershed.

The Gila National Forest allots 2.8 million of its total of 3.3 million acres to grazing as a part of fulfilling its multiple-use mandate. There are 142 total allotments, with 125 currently active (Pope, personal communication, 2008). In 2007, 206,251 animal use months (AUMs) of grazing were authorized of a total permitted number of 290,326. Total permitted numbers have been on a steady decline for the past fifteen years due to improved livestock management practices, higher costs of livestock production, and conflicts with threatened and endangered species. Authorized numbers fluctuated in recent years dependent upon forage conditions; drought years and low forage production in 2002 and 2003 led to authorized numbers well below the total permitted numbers. National Environmental Policy Act (NEPA) decisions with the implementation of USFS Best Management Practices (BMPs) have been enacted on 102 allotments within the last 15 years. Among these best management practices has been the exclusion of grazing from the riparian corridors of the San Francisco River and Gila River except for small areas. Grazing utilization standards are implemented and monitored on all active allotments on the GNF, with most allotments managed under either a “rest” or “deferred” rotational system where forage is allowed to regenerate during at least two out of three growing seasons.

The Apache-Sitgreaves National Forest administers 2 million acres of National Forest land. There were a total of 96 active allotments in 2007 (Jevons, 2008). As with the Gila, the trend on numbers of active grazing allotments has been decreasing in recent years. In 1983, a total of 128 grazing allotments existed; in 2000 the number had declined to 115 being analyzed and having management practices updated under NEPA. The Forest has concentrated in recent years on maintaining satisfactory conditions for wildlife habitat and watershed, riparian and forage vegetation, while recovering from recent major fires and still contending with ongoing drought conditions. Thirteen allotments in 2007 were not used for various reasons. The authorized number of AUMs in 2007 was 127,509. Recent years have seen some fluctuation of authorized numbers, ranging from a high of 187,035 in 2003 to a low of 89,603 in 2004. By rough comparison, permitted numbers in 1983 were 233,932 and 1985 saw permitted numbers of 213,819. “Permitted” refers to the number of livestock or AUMs showing on the ten year term permits. “Authorized” refers to the number of authorized livestock or AUMs determined by the District Ranger to be placed on the allotments in a given year. There is no necessary correlation between the two terms, as authorized numbers may be more, the same, or less than permitted numbers. Active range condition and trend studies are ongoing. Six allotments were consolidated for more effective resource management under NEPA in 2007. Grazing is permitted for cattle, horse, sheep, and burros.

Semi-arid regions with sparse ground cover, such as those found along the Gila River main-stem in Arizona, are particularly vulnerable to accelerated erosion due to the friable nature of the soils found in the Basin and Range province and the natural land surface gradients of the regional topography. Grazing activities, where not properly managed, has the potential to greatly aggravate erosion and sedimentation processes in such watercourses. This can occur due to multiple factors, including the denudation of shrubs and vegetative cover, contributing to more rainfall erosion potential and more rapid overland runoffs with higher velocities as a result of precipitation events; the cutting and chiseling actions of cattle hooves on river banks and terraces where cattle are not excluded from stream courses; the compaction of soil contributing to lower infiltration rates; and the stirring up of deposited sediments within the stream courses proper, again where cattle and livestock are not managed so as to restrict their access to streams.

The large amount of acreage given over to allotments within the GNF and A-S NF, and the Safford and Las Cruces BLM District offices, coupled with the relatively small areas set aside for wilderness or primitive area protection, suggest that grazing may be a contributor to the cumulative load of sediment in the Gila River watershed.

4.2.9 Logging

While logging activities do occur in the Forests within the Gila River watershed, activity is light and total sediment contribution from these activities is likely low. GNF reports that logging has been light since the closure of a mill near Reserve, New Mexico in the early 1990s. GNF's annual timber target ranged from 6000 CCF (hundred cubic feet) to 9000 CCF from 2002 to the present (Hernandez, 2008) with approximately 4000 CCF allotted to personal use products such as firewood annually. One operator in the Forest makes bids on opened timber sales, and several sales prior to 2005 received no bids. GNF reports that no new roads have been constructed to access logging areas.

Through the USDA Forest Service's Southwest Region, GNF participates in an agreement with the New Mexico Environment Department that seeks to implement a host of Best Management Practices pertaining to logging to support Clean Water Act objectives. The two agencies have agreed to develop preventative or mitigative land management practices to improve or protect water quality on National Forest System Lands. Though not an exhaustive compilation, areas of specific measures for the GNF include the following:

- Limitations on Operating Season
- Stream Course Protection
- Riparian Treatment Areas
- Treatment of Ephemeral Drainages
- Streamside Management Zone Designations
- Log Landing Stipulations
- Skid Trail Controls and Design
- Road Construction, Closure, and Maintenance Measures

The agreement was based upon mitigative measures outlined in the Clean Water Act and expanded where necessary to accommodate additional facets of logging practices. Site-specific BMPs are drafted and implemented where necessary to protect the resource and water quality. Additional guidelines were informed by the content of soil inventories on Forest lands, Forest Service Handbook 2209.18, and the experience of Forest personnel.

Logging on the A-S NF is relatively light, as well, though heavier than found on the GNF. Logging on a wide scale was essentially ceased in 1998 by environmental appeals (Nedrow, 2008). The Rodeo-Chedeski fire of 2002, which covered some 600,000 acres, resulted in a salvage operation afterwards lasting for four years. However, since then only one project has been opened to bid, though older on-going projects continue. The White Mountain Stewardship Project (WMSP) opened in 2004, with primary objectives being resource management in promoting forest health and reducing fire hazard to the town of Alpine by thinning small-diameter trees. Target acreage for the WMSP is 15,000 acres per year, with actual logging acreage averaging 6500 acres per year. Target volume for logging across the A-S NF has been consistent at approximately 50,000 CCF over the past five years and is expected to hold at this level for the next few years. The A-S NF logs about 10,000 CCF per year for fuel wood and personal use sales across the Forest. Currently, the only logging on the A-S NF within the bounds of the Gila River watershed is the WMSP project near Alpine. Volumes on this project ranged from 4737 CCF in 2006 to 8436 CCF in 2007.

Most logging on the A-S NF is now mechanized, and standard BMPs are followed with all mechanized equipment. One BMP of note is a requirement for straight in-out accessing of timber in ecologically sensitive areas where fallers or other mechanized equipment is used. Filter strips are utilized to protect riparian channels with widths determined by the grade of local topography. Streamside Management Zones are designated with the intention of providing sufficient sediment buffering capacity to protect water quality. Percentage of ground coverage is monitored to reduce the potential of erosive processes.

5.0 LINKAGE ANALYSIS

5.1 Narrative Bottom Deposits Standard and Suspended Sediment Concentrations

Reach 15040005-022 was previously listed on the state’s 303(d) list for violations of the turbidity standard in 1990. Arizona repealed its turbidity standard in 2002, while simultaneously adopting a suspended sediment concentration standard. With the repealing of the turbidity standard, the previous listing was dropped for the 2004 assessment. EPA overfiled on Reach 15040005-022 in 2004, asserting that violations of the Arizona narrative standard for bottom deposits (A.A.C. R18-11-108(A)(1)) had occurred, based upon exceedances of Arizona’s former turbidity standard. Insufficient suspended sediment concentration data points had been collected by ADEQ by the time of the 2004 assessment to comply with the requirements of Arizona’s Impaired Water Identification Rule, though continued sampling since then has in fact fulfilled these requirements and shown that a problem does exist based on suspended sediment concentration values. As mentioned previously, EPA overfiled on Reach15040005-022 specifically for SSC in the 2006/2008 assessment.

ADEQ collected and determined a number of corroborating metrics in the course of sampling for this TMDL, including macroinvertebrate samples leading to Index of Biotic Integrity (IBI) scores for three locations in and just above the impaired reach. See Table 2 for a summary of the metrics compiled to assess impairment. The supplemental data is mixed in its results, with the preponderance of data suggesting that there is a problem with excessive sediment in 15040005-022. Data in Table 2 is presented for informational purposes only; SSC data values alone are sufficient to place the reach on the 303(d) list and warrant this TMDL study.

15040005-022	***Upper Reach***	***32 53 53 / 109 28 09***	***Mid Reach***	***32 53 08 / 109 29 54***	***Lower Reach***	***32 52 28 / 109 30 40***
Metrics	***Score***	***Interpretation***	***Score***	***Interpretation***	***Score***	***Interpretation***
Macroinvertebrate Riffle IBI	**60.2**	>50; Meets biocriterion. Unimpaired	**61.18**	>50; Meets biocriterion. Unimpaired	**72.9**	>50; Meets biocriterion. Unimpaired
Linear Habitat Complexity Index	Insufficient features to calculate*	Failed/Degraded	Insufficient features to calculate*	Failed/Degraded	Insufficient features to calculate*	Failed/Degraded
Pool Facet Slope Analysis	Insufficient features to calculate*	Failed/Degraded	Insufficient features to calculate*	Failed/Degraded	Insufficient features to calculate*	Failed/Degraded
Percent Fines, <2mm	**75%**	Exceeds 50%, Impaired**	**73%**	Exceeds 50%, Impaired**	**91%**	Exceeds 50%, Impaired**
Relative Bed Stability	**0.009**	<0.03; unstable	**0.012**	<0.03; unstable	**0.012**	<0.03; unstable
Critical Shear Stress Analysis	Measured bankfull > calculated bankfull	Incision	Calculated bankfull > measured bankfull	Aggradation	Calculated bankfull >> measured bankfull	Aggradation
Tractive Force Determination	Incipient particle diameter ~D84	Channel in near equilibrium	Incipient particle diameter<<D84	High potential for sediment deposition	Incipient particle diameter ~D84	Channel in near equilibrium
Calculated mean bankfull depth to measured mean bankfull depth	Calculated Bkfl <MeasuredBkfl	Degradation	Measured Bkfl < calculated Bkfl	Aggradation	Measured Bkfl < calculated Bkfl	Aggradation

Table 2. Summary of geomorphic and bioassessment metrics applied to Reach 15040005-022

***Statistical analysis of results not possible for comparison with a reference reach due to lack of measurable features along longitudinal profile.**

**** Comparison made to proposed bottom standard implementation measures.**

5.2 Empirical Subwatershed Load Summations

Due to the size of the watershed, the high-order character of the Gila River and its perennial tributaries, the necessarily limited sampling design in both geographic extent and temporal duration, and the relatively undeveloped nature of the watershed, the approach taken to meet Arizona's 2003 suspended sediment concentration standard focused upon isolating representative cumulative watershed sediment load contributions at or near the mouth of the major contributing perennial tributaries, at critical points within the impaired reaches where USGS gauge data was available, and near the New Mexico state line. Given the scale of the project area, and the inaccessibility of a sizable portion of the watershed in New Mexico, sampling and modeling for individual ephemeral tributary, source use, source process, or parcel contributions to the total sediment load was impractical and unachievable with resource constraints. The one concession to a more specific and targeted land use analysis consisted of the analysis of data above and below the Duncan Valley agricultural area. Initial suppositions were that erosion due to agricultural practices might be a major contributor to sediment loading. Subsequent modeling with RUSLE above and below the agricultural area demonstrated that the agricultural valley was actually having a beneficial impact upon the Gila River hydrologic system by reducing load contributions on a per square mile basis.

Loadings were allocated amongst the various tributaries and subwatersheds of the Gila River based upon results of runs of the RUSLE model (Figure 3). Selection and use of the model stemmed from the recognition that the friable nature of the soils in the watershed and the susceptibility of specific watersheds to erosion, particularly in more sensitive areas lacking soil cover where grazing occurs, and the relative lack of canopy/ground cover and exposure of soils to precipitation in the low-lying desert areas were prime considerations in calculation of any needed reductions.

Suspended sediment concentrations were converted to their associated daily loads (i.e. multiplied by discharge and a conversion factor) and plotted against a standard target load value in a load duration curve. Load duration curves are expressed as the standard concentration (80 mg/l) multiplied by the discharge value in cubic feet per second and a conversion factor of 2.446 to convert units of mg/l into kg/day. Individual data points are likewise calculated with their respective concentration values substituted for the standard's concentration value. Load allocations for subwatersheds were determined by the relative percentages of net sediment production generated by the RUSLE model. Percentages were applied to the total sediment loads, and the loads as broken down by the standard classes of a load duration analysis (<10% exceeds flows, 10%-40% exceeds flows, 40-60% exceeds flows, 60-90% exceeds flows, >90% exceeds flows). Using this empirical linking approach, the sum of the total load allocations of the various subwatersheds is targeted to meet the load allocation necessary to be compliant with the state's suspended sediment concentration standard at the lowest impaired reach on the Gila.

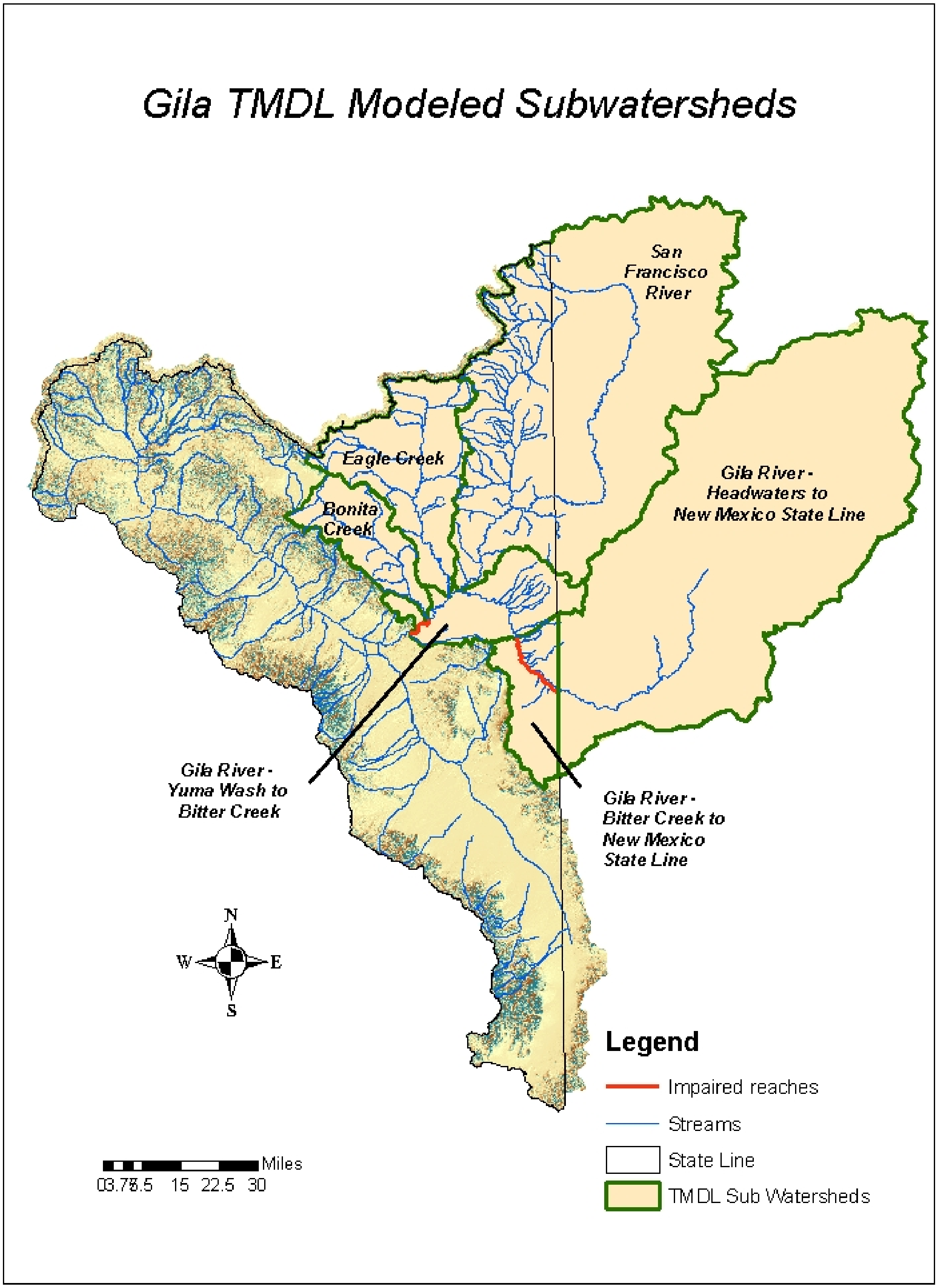

Figure 3. Subwatersheds of the Gila River watershed for TMDL Analysis

Because an additional impaired reach for sediment, Reach 15040002-004, Gila River –Bitter Creek to NM state line, is nested within the watershed as delineated from Reach 15040005-022, a comparative approach was employed with the objective of identifying the level of protection that allowed both reaches to be in attainment of the sediment standard. Sediment loads were calculated as simple reductions needed to achieve the allowable loads permitted by the state standard and as reductions needed when multiplied by the percentage of net sediment production generated by RUSLE for the watershed delineated from the downstream end of Reach 15040002-004. It was found that the percentage proration based on net annual sediment production provided the more stringent protection and also ensured downstream attainment with the sediment standard at Reach 15040005-022. Calculating simple reductions at the upstream reach compliant with the water quality standard would not permit the downstream reach to attain the standard. Consequently, the percentage proration method was used to determine allocations for Reach 15040002-004.

