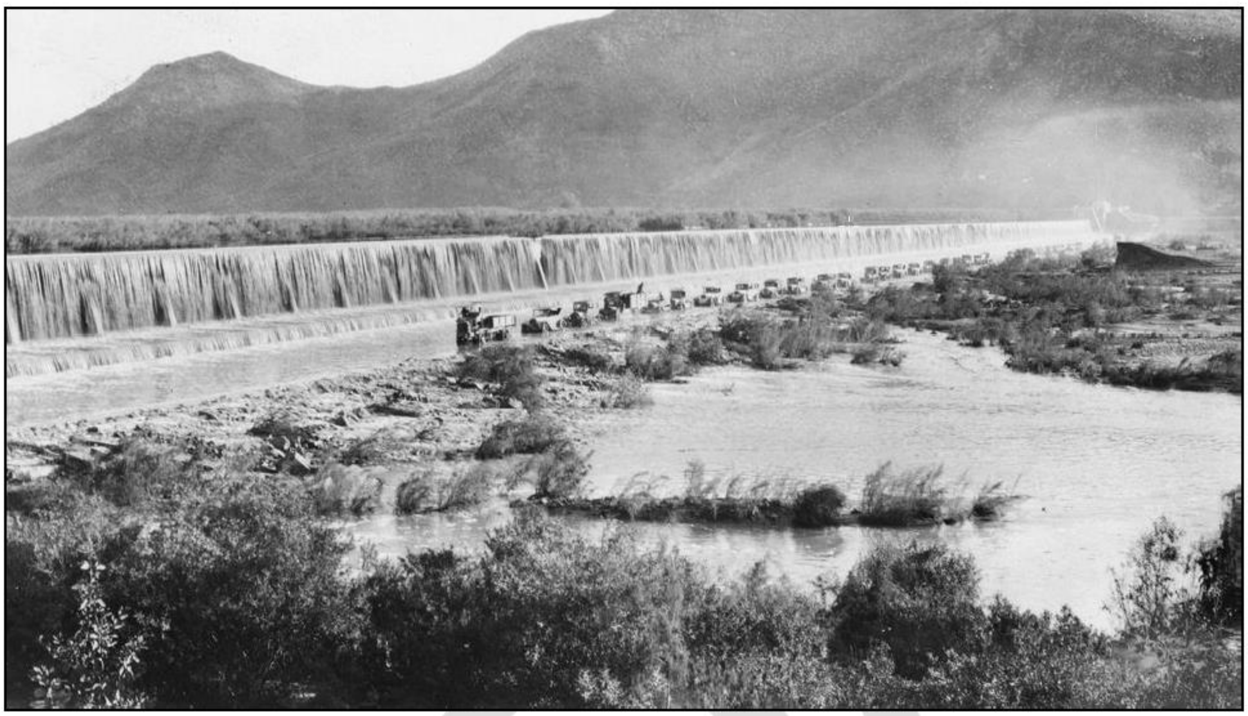
ADEQ
Arizona Department
of Environmental Quality

Gila River -

Centennial Wash to Gillespie Dam

Reach 15070101-008



TMDLs for:
Total Boron &
Total Selenium (Chronic)
November 2015

ADEQ OFR 15-03

Title Page:

Figure 1. 1922 photograph of Gillespie Dam on the Gila River. Automobile trains led across the dam's concrete apron by trucks in high flows. Credit Arizona Department of Transportation.

Contents

List of Tables

List of Figures

List of Abbreviations

4B3	Four-day biological average flow occurring once in three years
7Q10	Seven- day hydrologic design flow occurring once in ten years
AAC	Arizona Administrative Code
ACC	Arlington Canal Company
ADEQ	Arizona Department of Environmental Quality
ADWR	Arizona Department of Water Resources
AgI	Agricultural-irrigation (designated use)
AgL	Agriculture-Livestock watering (designated use)
AMA	Active Management Area
ARS	Arizona Revised Statutes
AZPDES	Arizona Pollution Discharge Elimination System
A&Wedw	Aquatic and Wildlife-effluent dependent water
BLM	Bureau of Land Management
BMP	Best Management Practice
BWCDD	Buckeye Water Conservation and Drainage District
CAP	Central Arizona Project
CASS	Central Arizona Salinity Study
cfs	cubic feet per second
CGP	Construction General Permit
CoP	City of Phoenix
CWA	Clean Water Act
DMR	Discharge Monitoring Report
EDR	Electrodialysis reversal
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization, United Nations
FC	Fish consumption
FO	Forward osmosis
HUC	Hydrologic Unit Code; a USGS watershed division
HW	headwaters
IFDM	Integrated on-Farm Drainage Management
IGFR	Irrigation Grand-fathered Right
Kg	kilograms
K-M	Kaplan-Meier
LA	Load Allocation
MGD	million gallons per day
mi	miles
MOS	Margin of Safety
MS4	Municipal Separate Storm Sewer System
MSGP	Multi-Sector General Permit

NEMO	Nonpoint Source Education for Municipal Officials
NLCD	National Land Cover Dataset
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
PBC	Partial Body Contact
RID	Roosevelt Irrigation District
RO	Reverse osmosis
sq. miles	square miles
SSWMP	Statewide Stormwater Management Plan
SWPPP	Stormwater Pollution Prevention Plan
SWMP	Stormwater Management Program
TDS	Total dissolved solids (also known as salinity)
TMDL	Total Maximum Daily Load
TSD	Technical Support Document (EPA, 1991). See References.
USGS	United States Geologic Survey
WLA	Waste Load Allocation
WPF	Water Protection Fund
WRCC	Western Regional Climate Center
WRF	Water Reclamation Facility
WSRV	West Salt River Valley
WWTP	Waste water treatment plant

1.0 Executive Summary

The Arizona Department of Environmental Quality (ADEQ) 1992 Clean Water Act (CWA) §303[d] Impaired Waters List listed the Gila River from Centennial Wash to the Gillespie Dam (HUC #15070101-008) (Figure **4**) as impaired for the Agricultural Irrigation (AgI) designated use due to total boron exceedances. Twenty-one of 23 samples collected in the 1989-90 period exceeded the AgI designated use criterion of 1,000 μg/L. These values were dissolved boron values, which were used as surrogates for total boron in the assessment. The reach has subsequently remained on the state's § 303(d) list for each assessment period since 1992 for the same impairment.

ADEQ's 2004 CWA §303[d] Impaired Waters List subsequently listed Reach 15070101-008 as impaired for the Aquatic and Wildlife effluent dependent water (A&Wedw) designated use due to chronic selenium exceedances. The reach was listed as impaired due to 18 of 23 samples from 1998 to 2002 exceeding the A&Wedw chronic standard of 2 μg/L. The reach has continued to be listed as impaired for selenium in each water quality assessment since 2004.

A two-year Total Maximum Daily Load (TMDL) investigation was undertaken in the summer of 2012 to identify the sources and causes of the impairments and to quantify the reductions necessary for the reach to attain water quality standards. Both impairment analytes were investigated simultaneously. Data were collected in storm flow and non-storm flow conditions on the Gila and Salt rivers at multiple locations and on tributaries and canals feeding the Gila or Hassayampa rivers. Both impairments were confirmed, and critical conditions and locations were identified. Critical conditions for both boron and selenium exceedances were found to be low-flow and non-storm conditions. Sampling for this TMDL project focused primarily upon "base flow" (i.e., continuous discharged flow) conditions, with storm flow data serving a subsidiary role. Boron and selenium both exhibited concentrations inversely proportional to flow magnitudes throughout the historical record, and both showed a similar pattern in project sampling.

Results of the TMDL study confirm that the reach is consistently impaired for both total boron and total selenium, with flow during dry conditions (60-90 percent flow exceedance range) identified as the most problematic flow regime. Only in flood or high-flow conditions do concentrations of the impairment analytes approach the attainment of standards. The reductions required to attain water quality standards are substantial, ranging from a low of 62.7 percent (boron, moist conditions) up to 93.6 percent (selenium, dry conditions). Low flows exacerbate loading problems. Concentration and load duration curves in Appendix A graphically depict the analytes' levels relative to water quality standards through the entire range of Gila River flows.

Nonpoint source contributors to the water quality problems include the following: discharges of agricultural irrigation tail and drain water, along with degraded excess irrigation supply water; certain industrial and wastewater discharges to the canal systems; and brackish or saline pumped groundwater discharges from the state-designated "waterlogged area." Interflow of infiltrated irrigation water finding its way to the Gila River channel also plays a role in the southwest project area. The principal problem consists of the recycling of irrigation water within and across irrigation districts after irrigation use, which leads to highly degraded water quality. The problems are persistent, as evidenced by repeated exceedances since the late 1980s, and significant, with exceedances routinely surpassing standards by a multiple factor for both boron and selenium.

Selected dischargers in the project area have been granted higher selenium permit limits than the Aquatic and Wildlife-effluent dependent water (A&Wedw) selenium standard based on the rationale that they discharge to the Buckeye Water Conservation and Drainage District canal system with an Agricultural Irrigation (AgI) designated use (Se standard of 20 μg/L) instead of the Gila River or its tributaries. This rationale is not defensible in this TMDL analysis, since canal discharges are likely to negatively impact loading in the impaired reach due to their hydrologic persistence and a higher unlikelihood of infiltration as compared to tributary discharges. Waste load allocations and recommendations for revised permit limits are established in the TMDL that are consistent with the attainment of water quality standards in the impaired reach. The conservative assumptions inherent in the TMDL analysis permitted the accommodation of modified higher-concentration permit limits for selenium in a separate subsidiary analysis, assuming all other TMDL load and waste load targets are met. In addition to the explicit margin of safety, a modest buffer of assimilative capacity remains after WLA assignments.

2.0 Background Information

2.1 Physiographic Setting

The Gila River basin is located in the Basin and Range province of North America. The basin extends from the continental divide in west-central New Mexico and includes all of southern Arizona. It has a drainage area of approximately 49,650 square miles upstream of the United States Geological Survey (USGS) gaging station at the Gillespie Dam (09519000), which is 167 river miles upstream from its confluence with the Colorado River. Major tributaries of the Gila River in Arizona include the Salt and Verde rivers, the San Pedro River, and the Hassayampa and Agua Fria Rivers. The latter two are in the project area. However, much of the Gila River watershed is essentially a non-contributing area to the impaired reach of these TMDLs due to upstream dams and diversions.

The Gila River main stem is regulated by two dams in Arizona – Coolidge Dam (capacity 1,073,600 acre-feet) and Ashurst-Hayden Diversion Dam where all flow is diverted primarily for irrigation purposes. Beyond Florence, the river bed is generally dry except where anthropogenic additions are made. Additional impoundments occur on the Salt River (total capacity 1,755,000 acre-feet), the Verde River (317,700 acre-feet), and the Agua Fria River (816,000 acre-feet) (USGS, 2010). The Gila River transits just south of the Phoenix metropolitan area in Pinal County and joins the Salt River near the cities of Avondale and Goodyear.

The Middle Gila watershed proper encompasses the Gila River drainage area below Coolidge Dam (San Carlos Reservoir) in the east to Painted Rock Dam in the west. It excludes the Santa Cruz River and San Pedro River drainages and the Salt River drainage above Granite Reef Dam. The Salt River drainage area below Granite Reef Dam is included in this watershed because the canals and diversions at the dam have hydrologically disconnected the Salt River system from the rest of the Salt River drainage. This area receives little rainfall. Therefore, surface water flow is primarily attributed to releases from upstream impoundments, effluent from wastewater treatment plants, and agricultural return flows.

The Phoenix metropolitan area, located in the 12,250 square mile watershed designated as the Middle Gila, consists of more than 4,192,887 people (Census Bureau, 2010). Land ownership is approximately: 25 percent private land, four percent state land, 65 percent federal land, and four percent tribal lands within the Middle Gila watershed. Within the metropolitan area, irrigated agriculture uses are rapidly being displaced by urbanization. Outside of the urbanized area, livestock grazing is the primary land use (NEMO, 2012).

Elevations range from 7,400 feet above sea level to 600 feet at Painted Rock Reservoir. Most of the watershed is below 5,000 feet in elevation, with low desert flora and fauna and warm water aquatic communities where perennial waters exist (ADEQ, 2004).

2.2 Climatic Setting

Hot summers and mild winters characterize the general climate of the Middle Gila River Basin. Average high temperatures range from the high 60s in January to the 100s with the highest temperatures starting in late June through early September. Average precipitation in the basin generally averages 8.5 inches per year for the study area (WRCC, 2012). Much of the rainfall in the basin occurs in June to September as a result of high intensity, short duration storms associated with the summer monsoon season. The basin picks up additional precipitation during the winter months from rain and snow storms.

From 1961-1990, the average annual precipitation for the entire Middle Gila Watershed was 12 inches. The Agua Fria River subwatershed receives the most rainfall with 15 inches of rain in an average year, while the Lower Gila River above Painted Rock Dam subwatershed, the most similar and proximate to the study area, typically received only 8 inches of precipitation.

For a 30-year record of temperature data (1961 – 1990), the average annual temperature for the Middle Gila Watershed was 67 degrees Fahrenheit. The Lower Gila River above Painted Rock Dam and the Middle Gila River subwatersheds both have the highest annual average temperature of 70 degrees (NEMO, 2012).

2.3 Hydrology

Gillespie Dam, the terminus of the impaired reach, has an interesting history, as might be surmised from Figure 2. Built in 1921 by a local farmer as an irrigation dam on the Gila River southwest of Buckeye, Arizona, the dam was improved incrementally over the years and recognized early on as one of the few viable places to cross the Gila River between the San Carlos Reservoir and Yuma(see title page photograph). The dam location became an official crossing as a part of U.S. Highway 80 when incorporated into the federal highway system in 1927. A steel truss bridge was constructed across the riverbed downstream of the dam that year by the state Highway Department and maintained as a part of the federal highway system until 1956. Since that time, the bridge has been decommissioned and is now a part of the Maricopa County road system. In 1981, the bridge was added to the National Register of Historic Places. The dam itself evolved from its earliest incarnations into a multiple-arch concrete gravity structure over 1,700 feet long and 56 feet in height. It served its purpose as an impoundment structure for several decades.

In January of 1993, historic rainfall and flooding hit central Arizona. On the morning of Jan. 9, 1993, a 150-foot section in the center of Gillespie Dam collapsed under the force of flooding upstream on the Gila and Salt rivers (Figure 2). The flood was estimated by USGS to have peaked at more than 200,000 cubic feet per second (cfs) at the time of the breach. The floods caused extreme damage to agricultural fields downstream, exposed and ruptured two buried natural-gas pipelines, and created the largest reservoir in Arizona at 2.5 million acre-feet behind Painted Rock Dam 40 miles further downstream. Gillespie Dam was never repaired. Today, flows in the Gila River at this location are almost entirely diverted into canals supplying downstream agricultural interests, and only a low earthen berm serves to impound Gila River water for canal diversions and distribution.

The origin of the impaired reach is designated as Centennial Wash. However, while before settlement and cultivation, Centennial Wash may have joined the Gila River channel proper, it is now physically separated by about 1.5 miles of agricultural fields and the transiting of the Arlington Canal on the area's western edge. Centennial Wash flows only in response to severe storms. Storm flows transiting Centennial Wash are generally blocked from joining the Gila River with excess diverted to the south by the structure of the Arlington Canal. In major events, however, storm flow can overtop the canal and close down old Highway 80 by overland flow across the highway and fields as it seeks to re-establish its former water course. This hydrologic phenomenon was observed in the course of project sampling in 2013 (Figure 3). Today there is no actual confluence with Centennial Wash on the Gila River, and estimations of the reach's length and on-the-ground origin are approximate. The study area reach is estimated at 5.7 miles in length.

The Middle Gila watershed, bounded on its lower end by Gillespie Dam, contains a total of 1,786 miles of major streams and canals. The Gila River is the longest river in the watershed at 263 miles within the boundaries of the Middle Gila Hydrologic Unit Codes (HUCs). Most streams in the Middle Gila watershed are intermittent or ephemeral, including major portions of the Gila River itself in this region when

Figure 2. Gila River at Gillespie Dam. Impaired reach above, and 1993 dam breach. Bridge is visible in lower right corner.

considered beyond the influence of anthropogenic inputs. Some channels are dry for years at a time, but are subject to flash flooding during high intensity storms (NEMO, 2012).

Major tributaries to the Gila River in the study area include the Salt River, the Agua Fria River, and the Hassayampa River, all of which are intermittent in flow (Figure **4**). Flow in the Gila River main channel is largely attributable to discharges from the City of Phoenix 91st Avenue Wastewater Treatment Plant (WWTP), which is designed to discharge up to 230 million gallons per day (equivalent to 355 cfs), into the Salt River channel. However, some of this discharge is piped to the Palo Verde Nuclear Generating Plant about 50 miles west of Phoenix for use in cooling operations. The remainder enters the Salt River channel through a series of constructed wetlands, which joins the intermittent Gila River downstream. Avondale and Goodyear WWTPs also add discharges to the Gila River on a periodic basis. Flow for the Gila River in this area is properly characterized as anthropogenic and effluent for those times of the year where storm flows are not adding hydrologic inputs.

Figure 3. Winter storm overland flow from Centennial Wash, January 2013. Flow overtopped the Arlington Canal and passed over Highway 80, forcing highway closure and inundating agricultural fields to the east. This photo taken from Highway 80 looking east.

A series of irrigation canals affiliated with three separate irrigation districts divert water from or return tail water to the Gila River or its tributaries from its confluence with the Salt River to Gillespie Dam. The irrigation districts are the Roosevelt Irrigation District (RID), the Buckeye Water Conservation and Drainage District (BWCDD), and the Arlington Canal Company (ACC) (Figure **4**). The canals of these districts are used to support extensive agricultural acreage in the southwest Phoenix metro area, around the town of Buckeye and near the communities of Arlington and Palo Verde, Arizona (Figure 6). Major canals in the area include the Roosevelt, Buckeye, South Extension, Buckeye Feeder, St. John's and Arlington canals. The Roosevelt and Buckeye canals terminate at the Hassayampa River, which receives their drain water. Roosevelt Canal flows infiltrate in the Hassayampa River channel, before reaching the Hassayampa River intermittent flows contributed by the Buckeye Canal. The Arlington Canal terminates immediately upstream of Gillespie Dam and adds its tail water directly to the Gila River. Downstream of Gillespie Dam, the Gila Bend and Enterprise canals divert most of the flow of the Gila River at Gillespie Dam to agricultural acreage around Gila Bend and in the Paloma Ranch vicinity near Painted Rock Reservoir.

The USGS currently maintains four active real-time gauging stations within the study area. Three of these sites are clustered at Gillespie Dam, where two diversions and diversion overflow into the Gila

River channel below the dam all occur. USGS 09519501 Gila River below Gillespie Dam (Low-Flow Station) takes measurements from the Gila River main stem channel on the Gillespie Bridge below the breached dam and below two diversions for agricultural irrigation canals traveling south towards Gila Bend, Arizona. The period of record extends from October 1992 to the present, and real time discharge data is provided. Field discharge measurements are represented at this site from 1983 to the present.

USGS 09519000 Enterprise Canal at Gillespie Dam gauges one of the two main diversions below the breached Gillespie Dam on the west side of the Gila River. Flows are diverted for agriculture north and west of Gila Bend. As with the Gila River low flow gauging station, instantaneous and daily discharge records are available from this site with the period of record extending from March 1974 to the present. No public-domain water quality data is associated with this site.

USGS 09518500 Gila Bend Canal at Gillespie Dam gauges a second diversion canal on the east side of the Gila River for flows directed to agricultural activities in the Paloma Ranch/Gila Bend vicinity. The period of record for this canal extends from October 1975 to the present. Both instantaneous and daily discharge data are available. Field discharge measurements date from September 1983 through the present. As with the other two sites, no public-domain USGS water quality data is available from this location.

USGS 09514100 Gila River at Estrella Parkway, near Goodyear is located approximately 30 miles upstream southwest of Goodyear, Arizona. Records include instantaneous and daily discharge records, field discharge measurements, peak stream flow data and limited water quality samples. The period of record extends from October 1992 to the present. Annual USGS water data reports are available for this site. Immediately downstream of the Buckeye Canal headworks, the site is dry except in time of exceptional storm flow.

An aggregated USGS site, Site 09518000 Gila River above Diversions, at Gillespie Dam is created by combining the daily discharge values of the three previously-mentioned Gillespie Dam sites. Data for this site dates in various forms to 1939, as the site name and locations have shifted somewhat over the years with the construction and subsequent failure of Gillespie Dam in 1993. Data available include instantaneous and daily mean values (calculated), peak flows, and water quality data collected since 1954. Boron and selenium data used to support this project date from 1974. No public-domain USGS water quality data is associated with USGS sites 09518500, 09519000, or 09519501. Water quality data for site 09514100 is limited to the period 1996-1998.

Because of the generally ephemeral/effluent-dependent character of the Gila River and the low-flow aggravations of water quality when boron and selenium concentration levels are considered, the defined project area is geographically constrained. The general areal focus for most flow categories to be evaluated can be considered to be the Gila River channel proper (generally within HUC 1507010102) and irrigation district boundaries for the Buckeye Water Conservation and Drainage District and the Arlington Canal Company, both of which are immediately adjacent or near the Gila River channel on the north and west sides respectively in the study area (Figure **4**). Southwestern suburbs of the Phoenix metropolitan area are also included. The extended project area boundary for inventory purposes includes the focused project area, the lower two 10-digit HUCs of Centennial Wash (1507010406 – Winters Wash, 1507010407 - Lower Harquahala Plains), the 10-digit HUC of Waterman Wash (1507010101), and the lower 10-digit HUC of the Hassayampa River (1507010305). In addition to these HUCs, outer boundaries include the Roosevelt Irrigation District northern boundary and Interstate 10 extending east to 83rd Avenue in west Phoenix. From this intersection, 83rd Avenue extending south to an intersection of a projected line from the eastern boundary of the Gila River Indian Reservation marks the eastern limit of the study area just north of the Salt River. The northern boundary of the Gila River Indian Community in the middle of the Salt River channel marks the southern extent of the study area, thus enclosing the contributions of the City of Phoenix's 91st Avenue WWTP. The Agua Fria River is considered a portion of the study area only where it is south of I-10; Lake Pleasant reservoir and the Waddell Dam ensure that flow almost never transits the entire length of the Agua Fria channel. However, an alternative discharge site for the City of Avondale's WWTP is enclosed in the lower part of the Agua Fria channel by the boundary. See Figure 5 for the full extent of the study area.

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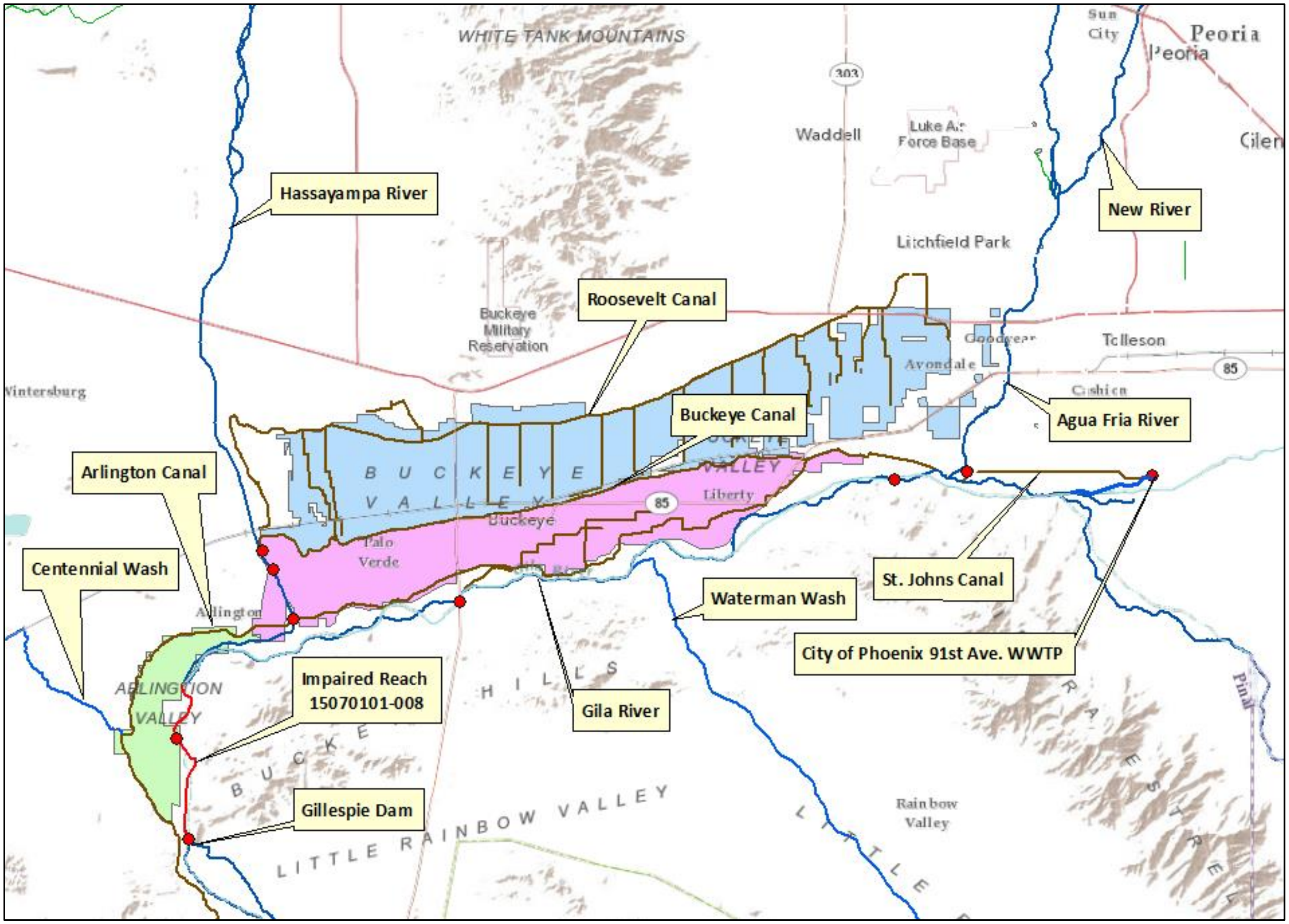

Figure 4. Large-scale view of canal systems and tributaries comprising focus of the TMDL study area. Irrigation Districts shaded. Impaired reach at lower left in red.

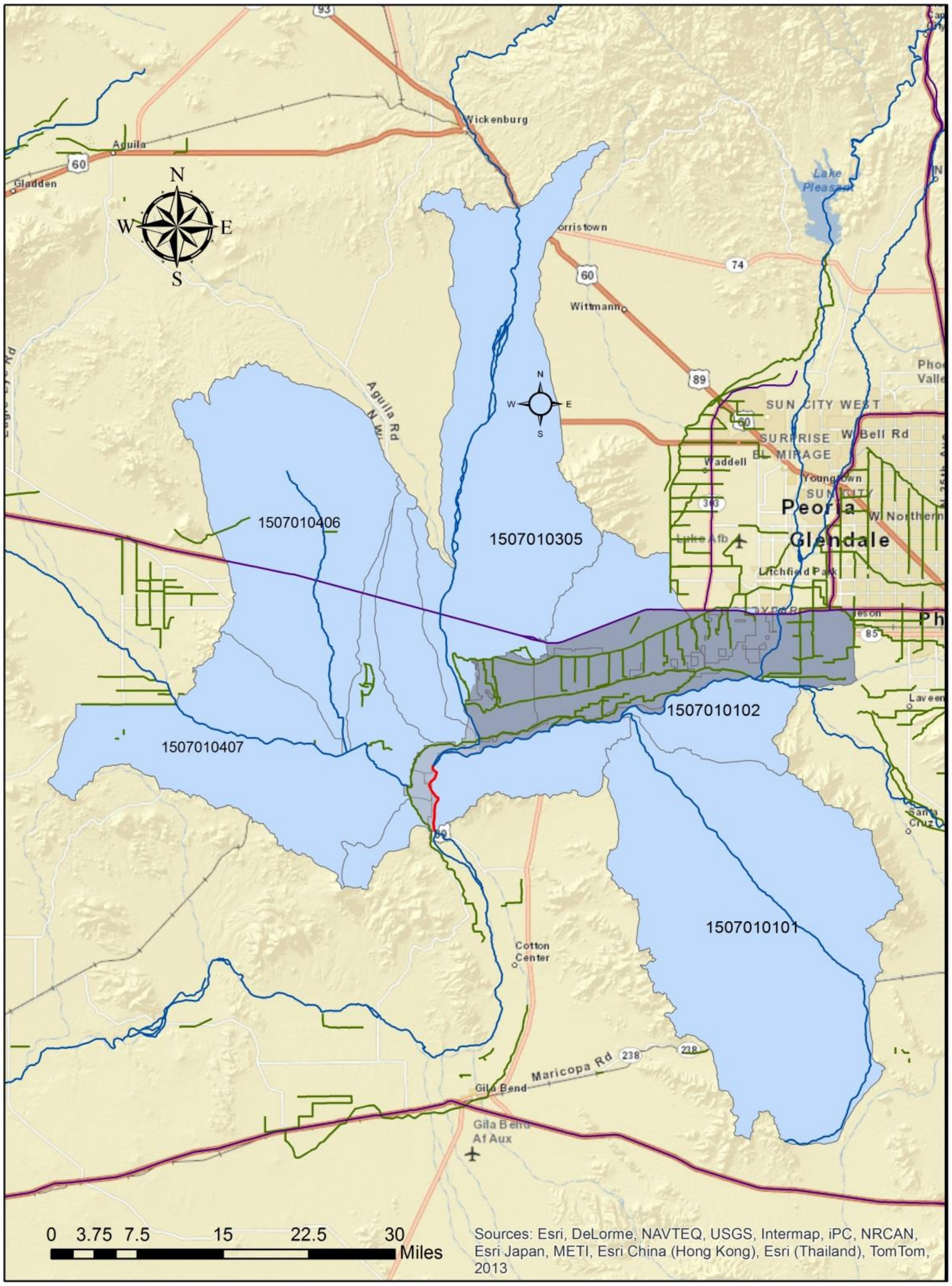

Figure 5. Middle Gila extended drainage area. Area canals shown in green; impaired reach in red.

