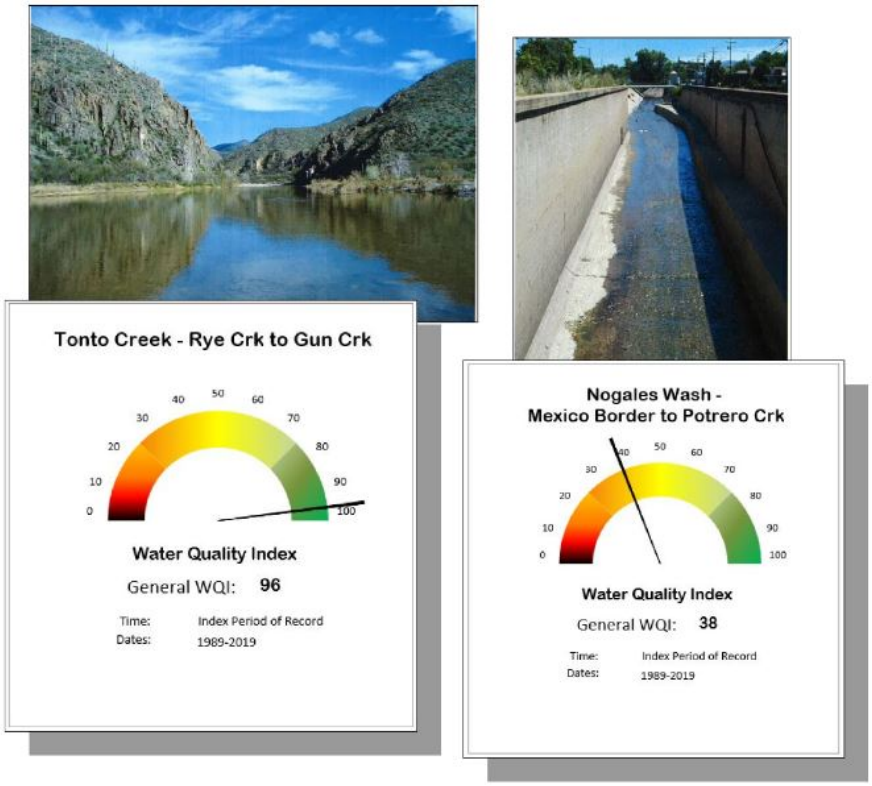
The Arizona Water Quality Index:

Trends and Exploratory Data Analysis

Long-term Ambient Monitoring and

Priority Impaired Reaches, 1989-2019



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Credits

This report represents the culmination of 31 years' worth of dedicated and highly competent work by the staff of ADEQ's Ambient Monitoring (formerly Surface Water Monitoring) and Total Maximum Daily Load Units, and the Arizona offices of the U.S. Geological Survey in collecting, storing, maintaining, analyzing, and evaluating water quality data from across the state of Arizona. Simply put, this report could not have been produced without the broad programmatic infrastructure that supports efforts like this one. The citizens of Arizona are fortunate to have such expertise on the job monitoring, reporting on, and working to protect the state's water quality.

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Abbreviations

ADEQ	Arizona Department of Environmental Quality
ARS	Arizona Revised Statutes
AWC	Aquatic & Wildlife- Cold Water (Designated Use)
AWE	Aquatic & Wildlife-Ephemeral Water (Designated Use)
AWQI	Analyte Water Quality Index
AWW	Aquatic & Wildlife- Warm Water (Designated Use)
AZ	Arizona
CALM	Consolidated Assessment and Listing Methodology
CV/CoV	Coefficient of Variation
CWA	Clean Water Act
FBC	Full Body Contact (Designated Use)
FSN	Fixed Station Network
GWQI	General Water Quality Index
KDE	Kernel Density Estimate
KT	Kendall-Tau
LTS	Long-term Sites
MAD	Median Absolute Deviation
MK	Mann-Kendall
PBC	Partial Body Contact (Designated Use)
PIR	Priority-impaired Reaches
POR	Period of Record
QA	Quality Assurance
SD	Standard Deviation
SEM	Standard Error of the Mean
SS	Statistically significant
SSC	Suspended sediment concentration
TMDL	Total Maximum Daily Load
USGS	United States Geological Survey
WBID	Waterbody Identification
WQ	Water Quality
WQI	Water Quality Index
WWTP	Waste Water Treatment Plant

1.0 Introduction: Need, Sites and Indices

One of the principal stated objectives of Arizona's ambient water quality monitoring program, along with characterizing the state's recent water quality in biennial water quality assessments mandated by the Clean Water Act (CWA), is to assess any trends over time in the state's water quality. A trend assessment allows a determination of whether water quality is improving, maintaining, or degrading, all of which are important to know in assessing whether statutory water quality goals in authorizing, sponsoring, and promulgating water quality programs are being met. The determination of long-term trends is as important as a water quality assessment in providing a complete picture of water quality, which should include both the short-term and long-term retrospective views. When a water body becomes officially impaired, focused remediation actions are often undertaken to improve the water quality of the impaired water body. Water quality status then becomes even more important, as it is vital to know if the state's efforts to improve matters are actually making progress towards the goal of restoring degraded waters.

Arizona Revised Statutes (ARS) 49-225 specifically authorizes and requires the conducting of trend analyses in the text of the law:

> ***49-225. Water quality monitoring***
>
> *A.* ***The director of environmental quality,*** *with the advice and cooperation of the Arizona department of agriculture and the director of water resources when appropriate,* ***shall conduct ongoing monitoring of the waters of the state including the state's navigable waters*** *and aquifers to detect the presence of new and existing pollutants, determine compliance with applicable water quality standards, determine the effectiveness of best management practices, agricultural best management practices and best available demonstrated control technologies, evaluate the effects of pollutants on public health or the environment* ***and determine water quality trends.***

The Clean Water Act (CFR 40), while not specifically calling for trend assessments of water quality, strongly suggests so by implication in laying out its overriding objective and in its authorization for the states to establish water quality monitoring programs and conduct research under the auspices of those programs:

> *The Federal Water Pollution Control Act is amended to read as follows:*
>
> *TITLE I--RESEARCH AND RELATED PROGRAMS*
>
> *SEC. 101 [33 U.S.C. 1251] Declaration of Goals and Policy*
>
> *(a) The objective of this Act is to* ***restore and maintain the chemical, physical, and biological integrity of the Nation's waters****. ….*

> *(b) It is the policy of the Congress to recognize, preserve, and protect the primary responsibilities and rights of States to* ***prevent, reduce, and eliminate pollution****, to plan the development and use (including restoration, preservation, and enhancement) of land and water resources…It is further the policy of the Congress* ***to support and aid research relating to the prevention, reduction, and elimination of pollution…***

In the CWA's stated primary objective, restoration and maintenance of the integrity of the Nation's waters suggests by implication that time should be considered in assessing whether the objective is being met, or, failing that, whether progress is being made towards meeting the objective. Likewise, an assessment of whether pollution is being prevented or reduced necessarily includes some consideration of a time element, which implies some type of trend assessment.

Arizona's ambient water quality monitoring program had incorporated trend analysis as a program goal through the 1990s and into the mid-2000s; however, as of 2005, the goal had not come to fruition. This was due to a number of factors, which were succinctly laid out in ADEQ's Sample Plan for FY 2006, when the pursuit of trend analysis as a program objective was formally suspended:

> *Starting in FY 06, SWMSU [Surface Water Monitoring and Standards Unit] will begin a 5-year phase out of the Fixed Station Network (FSN) monitoring program The FSN monitoring program is a statewide data collection program whose primary purpose is to characterize baseline water quality of perennial, wadeable streams at a network of long-term sampling sites and to provide data to determine long-term water quality trends. …*
>
> *While ADEQ collected water quality data at long-term FSN sites for many years, the data collection effort was not consistent enough over a long enough period of record to produce a data set that could be used to determine water quality trends. Changes in monitoring program design, monitoring objectives, staffing levels, data collection protocols and procedures, and analytical methods over time have made it difficult to produce comparable data over the long-term that could be used for trend analysis. ADEQ has not analyzed the data collected nor produced any water quality trend reports over the lifetime of the FSN Monitoring Program. … It is unlikely that SWMSU will produce trend analyses in the foreseeable future given current staffing and competing priorities for water quality data. …*

With the development of Arizona's water quality index in 2015 and its steady maturation in the years since, the state finally has a means of overcoming previous obstacles and achieving the objective of trend analysis. As mentioned in a white paper produced for Arizona's water quality index (McCarty, 2018), one of the prime advantages of using indices for trend analyses is that all results are placed on the same scale for comparison. The advantage of this is that differences in reporting laboratories, methods of laboratory analysis, sensitivity of detection limits, monitoring program designs, collection protocols, or lab reporting conventions over time are all rendered moot as long as data credibility is achieved. Following is an excerpt from the white paper:

> *The A[z]WQI shows great promise as a metric to evaluate improvement in water quality over time. Trend analysis of indices is one of the prime reasons to pursue development and implementation of the index. Provided that care is taken to ensure data sets are consistent in composition and durations, trends with statistical significance could be determined with a good*

degree of reliability. … Other features and advantages of the index are numerous; the scale is simple and easily understandable, requiring only a general orientation as to what constitutes a top score (100). The index is readily scalable in terms of spatial application, whether in application to a single site, a stream reach, or more broadly to an entire stream when designated uses are consistent across all reaches. The index also has great flexibility when considered temporally, as it can be calculated for any time frame of interest, provided enough data is available to generate indices that satisfy data-adequacy criteria. Lastly, further development and adaptation here in Arizona of the index's conceptual basis has allowed for the creation and use of analyte-specific indices, with a modified mathematical basis, to assess the degree of severity of any individual variable's impairment.

(McCarty, 2018)

An added feature of the water quality index is that it does not focus on the water quality result itself as reported by laboratories, but rather on its quantitative conversion and comparison to standards benchmarks, thereby evaluating the frequency and magnitude of ***exceedances*** of water quality standards. In doing so, it captures any trends relative to those standard thresholds instead of detection limit thresholds, as a trend analysis on raw results would. Ultimately, the state's waters' performance relative to water quality standards is the desirable objective to be known to determine whether negative impacts potentially affecting human health and the environment are occurring. Arizona's water quality index is the ideal tool for this job.

This report is not restricted solely to trend analyses, however. With the compilation and conversion of 31-years' worth of water quality data into indices, a rare opportunity presents itself to characterize the data using the established tools of exploratory data analysis. Boxplots, histograms, percentile analyses, kernel density estimates, summary statistics and other statistical methods will be employed to delve into the dataset and draw conclusions that may not be necessarily apparent at first glance.

1.1 Long-term Sites / Reaches (LTS)

1.1.1 Purpose and History

ADEQ's ambient water quality monitoring program has collected water quality data to assess the biological, chemical, and physical integrity of Arizona's rivers, streams, lakes, and reservoirs since shortly after the agency's inception in 1987. Historically, the objectives of ADEQ's ambient monitoring program have been to:

1. Collect data to characterize baseline water quality conditions,
2. Determine compliance with applicable surface water quality standards,
3. Provide data to determine water quality trends at long-term Fixed Station Network (FSN) sites,
4. Provide data to support Clean Water Act §305(b) water quality assessments, and
5. Provide data to support the development of new water quality standards for physical and biological integrity.

(ADEQ, 2004)

The core ambient monitoring program for most of the first two decades of the agency's existence was the Fixed Station Network (FSN) monitoring program. The FSN monitoring program was a statewide data collection program whose primary purpose was to characterize baseline water quality of perennial, wadeable streams and to provide data to determine long-term water quality trends. FSN sampling sites were sampled quarterly each year. The FSN Monitoring Program incorporated longer monitoring periods (20+ years) and lower site densities per watershed than other ADEQ monitoring programs. Long-term FSN sites were established on wadeable, perennial streams in nine of the ten major watersheds in the state (ADEQ, 2004). After 2006, the agency transitioned to a probabilistic random sampling design in order to draw conclusions and make inferences about water quality state-wide (including waters that had not been visited/monitored), and FSN sites were subsequently not sampled as regularly, though being reliable sites, they were still sampled on an intermittent basis.