6.0 MODELING AND ANALYTICAL APPROACHES

The approaches chosen for modeling sediment loads and calculating the TMDL for reaches 15040005-022 and 15040002-004 consisted of load duration curves supplemented with the RUSLE model applied at a watershed scale through a GIS algorithm. The load duration curve approach was chosen for its flexibility, its capacity to identify and address flow-dependent conditions, and the ability to classify and analyze various data points individually in accordance with the requirements of Arizona's water quality standard for suspended sediment. Long-term USGS streamflow gauges in the watershed permitted in-depth examination of flow histories.

Arizona's 2003 suspended sediment concentration standard explicitly calls for samples to be considered only at or near baseflow, and at times other than during or soon after precipitation events. A storm event identification analysis and screening of data based on base flow recession coefficients and magnitude of flow change was applied to the data set to ensure data used in TMDL calculations and reductions was compliant with the standard. Appendices A and B present the method and statistics associated with a consideration of Reaches 15040005-022 and 150400002-004.

6.1 Flow and Load Duration Curves

ADEQ has chosen to employ a flow and load duration curve approach in conjunction with the RUSLE model for estimating soil loss within the watershed in order to determine total maximum daily loads and calculate necessary reductions. Cleland (EPA, 2007a) provides the following discussion on the elements and merits of a load duration curve method:

> *The percentage of time during which specified flows are equaled or exceeded may be evaluated using a flow duration curve (Leopold, 1994). Flow duration analysis looks at the cumulative frequency of historic flow data over a specified period. The duration analysis results in a curve, which relates flow values to the percent of time those values have been met or exceeded. Thus, the full range of stream flows is considered. Low flows are exceeded a majority of the time, whereas floods are exceeded infrequently. …*
>
> *The development of a flow duration curve typically uses daily average discharge rates, which are sorted from the highest value to the lowest. Using this convention,*

flow duration intervals are expressed as percentage, with zero corresponding to the highest stream discharge in the record (i.e. flood conditions) and 100 to the lowest (i.e. drought conditions). Thus, a flow duration interval of sixty associated with a stream discharge of 82 cubic feet per second (cfs) implies that sixty percent of all observed stream discharge values equal or exceed 82 cfs…

…A duration curve framework is particularly useful in providing a simple display that describes the flow conditions under which water quality criteria are exceeded. Stiles (2002) describes the development of a load duration curve using the flow duration curve, the applicable water quality criterion, and the appropriate conversion factor. Ambient water quality data, taken with some measure or estimate of flow at the time of sampling, can be used to compute an instantaneous load. Using the relative percent exceedance from the flow duration curve that corresponds to the stream discharge at the time the water quality sample was taken, the computed load can be plotted in a duration curve format (Figure 5).

By displaying instantaneous loads calculated from ambient water quality data and the daily average flow on the date of the sample (expressed as a flow duration curve interval), a pattern develops, which describes the characteristics of the impairment. Loads that plot above the curve indicate an exceedance of the water quality criterion, while those below the load duration curve show compliance. The pattern of impairment can be examined to see if it occurs across all flow conditions, corresponds strictly to high flow events, or conversely, only to low flow conditions.

Duration Curve Zones

Flow duration curve intervals can be grouped into several broad categories or zones, in order to provide additional insight about conditions and patterns associated with the impairment. For example, the duration curve could be divided into five zones: one representing high flows, another for moist conditions, one covering median or mid-range flows, another for dry conditions, and one representing low flows. Impairments observed in the low flow zone typically indicate the influence of point sources, while those further left generally reflect potential nonpoint source contributions. This concept is illustrated in Figure 5. Data may also be separated by season (e.g. spring runoff versus summer base flow). For example, Figure 5 uses a "+" to identify those ambient samples collected during primary contact recreation season (April – October).

Runoff Events and Storm Flows

The utility of duration curve zones for pattern analysis can be further enhanced to characterize wet-weather concerns. Some measure or estimate of flow is available to develop the duration curves. As a result, stream discharge measurements on days preceding collection of the ambient water quality sample may also be examined. This concept is illustrated in Figure 4 by comparing the flow on the day the sample was collected with the flow on the preceding day. Any one-day increase in flow (above some designated minimum threshold) is assumed to be the result of surface runoff (unless the stream is regulated by an upstream reservoir). In Figure 4, these samples are identified with a red shaded diamond.

Similarly, stream discharge data can also be examined using hydrograph separation techniques to identify storm flows. This is also illustrated in Figure 4. Water quality *samples associated with storm flows (SF) greater than half of the total flow (SF>50%) are uniquely identified on the load duration curve, again with a red shaded diamond (EPA, 2007a).*

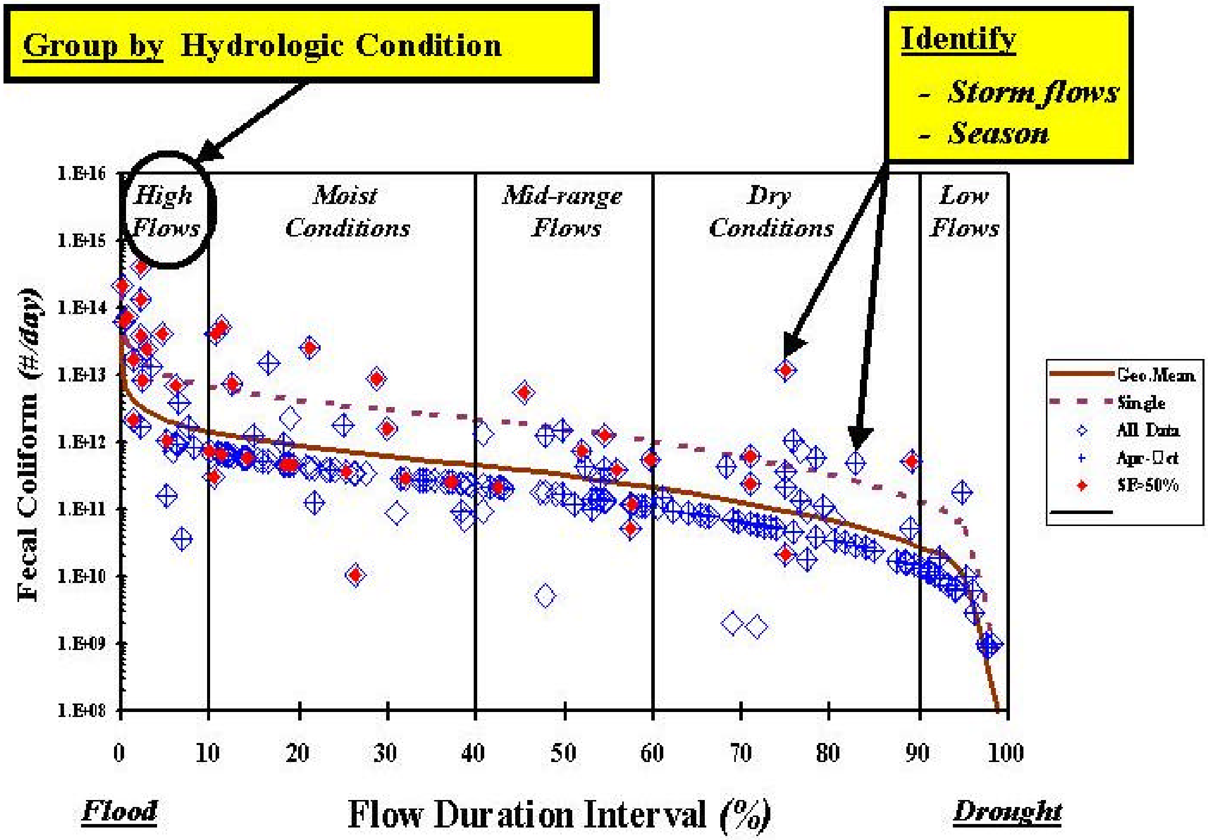

Figure 4. Sample Load Duration Curve

(Illustration courtesy of EPA, 2007a)

ADEQ has chosen to employ a similar, though modified approach to the method outlined above for runoff events and storm flows. The modified method is intended to distinguish between storm flow events (i.e., any flow showing any amount of storm flow influence) and non-storm flow discharges and to mark storm flow events for exclusion from consideration. The method is extensively outlined in Appendix A, with discussion and rationales for the selection of one, four, and seven day event windows included. Arizona's water quality standard for suspended sediment explicitly mandates that samples considered for assessment must be taken "at or near base flow" and "not during or soon after a precipitation event."

As outlined in Cleland's presentation, the subdivision of the flow frequency curve into five zones corresponding to high flows (0-10% flow exceeds), moist conditions (10-40% flows exceed), mid-range flows (40-60% flows exceed), dry conditions (60-90 percent flows exceed), and low flows (>90% flows exceed) was executed for analysis and TMDL calculations. Statistics for each reach's base flow recession coefficients for the one, four and seven day time windows may be found in Appendix B. Load duration curves for primary project locations may be found in Appendix C.

6.2 Revised Universal Soil Loss Equation Model

RUSLE is a standard model developed by the United States Department of Agriculture's Agriculture Research Service in conjunction with the Soil Conservation Service (now known as that Natural Resources Conservation Service or NRCS) to predict upland erosion and soil loss in watersheds. It is a further development and refinement of the Universal Soil Loss Equation (USLE), developed by the same agencies. The initial intent of the USLE was to allow farmers to calculate and predict erosive potential upon agricultural fields. RUSLE is expressed as:

$$\mathbf{A = RKLSCP}$$

Where A = average annual soil loss due to sheet and soil erosion in mass units per area units per year (e.g., tons/acre/year, kilograms/square mile/year, etc.)
R = rainfall factor
K = soil erodibility factor
L = slope length factor
S = slope gradient factor
C = crop management factor
P = erosion control practice factor

The differences between the two models are involved and of a degree of detail not appropriate for comprehensive presentation in this context. Generally speaking, RUSLE is a refinement of the USLE, incorporating such additional features and considerations as data from more stations in the western U.S. for the R factor, incorporation of seasonal adjustments to the K factor, refinements of the LS factor to accommodate more advanced hydraulic and hydrologic variables in erosive processes, and differences in the computation of C factors.

ADEQ used a GIS algorithm for application of RUSLE integrated with the Spatially Explicit Delivery Model (SEDMOD) to the Upper Gila River watershed to cover the large amount of area and many calculations involved. The model was developed by Lockheed Martin Environmental Services under contract to EPA.

ADEQ chose to use the model both for its ability to shed some light upon erosion potentials within the watershed and for its ability to supply parameters for the water quality analysis that were not otherwise determinable. RUSLE's applicability in large-scale watershed analysis for TMDL development is limited for three principal reasons. The first is the scale of the watersheds involved in this project (several thousand square miles) differs from the scale for which the USLE was originally derived and applied on a local level for individual farms and fields. A loss of resolution and concomitant accuracy in results is thus expected when the model is applied on a larger scale. RUSLE's examination of sediment detachment and transport functions, with less focus on deposition and sediment delivery rates at the pour point of the watershed, also relegates the model to a supporting status in the TMDL evaluation. The third reason for limiting the prominence RUSLE assumes in this TMDL study is that its output is expressed only in terms of an annual average, with no further refinement available in terms of seasonal or storm event differences. For an analysis of sedimentation problems varying with flow magnitudes, RUSLE is helpful only in filling in the broad strokes and watershed-level processes that underlie the suspended sediment exceedances and supplying information for educated estimates where necessary.

In this study, RUSLE was used to determine the respective net sediment production for each of the subwatersheds comprising a component of the entire watershed to the confluence of Yuma Wash. By choosing to focus on net sediment delivery rates by subwatershed instead of the percentage of total watershed area, focus is placed upon the subwatersheds particularly subject to erosion problems, where more stringent load reductions are called for. Net sediment productions were summed and subwatersheds were then assigned a percentage allocation based upon their percentage of net sediment delivery. A conservative assumption was built into the analysis in that the net sediment delivery for the watershed as a whole was less than the sum of the subwatersheds comprising it due to deposition within the reaches below the subwatersheds. The calculation of percentage allocations and their derivative load reductions is thus higher in using this approach than it would be by applying the percentages only to the sediment delivery load at Yuma Wash or Bitter Creek.

RUSLE was also used to model and predict sediment loads where data gaps exist in areas which were inaccessible for sampling, for data sets where limited data values were available for analysis after exclusion for storm events, and to draw inferences in areas where subwatersheds melded into larger watersheds and water quality data collected could only be assessed based on cumulative loads to those points. As such, RUSLE’s direct influence upon load reduction calculations is limited and identified as such in the results.

A compilation of pertinent RUSLE model outputs for the Upper Gila River TMDL study is presented in Table 3.

6.3 Natural Background Determinations

Determinations of natural background conditions in the Gila River watershed are complicated due to the size of the watershed, the numerous contributing subwatersheds, the distance of relatively pristine sites selected for analysis from the project area, and the lack of any historical data predating human influence in the watershed. The Gila River watershed has seen human habitation and activity for well over one hundred years. Consequently, it is not possible to obtain a pure and pristine reading on sediment concentrations or general water quality parameters within watershed boundaries. The best available option consists of finding sites near the headwaters of respective watersheds, or on low-order perennial tributaries in relatively undisturbed regions, and using these values as the best available approximation of an unaffected natural background value.

Natural background concentrations were determined individually for each of the three perennial Arizona tributaries (Eagle Creek, Bonita Creek, and the San Francisco River) by analyzing selected sites relatively unimpacted by anthropogenic influence within each watershed. Background was determined as an average concentration for each watershed of suspended sediment concentration values and then translated into a percentage relative to the state’s suspended sediment water quality criterion. For the headwaters of the Gila River in the mountains of central New Mexico, an area not within the purview of ADEQ, a value of 10% was assumed. This value accords closely with the 9.89% calculated as a natural background concentration for the San Francisco River watershed, an adjacent drainage that shares morphologic and ecosystem similarities with the Gila River watershed. Gila River reaches for the Bitter Creek to NM state line and Yuma Wash to Bitter Creek were also assigned a value of 10% based upon consideration that these waters originated from the headwaters in New Mexico and that any natural background contributions within these subwatersheds with friable soils and high erosivity potential would likely reflect a higher value rather than the lower values exhibited by the perennial tributaries.