2.4 Geology

The study area is characterized by wide and flat desert plains marked with alluvial deposits, extensive agricultural acreage surrounding the Gila River and evolved in part from riverine deposits on the floodplains, and isolated mountain ranges typical of the Basin and Range Province of western North America.

Arizona Non-point Source Education for Municipal Officials (NEMO) reports on the geology of the area:

> The Middle Gila Watershed straddles the margin of the Basin and Range and the Transition Zone, two of the three geologic provinces found in the state of Arizona. The geology of the watershed is complex, varying widely in age, lithology, and structure. The Agua Fria National Monument is located in the transition zone of central Arizona, between the Colorado Plateau Province to the Northeast and the Basin and Range Province to the Southwest. It is situated between the New River Mountains (Moore Gulch shear zone) to the East and the Bradshaw Mountains (Shylock shear zone) to the West. Just north of the monument is the Estler basalt volcanic center (Estler peak area) and south is the Black Canyon Dispositional Basin (Chalk Canyon & Hickey Formations).
>
> The Precambrian rocks in this area consist primarily of granite that weathers to rounded boulders and knobs, and flaky, silvery schist. Flat lying layers of whitish limestone, siltstone, and water-laid volcanic ash are found in Tertiary-age lake sediments, and Quaternary and Tertiary lava flows cap the higher mesas. The dark metamorphic rocks that form a skin around the Bradshaw Mountains are about 1.7 million years old, are also present in Black Canyon to the east. The Bradshaws have at their core a Precambrian mass of granite that intruded the metamorphic rocks (Chronic 1983). The northwestern section of the Middle Gila Watershed contains several mountain ranges comprised of Precambrian and late Cretaceous granite; these mountain ranges, which include the Vulture Mountains and the White Tank Mountains, are heavily faulted and bear remnants of a vast lava plateau that once dominated the area. Located in the heart of the watershed, the floor of the Phoenix Basin is nearly level. It contains deposits of salt and anhydrite that suggest the existence, at some time, of a large saline lake similar to the Salton Sea. To the east of Phoenix, the Superstition Mountain Range is composed almost entirely of mid-Tertiary volcanic rocks. The Superstition volcanic field contains five partially overlapping calderas, the result of the collapse of emptied magma chambers following a series of violent explosions that shaped the geology of the area. The most common rock type is alluvium which comprises 50% of the watershed (NEMO, 2012).

2.5 Land Use

The land uses for the affected reach and the defined project area generally encompass urban areas (development), open desert range (scrub), and agricultural areas. As depicted by Figure 6, agricultural acreage is extensive in the West Valley along the Gila River watercourse on the north side of the river with the acreage irrigated by a series of canals paralleling the Gila River for approximately 20 miles from the Avondale and Goodyear areas west to the Hassayampa River. Agriculture has been practiced in this area since the late 1800s. Table 1 breaks down the project area according to the classifications of the National Land Cover Dataset of 2006.

NLCD 2006 Classification	Area, sq. km	Area, sq. mi	Percentage Coverage
Scrub/Shrub	9,392.51	3,627.85	77.02%
Cultivated Crops	906.76	350.23	7.44%
Grasslands/Herbaceous	762.65	294.57	6.25%
Developed, open space	347.99	134.41	2.85%
Developed, low intensity	278.77	107.67	2.29%
Developed, medium intensity	175.14	67.65	1.44%
Woody wetlands	145.72	56.28	1.19%
Pasture/Hay	65.87	25.44	0.54%
Open water	46.84	18.09	0.38%
Emergent Herbaceous Wetlands	36.81	14.22	0.30%
Developed, high intensity	26.94	10.41	0.22%
Bare Rock/Sand/Clay	8.60	3.32	0.07%
Evergreen Forest	0.04	0.02	<0.01%
Deciduous Forest	0.03	0.01	<0.01%
Totals:	**12,194.65**	**4,710.18**	**100.00%**

Table 1. Extended project area breakdown by land use classification

Though scrub/shrub lands account for more than three-fourths of the extended project area, the contributing area for the great majority of the time is much smaller, consisting of the areas of the irrigation districts proper and the southwestern regions of the Phoenix metropolitan area. These areas generally adjoin the Gila River channel or are within five miles of it. This area breakdown is shown in Table 2. In addition to agricultural acreage and development, and a much smaller percentage of open range country, woody wetlands in the river bottom comprise a notable percentage of areal coverage. Much of this category consists of tamarisk/salt cedar invasives.

NLCD 2006 Classification	Area, sq. km	Area, sq. mi	Percentage Coverage
Cultivated crops	262.22	101.28	57.28%
Scrub/shrub	76.25	29.45	16.65%
Development, light intensity	37.48	14.48	8.19%
Development, open space	34.38	13.28	7.51%
Woody wetlands	27.37	10.57	5.98%
Development, medium intensity	12.03	4.65	2.63%
Development, high intensity	3.84	1.48	0.84%
Pasture/Hay	2.19	0.85	0.48%
Open water	1.41	0.54	0.31%
Emergent herbaceous wetlands	0.49	0.19	0.11%
Grasslands/Herbaceous	0.14	0.05	0.03%
Bare rock/sand/clay	0.04	0.01	0.01%
Totals:	**457.82**	**176.83**	**100.00%**

Table 2. Contributing area land use breakdown, dry conditions

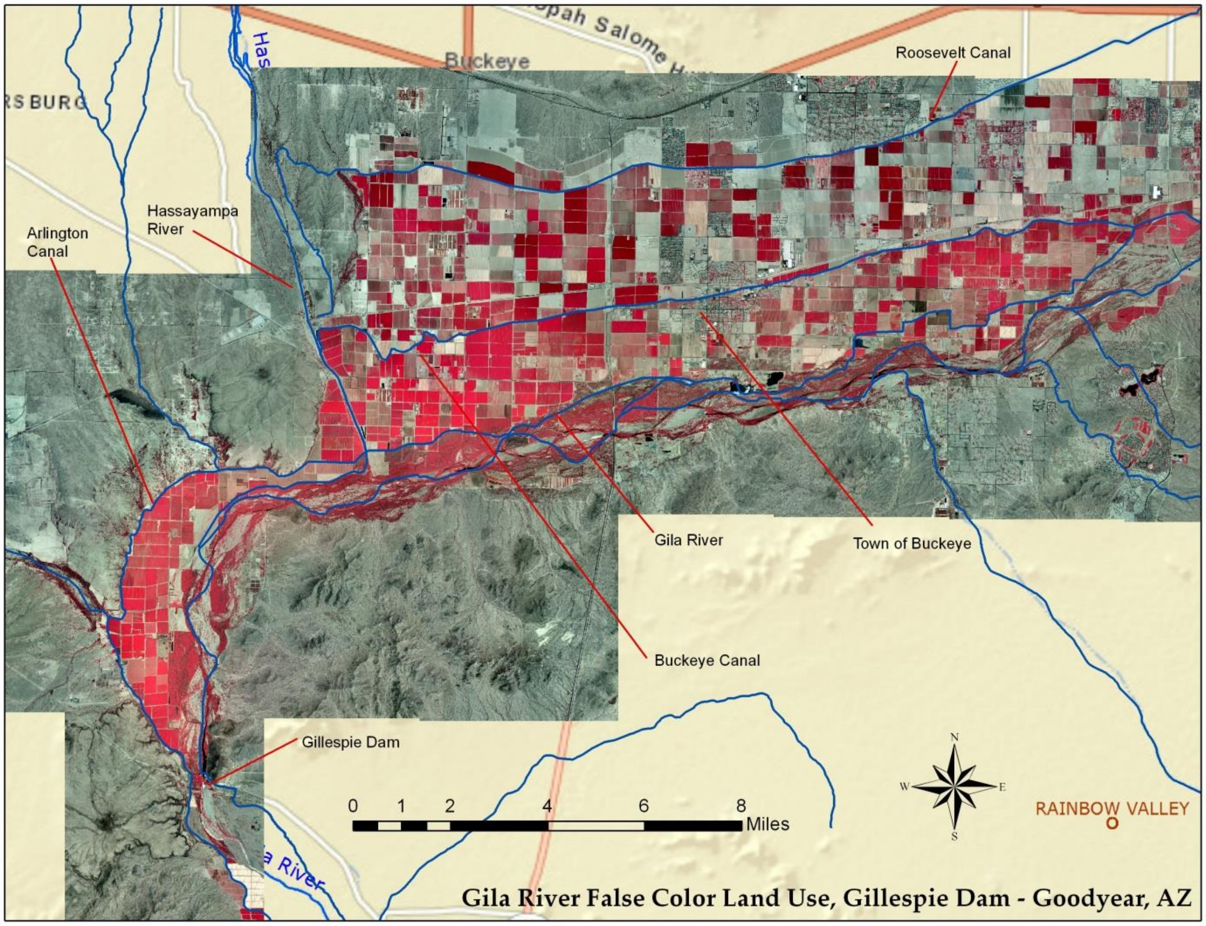

Figure 6. Middle Gila River Agricultural Land Uses, TMDL Study Area. Infrared reflectance view.

3.0 Numeric Targets

This project addresses Reach #15070101-008 (Gila River - Centennial Wash to Gillespie Dam) for boron and selenium impairments of the reach's designated uses. The listed reach has been designated as impaired for the AgI use (boron) and the A&Wedw chronic use (selenium).

3.1 Beneficial Use Designations

Designated beneficial uses, such as fish consumption, recreation, agriculture, and aquatic biota, are described in Arizona Administrative Code (A.A.C.) R18-11-104 and are listed for specific surface waters in Appendix B of A.A.C. R18-11. The Gila River in Reach 15070101-008 is currently protected for the following designated uses: Aquatic and Wildlife-effluent-dependent water (A&Wedw); Fish Consumption; Partial Body Contact; Agriculture Irrigation (AgI); and Agriculture Livestock.

3.2 Applicable Water Quality Standards

Water quality standards for a stream reach are based upon the designated uses assigned to it according to the AAC Title 18, Chapter 11 (18 AAC 11). The applicable water quality standards considered by this TMDL are numeric standards for both boron and selenium. Both may be found in Appendix A. of Arizona's water quality standards. The total boron standard for the AgI designated use is 1,000 μg/L. The chronic standard for the impaired A&Wedw use of selenium is 2.0 μg/L. Each standard addressed in this study represents the most stringent standard for the designated use.

3.3 Clean Water Act §303(d) List

The ADEQ 1992 CWA §303[d] Impaired Waters List listed the Gila River from Centennial Wash to the Gillespie Dam (HUC #15070101-008) as impaired for the AgI designated use due to total boron exceedances. ADEQ water quality data showed 21 of 23 samples collected in the 1989-90 period exceeding the AgI designated use criteria of 1,000 μg/L (Table 3). These values were dissolved boron values, which were used as surrogates for total boron. Reach 15070101-008 remains on the impaired waters list for total boron impairment as of the 2012/2014 assessment.

ADEQ's 2004 CWA §303[d] Impaired Waters List listed Reach 15070101-008 as impaired for the A&Wedw designated use due to chronic selenium exceedances. The reach was listed as impaired due to 18 of 23 samples from 1998 to 2002 exceeding the A&Wedw chronic standard of 2 μg/L (Table 4).The reach has continued to be listed as impaired for selenium since 2004.

3.4 Load Determinations

Load allocations expressed in these TMDLs are presented both as concentration-based values drafted directly from Arizona's water quality standards and as mass-based load calculations expressed in terms of mass units per day. Further discussion on the use of and distinction between the two presentations is found in Section 7.1. Both concentration-based and mass-based targets were developed based on the standards for the designated uses determined as impaired for each constituent of concern. Selenium targets were based upon the chronic water quality standard for the A&Wedw designated use expressed in Arizona's water quality standards. Boron targets were based upon the standard for the AgI designated use. Concentrations of each are expressed in terms of micrograms per liter (μg/L) throughout this document. Loads used in the load duration curve analyses are the product of concentrations and flows with an appropriate conversion factor applied. Aggregate loads are expressed in terms of kilograms per day (kg/day). The conversion factor used to convert from μg/L to kg/day is 0.002446.

Aggregate load target determinations and existing load calculations in the TMDL document are originally derived from the appropriate concentration values for each impairment analyte, as expressed in the Arizona water quality standards and in data reporting. Consequently, attainment of the TMDLs presented will result in waters that meet water quality standards. 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.

Site Name		Date	Boron, µg/L
GILA RIVER - ABOVE DIVERSION AT GILLESPIE DAM	**09518000**	11-DEC-1990	1300
		16-NOV-1990	1500
		16-OCT-1990	1500
		18-SEP-1990	1000
		16-AUG-1990	400
		31-JUL-1990	1500
		12-JUN-1990	2000
		15-MAY-1990	1600
		17-APR-1990	1800
		20-MAR-1990	1700
		14-FEB-1990	1400
		17-JAN-1990	1400
		18-DEC-1989	1400
		22-NOV-1989	1500
		11-OCT-1989	1500
		15-AUG-1989	2000
		18-JUL-1989	1800
		28-JUN-1989	2000
		25-MAY-1989	1800
		19-APR-1989	1700
		27-MAR-1989	1300
		16-FEB-1989	1600
		18-JAN-1989	1200

Table 3. CWA 1992 Assessment listing data, boron

Site Name		Date	Selenium, µg/L
GILA RIVER - ABOVE DIVERSION AT GILLESPIE DAM	**09518000**	17-Oct-2002	7
		27-AUG-2002	11
		25-APR-2002	13
		22-MAR-2002	9
		04-OCT-2001	2
		26-JUL-2001	5
		20-JUN-2001	6
		11-APR-2001	9
		29-NOV-2000	6
		18-AUG-2000	4
		27-JUN-2000	3
		28-MAR-2000	4
		23-NOV-1999	5
		09-SEP-1999	11
		24-MAY-1999	4
		30-MAR-1999	ND : 1
		26-FEB-1999	ND : 1
		14-DEC-1998	2
		01-OCT-1998	6
		22-JUL-1998	5
		16-JUN-1998	6.3
		06-APR-1998	ND : 4
		27-JAN-1998	15.5

Table 4. CWA 2004 Assessment listing data, selenium

Load allocation presentations other than aggregate load allocations are expressed directly in terms of concentrations as outlined in the water quality standards.

Reporting limits for data used in the analysis varied with the source. Historical USGS data employed a reporting limit of 1 μg/L for selenium analyses. ADEQ project data used a reporting limit of 2 μg/L, with limits below 2 μg/L coming into use for background sampling late in the project timeline. ADEQ used a reporting limit of 200 μg/L for boron analyses in the project data collection. Reporting limits were not ascertainable for historical USGS boron reporting. Concentrations were routinely well above the reporting limits for both boron and selenium in the project dataset. Boron reporting had only one non-detect value in historical USGS data, and an additional one in ADEQ project data in a total data set of over 240 values. Selenium non-detects comprised less than 10 percent of the historical USGS dataset, and less than 20 percent of ADEQ project data in a total dataset of 260 values.

Critical conditions for boron and selenium exceedances are low flow and non-storm conditions. Consequently, sampling for this TMDL project focused primarily upon “base flow” (i.e., continuous and regulated flow) conditions, with storm flow data serving a subsidiary role.

4.0 Sources

4.1 Point Sources

4.1.1 NPDES/AZPDES Permitted Sources

The City of Phoenix 91st Avenue Wastewater Treatment Plant (WWTP) is operated under NPDES Permit AZ0020524 and discharges into the channel of the Salt River upstream of the Salt River’s confluence with the Gila River. Permit requirements require monitoring and reporting of discharge rates on a weekly basis. The 91st Avenue WWTP is by far the largest permitted discharger to the Salt/Gila River system in the project area. Points of discharge have been modified in recent years with the creation of the Tres Rios Wetland Project adjacent to the Salt River channel. The primary goals of the Tres Rios Wetland Project consist of flood protection for local residents and habitat restoration for native fauna, with subsidiary goals of water quality improvement, recreational opportunities, and the education of citizens of the importance of wetlands (City of Phoenix, 2014).

The City of Phoenix (CoP) 91st Avenue WWTP is required to report concentrations of selected water quality parameters on monthly, quarterly, and annual bases for various constituents. Boron and selenium concentrations are among the regulated constituents.

Numerous other AZPDES individual permittees have been identified in the extended project area. They are summarized in Table 5. Some of these facilities have not yet been constructed; these are noted in the “Status” column. Permittees are assessed as having a probable likelihood to affect loading of the Gila River system for boron and selenium if their physical plant locations are within Zone 1 of the project area as discussed in Section 7.2 or in close proximity to the Gila River channel. Likelihood is considered probable if discharges persist as surface water flow in either canals or the river network, thus exhibiting hydrologic continuity with and the potential to add selenium and boron loading to the impaired reach. Further discussion of permittees requiring a waste load allocation (WLA) follows in Section 7.3.

Discharge Monitoring Reports (DMRs) for the facilities identified as needing WLAs were reviewed in the research for this study. Various time periods were examined for the permittees of the area, depending on data readily available. Generally, data for a three- to five- year period was examined, with time periods of 2008-2012 and 2009-2013 most common. Summaries of DMR data for facilities reviewed are presented in Appendix E.

For boron reporting, none of the facilities exhibited a mean value exceeding the Arizona AgI water quality standard, though it is noted that the City of Goodyear Corgett Wash facility's mean value of boron approached the water quality standard at 970 μg/L. The Corgett Wash facility reported a high value of 1,200 μg/L for the eight results reviewed, with one additional result reported exactly at the standard; the high value still met permit limits, where a maximum daily value of 1,500 μg/L was allowable. Buckeye Sundance Water Reclamation Facility (WRF) reported one of 40 samples exceeding the boron water quality standard at 1,010 μg/L. This sample, too, was accommodated by the higher maximum daily permit limit of 1,460 μg/L. No data was available for review from Central Buckeye, as boron was not required to be monitored by the permit. The proposed Palo Verde WWTP also had no boron data for review. With rare exceptions, discharges from regulated permittees are not adding to boron loading for the impaired reach.

Selenium reporting for these same facilities illustrated a more significant problem, with several facilities reporting values in excess of either their permit limits or the chronic A&Wedw water quality standard for the Gila River serving as the eventual receiving water for permittee discharges. Three of these facilities or operations have higher selenium permit limits than the A&Wedw water quality standard of the impaired reach; this matter is comprehensively discussed in Section 7.3. Here discussion is confined solely to reporting of monitored results from regulated facilities. JRC Goodyear, LLC and City of Goodyear 157th Avenue WWTP both reported selenium means exceeding 2.0 μg/L for their respective time periods reviewed. These two facilities also reported high values well in excess of the standard, ranging from 8 to 11 μg/L. Thus, while the facilities are currently in compliance with their permit limits (Table 16, Section 7.3), they are nevertheless adding selenium loading which contributes to the impairment through the canal system to the Gila River's impaired reach. Selected wells of the Salt River Project in the southern portion of SRP's designated Area 26 also reflect a mean value in excess of the Gila River standard at 3 μg/L, with values ranging from below the reporting limit of 1 μg/L to 6 μg/L.

The Corgett Wash facility has also discharged high concentrations of selenium, with a high value of 5.0 μg/L during the reporting period reviewed. Additionally, the Tolleson and Central Buckeye WWTPs have reported high values exceeding either the Gila River A&Wedw standard or their maximum daily permit limit. Corgett Wash and Tolleson currently have permit limits consistent with Gila River selenium standards. Central Buckeye is noted to have no numeric permit limits for selenium (effluent characterization testing only required), yet it had several discharges exceeding the Gila River's chronic

A&Wedw water quality standard for the period reviewed. Central Buckeye was not required to have selenium permit limits at permit issuance because reasonable potential for selenium water quality exceedances in the immediate receiving water (Arlington Canal, with an AgL standard of 50 μg/L) did not exist. Percentages of reporting above the selenium water quality standard for seven of the nine facilities showing such exceedances ranged from a low of 8.7 percent to a high of 100 percent, with a grand mean value of 52.4 percent. Dischargers are thus adding to excessive selenium loading for the impaired reach. In part, the selenium loading is a consequence of the salinity of the water supply available in the area; Corgett Wash and 157th Avenue, both Goodyear plants, are receiving water from Goodyear businesses and neighborhoods which are supplied by groundwater through the City of Goodyear. Portions of this area are documented to fall in locations of high saturated soil conductivity with poor groundwater quality. The details of JRC Goodyear's water supply are unknown, but JRC's supply is likely groundwater of either its own wells or the City of Goodyear's municipal supply due to its location in Goodyear. The City of Buckeye is also supplied by local groundwater in an area of documented brackish groundwater quality.

Of note, the City of Phoenix is not contributing to excessive selenium loading as cataloged in DMRs, as review of their recent history determined that in excess of 150 samples showed no reportable levels of selenium. The selenium detection limits for these samples varied; for the current permit term, detection levels did not exceed 2.0 μg/L.

AZPDES (NPDES) #	Name	Serving	Status
22357	City of Goodyear 157th Ave WRF	Goodyear	Existing
25747	JRC Goodyear, LLC (Lockheed Martin)	Lockheed Martin, Gdyr	Existing
24881	Buckeye Sundance WRF	Buckeye	Existing
23281	Wolf WRC	Avondale	Existing
20524	CoP 91st Ave WWTP*	Phoenix	Existing
20338	Tolleson WWTP	Tolleson	Existing
25500	Palo Verde WWTP	Buckeye	Proposed
25691	Sun Valley South WRF	Buckeye	Proposed
25135	City of Goodyear Rainbow Valley WRF	Goodyear	Existing
25127	Tartesso WRF	Buckeye	Existing
23582	City of Goodyear Corgett Wash WRF	Goodyear	Existing
24341	Salt River Project Wells	SW Valley	Existing
25453	Hassayampa Ranch WRF	Tonopah	Proposed
25313	Central Buckeye WWTP	Buckeye	Existing
25216	Festival Ranch WRF	Buckeye	Existing
25518	Trillium West WWRF	Buckeye	Proposed
25585	Balterra Wastewater Treatment Facility	Tonopah	Proposed

Table 5. AZPDES/NPDES Permittees in Extended TMDL Project Area *- NPDES Permittee

4.1.2 MSGP/CGP Permitted Sources

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 storm water runoff resulting from mining, non-mining, and construction operations and activities. These general permits cover operations that do not expect to have or need individual permits for routine discharges to Arizona waters. They are, however, required to have permit coverage for storm water discharges. Under the CWA and Arizona Revised Statutes, it is illegal to have a point source discharge of pollutants that is not authorized by a permit, including storm water 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 storm water runoff. While storm water per se is not the critical condition of concern for these TMDLs, inadequate site controls resulting in run-off from construction and industrial sites can potentially add to the watershed loading of boron and selenium through the transport of sediment into river and stream channels of the network.

As of July 2015, one facility has current permit coverage in the defined project area under MSGP coverage. It is a sand and gravel operation, itemized in Table 6. There are 92 permittees operating under the CGP in the project area as of the same date. Of these, 73 are active permittees; 19 are inactive. The number of permittees covered under the CGP fluctuates widely over short time periods; construction projects requiring coverage under the CGP are typically projects of relatively short duration covering a limited areal extent. Because of the short-term coverage and rapid turnover of permittees, CGP permittees are not itemized in the TMDLs. Waste load allocations for general permittees are addressed in Section 7.

FACILITY NAME	Begin date	End date	Activity	City	Type
CEMEX - BUCKEYE BELOAT PLANT	2/1/2011	1/31/2016	A	BUCKEYE	MINING AND NONMINING

Table 6. MSGP Permittees in the project area. Activity code 'I' indicates an inactive facility with an open permit; 'A' indicates an active facility.

4.1.3 Municipal Separate Storm Sewer Systems

The Arizona Department of Transportation (ADOT) has statewide Municipal Separate Storm Sewer System (MS4) permit coverage as a Medium-to-Large municipal operation for its facilities and infrastructure. ADOT operates its storm water program under a separate individual permit (AZS000018-2008) and program known as the Statewide Stormwater Management Plan (SSWMP). Arizona has one state highway (SR 85) that transits the TMDL watershed. ADOT's SSWMP states:

ADOT is considered a large MS4 by virtue of ADOT-owned conveyances or systems of conveyances used for collecting and conveying storm water. These include drainage systems, catch basins, curbs, gutters, ditches, man-made channels or storm drains associated with roads and highways constructed, maintained, or operated by ADOT. The Arizona Department of Environmental Quality (ADEQ) determined

ADOT is required to meet the Phase II MS4 community requirements in addition to the Phase I requirements.…

ADOT's current AZPDES Permit was issued on September 19, 2008 by ADEQ. This Permit replaces the original National Pollutant Discharge Elimination System (NPDES) Permit issued by USEPA on September 30, 1999. The scope of the current Permit includes all storm water discharges associated with construction sites, industrial facilities, and MS4s under ADOT's control.

Several entities represented in the project area are classified as small MS4s for the purposes of storm water discharges and are regulated under ADEQ's 2002 General Permit (AZG2002-002), which has expired but been administratively extended. In accordance with the Small MS4 General Permit, each MS4 is required to prepare and implement a Stormwater Management Program Plan (SWMP). The SWMP documents the control measures and best management practices the MS4 must establish to meet the terms and conditions of the MS4 General Permit. Tolleson, Avondale, Goodyear, Buckeye, and Maricopa County are all covered under the 2002 permit.

The City of Phoenix, also a holder of MS4 coverage, has no storm water outfalls in the defined project area.

Waste load allocations for MS4s are addressed in Section 7.3.2.

4.2 Nonpoint Sources

4.2.1 Boron Background and Natural Distribution

Though boron is considered essential as a plant nutrient, it becomes toxic to plants at excessive concentrations. Arizona's agricultural irrigation standard is set at 1,000 μg/L, a level protective of the most sensitive plants and crops. Effects for sensitive crops, including all forms of citrus fruit trees, grapes, apricots, pear, plum, walnut and pecan, may be seen for concentrations exceeding 1,000 μg/L. Semi-tolerant crops, including oats, milo (sorghum), wheat, barley, corn, and Pima cotton, begin to show effects at approximately 2,000 μg/L. Crops such as lettuce and cabbage and onions and alfalfa are considered tolerant to boron, and are able to grow in the presence of concentrations up to 3,000 μg/L.

Boron is a relatively common element in the earth's crust, accounting for approximately 7.5 parts per million (ppm) in the earth's igneous rocks, and an average of 100 ppm in the earth's sedimentary rocks. Thus, while it is only the 40^{th} most prevalent element in the crust for igneous rocks, it is the twentieth most prevalent element in sedimentary lithology (Hem, 1985). Boron readily forms minerals in the earth's crust, including colemanite ($Ca_2B_6O_{11}*5H_2O$), kernite ($Na_2B_4O_7*4H_2O$), and borax ($Na_2B_4O_7 \cdot 10H_2O$). Boron is associated with volcanism and fumaroles.

Boron tends to be present in soils to a higher degree in arid and semi-arid environments, due to the restricted drainage and opportunity to leach boron from soils these climates provide. Though borax and borates can only be profitably mined in a few locations worldwide, they are mined extensively in the closed basins of southeastern California in an environment and climate similar to central Arizona's. In seawater, boron constitutes an average concentration of 4.5 mg/L, the 11^{th} most prevalent element or molecule. In river water, boron is considered a minor element where present, but it is present generally in concentrations ranging from a few micrograms per liter up to several thousand micrograms per liter. Boron is readily soluble in water. Boric acid (H_3BO_3) is a common aqueous form (also expressed as B (OH_3), and boron is rarely found in elemental form, due to its ready propensity to combine with oxygen.

Natural waters typically carry some level of boron, due to its relative easy solubility in water and availability. Hem (1985) asserts that boron concentrations in river water typically exhibit levels of up to a few tenths of a milligram/liter. This is borne out by the background levels of this study. However, due to the ephemeral/effluent-dependent character of the river network in the study area, there is no true "natural background" for the TMDL analysis. Instead, background must be considered as a composite value including Hassayampa River water upstream from the vicinity of Wickenburg (prior to infiltration), boron values from effluent from the City of Phoenix WWTP, and boron from the groundwater comprising water in the Roosevelt Canal.

4.2.2 Selenium Background and Natural Distribution

The discovery that selenium can bio-accumulate in the food chain has brought selenium issues in water quality to the forefront of research in recent decades. Agricultural runoff remains today one of the primary contributors to rising selenium concentrations in national waterways. Irrigation activities have been identified as one of the prime mechanisms by which selenium concentrations can escalate beyond levels naturally found in the waters.