Until 2018, ADEQ entered into a joint funding agreement with the U.S. Geological Survey (USGS) in operating the ADEQ / USGS Cooperative Fixed Station Network monitoring program to monitor surface water quality in Arizona's larger rivers. USGS collected data at selected sites statewide using USGS sampling protocols and provided the data to ADEQ at the conclusion of each year to meet the purposes of ADEQ's ambient monitoring program (ADEQ, 2004).

Table 1 provides an itemized list of the 38 sites from both the ADEQ ambient monitoring program and the USGS cooperative program. These sites were used in characterizing the indices, basic statistics, and trends for the long-term sites (LTS) and by extension their parent reaches in this report. The source agency is identified in the column "Site Agency."

1.1.2 Rationales and Sampling Site Location and Frequency Criteria

For trend analysis, long-term sites were selected to be representative of water quality throughout a stream reach or watershed. If possible, sampling sites were located at or near U.S. Geological Survey or other agency discharge gaging stations to supplement ADEQ FSN data with continuous discharge records at the sample site. Sample sites were selected using the following criteria:

- Sites were located on perennial, wadeable streams;
- Sites were located to be representative of surface waters with both cold and warm water aquatic life designated uses;
- Sites were located to measure water quality impacts where they existed from nonpoint source discharges, including discharges from recreation, grazing, mining, and agricultural activity;
- Sites were selected in locations with reasonable road access that require a minimum of hiking to reach the sampling site. In general, sites that were accessible only from private land were avoided to limit the possibility of restricted or forbidden access from private property owners. (ADEQ, 2004)

Long-term sampling sites were sampled on a quarterly basis. Quarterly sampling ensured that seasonal variability of water quality was addressed and characterized. Additionally, a seasonal distribution requirement, adopted as a water quality assessment method in the implementation of Arizona's Impaired Water Identification Rule (Arizona Administrative Code, R18-11 Article 6),

stipulates that sampling in three of four seasons was necessary to meet minimal requirements for water quality assessment. A version of this requirement was coded into index stability scores to be subsequently discussed.

Site Description	Site Agency	WBID	Waterbody	Reach Description
Colorado River at Lee's Ferry	USGS	AZ14070006-001	Colorado River	Glen Canyon Dam - Lees Ferry
Little Colorado River below Springerville	ADEQ	AZ15020001-009	Little Colorado River	Nutrioso Creek - Tributary
West Fork of the Little Colorado River at Government Springs near Greer	ADEQ	AZ15020001-013B	Little Colorado River West Fork	Government Spring - Little Colorado East Fork
Little Colorado River at Woodruff	ADEQ	AZ15020002-004	Little Colorado River	Silver Creek - Carr L Wash
Colorado River at Parker Dam	USGS	AZ15030104-020	Colorado River	Bill Williams River - Osborne Wash
Colorado River at Northern International Boundary above Morelos Dam	USGS	AZ15030107-001	Colorado River	Main Canal - Mexico Border
Big Sandy River above Highway 93 Bridge	ADEQ	AZ15030201-004	Big Sandy River	Bitter Creek - Burro Creek
Trout Creek near Wikieup	ADEQ	AZ15030201-014	Trout Creek	Cow Creek - Knight Creek
Burro Creek at Six Mile Crossing	ADEQ	AZ15030202-004	Burro Creek	Boulder Creek - Black Canyon
Santa Maria River below Highway 93 Bridge	ADEQ	AZ15030203-009	Santa Maria River	Bridle Creek - Alamo Lake
Gila River at the Old Safford Bridge	ADEQ	AZ15040002-001	Gila River	Cottonwood Creek - San Francisco River
San Francisco River below Clifton	ADEQ	AZ15040004-001	San Francisco River	Limestone Gulch - Gila River
San Francisco River above Clifton	ADEQ	AZ15040004-003	San Francisco River	Blue River - Limestone Gulch
San Francisco River above Luna Lake near Alpine	ADEQ	AZ15040004-023	San Francisco River	Headwaters - Nm State Line -
Blue River at Juan Miller Road Crossing	ADEQ	AZ15040004-025B	Blue River	Strayhorse Creek - San Francisco River
Gila River at the head of the Safford Valley	USGS	AZ15040005-022	Gila River	Bonita Creek - Yuma Wash
San Pedro River at Palominas; San Pedro River at Charleston	ADEQ; USGS	AZ15050202-008	San Pedro River	U.S. Mexico Border - Charleston
San Pedro River below Eskiminzin Wash	ADEQ	AZ15050203-001	San Pedro River	Aravaipa Creek - Gila River
San Pedro River at Cascabel	ADEQ	AZ15050203-011	San Pedro River	Hot Springs Canyon - Redfield Canyon
Santa Cruz River at International Boundary	ADEQ	AZ15050301-010	Santa Cruz River	Mexican Border - Nogales WWTP Outfall
Nogales Wash at the Morley Avenue Tunnel	ADEQ	AZ15050301-011	Nogales Wash	Mexican Border - Potrero Creek
Salt River near Roosevelt	USGS	AZ15060103-004	Salt River	Pinal Creek - Roosevelt Lake
Pinto Creek above Henderson Ranch Ford	ADEQ	AZ15060103-018C	Pinto Creek	West Fork Pinto Creek - Roosevelt Lake
Pinal Creek at Inspiration Dam	ADEQ	AZ15060103-280E	Pinal Creek	See Ranch Crossing - Unnamed Tributary
Tonto Creek above Gun Creek	ADEQ	AZ15060105-008	Tonto Creek	Rye Creek - Gun Creek
Tonto Creek below Christopher Creek confluence	ADEQ	AZ15060105-013A	Tonto Creek	Headwaters - Unnamed Tributary