Watershed	*San Francisco River*	*Gila - NM line to headwaters (New Mexico)*	*Eagle Creek*	*Gila –Yuma Wash to Bitter Creek (Arizona)*	*Bonita Creek*	*Gila – Bitter Creek to NM state line (Arizona)*
Land area in square miles	2791.98	3342.73	663.19	393.99	314.16	259.41
Percentage of total watershed area	35.95%	43.05%	8.54%	5.07%	4.05%	3.34%
Weighted average gross soil erosion, Kg/sq mi/yr	2,540,347	1,644,792	2,560,780	1,900,585	1,594,047	788,351
Gross sediment production, Kg/yr	7,092,549,720	5,498,100,892	1,698,277,477	748,820,148	500,785,550	204,502,930
Weighted average soil surface erodibility, 0 – 0.72	0.20	0.17	0.16	0.14	0.12	0.22
Weighted average soil surface cover (C factor)	0.072	0.073	0.095	0.117	0.107	0.116
Weighted average net sediment delivery, kg/sq mi/yr	343,560	198,835	379,289	284,790	256,311	111,327
Annual net sediment delivery, Kg/yr	959,214,582	664,653,154	251,539,430	112,205,716	80,522,608	28,878,903
Percentage net sediment delivery by subwatershed	45.74%	31.70%	12.00%	5.35%	3.84%	1.38%
Weighted average susceptibility to mass wasting, normalized scale 1.0-3.0	1.6	1.4	1.6	1.5	1.5	1.1

Table 3. Selected Revised Universal Soil Loss Model Results

Cumulative natural background contributions were determined as a weighted average of respective contributing subwatershed concentrations based on each subwatershed's percentage of net sediment production as determined by RUSLE (Table 4). Each subwatershed's load allocation was adjusted by apportioning the load allocation between the determined percentage of natural background and the remainder of the calculated load allocation. Table 4 presents details concerning natural background data.

Watershed	*Natural background sites*	*Average SSC Concentration*	*Percentage, NB to Water Quality Standard*
San Francisco River	UGKPK000.12 UGCMB004.23	7.91 mg/l	9.89%
Eagle Creek	UGEAG056.85	6.62 mg/l	8.28%
Bonita Creek	UGBON000.17 UGBON003.68	6.77 mg/l	8.47%
Gila River, NM state line to Headwaters	N.A.	N.A.	10%
Gila River, Bitter Creek to NM State Line	N.A.	N.A.	10%
Gila River, Yuma Wash to Bitter Creek	N.A	N.A.	10%
Gila River Watershed, Cumulative Weighted Natural Background	—	—	**9.68%**

Table 4. Natural Background, Suspended Sediment Concentration

7.0 TMDL CALCULATIONS

7.1 Data Used for TMDL Calculations

Data on discharges and sediment measurements were compiled and collected from two sources. Flow histories were uniformly drawn from a series of USGS real-time gauging stations in the watershed, which are summarized in Table 5. Flow values were supplemented by manual measurements at the time of data collection by ADEQ field personnel. Where USGS collected sediment data, this was incorporated into the data set and included in the TMDL analysis. Periods of record were generally shorter and more episodic for sediment data collection.

ADEQ's TMDL program sampled at or near the sites listed in Table 6 for flow and suspended sediment concentrations a total of eight times during 2007. Additional ADEQ samples were considered from the Ambient Monitoring Program from previous years. ADEQ sampling is summarized in Table 6.

Site	***USGS Designation***	***Flow Period of Record Beginning Analyzed***	***Flow Period of Record Termination Analyzed***	***USGS Number of Sediment samples***	***Sediment Period of Record Beginning***	***Sediment Period of Record Termination***
Gila at head of Safford Valley near Solomon	09448500	10-01-1920	2-7-2008	151	7-15-1965	12-6-2006
Bonita Creek	09447800	8-1-1981	6-2-2008	--	N.A. (flow only)	N.A. (flow only)
Eagle Creek	09447000	4-1-1944	5-12-2008	--	N.A. (flow only)	N.A. (flow only)
San Francisco River	09444500	10-23-1910	5-13-2008	49	10-03-1963	5-18-1983
Gila at Redrock, New Mexico	09431500	10-01-1930	6-30-2008	290	7-24-1974	5-18-2005
Gila at Duncan, Arizona	09439000	11-27-2002	3-13-2008	--	N.A. (flow only)	N.A. (flow only)

Table 5. USGS streamflow gauges and sediment sampling sites

Site	***ADEQ Designation***	***Arizona Associated Reach ID***	***ADEQ Total Number of Sediment samples within reach***	***ADEQ Sediment POR Beginning***	***ADEQ Sediment POR Termination***
Gila at head of Safford Valley near Solomon	UGGLR448.61	15040005-022*	25	9-28-2005	12-10-2007
Bonita Creek	UGBON000.17	15040005-030	10	9-28-2005	12-8-2007
Eagle Creek	UGEAG011.51	15040005-025	11	11-18-2002	12-9-2007
San Francisco River	UGSFR006.42	15040004-001	23	10-30-2002	12-09-2007
Gila at New Mexico State Line	UGGLR505.96	15040002-004	15	10-30-2002	4-17-2006
Gila at Duncan, Arizona	UGGLR501.45	15040002-004	8	2-4-2003.	12-10-2007
Gila above FID Point of Diversion, New Mexico	UGGLR515.55	N.A.**	6	3-27-2007	12-10-2007

Table 6. ADEQ ambient and project sampling locations

* sampled also at UGGLR451.46 ** AZ reach IDs inapplicable in New Mexico.

The 2003 water quality standard which is the subject of this TMDL explicitly requires some determination of representative stream flow conditions as stated in Arizona's suspended sediment standard (A.R.S R18-11-109 C), recognizing that floods originating from storm flow events routinely produce exceedances of state water quality standards and such values, when unidentified and sampled out of proportion to the frequency exceedance assumptions built into assessment methodology, may not be indicative or representative of normal or typical water quality conditions of the stream. The concept of *base flow* and language pertaining to the recency of precipitation events have been invoked in the 2003 state water quality standard for suspended sediment concentration to codify the conditions being targeted for the gathering of representative water quality samples. Consequently, data collected and analyzed in this TMDL were screened for compliance with the intent of the 2003 water quality standard. Appendices A and B extensively discuss the screening method in all of its particulars. Data was not screened in accordance with the wording of the 2009 standard which states that ADEQ will not use data collected during or within 48 hours of a local storm event. Using the methodology in this TMDL, which examined the threshold levels of base flow recession coefficients coupled with the magnitude of flow change, storm events are not considered to be concluded until the base flow recession coefficient falls below the threshold value indicating the onset of a storm. The language in the new standard allows for a 48 hour grace period after storm events, which is actually a broader exclusion than the TMDL was calculated for. This is an implicit additional margin of safety built into the analysis if it is considered by the provisions of the 2009 standard. The TMDL as calculated by this method is thus protective of the 2009 water quality standard as well as the 2003 standard, though its intent was to evaluate and assess reductions in accordance with the 2003 standard.

The load duration curve modeling approach requires values of flows supplied for the midpoint of each category in order to determine the appropriate target load for the class: the 5^{th} percentile for Category 1 (0.1%-10% flows), the 25^{th} percentile for Category 2 (10%-40% flows), the median or 50^{th} percentile for Category 3 (40%-60% flows), the 75^{th} percentile for Category 4 (60%-90%), and the 95^{th} percentile flow exceedance value for Category 5 (90%-99.9% flows). Marker flow values for all reaches and tributaries representing modeled subwatersheds are compiled in Table 7. It should be noted that only the five marker flow values for the Gila River near Solomon and the 95^{th} percentile flow value for the Gila at Duncan were directly used in calculations to determine geometric mean targets. Other subwatershed and category contributions towards the TMDL values were calculated from prorations based upon the net sediment delivery ratio as supplied by RUSLE. See Sections 6.2 and 7.3 for further discussion on the methods. Flow values not used in calculations are compiled here and presented for information regarding the relative flow differences between subwatersheds.

A unit conversion factor of 2.446 was used in conjunction with flow in all sediment calculations to convert sediment concentrations in mg/l into loads expressed in kilograms per day.

Flow Values, cfs	***Flow Exceedance Percentiles***				
	5th	**25th**	**50th**	**75th**	**95th**
Gila at head of Safford Valley near Solomon	1750	361	176	106	49
Bonita Creek	16	5.9	4.2	2.9	1.7
Eagle Creek	155	40	29	20	13
San Francisco River	787	161	75	50	26
Gila at Redrock, New Mexico	777	186	92	60	20
Gila at Duncan, Arizona	929	197	91	46	1.5

Table 7. Flow Values used in Target Load Calculations

7.2 Reach 15040005-022 TMDL Allocations

After screening data for non-storm flow events, exclusive of one, four, and seven day event windows (see Appendix A for an extensive discussion about the screening method), reductions were calculated for the five flow categories of a load duration curve approach for each of the major contributing watersheds (Figure 3). Target load values and necessary reductions are shown in Table 8. Only data points meeting the operational definitions of non-storm flow conditions were used in determining reductions necessary, in compliance with Arizona’s 2003 suspended sediment water quality standard. For cumulative load data and calculations of load reductions necessary for Reach 15040005-022, refer to Table 9. Discussion of results and allocations is presented in Section 7.4.

Calculations for both load duration analyses and TMDL reductions were made in units of kilograms per day. Arizona’s 2003 SSC water quality standard is expressed as a geometric mean. However, the geometric mean is not a conservative value amenable to allocation in a mass-balance analysis such as a TMDL (Parkhurst, 1998), and as allocations were to be made based on the relative percentages of net sediment production predicted by the RUSLE model, it was necessary to convert existing loads and load allocation values into their corresponding arithmetic means. In two class evaluations, the arithmetic mean and the geometric mean pointed to different assessments of attainment. In these two categories, the assessment determined by the geometric mean controlled the assessment of the arithmetic mean to reflect the water body’s attainment or lack thereof with the standard as expressed. In all other categories, where arithmetic means confirmed the assessment of the geometric mean calculations, percentage reductions were evaluated and calculated using the arithmetic mean.

For existing loads with established data sets, it is a simple matter to calculate the arithmetic mean from the same data that generated the original geometric means. However, for the establishment of the allocations, an abstraction from the cumulative allowable load calculated from a geometric mean, no inherent relationship existed between arithmetic means and geometric means to inform the setting of the load allocation value. In these cases, the ratio of the logarithms of the geometric mean to the arithmetic mean for the existing data sets were determined across all five categories of flow conditions and averaged to provide a linking relationship between the arithmetic and geometric means. In this analysis, one extreme outlier value in a Category 5 was excluded from the log ratio calculation to allow for a more consistent relationship among the categories. This extreme outlier, however, was fully considered in the data set when determining necessary load reductions.

Where calculations show that Reach 15040005-022 is meeting its TMDL target in select categories, further calculation and analysis by subwatershed for reductions are not carried out except in the case of the Gila River from Bitter Creek to the New Mexico State Line (Reach 15040002-004), which is listed on the 303(d) list for sediment. Reach 15040002-004 is addressed comprehensively in Section 7.3. In categories where the impaired reach already meets loading allocations and no reductions are called for, the presentation of subwatershed prorated values for comparisons and assessment carries the risk of mischaracterizing water quality out of an appropriate context.

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Extensive discussion regarding waste load allocations may be found in Section 4.1, which details potential point source contributions from both New Mexico and Arizona. It is reiterated that Arizona has no jurisdiction over New Mexico lands and that New Mexico point source contributions are treated as general load allocations to the State of New Mexico in this TMDL.

Reach 15040005-022: Gila River - Yuma Wash to Bonita Creek **TMDL calculations, Kg/day**			*Category 1 *** *High Flows*	*Category 2* *Moist Conditions*	*Category 3* *Mid-Range Flows*	*Category 4* *Dry Conditions*	*Category 5* *Low Flows*
Cumulative Net Sediment production, Kg/day	Percentage net sediment production	**Cumulative Sediment Target Values**					
5,745,245	100%	Reach 15040005-022					
		Geomeans (Kg/day):	342,300	70,612	34,426	20,734	9,584
		Arithmetic Means (Kg/day):	920,027	167,912	77,425	44,832	19,520
		Load Allocations by Subwatershed					
		(Allocated by Arithmetic Mean Values, Kg/day)					
2,627,985	45.742%	San Francisco River	341,295	62,289	28,722	16,631	7,241
1,820,968	31.695%	Gila River- Headwaters to NM state line	236,200	43,108	19,877	11,510	5,011
689,149	11.995%	Eagle Creek	91,099	16,626	7,666	4,439	1,933
307,413	5.351%	Gila River, Yuma Wash - Bitter Creek	39,875	7,277	3,356	1,943	846
220,610	3.840%	Bonita Creek	29,102	5,311	2,449	1,418	617
79,120	1.377%	Gila River, Bitter Creek - NM state line	10,263	1,873	864	500	218
		Waste Load Allocations	#	#	#	#	#
		Margin of safety: 10%	92,003	16,792	7,742	4,483	1,952
		Cumulative Natural Background, Kg/d	80,191	14,635	6,748	3,908	1,701
		TMDL, Arithmetic Means, Kg/day:	920,027	167,912	77,425	44,832	19,520

A dual-option WLA is established for existing and future permittees covered under the MSGP and CGP for stormwater outfalls. See Sections 4.1.1 and 4.1.2.

Reductions Summary Table	**Reductions Needed:**	*Category 1* *High Flows*	*Category 2* *Moist Conditions*	*Category 3* *Mid-Range Flows*	*Category 4* *Dry Conditions*	*Category 5* *Low Flows*
Geometric Mean	Cumulative,	**95.1%**	**78.9%**	**45.9%**	**Meets**	**Meets**
Arithmetic Mean	Reach 15040005-022	**91.7%**	**88.3%**	**54.3%**	+	+
Arithmetic Mean	San Francisco River	*	**59.5%**	**62.6%**	--	--
Subwatershed	Gila River- Headwaters to NM state line	*	**74.4%**	**84.3%**	--	--
Breakdown	Eagle Creek	No data	*	**Meets**	--	--
	Bonita Creek	No data	No data	No data	--	--
	Gila River - Bitter Creek - NM state line	* **	**90.7%** **	**78.8%** **	**44.3%** **	* **
	Gila,Yuma Wash - Bitter Creek	**98.2%**	**97.5%**	**90.4%**	--	--

+ Geometric mean assessments differ from arithmetic mean assessments. Geometric mean determinations substituted.

* Insufficient data: fewer than four data points in the data set.

** Modeled Values - derived from calculations.

-- Reductions not called out except for 303(d) listed reaches where 15040005-022 loads show category meets TMDL requirements.