USGS (1997) reported:

> Before 1980, regulation of irrigation return flow from agricultural projects focused mainly on management of salts, nutrients, and pesticide residues. In the early 1980's, selenium mobilized by irrigation water was discovered to be the cause of congenital deformities and mortality of birds at Kesterson Reservoir, a National Wildlife Refuge in central California. This unforeseen result of using irrigation drain water to sustain a wetland prompted the U.S. Department of the Interior (DOI) to create the National Irrigation Water Quality Program (NIWQP) to determine whether events at Kesterson could happen elsewhere in the United States.

Selenium is a trace element essential for human health, but one which has a comparatively low toxic threshold for both humans and wildlife. As a metalloid, selenium shares many chemical characteristics with its cousin sulphur and may frequently be found interchangeably with sulphur in natural environments where both exist. However, selenium is not as prevalent as sulphur in the natural environment, comprising less than one part per million of average composition of the major geologic rock classes worldwide (Hem, 1985). It is usually found in sandstones and shales of Tertiary age, particularly of marine origin. In the continental United States, these formations are exposed in the arid and semi-arid West (Seiler, 1999). Selenium-bearing formations are not as frequently found in temperate and humid locations, in part due to paleogeographic considerations including the locations and extents of shallow seas and depositional environments in the Mesozoic era. The weathering of the source geologic units creates seleniferous soils which can be susceptible to selenium liberation upon exposure to water.

A USGS study determined that mean selenium concentrations in soils average 0.39 ppm nationwide. Ranges from other cited studies in the same report extended from less than 0.1 ppm up to 4.3 ppm. Though locations of site-specific analyses of the report were not supplied, central Arizona soils appear to typically exhibit values at 0.1 ppm and below.

4.2.3 Agriculture and Irrigation Activities

4.2.3.1 Irrigation Districts and Water Supply

As mentioned in Section 2.3, several irrigation districts operate in the defined project area. The irrigation districts are the Roosevelt Irrigation District (RID), the Buckeye Water Conservation and Drainage District (BWCDD), and the Arlington Canal Company (ACC) (Figure **4**). The canals of these districts are used to support extensive agricultural acreage in the southwest Phoenix metro area, around the town of Buckeye and near the communities of Arlington and Palo Verde, Arizona (Figure 6). Major canals in the area include the Roosevelt, Buckeye, South Extension, Buckeye Feeder, St. John's and Arlington canals. In addition to the canals, laterals and drains of the districts, all districts engage in groundwater pumping to either fully supply their water demands or to augment existing supplies, usually effluent and tail water/ drain water collected from up gradient neighboring or nearby districts. The groundwater pumping is in support of agricultural uses. More discussion on pumping is presented in Section 4.2.5. The water supplied for the districts, regardless of source, constitutes a loading source for the pollutants addressed by these TMDLs; consequently, general discussion regarding the districts and irrigation practices as nonpoint source contributors is warranted.

The Roosevelt Irrigation District (RID) was formed in 1923 (RID, 2015). District irrigation lands stretch from the outskirts of Goodyear west to the Hassayampa River (Figure 4). It occupies the northernmost tier of irrigation district lands in this area. Roosevelt draws most of its water from an extensive set of groundwater wells, both within the RID area, and outside of it in the western Phoenix metro area. The district also has an agreement with the City of Phoenix under an exchange with SRP for up to 30,000 acre-feet annually (AFA) of effluent from the City of Phoenix's 23rd Ave. WWTP (ADWR, 2010). RID administers 50 miles of main canals, 136 miles of laterals, and numerous operating wells supplying the canals (ibid.). RID owns and operates 102 wells with approximately half located to the east and half to the west of the Agua Fria River. The RID wells west of the Agua Fria River are, for the most part, located on or adjacent to District lands. Water produced from all these wells is transported to the RID customers through conveyance channels and laterals owned and operated by RID. In addition to the approximately 51 wells located to the west of the Agua Fria, RID identifies five wells east of the Agua Fria River in or adjacent to the project area, defined as south of (or in close proximity to) I-10, north of the Salt and Gila river channels, and west of 83rd Avenue for an approximate total of 56 wells in the project area (Figure 5, Figure 15) (Neese, 2015). Estimated acreage of the RID is 38,000 acres (ADWR, 2010), with an estimated water demand of 144,000 AF as of 2012 (ADWR, 2013b).

The Buckeye Water and Conservation Drainage District (BWCDD) serve an estimated 16,000 acres south of the RID adjacent to the Gila River channel between the Agua Fria and Hassayampa Rivers (Figure 4). Its estimated water demand is approximately 130,000 AFA (BWCDD, 2015a). The Buckeye district receives its water from City of Phoenix effluent from the 91st Ave, WWTP, SRP obligation water under contract via the Buckeye Feeder Canal, and 19 wells on district lands. When available, additional water from the Gila River augments its supplies (BWCDD, 2015c). Some recycled tail and drain water is received from the Roosevelt Irrigation District. The current Buckeye district was formed in 1922 to administer the Buckeye Canal itself, which was built in 1885 (BWCDD, 2015b). Portions of the BWCDD fall within the state designated “water-logged zone” where special legislative allowances are made for pumping and reporting groundwater withdrawals without the limitations that normally apply elsewhere within the state (ADWR, 1999b). More discussion on the water-logged designation follows in Section 4.2.5.

The Arlington Canal Company (ACC) supplies water to approximately 4200 acres of land in the far southwest valley (Figure 4). The company was formed in 1899, and the canal was built over the 1899-1900 period by area farmers and homesteaders. Water originally consisted of diversions from the Gila River (BWCDD, 2015c). Today, groundwater withdrawals and tail water from the BWCDD comprise the makeup of Arlington Canal flows. ADEQ and state records indicate eleven wells supply water along the course of the Arlington Canal prior to its joining with the Gila River just above Gillespie Dam in the impaired reach, though 2012 reporting indicates only eight were pumped during the year (ADWR, 2013a). Estimated annual water demand in 2012 was approximately 29,000 AFA (ibid.).

4.2.3.2 Irrigation Practices

In the study area, there is some degree of progressive recycling of irrigation water in these local irrigation districts. Unfortunately, the districts themselves do not track or quantify the amount of water coming into their networks from other districts, making detailed analysis of loading across irrigation district boundaries unviable. Tail water and drain water from the Roosevelt Irrigation District is collected by the Buckeye Main Canal at numerous locations along its length; Buckeye Canal water quality shows a progressive degradation from a mean TDS value of 1,615 mg/L at the origin to a mean TDS value of 2,170 mg/L near the canal’s terminus. Boron, likewise, accumulates through the length of the canal system, from a mean concentration of 568 μg/L at the intake to a mean of approximately 1,720 μg/L near the terminus, where water is discharged into the Hassayampa River channel. The Hassayampa River joins the Gila River channel three to four miles downstream of the discharge point. Likewise, the Arlington Canal Company receives a portion of its water supply from tail water and drain water discharges from the Buckeye Water and Conservation District canals, including the main canal and laterals. Direct data for Arlington Canal water are not available; project data shows TDS values for BWCDD drain water averaging 4,620 mg/L, with boron values averaging 4,060 μg/L. Arlington Canal water excess is discharged into the Gila River at Gillespie Dam. This degraded water quality for boron due to irrigation water recycling poses a problem with implications for agricultural limitations on crop yields for downstream users of the water discharged to the Gila River – the Paloma Ranch west of Gila Bend, and the water users of the Enterprise Canal on the west side of the Gila River downstream of Gillespie Dam.

Irrigation water recycling is also considered a prime cause of escalating and adverse concentrations of selenium. It is closely tied to the salinity of the soils through which it percolates. Water applied to agricultural fields brings with it a baseline level of total dissolved solids (TDS) as a part of its chemical constitution. The soil to which the water is applied also has its innate levels of elements and minerals generally adsorbed onto soil particle surfaces from previous water applications. The percolation of irrigation water through the vertical soil profile brings these adsorbed elements into solution. If insufficient excess of water is applied to leach the salts throughout the rooting zone, the transpiration of crops pulls water out of the soil and leaves the dissolved minerals behind in the rooting zone. Consequently, a build-up of salts adverse to crop health can occur at various soil depths. If the salts are concentrated enough, plant damage or even mortality may result.

Many irrigation programs and designs work assiduously to keep salt build-ups from occurring in the rooting zone. Generally, this is done in two ways. Additional water over and above the consumptive use requirement is applied to the crops to ensure adequate water availability throughout the root zone and to dissolve and transport soil concentrations of salt out of the root zone. The additional water applied to accomplish this is called the "leaching requirement." Additionally, groundwater is either pumped out of the fields water is applied to, or drainage systems are put into place beneath the fields to ensure higher TDS waters are moved out of the crops' root zones after the irrigation purpose has been served. Drain water or tail water already used in irrigation typically has a significantly higher level of salinity in total dissolved solids (TDS) than irrigation source water. If this water is re-used, the concentration continues to increase. Selenium tends to increase with salinity.

Because drain water frequently is reused for irrigation downstream, it can be a source of selenium to other areas. An example of an area contaminated by imported selenium is the Imperial Valley in California, which receives selenium from drain water discharged to the Colorado River from irrigated areas in Utah, Colorado, and New Mexico. Because Imperial Valley has no local geologic source of selenium, it is contaminated because irrigation water supplies the selenium (Seiler, 1995).

Though there are no known geologic units in the project area that meet the criteria for the most susceptibility for the presence of selenium (i.e., marine units of Cretaceous/Tertiary origin and exposure to a water source), source water and groundwater both contain selenium in varying concentrations. In particular, groundwater used to supplement irrigation district supplies shows mean concentrations at high levels. WWTP effluent occasionally shows selenium levels in excess of the state's chronic standard; this is unsurprising, since a portion of the City of Phoenix's water supply derives from Colorado River water delivered via the Central Arizona Project (CAP) Canal. Historically, the Colorado River has consistently demonstrated selenium levels above state chronic standards.

4.2.4 Water Importation and Use of High-TDS Waters

In addition to boron and selenium naturally available in the soils and geologic units of central Arizona, consideration must be given to the pre-existing boron and selenium concentrations in waters high in TDS imported to and used in the Phoenix metropolitan area as a part of the water supply available to the Valley. This includes CAP water imported from the Colorado River, local groundwater, and water from the Salt and Verde rivers and their reservoirs. Practically speaking, in the aggregate, this water may be considered background in that it sets the base level of expected concentrations, beneath which it is highly improbable to expect improvement, but the water cannot be considered entirely "natural background," since easily more than two-thirds of the water is imported from outside the local area.

Two major changes in the past century in the Phoenix metropolitan area have resulted in a disruption of the region's normal salt balance. These changes consisted of the initial damming of the Salt and Verde Rivers in the early 20th century, along with upstream damming of the Gila River, and the importation and use of CAP water beginning in 1985. The damming of the major rivers was responsible for an estimated 500,000 tons of salt deposited via irrigation activities annually, while the beginning of use of CAP water imported from outside the area resulted in an additional estimated 660,000 tons of salt on an annual basis (CASS, 2003). With all sources considered, it is estimated that 1.45 million tons of salt enter the Phoenix-area system annually, while the Gila River and groundwater migration are estimated to carry only 372,000 tons of salt out of the area annually (CASS, 2003).

Given the high levels of correlation found between TDS and both boron and selenium in the study (Section 5.0, Appendix C), it can be readily surmised that boron and selenium importation via the water supplied to central Arizona constitutes an added source to the nonpoint source inventory compiled here.

4.2.5 Groundwater Pumping

Groundwater data compiled from ADEQ records were examined to determine whether groundwater was of generally better or worse water quality for the constituents of concern and TDS as compared to surface water supplies prior to irrigation use. Data points available for consideration were not numerous and spanned a duration of several decades. Caution regarding inferences is therefore warranted. Project study objectives did not extend to a thorough examination of groundwater quality and the groundwater-surface water interactions of the hydrologic cycle; these considerations were outside the scope of the TMDL study. Nevertheless, some limited observations and the suggestions of patterns can be gleaned from the data.

Data were classified into four depth categories – shallow (0-100 feet), moderately shallow (100-500 feet), moderately deep (500-1,000 feet), and deep (more than 1,000 feet). Boron, selenium, and TDS were surveyed, with dissolved and total values of boron and selenium grouped together for analysis. Results were summarized by township and range. Existing data shows an inconsistent pattern of increasing concentrations from west to east along the Gila River, with most categories, though not all, exceeding target concentrations for the TMDLs. The TDS threshold of 1,525 mg/L determined in Section 7.4.2 was used for comparison with groundwater TDS values. Results show that groundwater from these areas is generally of worse quality than surface water/effluent supplies.

Consequently, it appears that groundwater pumping is in part contributing to excessive boron and selenium levels in water discharged to the Gila River and its tributaries. While not all pumping is problematic, several drainage wells in the southern portion of the BWCDD and supply wells for the ACC tap areas of brackish or saline groundwater in the state legislatively-decreed "waterlogged area." Several of these well locations are located in areas of some of the highest soil salinity in the project area with well depths reported as either 200-400 feet or 100-200 feet depending on location within the district (Gerak, 2014). These depths correlate with the moderately-shallow depth category in the groundwater analysis. Water in the designated waterlogged area is exempt from state restrictions on amount of water that can be pumped and from irrigation duties that normally accompany pumping to provide a financial disincentive for excessive water use. The Arizona Department of Water Resources summarizes the situation:

> Legislation was passed in 1985 authorizing a study to identify major causes of the waterlogging problems in the West Salt River and Hassayampa Sub basins. Laws 1985, Ch. 319, 1. Upon completion of the study and subsequent review by the Department and the public, House Bill 2353 was passed. Laws 1988, Ch. 97,1. This legislation exempted the Arlington Canal Company (Arlington), the Buckeye Water Conservation and Drainage District (Buckeye), and the St. Johns Irrigation District (St. Johns) during the first, second, and third management periods from the conservation requirements for the distribution of groundwater. In addition, this legislation exempted persons using groundwater pursuant to an IGFR [irrigation grand-fathered right] on certain waterlogged farm areas located in or near Buckeye, Arlington, and St. Johns from irrigation water duties and the payment of withdrawal fees. These exemptions became effective on January 1, 1989 and extended until the end of the third management period, December 31, 2009. A.R.S. 45-411.01(A). These exemptions were extended through the fourth management period (through 2019) under legislation approved in 2001. Prior to December 15, 2015, the Department will review the hydrologic conditions influencing the designated waterlogged areas, consult with representatives of Buckeye, Arlington, and St. Johns, and submit a recommendation to the Governor and legislative leadership regarding further extensions of the exemptions. A.R.S. 45-411.01(F). (ADWR, 1999b)

Refer to Table 7 and Figures 7-9 for summaries of groundwater quality.

Analyte	Township/Range	SHALLOW	MOD. SHALLOW	MOD. DEEP	DEEP
Boron, μg/L	**C15**	640.86	658.74	907.50	
Boron, μg/L	**C14**	2966.67	3492.67		230.00
Boron, μg/L	**C13**	1500.00	3000.00	2720.50	
Boron, μg/L	**B14**		3539.69	4800.00	2690.00
Boron, μg/L	**B13**		3850.00	920.00	7400.00
Boron, μg/L	**B12**		2314.58	812.48	1514.85
Selenium, μg/L	**C15**	6.45	10.61		
Selenium, μg/L	**C14**	6.40	14.00		
Selenium, μg/L	**C13**	NDs	10.00	12.00	
Selenium, μg/L	**B14**		20.00	27.00	3.00
Selenium, μg/L	**B13**		16.50	6.00	33.00
Selenium, μg/L	**B12**		9.50	7.50	7.50

TDS, mg/L	**C15**	1162.74	1332.08		520.00
TDS, mg/L	**C14**	3625.00		2400.00	
TDS, mg/L	**C13**	3200.00	3800.00		1510.00
TDS, mg/L	**B13**		2050.00		
TDS, mg/L	**B12**		2119.67	920.00	632.00

Table 7. Average groundwater concentrations by township/range

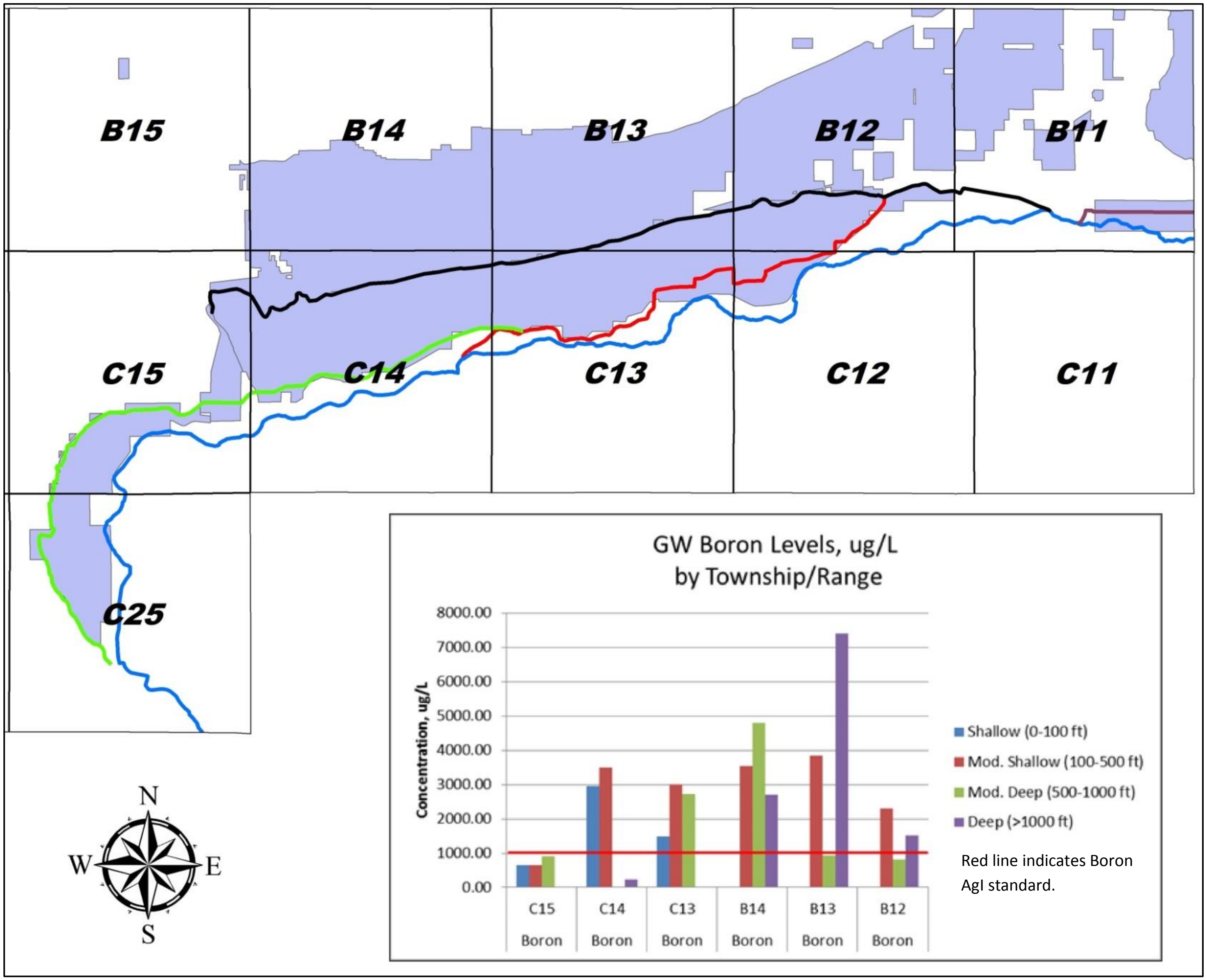

Figure 7. Groundwater boron concentrations by township and range

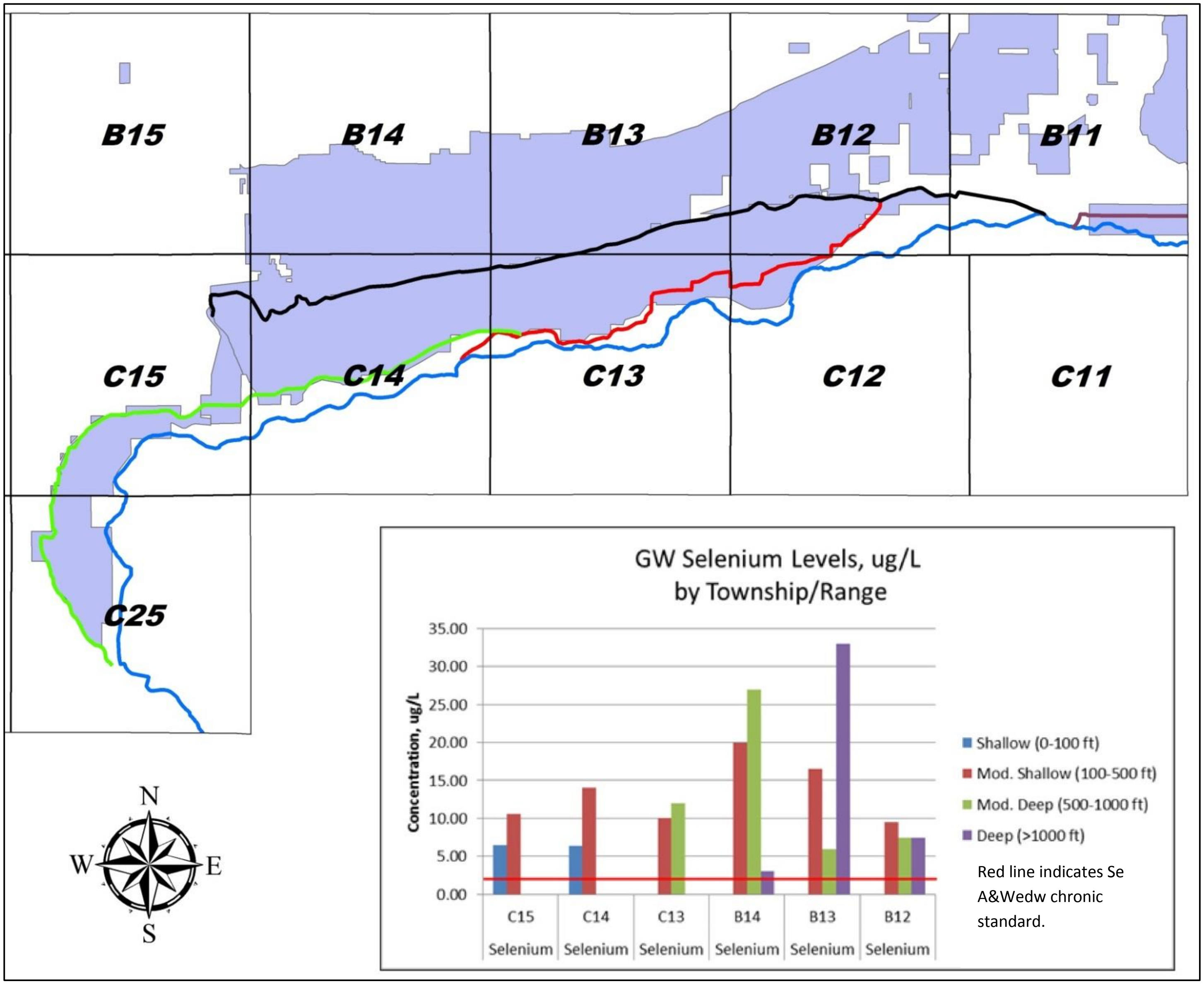

Figure 8. Groundwater selenium concentrations by township and range

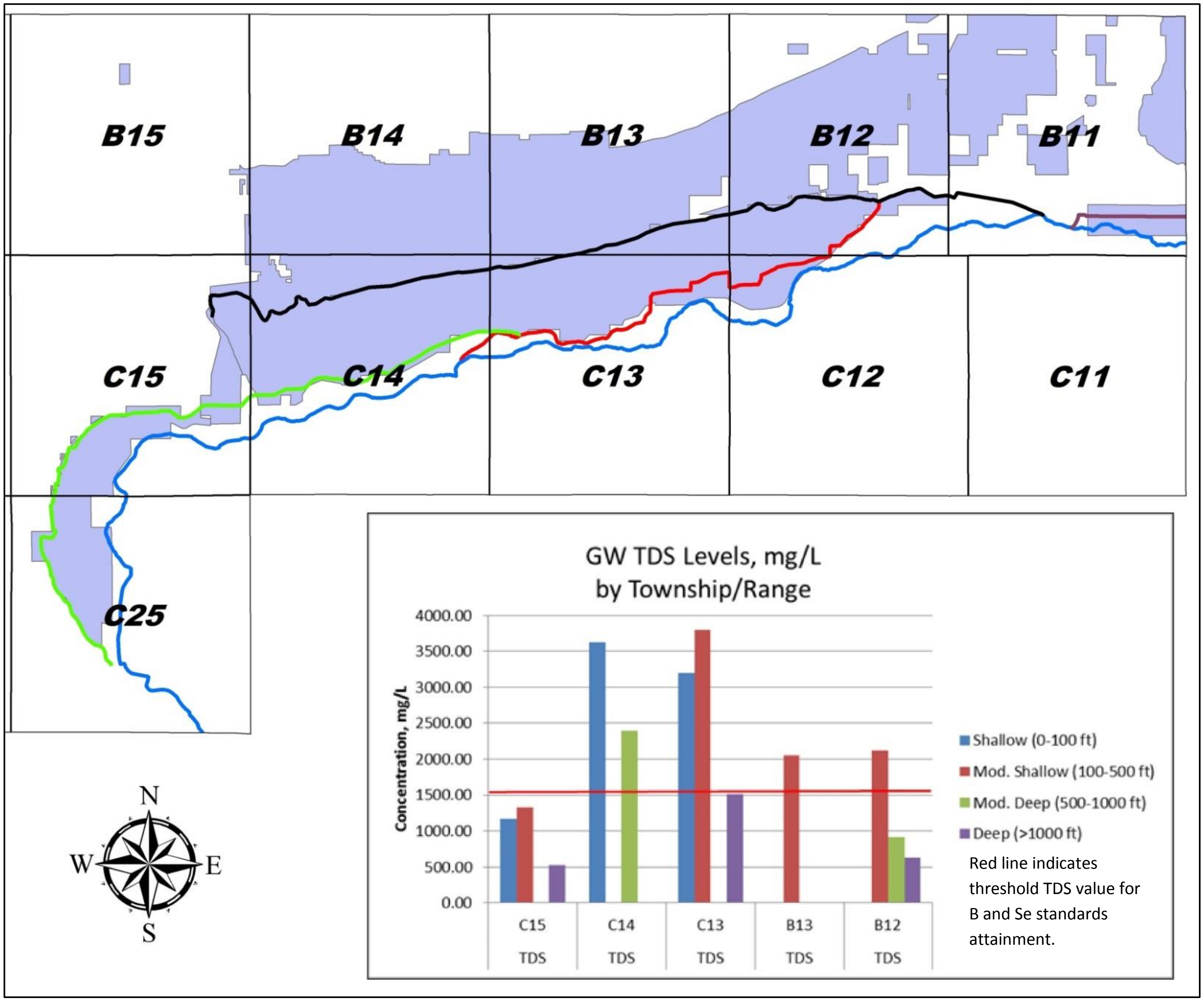

Figure 9. Groundwater TDS concentrations by township and range

5.0 Linkage Analysis

Statistical analysis showed high degrees of positive correlation between the constituents of concern and TDS values recorded in the water column. The logarithms of selenium values showed an R (correlation) coefficient of 0.758 against the log of TDS with a p-value for the regression of 0.001. Likewise, the logarithm of boron values regressed against the log of TDS showed a high correlation of 0.956 with a p-value of less than 0.001 for the regression. Boron and selenium are thus closely correlated to the TDS (salinity) values of the source water, with boron showing a particularly high affinity. Figure 10 exhibits the details of the regressions.

Salinity of source water can be tracked and tested as it degrades throughout the canal and river systems as previously mentioned. Two-sample t-tests were run on two different groupings using project data to compare means for statistical differences. The test was controlled by the requirement that sample visits exhibited “base flow” conditions (i.e., non-storm flow), with some data points excluded as a consequence. Buckeye Canal samples collected near the origin/intake of the main canal were tested against a grouped set of samples collected near the terminus of the main canal and Hassayampa River water further downstream. All water in the Hassayampa River at the collection point was attributable to Buckeye Canal discharge in base flow conditions. Results showed a mean TDS value of 1,666 mg/L near the origin, and a mean of 2,313 mg/L near the terminus. One-tailed (“less than”) hypothesis testing for a difference in the means showed statistical significance at a p-value of less than 0.001. Similarly, a second set of data was tested for differences at the head of the project area (Salt River at the 91st Avenue WWTP discharge site) and at a grouping for two collection locations in the impaired reach of the Gila River itself. One site was at Gillespie Dam; the other site was on the Gila River near Centennial Wash. As with the Buckeye Canal t-test, control consisted of screening the dataset for data only collected in “base flow” conditions. The mean TDS value for Salt River discharges was 1,061 mg/L, while the mean TDS value in the impaired reach was 3,404 mg/L. This one-tailed test also showed a statistically-significant difference in the two groups with headwater discharge being confirmed as having salinity significantly less than downstream water at a p-value of less than 0.001. Since natural waters from outside this closed system were controlled for (in non-storm conditions, only releases and discharges account for the surface water present in the study area), we can conclude that there are factors and processes at work in the study area degrading water quality and contributing to increasing salinity levels as water travels through the network. Please refer to Figure 11 for graphed results of these two tests.