Site Description	Site Agency	WBID	Waterbody	Reach Description
Salt River below Stewart Mountain Dam	USGS	AZ15060106A-003	Salt River	Stewart Mountain Dam - Verde River
Verde River near Clarkdale	USGS	AZ15060202-025	Verde River	Sycamore Creek - Oak Creek
Verde River at Perkinsville Bridge	ADEQ	AZ15060202-037	Verde River	Munds Draw - Railroad Draw
Verde River below Bartlett Dam	USGS	AZ15060203-004	Verde River	Bartlett Lake Dam - Camp Creek
Verde River below Tangle Creek above Horseshoe Dam	USGS	AZ15060203-018	Verde River	Tangle Creek - Horseshoe Lake
East Verde River at Highway 87 bridge	ADEQ	AZ15060203-022B	East Verde River	Ellison Creek - American Gulch
East Verde River near Childs	USGS	AZ15060203-022C	East Verde River	American Gulch - Verde River
Verde River at Beasley Flat	ADEQ	AZ15060203-025	Verde River	West Clear Creek - Fossil Creek
Gila River above diversions at Gillespie Dam	USGS	AZ15070101-008	Gila River	Hassayampa River – Gillespie Dam (Gila River)
Hassayampa River at Box Canyon near Wickenburg	ADEQ	AZ15070103-004	Hassayampa River	Cottonwood Creek - Martinez Wash
Hassayampa River below Milk Creek near Wagoner	ADEQ	AZ15070103-007B	Hassayampa River	Unnamed Tributary – Blind Indian Creek
Gila River near Dome	ADEQ	AZ15070201-003B	Gila River	Castle Dome Wash - Fortuna Wash

Table 1. Fixed Station Network Long-term sites and reaches

1.2 Priority-Impaired Reaches (PIR)

1.2.1 Purpose and History

From the data collected by ADEQ's ambient monitoring program, waters identified as failing to meet Arizona's water quality standards in biennial water quality assessments mandated by the Clean Water Act are placed on an impaired waters list and scheduled for a TMDL analysis. ADEQ's TMDL program began in 1996. More intensive sampling to determine sources and loading was undertaken in TMDL follow-up work. Through both CWA 305(b) Assessments and TMDLs, waters have been identified as either impaired (TMDL not completed) or non-attaining (TMDL completed, but water quality as of yet unimproved).

In 2017, ADEQ moved to fast track the improvement of impaired waters by identifying select perennial and intermittent impaired reaches across the state for focused surveying, remediation and grant solicitation activities. Reaches identified were considered priority-impaired reaches (PIRs); these reaches fell into two broad categories:

1) Metals / Mining-related impairments
2) *E. coli* / Recreational water impairments

As denoted in the list above, metal impairments have received top priority beginning in 2018. Priority Impaired reaches have received focused and intensive sampling efforts in recent years. Forty-eight reaches have been identified as priority impaired reaches; of these, 24 had sufficient samples over the annual series of water quality indices to allow for meaningful trend assessments and determinations using the method of Helsel and Hirsch (Helsel, 2002). The remainder were characterized over the entire period of record for this report spanning 1989 to 2019.

Priority impaired reaches were assessed using the Analyte Water Quality Index for their impairment analyte. All priority impaired reaches are listed in Table 2.

1.2.2 Rationales and Sampling Site Location and Frequency Criteria

Unlike the long-term sites discussed previously, sites associated with impaired reaches were not selected to be representative of perennial flows over long periods. Instead, the primary consideration for PIR sites was utility in characterizing and quantifying source loading for the impairment analyte as well as representing one location in an extensive effort to determine each source contributing to a parent impairment. Sampling in most cases was carried out during critical conditions – those conditions contributing to worst-case representations of the impairment. These conditions might be related to high or low flows, seasonal recreational pressures, or periods where anthropogenic activities negatively affecting water quality were aggravated. In most cases, the critical conditions were stormflow events. During these events, samples were collected both manually and through regular automated sampling devices where possible[1] on a pre-determined schedule once a triggering flow threshold was reached.

[1] *E. coli* results were all manually sampled; short holding times for bacterial tests precluded the use of automated equipment to sample for this analyte.

Sampling sites for PIR reaches tended to be both more remote in most cases and clustered within a specific project area to fulfill the sampling rationales and criteria of the TMDL projects. In summary, the criteria that guided the selection and use of these sites included the following:

- Sites were located on reaches with known impairments;
- For priority impairment designation, sites were located on perennial or intermittent waterways;
- Sites were located to measure water quality impacts from nonpoint source discharges, including discharges from recreation, grazing, mining, and agricultural activity and/or baseline source characterization;
- Sites were selected in locations with reasonable road access that require a minimum of hiking to reach the sampling site. Sites required somewhat more accessibility that LTS sites (primarily for deployment and removal of automated equipment).
- Sites required sufficient flow during a time-delimited project, particularly during the identified critical conditions, to contribute to the analysis effort; however, regular quarterly sampling for an extended period was not envisioned as necessary.

Priority-impaired reaches are itemized in Table 2. These sites were also used, along with the LTS sites/reaches, in analyzing the data generating the indices, basic statistics, and trends laid out in this report.

A map of all long-term sites/reaches and priority impaired reaches referred to in this report is displayed in Figure 1.