Table 8. Reach 15040005-022 Load Allocations and Summary of Reductions

Reach 15040005-022: Yuma Wash to Bonita Creek **TMDL calculations, Geomean Kg/day**		*Category 1* *High Flows*	*Category 2* *Moist Conditions*	*Category 3* *Mid-Range Flows*	*Category 4* *Dry Conditions*	*Category 5* *Low Flows*
Cumulative Sediment Target Values						
Reach 15040005-022 Existing		**5,686,864**	**271,857**	**51,771**	**14,650**	**4,853**
Reach 15040005-022 Target TMDL		342,300	70,612	34,426	20,734	9,584
Reach 15040005-022 Target - 10% MOS		308,070	63,551	30,983	18,661	8,626
Reach 15040005-022 Natural	0.0968462	29,835	6,155	3,001	1,807	835
Reach 15040005-022 Load Allocation		**278,235**	**57,396**	**27,983**	**16,853**	**7,790**
Reductions Needed		**95.1%**	**78.9%**	**45.9%**	**Meets**	**Meets**
Reach 15040005-022: Yuma Wash to Bonita Creek **TMDL calculations, Arithmetic Means, Kg/day**		*Category 1* *High Flows*	*Category 2* *Moist Conditions*	*Category 3* *Mid-Range Flows*	*Category 4* *Dry Conditions*	*Category 5* *Low Flows*
Cumulative Sediment Target Values						
Reach 15040005-022 Existing		**8,994,546**	**1,162,819**	**137,753**	**66,503**	**156,652**
Reach 15040005-022 Target TMDL		920,027	167,912	77,425	44,832	19,520
Reach 15040005-022 Target - 10% MOS		828,024	151,121	69,682	40,349	17,568
Reach 15040005-022 NB (composite)	0.09685	80,191	14,635	6,748	3,908	1,701
Reach 15040005-022 Load Allocation		**747,833**	**136,485**	**62,934**	**36,441**	**15,867**
Reductions Needed		**91.7%**	**88.3%**	**54.3%**	+	+
TMDL Reduction Calculations, Arithmetic Means Kg/day						
Load Allocations by Subwatershed						
San Francisco River - Existing		**1,390,942**	**153,983**	**76,801**	--	--
San Francisco River - Target		378,754	69,126	31,874	--	--
San Francisco Natural Background	9.89%	37,459	6,837	3,152	--	--
San Francisco Load Allocation (-NB)		**341,295**	**62,289**	**28,722**	--	--
Reductions Needed		*	59.5%	62.6%	--	--
Eagle Creek Existing		No data	**692** ^	**129** ^	--	--
Eagle Creek Target		99,323	18,127	8,358	--	--
Eagle Creek Natural Background	8.28%	8,224	1,501	692	--	--
Eagle Creek Load Allocation (-NB)		**91,099**	**16,626**	**7,666**	--	--
Reductions Needed		No data	*	Meets	--	--
Bonita Creek Exisitng		No data	No data	No data	--	--
Bonita Creek Target		31,795	5,803	2,676	--	--
Bonita Creek Natural Background	8.47%	2,693	492	227	--	--
Bonita Creek Load Allocation (-NB)		**29,102**	**5,311**	**2,449**	--	--
Reductions Needed		No data	No data	No data	--	--
Gila River- Headwaters to NM State Line Existing		**220,131** *	**168,214**	**126,401**	--	--
Gila River- Headwaters to NM State Line Target		262,444	47,898	22,086	--	--
Gila HW-NM Natural background	10.0%	26,244	4,790	2,209	--	--
Gila, HW-NM, Load Allocation (-NB)		**236,200**	**43,108**	**19,877**	--	--
Reductions Needed		*	74.4%	84.3%	--	--
Gila River - Bitter Creek - HW Cumulative Exisitng		4,544,768 ***	319,611 **	64,836 **	14,268 **	2,394 **&*
Gila, Bitter-NM State Line, NSD weighted Coefficient		**285,866** ***	**20,104** **	**4,078** **	**897** **	**151** **&*
Gila, Bitter Creek - NM State Line Target		11,403	2,081	960	556	21 &
Gila, Bitter Creek - NM State Line Natural Background		1,140	208	96	56	2 &
Gila River - Bitter Creek - NM State Line Load Allocation		**10,263**	**1,873**	**864**	**500**	**218** **&
Reductions Needed		*	90.7%	78.8%	44.3%	* &
Gila,Yuma Wash - Bitter Creek Existing		**2,273,170** #	**293,876** #	**34,814** #	--	--
Gila,Yuma Wash - Bitter Creek Target		44,305	8,086	3,729	--	--
Gila,Yuma Wash - Bitter Creek Natural Background (.0968		4,431	809	373	--	--
Gila,Yuma Wash - Bitter Creek Load Allocation		**39,875**	**7,277**	**3,356**	--	--
Reductions Needed		98.2%	97.5%	90.4%	--	--

* * Insufficient data: less than four data points in the data set.
** Modeled Values - derived from calculations.
++ Value calculated as subwatershed net sediment delivery multiplied by modeled existing load
\+ Geometric mean assessments differ from mean assessments. Geometric mean determinations substituted.
\# Figures modeled as composite loads comprised of the product of average flow and average concentration.
NSD percentage allocation of Solomon total load applied.
& Category targets and reductions calculated from more conservative Arizona water quality standard numbers.
^ Existing load presented as instantaneous load average using measured discharge due to water diversions upstream of sampling locatio
Daily mean flow/load calculations do not account for water diversions.

Table 9. Load Reduction Calculations, Reach 15040005-022

7.3 Reach 15040002-004 TMDL Allocations

The Gila River from Bitter Creek to the New Mexico state line also requires load reductions in suspended sediment. Because of its unique location and status as impaired nested within the larger Gila watershed as delineated from Reach 15040005-022 further downstream, load determinations and allocations generally must be applied in a more stringent fashion than the water quality standard permits at this location in order that the downstream reach may still be attaining its TMDL. Consequently, in most flow categories load target values and percent reductions necessary are reduced in proportion to the net sediment load as determined by RUSLE attributable to the watershed as delineated from the Bitter Creek confluence.

Refer to the comparative analysis in Table 10 of the sediment loads allocated by the state water quality standard (2003) within the impaired reach and the sediment loads mandated by the proration of sediment loads allocated in Reach 15040005-022 further downstream. The figures illustrate that in four of the five flow categories, the prorated sediment load value from Reach 022 is more protective of state's designated use. This more protective sediment load target is adopted for the TMDL in the high flow, moist condition, mid-range, and dry condition categories. In the low flow category, the enforcement of sediment load limits as calculated by the state water quality standard in Reach 004 is actually the more protective value. For this sole category, the TMDL adopts the sediment target load limit from load duration calculations within impaired Reach 004. Margins of safety are implicitly provided for in that prorated target values lower than the water quality standard requires in Reach 004 are employed; no explicit allocations for an MOS is thus made for the high flow, moist condition, mid-range and dry conditions flow categories. Implicit margins of safety range from 45.5% to 60.2% for these four categories. For the low flow category, an explicit margin of safety allocation of 10% is made and included in the TMDL calculations. Natural background percentages were contributed from the previous analysis.

The Gila River watershed encompasses parts of both Arizona and New Mexico. This holds true for the two largest subwatersheds in the Gila as well: the Gila River main stem upstream of the San Francisco River, and the San Francisco River watershed. While detailed waste load allocations under Arizona's jurisdictional control were available for analysis, consideration and inclusion, New Mexico point source information is not available for consideration in the TMDL, nor does it serve any purpose to analyze New Mexico's waste load allocations in a discriminative way for purposes of regulatory limits, inasmuch as Arizona has no jurisdictional authority over New Mexico lands. Furthermore, New Mexico does not have quantitative sediment standards for water quality in the state as a benchmark to begin calculations from. Consequently, New Mexico was considered as a single aggregated load allocation on the main stem of the Gila River, with the allocation granted on the basis of results from the RUSLE net sediment delivery quantities in kilograms per day. The small portion of the Gila watershed upstream of the Bitter Creek confluence which was not in New Mexico was analyzed as a second load allocation. Percentages of net sediment delivery attributed to each subwatershed are outlined in Table 10.

Differences in method category selection for sediment target loads likely arise because of the necessity of considering a trimmed flow history for Reach 004. Due to agricultural diversions upstream of Reach 004 and intermittency of flow on the Gila River in the open desert, approximately ten percent of days represented in the flow history were days of no flow at USGS site 09439700 in Duncan. The inclusion of these null flow values in load duration calculations skewed the construction of flow and load duration curves and essentially created a category for low flows that was devoid of almost all populated positive flow values; the 95% flow exceeds value used for calculation of target loads for category 5 flows was not a positive number. To consider and calculate meaningful numbers and load reductions, only those flows were ranked and given percentile values which showed actual flow at this site. This had the effect of compressing the flow history at Duncan relative to the record at USGS site 09448500 near Solomon, where perennial flow is well-established and a lowest-recorded flow of 31 cfs is on record. By doing so, meaningful load and flow numbers other than zero were generated and used for Reach 004; a much lower sediment load target than mandated by the prorated Reach 022 targets still results for low flow category in Reach 004 as a consequence of the modification of the method. Thus, while there is a disparity in the construction of the load duration curves between the two reaches, careful analysis and consideration justifies the alteration of the approach and allows for completion of all five categories of load target calculations. This mixed approach for the final flow category resulted in the Bitter Creek to New Mexico subwatershed meeting its TMDL allocation when analyzed within Reach 15040005-022's design, but falling short of meeting its TMDL allocation when analyzed from the perspective of Reach 15040002-004. Conservative and more protective assumptions dictate the selection of the more stringent criteria.

Cumulative existing loads for Reach 15040002-004 were modeled figures; the data collected for Reach 15040002-004 was sparse in nature and did not reflect contributions from uplands below the town of Duncan or contributions from agriculture return flows. When storm event identification analysis was applied to the data set, no data points in the two high flow categories filtered through the non-storm flow screen, and only one data point exceeding the state's 2003 standard was represented in the mid-range flow category (Appendix C). When geometric mean analysis was applied across the categories, it was found that insufficient data points existed for categories 1, 2, 3 and 5 (High flows, Moist conditions, Mid-Range flows, Low Flows) to make any confident assertions pertaining to existing loading. Inasmuch as the reach is listed as impaired, it was deemed insufficient to present an analysis based on limited existing loading figures that did not support the designation as impaired.

Modeled existing loading was determined by analyzing cumulative loads for the Gila River near Clifton and cumulative loads for the Gila River near Redrock, New Mexico. Linear interpolation between respective category's figures for these two sites was performed using the watershed's cumulative net sediment delivery values to each sampling site as determined by RUSLE to determine the cumulative existing loading at the Bitter Creek-Gila River confluence. The NSD coefficient applied to interpolate between these known existing loads was 0.5836. Since existing load figures supplied by the model represented cumulative loads, the Bitter Creek to New Mexico state line subwatershed was then further isolated for its specific contributions based upon the percentage of net sediment delivery attributable to this subwatershed relative to the entire watershed from the Bitter Creek confluence to the headwaters. The coefficient applied to determine this subwatershed's contribution relative to the total was 0.0629.

As with Reach 15040005-022, abstracting arithmetic mean allocation values from geometric means required the application of a ratio of the logarithms of the geomean to the arithmetic mean. Ratios were calculated for all five categories and averaged across categories for a more robust conversion value. The ratio used for the conversions was 0.901. As mentioned previously, it was necessary to present allocation targets as arithmetic means since they are prorations of Reach 15040005-022 cumulative loads, and geometric means are not conservative in a mass-balance analysis.

For actual load reductions necessary for Reach 15040002-004, refer to Table 11.

Reach 15040002-004. Bitter Creek to New Mexico

Arizona WQ standards-based target values shown for comparative purposes.

Underlined target loads represent the category selection for TMDL calculation.

Net Sediment production, Kg/day	Percentage net sediment production	TMDL calculations, Kg/day	Category 1	Category 2	Category 3	Category 4	Category 5
		Cumulative Sediment Target values	High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
		Reach 15040002-004, Gila Bitter Creek to NM					
1,943,209	100.000%	Geomean Standard-mandated	181,722	38,533	17,800	8,998	**293**
		Prorated Reach 022 Values	**113,199**	**23,351**	**11,385**	**6,857**	3,170
		Arithmetic Mean					
		Standard mandated	687,544	122,947	52,172	24,468	**548**
		Prorated Reach 022 Values	**273,847**	**49,979**	**23,046**	**13,344**	5,810
		Load Allocations (Arithmetic Means, Kg/day)					
1,820,968	93.709%	Gila, Headwaters to NM state line	236,200	43,108	19,877	11,510	416
122,241	6.291%	Reach 15040002-004, Gila Bitter Crk to NM	10,263	1,873	864	500	28
		Waste Load Allocations	0	0	0	0	0
		MOS allocation, kg/day	0	0	0	0	55
		Natural Background Allocatior 10%	27,385	4,998	2,305	1,334	49
		Margins of Safety:	#	#	#	#	10.0%
		TMDL:	273,847	49,979	23,046	13,344	548

Margin of safety: None explicitly included for Categories 1-4. Margin implicit in the use of more stringent prorated Solomon target values relative to standard-mandated values.

Reductions Summary Table		*Category 1*	*Category 2*	*Category 3*	*Category 4*	*Category 5*
Cumulative Load Reductions		*High Flows*	*Moist Conditions*	*Mid-Range Flows*	*Dry Conditions*	*Low Flows*
Geomean	Cumulative,	* **	89.3% **	0.7% **	**Meets** **	* **&
Arithmetic Mean	Reach 15040002-004	* **	85.9% **	68.0% **	+ **	* +&**
Arithmetic Mean	Gila River- Headwaters to NM state line	* +	74.4%	84.3%	--	90.9% &
Subwatershed Breakdown	Gila River - Bitter Creek - NM state line	* **	90.7% **	78.8% **	--	* **&

+ Geometric mean assessments differ from mean assessments. Geometric mean determinations substituted.

& Category targets and reductions calculated from more conservative Arizona water quality standard numbers (not prorated from Solomon loads)

** Modeled Values - derived from calculations.

* Insufficient data; fewer than four data points in data set

Table 10. Reach 15040002-004 Load Allocations and Summary of Reductions

Reach 15040002-004: Gila River - Bitter Creek to NM state line	*Category 1 High Flows*	*Category 2 Moist Conditions*	*Category 3 Mid-Range Flows*	*Category 4 Dry Conditions*	*Category 5 Low Flows*
TMDL Reduction Calculations, Geomeans Kg/day					
Reach 15040002-004 Existing (prorated from RUSLE net sedir	**2,047,285** ** *	**197,327 ****	**10,316 ****	**4,429 ****	**1,082** &*
Reach 15040002-004 TMDL Load Capacity	113,199	23,351	11,385	6,857	293
Reach 15040002-004 TMDL - MOS	113,199 $	23,351 $	11,385 $	6,857 $	264
Reach 15040002-004 Natural Background	11,320	2,335	1,138	686	26
Reach 15040002-004 Load Allocation	**101,879** **	**21,016** **	**10,246** **	**6,171** **	**238**
Cumulative Reductions Needed	*	**89.3%**	**0.7%**	**Meets**	*
TMDL Reduction Calculations, Arithmetic Means Kg/day					
Reach 15040002-004 Existing (prorated from RUSLE net sedim	**4,544,768 ****	**319,611 ****	**64,836 ****	**14,268 ****	**2,395** &*
Reach 15040002-004 Target TMDL	273,847	49,979	23,046	13,344	548
Reach 15040002-004 Target - 10% MOS	273,847 $	49,979 $	23,046 $	13,344 $	493
Reach 15040002-004 Load Allocation	273,847	49,979	23,046	13,344	493
Reach 15040002-004 Load Allocation (-NB)	**246,462** **	**44,981** **	**20,741** **	**12,010** **	**444**
Cumulative Reductions Needed	*	**85.9%**	**68.0%**	+	*

TMDL Reduction Calculations, Arithmetic Means Kg/day					
Load Allocations by Subwatershed					
Gila River- Headwaters to NM State Line Existing	**220,131 ***	**168,214**	**126,401**	--	**4,578**
Gila River- Headwaters to NM State Line Target	262,444	47,898	22,086	--	462 &
Gila HW-NM Natural background 0.1	26,244	4,790	2,209	--	46
Gila, HW-NM, Load Allocation (-NB)	**236,200**	**43,108**	**19,877**	--	**416** &
Reductions Needed	* +	74.4%	84.3%	--	90.9% &
Gila, Bitter-NM State Line, NSD weighted Coefficient	**285,866** ** *	**20,104** **	**4,078** **	--	**151** ** *
Gila River - Bitter Creek - NM State Line Target	11,403	2,081	960	--	31 &
Gila River - Bitter Creek - NM State Line Natural Background (	1140	208	96	--	3
Gila River - Bitter Creek - NM State Line Load Allocation	**10,263** **	**1,873** **	**864** **	--	**28** **&
Reductions Needed	*	90.7%	78.8%	--	* &

* * Insufficient data; fewer than four data points in category

** Modeled Values - derived from calculations. No data

++ Value calculated as subwatershed net sediment delivery*modeled existing load

\+ Geometric mean assessments differ from mean assessments. Geometric mean determinations substituted.