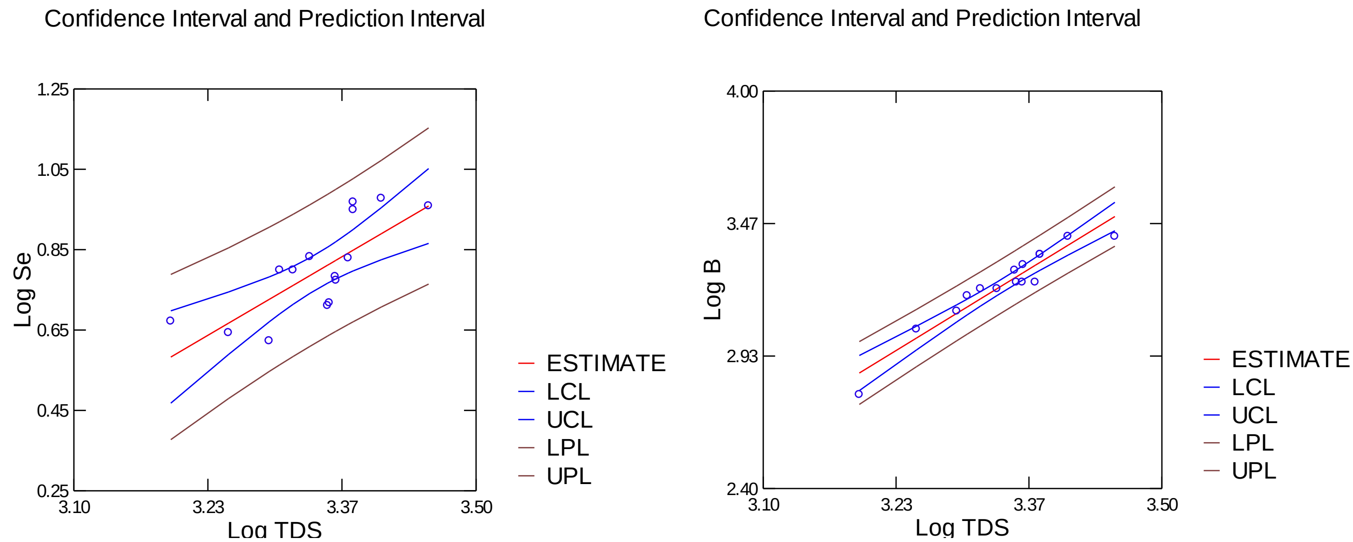

Figure 10. Log-log least square regressions for selenium (left) and boron (right) vs. TDS

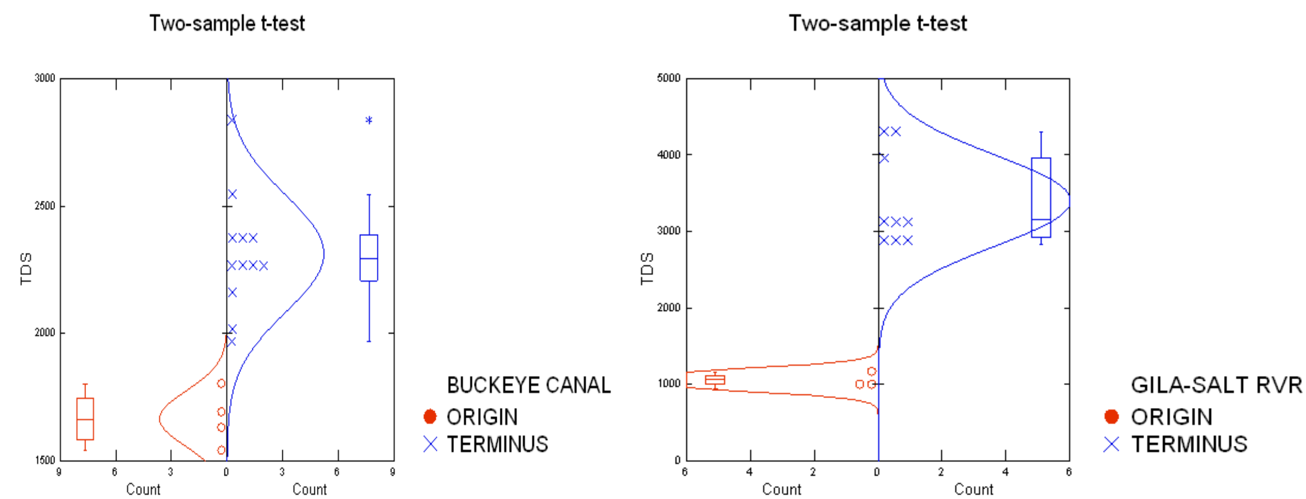

Figure 11. Results of two sample t-tests demonstrating increasing salinity values through the project area

Acronyms: LCL – Lower confidence level; UCL – Upper confidence level; LPL – Lower prediction level; UPL – Upper prediction level.

Salinity in the soils of the agricultural lands in the West Valley of the Phoenix metro area is a well-known and long-standing problem. The Bureau of Reclamation convened a study group in 2001 to study, address, and make recommendations for the problem of increasing salinity in central Arizona waters. The resulting Central Arizona Salinity Study (CASS) took a comprehensive look at the existing situation and recommended options for the future in two reports issued in the past decade. The first CASS report (2003) outlined the processes by which soil and water salinity are increased in arid and semi-arid agricultural regions relying on irrigation:

1. When water with moderate to high salinity is applied to agricultural fields, water is taken in and salts are left behind in the root zone through the crops' uptake and transpiration.

2. The increasing presence of salts in the root zone makes it more difficult for crops to take in water due to a higher osmotic gradient, which both reduces crop yield and increases the need for irrigation to flush salts out of the root zone.
3. This high-salt content unsaturated zone water percolates downward over time to mix with ground water supplies, causing groundwater levels to rise with the high-salinity water remaining on top.
4. If groundwater surfaces or enters the root zone, it is capable of spoiling the land for agricultural uses.

CASS concludes on a sobering note:

> The environmental impact of accumulating nearly 1.1 million tons of salts annually in the Phoenix metropolitan area is not entirely known at the present time, as it is a relatively new phenomenon related primarily to the use of surface waters high in TDS. Many of these salts have accumulated in the southwestern portion of the Phoenix metropolitan area near the Gila River, making the local groundwater very high in TDS. The Gila River itself is also high in TDS (averaging approximately 2,350 mg/L TDS), a direct result of agricultural return flows and effluent (CASS, 2003).

The Natural Resources Conservation Service (NRCS) has thoroughly documented this problem previously through their studies and mapping efforts. Mapping derived from the SSURGO database illustrates the soil salinity distribution throughout the irrigation districts adjacent to the Gila River. Of particular note are the high salinities in the designated waterlogged areas on the north terraces of the Gila River and in the impaired reach vicinity between Centennial Wash and Gillespie Dam. Figure 12 on the following page is compiled from NRCS's WebSoil mapping application. Soil (saturated) conductivity is an indirect measure of the amount of dissolved ions held in solution, which is directly proportional to the level of total dissolved solids or salinity of the water in the vadose zone and/or aquifers beneath.

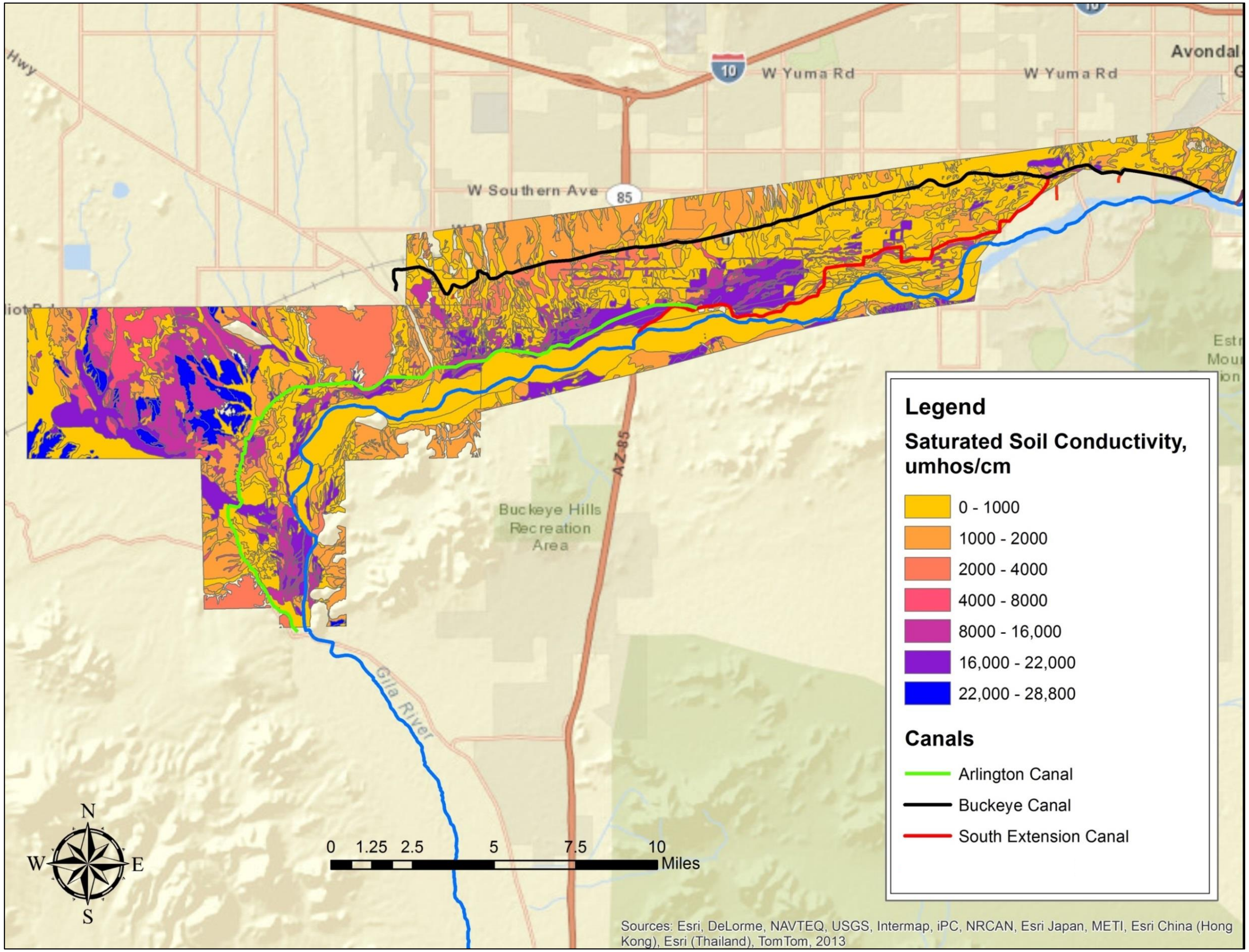

Figure 12. Saturated Soil Conductivity, Middle Gila Project Area. Data from WebSoil application, NRCS.

6.0 Analytical Methods

6.1 Flow, Concentration, and Load Duration Curves

ADEQ has chosen to employ a flow and load/concentration duration curve approach in conjunction with the Environmental Protection Agency's (EPA's) DFLOW model (for low flow determinations applied to selenium chronic exceedances) 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….
>
> 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).

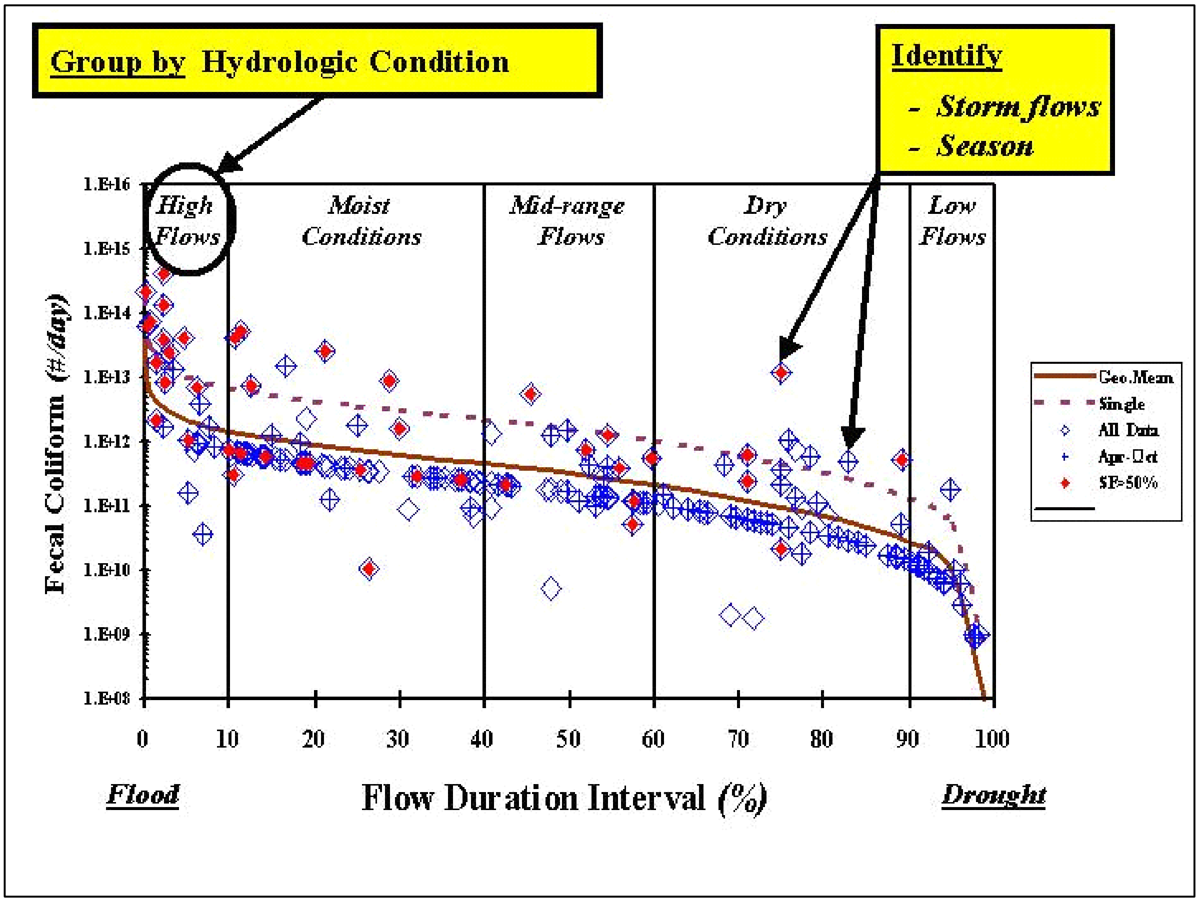

Figure 13**. Sample Load Duration Curve (Illustration courtesy of EPA, 2007a)**

As outlined in Cleland's presentation, the subdivision of the flow frequency curve into five zones corresponding to high flows (0-10 percent flow exceeds), moist conditions (10-40 percent flows exceed), mid-range flows (40-60 percent flows exceed), dry conditions (60-90 percent flows exceed), and low flows (>90 percent flows exceed) was executed for analysis and TMDL calculations. Concentration duration codes are a variation of load duration curves which can illustrate underlying trends in the data partially obscured by the inclusion of flows in the calculations. The same category breakdown is adopted in a concentration duration curve, but the target concentration does not vary and thus exhibits as a horizontal line crossing all categories, in contrast to the load curve illustrated above. Load and concentration duration curves for boron and selenium for Reach 15070201-008 may be found in Appendix A of this report.

6.2 Regressions of historical data against TDS

Multiple and single linear regressions were conducted to provide predictive capability for forecasting boron and selenium values for given levels of TDS in mg/L. Exploratory data analysis was undertaken to examine the effect and interplay of USGS mean daily flow values and measured TDS levels. TDS alone was found to be the most predictive variable due to collinearity influences in the mean daily flow value. A linear plot sufficed for boron, while a log-linear equation proved to be the best fit for selenium. Results are presented and summarized in Appendix C.

7.0 TMDL Targets and Allocations

Target loads for both the boron and selenium TMDLs have been established at levels that will ensure Arizona's water quality standards for each constituent will be met. Numerous data are available for consideration for both analytes in the historical record to determine existing loading with a high degree of confidence. Additionally, a flow record collected by the USGS dating to December 1939 establishes flow category limits with a high degree of stability and confidence.

Boron targets are established for the 90th percentile of boron data by category, consistent with Arizona's binomial assessment criteria calling for no more than a 10 percent exceedance rate with 90 percent confidence for designated uses other than human health and aquatic and wildlife uses. Flows used for calculating boron load targets are category median flows. Please refer to Table 8 below for a summary of category flow magnitudes at Gillespie Dam. Selenium targets, by contrast, are established by consideration of the selenium average concentration per category. Averages were used for selenium in recognition that chronic standards of an aquatic and wildlife designated use are concerned with long-term exposure rates to adverse concentrations of selenium in the environment. Instead of employing the upper confidence level of the category concentration averages, conservative flows at the lower bound of the category were used to build in an implicit margin of safety (MOS) over and above an explicit 10 percent MOS. Use of category lower-bound flows carries an additional benefit in that the 99th percentile flow of the record is equivalent to the 4B3 flow of 4.07 cfs for the Gillespie Dam site, which shows cumulative effects of all upstream loading. Use of this value at the low end of the flow record ensures that only one excursion of the flow magnitude in a three-year period is statistically expected. Since low-flow conditions have been determined as the critical conditions for exceedances, the use of this statistically based parameter is appropriate. These lower-bound flows are also summarized in Table 8.

Flow category values	**Category 1 High Flows 0.1%-10%**	**Category 2 Moist Conditions 10%-40%**	**Category 3 Mid-Range Flows 40%-60%**	**Category 4 Dry Conditions 60%-90%**	**Category 5 Low Flows 90%-99%**
Category Median Flows (cfs)	764	166	86	34	9.3
Category Lower Bound Flows (cfs)	320	113	63	14	4.07*

- - Lower bound flow for Category 5 is coincident with 4B3 flow for the Gila at Gillespie flow record.

Table 8. Flow category values employed for load targets

A 4B3 flow is a biological design flow criteria analogous (and close in magnitude) to a more commonly known hydrologic design flow known as a 7Q10 flow. Whereas a 7Q10 flow seeks to determine the tenth percentile of the lowest seven day average of flows in an annual series, the 4B3 flow is predicated on a four-day average flow level occurring once in three years as statistically determined. The four-day average of a 4B3 flow coincides with the generally accepted toxicological definition of the onset of chronic conditions (conditions persisting for more than 96 consecutive hours). The EPA model DFLOW was used to determine both of these flow values for the Gila River at Gillespie Dam. The results are expressed in Table 9 below.

Load targets by category for each analyte are set forth in Table 10.

4B3 (in cfs)	Percentile	Excursions per 3 yrs.	7Q10 (in cfs)	Percentile	Excursions per 3 yrs.
4.07	1.03%	1	4.8	1.34%	1.88

Table 9. 4B3 and 7Q10 flow comparison, Gila River above Gillespie Dam

Gila River at Gillespie Dam

TMDL Targets
Total Boron
Based on 90th Percentiles

	TMDL target, Kg/day	MOS	Aggregate Load Allocations	WLAs	Q (Cat. Median)
Cumulative (Wtd.)	378.0	37.8	340.2	**	154.53
Category 1 (0.1-10 FPE)	1,868.7	186.9	1,681.9	**	764
Category 2 (10.1-40 FPE)	406.0	40.6	365.4	**	166
Category 3 (40.1-60 FPE)	210.4	21.0	189.3	**	86
Category 4 (60.1-90 FPE)	83.2	8.3	74.8	**	34
Category 5 (90.1-99.9 FPE)	22.7	2.3	20.5	**	9.3

** - All WLAs are concentration-based
FPE - Flows Percent Exceeding

Total Selenium
Based on Averages

	TMDL target, Kg/day	MOS	Aggregate Load Allocations	WLAs	Q (Lower bound of Cat.)
Cumulative (Wtd.)	0.407	0.041	0.366	**	83.1
Category 1 (0.1-10 FPE)	1.565	0.157	1.409	**	320
Category 2 (10.1-40 FPE)	0.553	0.055	0.498	**	113
Category 3 (40.1-60 FPE)	0.308	0.031	0.277	**	63
Category 4 (60.1-90 FPE)	0.068	0.007	0.062	**	14
Category 5 (90.1-99.9 FPE)	0.020	0.002	0.018	**	4.07 *

** - All WLAs are concentration-based
FPE - Flows Percent Exceeding
* - 4B3 flow, corresponding to 4 day avg. low flow value exceeded once in three years

Table 10. TMDL targets by category for boron and selenium. Targets in red font indicate critical condition.

7.1 Background

The project area is unique in that there is no true representative "natural background" to be evaluated in base flow conditions within the area boundaries. Aside from storm flows adding hydrologic inputs from beyond project area boundaries, all water feeding or existing in the Gila River in this area is released and/or discharged either directly or indirectly from anthropogenic sources or attributable to groundwater interflow and upwelling near the mountains. The Phoenix 91st Ave WWTP supplies the majority of the source flow in the river through its regulated releases into the Salt River channel in the Tres Rios Wetlands Project. The little water arising in the Gila River channel itself above the Salt River confluence, which joins the City of Phoenix's (CoP) discharges in Tres Rios, is groundwater forced to the surface by the foot of the Estrella Mountain Range and is not considered a representative indicator of surface water chemical levels. The Gila River above the Salt River confluence arises outside of project area boundaries and is under the administration of the Gila River Indian Community. All water below Tres Rios is taken into the Buckeye Canal for distribution throughout the BWCDD; the Gila River channel below the diversion is populated only with isolated ponds or short stretches of flow which infiltrate in the river's flood plain for approximately 15 miles downstream of the diversion. Discharge from the Salt River Project canal system to the Agua Fria River and canal drain water from the Buckeye district, including excess from the South Extension Canal, and three identified main drains on the BWCDD - old Highway 80 drain, Suzy Dean, and Watson (Gerak, personal communication, 2014) - constitute the only consistent additions to the hydrologic system above the Hassayampa River. All of these are heavily impacted by anthropogenic loading. Furthermore, as a NPDES permittee accounted for in waste load allocations (Section 7.3), the 91st Ave WWTP supplying most of the source water to the system would be doubly accounted for in the loading equations for the system in attempting to consider their discharges as a natural background summation term. Consequently, baseline levels of loading for this project are considered "background loading" as opposed to "natural background loading," and are quantified and presented here as ancillary information to the TMDL loading summations. Background loading will not be quantified separately within the TMDL loading equations; it shall be considered as an integral part of the loading allocation concentrations. Information on background concentrations is presented here to demonstrate that achievement of water quality standards is possible with effective management practices.

The water population considered for background loading consists of project sampling data from the outfall of the 91st Ave. WWTP, source water values from the groundwater constituting Roosevelt Irrigation District supplies, and data from the Hassayampa River 48 miles above its confluence at a Nature Conservancy property south of Wickenburg. The Hassayampa River infiltrates shortly below this sampling location and remains ephemeral for 45 miles downstream until it receives Roosevelt and Buckeye District drain water three to five miles above the Gila River. It is the only natural, un-impounded water course with the likelihood for its flow to join the Gila River. The main stems of both the Salt and Agua Fria rivers flow through the Phoenix metropolitan area and are impounded at locations upstream of the project area, thus preventing their possible use in a background evaluation.

Data from the chosen three sources was evaluated and summarized by the Kaplan-Meier (K-M) method for the determination of nonparametric thresholds. The method allows for the inclusion of left-censored data. A total of 26 data points for boron were evaluated by concentration from these three sources. Of the 26, four were non-detects at a method reporting limit of 200 μg/L, while an additional seven samples were quantified at levels below this. Values ranged from 130 μg/L to 520 μg/L. The median value determined by K-M for the set was 230 μg/L, while the 90th percentile of the set was determined as 500 μg/L. The 90th percentile is presented here as a standard point of comparison consistent with the 90th percentile values evaluated in loading allocation determinations to follow. As previously mentioned, the boron water quality standard for the AgI designated use is 1,000 μg/L. Background loading shows that the boron water quality standard can be met with source water unaffected by nonpoint source loading.

Fewer data points are available for consideration for selenium background loading. While the same three sites were employed, much historical data often was not reported with detection limits low enough to evaluate whether the chronic selenium standard of 2.0 μg/L was being met. Consequently, 14 data points were excluded from the set for consideration due to inadequate reporting limits. Of the remaining 12, eight were non-detects at the threshold of 2.0 μg/L, while one high detection at the CoP's outfall was recorded at 3.8 μg/L. Detected values ranged from 1.05 to 3.8 μg/L. The K-M average for the set was 1.392 μg/L. The average is presented here in keeping with the manner that load allocations were developed for selenium. With a selenium water quality standard of 2.0 μg/L, background data for selenium also shows that water quality standard attainment is possible to achieve where there is no nonpoint source water quality degradation.

If all wastewater-influenced samples are removed from the dataset and only the subset of natural waters outside the defined project area is considered for background, a total of thirteen events remain. Eight of these events are associated with selenium samples where the reporting limit was not low enough to evaluate against the selenium water quality standard. The remaining five were all non-detects at a level of 2 μg/L (ND : 2.0), thus establishing both the median and the 90th percentile value as below the water quality standard. For the thirteen boron samples evaluated with K-M testing, a mean of 157 μg/L and a median of 140 μg/L were determined. The 90th percentile was found to be non-detectable at 200 μg/L. This subset establishes that parent geology in the region allows water quality standards to be met.

Background data are itemized and presented in Table 20 found in Appendix B.

7.2 Load Allocations

Load allocations for individual areas have been established for four different zones in the project area. In most flow conditions, including the most critical ones to address, flow that contributes directly to boron and selenium loading originates in the immediate Gila River vicinity west of State Route 85 (SR 85). When flow is continuous from upstream areas (i.e. east of SR 85 or from north of I-10 on the Hassayampa River), it is usually a result of storm flow conditions which generally ameliorate loading and dilute concentrations for both boron and selenium. While there are additional inputs to the Gila River between the eastern edge of the project area boundary and SR 85, they infiltrate before adding to loading in the impaired reach the vast majority of the time. Consequently, all hydrologic inputs to the Gila River upstream of the Hassayampa River confluence (west of SR 85) can be grouped into one contributing subwatershed or Loading Allocation Zone (LA1). All persisting contributions by the Hassayampa River, its tributaries, and its contributing areas (including persisting Buckeye Canal discharge) outside of recognized irrigation district boundaries are grouped into Loading Allocation Zone 2 (LA2). The contributing subwatershed area between the Hassayampa River confluence and the Arlington Canal discharge segment at the base of Gillespie Dam is considered Loading Allocation Zone 3 (LA3). Arlington Canal itself and any persisting flows joining the Arlington Canal from areas in the Centennial Wash subwatershed are considered Loading Allocation Zone 4 (LA4). In summary, two loading zones are subwatershed areas bounded by major canals, and two loading zones are tributary flows or contributing canals flows. Refer to Figure 14 for a map of the loading allocation zones. Infrequent storm flow contributions from the desert lands to the south or east of the Gila River will be considered as loading attributable to a zone relative to its Hassayampa River confluence orientation. Source loading east of an extension of the Hassayampa River to the Buckeye Hills area will be assigned to Zone 1, while source loading to the west of an extension of the Hassayampa River in the same area will be assigned to Zone 3.

Load allocation zone targets are established on a concentration basis due to the inability to determine flows for all sampling visits and events in the project area. Concentration targets are established equivalent to water quality standards less a 10 percent MOS based on a proportionality rationale. If each loading zone attains its target concentration and all WLAs are in compliance, the cumulative total maximum daily load at the reach's terminus will attain state water quality standards for both boron and selenium at the cumulative flow value.

Reductions by loading zone have been determined using project data. Zone targets and reductions are presented in Table 11. LA Zone 3 (Subwatershed 2, Hassayampa-Arlington Canal area) has been highlighted for each constituent as the most critical zone to address to reduce loading based on the greatest percentage reductions necessary to meet the water quality target. However, all zones require reductions of substantial magnitudes.

Aggregate load allocations (TMDL less the MOS) are shown in Table 11.