WBID	Watershed	Waterbody	Reach Description	Impairment(s)	Annual Series
AZ15020007-007	Little Colorado	Puerco River	Dead Wash - Ninemile Wash	Metals	
AZ15030202-005A	Bill Williams	Boulder Creek	Wilder Creek – Butte Creek	Metals	Yes
AZ15030202-006B	Bill Williams	Boulder Creek	Tributary - Wilder Creek	Metals	
AZ15040005-022	Upper Gila	Gila River	Bonita Creek - Yuma Wash	Metals	Yes
AZ15050100-012B	Middle Gila	Mineral Creek	Devils Canyon - Gila River	Metals	
AZ15050100-012D	Middle Gila	Mineral Creek	End Of Diversion Channel - Gila River	Metals	Yes
AZ15050100-014A	Middle Gila	Queen Creek	Headwaters - Superior WWTP Outfall	Metals	Yes
AZ15050100-014B	Middle Gila	Queen Creek	Superior WWTP Outfall - Potts Canyon	Metals	Yes
AZ15050100-014C	Middle Gila	Queen Creek	Potts Canyon - Witlow Canyon	Metals	
AZ15050100-1818	Middle Gila	Arnett Creek	Headwaters - Queen Creek	Metals	
AZ15050202-003	San Pedro	San Pedro River	Walnut Gulch - Dragoon Wash	*E. Coli*	Yes
AZ15050202-006	San Pedro	San Pedro River	Charleston - Babocomari River	Metals	Yes
AZ15050202-008	San Pedro	San Pedro River	U.S. Mexico Border - Charleston	Metals	Yes
AZ15050202-008	San Pedro	San Pedro River	U.S. Mexico Border - Charleston	*E. Coli*	
AZ15050203-022A	San Pedro	Copper Creek	Headwaters - Copper Creek Road	Metals	
AZ15050301-025A	Santa Cruz	Harshaw Creek	Headwaters - 31°27'43.9''/110°43'21.1''	Metals	
AZ15050301-558A	Santa Cruz	Three R Canyon	Headwaters - Unnamed Tributary To Three R Canyon	Metals	
AZ15050301-558B	Santa Cruz	Three R Canyon	Unnamed Tributary To Three R Canyon	Metals	
AZ15050301-558C	Santa Cruz	Three R Canyon	Cox Gulch - Sonoita Creek	Metals	
AZ15050301-560	Santa Cruz	Cox Gulch	Headwaters - Three R Canyon	Metals	
AZ15050301-561B	Santa Cruz	Alum Gulch	31°28'20"/110°43'51" - 31°29'17"/110°44'25"	Metals	Yes
AZ15050301-641	Santa Cruz	Unnamed Tributary To Alum Gulch	Headwaters - Alum Gulch	Metals	
AZ15050301-888	Santa Cruz	Unnamed Tributary To Harshaw Creek	Headwaters - Harshaw Creek	Metals	
AZ15050301-889	Santa Cruz	Unnamed Tributary To Three R Canyon	Headwaters - Three R Canyon	Metals	
AZ15050301-890	Santa Cruz	Unnamed Tributary To Cox Gulch	Headwaters - Cox Gulch	Metals	
AZ15060103-018B	Salt	Pinto Creek	Ellis Ranch Tributary – West Fork Pinto Creek	Metals	Yes

WBID	Watershed	Waterbody	Reach Description	Impairment(s)	Annual Series
AZ15060103-018C	Salt	Pinto Creek	West Fork Pinto Creek – Roosevelt Lake	Metals	Yes
AZ15060103-887	Salt	Gibson Mine Tributary	Headwaters – Pinto Creek	Metals	Yes
AZ15060202-016	Verde	Oak Creek	Spring Creek - Verde River	*E. Coli*	Yes
AZ15060202-017	Verde	Oak Creek	Dry Creek - Spring Creek	*E. Coli*	Yes
AZ15060202-018A	Verde	Oak Creek	West Fork Oak Creek - Unnamed Tributary	*E. Coli*	Yes
AZ15060202-018B	Verde	Oak Creek	Unnamed Tributary - Manzanita Campground	*E. Coli*	Yes
AZ15060202-018C	Verde	Oak Creek	Manzanita Campground - Dry Creek	*E. Coli*	Yes
AZ15060202-019	Verde	Oak Creek	Headwaters - West Fork Oak Creek	*E. Coli*	Yes
AZ15060202-022	Verde	Spring Creek	Coffee Creek - Oak Creek	*E. Coli*	Yes
AZ15060202-025	Verde	Verde River	Sycamore Creek - Oak Creek	*E. Coli*	Yes
AZ15070102-033A	Middle Gila	Lynx Creek	Headwaters - Unnamed Tributary To Lynx Creek	Metals	
AZ15070102-034B	Middle Gila	Big Bug Creek	Eugene Gulch – Agua Fria River	Metals	Yes
AZ15070102-036B	Middle Gila	Turkey Creek	Unnamed Tributary - Poland Creek	Metals	Yes
AZ15070102-123	Middle Gila	Money Metals Tributary	Headwaters - Unnamed Tributary	Metals	
AZ15070102-1994	Middle Gila	Unnamed Tributary To Eugene Gulch	Headwaters - Eugene Gulch	Metals	
AZ15070102-234	Middle Gila	Unnamed Tributary To Big Bug Creek	Headwaters - Big Bug Creek	Metals	
AZ15070103-007A	Middle Gila	Hassayampa River	Headwaters - Copper Creek	Metals	Yes
AZ15070103-239	Middle Gila	French Gulch	Headwaters - Hassayampa River	Metals	
AZ15070103-349	Middle Gila	Cash Mine Creek	Headwaters - Hassayampa River	Metals	
AZ15070103-415	Middle Gila	Unnamed Tributary To Cash Mine Creek	Headwaters - Cash Mine Creek	Metals	
AZ15080301-090A	Rios de Mexico	Mule Gulch	Headwaters - Just Above The Lavender Pit	Metals	
AZ15080301-337	Rios de Mexico	Brewery Gulch	Headwaters – Mule Gulch	Metals	Yes

Table 2. Priority-impaired reaches

Figure 1. State map of LTS and PIR reaches

1.3 General Water Quality Indices

The Arizona Water Quality Index is a tool developed to communicate water quality information in a concise and understandable way to the public, water quality professionals, and decision-makers. An additional benefit of the index is that it is suitable as a consistent scale for the determination of trends over long periods and basic statistical characterizations, as well as an aggregating number by which water quality can be evaluated in a reliable way over an entire period of record. The WQI operates on a set of disparate water quality data with water quality standards that differ by constituent from locations having differing designated uses. It generates a single standardized number reported on a scale from 0 to 100, with 100 representing the best water quality for a reach. The criterion for a top score is the uniform attainment of water quality standards applying to the reach or site identified. Indices can be tracked over time to demonstrate improving or degrading water quality conditions. A sub-index generated from the body of data can report on the severity of single impairment analytes on the same scale. The general index considers the percentage of distinct chemical parameters exhibiting exceedances relative to the population of distinct chemical parameters, the percentage of water quality exceedances relative to the total population of individual water quality results, and the magnitude of excursions over the most restrictive water quality standard. A combination of the method, a data set of core parameters (defined below) and any impairment analytes, and water quality standards serving as the criteria by which these data are evaluated comprise the three essential elements that must be in place for an index to be generated. (McCarty, 2018)