\# Figures modeled as composite loads comprised of the product of average flow and average concentration. NSD percentage allocation of Solomon total load applied.

$ Margin of safety implicit in the use of prorated Solomon arithmetic mean loads.

& Category targets and reductions calculated from more conservative Arizona water quality standard numbers (not prorated from Solomon loads)

Table 11. Load Reduction Calculations, Reach 15040002-004

7.4 Reductions and Conclusions

Results show that extensive reductions are called for in many locations and for many flow categories within the watershed. The Gila River at the New Mexico state line is already in non-attainment with Arizona water quality standards, with needed arithmetic mean reductions ranging from 74% to 84% (average 79 % reduction). Additional loading occurs in the Bitter Creek subwatershed below Duncan for four flow categories, though only three can be quantified with confidence. Data points to heavy sediment loading in the Yuma Wash to Bitter Creek subwatershed, with needed reductions ranging from 90% to 98%. The San Francisco River is also a large sediment loading contributor, with reductions needed in three of five flow categories averaging 65.9 % for the three. One San Francisco class was qualified due to limited data; this qualified class provisionally indicated a 75.5% reduction was necessary to meet the subwatershed load allocation. Eagle Creek and Bonita Creek had limited data from which to calculate reductions and draw inferences, but where data existed, both tributaries were within their respective loading limits, though the RUSLE model showed susceptibility to erosion in the Eagle Creek watershed. Cumulatively, Reach 15040005-022 meets loading requirements in the two lowest flow categories, and requires reductions for the three highest categories ranging from 45.9% to 95.1% in a geomean analysis. Reach 15040002-004, as a subwatershed nested within Reach 15040005-022's larger watershed, is required to meet a more stringent prorated load from Reach 15040005-022's requirements in four of the five flow categories. These more stringent requirements, which were not derived from a direct load duration application to Reach 15040002-004, were adopted to ensure that Reach 022 downstream would meet its TMDL. For the fifth (low flow) category, a more conservative number was required by using the direct load duration analysis and target for Reach 004 itself; this number was adopted as the load allocation for Reach 004 in the low flow category. For Reach 15040002-004, implicit margins of safety were used for the four flow categories prorated from Reach 022, whereas an explicit MOS was adopted for the fifth flow category.

The Reductions Summary matrices in Tables 8 and 10 illustrate that for the larger rivers and their subwatersheds (Gila and San Francisco), from three to four categories are showing sizable reductions are necessary; in some cases, these reductions will require improvements by an order of magnitude or more to comply with Arizona's SSC water quality standard. Higher percentage reductions are generally, but not exclusively, required in the categories of flood flows, moist conditions, and mid-range flows. The distribution of reductions called for suggests that in general, sediment loading is not attributable to point source contributions, but to bank erosion, uplands erosion, riparian area contributions, and the mobilization of sediments previously stored within the stream channel due to nonpoint source contributions.

By contrast, Bonita Creek and Eagle Creek show good water quality in regards to sediment loading, though data is somewhat limited in adequately representing the full range of possible flows for these two streams. As mentioned previously, Eagle Creek is susceptible to more severe sediment problems than it is currently exhibiting in its water quality data; RUSLE modeling determined that as a weighted average on a per square mile annual basis, Eagle Creek generates the most gross sediment production of any of the modeled subwatersheds with the San Francisco River watershed close behind (Table 3).

In consideration of Reach 15040002-004, a modified run of the RUSLE model used in the TMDL analysis for the Duncan Valley agricultural area determined that agricultural practices are having a net beneficial effect on reducing sediment loads in the Gila River, likely due in part to the lower gradients in the fields adjacent to the river, but also evidence of responsible agricultural land management practices in the area. Gross sediment production for the subwatershed from the west (downstream) end of the

Duncan Valley to the state line was 11,765 kg/sq mi/year as opposed to 24,780 kg/sq mi/year for the Gila River watershed above Canador Peak at the east (upstream) end of the Duncan Valley. Net sediment delivery for the former was 434 kg/hectare/year as compared to the latter's 782 kg/hectare/year.

On the whole, existing samples collected for the Gila River at Duncan show lower concentrations of sediment in the water column than the USGS site at Redrock, New Mexico upstream of the agricultural area. Some of this effect may be due simply to the practice of agricultural water diversions and its consequent reduction of the hydraulic power of the Gila River and its capacity to carry sediment loads. Another contributing factor is the actual diversion of a portion of the sediment loads out of the Gila River. Assistance has been sought in previous years from farmers in the area for Section 319 grant funding to clean sediment out of the Franklin Irrigation District canal system. Regardless, the net effect in both modeled loading and in data collection rebuts an earlier hypothesis that agricultural activities were exacerbating sediment loading problems for Reach 15040002-004. While it may always be possible to further improve erosion control practices associated with agriculture in the area, this possible anthropogenic source does not appear to be the active and contributing source initially suspected. Even though sizable reductions are called for in the Bitter Creek – New Mexico subwatershed, it is important to remember that the existing load is a modeled and linearly interpolated value, and much of the contribution appears to be occurring downstream of the town of Duncan and the Duncan Valley area.

8.0 TMDL IMPLEMENTATION

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. This section serves as the implementation plan for the Gila River suspended sediment concentration TMDLs. 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 attainment of applicable surface quality standards is expected to be achieved." The implementation plan is voluntary for the stakeholders of the region and meant only to suggest possible improvements and best management practices that can be employed to improve water quality.

This implementation plan is intended to provide a general framework in this TMDL for addressing the Gila River SSC problem with broad-brush guidance and subsequently providing more focused and region-specific recommendations and guidance for the implementation of more specific improvement measures on a sub-basin scale as stakeholders and interested parties come forward with proposals. ADEQ also plans to continue its close cooperation with the New Mexico Environment Department, recognizing that both states are partners in the effort to improve Gila River water quality. A basin as large as the Upper Gila watershed, consisting of more than 7800 sq. mi. above the USGS gauge site 09448500 (Gila River at the head of the Safford Valley near Solomon, AZ) and presenting multi-state jurisdictional issues, poses special challenges in the development of a TMDL implementation plan. Actual on-the-ground improvements in water quality will rely upon the voluntary initiative and actions of stakeholder groups and interested individuals employing standard BMPs at a local scale throughout the entire watershed. The scope of the cumulative problem is large enough that ongoing cooperation amongst many stakeholders, working within the framework of this TMDL, will be necessary to effect long-term improvements over several years. Water quality improvement for the Gila River will ultimately come in incremental steps from many different directions and many different benefactors.

Congress amended the Clean Water Act in 1987 to establish the Section 319 Nonpoint Source Management Program. As a result of this new federal program, states have an improved framework in their efforts to reduce nonpoint source pollution. The ADEQ Water Quality Improvement Grant Program allocates Section 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. There is a 40% match requirement to nonpoint source funds disbursed through the Section 319 program.

8.1 Best Management Practices

Voluntary responsibility for on-the-ground implementation will rest in large part with the U.S. Forest Service and the Bureau of Land Management, whose acreage in the GNF, A-S NF, BLM Las Cruces District, and BLM Safford District comprise the majority of the total watershed area. Private landowners can also play a role in improving the Gila's sediment water quality problem. Improvements in non-point source pollution problems are typically addressed through the implementation of best management practices (BMPs). Best management practices to control nonpoint source pollution problems are a combination of structural and non-structural (management or cultural) practices that landowners or land management agencies decide upon to be the most effective and economical way of controlling a specific water quality problem without disturbing the quality of the environment (NEMO, 2008). BMPs are usually tied to specific land use practices, such as agriculture, grazing, logging, construction, mining, or unimproved road crossings/maintenance, but some are directly related to managing the flow and erosive potentials of the stream course proper. Many BMPs are interdisciplinary in their application and can provide benefits for more than one type of land use or geomorphic process. Land use practices common in the watershed include all discussed in Section 4.0, including agriculture, grazing, logging, road crossings, mining, and light development. Necessarily, because of the scale of the watershed and the differing state jurisdictions, only broad scope BMPs can be suggested here, and suggestions are not to be construed as an all-inclusive list nor as required measures mandated by this TMDL.

Best management practices for grazing activities include fencing of exclusion zones along riparian corridors to protect stream banks, installation of troughs and watering holes away from stream courses, management of cattle use of grazing allotment lands, primarily through rest and rotation grazing strategies, controlled stream crossings where livestock must cross streams, and establishment of riparian buffer zones and filter strips.

Where agricultural activities are concerned, water quality is benefitted through BMPs by the establishment of filter strips and riparian buffer zones, the use of contour plowing and terracing , the management of irrigation by several practices, including the control of tail water return, the engineering of irrigation water control structures such as canals, head gates, and pipelines; the judicious use of stream bank stabilization measures, and mild engineering measures such as the installation of brush layers, erosion control fabrics, and willow plantings.

Mining activities typically employ detention ponds, erosion control fabrics and linings, rock rip rap, and grade stabilization structures as best management practices. The use of straw wattles or bale barriers is often called for on unvegetated slopes.

Logging activities, though light in the Gila River watershed, can also contribute to sediment concerns for water quality, thus warranting a set of BMPs specific to logging. Measures typically include seasonal restrictions upon when logging may occur, slope thresholds and pad dimensioning for landing zones and skid trails, the prohibition or restriction of new road establishment for logging activities, and selective logging, as opposed to clear-cut methods.

Unimproved road BMPs include measures such as armoring of stream crossings, containment of sediment on site when road construction activities are taking place, and the proper grade engineering controls to control drainage on and along the sides of the roads. Proper road siting also plays a role in maintaining grade stability and sedimentation rates that do not degrade water quality.

8.2 Gila River Watershed Improvement Plan and Strategies

The State of New Mexico drafted a comprehensive watershed improvement plan for its portion of the Gila and San Francisco Rivers in 2007 addressing watershed conditions, Clean Water Act Implementation on the Gila River Watershed, Section 319 Funding, TMDLs for portions of the Gila River hydrologic system, and resources available to address the issues in the watershed. Numerous maps and summary tables cataloged each of the problem areas identified. The Watershed Improvement Plan (WIP) is a required submission in New Mexico to secure Section 319 funding from the Environmental Protection Agency. Intended as an umbrella document, more specific planning for individual problem areas is called for where necessary. The nine key elements EPA requires for Section 319 funding are addressed in the document. These nine elements include:

a) identify causes and sources of pollution
b) identify specific indicators and quantify targets, including load reductions
c) identify most effective management practices to achieve targets
d) develop an implementation schedule
e) identify interim milestones to be achieved
f) develop measurement criteria
g) outline a monitoring plan
h) develop an information component
i) outline technical and financial assistance needed for implementation of project components.

Arizona began a demonstration project intended to produce a similar document cataloging needed improvements watershed-wide. Three Arizona watershed planning groups were invited to submit proposals and WIPs for their respective watersheds in September of 2008. The Gila Watershed Partnership, based in Safford, was one of the watershed groups invited to compete. EPA has approved limited 319 funding for the planning process and document creation in this demonstration effort, recognizing that inventory and prioritization of projects in a watershed-wide approach should lead to more efficient and productive expenditures of Section 319 funds leading to more water quality improvements and attendant de-listings of water quality impaired reaches.

As of March 2011, the Watershed Improvement Plan for the Gila Watershed Partnership was nearing completion of its two-year time frame. The document is currently in the final stages of its write-up and should provide cataloging and prioritization of projects within the Arizona portion of the Gila River watershed above the impaired reaches. The demonstration project associated with the plan write-up consisted of the construction of sediment retention basins, which were also near completion.

8.3 Healthy Lands Initiative

In 2007, the federal Department of the Interior allocated $21.9 million to a new program called the Healthy Lands Initiative designed to encourage landscape-wide approaches to improving the quality of rangelands in the western U.S. The program is ongoing for FY 2009, with several western U.S. states participating. Arizona is currently not participating. The Bureau of Land Management participates as a federal partner in the program. Bill Brandau, former head of the Safford District of the BLM advocated investigation and use of these resources in the implementation efforts for this TMDL project.
BLM, releases characterize the program as follows:

> *The Healthy Lands Initiative (HLI) is a central feature of the President's proposed Interior Department budget for Fiscal Year 2009.The overall aim of the Initiative is to improve the health and productivity of the public lands in today's fast-growing West. The Initiative is characterized by the broad scale of the acreage it seeks to restore and conserve, and the accelerated pace at which results are expected. The Initiative will enable and encourage local BLM managers to set priorities and manage across landscapes and mitigate impacts to an array of resources in ways not previously available to them. The President's budget for Fiscal Year 2009 includes a request for $14.9 million for HLI, an increase of $10 million above the level enacted in Fiscal Year 2008.*
>
> *Demand for a variety of public land uses and products in the U.S. is at an all-time high because of the country's changing demographics and needs. Land health is being affected by pressures such as community expansion, wildfires, unmatched demand for energy resources, ever-expanding recreation uses, and invasive weeds. These pressures often interact to affect large landscapes and ecosystems, particularly those in the growing wildlife-energy interface. A different management approach is urgently needed to meet these challenges. and help avoid restrictions on uses of public lands that would directly affect the nation's energy security and quality of life.*
>
> *The landscape-level approach is the first step, and will be focused so as to realize results in one to three years. The key is keeping resources healthy. Healthy lands support rural and urban economies across the West. The Initiative recognizes that conserving wildlife and habitat is also beneficial to local communities, particularly those whose economies are tied to fish, wildlife, and healthy watersheds. The Initiative gives managers flexibility to identify lands where a particular resource might be emphasized in order to encourage sustained health and balance across a broader landscape or ecosystem.*
>
> *Partnerships are an integral part of the Initiative. Public-private cooperation, incentives for landowners and private industry, and other non-traditional approaches will engage stakeholders while generating additional funds and resources. (Healthy Lands Initiative National, 2008)*

As of January 2011, Arizona has taken steps to participate in the Healthy Lands Initiative. Rem Hawes of the Arizona BLM states that Arizona currently has two projects within state borders supported by HLI funds, though the project area of this TMDL is not currently included in these efforts to improve rangeland conditions. Projects may originate with the BLM, or stakeholders and other interested parties may come forward with proposals and applications to participate in the effort. The program is overseen by the BLM as a matching program for money, time, or materials, with the intent, but not the requirement, that matches be 50:50. BLM has turned the local administration of the HLI over to Arizona's Association of National Resource Conservation Districts (NRCDs) where landowners and stakeholders can apply for funds for specific projects intended to promote rangeland health. The HLI continues to be funded in 2011, and currently there is no termination date associated with the initiative.