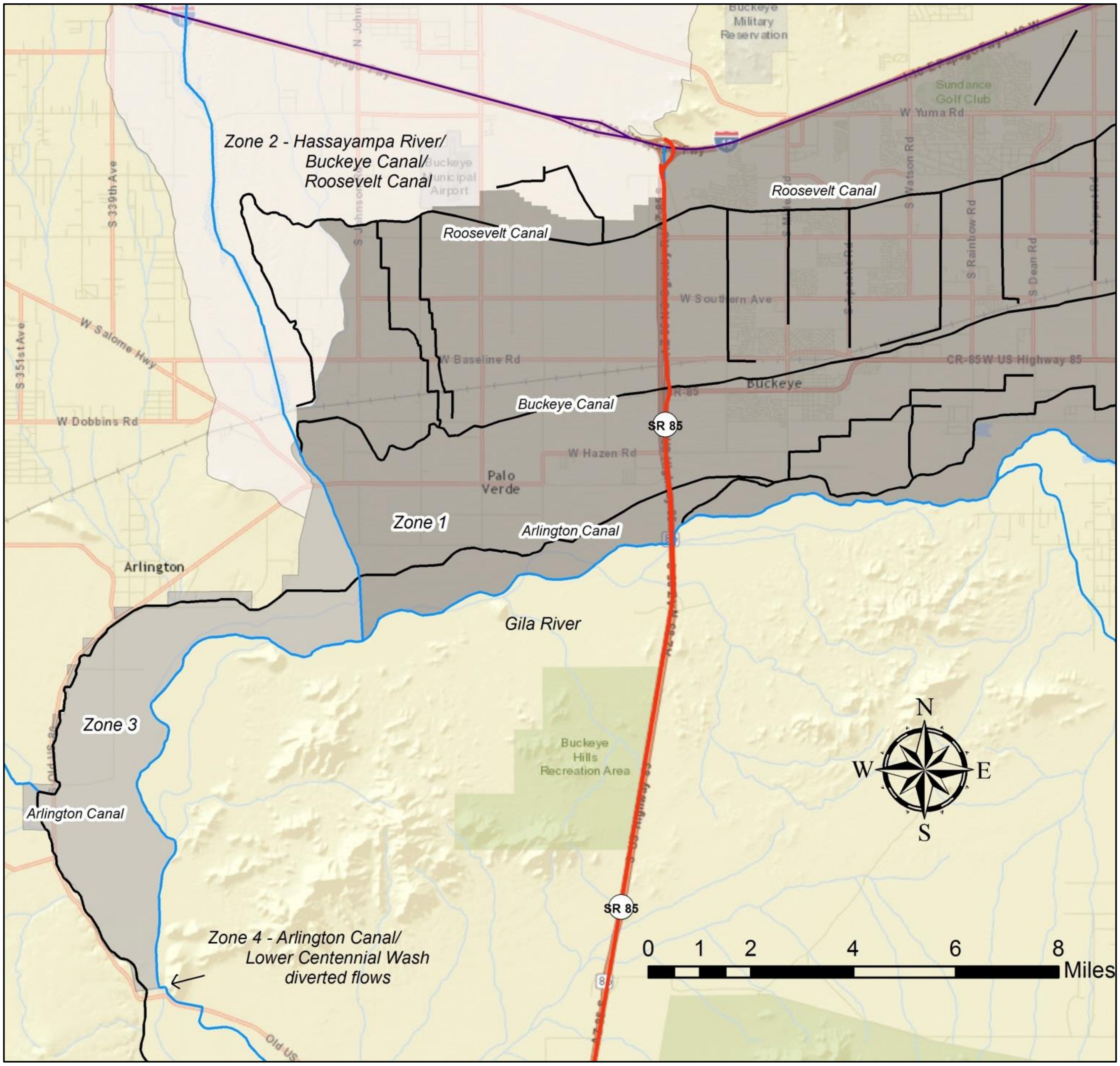

Figure 14. Load allocation zone map

Load Allocations

Boron 90th Percentile Concentration Target

LA Zone	Total TMDL Concentration µg/L)	Load Allocation Target Concentration	Existing 90th P-tile Concentration (µg/L)	Number of Data Events	Percent Reduction LA
LA1	1000	900	4290	7	79.0%
LA2	1000	900	2440	15	63.1%
LA3	1000	900	4869	9	81.5%
LA4	1000	900	1868	4	51.8%
				Median Percent Reduction:	71.1%

Selenium Average Concentration Target

LA Zone	Total TMDL Concentration (µg/L)	Load Allocation Target Concentration	Existing Average Concentration (µg/L)	Number of Data Events	Percent Reduction LA
LA1	2.0	1.8	6.63	7	72.8%
LA2	2.0	1.8	6.57	15	72.6%
LA3	2.0	1.8	10.66	9	83.1%
LA4	2.0	1.8	4.63	4	61.1%
				Median Percent Reduction:	72.7%

Table 11. Load allocation concentration levels and targets by zones. Critical zone shown in red highlight.

7.3 Waste Load Allocations

7.3.1 Individual Permittees

Several dischargers holding individual AZPDES or NPDES permits are identified as requiring a WLA by virtue of their locations and points of discharge. Locations within Zone 1 of the project area boundary discharging to a major canal or a drain, along with the City of Goodyear's Corgett Wash WRF, are considered as having a probable likelihood for discharges to impact boron and selenium loading in the impaired reach (Figure 15). Other zones either consist of ephemeral flow regime conditions or have no identified permitted dischargers within their boundaries. Dischargers in Zones 2 and 4, while identified for a comprehensive inventory in the TMDLs, are considered to be lacking probable likelihood to adversely affect loading in the impaired reach, as flows would only reach the impaired reach in storm flow conditions. Any such storm flow conditions would be of a large magnitude such that a dilution effect on loading for the constituents of concern would be expected, as reflected in the sampling for this project and shown in the duration curves of Appendix A. The dischargers of Zone 1 needing a WLA are itemized in Tables 14 and 15. One discharger is only a proposed facility at this point, as indicated by the "Status" column in the tables; this facility is included in allocation assignment because a permit has already been issued for its future operations.

Canals in the Phoenix area draining eventually to the Gila River or its tributaries generally carry only the designated uses of AgI and AgL. The Arlington Canal has only an AgL use. While the boron water quality standard applies directly to canals with the AgI use, selenium water quality standards for the A&Wedw designated use as applied to the Gila River do not apply directly to canals of the study area. Generally, the determination of receiving waters in permit reviews and renewals is restricted only to the immediate discharge location, or to a major tributary in the immediate vicinity. Consequently, since other major tributaries of the Gila River do not carry an AgI designated use, discharge permits to locations other than the Gila River channel do not generally incorporate boron into the constituents of concern unless they drain directly to the Gila River within a short distance. Similarly, for selenium, some permits have allowed discharge limits at a higher concentration levels to the canal systems of Zone 1 than is acceptable for the Gila River. Consideration of the probable likelihood of impacts on downstream waters is expanded for the TMDLs than for AZPDES permits in this context. Discharges to the canal systems, which have been previously allowed greater latitude in permitting, are considered more likely in the TMDL analysis to adversely affect loading in the impaired reach than a permitting determination of receiving waters would indicate. This higher likelihood is due to the persistence of the water throughout the network with an eventual hydrologic nexus to the impaired reach. Water discharged 15 or 20 miles from the reach into the canals is considered a higher risk for excessive loading than water discharged to the intermittent Gila River or tributary river beds fewer miles away. The latter is highly likely to infiltrate before entering the impaired reach, while the former is demonstrably unlikely to infiltrate. Consequently, facilities discharging to canals with no permit limits in Zone 1 must have a WLA to ensure standards attainment in the impaired reach.

An analysis of the total of the authorized discharges' CFS equivalents (based on maximum design capacity where available) shows that permittees discharging to the hydrologic network where flow persists currently account for approximately 298 cfs of authorized discharged flow. The majority of this total is CoP's authorized discharges. The median of all daily mean flows for the Gila River at Gillespie Dam is 86 cfs. Disregarding consumptive use and infiltration, the total authorized discharge represents a flow value exceeding the upper 12th percentile of the flow history of the Gila River at Gillespie Dam. Its adoption as the basis of mass-based WLAs could severely constrain aggregate load allocations; in fact, for four of the flow classes for the impaired reach, there would be no room in the TMDL calculation to accommodate any aggregate load allocations.

For this reason and others, including intermittent or infrequent discharges and the lack of detailed flow volume data throughout the canal systems, the TMDL analysis is a concentration-based analysis. While aggregate mass-based loads determined in the impaired reach are presented in support, sufficient flow data is not available to comprehensively parse out mass-based loads for each contributing source or source area. Consequently, these TMDLs adopt a concentration-neutral premise to form the framework of WLA consideration. The concentration-neutral premise asserts that if all sources and dischargers are assumed to be discharging at the impaired reach's water quality standard concentrations for the analytes of concern, then regardless of flow variability, total loading of the system will be consistent with the water quality standards in the reach of concern. A corollary of this premise is that in those cases where concentrations are permitted at levels above the water quality standard, additional loading attributable to the higher concentrations must be offset by a buffer of additional assimilative capacity of the receiving waters elsewhere, either in the system itself or in the analysis.

For consideration of selenium WLAs, three permittees will require adjustment of existing selenium permit limits and an additional two without numeric selenium effluent limits will require limits to be applied consistent with the concentration-neutral premise of these TMDLs. For boron WLA considerations, while no existing numeric limits require adjustment, eight permittees in the project area currently have no numeric effluent limits applied to at least one of their outfalls or PODs and thus will require the addition of boron numeric effluent limits. Selected SRP wells are subject to the application of a WLA by virtue of their locations in the defined TMDL project area. SRP wells having a WLA applied are outlined in Table 12.

SRP Groundwater wells	
00.0E-05.5N	04.0E-04.2N
00.4W-03.3N	03.0E-01.0N
01.0E-06.0N	03.0E-02.3N
02.0E-04.9N	03.0E-04.0N
02.3E-01.3N	03.5E-06.0N
04.0E-05.0N	--

Table 12. SRP wells with TMDL WLA application

7.3.1.1 Selenium WLAs

The selenium TMDL analysis was framed more conservatively than the boron TMDL analysis. Whereas the boron load duration analysis (Section 7.0) used mid-point flows of each flow category for the determination of category targets, the selenium analysis used lower-bound flows for the setting of category targets. When analyzed in the aggregate, the use of lower-bound flows for the analysis results in a weighted average buffer of

71.4 cfs of additional assimilative capacity available to accommodate the greater selenium loading of higher-limit permittees. See Table 13 for a flow summary. This buffer allows for some discharge concentrations over the water quality standard of the impaired reach. However, existing permit limits higher than the Gila River's chronic selenium standard will require modification to be consistent with the assimilative capacity available.

Flow Category	***Median Flows, cfs***	***Weight***	***Lower-Bound Flows, cfs***	***Weight***
1	764	0.1	320	0.1
2	166	0.3	113	0.3
3	86	0.2	63	0.2
4	34	0.3	14	0.3
5	9.3	0.1	4.07	0.1
	Weighted Flow	154.5	Weighted Flow	83.1
			Difference:	71.4

Table 13. Assimilative flow capacity buffer

Three dischargers in the TMDL project area are currently permitted to discharge selenium concentrations consistent with the AgI standard of 20 μg/L for Phoenix-area canals or with site-specific limits. These dischargers include the City of Goodyear 157th Ave. WRF (Outfall 2), JRC Goodyear, LLC (Outfalls 1, 2, and 3), and the wells of the Salt River Project itemized previously. These facilities or operations hold AZPDES permit #s 22357, 25747, and 24341 respectively. As outlined previously (Section 4.1.1), canal water has been observed to persist after transit through the canal systems and is thereby adding excess loading for selenium to the impaired reach. Consequently, to ensure concentration-neutral conditions consistent with the identified buffer, it is necessary to evaluate discharge monitoring reported data for each permittee with the higher limits to determine current performance and set appropriate waste-load allocations for these facilities/operations.

Pre-TMDL permit limits for selenium are shown in Table 16. Determination of current performance for the three permittees with higher limits proceeded through the examination of the last three to five years of reported selenium data and additional data submitted by permittees during the public comment period. For the wells of the Salt River Project south of I-10 in SRP's Area 26 (bounded on the east by 83rd Avenue), due to limited data availability for each well, individual well reporting was aggregated and treated as a single group . The mean, standard deviation and coefficient of variation were determined for each permittee's data. Using the current performance mean as representative of the long-term average (LTA) for the facility or operation, methods consistent with EPA's 1991 *Technical Support Document for Water Quality-Based Toxics Control* (TSD) were employed on each data set to establish recommended concentration-based permit limits for the waste load allocation (WLA), the average monthly limit (AML) and the maximum daily limit (MDL). These limits are reflected in Table 14. Limits are reported to one significant figure consistent with permit calculations, excepting limits of 10 or higher, which are reported to the nearest whole number.

Current-performance selenium waste load allocations based on standard TSD calculations were also applied for the two permittees in the project area currently without numeric selenium effluent limits. This group includes the City of Buckeye Sundance Water Reclamation Facility (AZPDES #24881) and the Central Buckeye WWTP (AZPDES #25313). Recommended selenium permit limits for these two permittees are also reflected in Table 12.

The recommended limits require an equivalent of 40.5 cfs of assimilative capacity for accommodation at the A&Wedw chronic standard of 2.0 μg/L. An additional 30.9 cfs of assimilative capacity remains in the buffer as an added margin of safety after accommodation of the recommended permit limits.

Recommendations for
Adjusted Permit Limits, Selenium

All concentrations in ug/L

Permit #	Facility/Operation Name	Points of Discharge	WLA	AML	MDL
22357	City of Goodyear 157th Ave WRF	Outfall 2	6	5	11
25747	JRC Goodyear, LLC (Lockheed Martin)	Outfall 1	22	18	29
		Outfall 2	13	11	19
		Outfall 3	8	7	12
24881	Buckeye Sundance WRF	All outfalls	3	3	5
25313	Central Buckeye WWTP	Outfall 1	2	2	4
24341	Salt River Project	GW wells, Area 26 S of I-10*	6	–	10

* - Includes wells 1.0E-6.0N and 3.5E-6.0N north of boundary

Table 14. Recommendations for adjusted permit limits, selenium

7.3.1.2 Boron WLAs

Table 17 details existing permit limits for discharges containing boron. The table shows several permittees without boron limits on one or more outfalls or points of discharge. Since a TMDL analysis is essentially a pollutant budget aimed at isolating and quantifying water quality loading for the purpose of water quality improvement, unquantified loading additions from permitted sources cannot be allowed in the context of the analysis. Except for Central Buckeye WWTP, WLAs equivalent to the AgI boron water quality standard are therefore applied to each permittee's outfall(s) or PODs within Zone 1 of the project area boundary where numeric limits do not currently exist. Outfalls where numeric limits are currently applied retain their existing permit limits.

The City of Buckeye submitted data for the Sundance and Central Buckeye facilities during the public comment period and requested a current-performance analysis for boron for each. Due to existing permit limits for the Sundance WRF (Table 15) and the anti-backsliding provisions of the Clean Water Act [Section 402(o), Section 303(d) (4) (A)], the current Sundance permit limits for boron remain unchanged by the TMDLs. Recommended permit limits for the Central Buckeye WWTP are established at an AML of 1231 μg/L and an MDL of 1682 μg/L. The WLA is likewise 1231 μg/L. The higher current performance limits for boron at this facility result in an additional 3.5 kg/day of boron loading over a concentration-neutral limit load at a concentration of 1000 μg/L. The additional loading reduces the explicit margin of safety by approximately 1% (Table 8).

The methods used to determine the permit limits, as with the selenium WLAs, were derived from TSD methods. For human-health related criteria, such as the AgI use, the average monthly limit value defaults to the water quality standard of 1000 μg/L.

The newly applied WLAs and recommended permit limits consistent with them are summarized in Table 15 below. DMR data for each facility or operation in Table 15 where data are available indicates WLAs can be met.

WLAs and Permit Limit Recommendations, Boron

Permit #	Facility/Operation Name	Points of Discharge	WLA	AML	MDL
22357	City of Goodyear 157th Ave WRF	Outfall 2	1000	1000	1459
25747	JRC Goodyear, LLC (Lockheed Martin)	Outfall 1	1000	1000	1459
		Outfall 2	1000	1000	1459
23281	Wolf WRC	Outfall 1	1000	1000	1459
20524	CoP 91st Ave WWTP	Outfall 1	1000	1000	1459
		Outfall 2	1000	1000	1459
		Outfall 4	1000	1000	1459
		Outfall 5	1000	1000	1459
25500	Palo Verde WWTP	Outfall 1	1000	1000	1459
25313	Central Buckeye WWTP	Outfall 2	1231	1231	1682
24341	Salt River Project	GW wells, Area 26 S of I-10*	1000	–	1000

* - Includes wells 1.0E-6.0N and 3.5E-6.0N north of boundary

Table 15. Boron WLAs and permit limit recommendations for dischargers/outfalls without numeric limits or requiring modified limits

7.3.1.3 Other WLA and Permit Implementation Considerations

The point of compliance for individual permittees unless otherwise specified is at each permitted outfall detailed in the permit and these TMDLs. For the SRP wells requiring a WLA, the point of compliance is at the outfall for each individual well for both boron and selenium.

For compliance purposes, WLAs are considered as annual means for both boron and selenium. SRP's wells are considered in the aggregate as a single grouped WLA for both selenium and boron. The annual mean of all grouped SRP wells shall determine adherence to the WLA. For all AZPDES permittees, MDLs (maximum daily limits) and AMLs (average monthly limits) where they are incorporated are applicable for the time frames indicated by their terminology. Consistent with their existing permit, SRP is not required to meet an AML value for either boron or selenium due to irregular and infrequent sampling of wells. SRP retains their existing permit MDL of 1000 μg/L for boron as applicable to other wells under permit coverage. The MDL will also apply to the wells itemized previously.

Mass-based limits for higher-limit permittees for both boron and selenium are set based upon the concentrations listed and the permitted design capacities of the facilities/outfalls as permitted at the time of the draft TMDL release in 2015. For SRP wells, the mass-based limits are based upon the concentrations presented and average annual flow value for the Buckeye Feeder Canal for calendar years 2012-2014 as measured at the Buckeye Feeder Canal gauge station. The addition of outfalls or the change of locations of outfalls with no changes in discharge capacity for these facilities does not require a reconsideration of loading under this TMDL, but requests for permit modifications for higher-limit permittees involving facility design capacity expansions will be contingent upon remaining capacity available to accommodate the expansion and will be considered on a case-by-case basis after TMDL finalization and approval.

Sampling frequency requirements in permits requiring revision shall be determined by the ADEQ Permits Unit. Permits are not required to be revised until they are due for renewal.

SRP wells not itemized in the table are not deemed to be a part of the TMDL analysis and therefore require no WLA for these TMDLs, nor do these other wells require any alteration of existing permit limits. Likewise, existing individual permittees not assigned an allocation in the extended project area as shown in Figure 5 (Zone 2, Zone 4, and Rainbow Valley above the Corgett Wash facility) do not require WLAs in these TMDLs and therefore require no revision of their existing permits.

Existing permit limits referenced in Table 16 and Table 17 are set as concentration-based waste load allocations in these TMDLs and cannot be altered without a re-consideration of TMDL loading for the entire project area.

All future applicants for AZPDES/NPDES permits in the project area of the TMDLs where WLAs are required (Figure 15) must have boron and selenium permit limits set, even if reasonable potential for exceedances is not present. TMDL loading cannot be evaluated without numeric permit limits. Future applicants will have WQBELs set from WLAs based on the TSD methods outlined in this TMDL when additional available assimilative capacity exists.

7.3.2 General Permittees and MS4s

For selenium, a concentration-based WLA equivalent to the A&Wedw chronic water quality standard for total selenium (2.0 μg/L) is established for existing and future permittees covered under all sectors of the MSGP, CGP, and MS4s. This WLA is applied as a water quality based effluent limit (WQBEL) to all existing and future general and MS4 permittees in the defined project area (Figure 15, dark gray area).

For boron, a concentration-based WLA equivalent to the AgI water quality standard for total boron (1,000 μg/L) is established for existing and future permittees covered under all sectors of the MSGP, CGP, and MS4s. This WLA is applied as a water quality based effluent limit (WQBEL) to all existing and future general and MS4 permittees in the defined project area (Figure 15, dark gray area).

ADEQ will require general permittees to meet the terms of the WLA in one of the following ways:

- The pertinent water quality standard shall be met as a concentration-based waste load allocation for each of the individual storm water outfalls or other points of discharge as identified in the permittee's approved SWPPP or

- Permittees can demonstrate through monitoring and reporting that either discharges are not reaching receiving waters with the applicable designated use, or discharges reaching waters with the applicable designated use are not causing or contributing to exceedances of the appropriate water quality standard in the receiving water.

ADEQ may impose additional monitoring requirements to determine compliance in context with the general permit. Specific monitoring requirements and Best Management Practices (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 and pertinent sections of the 2013 ADEQ CGP.

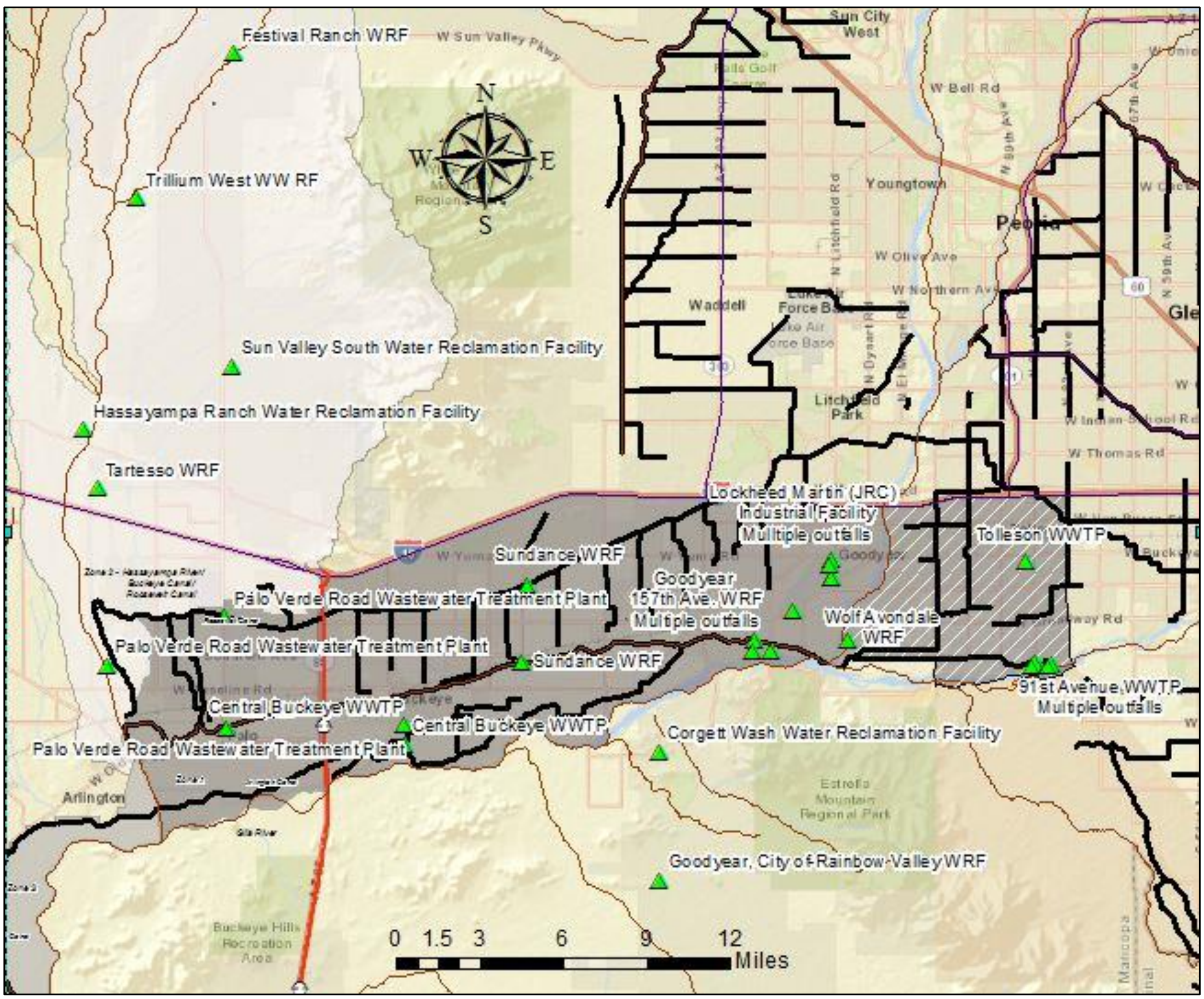

Figure 15. Locations of AZPDES/NPDES permittees. Permittees in darkened zone and Corgett Wash WRF require a WLA. Hatched area east of the Agua Fria River delineates general location of SRP wells requiring a WLA.

Se Permit Limits Monthly Avg. Concentration (ug/L)	Daily Max Concentration (ug/L)	AZPDES (NPDES) #	Name	Serving	Status		Max Design Flow	Notes	CFS Equivalent	Assigned WLAs
Gila: 2	3	22357	City of Goodyear 157th Ave WRF	Goodyear	Existing		4.0 MGD	(5)	6.19	Permit limits
BWCDD: 16.4	32.8									6 ug/L
20	29	25747	JRC Goodyear, LLC (Lockheed Martin)	Lockheed Martin, Gdyr	Existing	Outfall 3	0.065 MGD	(5)	0.1	8 ug/L
(Assessment Levels)						Outfall 1	0.031 MGD			22 ug/L
						Outfall 2	0.0825 MGD			13 ug/L
None	None	24881	Buckeye Sundance WRF	Buckeye	Existing		3.5 MGD	(5)	5.42	3 ug/L
2	3	23281	Wolf WRC	Avondale	Existing		9.0 MGD	(1)	13.93	Permit limits
2	3.67	20524	CoP 91st Ave WWTP	Phoenix	Existing	Outfall 1	89.0 MGD		137.7	Permit limits
2	3.67					Outfall 2	89.0 MGD	(4)	137.7	Permit limits
2	3.67					Outfall 4	1.2 MGD		1.86	Permit limits
2	3.67					Outfall 5	80 MGD		123.78	Permit limits
2	3	20338	Tolleson WWTP	Tolleson	Existing		17.5 MGD	(2)	27.08	Permit limits
2	3	25500	Palo Verde WWTP	Buckeye	Proposed		0.5 MGD	(5)	0.77	Permit limits
2	3	23582	City of Goodyear Corgett Wash WRF	Goodyear	Existing		0.8 MGD		1.24	Permit limits
None: ECT	None: ECT	25313	Central Buckeye WWTP	Buckeye	Existing		4.0 MGD	(3), (5)	6.19	2 ug/L
--	20	24341	Salt River Project	SW Phoenix metro area	Existing		N.A.	(6)	12.8	6 ug/L

Notes:
(1) Avg. 4.87 MGD, 2008-2012
(2) 6.89 MGD (avg daily)
(3) expanding to 6.0 MGD (9.28 CFS expanded equivalent)
(4) Exclusive alternate to Outfall 1
(5) Discharge to Buckeye Canal system; see Figure 15.
(6) Flow value used is average daily flow for Buckeye Feeder Canal for 2012-2014
PVNGP- Palo Verde Nuclear Generating Plant
ECT: Effluent Characterization Testing

Table 16. Individual permittees selenium waste load allocations

B Permit Limits Month Avg. Concentration (ug/L)	Daily Max Concentration (ug/L)	AZPDES (NPDES) #	Name	Serving	Status		Max Design Flow	Notes	CFS Equivalent	Assigned WLAs
Gila River: 1000	**1450**	22357	City of Goodyear 157th Ave WRF	Goodyear	Existing		4.0 MGD	(5)	6.19	Permit limits to Gila River
BWCDD: None	None									1000 ug/L
1 outfall: 1000	**1144**	25747	JRC Goodyear, LLC (Lockheed Martin)	Lockheed Martin, Gdyr	Existing	Outfall 3	0.065 MGD	(5)	0.1	Permit limits
None	None					Outfall 1	0.031 MGD			1000 ug/L
None	None					Outfall 2	0.0825 MGD			1000 ug/L
1000	**1460**	24881	Buckeye Sundance WRF	Buckeye	Existing		3.5 MGD	(5)	5.42	Permit limits
None	None	23281	Wolf WRC	Avondale	Existing		9.0 MGD	(1)	13.93	1000 ug/L
None	None	20524	CoP 91st Ave WWTP	Phoenix	Existing	Outfall 1	89.0 MGD		137.7	1000 ug/L
None	None					Outfall 2	89.0 MGD	(4)	137.7	1000 ug/L
None	None					Outfall 4	1.2 MGD		1.86	1000 ug/L
None	None					Outfall 5	80 MGD		123.78	1000 ug/L
1000	**1459**	20338	Tolleson WWTP	Tolleson	Existing		17.5 MGD	(2)	27.08	Permit limits
None	None	25500	Palo Verde WWTP	Buckeye	Proposed		0.5 MGD	(5)	0.77	1000 ug/L
1000	**1500**	23582	City of Goodyear Corgett Wash WRF	Goodyear	Existing		0.8 MGD		1.24	Permit limits
None	None	25313	Central Buckeye WWTP	Buckeye	Existing		4.0 MGD	(3), (5)	6.19	1231 ug/L
--	--*	24341	Salt River Project	SW Phoenix Metro Area	Existing		N.A.	(6)	12.8	1000 ug/L

Notes:
(1) Avg. 4.87 MGD, 2008-2012
(2) 6.89 MGD (avg daily)
(3) expanding to 6.0 MGD (9.28 CFS expanded equivalent)
(4) Exclusive alternate to Outfall 1
(5) Discharge to Buckeye Canal system; see Figure 15.
(6) Flow value used is average daily flow for Buckeye Feeder Canal for 2012-2014
PVNGP- Palo Verde Nuclear Generating Plant
* - SRP wells assigned an allocation have no permit limits in 2011 renewal.

Table 17. Individual permittees boron waste load allocations

7.4 Results and Discussion

Table 18 exhibits aggregate load reductions necessary for the impaired Gillespie Dam reach to come into attainment status. These figures are presented as mass-based (kg/day) values. In each instance, Category 5 (Low flow) data was lacking for both analytes. The top row of data for each analyte's summary table presents an overall existing load benchmark for the entire population of data. The TMDL target and aggregate load allocation (TMDL less MOS) for this row are weighted summations based on the percentage of the flow duration curve each populated data category occupies compared to the total class percentages occupied (i.e., Class 5 excluded due to a lack of data). The critical condition (highlighted) has been identified as the lowest flow category for each analyte with data to evaluate; for both analytes, this was Category 4 (Dry Conditions). These tiers reflect the greatest necessary reductions of the populated classes. Refer to the load duration curves in Appendix A for graphical representations of this summary data.