1.3.1 GWQI Mathematical Basis

Arizona adopted and modified for its own use the approach employed first by the Province of British Columbia in 1995, then later by the Canadian Ministry of the Environment (CCME, 2001). The general index is calculated from three factors: the scope (extent) of water quality standards exceedances (F_1), the frequency of exceedances (F_2), and the magnitude of exceedances (F_3). The formulation of the general index is:

$$WQI = 100 - \left(\frac{\sqrt{{F_1}^2 + {F_2}^2 + {F_3}^2}}{1.732} \right)$$

Where $F_1 = \left(\frac{Number\ of\ failed\ variables}{Total\ number\ of\ variables} \right) \times 100$

And $F_2 = \left(\frac{Number\ of\ failed\ tests}{Total\ number\ of\ tests} \right) \times 100$

And $F_3 = \left(\frac{nse}{0.01 * nse + 0.01} \right)$

Supporting the main calculation,

$$nse = \frac{\sum_{i=1}^{n} excursion_i}{Total\ number\ of\ tests}$$

When the test value must not exceed the objective:

$$excursion_i = \left(\frac{Failed\ Test\ Value_i}{Objective_j}\right) - 1$$

Otherwise, when the test value must not fall below the objective:

$$excursion_i = \left(\frac{Objective_j}{Failed\ Test\ Value_i}\right) - 1$$

1.3.2 GWQI Data

As a measure originating with the Impaired Waters Identification Rule (A.A.C. 18-11-6) in 2002 (ADEQ, 2002), the core parameter data set addressing each designated use was developed to ensure that data sets considered for possible impairment listings met minimal requirements for numbers of samples, seasonal distribution of those samples, and temporal and spatial independence of the data considered. Each designated use for a stream reach had certain water quality variables designated as core parameters. These variables were chosen to ensure that the most important elements for the meeting of the designated use reflect satisfactory conditions and thereby allow the use to be fulfilled. Each designated use had its own set of water quality variables selected, with those selected reflecting best professional judgment as to which variables were the most critical to consider when evaluating whether uses were hampered. The following discussion is presented in ADEQ's 2016 Clean Water Act Assessment document (ADEQ, 2017):

> *Although all parameters with numeric standards are used for assessment, ADEQ has chosen a set of indicators, called "core parameters," necessary to assess whether each designated use is attaining standards. Arizona's core parameters are shown in the table below. Core parameters were selected based on EPA's CALM guidance (2002), although they are limited due to the lack of narrative standards implementation procedures. CALM guidance places strong emphasis on narrative water quality standards, suggesting that core indicators should include bioassessments, habitat assessments, ambient toxicity testing, contaminated sediment, health of individual organisms, nuisance plant growth, algae, sediments, and even odor and taste.*
>
> *… Core parameters were chosen using the following criteria:*
>
> - *Frequently exceeded standards in past assessments;*
> - *Routinely included in ambient monitoring suites;*
> - *Lab reporting limits routinely below applicable surface water criteria;*
> - *Critical toxicity recognized; and*
> - *Standards and implementation procedures support application of the criteria.*

… Core parameters must be sampled at least three times and samples must be reasonably distributed at different times of the year to reflect seasonal changes (seasonally distributed). For assessment purposes, it is ensured that at least one sample is collected in each of the four seasons: winter (January – March), spring (April – June), summer (July – September), and fall (October – December If this does not occur, and the designated use is not "impaired," then the designated use is assessed as "inconclusive."

(ADEQ, 2017)

The core parameter set provides a standardized scaffold by which water quality index determinations can be calculated consistently from one determination to the next. Retrieval of all core parameters for all of the designated uses of a site or reach ensures that important variables for the most fundamental and essential assessment of the condition of water quality are considered. Table 3 outlines the current core parameter data set.

DESIGNATED USE	CORE PARAMETERS
Aquatic and Wildlife	Dissolved oxygen (not required if ephemeral) Stream flow (if a stream) Sample depth (if a lake) pH Total nitrogen (if nutrient standards established) Total phosphorus (if nutrient standards established) Dissolved cadmium, copper, and zinc and hardness
Fish Consumption	Total mercury
Full Body or Partial Body Contact	*Escherichia coli* (not required if ephemeral) pH
Domestic Water Source	Nitrate/nitrite or nitrate pH Fluoride Total arsenic, chromium or chromium VI, and lead
Agricultural Irrigation	pH Total boron and manganese
Agricultural Livestock Watering	pH Total copper and lead

Table 3. Core parameter data set by designated use

No data set for the determination of WQIs can be considered complete if it omits data for water quality variables previously determined as impaired for the reach or water body of concern. Any analytes formally listed as impaired for the reach being considered are included with the core parameter data set when determining general water quality indices.

1.3.3 GWQI Standards / Thresholds

Arizona water quality standards generally serve as the basis for the criteria considered in the index calculations. An exceedance of the water quality standard is the yardstick by which the index is decremented from a top score of 100. An exceedance will simultaneously count as:

1) one of *n* water quality variables showing adverse water quality impacts in the scope term (F_1) of the calculation (Equation 2),

2) one of the total number of results in the data set showing adverse impacts in the frequency term (F_2) of the calculation, and
3) the magnitude of the exceedance is tabulated relative to the standard for the amplitude term (F_3) of the index calculation.

The index follows a modified and streamlined methodology developed specifically for it and thus may occasionally generate results that do not necessarily accord with the assessment status of the reach or waterbody.