It is strongly encouraged that the federal partners in this effort take advantage of the funding in order to make the necessary watershed improvements on a broad scale that will eventually pay dividends in the form of improved water quality with less sedimentation.

8.4 Time Frame and Future Monitoring

A.R.S 49-234 mandates that a time frame be established for the implementation plan by which attainment of water quality standards is expected to be achieved. It should be stated at the outset that there are no "magic bullet" solutions that can immediately be implemented that will make a measureable and immediate improvement on the Gila River's sediment loading problem. Due to the influence of a number of factors, outlined below, improvement in sediment loading is expected to occur quite slowly and incrementally and will not likely be noticed in any short-term scenario:

- scale of the watershed (approximately 8000 square miles);
- numerous small-scale sediment loading contributions not easily isolated;
- widespread dispersal of diffuse nonpoint sources;
- multi-state jurisdictions with Arizona's nonexistent ability to regulate activities impacting water quality in New Mexico;
- voluntary as opposed to mandatory nature of on-the-ground implementation measures to improve sediment problems;
- natural conditions including the inherent friability of soils in the watershed, the existence of landslide-prone areas in the Blue River subwatershed (ADEQ, 2002a) and the lack of soil cover in the open desert country that constitutes a portion of the Gila's watercourse;
- amount of sediment currently stored in the hydrologic system as in-channel storage as the result of over 100 years of land use activities synergistically operating with natural processes;
- relatively light human footprint on the region.

A twenty year time frame is expected before improvement may begin to be noticed, and attainment with Arizona water quality standards as currently expressed is realistically expected to be decades away. Effectiveness monitoring by ADEQ will commence in five years, but, improvement is not expected to be noted for many years.

For the purposes of implementation and effectiveness evaluations, stakeholders engaged in monitoring activities are encouraged to consider and evaluate monitoring results in terms of concentrations as stated in the Arizona water quality standards. As with permittees' monitoring under the MSGP and CGP, SSC results that meet Arizona's water quality concentration-based criteria will be considered consistent with the provisions governing the remainder of this TMDL. The State's 2009 SSC warm-water standard requiring a median value of 80 mg/l with a minimum sample set size of four independent samples (with at least a seven day interval between samples) is in effect for assessment of results.

It is recommended that sites be sampled for SSC quarterly at a minimum in hydrologic conditions that represent all parts of the flow regime, including stormflow, snowmelt, and baseflow conditions, as well as in the irrigation diversion season and outside of it for sites in the Duncan Valley area associated with Reach 15040002-004. For interested stakeholders and other parties doing follow-up monitoring, ADEQ recommends the sites listed in Table 12 to best characterize subwatershed water quality conditions. Sites recommended have been considered for accessibility, suitability for project objectives, land ownership status and other factors. Where private lands are involved, permission will be required to be granted by the landowner

After the TMDL has been completed, ADEQ will review the status of the waterbody at least once every five years to determine if attainment of applicable surface water quality standards has been achieved. If attainment of applicable surface water quality standards has not been achieved, ADEQ will evaluate whether modification of the TMDL implementation plan is required (A.R.S. § 49-234).

ADEQ will continue to monitor the Gila River and its tributaries, both as a routine part of its ambient monitoring program on a triennial basis, and for effectiveness evaluations of water quality improvement measures five years from the date of this report. The department will use load evaluation criteria presented in this TMDL document as opposed to the concentration-based criteria recommended to stakeholders to evaluate loading reductions and improvements in the impaired reaches and contributing subwatersheds. These two approaches are complementary, with loads being derived from concentrations. However, the more intricate nature of the loading analysis with a nested subwatershed approach makes it more suitable for application to the agency with personnel experienced in the determination, application, and interpretation of loading data in a load duration analysis.

Site	***ADEQ Designation***	***Arizona Associated Reach ID***	***Latitude/ Longitude (NAD27)***	***Nearest USGS Site***	***Land Owner / Administrator***
Gila at head of Safford Valley near Solomon	UGGLR448.61	15040005-022*	32°52'06", 109°30'38"	09448500 (co-located)	Private (Clonts property)
Bonita Creek	UGBON000.17	15040005-030	32°53’45” 109°28’45”	09447800 (upstream)	BLM
Eagle Creek	UGEAG011.51	15040005-025	33°03'52" 109°26'30"	09447000 (upstream)	Freeport-McMoRan-Morenci
San Francisco River	UGSFR006.42	15040004-001	33°00'28.3" 109°18'54.2"	09444500 (upstream)	Private (Public access granted)
Gila at New Mexico State Line	UGGLR505.96	15040002-004	32°41'12.6" 109°03'07.8"	09439000 (downstream)	Private (Unknown)
Gila at Duncan, Arizona	UGGLR501.45	15040002-004	32°43'28" 109°05'57"	09439000 (co-located)	AZ DOT (Hwy 75 Right of Way)

Table 12. Recommended Implementation Monitoring Sites

8.5 TMDL Statute Requirements

8.5.1 Environmental, Economic, and Technological Feasibility

ADEQ believes that it is environmentally feasible to achieve the load allocations presented on a project-wide scale. Though percent reductions necessary in high flow conditions are relatively high, this is likely a result of years of channel storage of sediments and ongoing nonpoint source pollution from uplands replenishing the sediment stored in channels that has not to date been adequately addressed. While improvement in conditions is expected to be incremental and slow due to a number of factors, the prime factors being the size of the watershed and high-order character of the hydrologic network in the impaired reaches, the TMDL has been written to attain water quality standards, with percentage reductions calculated based upon appropriate water-quality targets. Arizona will rely on our sister state New Mexico to do its part to improve water quality in the uplands and drainages in New Mexico; ADEQ has consulted with the NMED throughout the course of this TMDL development and plans to continue working closely with New Mexico once the TMDL is implemented. Improvement in Gila River water quality depends to a substantial degree upon the ceasing of anthropogenic aggravations of the excessive sedimentation in the resupply of in-channel sediment load after clearing. Even so, consistently attaining assessments are not far off currently, as the threshold for designation of impairment was not surpassed with a high number of geomean exceedances for the listings under consideration.

Regarding the wasteload allocation specific to current and/or future NPDES permittees in the basin, as well as those seeking coverage under the department's MSGP or CGP, ADEQ has established environmentally feasible wasteload allocations as stated in Section 4.1.2. Inasmuch as the premise behind the issuing of each permit to a discharger or potential discharger is that water quality standards shall be met in waters with the A&Ww designated use and in the impaired reaches of the Gila River, the wasteload allocations set forth in the TMDL are consistent with the permitting considerations governed by the State's water quality standards as well as the standards themselves. While load allocations (LAs) are to be reasonable and minimize uncertainty to the extent possible (EPA, 1991), it is noted that these characteristics are to be considered for the overall loading scheme and not specifically considered for individual wasteload allocations against the allocation scheme as a whole. EPA defines a load allocation in 40 CFR 130.2 (g) as follows:

The portion of a receiving water's loading capacity that is attributed either to one of its existing or future nonpoint sources of pollution or to natural background sources. Load allocations are best estimates of the loading, which may range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint source loads should be distinguished.

Furthermore, EPA states in the previously cited source:

For traditional water pollution problems, such as dissolved oxygen depletion and nutrient enrichment, there are well validated models that can predict effects with known levels of uncertainty. This is not true for such non-traditional pollution problems as urban stormwater runoff and pollutants that involve sediment and bioaccumulative pathways. Predictive modeling for these problems therefore uses conservative assumptions, but in many cases the degree of certainty cannot be well quantified …For TMDLS involving these non-traditional problems, the margins of safety should be increased and additional monitoring required to verify attainment of water quality standards and provide data needed to recalculate the TMDL, if necessary.

ADEQ believes it has fully met its obligation in developing a reasonable load allocation scheme. Permittees are being held to a WLA in the TMDL no more stringent than the current water quality standard. Discharge Monitoring Reports to date have shown no problems complying with the water quality standards.

On a project-wide scale, economic feasibility is also considered reasonable; the vast majority of land (approximately 75%) within the Gila River watershed is federal or reservation land, and the costs of addressing nonpoint source pollution on these lands fall to other parties, including the U.S. Forest Service in the Gila and Apache-Sitgreaves National Forests and the Bureau of Land Management. New Mexico acreage makes up more than 2/3rds of watershed area; where federal lands do not exist in the Gila watershed in New Mexico, the state of New Mexico is responsible for addressing costs. State lands in both New Mexico and Arizona comprise a fair percentage of the remaining area. In short, any costs incurred in meeting the allocations of this TMDL are distributed widely, and federal Section 319 grant monies are available to private parties and landowners to assist in defraying costs for voluntarily-implemented measures and projects to improve nonpoint source pollution on a local scale.

For individual permittees in the watershed, economic feasibility has already been established by the premises from which WLAs were drafted. Permittees operating under general permits are already required by the terms of the MSGP and CGP to monitor and/or implement best management practices to safeguard water quality in flows resulting from storm events. Furthermore, local storm events where discharges from designated basins exceed a duration of 48 hours are expected to be relatively rare occurrences, and where water quality exceedances become apparent for these stormwater discharges, improvement of best management practices already employed is expected to mitigate the issue. Additional costs to the permittees, where incurred at all, are expected to be nominal.

Technological feasibility is also well within means on a project-wide scale, as an extensive set of tested, low-cost, and no- to minimal- engineering control best management practices (BMPs) are available for implementation, many of which have been developed and used successfully by federal land management agencies for years. This knowledge is widely and publicly available. These points have been addressed in Sections 8.0 to 8.3 of the draft TMDL document.

Technological feasibility specific to individual permittees is, as in the larger scale of the project, assessed by the existence and employment of best management practices (BMPs) to mitigate stormwater pollution on a local basis. Permittees operating under a general permit have already agreed to employ BMPs to improve water quality. As mentioned previously, a wide menu of tested and no- to minimal-engineering control BMPs developed largely by federal land management agencies is available in the public domain. Permittees have accepted the responsibility and obligation to monitor and improve BMPs, if necessary, to protect water quality in discharges exiting their respective sites. These additional actions would be required only in the event of a) discharges exceeding 48 hours in duration and b) BMPs already in place are inadequate to achieve their intended objectives, in which case the permittee is obligated by the MSGP to correct or improve. Technological feasibility, then, is built into the permitting framework and nonpoint source implementation measures that are already called for or under employment for permittees in the watershed.

8.5.2 Cost/Benefit Associated with Allocation Achievement

Cost considerations have previously been addressed under the “economic feasibility“ factor discussion. For specific permittees in the watershed, little is expected in the way of additional expense to monitor and improve BMPs, if necessary, that permittees are already obligated to perform as a part of the MSGP. These additional minimal expenses would be incurred only in the event of a) discharges exceeding 48 hours in duration and b) BMPs already in place are inadequate to achieve their intended objectives, in which case permittees obligated by the MSGP to correct or improve. As mentioned, stormwater data submitted to date does not indicate that any additional expense would have been incurred by the WLAs. ADEQ expects minimal additional costs resulting from the application of a WLA for two reasons: storms producing runoff for more than 48 hours from sub basins of small areal extent are likely relatively rare occurrences, and BMPs already called for by the MSGP should be sufficient to mitigate any potential problems.

On a project-wide evaluation, extensive discussion has been previously presented regarding cost-sharing between federal agencies, the states involved, private landowners who can apply for Section 319 funds, and tribes.

Benefits resulting from actions improving water quality in the Gila include making the waters of the Gila River compliant with the objectives of the Clean Water Act, i.e. "to restore and maintain the physical, chemical, and biological integrity of the nation's waterways" and ensuring that waterways are "fishable and swimmable." It is salient to note that these goals are not mere abstract objectives devoid of any practical or substantive content; illnesses due to swimmers' exposure to impaired bacteriological water quality on the Gila River have resulted on the San Carlos Apache Reservation within the past five years, and ADEQ has found that excessive sediment loads and poor bacteriological water quality routinely appear in tandem in Arizona streams and rivers impaired for one or both of these constituents. The benefits resulting from improved Gila River water quality are benefits that have very real community health and financial values associated with them. It is concluded that the costs possibly incurred in improving Gila water quality are minimal, dispersed in nature, appropriate, commensurate with and offset by the benefits that would accrue to re-establishing the Gila River as an unimpaired waterway.

8.5.3 Pollutant Loading Reductions Previously Achieved

Arizona's TMDL statute requires consideration of any pollutant loading reductions that are reasonably expected to be achieved as a result of other legally required actions or voluntary measures in TMDL analyses. Nonpoint source pollution remediation efforts have been ongoing for a number of years in the Gila River watershed in both Arizona and New Mexico.

ADEQ's Section 319 grant program has awarded grant money and tracked the progress of nonpoint source pollution improvement efforts in Arizona since program inception. EPA databases provide information on approved New Mexico NPS projects within the Gila River watershed boundaries. For sediment, total nitrogen, and total phosphorus, load reductions attributable through specific projects are estimated using modeling techniques. These reductions in loadings must be viewed with caution in relation to the TMDL target values presented in this document, since a direct correspondence does not exist even though the units of comparison can be manipulated to match. Model loading reductions presented in Appendix D. are presented in tons per year, with reductions broken out over the authorized project period on an annual basis. This reporting convention can be converted to match the Kg/day target units used in the TMDL analysis, but the resulting figure takes no account of the variability of stormflow in the river's hydrologic regime. It is well-known that much greater loadings are moved by and result from heavy and intense precipitation events causing great spikes in stream hydrographs than occur in smaller events resulting in elevated, but much lesser flows. Thus, there is a considerable element of abstraction in the figures presented. Additionally, it is noted that the STEPL and RUSLE models used for estimating load reductions for these projects focus on only overland flow with associated sheet and rill erosion, thus limiting applicability of loading reduction estimates to only those periods where sufficient active precipitation is occurring to meet the conditions of the modeling assumptions. Uncertainties arise when trying to apply wide-spread loading reduction estimates over long periods of time using modeled values relying upon storm-originated processes to a hydrologic network's widely variable flow regime and annual hydrograph. A simple one-to-one comparison with figures set as targets in the TMDL analysis is therefore not possible.

With the caveats mentioned above, total sediment loading reductions estimated to date in the Gila watershed above the lowest impaired reach for authorized and funded NPS projects in both Arizona and New Mexico are 616,081 kg/day. Of this, 578,427 kg/day are estimated to be reduced in the Gila River proper; 41,201 kg/day have been modeled as reduced from the Eagle Creek watershed, and 679 kg/day have been modeled as reduced from the San Francisco River watershed. Refer to Table 13 for a breakdown by HUCs.

HUC ID	Load Reduction, Kg/day	HUC Name
15040002	569,188	Upper Gila-Mangas
15040005	41,201	Eagle Creek
15040005	7,984	Gila Main Stem - Gila Box
15040001	1,254	Upper Gila - Headwaters
15040004	679	San Francisco River

Table 13. Estimated Loading Reductions by HUCs, CWA Section 319 NPS Projects

9.0 PUBLIC PARTICIPATION

Stakeholder and public participation was encouraged and received throughout the development of this TMDL. ADEQ held two public meetings in Safford, Arizona, the first on February 21, 2007 to introduce the Gila River TMDL project and subsequently on April 8, 2009 to present findings and results after sampling and analysis was complete. Stakeholders and interested parties contacted throughout the project timeline included the Gila Watershed Partnership, Safford District of the BLM, Franklin Irrigation District, Greenlee County, Phelps Dodge (now Freeport-McMoRan), Natural Resource Conservation Service – Safford Office, U.S. Geological Survey, and the University of Arizona Cooperative Extension Office in Solomon. Public comment was invited for a 45 day period after the TMDL was submitted to the Arizona Administrative Review. Copies of the final TMDL will be provided to land management agencies including the A-S NF, the GNF, and the Safford and Las Cruces Districts of the Bureau of Land Management.