Results of the TMDL study confirm that the reach is consistently impaired for both total boron and total selenium with dry conditions identified as the most problematic flow regime. Only in flood or high flow conditions do concentrations of the impairment analytes approach the attainment of standards. Since water courses of the area other than the Salt River (Waterman Wash, Centennial Wash, Hassayampa River, and the Agua Fria River) are generally ephemeral, and critical loading conditions were identified as dry conditions, source inputs were relatively geographically limited and meteorologically distinct. These characteristics thus contributed to a more definitive identification of problem sources and processes. Discharges of agricultural irrigation tail water and degraded excess supply water, brackish or saline pumped groundwater discharges from the state-designated "waterlogged area," and the industrial and wastewater discharges of some permittees, in descending order of significance, are all contributors to the problem. Interflow of infiltrated irrigation water finding its way to the Gila River channel also plays a role in certain areas. The recycling of irrigation water within and across irrigation districts leads to highly-degraded water quality of discharged volumes into the Gila River itself or the Hassayampa River. The problems are persistent, as evidenced by repeated water quality standards exceedances since the late 1980s. The problems are also significant; exceedances generally surpass standards by a multiple factor for both boron and selenium. Boron and selenium concentrations consistently exhibit an inverse relationship to flow magnitudes. Concentration and load duration curves in Appendix A graphically depict the analytes' levels relative to standards through the entire range of Gila River flows.

The historical record provides a great deal of data for evaluation. The number of samples available for evaluation for boron is 244; for selenium, 260. Each category, except Category 5, has enough data for strong determinations of existing loading. The effect of this number of samples is to reduce the size of the confidence interval around mean determinations and to allow for more robust determinations of the 90th percentile load for boron loading.

In part, the reductions necessary for Category 1 are relatively high because of the sheer volume of flow reflected in the category as a multiplier; when considered by concentrations alone (Appendix A). Category 1 is only a modest contributor to the problem of impairment. In either event, Category 1 contributions are the least problematic among the populated categories due to the dilution effects of flooding. This phenomenon was confirmed during sampling in storm flow events at Gillespie Dam and at other specific locations in the project area during the project’s duration, which showed lower concentrations than those typically measured for each analyte. As the table clearly demonstrates, when loads are considered, percent reductions necessary steadily increase once Category I has been accounted for.

Though these cumulative loading results generally fall short of requiring one complete order of magnitude reduction for the aggregate load allocations, the reductions required are substantial, ranging from a low of 62.7 percent (boron, moist conditions) up to 93.6 percent (selenium, dry conditions). Cumulative class-weighted single-figure reductions necessary for comparison incorporating all flow classes are 73.1 percent (boron) and 87.8 percent (selenium).

Percent Reductions Required by Flow Catogory

Boron, Total	Number of samples	Existing Loads, Kg/day	TMDL target, Kg/day	Aggregate Load Allocations, Kg/day	Percent Reductions, TMDL Target	Percent Reductions, Aggregate Load Allocations
Cumulative	244	1,396.8	417.0	375.3	70.1%	73.1%
Category 1 (0.1-10 FPE)	50	5,721.2	1,868.7	1,681.9	67.3%	70.6%
Category 2 (10.1-40 FPE)	110	979.9	406.0	365.4	58.6%	62.7%
Category 3 (40.1-60 FPE)	50	570.4	210.4	189.3	63.1%	66.8%
Category 4 (60.1-90 FPE)	34	417.1	83.2	74.8	80.1%	82.1%
Category 5 (90.1-99.9 FPE)	0	--	22.7	20.5	N.A.	N.A.

Selenium, Total	Number of samples	Existing Loads, Kg/day	TMDL target, Kg/day	Aggregate Load Allocations, Kg/day	Percent Reductions, TMDL Target	Percent Reductions, Aggregate Load Allocations
Cumulative	260	3.32	0.449	0.404	86.5%	87.8%
Category 1 (0.1-10 FPE)	57	8.53	1.565	1.409	81.6%	83.5%
Category 2 (10.1-40 FPE)	127	2.22	0.553	0.498	75.1%	77.6%
Category 3 (40.1-60 FPE)	50	1.51	0.308	0.277	79.6%	81.7%
Category 4 (60.1-90 FPE)	26	0.97	0.068	0.062	92.9%	93.6%
Category 5 (90.1-99.9 FPE)	0	--	0.020	0.018	N.A.	N.A.

FPE - Flow Percent Exceedance

Cumulative weighted TMDL targets adjusted to reflect populated categories only.

Table 18. Load reductions required, Gila River. Critical condition categories shaded in red.

8.0 TMDL Implementation

TMDL implementation plans are required by A.R.S. 49-234, paragraphs G, H, & J for those navigable waters listed as impaired and for which a TMDL has been completed pursuant to §303(d) of the Clean Water Act. This section and Appendix D serve as the implementation plan for the Middle Gila River boron and selenium TMDLs. Appendix D consists of excerpts from EPA's Management Measures to control nonpoint source pollution. 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 meant to suggest possible improvements and BMPs that can be employed to improve water quality. The time frame for the attainment of water quality standards is dependent upon the degree to which improvements are made and the timeline of those improvements in land use practices. Wholesale and prompt adoption and implementation of measures that will improve water quality and deliver economic gains in the long run will result in rapid improvement in boron and selenium loading, particularly since the project area is usually hydrologically-constrained, and unaccounted outside influences from other sources are minimal. An initial time frame of five years from the date of approval of these TMDLs is provisionally established.

Permitting considerations adopted by these TMDLs in support of achieving implementation aims are comprehensively presented in Section 7.3. In summary, individual permittees currently discharging to the Gila River or its immediate tributaries within the defined project area (or otherwise specifically included) have waste load allocations set equal to their current permit limits, as these limits are consistent with water quality standards in the impaired reach (Table 16, Table 17). Individual permittees with higher permit limits than Gila River standards and discharging to one of the canal systems in the project area have altered permit limits recommended for future permit renewals, with customized current performance waste load allocations determined based on facility/operation data (Table 14, Table 15). All permittees in the defined central project area previously considered as lacking reasonable potential for boron exceedances and therefore not given AZPDES permit limits for boron have had boron waste load allocations applied and recommended boron permit limits for future permit renewals presented. Individual permits will be revised as necessary to be compliant with these TMDLs as they come up for their next renewals; all permits within the central defined project area will thus be evaluated against TMDL requirements within a five year period from the date of TMDLs approval. General permittees and MS4s have been given a two-tier option for meeting the requirements of their waste load allocations, as presented in Section 7.3.2. The water quality standards of the impaired reach serve as the benchmark for consideration for both tiers.

Table 19 establishes a provisional time frame for implementation-related activities after EPA approval of these TMDLs.

Date	Activity
2015/2016	Attend initial stakeholder organizing meeting
2017	(Proposed) Initiation of NPS project
2020	All individual AZPDES permits needing revision revised
2020	Effectiveness Monitoring commences

Table 19.TMDL implementation timeline

This implementation plan is intended to provide a general framework for addressing the Gila River boron and selenium nonpoint source problems with broad-brush guidance; it will subsequently provide more focused recommendations and guidance for the implementation of more specific improvement measures on a local scale as stakeholders and interested parties come forward with proposals. Actual on-the-ground improvements in water quality will rely upon the initiative and actions of stakeholder groups and interested individuals employing standard BMPs at a local scale throughout the entire project area. 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 §319 Nonpoint Source Management Program. As a result of this federal program, states have an improved framework in their efforts to reduce nonpoint source pollution. The ADEQ Water Quality Improvement Grant Program allocates §319 grant funds from the EPA to interested parties for implementation of nonpoint source management and watershed protection. Under §319, state, private/public entities, and Indian tribes receive grant money to implement on-the-ground water quality improvement projects to control nonpoint source pollution. There is a 40 percent match requirement to nonpoint source funds disbursed through the §319 program. Other possible sources of funding that stakeholders may wish to investigate include the programs of the Natural Resources Conservation Service (NRCS) – Agricultural Management Assistance, Conservation Stewardship Program, and Environmental Quality Incentives Program, all funded through the Farm Bill; ADWR's Water Protection Fund; and the Water Infrastructure Finance Authority (WIFA) of Arizona's grant and loan programs, including the Clean Water Revolving Fund.

Assumption of voluntary responsibility for on-the-ground implementation will rest in large part with the three major irrigation districts, whose areas comprise the majority of the contributing watershed in low flow and dry conditions, the critical conditions identified by these TMDLs. The three irrigations districts, as identified previously in these TMDLs, consist of the following:

- Roosevelt Irrigation District (RID)
- Buckeye Water and Conservation Drainage District (BWCDD)
- Arlington Canal Company (ACC)

These three districts are the prime stakeholders and actors within the project's defined areal scope. ADEQ encourages the districts to consider their practices and policies with an eye towards identifying and voluntarily implementing best management practices (BMPs) consistent with their objectives and capabilities that can ameliorate excessive boron and selenium loading in the Gila River. The districts stand to be the prime beneficiaries for themselves and benefactors for their customers for improvements in water quality that have the potential to increase crop yields, reduce water losses, and reduce costs over the long run. Their actions towards improving water quality will also be welcomed by their neighbors downstream in the Gila Bend area that also rely on Gila River water for agricultural activities. Individual private landowners can also play a role in improving the Gila River's boron and selenium water quality problem through the implementation of local-scale BMPs on their land. WWTPs in the area also have a role to play, since documented discharge reports periodically show selenium discharges in particular exceeding permit limits.

Improvements in non-point source pollution problems are typically addressed through the implementation of BMPs. BMPs to control nonpoint source pollution problems are a combination of structural and non-structural (management or cultural) practices that landowners or land and water managers 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. Many BMPs are interdisciplinary in their application and can provide benefits for more than one type of land use or geomorphic process. Only BMPs of a broad scope are suggested here, and suggestions made here are not to be construed as an all-inclusive list nor as required measures mandated by this TMDL.

As current agricultural and irrigation practices are considered the prime nonpoint source stressors to the Gila River for the impaired reach, the implementation plan must pay particular attention to suggestions for the improvement of these practices. Water quality standards attainment is unlikely unless current practices are modified. Where agricultural activities are concerned, water quality is generally benefitted through BMPs by the establishment of filter strips and riparian buffer zones; 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, advantageous scheduling of irrigation activities, and light engineering measures. Measures like these are addressed further in Appendix D, which considers and addresses agriculture on a nation-wide basis. For the major canals of the study area, it is specifically recommended that canals that have not been lined with concrete are modified with that improvement, or piping be considered for the transport of irrigation water where feasible. The Roosevelt Canal serves as a model in this regard. Not only would the improvement prevent the infiltration of large concentrated slugs of marginal-quality water with eventual uncontrolled interflow to the Gila River channel, but it would also carry long-term economic benefits for members of the irrigation districts and the district administrations themselves. The loss of water in unlined canals constitutes an ongoing economic inefficiency, as this water must be paid for and yet serves no purpose in its loss. Appendix D presents a more comprehensive listing of potential measures available. It is excerpted from EPA's Management Measures for agricultural water. It highlights several BMPs that can improve water quality. Additional references are cataloged in the reference section.

The Food and Agriculture Organization of the U.N. (FAO) summarizes irrigation water quality issues as follows. These conclusions are directly pertinent to the study at hand:

> Agricultural subsurface drainage water presents the single greatest threat to water quality. The need for drainage is often quoted as a mechanism to eliminate the hazards from waterlogging and salinity in irrigated land. A drainage scheme can be implemented for engineering or economic reasons, but *in either case the drainage water created by the scheme will contain a high concentration of salts. Careful consideration must be given to its disposal so that the water supplies downstream are not polluted*. (emphasis added)
>
> *The disposal of highly saline drainage water into river courses may need to be controlled in order to meet certain minimum standards of water quality for irrigated agriculture in downstream areas. Changes in downstream agricultural practices may be necessary to adapt to the inferior water quality, or alternative schemes may need to be implemented where the drainage or other wastewater is isolated form the main water supply.* … (Ayers, 1985).

In subsequent passages, FAO comments on the desirability of re-using wastewater from domestic sources, thereby releasing higher quality water for other purposes. This measure has already been adopted in the region, with effluent comprising almost the entirety of surface water flow in the project area. FAO also advocates the re-use of irrigation water multiple times, until no further use is possible. For reasons subsequently discussed, the combination of this practice with the release of degraded water into waterways at the end of the system is exacerbating water quality problems for the Gila River.

Generally, there have been three main approaches recognized that can be considered in pollutant reductions. Ayers (1976) identified the three approaches as:

1. Establishment of a “No-discharge” policy whereby no waste water or return flow water is allowed off the farm.
2. Establishment of a practice of diluting waste water to acceptable water quality before discharge.
3. Allow the discharge of waters that cannot be further used for any purpose while disallowing the discharge of water that still has possible uses.

Each of these approaches has their own merits and drawbacks, which Ayers discusses further.

Not mentioned in this discussion is a fourth possibility – that of preventing excessive degradation of water supplies by adopting a single-use strategy before discharge. In several respects, this may prove to be the most viable, cost-effective, and versatile approach available, addressing both quantity and quality concerns. Further discussion on such an approach follows in Section 8.1.1.

For this implementation plan, water quality concerns alone are being considered in the presentation of possible solutions. Measures discussed subsequently as possible remedies to the excess loading of boron and selenium, along with high-salinity discharges, do not consider any possible water quantity claims on water by downstream users. Investigation of surface water rights of downstream (below Gillespie Dam) users of Gila River effluent is beyond the scope of these TMDLs. Some BMPs suggested affect the quantity of water available for further use downstream; others do not. Measures suggested that would reduce or entirely curtail discharges to the Gila River may not be feasible or appropriate if downstream surface water claims exist and are legally enforceable. As with many other water-related issues for such a scarce resource in Arizona, there are trade-offs to be thoroughly considered between quantity and quality in the adoption of any measures to improve water quality.

8.1 Irrigation Strategies

8.1.1 Single-Use Irrigation

California's San Joaquin Valley has dealt with some of the same issues affecting the Middle Gila area of Arizona with innovative strategies. The State Resources Water Control Board of California promotes single-use irrigation in areas where high salinity is a concern and other options are insufficiently developed or infeasible:

> A few examples exist, e.g. the San Joaquin River Water Quality Improvement Project (SJRIP) operated by Panoche Drainage District, where drainage water is used only a single time for the irrigation of salt-tolerant crops and forages… Although not the preferred system for long-term sustainability, single use may be employed in the initial stages of a drainage water re-use project when a means of drainage water disposal is needed and a long-term commitment and funds for the installation of a complete drainage system have not been secured. However, in order to control soil salinization, maintain the permeability of the soil and productivity of the plants growing in the re-use area, and stay in compliance with environmental regulations, it is likely that tile drains would need to be installed throughout the re-use area. Eventually, it would need to convert to a multiple re-use system similar to IFDM (Westside RCD, 2005).

It is noted here that the irrigation districts surrounding Yuma, Arizona have successfully incorporated a long-term single-use strategy for their irrigation needs. Irrigation water throughout their systems is applied only one time to the land's surface. Drainage water pumped or drained from productive lands is discharged to a separate concrete-lined drainage system, which is then conveyed apart from the main source water supply canal system for eventual blending and treatment where appropriate with Colorado River water before the water is returned to the Colorado River and crosses the U.S. border at Morelos Dam. Such an approach, with modifications appropriate to the Middle Gila area, may be feasible for this region as well.

8.1.2 Integrated on-Farm Drainage Management

Alternatively, the same document presents a model of an Integrated on-Farm Drainage Management (IFDM), where irrigation water is re-used within the boundaries of the farm to a point where further effective re-use is not possible. IFDM is an integrated water management system designed to manage irrigation, surface, and subsurface drainage flows within a farming unit and to provide the ultimate disposal of all drainage water, including saline water, in an environmentally sound manner (Westside RDC, 2005). It is summarized in the following excerpt:

> An IFDM system is an on-farm water and salt management system, using saline drainage water for irrigation as a means to manage salinity and to dispose of saline drainage water. There is no set configuration or design of an IFDM system. The following component description is based on the experimental IFDM system currently in use at Red Rock Ranch (RRR) and is only presented here to highlight potential considerations for the design of an IFDM system. The RRR system includes a border strip of trees to intercept regional groundwater flow, crop production areas for salt-sensitive crops, salt-tolerant crops and halophytes and a solar evaporator. Each of the production areas has a subsurface tile system that drains to a sump, sump pumps and piping to move the collected subsurface drainage water to each of the cropping areas or to the salt harvest area.
>
> In the first production area, irrigation or surface (tail water) water is used to irrigate salt-sensitive crops. This generally will be the largest production area in a system. The subsurface drainage water from the salt sensitive area is collected and may be blended with fresh water or tail water for use on the next production area, which is cropped with salt-tolerant plants. Drainage water from this production area is collected and used to irrigate salt-tolerant crops, such as forage grasses and halophytes. Drainage water from the halophyte production area is discharged to the solar evaporator (salt harvest area) for final disposal, leaving dry salt as a product, which may be disposed of, marketed or stored.
>
> Since all of the production areas will have subsurface drainage and pumping systems installed, there is no requirement to maintain a fixed position for each of the aforementioned production areas. It may be possible to move these areas around within the system. This will depend on the salinity status in the soil profile and the groundwater quality. This would entail developing practices such as the cyclic use of saline and good quality water…(Ibid, 2005).

The remaining brine concentrate after irrigation cycles is then treated through the use of solar evaporators, which are worthy of independent discussion as a BMP:

> The Salt Harvest Area is the final treatment point of saline drainage water in the IFDM system. As a result of the evaporation that occurs in the solar evaporator, a dry salt product will be produced. … The salt harvest area consists of a solar evaporator or solar evaporator and water catchment basin. “Solar evaporator” means an on-farm area of land and its associated equipment that meets all of the following conditions:
>
> 1. It is designed and operated to manage agricultural drainage water discharged from the IFDM system.
> 2. The area of the land that makes up the solar evaporator is equal to, or less than, two percent of the area of the land that is managed as the IFDM system.
> 3. Agricultural drainage water from the IFDM system is discharged to the solar evaporator by timed sprinklers or other equipment that allows the discharge rate to be set and adjusted as necessary to avoid standing water within the solar evaporator or, if

a water catchment basin is part of the solar evaporator, within that portion of the solar evaporator that is outside the basin.
4. The combination of the rate of discharge of agricultural drainage water to the solar evaporator and subsurface tile drainage under the solar evaporator provides adequate assurance that constituents in the agricultural drainage water will not migrate from the solar evaporator into the vadose zone or waters of the state in concentrations that pollute or threaten to pollute the waters of the state (Ibid, 2005).

In such a scenario, the goal is to prevent the discharge of any high-TDS waters. Of note, each of these methods has their merits for controlling water quality. Single-use does so by limiting water's exposure to salts in the soil profile. Re-use, with salinity mitigation measures incorporated, does so by extracting maximal use out of water on the farms, but then prevents any discharge of the resulting brine that degrades in-stream water quality. Either approach used exclusively would be an appropriate improvement measure to be adopted. However, the worst-case scenario results from mixing the two approaches by allowing water to discharge to the waters of the United States *after* attempting to extract maximal use from it. Such a misguided approach ensures that discharged water quality will be much worse than it otherwise would be and directly contributes to the impairment of the Gila River.

8.1.3 Blending

One method for improving water quality consists of blending waters if higher quality water is available:

> Changing water supplies is a simple but drastic solution to a water quality problem. This is only possible if a better quality supply is available. For example, a poor quality groundwater is usually abandoned if a better quality supply becomes available, but this is not necessary if there is still a water supply shortage. Under these conditions, consideration should be given to blending the poorer with the better quality supply, thus increasing the total quantity of usable water available. Blending will not reduce the total salt load but may allow more crop area to be planted because of the increase in volume caused by dilution. The guidelines of Table 1 can be used to evaluate the usability of the blended supply which should also be evaluated carefully to ensure that the total quantity of additional water needed for salinity control (the additional leaching requirement) does not exceed the net gain in amount of blended water available. The quality of the blended water can be found by using equation (13):
>
> $$\text{Concentration of the blended water} = \left[\text{Concentration of water (a)} \cdot \text{proportion of water (a) used}\right] + \left[\text{Concentration of water (b)} \cdot \text{proportion of water (b) used}\right] \quad (13)$$
>
> where the concentration can be expressed as either ECw or me/l but the same units of concentration must be used throughout the equation.

> Blending water supplies for salinity control is not a common practice. Most users alternate between the two supplies. Alternating use can be beneficial, particularly in locations where winter rains or winter irrigations are used to meet most or all of the leaching requirement. Since the total salt load applied will remain the same, it may be advisable to use the better quality supply in the early part of the cropping season and the poorer quality blend later when the crop is less sensitive to salinity. An example of blending is given in Example 5 and Table 10 (Ayers, 1985).

Currently, blending in the project area canals is done to augment the water supply, as waters with reasonable quality at canal origins becomes progressively degraded by the addition of lower-quality water throughout the system. The use of blending specifically to improve water quality has neither been examined nor implemented. Any such strategy would rely upon the availability of higher-quality water and the legality of such approaches in Arizona, where groundwater extraction is strictly regulated. One possibility for exploration might be the diversion and/or impoundment of excess storm water flow in the Gila or Hassayampa rivers for supplementation and blending during low-flow periods.

8.1.4 Evaporation Ponds/ Artificial Groundwater Recharge

One possibility for the use of excess and recycled irrigation water is the employment of evaporation ponds, which can also serve as local groundwater recharge basins. The CASS Phase II report summarizes:

> Artificial groundwater recharge is a common practice used for excess effluent to store water for future reuse. Effluent recharge requires a recharge permit from ADWR and an Aquifer Protection Permit (APP) from the Arizona Department of Environmental Quality (ADEQ). Soil aquifer treatment, while quite effective in improving water quality for a number of parameters, does not reduce TDS. Over time, effluent recharge can increase the salinity of native groundwater. If salinity concentration in effluent is significantly greater than native groundwater, the storage/recharge project may not meet anti-degradation standards of the ADEQ APP program and may not be permitted (CASS, 2006).

One typical drawback to this approach has to do with the extensive land requirements necessary for adequate spreading and recharge. In urban areas, such land requirements can be cost-prohibitive. In the project area, there exists a great deal of open desert land to the west of the Hassayampa River channel, where costs would likely be considerably lower. The possibility of high TDS effluent degrading existing groundwater supplies cannot be dismissed, yet as Figure 12 shows, areas of Centennial Wash and to the west of Arlington, Arizona likely already have brackish groundwater, judging from soil salinity values. The addition of high-salinity groundwater to these aquifers may not appreciably affect the aquifers' existing TDS values.

8.2 Salinity Control in Central Arizona

CASS has produced two detailed and comprehensive reports examining the increasing salinity problem in central Arizona and recommending solutions. Salinity is an all-pervasive and persistent problem, and solutions do not come without substantial cost and the commitment of parties involved, namely, the municipalities and other legal administrative entities of the state. CASS's Phase I report focused on solutions to prevent the importation of high-TDS waters into central Arizona. A number of the proposals consisted of the construction of reverse osmosis plants along the CAP and Salt River to pre-treat waters entering the Phoenix municipal water utilities to an acceptable level of TDS (generally considered 450 mg/L). The recommendations of this report are considered too broad-scale and beyond the scope of these TMDLs for consideration, though their adoption might well improve source water quality.

CASS's Phase II report focused in part upon the reclamation of brackish groundwater, with specific attention given to the southwest Phoenix metro area and the City of Goodyear as a test case. The recommendations of this report are more pertinent to these studies and are in part excerpted here. Though the report is geared towards discussion and solutions for augmenting water supplies, the methods by which water quality may be improved are also applicable in part for the reclamation of discharged agricultural drain and tail water. CASS concludes the report as follows:

> Through the review of existing brackish treatment facilities, regulatory codes, water quantity and quality, and several treatment processes, the use of brackish groundwater in central Arizona to supplement potable water supplies can be determined. Based on the work completed to date, the following conclusions in regard to viability of brackish groundwater desalination can be made.

- **Benchmarking** – Brackish groundwater in the southwestern U.S. is desalted using either RO [reverse osmosis] membranes or EDR [electro-dialysis reversal]. RO seems to be more prominent due to the need to remove other constituents in addition to TDS. The most common concentrate disposal methods include evaporation ponds, discharge to sanitary sewers, and ocean outfalls.
- **Regulatory Issues** – Permeate from the desalination of brackish groundwater will need to meet all federal, state, and local water quality regulations. In addition, pumped groundwater must meet ADWR's Groundwater Management Code to assure long-term water supplies. However, there may be some relief of this requirement in certain waterlogged areas.
- **Water Quantity and Quality** – Water quantity in the WSRV [West Salt River Valley] is still under investigation to determine the long-term viability of this water source. However based on water quality data available from ADWR and CASS participants, it appears that this brackish groundwater source will need to be treated for nitrates and silica in addition to TDS.
- **Treatment Options –** RO and EDR are the most viable treatment options at this time for brackish groundwater desalination. However, EDR is a sole source product, which may limit the ability for utilities to use this technology. In addition, feed water quality may dictate which technology should be used. In many cases, it may be beneficial to use a blending scenario in order to meet water quality goals. These blending scenarios may also mitigate the need to post-treat or stabilize water prior to sending to the distribution system.

- **Concentrate Management –** Two main concentrate disposal alternatives are currently being used by desalination facilities: evaporation ponds and sanitary sewer discharge. Both technologies have downfalls that may limit the amount of brackish groundwater than can be utilized. Until new concentrate management options are developed, the use of brackish groundwater is limited.

Future Research Needs

As the population in the Phoenix metropolitan area continues to grow from 3 million to 12 million, future additional water sources will be needed. Brackish groundwater may provide an additional source; however, there are currently several limitations to implementing the use of this water source. The main limitation is the lack of convenient concentrate management strategies. At present, sewer disposal or evaporation ponds are most commonly used. The drawbacks to evaporations ponds include the large amount of land needed and acceptability by nearby well owners and residential neighbors. Therefore, sewer disposal is generally the most popular option assuming that the surrounding sewer system and WWTP can handle the additional load. Since these concentrate management options are not viable long-term solutions, future research which focuses on evaluating additional concentrate options/technologies, is necessary.

Along with concentrate management technologies, the further advances of RO and EDR technologies to recover more water, and thus produce less brine, is (sic) also desirable. This research may include developing better membranes for RO and EDR or development of new desalination technologies, such as FO [forward osmosis].

[CASS, 2006]

9.0 Public Participation

Stakeholder and public participation was encouraged and received throughout the development of these TMDLs. ADEQ held an introductory public meeting in Buckeye in 2013, where the TMDL project was introduced; subsequently, ADEQ held the final public meeting, also in Buckeye, near the conclusion of the project to present findings and results after sampling and analysis was complete. Stakeholders and interested parties contacted throughout the project duration included the cities of Buckeye, Goodyear, Avondale, and Phoenix, the Salt River Project, the Roosevelt Irrigation District, the Buckeye Water Conservation and Drainage District, the Arlington Canal Company, the Natural Resource Conservation Service, and individual local stakeholders. In concert with these TMDLs, legacy pesticide impairment listings for DDT, chlordane, and toxaphene in fish tissue were delisted for the same reach, along with 12 other reaches in the vicinity. This effort involved notification of a related and sometimes overlapping set of stakeholders and additionally included the Arizona Game and Fish Department and the U.S. Fish and Wildlife Service. Public comment on the TMDLs was invited for an initial 30 day period after the final public meeting and subsequently extended for an additional week to allow for additional comment submissions. The TMDLs were subsequently submitted to the Arizona Administrative Review for a 45 day notice period. Copies of the final TMDL will be provided to the NRCS Avondale office along with any other interested stakeholders.