For core parameters, results are considered only for the designated use that the parameter represents (Table 3), though the analyte may have standards for multiple designated uses. In cases where the same parameter spans multiple designated uses in the core parameter set (e.g., pH), results are compared only once to the most stringent applicable standard for an analyte. For example, in considering pH, several designated uses with different ranges, apply:

- Aquatic and Wildlife (A&W) uses pH standard range: 6.5-9.0
- Full/Partial Body Contact (FBC/PBC) pH standard range: 6.5-9.0
- Domestic Water Source (DWS) pH standard range: 5.0-9.0
- Agricultural Irrigation (AgI) pH standard range: 4.5-9.0
- Agricultural Livestock Watering (AgL) pH standard range: 6.5-9.0

Inspection determines that the narrowest (i.e., most stringent) ranges belong to the A&W, Body Contact, and AgL uses. Though it makes no practical difference which of the three most stringent uses is selected in this case, the Full or Partial Body Contact use is selected as the representative standard range to apply. For any impairment analytes added to the data set for a given reach, the designated use impaired by the analyte for that reach is the one applicable in selecting a standard for index calculations. In most cases, this is the most stringent standard applicable. In cases where the same analyte impairs multiple uses for a reach, the most stringent standard (and thus the most severe impairment calculation) is the one selected. For example, for WBID 15030202-005A (Boulder Creek), there are four total arsenic use impairments – full body contact (standard threshold: 30 ug/L), fish consumption (standard threshold: 80 ug/L), agricultural livestock watering (standard threshold: 200 ug/L), and agricultural irrigation (standard threshold: 2,000 ug/L). Full body contact provides the most stringent of the applicable standards of the existing designated use impairments and is the one selected for use in the index.

Visit-specific hardness levels are considered for dissolved metals calculations, with each result compared to the standard applicable for the reported hardness value for that sample. Chronic standards are used for comparison for aquatic and wildlife uses of cold, warm, and effluent-dependent water streams or sites. Acute dissolved standards are used for comparison for the ephemeral A&W designated use.

WQI standards consider mean standards for site-specific nutrient standards where they exist, as well as single sample maximum value standards and hardness-dependent metal standards. Other types of specialized standards, such as nutrient annual means as outlined in the Arizona Administrative Code, 90th percentiles, and medians dependent on flow character are not incorporated. Other assessment methods, including limitations on time frames for certain E. coli evaluations for impairments, have not been adopted for the index.

1.3.4 GWQI Method

A combination of Python and Structured Query Language (SQL) was used to retrieve approved data from ADEQ's water quality database and apply the mathematical calculations laid out in Section 1.3.1 to the data set. Python 2.7 was the version used for the script. Extensive use was made of the Python library Pandas, and the Python library SQLAlchemy allowed for embedded SQL database retrievals for the main dataset, as well as from several supporting views and tables. These supporting products included an aggregated designated uses view by waterbody ID (WBID), a nutrient standards table designed to provide site-specific nutrient standards to the program for the WBIDs where nutrient standards applied, and a materialized view consolidating various lab chemical protocols of the original database structure into succinct and all-inclusive categories defined by substance name and analysis type. A compound function for summing constituent analytes (such as Kjeldahl Nitrogen and inorganic nitrate/nitrate as constituents of total nitrogen reporting) was developed, as was a custom class definition for storing the components, attributes, and sub-metrics of the index calculation.

Inputs to the program were provided by a standardized Microsoft Excel template file that listed the WBID, the Hydrologic Unit Code (HUC), the reach number, start date, end date of the time frame, and any impairment analytes the reach had previously been listed for. Indices were run in batches based on assembled content of the input files. Outputs included a support Excel workbook for each reach processed, with query data retrievals and major processing sub-sets written into the file during the run for QC checking of the data in review. Also included as an output was an Excel batch summary file that compiled and itemized the various sub-metrics and components of the calculations for all processed reaches in a run for easy comparison and evaluation.

Some limitations applied to the data sets evaluated. Duplicate samples were not considered in index calculations, and data associated with automated samplers for stormflow events were excluded due to excessive redundancy and a tendency to skew datasets either positively or negatively. This was due to the collection of anywhere from 12 to 24 samples within a 24-hour period. Future improvements to the index will incorporate the ability to include a single most representative value from these sets (maximum for acute exceedances; medians for chronic exceedances).

It is also noted here that no lakes trends were evaluated for either the GWQI or the AWQI; while historical data does exist for Arizona's lakes and reservoirs in sufficient quantities to allow for some type of trend analysis, an Arizona lakes index specifically targeted to lakes and their different chemical and biological characteristics is still in development stages. Furthermore, the ADEQ Clean Lakes program historically did not have the equivalent of ADEQ's FSN program with a principal objective of characterizing long-term trends. This makes an effort to characterize Arizona lake trends a lower priority at present.

1.4 Analyte Water Quality Indices

Analyte-specific indices are termed analyte water quality indices (AWQIs) as opposed to the general water quality indices (GWQI) discussed above. AWQIs are applied to the priority impaired reaches in this report, while GWQIs are applied to the long-term sites/reaches.

1.4.1 AWQI Mathematical Basis

The scope, frequency, and amplitude components of the WQI can be modified to yield an index number specific to a given analyte. This approach is valuable in assessing the severity of individual impairments on the same scale of 0 to 100 as the general index. In essence, the scope term of index calculation drops out, and the index is determined with the frequency and amplitude components alone. For the sake of continuity and clarity, the sub-terms are not re-numbered in the equation below. With preparatory calculations the same as for the general index for the retained sub-indices, the Analyte WQI is then calculated as:

$$Analyte\ WQI = 100 - \left(\frac{\sqrt{{F_2}^2 + {F_3}^2}}{1.414} \right)$$

Where F2 and F3 are as previously defined (with the same supporting calculations), with the exceptions that F_2 is restricted to the number of exceedances and results for the individual analyte alone and

F_3, likewise, is calculated based on only the individual analyte being considered.

The denominator of 1.414 is derived from the elimination of the scope term (F_1), resulting in a maximum possible numerator value of 141.4. Since both sub-indices are capped at 100, the maximum numerator is:

$$\sqrt{100^2 + 100^2} = \sqrt{20{,}000} = 141.4$$

Division by 1.414 allows for reporting on the 0-100 scale with 100 as a maximum.