As the TMDL addresses water quality issues that have interstate implications, collaboration and interaction was solicited throughout the sampling and writing process of the TMDL with the New Mexico Environment Department.

APPENDIX A. NON-STORM FLOW DETERMINATIONS

Flow Regime Determination for Suspended Sediment Concentration Analyses

The 2003 water quality standard which is the subject of this TMDL explicitly requires some determination of representative stream flow conditions as stated in Arizona's suspended sediment standard (A.R.S R18-11-109 C), recognizing that floods originating from storm flow events routinely produce exceedances of state water quality standards and such values, when unidentified and sampled out of proportion to the frequency exceedance assumptions built into assessment methodology, may not be indicative or representative of normal or typical water quality conditions of the stream. The concept of *base flow* has been invoked in the 2003 state water quality standard for suspended sediment concentration to codify the conditions being targeted for the gathering of representative water quality samples.

Arizona's water quality standard for suspended sediment concentration explicitly restricts samples used to determine impairment to those collected showing a representative snapshot of stream conditions. A.A.C. 18-11-109, states:

The following water quality standard for suspended sediment concentration, expressed as a geometric mean (four sample minimum) shall not be exceeded. The standard applies to a surface water that is at or near base flow and does not apply to a surface water during or soon after a precipitation event: A&Wc, A&Ww 80 mg/l.

Of particular note are the phrases "at or near base flow" and "does not apply…during or soon after a precipitation event." The language implies two conditions necessary for the application of the standard, one having to do with the magnitude of discharge relative to the entire discharge history (or in a determined time window), and the other with the stability of discharge values over some time period. The intent of the language is clearly to exclude storm-flow data from data sets considered for assessment as being non-representative conditions, recognizing that *stable* flow values and flows exclusive of extreme magnitudes are the conditions permitting representative water quality samples to be collected.

For the purposes of TMDL analysis, the terms *flood flows* and *storm flows* are used interchangeably, in recognition of the fact that either the instability of flows over a defined time period (storm flows) or the magnitude of flow when elevated (flood flows) can be sufficient to prevent the collection of representative samples or skew the data set if included and analyzed. Conversely the terms *base flow, stable flow* and *non storm flow* are also considered synonymous in the context of this TMDL analysis.

Hydrograph Separation Methods and Storm Flow Determinations

Base flow is defined as the portion of a stream's flow attributable to groundwater recharge and interflow (flow between the vadose zone and the surface) and excluding direct precipitation and overland flow. One characteristic of base flow is that it tends to be relatively stable within time limits, and thus presents an ideal flow condition to collect water quality samples reflecting typical values. Hydrologists have traditionally used a graphic technique called base flow separation on hydrographs to partition the various components and magnitudes of discharge for any single storm hydrograph. Briefly, the technique consists of drawing a line from the foot of the rising limb of the hydrograph during a storm to a point on the receding arm of the hydrograph where the curve begins to flatten out. The components of flow below the superimposed line are attributable to base flow, while the components of the hydrograph above the drawn line are attributable to precipitation and the effects of precipitation events (Figure 5).

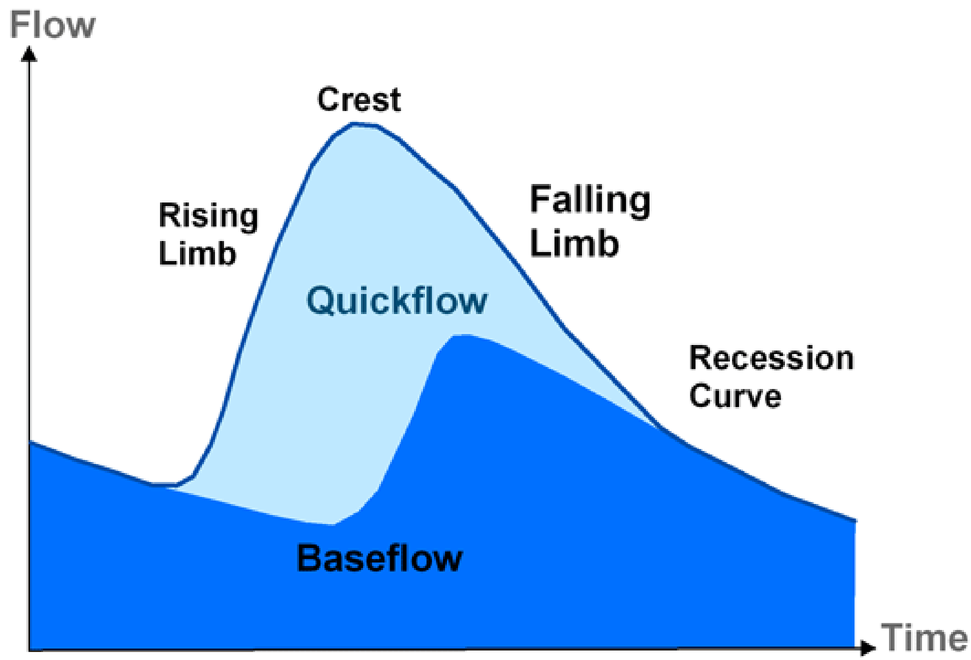

Figure 5. Graphic Base Flow Separation

(Illustration courtesy of Connected Water, 2008)

Some water quality studies use the technique of base flow separation to partition the total flow value into proportions of total flow which can be attributed to base flow and storm flow on any given date. However, ADEQ has noted over years of sample collection that flood flows or hydrograph spikes carry higher concentrations of almost all analytes, particularly suspended sediment, throughout their durations, which decrease in magnitude as the stream recovers a status of relative stasis. To partition a total load proportionally between a base flow fraction and a storm flow fraction gives a misleading impression of concentrations considered normal or typical for the stream, since the stream's power as exhibited by its increased velocity and volume does not increase in a merely multiplicative fashion, but in exponential fashion. Likewise, concentrations of analytes carried by a stream in a hydrograph spike do not increase merely in an additive manner. For the purpose of TMDL data analysis for this project, it is necessary to identify and exclude the periods in the time series of discharges where the hydrograph is actively changing to a degree that indicates the stream is under the influence of a storm event. By doing so and examining data collected outside the storm flow windows, a better and more accurate perspective of the true impairment status of the stream can be gained that is fully compliant with the letter of Arizona's suspended sediment water quality standard. The magnitude and duration of the change in flow, while consequential, are secondary in importance to the identification of days in the flow history where the mean discharge of the stream shows a state of instability relative to preceding days' flows.

A method to achieve this identification of storm-flow influenced days can be achieved mathematically by a comparison of adjacent days' mean flow values. The rate of decline of flow from a hydrograph crest to a condition of relative stability is governed by a natural logarithm exponential decay formula:

$$\mathbf{Q=Q_0e^{-\alpha t}}$$

Where Q is flow in cubic feet per second in the current time step
Q_0 is previous time step's flow in cubic feet per second

α is a base flow recession coefficient
And t is the time interval in hours or days.
Solving for alpha, the variable needed to analyze flow recession data, we have

$$\alpha = -\frac{1}{t}\ln(Q/Qo)$$

Where a continuous flow history is available in daily or hourly increments, any given day's flow can be compared to the previous day's flow and the base flow recession (BFR) coefficient (α) can be determined for the preceding time step. In a daily analysis relative to the previous day, *t* defaults to 1 and thus can be disregarded. Negative calculated coefficients represent an increase in flow relative to the previous day, whereas positive recession coefficients represented decreasing flow. Recession coefficients of 0.00 indicated no flow, no flow data recorded, or constant flow values from one day to the next. By determining a recession coefficient threshold when flow decreases are diminishing on successive days and setting criteria to ensure both the relative stability of recession coefficient values at or below the threshold value and a storm-onset threshold, flow values for any given day can be considered in the context of preceding days' flows and categorized as storm-related flows or non-storm related flows. This method lends itself well to rapid calculation of large amounts of flow data and case-by case consideration of whether any particular flow value is representative of storm flow conditions or non-storm flow.

The method is flexible, adaptable and widely applicable to either daily or hourly time series flow data, based on durations as minimal as one time step or as long a time step duration as the analyst desires to establish. Criteria can be established universally or unique to the analysis of any given site, and adapted in various defensible ways suitable to the analysis at hand. Criteria applied to characterize a flow time series as storm-flow influenced for this TMDL data analysis are the following:

- Unique and reach-specific base flow recession coefficient thresholds determined by analysis of each reach's flow history and drawn from the entire population of calculated BFR coefficients available for analysis.
- Flow event termination threshold calculated as 1.5 times the interquartile range of BFR coefficients for the site added to the 75^{th} percentile value of the BFR coefficient.
- Flow event duration is determined by stabilization of flow as identified by the recession of the BFR coefficient below the BFR coefficient event termination threshold value.
- Flow event commencement marked by a negative BFR coefficient whose magnitude's absolute value exceeds the threshold determined for event termination.

Event windows of one, four, and seven days were chosen to analyze flow data to correspond to the various types of precipitation events and hydrologic responses within the watershed. One day windows were designed to catch local precipitation events with a relatively flashy response consisting of a sudden spike and quick recession of flow. The four day window was designed to catch meso-scale monsoon events covering a sizable extent of the contributing watershed upstream of the flow site where response times would be slower and more prolonged than a local stormburst. Seven day event windows were designed to characterize large winter storms of multiple-day durations covering a majority of the watershed's area. The flagging of any one of the three categories was considered sufficient evidence to screen the data from consideration of attainment of the water quality standard.

Conservative assumptions built into this analysis include the following:

- With central tendency of the data set tending towards zero, extending the threshold value from the 75th percentile value by 1.5*IQR ensures a higher event termination threshold, thus constraining the flow event duration more tightly and allowing for more flows to be classified as non-storm flow influenced.
- Establishment of a minimum flow event commencement threshold ensures that minor increases in discharge values over the time period of interest do not trigger classification as the onset of a storm event.
- Flow magnitude changes are implicit in the calculation of the BFR coefficient.

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The BFR coefficient method applied to sites where continuous flow histories exist provides a tool by which episodic site visits and data associated with those visits may be placed in a context of flows near the same date to determine whether storm flow or non-storm flow conditions exist at the sample collection time. As such, the use of this tool as a screening device allows winnowing of the data set for the consideration of exceedance events, load calculations, and load reductions that are fully accordant with the intent of the water quality standard, and identifies and screens from consideration data that are not in accordance with the intent of the water quality standard.

APPENDIX B. STORM EVENT IDENTIFICATION ANALYSIS

Reach 15040005-022 Storm Event Identification Analysis

To consider flow categorization for Reach 15040005-022, flow data was downloaded from the USGS site for the Gila River at the head of Safford Valley near Solomon (09448500). Recession coefficients were calculated for each day's previous one, four and seven day periods, and the interquartile range of the distribution of recession coefficients was determined. An outlier threshold was chosen to represent the end of hydrologic (precipitation/runoff) events at 1.5 times the interquartile range (IQR) added to the maximum IQR coefficient for determining the event termination threshold. The determination of this outlier threshold follows a standard non-parametric practice deemed to be a rough equivalent to establishing a three-sigma outlier threshold value for normally distributed data.

Dual criteria were employed for determining whether flood flow regimes were prevalent at the time of sample collections. Flow magnitudes were considered in conjunction with BFR coefficients. A flow greater than or equal to the 10% flow exceeds value for a site was designated as a flood flow value strictly on the basis of its BFR coefficient. For flows less than the 10% flow exceeds value and greater than the 75 percent exceeds value, a difference in flow magnitude of 0.25 log cycles within the specified time window for flows constituted a marker for magnitude change. Flows less than 75 percent exceeds values were required to achieve a 0.5 log cycle difference to record the same marker. Transient and insignificant flow variations were thus prevented from designating instable flow conditions.

The conjunction of a BFR coefficient exceeding its time window's threshold for instability and a flow magnitude change meeting the conditions outlined above was considered reasonable and sufficient evidence of stream hydrologic condition instability and a corresponding measure of the discharge change significance. Analyst best professional judgment was also used to review data calculations and compare to actual hydrograph representations. Two events were reclassified from storm flow events to stable flow events based on such reviews.

Table 14 summarizes Reach 15040005-022's base flow recession coefficient population characteristics.

Base Flow Recession Coefficients	1 day Interval	4 day Interval	7 day Interval
25th percentile value:	-0.02	-0.07	-0.02
Median:	0.02	0.125	0.01
75th percentile value:	0.06	0.18	0.04
Magnitude Interquartile range:	0.08	0.25	0.06
Outlier Threshold, event termination [(1.5 * IQR) +75th P-tile.]	0.18	0.56	0.13
Storm Flow Onset Threshold	-0.18	-0.56	-0.13

Table 14. BFR Coefficient Population Characteristics, 09448500

Reach 15040002-004 Storm Event Identification Analysis

To consider flow categorization for Reach 15040002-004, flow data was downloaded from the USGS site for the Gila River at Duncan, Arizona (09439000). As with reach 15040005-022, recession coefficients were calculated for each day's previous one, four and seven day periods, and the interquartile range of the distribution of recession coefficients was determined.

The same dual criteria employed with reach 15040005-022 were used for reach 15040002-004. Flows greater than the 10% flow exceedance value were required to have a BFR coefficient indicating instability. For flows less than this threshold, flow magnitude change generally had to be 0.25 log cycles, except for flows below the 75th percentile, which required 0.5 log cycles. BFR coefficients had to meet or exceed the values listed in Table 15 for the time window of consideration.

The conjunction of a BFR coefficient exceeding its time window's threshold for instability and a flow magnitude change meeting the conditions outlined above was considered reasonable and sufficient evidence of stream hydrologic condition instability and a corresponding measure of the discharge change significance. Analyst best professional judgment was also used to review data calculations and compare to actual hydrograph representations. In one case under review, flags and notes attached to original field sampling worksheets indicating precipitation within the previous 48 hours was used to designate a storm hydrologic response.

Table 15 summarizes Reach 15040002-004's base flow recession coefficient population characteristics.