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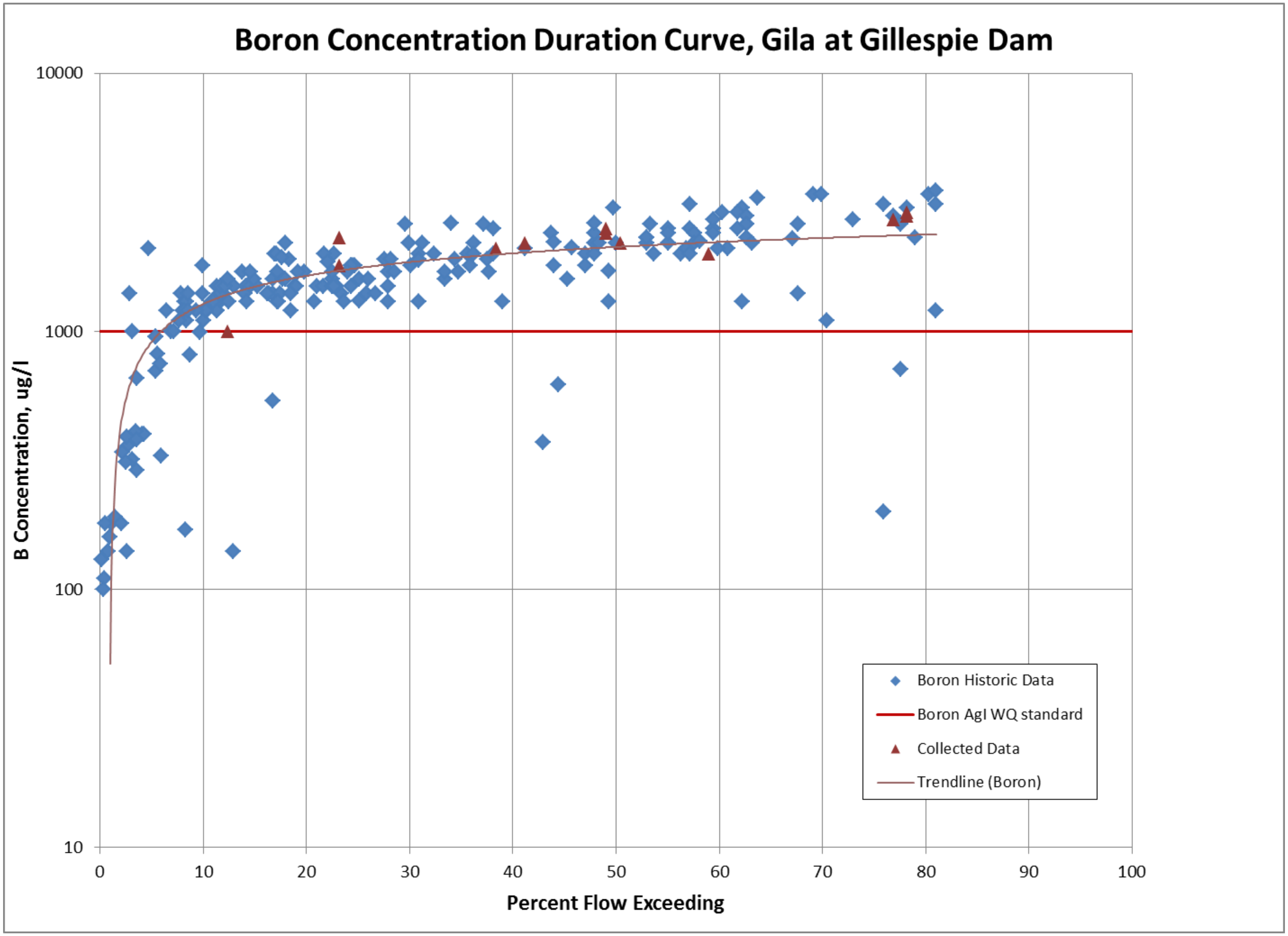
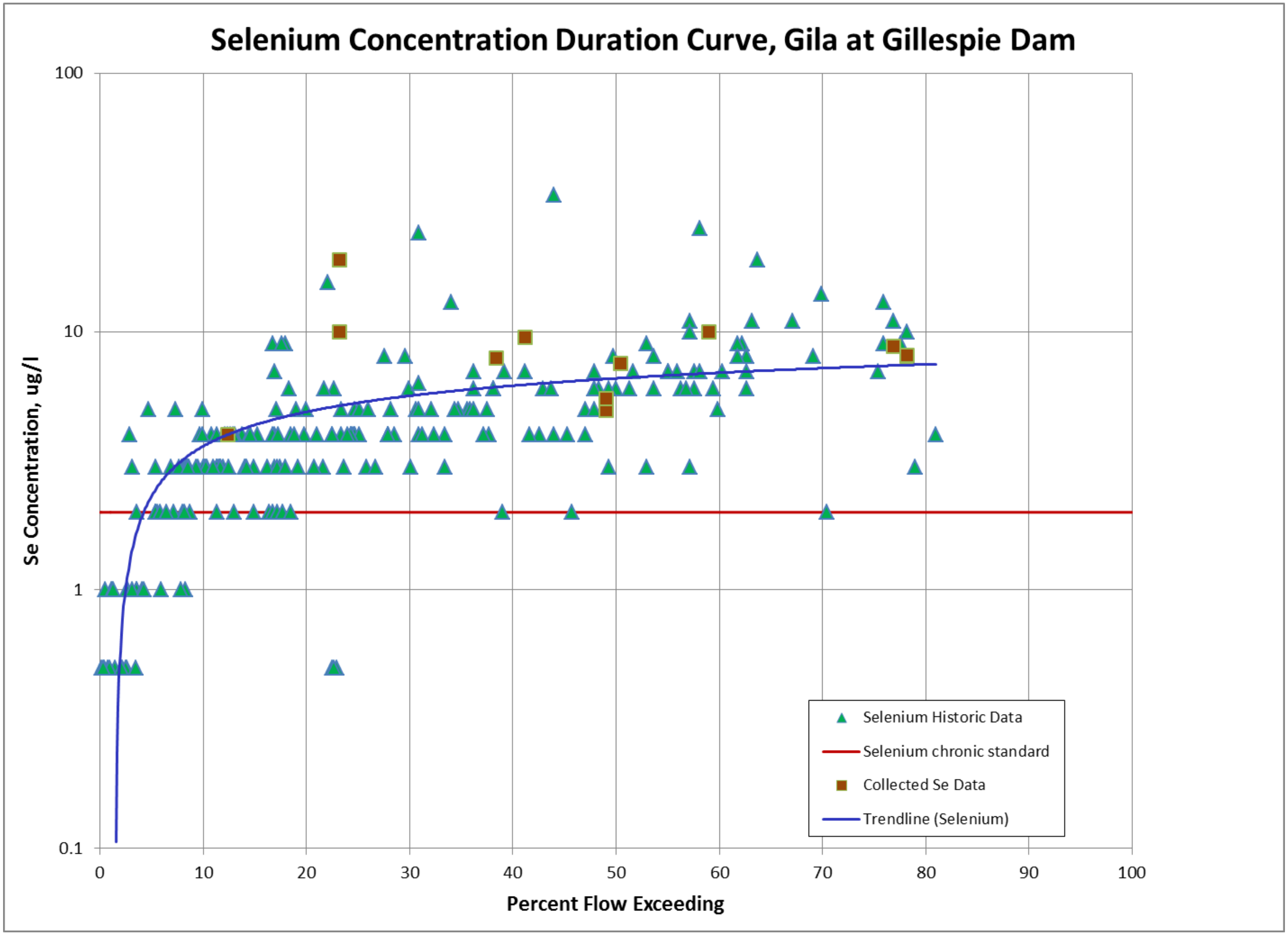
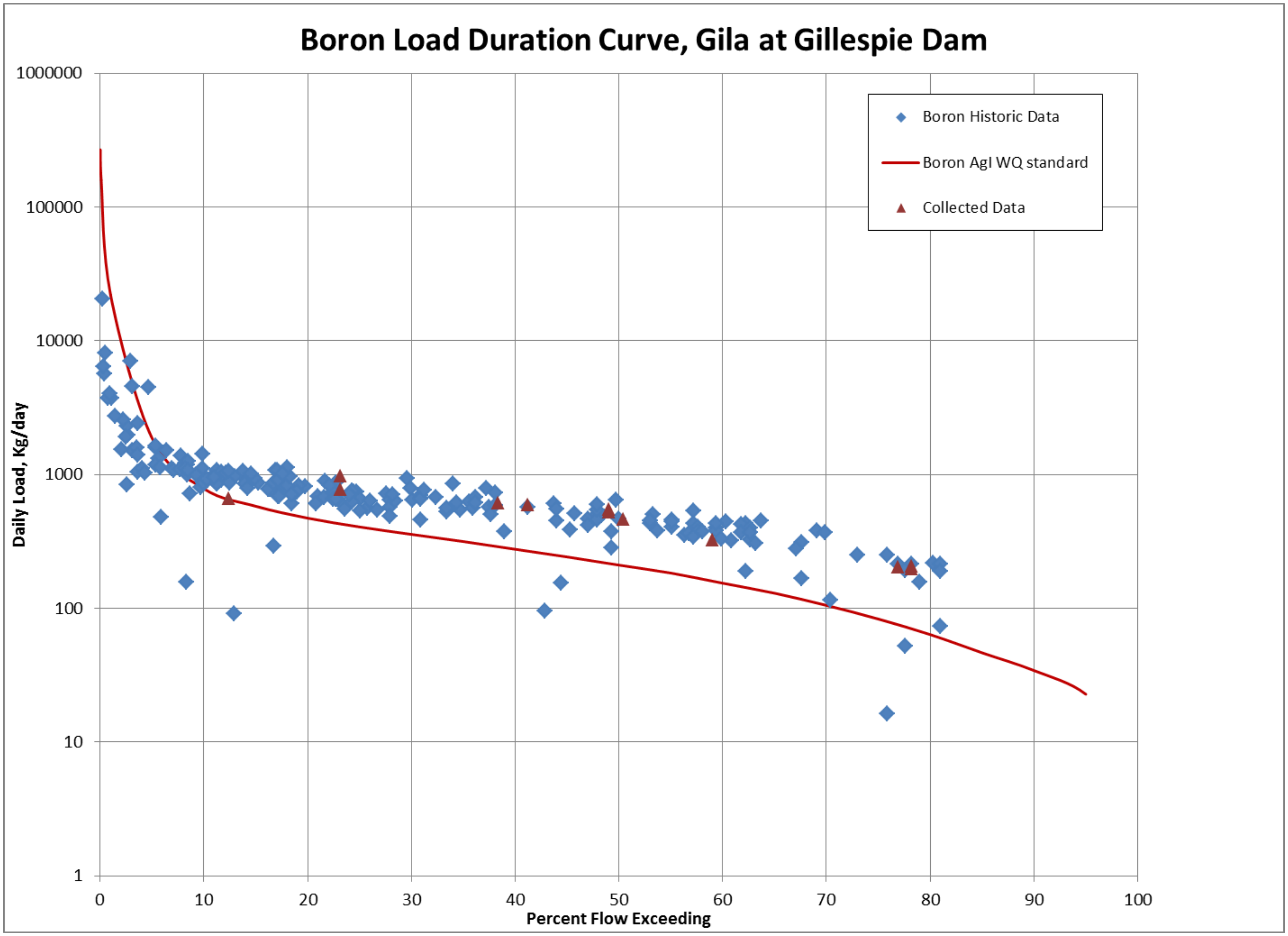
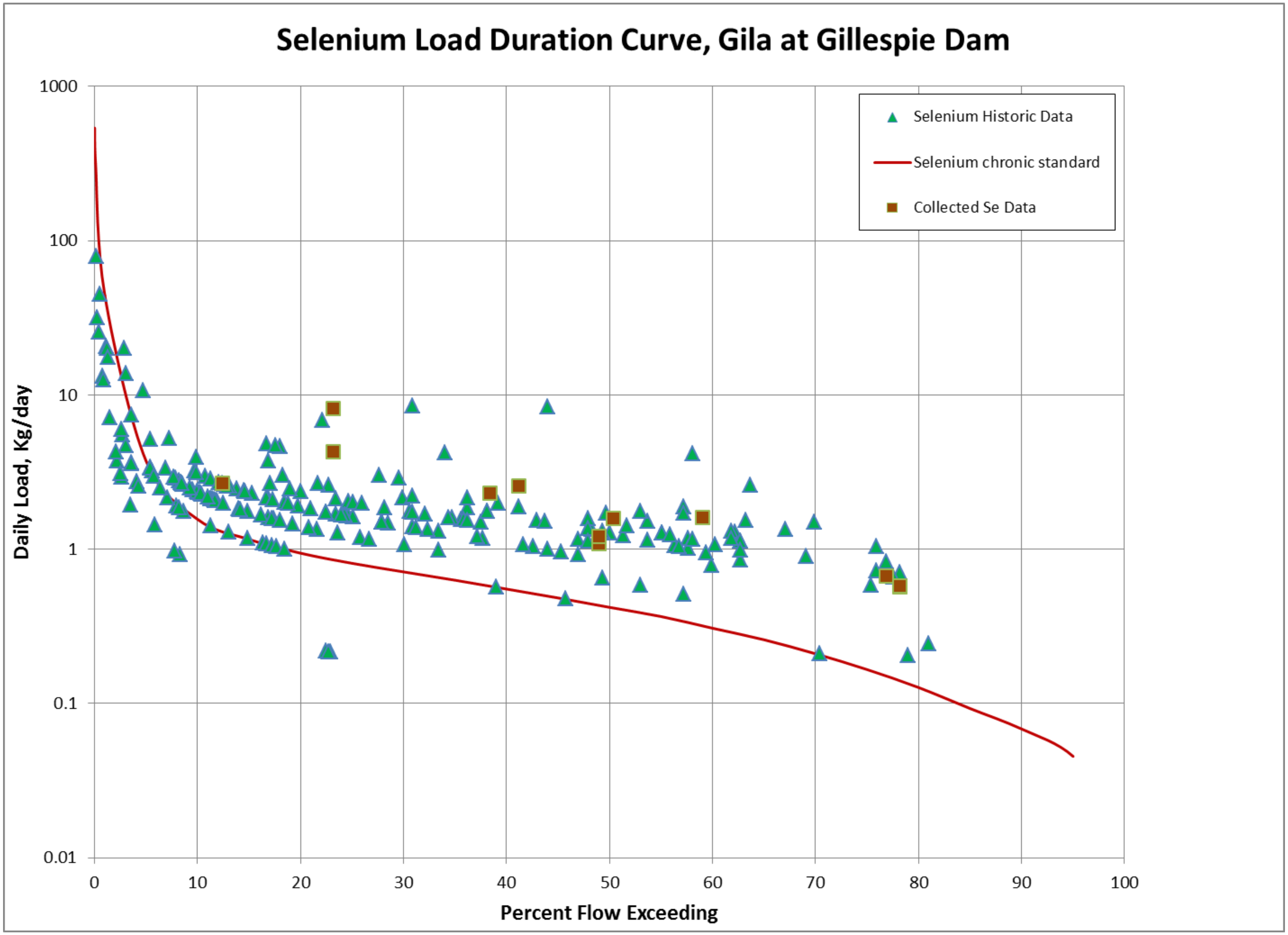
Appendix A: Duration Curves


Boron Concentration Duration Curve, Gila at Gillespie Dam
B Concentration, ug/l
10000
1000
100
10
0
10
20
30
40
50
60
70
80
90
100
Percent Flow Exceeding
Boron Historic Data
Boron Agl WQ standard
Collected Data
Trendline (Boron)


Selenium Concentration Duration Curve, Gila at Gillespie Dam
Se Concentration, ug/l
100
10
1
0.1
0
10
20
30
40
50
60
70
80
90
100
Percent Flow Exceeding
Selenium Historic Data
Selenium chronic standard
Collected Se Data
Trendline (Selenium)


Boron Load Duration Curve, Gila at Gillespie Dam
Daily Load, Kg/day
1000000
100000
10000
1000
100
10
1
0
10
20
30
40
50
60
70
80
90
100
Percent Flow Exceeding
Boron Historic Data
Boron AgI WQ standard
Collected Data


Selenium Load Duration Curve, Gila at Gillespie Dam
Selenium Historic Data
Selenium chronic standard
Collected Se Data
Daily Load, Kg/day
1000
100
10
1
0.1
0.01
0
10
20
30
40
50
60
70
80
90
100
Percent Flow Exceeding

Appendix B: Background Data

Site Description	Date	BORON, TOTAL (µg/L)	SELENIUM, TOTAL (µg/L)
HASSAYAMPA RIVER - AT NATURE CONSERVANCY	22-OCT-2008	140	ND : 5.0
HASSAYAMPA RIVER - AT NATURE CONSERVANCY	04-FEB-2009	130	ND : 5
HASSAYAMPA RIVER - AT NATURE CONSERVANCY	04-JUN-2009	140	ND : 5.0
HASSAYAMPA RIVER - AT NATURE CONSERVANCY	22-OCT-2008	140	ND : 5
HASSAYAMPA RIVER - AT NATURE CONSERVANCY	15-AUG-2008	140	ND : 5.0
HASSAYAMPA RIVER - AT NATURE CONSERVANCY	18-OCT-2001	160	ND : 5.0
HASSAYAMPA RIVER - AT NATURE CONSERVANCY	05-APR-2002	180	ND : 5.0
HASSAYAMPA RIVER - AT NATURE CONSERVANCY	17-JAN-2002	180	ND : 5.0
HASSAYAMPA RIVER - AT NATURE CONSERVANCY	06-JUN-2012	230	ND : 2.0
SALT RIVER - AT 91ST AVENUE WWTP DISCHARGE USGS 09512407	26-OCT-2012	330	ND : 2.0
SALT RIVER - AT 91ST AVENUE WWTP DISCHARGE USGS 09512407	26-OCT-2012	340	ND : 2.0
SALT RIVER - AT 91ST AVENUE WWTP DISCHARGE USGS 09512407	14-MAY-2012	370	ND : 2.0
SALT RIVER - BELOW TRES RIOS DISCHARGE	20-FEB-2002	460	ND : 25
SALT RIVER - BELOW TRES RIOS DISCHARGE	20-FEB-2002	460	ND : 25
SALT RIVER - BELOW TRES RIOS DISCHARGE	20-NOV-2001	460	ND : 5.0
SALT RIVER - BELOW TRES RIOS DISCHARGE	09-AUG-2002	480	ND : 5.0
SALT RIVER - AT 91ST AVENUE WWTP DISCHARGE USGS 09512407	27-FEB-2013	480	3.8
SALT RIVER - BELOW TRES RIOS DISCHARGE	06-MAY-2002	500	ND : 5.0
SALT RIVER - BELOW TRES RIOS DISCHARGE	06-MAY-2002	520	ND : 5.0
HASSAYAMPA RIVER - AT NATURE CONSERVANCY	28-MAR-2012	ND : 200	ND : 2.0
HASSAYAMPA RIVER - AT NATURE CONSERVANCY	07-DEC-2011	ND : 200	ND : 2.0
HASSAYAMPA RIVER - AT NATURE CONSERVANCY	06-SEP-2011	ND : 200	ND : 2.0
HASSAYAMPA RIVER - AT NATURE CONSERVANCY	06-SEP-2011	ND : 200	ND : 2.0
R.I.D. MAIN CANAL AT JOHNSON RD	19-MAR-2014	500	1.39
R.I.D. EAST LATERAL IN BUCKEYE	19-MAR-2014	520	1.08
R.I.D. MAIN CANAL GOODYEAR	19-MAR-2014	480	1.05

Table 20. Background Data. Red-shaded cells indicate data excluded due to detection limits above the WQ standard.

Appendix C: Predictive Modeling
TDS Regression on Historical Data

Historical water quality data for the Gillespie Dam site was evaluated by single and multiple linear regressions to determine the critical variable values beyond which exceedances of the boron and selenium standards were likely. TDS and mean daily flow were selected as the explanatory variables for consideration. For boron, 183 data points for which correlating TDS data were available were examined. One data point outlier was eliminated from consideration after consultation with USGS (the collecting agency for the data) for a total of 182 data points. The strongest relationship was found to be a linear relationship considering only TDS as the explanatory variable for boron. An R^2 value of 0.879 was obtained with a corresponding p-value of less than 0.001. Homoscedasticity was exhibited in the residual plot of the regression. The regression equation was determined to be:

B (concentration, μg/L) = 0.784*TDS (mg/L) -258.36

With this equation, solving for TDS with a boron standard of 1,000 μg/L yields a critical TDS value of **1,605** mg/L. TDS values in the impaired reach above this level are likely to show boron exceedances. Plots for the regression are shown in Figure 16.

A similar analysis was carried out for 205 historical selenium data points for which correlating TDS values were available. No data was excluded from the selenium data set. Again, the strongest predictive relationship was found in consideration of only TDS as an explanatory variable. Selenium, however, differed from boron in that heteroscedasticity was exhibited in a strict linear-linear plot. Consequently, selenium data were transformed with base-10 logs such that a log-linear plot of selenium versus TDS yielded acceptable results. An R^2 value of 0.753 was determined through this analysis, with p-values for both the constant and TDS variable of less than 0.001. Several substituted selenium values were used in this analysis where dissolved selenium values exceeded their coinciding total selenium values in the data record. These larger values were used instead of total values, since by definition, the total values must at least equal the dissolved fraction analysis. Regression results were stronger after the substitution, since several low outliers were replaced by this substitution. The final predictive equation for selenium was:

$$\mathbf{Log_{10}(Se)\ (concentration,\ \mu g/L) = (3.467x10^{-4})\ *TDS\ (mg/L) - 0.228}$$

A similar solving for the TDS threshold value beyond which chronic selenium exceedances would be likely found a critical TDS value of **1,525** mg/L. In consideration of both boron and selenium, the more restrictive TDS predictive value of 1,525 mg/L is adopted as a benchmark evaluation of whether both analytes are likely to meet their water quality standard and TMDL targets.

Evaluation of data from the project sampling effort suggests that recycling of source water will prevent targets from being met. Data from source water prior to irrigation shows a mean TDS value of approximately 1,000 mg/L. Data from water that appears to have been through one cycle of irrigation, which is then discharged to the main canal or the hydrologic network shows a mean TDS value of about 2,500 mg/L. Data from locations which suggest up to two cycles have occurred, whether partially or in full, or where groundwater is being actively extracted from the designated waterlogged areas show an

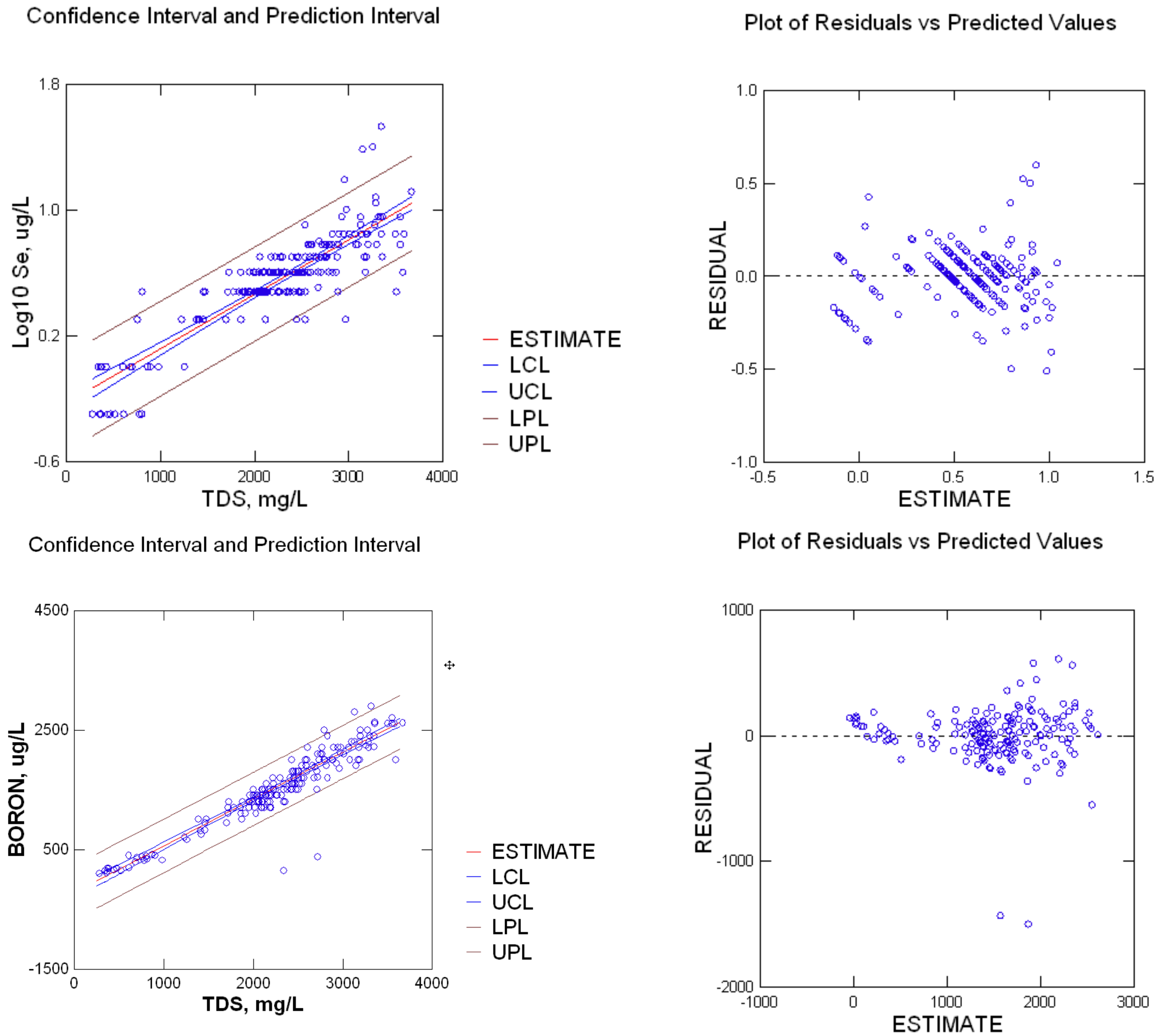


Figure 16. Boron and selenium concentrations vs TDS

Acronyms: LCL – Lower confidence level; UCL – Upper confidence level; LPL – Lower prediction level; UPL – Upper prediction level.

average TDS value of around 4,000 mg/L. These circumstances strongly suggest that alternative methods of discharge of excess water be examined.

Appendix D: Irrigation Water Management Measures

Excerpts from

Management Measures for Agricultural Sources

Irrigation Water Management

To reduce nonpoint source pollution of surface waters caused by irrigation:

1. Operate the irrigation system so that the timing and amount of irrigation water applied match crop water needs. This will require, as a minimum: (a) the accurate measurement of soil-water depletion volume and the volume of irrigation water applied, and (b) uniform application of water.
2. When chemigation is used, include backflow preventers for wells, minimize the harmful amounts of chemigated waters that discharge from the edge of the field, and control deep percolation. In cases where chemigation is performed with furrow irrigation systems, a tail water management system may be needed.

The following limitations and special conditions apply:

1. In some locations, irrigation return flows are subject to other water rights or are required to maintain stream flow. In these special cases, on-site reuse could be precluded and would not be considered part of the management measure for such locations.
2. By increasing the water use efficiency, the discharge volume from the system will usually be reduced. While the total pollutant load may be reduced somewhat, there is the potential for an increase in the concentration of pollutants in the discharge. In these special cases, where living resources or human health may be adversely affected and where other management measures (nutrients and pesticides) do not reduce concentrations in the discharge, increasing water use efficiency would not be considered part of the management measure.
3. In some irrigation districts, the time interval between the order for and the delivery of irrigation water to the farm may limit the irrigator's ability to achieve the maximum on-farm application efficiencies that are otherwise possible.
4. In some locations, leaching is necessary to control salt in the soil profile. Leaching for salt control should be limited to the leaching requirement for the root zone.
5. Where leakage from delivery systems or return flows supports wetlands or wildlife refuges, it may be preferable to modify the system to achieve a high level of efficiency and then divert the "saved water" to the wetland or wildlife refuge. This will improve the quality of water delivered to wetlands or wildlife refuges by preventing the introduction of pollutants from irrigated lands to such diverted water.
6. In some locations, sprinkler irrigation is used for frost or freeze protection, or for crop cooling. In these special cases, applications should be limited to the amount necessary for crop protection, and applied water should remain on-site.

1. Applicability

This management measure is intended to be applied by States to activities on irrigated lands, including agricultural crop and pasture land (except for isolated fields of less than 10 acres in size that are not contiguous to other irrigated lands); orchard land; specialty cropland; and nursery cropland. Those landowners already practicing effective irrigation management in conformity with the irrigation water management measure may not need to purchase additional devices to measure soil-water depletion or the volume of irrigation water applied, and may not need to expend additional labor resources to manage the irrigation system. Under the Coastal Zone Act Reauthorization Amendments of 1990, States are subject to a number of requirements as they develop coastal nonpoint programs in conformity with this measure and will have some flexibility in doing so. The application of management measures by States is described more fully in *Coastal Nonpoint Pollution Control Program: Program Development and Approval Guidance*, published jointly by the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce.

2. Description

The goal of this management measure is to reduce nonpoint source pollution of surface waters caused by irrigation. For the purposes of this management measure, "harmful amounts" are those amounts that pose a significant risk to aquatic plant or animal life, ecosystem health, human health, or agricultural or industrial uses of the water.

A problem associated with irrigation is the movement of pollutants from the land into ground or surface water. This movement of pollutants is affected by the pathways taken by applied water and precipitation (Figure 2-15); the physical, chemical, and biological characteristics of the irrigated land; the type of irrigation system used; crop type; the degree to which erosion and sediment control, nutrient management, and pesticide management are employed; and the management of the irrigation system.

Return flows, runoff, and leachate from irrigated lands may transport the following types of pollutants:

- Sediment and particulate organic solids;
- Particulate-bound nutrients, chemicals, and metals, such as phosphorus, organic nitrogen, a portion of applied pesticides, and a portion of the metals applied with some organic wastes;
- Soluble nutrients, such as nitrogen, soluble phosphorus, a portion of the applied pesticides, soluble metals, salts, and many other major and minor nutrients; and
- Bacteria, viruses, and other microorganisms.

Transport of irrigation water from the source of supply to the irrigated field via open canals and laterals can be a source of water loss if the canals and laterals are not lined. Water is also transported through the lower ends of canals and laterals because of the flow-through requirements to maintain water levels in them. In many soils, unlined canals and laterals lose water via seepage in bottom and side walls. Seepage water either moves into the ground water through infiltration or forms wet areas near the canal or lateral. This water will carry with it any soluble pollutants in the soil, thereby creating the potential for pollution of ground or surface water.

Since irrigation is a consumptive use of water, any pollutants in the source waters that are not consumed by the crop (e.g., salts, pesticides, nutrients) can be concentrated in the soil, concentrated in the leachate or seepage, or concentrated in the runoff or return flow from the system. Salts that concentrate in the soil profile must be removed for sustained crop production.

For additional information regarding the problems caused by these pollutants, see Section I.F of this chapter.

Application of this management measure will reduce the waste of irrigation water, improve the water use efficiency, and reduce the total pollutant discharge from an irrigation system. It is not the intent of this management measure to require the replacement of major components of an irrigation system. Instead, the expectation is that components to manage the timing and amount of water applied will be provided where needed, and that special precautions (i.e., backflow preventers, prevent tail water, and control deep percolation) will be taken when chemigation is used.

Irrigation scheduling is the use of water management strategies to prevent over-application of water while minimizing yield loss due to water shortage or drought stress (Evans et al., 1991d). Irrigation scheduling will ensure that water is applied to the crop when needed and in the amount needed. Effective scheduling requires knowledge of the following factors (Evans et al., 1991c; Evans et al., 1991d):

- Soil properties;
- Soil-water relationships and status;
- Type of crop and its sensitivity to drought stress;
- The stage of crop development;
- The status of crop stress;
- The potential yield reduction if the crop remains in a stressed condition;
- Availability of a water supply; and
- Climatic factors such as rainfall and temperature.

Much of the above information can be found in Soil Conservation Service soil surveys and Extension Service literature. However, all information should be site-specific and verified in the field.

There are three ways to determine when irrigation is needed (Evans et al., 1991d):

- Measuring soil water;
- Estimating soil water using an accounting approach; and
- Measuring crop stress.

Soil water can be measured using a range of devices (Evans et al., 1991b), including tensiometers, which measure soil water suction; electrical resistance blocks (also called gypsum blocks or moisture blocks), which measure electrical resistance that is related to soil water by a calibration curve; neutron probes, which directly measure soil water; Phene cells, which are used to estimate soil water based on the relationship of heat conductance to soil water content; and time domain reflectometers, which can be used to estimate soil water based on the time it takes for an electromagnetic pulse to pass through the soil. The appropriate device for any given situation is a function of the acreage of irrigated land, soils, cost, and other site-specific factors.

Accounting approaches estimate the quantity of soil water remaining in the effective root zone and can be simple or complex. In essence, daily water inputs and outputs are measured or estimated to determine the depletion volume. Irrigation is typically scheduled when the allowable depletion volume is nearly reached.

Once the decision to irrigate has been made, it is important to determine the amount of water to apply. Irrigation needs are a function of the soil water depletion volume in the effective root zone, the rate at which the crop uses water, and climatic factors. Accurate measurements of the amount of water applied are essential to maximizing irrigation efficiency. The quantity of water applied can be measured by such devices as a totalizing flow meter that is installed in the delivery pipe. If water is supplied by ditch or canal, weirs or flumes in the ditch can be used to measure the rate of flow.

Deep percolation can be greatly reduced by limiting the amount of applied water to the amount that can be stored in the plant root zone. The deep percolation that is necessary for salt management can be accomplished with a sprinkler system by using longer sets or very slow pivot speeds or by applying water during the non-growing season.

Reducing overall water use in irrigation will allow more water for stream flow control and will increase flow for diversion to marshes, wetlands, or other environmental uses. If the source is ground water, reducing overall use will maintain higher ground-water levels, which could be important for maintaining base flow in nearby streams. Reduced water diversion will reduce the salt or pollutant load brought into the irrigation system, thereby reducing the volume of these pollutants that must be managed or discharged from the system.

Although this management measure does not require the replacement of major components of an irrigation system, such changes can sometimes result in greater pollution prevention. Consequently, the following is a broader discussion of the types of design and operational aspects of the overall irrigation system that could be addressed to provide additional control of nonpoint source pollution beyond that which is required by this management measure. Overall, five basic aspects of the irrigation system can be addressed:

1. Irrigation scheduling;
2. Efficient application of irrigation water;
3. Efficient transport of irrigation water;
4. Use of runoff or tail water; and
5. Management of drainage water.

This management measure addresses irrigation scheduling, efficient application, and the control of tail water when chemigation is used. The efficient transport of irrigation water, the use of runoff or tail water, and the management of drainage water are additional considerations.

Although not a required element of this management measure, the seepage losses associated with canals and laterals can be reduced by lining the canals and laterals, or can be eliminated by conversion from open canals and laterals to pipelines. Flow-through losses will not be changed by canal or lateral lining, but can be eliminated or greatly reduced by conversion to pipelines.

Surface irrigation systems are usually designed to have a percentage (up to 30 percent) of the applied water lost as tail water. This tail water should be managed with a tail water recovery system, but such a system is not required as a component of this management measure unless chemigation is practiced. Tailwater recovery systems usually include a system of ditches or berms to direct water from the end of the field to a small storage structure. Tailwater is stored until it can be either pumped back to the head end of the field and reused or delivered to additional irrigated land. In some locations, there may be downstream water rights that are dependent upon tail water, or tail water may be used to maintain flow in streams. These requirements may take legal precedence over the reuse of tail water.

Well-designed and managed irrigation systems remove runoff and leachate efficiently; control deep percolation; and minimize erosion from applied water, thereby reducing adverse impacts on surface water and ground water. If a tail water recovery system is used, it should be designed to allow storm runoff to flow through the system without damage. Additional surface drainage structures such as filter strips, field drainage ditches, subsurface drains, and water table control may also be used to control runoff and leachate if site conditions warrant their use. Sprinkler systems will usually require design and installation of a system to remove and manage storm runoff.

A properly designed and operated sprinkler irrigation system should have a uniform distribution pattern. The volume of water applied can be changed by changing the total time the sprinkler runs; by changing the pressure at which the sprinkler operates; or, in the case of a center pivot, by adjusting the speed of travel of the system. There should be no irrigation runoff or tail water from most well-designed and well-operated sprinkler systems.

The type of irrigation system used will dictate which practices can be employed to improve water use efficiency and to obtain the most benefit from scheduling. Flood systems will generally infiltrate more water at the upper end of the field than at the lower end because water is applied to the upper end of the field first and remains on that portion of the field longer. This will cause the upper end of the field to have greater deep percolation losses than the lower end. Although not required as a component of this management measure, this situation can sometimes be improved by changing slope throughout the length of the field. This type of change may not be practical or affordable in many cases. For example, furrow length can be reduced by cutting the field in half and applying water in the middle of the field. This will require more pipe or ditches to distribute the water across the middle of the field.

3. Management Measure Selection

This management measure was selected based on an evaluation of available information that documents the beneficial effects of improved irrigation management (see Section II.F.4 of this chapter). Specifically, the available information shows that irrigation efficiencies can be improved with scheduling that is based on knowledge of water needs and measurement of applied water. Improved irrigation efficiency can result in the reduction or elimination of runoff and return flows, as well as the control of deep percolation. Secondly, backflow preventers can be used to protect wells from chemicals used in chemigation. In addition, tail water prevention, or tail water management where necessary, is effective in reducing the discharge of soluble and particulate pollutants to receiving waters.

By reducing the volume of water applied to agricultural lands, pollutant loads are also reduced. Less interaction between irrigation water and agricultural land will generally result in less pollutant transport from the land and less leaching of pollutants to ground water.

The practices that can be used to implement this measure on a given site are commonly used and are recommended by SCS for general use on irrigated lands. By designing the measure using the appropriate mix of structural and management practices for a given site, there is no undue economic impact on the operator. Many of the practices that can be used to implement this measure (e.g., water-measuring devices, tail water recovery systems, and backflow preventers) may already be required by State or local rules or may otherwise be in use on irrigated fields. Since many irrigators may already be using systems that satisfy or partly satisfy the intent of the management measure, the only action that may be necessary will be to determine the effectiveness of the existing practices and add additional practices, if needed.

4. Effectiveness Information

Following is information on pollution reductions that can be expected from installation of the management practices outlined within this management measure.

In a review of a wide range of agricultural control practices, EPA (1982) determined that increased use of call periods, on-demand water ordering, irrigation scheduling, and flow measurement and control would all result in decreased losses of salts, sediment, and nutrients. Various alterations to existing furrow irrigation systems were also determined to be beneficial to water quality, as were tail water management and seepage control.

Logan (1990) reported that chemical backsiphon devices are highly effective at preventing the introduction of pesticides and nitrogen to ground water. The American Society of Agricultural Engineers (ASAE) specifies safety devices for chemigation that will prevent the pollution of a water supply used solely for irrigation (ASAE, 1989).

Properly designed sprinkler irrigation systems will have little runoff (Boyle Engineering Corp., 1986). Furrow irrigation and border check or border strip irrigation systems typically produce tail water, and tail water recovery systems may be needed to manage tail water losses (Boyle Engineering Corp., 1986). Tailwater can be managed by applying the water to additional fields, by treating and releasing the tail water, or by reapplying the tail water to upslope cropland.

The Rock Creek Rural Clean Water Program (RCWP) project in Idaho is the source of much information regarding the benefits of irrigation water management (USDA, 1991). All crops in the Rock Creek watershed are irrigated with water diverted from the Snake River and delivered through a network of canals and laterals. The combined implementation of irrigation management practices, sediment control practices, and conservation tillage has resulted in measured reductions in suspended sediment loadings ranging from 61 percent to 95 percent at six stations in Rock Creek (1981-1988). Similarly, 8 of 10 sub-basins showed reductions in suspended sediment loadings over the same time period ….

In California it is expected that drip irrigation will have the greatest irrigation efficiency of those irrigation systems evaluated, whereas conventional furrow irrigation will have the lowest irrigation efficiency and greatest runoff fraction. Tailwater recovery irrigation systems are expected to have the greatest percolation rate. Plot studies in California have shown that in-season irrigation efficiencies for drip irrigation and Low Energy Precision Application (LEPA) are greater than those for improved furrow and conventional furrow systems. LEPA is a linear move sprinkler system in which the sprinkler heads have been removed and replaced with tubes that supply water to individual furrows (Univ. Calif., 1988). Dikes are placed in the furrows to prevent water flow and reduce soil effects on infiltrated water uniformity.

Mielke et al. (1981) studied the effects of tillage practice and type of center pivot irrigation on herbicide (atrazine and alachlor) losses in runoff and sediment. Study results clearly show that, for each of three tillage practices studied, low-pressure spray nozzles result in much greater herbicide loss in runoff than either high-pressure or low-pressure impact heads.

5. Irrigation Water Management Practices

As discussed more fully at the beginning of this chapter and in Chapter 1, the following practices are described for illustrative purposes only. State programs need not require implementation of these practices. However, as a practical matter, EPA anticipates that the management measure set forth above generally will be implemented by applying one or more management practices appropriate to the source, location, and climate. The practices set forth below have been found by EPA to be representative of the types of practices that can be applied successfully apply to achieve the management measure described above.

The U.S. Soil Conservation Service practice number and definition are provided for each management practice, where available. Also included in italics are SCS statements describing the effect each practice has on water quality (USDA-SCS, 1988).

Irrigation Scheduling Practices

Proper irrigation scheduling is a key element in irrigation water management. Irrigation scheduling should be based on knowing the daily water use of the crop, the water-holding capacity of the soil, and the lower limit of soil moisture for each crop and soil, and measuring the amount of water applied to the field. Also, natural precipitation should be considered and adjustments made in the scheduled irrigations.

Practices that may be used to accomplish proper irrigation scheduling are:

- *a. Irrigation water management (449): Determining and controlling the rate, amount, and timing of irrigation water in a planned and efficient manner.*

Management of the irrigation system should provide the control needed to minimize losses of water, and yields of sediment and sediment attached and dissolved substances, such as plant nutrients and herbicides, from the system. Poor management may allow the loss of dissolved substances from the irrigation system to surface or ground water. Good management may reduce saline percolation from geologic origins. Returns to the surface water system would increase downstream water temperature.

The purpose is to effectively use available irrigation water supply in managing and controlling the moisture environment of crops to promote the desired crop response, to minimize soil erosion and loss of plant nutrients, to control undesirable water loss, and to protect water quality.

To achieve this purpose the irrigator must have knowledge of (1) how to determine when irrigation water should be applied, based on the rate of water used by crops and on the stages of plant growth; (2) how to measure or estimate the amount of water required for each irrigation, including the leaching needs; (3) the normal time needed for the soil to absorb the required amount of water and how to detect changes in intake rate; (4) how to adjust water stream size, application rate, or irrigation time to compensate for changes in such factors as intake rate or the amount of irrigation runoff from an area; (5) how to recognize erosion caused by irrigation; (6) how to estimate the amount of irrigation runoff from an area; and (7) how to evaluate the uniformity of water application.

Tools to assist in achieving proper irrigation scheduling:

- *b. Water-measuring device: An irrigation water meter, flume, weir, or other water-measuring device installed in a pipeline or ditch.*

The measuring device must be installed between the point of diversion and water distribution system used on the field. The device should provide a means to measure the rate of flow. Total water volume used may then be calculated using rate of flow and time, or read directly, if a totalizing meter is used.

The purpose is to provide the irrigator the rate of flow and/or application of water, and the total amount of water applied to the field with each irrigation.

- **c. Soil and crop water use data: From soils information the available water-holding capacity of the soil can be determined along with the amount of water that the plant can extract from the soil before additional irrigation is needed.**

Water use information for various crops can be obtained from various USDA publications.

The purpose is to allow the water user to estimate the amount of available water remaining in the root zone at any time, thereby indicating when the next irrigation should be scheduled and the amount of water needed. Methods to measure or estimate the soil moisture should be employed, especially for high-value crops or where the water-holding capacity of the soil is low.

Practices for Efficient Irrigation Water Application

Irrigation water should be applied in a manner that ensures efficient use and distribution, minimizes runoff or deep percolation, and eliminates soil erosion.

The method of irrigation employed will vary with the type of crop grown, the topography, and soils. There are several systems that, when properly designed and operated, can be used as follows:

- *d. Irrigation system, drip or trickle (441): A planned irrigation system in which all necessary facilities are installed for efficiently applying water directly to the root zone of plants by means of applicators (orifices, emitters, porous tubing, or perforated pipe) operated under low pressure (Figure 2-20). The applicators can be placed on or below the surface of the ground (Figure 2-21).*

Surface water quality may not be significantly affected by transported substances because runoff is largely controlled by the system components (practices). Chemical applications may be applied through the system. Reduction of runoff will result in less sediment and chemical losses from the field during irrigation. If excessive, local, deep percolation should occur, a chemical hazard may exist to shallow ground water or to areas where geologic materials provide easy access to the aquifer.

- *e. Irrigation system, sprinkler (442): A planned irrigation system in which all necessary facilities are installed for efficiently applying water by means of perforated pipes or nozzles operated under pressure.*

Proper irrigation management controls runoff and prevents downstream surface water deterioration from sediment and sediment attached substances. Over irrigation through poor management can produce impaired water quality in runoff as well as ground water through increased percolation.

Chemigation with this system allows the operator the opportunity to manage nutrients, wastewater and pesticides. For example, nutrients applied in several incremental applications based on the plant needs may reduce ground water contamination considerably, compared to one application during planting. Poor management may cause pollution of surface and ground water. Pesticide drift from chemigation may also be hazardous to vegetation, animals, and surface water resources. Appropriate safety equipment, operation and maintenance of the system is (sic) needed with chemigation to prevent accidental environmental pollution or backflows to water sources.

- *f. Irrigation system, surface and subsurface (443): A planned irrigation system in which all necessary water control structures have been installed for efficient distribution of irrigation water by surface means, such as furrows, borders, contour levees, or contour ditches, or by subsurface means.*

Operation and management of the irrigation system in a manner which allows little or no runoff may allow small yields of sediment or sediment-attached substances to downstream waters. Pollutants may increase if irrigation water management is not adequate. Ground water quality from mobile, dissolved chemicals may also be a hazard if irrigation water management does not prevent deep percolation. Subsurface irrigation that requires the drainage and removal of excess water from the field may discharge increased amounts of dissolved substances such as nutrients or other salts to surface water. Temperatures of downstream water courses that receive runoff waters may be increased. Temperatures of downstream waters might be decreased with subsurface systems when excess water is being pumped from the field to lower the water table. Downstream temperatures should not be affected by subsurface irrigation during summer months if lowering the water table is not required. Improved aquatic habitat may occur if runoff or seepage occurs from surface systems or from pumping to lower the water table in subsurface systems.

- *g. Irrigation field ditch (388): A permanent irrigation ditch constructed to convey water from the source of supply to a field or fields in a farm distribution system.*

The standard for this practice applies to open channels and elevated ditches of 25 ft^3/second or less capacity formed in and with earth materials.

Irrigation field ditches typically carry irrigation water from the source of supplying to a field or fields. Salinity changes may occur in both the soil and water. This will depend on the irrigation water quality, the level of water management, and the geologic materials of the area. The quality of ground and surface water may be altered depending on environmental conditions. Water lost from the irrigation system to downstream runoff may contain dissolved substances, sediment, and sediment-attached substances that may degrade water quality and increase water temperature. This practice may make water available for wildlife, but may not significantly increase habitat.

- *h. Irrigation land leveling (464): Reshaping the surface of land to be irrigated to planned grades.*

The effects of this practice depend on the level of irrigation water management. If plant root zone soil water is properly managed, then quality decreases of surface and ground water may be avoided. Under poor management, ground and surface water quality may deteriorate. Deep percolation and recharge with poor quality water may lower aquifer quality. Land leveling may minimize erosion and when runoff occurs concurrent sediment yield reduction. Poor management may cause an increase in salinity of soil, ground and surface waters. High efficiency surface irrigation is more probable when earth moving elevations are laser controlled.

Practices for Efficient Irrigation Water Transport

Irrigation water transportation systems that move water from the source of supply to the irrigation system should be designed and managed in a manner that minimizes evaporation, seepage, and flow-through water losses from canals and ditches. Delivery and timing need to be flexible enough to meet varying plant water needs throughout the growing season.

Transporting irrigation water from the source of supply to the field irrigation system can be a significant source of water loss and cause of degradation of both surface water and ground water. Losses during transmission include seepage from canals and ditches, evaporation from canals and ditches, and flow-through water. The primary water quality concern is the development of saline seeps below the canals and ditches and the discharge of saline waters. Another water quality concern is the potential for erosion caused by the discharge of flow-through water. Practices that are used to ensure proper transportation of irrigation water from the source of supply to the field irrigation system can be found in the *USDA-SCS Handbook of Practices*, and include: irrigation water conveyance, ditch and canal lining (428); irrigation water conveyance, pipeline (430); and structure for water control (587).

Practices for Utilization of Runoff Water or Tailwater

The utilization of runoff water to provide additional irrigation or to reduce the amount of water diverted increases the efficiency of use of irrigation water. For surface irrigation systems that require runoff or tail water as part of the design and operation, a tail water management practice needs to be installed and used. The practice is described as follows:

- *i. Irrigation system, tail water recovery (447): A facility to collect, store, and transport irrigation tail water for reuse in the farm irrigation distribution system.*

The reservoir will trap sediment and sediment attached substances from runoff waters. Sediment and chemicals will accumulate in the collection facility by entrapping which would decrease downstream yields of these substances.

Salts, soluble nutrients, and soluble pesticides will be collected with the runoff and will not be released to surface waters. Recovered irrigation water with high salt and/or metal content will ultimately have to be disposed of in an environmentally safe manner and location. Disposal of these waters should be part of the overall management plan. Although some ground water recharge may occur, little if any pollution hazard is usually expected.

Practices for Drainage Water Management

Drainage water from an irrigation system should be managed to reduce deep percolation, move tail water to the reuse system, reduce erosion, and help control adverse impacts on surface water and groundwater. A total drainage system should be an integral part of the planning and design of an efficient irrigation system. This may not be necessary for those soils that have sufficient natural drainage abilities.

There are several practices to accomplish this:

- *j. Filter strip (393): A strip or area of vegetation for removing sediment, organic matter, and other pollutants from runoff and waste water.*

Filter strips for sediment and related pollutants meeting minimum requirements may trap the coarser grained sediment. They may not filter out soluble or suspended fine-grained materials. When a storm causes runoff in excess of the design runoff, the filter may be flooded and may cause large loads of pollutants to be released to the surface water. This type of filter requires high maintenance and has a relative short service life and is effective only as long as the flow through the filter is shallow sheet flow.

Filter strips for runoff form concentrated livestock areas may trap organic material, solids, materials which become adsorbed to the vegetation or the soil within the filter. Often they will not filter out soluble materials. This type of filter is often wet and is difficult to maintain.

Filter strips for controlled overland flow treatment of liquid wastes may effectively filter out pollutants. The filter must be properly managed and maintained, including the proper resting time. Filter strips on forest land may trap coarse sediment, timbering debris, and other deleterious material being transported by runoff. This may improve the quality of surface water and has little effect on soluble material in runoff or on the quality of ground water.

All types of filters may reduce erosion on the area on which they are constructed. Filter strips trap solids from the runoff flowing in sheet flow through the filter. Coarse-grained and fibrous materials are filtered more efficiently than fine-grained and soluble substances. Filter strips work for design conditions, but when flooded or overloaded they may release a slug load of pollutants into the surface water.

- *k. Surface drainage field ditch (607): A graded ditch for collecting excess water in a field.*

From erosive fields, this practice may increase the yields of sediment and sediment-attached substances to downstream water courses because of an increase in runoff. In other fields, the location of the ditches may cause a reduction in sheet and rill erosion and ephemeral gully erosion. Drainage of high salinity areas may raise salinity levels temporarily in receiving waters. Areas of soils with high salinity that are drained by the ditches may increase receiving waters. Phosphorus loads, resulting from this practice may increase eutrophication problems in ponded receiving waters. Water temperature changes will probably not be significant. Upland wildlife habitat may be improved or increased although the habitat formed by standing water and wet areas may be decreased.

- *l. Subsurface drain (606): A conduit, such as corrugated plastic tile, or pipe, installed beneath the ground surface to collect and/or convey drainage water.*

Soil water outletted to surface water courses by this practice may be low in concentrations of sediment and sediment-adsorbed substances and that may improve stream water quality. Sometimes the drained soil water is high in the concentration of nitrates and other dissolved substances and drinking water standards may be exceeded. If drainage water that is high in dissolved substances is able to recharge ground water, the aquifer quality may become impaired. Stream water temperatures may be reduced by water drainage discharge. Aquatic habitat may be altered or enhanced with the increased cooler water temperatures.

- *m. Water table control (641): Water table control through proper use of subsurface drains, water control structures, and water conveyance facilities for the efficient removal of drainage water and distribution of irrigation water.*

The water table control practice reduces runoff, therefore downstream sediment and sediment-attached substances yields will be reduced. When drainage is increased, the dissolved substances in the soil water will be discharged to receiving water and the quality of water reduced. Maintaining a high water table, especially during the nongrowing season, will allow denitrification to occur and reduce the nitrate content of surface and ground by as much as 75 percent. The use of this practice for salinity control can increase the dissolved substance loading of downstream waters while decreasing the salinity of the soil. Installation of this practice may create temporary erosion and *sediment yield hazards but the completed practice will lower erosion and sedimentation levels. The effect of the water table control of this practice on downstream wildlife communities may vary with the purpose and management of the water in the system.*

- *n. Controlled drainage (335): Control of surface and subsurface water through use of drainage facilities and water control structures.*

The purpose is to conserve water and maintain optimum soil moisture to (1) store and manage infiltrated rainfall for more efficient crop production; (2) improve surface water quality by increasing infiltration, thereby reducing runoff, which may carry sediment and undesirable chemicals; (3) reduce nitrates in the drainage water by enhancing conditions for denitrification; (4) reduce subsidence and wind erosion of organic soils; (5) hold water in channels in forest areas to act as ground fire breaks; and (6) provide water for wildlife and a resting and feeding place for waterfowl.

Practices for Backflow Prevention

- *o. The American Society of Agricultural Engineers recommends, in standard EP409, safety devices to prevent backflow when injecting liquid chemicals into irrigation systems (ASAE Standards, 1989).*

The process of supplying fertilizers, herbicides, insecticides, fungicides, nematicides, and other chemicals through irrigation systems is known as chemigation. A backflow prevention system will "prevent chemical backflow to the water source" in cases when the irrigation pump shuts down (ASAE, 1989).

Three factors an operator must take into account when selecting a backflow prevention system are the characteristics of the chemical that can backflow, the water source, and the geometry of the irrigation system. Areas of concern include whether injected material is toxic and whether there can be backpressure or backsiphonage (ASAE, 1989; USEPA, 1989b).

Several different systems used as backflow preventers are:

1. **Air gap.** A physical separation in the pipeline resulting in a loss of water pressure. Effective at end of line service where reservoirs or storage tanks are desired.
2. **Check valve with vacuum relief and low pressure drain.** Primarily used as an antisiphon device (Figure 2-22).
3. **Double check valve.** Consists of two single check valves coupled within one body and can handle both backsiphonage and backpressure.

4. **Reduced pressure principle backflow preventer.** This device can be used for both backsiphonage and backpressure. It consists of a pressure differential relief valve located between two independently acting check valves.
5. **Atmospheric vacuum breaker.** Used mainly in lawn and turf irrigation systems that are connected to potable water supplies. This system cannot be installed where backpressure persists and can be used only to prevent backsiphonage.

[EPA, 1993]

Appendix E: Discharge Monitoring Report Summaries

Discharge Monitoring Report (DMR) Data, Selenium	Avondale	Tolleson	JRC #3 (BWCDD outfall)	JRC #2 (BWCDD outfall)	JRC #1 (BWCDD outfall)	Buckeye Sundance	Goodyear Corgett Wash	City of Phoenix 91st Ave. WWTP	Goodyear 157th (BWCDD outfall)	Central Buckeye	Palo Verde WWTP
Number of samples	46	29	7	8	5	7	12	163	14	12	No data- not yet constructed
Mean (1/2 DL) (LTA)	1.38	1.53	4.59	7.08	3.20	1.29	1.65	1.00	3.24	1.49	--
Maximum value, µg/L	3	5	8	11	9	2	5	ND : 2	8.9	3	--
Number exceedances of Gila River WQS	4	4	6	7	5	0	4	0	8	4	--
Percentage exceedances of Gila River WQS	8.70%	13.79%	85.70%	87.50%	100.00%	0.00%	33.33%	0.00%	57.14%	33.33%	--
Accommodated in permit limits?	No	No	Yes: Designated use AgI (20 µg/L) for canal discharges determined permit limit.	Yes: Designated use AgI (20 µg/L) for canal discharges determined permit limit.	Yes: Designated use AgI (20 µg/L) for canal discharges determined permit limit.	Yes: No permit terms	No	No	Yes: Designated use AgI (20 µg/L) for canal discharges determined permit limit.	Yes: ECT testing only. Designated use AgL (50 mg/L) for Arlington Canal discharges determined assessment levels.	No
Number exceedances of permit limits	0	2	0	0	0	N.A.	1	0	0	N.A.	N.A.
Date from:	Jul-08	Feb-05	Dec-08	Dec-08	Dec-08	Jul-08	Apr-07	Jan-10	Jan-09	Jan-09	N.A.
Date to:	Nov-12	Dec-09	Jul-12	Jul-12	Jul-12	Jun-12	Dec-11	Dec-13	Dec-13	Dec-13	N.A.

Table 21. DMR Summary, Selenium, MG Permittees

Discharge Monitoring Report (DMR) Data, Boron	**Avondale**	**Tolleson**	**JRC #3 (BWCDD outfall)**	**JRC #2 (BWCDD outfall)**	**JRC #1 (BWCDD outfall)**	**Buckeye Sundance**	**Goodyear Corgett Wash**	**City of Phoenix 91st Ave. WWTP**	**Goodyear 157th (BWCDD outfall)**	**Central Buckeye**	**Palo Verde WWTP**
Number of samples	7	12	5	7	6	40	8	54	8	No data	No data - not yet constructed
Mean	**422.86**	**440.00**	**334.00**	**237.14**	**66.67**	800.65	970	**380.67**	**613.75**	--	--
Highest value	**470**	**510**	**450**	**320**	**220**	1010	1200	**442**	**730**	--	--
Number exceedances of WQS	0	0	0	0	0	1	1	0	0	--	--
Percentage exceedances of Gila River WQS	0.0%	0.0%	0.0%	0.0%	0.0%	2.5%	12.5%	0.0%	0.0%	--	--
Accommodated in permit limits?	No limits assigned	Consistent with TSD methodology	No limits assigned	No limits assigned	No limits assigned	Consistent with TSD methodology	Consistent with TSD methodology	No limits assigned	No limits assigned	No limits assigned	No limits assigned
Number exceedances of permit terms	N.A.	0	N.A.	N.A.	N.A.	0	0	N.A.	N.A.	N.A.	N.A.
Date from:	Jul-08	Feb-05	Jun-09	Dec-08	Jun-09	Jul-08	Apr-07	Jan-10	Jan-09	N.A.	N.A.
Date to:	Nov-12	Dec-09	Jul-12	Jul-12	Jul-12	Jun-12	Dec-11	Dec-13	Dec-13	N.A.	N.A.

Table 22. DMR Summary, Boron, MG Permittees