Base Flow Recession Coefficients	1 day Interval	4 day Interval	7 day Interval
25th percentile value:	-0.03	-0.11	-0.18
Median:	0.03	0.10	0.12
75th percentile value:	0.09	0.30	0.42
Magnitude Interquartile range:	0.12	0.41	0.60
Outlier Threshold, event termination [(1.5 * IQR) +75th P.V.]	0.27	0.92	1.33
Storm Flow Onset Threshold	-0.27	-0.92	-1.33

Table 15. BFR Coefficient Population Characteristics, 09439000

APPENDIX C. LOAD DURATION CURVES

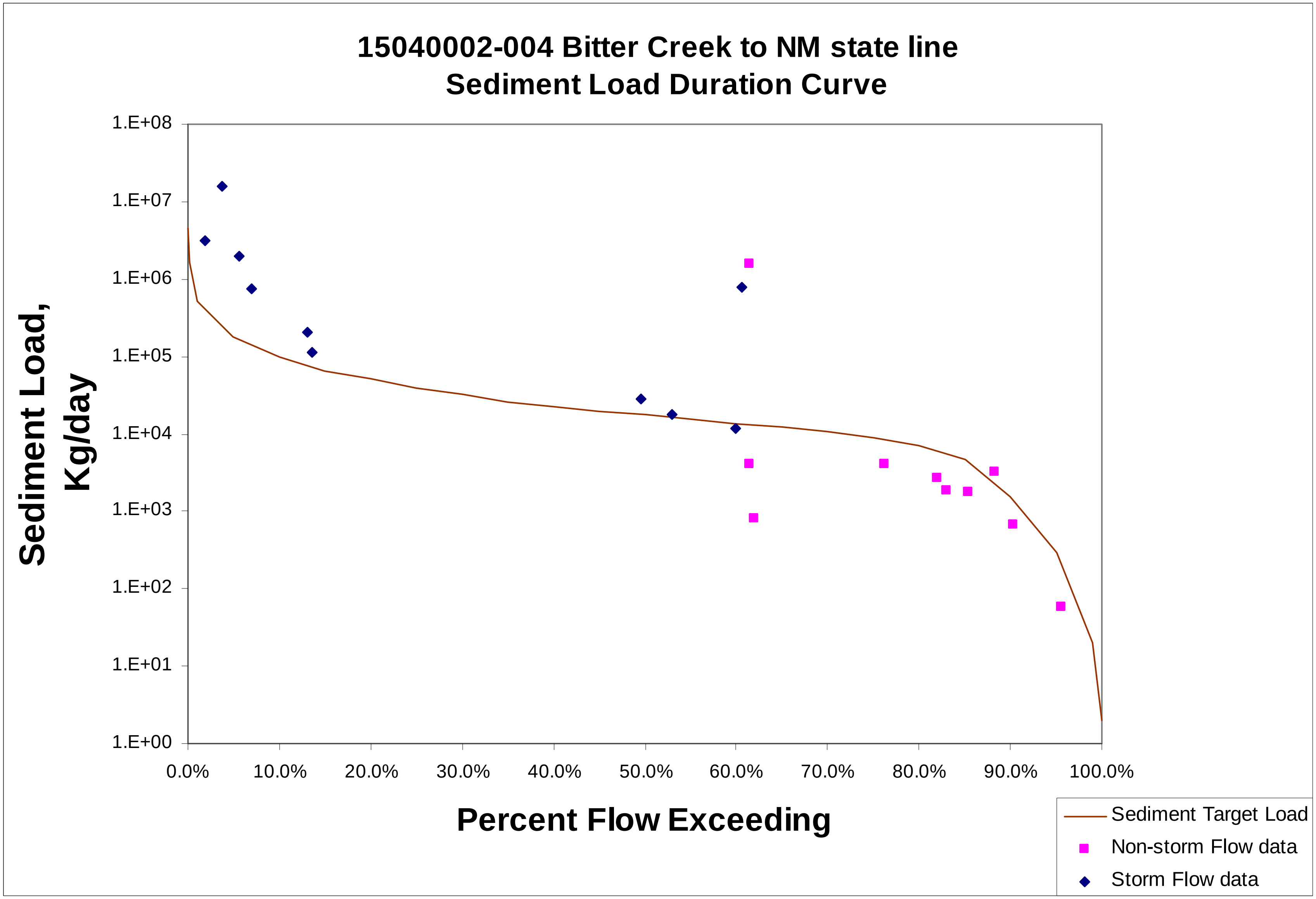

Figure 6. USGS 09439000 Gila River at Duncan, Arizona Sediment Load Duration Curve

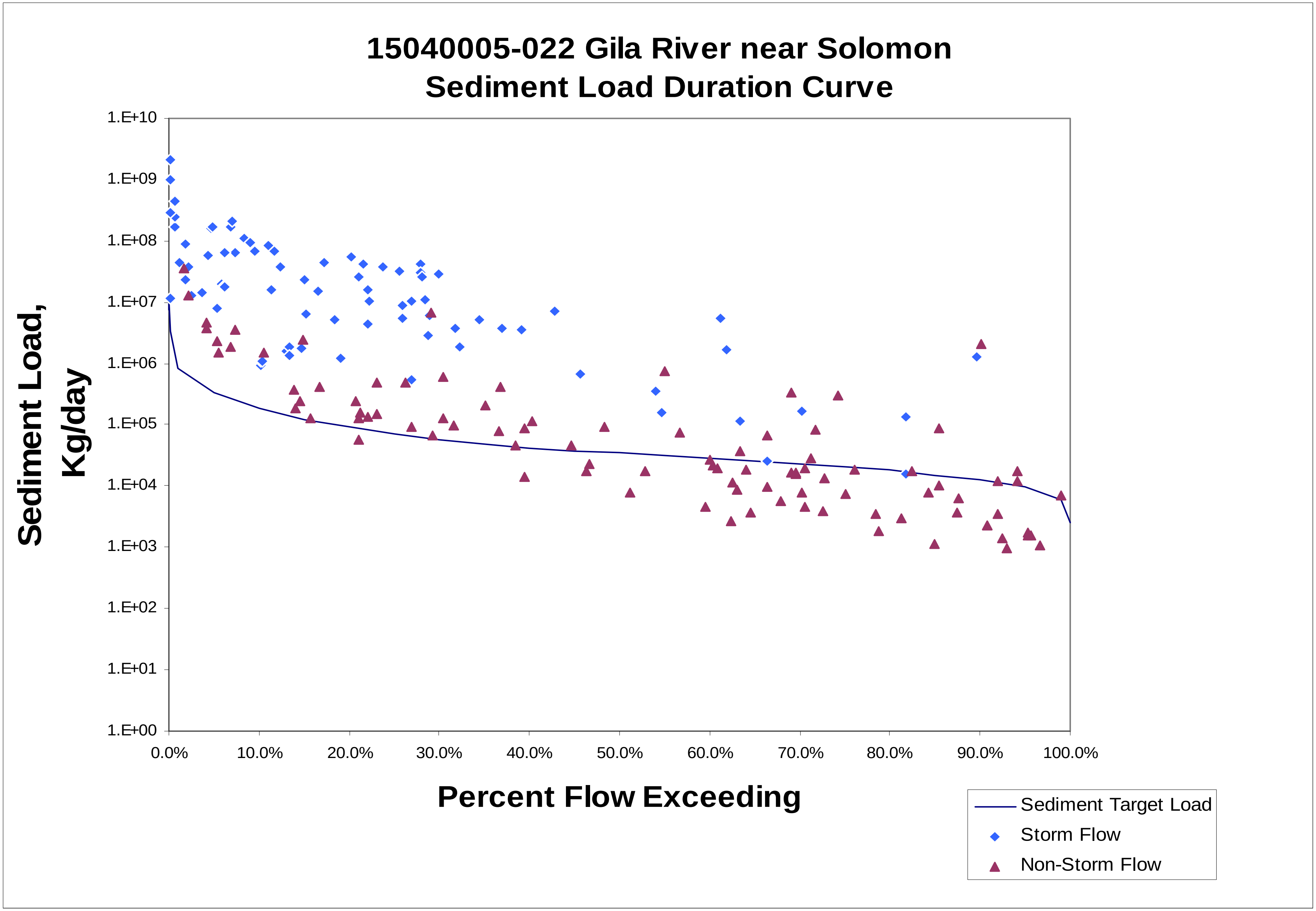

Figure 7. USGS 09448500 Gila River near Solomon, AZ Sediment Load Duration Curve

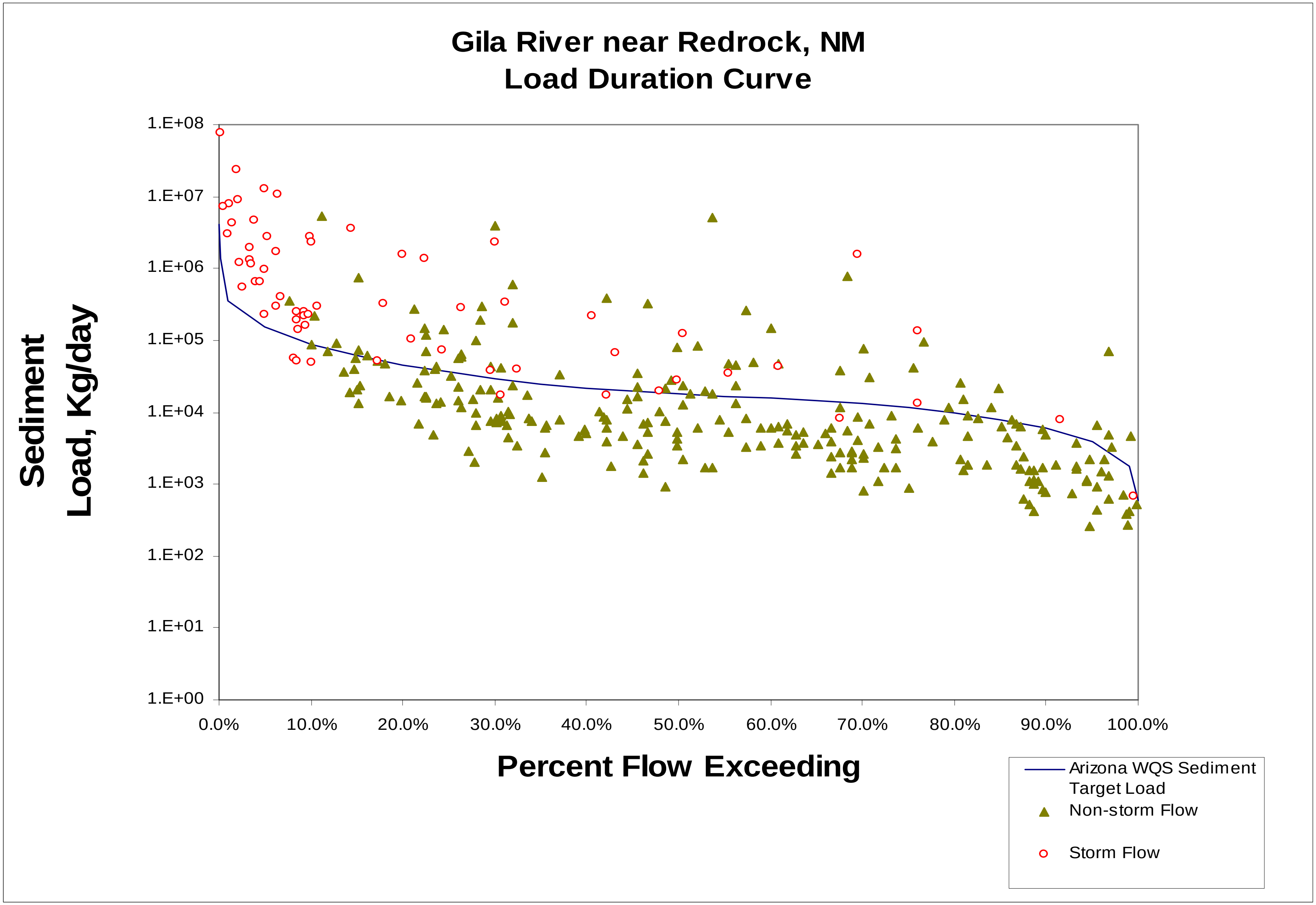

Figure 8. USGS 09431500 Gila River near Redrock, NM Sediment Load Duration Curve

APPENDIX D. SECTION 319 PROJECTS, ARIZONA AND NM GILA RIVER BASIN

State	HUC8	State Project Number	Project Title	Total 319h Funds	Pollutant Type	Load Reduction Estimate (Tons/Yr)	Load Reduction Estimate (Kg/day)	Watershed	Project Start Date	Project End Date	Load Reduction Comments
AZ	15040002	9-004	Gila River Water Quality Improvement - Duncan Valley	$250,520	Sedimentation-Siltation	189000	469,756	Gila Main Stem - Mangas	7/30/2007	6/30/2009	Arrived at through RUSLE calculations and volumetric calculation of the amount of sediment that is removed from the canal and stock piled plus erosion created by canal breaks.
	15040004	'7-007	Kaler Ranch Erosion Control Project	$167,000	Sedimentation-Siltation	20	50	SFR	2/3/2005	9/13/2006	STEPL model
						60	149	SFR	2/3/2005	9/13/2006	
		8-007	Eagle Creek Watershed Restoration Project	$252,199	Sedimentation-Siltation	0	0	Eagle	5/17/2006	4/30/2010	STEPL model
						0	0	Eagle	5/17/2006	4/30/2010	
						0	0	Eagle	5/17/2006	4/30/2010	
						7.4	18	Eagle	5/17/2006	4/30/2010	
						93.9	233	Eagle	5/17/2006	4/30/2010	
						210.6	523	Eagle	5/17/2006	4/30/2010	
						290.4	722	Eagle	5/17/2006	4/30/2010	
						617.2	1,534	Eagle	5/17/2006	4/30/2010	
		8-008	Kaler Ranch Erosion Control Project	$169,800	Sedimentation-Siltation	93.6	233	SFR	5/9/2006	11/12/2008	STEPL model

Table 16. Section 319 NPS Sediment Reduction Projects

State	HUC8	State Project Number	Project Title	Total 319h Funds	Pollutant Type	Load Reduction Estimate (Tons/Yr)	Load Reduction Estimate (Kg/day)	Watershed	Project Start Date	Project End Date	Load Reduction Comments
AZ	15040004	10-003	Eagle Creek Watershed Restoration - Double Circles Ranch Phase III	$92,294	Sedimentation-Siltation	137.5	342	Eagle	8/11/2008	6/30/2010	STEPL model
		10-008	The Gila River Box Conservation Area Livestock Deterrent Fence	$126,900	Sedimentation-Siltation	1606.2	3,992	Gila Main Stem	2/18/2009	2/19/2009	STEPL model
		8-007	Eagle Creek Watershed Restoration Project	$360,930	Sedimentation-Siltation	0	0	Eagle	5/17/2006	4/30/2010	
						0	0	Eagle	5/17/2006	4/30/2010	
						0	0	Eagle	5/17/2006	4/30/2010	
						7.4	18	Eagle	5/17/2006	4/30/2010	
						93.9	233	Eagle	5/17/2006	4/30/2010	
						210.6	523	Eagle	5/17/2006	4/30/2010	
						290.4	722	Eagle	5/17/2006	4/30/2010	
						617.2	1,534	Eagle	5/17/2006	4/30/2010	
		9-003	Eagle Creek Watershed Restoration - Double Circles Ranch	$61,953	Sedimentation-Siltation	14000	34,797	Eagle	7/30/2007	7/16/2009	STEPL model
NM	15040001	07-B	Black Canyon Creek (Continuation)	$9,749	Sedimentation-Siltation	10.3	26	Upper Gila	7/1/2007	11/30/2010	Unknown
						15.4	38	Upper Gila	7/1/2007	11/30/2010	Unknown
		2005-F	Collaborative Restoration Forestry (Silver City)	$252,140	Sedimentation-Siltation	479	1,191	Upper Gila	7/1/2005	12/30/2007	Unknown
	15040002	'01-G	Gila Riparian BMP Project	$88,313	Sedimentation-Siltation	5	12	Gila Main Stem - Mangas	10/30/2002	12/15/2004	Unknown
		'2001-I	Mangas Water Quality Project	$117,000	Sedimentation-Siltation	0.3	1	Gila Main Stem - Mangas	11/15/2001	12/13/2004	Unknown
		2002-C	Mangus Water Quality Project Phase II	$471,228	Sedimentation-Siltation	40000	99,419	Gila Main Stem - Mangas	7/1/2004	12/30/2007	Unknown
	15040004	07-H	Tularosa River Watershed improvement Project	$36,700	Sedimentation-Siltation	4.7	12	SFR	7/1/2007	9/15/2008	Unknown
		11	Centerfire/Black Bob Phase I	$14,290	Sedimentation-Siltation	1.2	3	SFR	10/1/2006	9/15/2008	Unknown

Table 16, Cont. Section 319 NPS Sediment Reduction Projects

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