1.4.2 AWQI Data, Standards/Thresholds, and Methods

The AWQI 's general approach is similar to the GWQI's with a few notable exceptions. Sets of core parameters do not apply to analyte runs, which are focused on the analytes that PIRs are listed as impaired for. Water quality standards applied to AWQIs are the same as those applied to GWQIs. A run of an AWQI requires a WBID, the analyte of concern, and the designated use that is being used as the standard benchmark for comparison. Additional inputs include the HUC, the reach number, and the start date and end date for the period of interest. If a reach is impaired for more than one analyte, separate AWQIs are generated for each analyte of impairment. A modified method of considering exceedances is implemented. In keeping with the requirement that one analyte is considered at a time, the scope term (F_1) of the GWQI becomes superfluous and is thus dropped from consideration. An exceedance in the AWQI data set then simultaneously counts as:

1) one of the total number of results in the data set showing adverse impacts in the frequency term (F_2) of the calculation, and
2) the magnitude of the exceedance is tabulated relative to the standard for the amplitude term (F_3) of the index calculation.

Methods of calculation for AWQIs are similar to those of GWQIs. Python with embedded SQL was the tool of choice, as detailed in Section 1.3.4. Modifications specific to analyte index calculations were made from the GWQI source code and saved separately for execution. Coding was simplified in some respects, namely by the elimination of the need to build a list of parameters to be queried for and by the direct supplying of a designated use in the input file. Input and output methods were the same, differing only in the content supplied.

It is important to note that with analyte indices for impairment analytes, reporting near the lower end of the WQI scale is more likely due to the possibility of severe impairments. The user is advised to be mindful that multiple log scales of reporting are being compressed within a 100-point scale. Consequently, indices below 10 represent aggregated exceedances more than a one order of magnitude over the standard (threshold of no exceedances = 100). Indices below one (1) represent aggregated exceedances more than two orders of magnitude beyond the standard. This is particularly an important point to remember when looking for trends of improvement – waterbodies reporting in these low tiers with ample data supporting the value may require a long time to exit those tiers. Much territory in the magnitude of exceedance sub-metric must be transited before the index value will broach the thresholds associated with index values of one or ten.

2.0 General Characterization of Water Quality Indices

2.1 Long-Term Sites/Reaches (LTS)

Annual general WQIs were run for the 38 historical ADEQ Fixed Station Network monitoring sites over a 31-year period from 1989 to 2019. This set included a dozen sites on major rivers contracted to the U.S. Geological Survey by ADEQ. Summary statistics by WBID and for the entire data set were compiled, including boxplots for each type, histograms, medians, means, frequency distributions, and percentiles. All annual GWQIs are presented in Appendix C.

2.1.1 LTS Summary Statistics

Summary statistics were run in EPA's ProUCL program. Data was imported in spreadsheet form and run, both as a complete set, and when grouped by Waterbody ID. Boxplots and histogram graphs were generated using Python's Seaborn library after importation into a Python Pandas data frame from ProUCL. Table 4, Table 6, and Table 7 present values from the summary statistics for GWQIs. Table 5 breaks down the frequency and percentage of indices per histogram bin. Figure 2 and Figure 3 present a boxplot and histogram summarizing all yearly GWQIs generated for the data set. The histogram/kernel density estimate in Figure 2 (and all subsequent histogram/KDE figures) shows a scale for the raw count of the number of elements (years, in this case) in the defined histogram bins on the left side of the graph, and a scale for the percentage represented by the kernel density estimate curve (expressed in decimal form) on the right side of the graph.

Summary Statistic	Value	Percentile	Value
Maximum	100	**99th**	100
Mean	91.5	**95th**	100
Minimum	4	**90th**	100
Geo-Mean	89.3	**80th**	100
Standard Deviation	14.22	**75th (Q3)**	100
Standard Error of Mean	0.644	**50th (Q2)**	97
Median Absolute Deviation / 0.675	4.448	**25th (Q1)**	89
Skewness	-2.924	**20th**	86
Coefficient of Variation	0.155	**10th**	75.7

Table 4. Summary statistics, GWQI data set

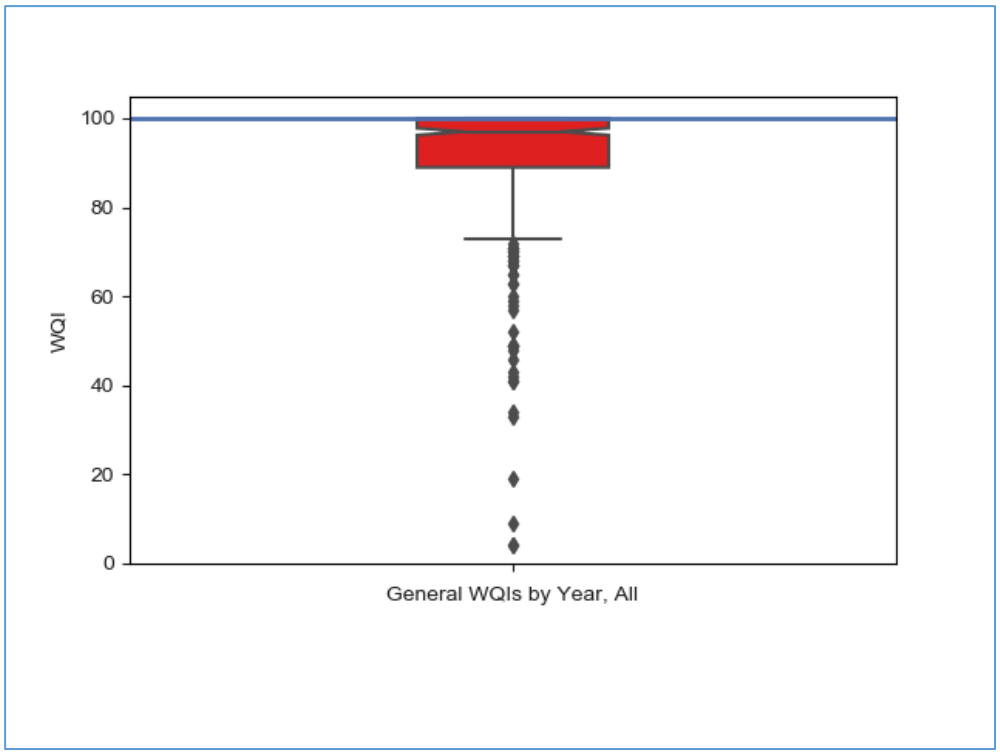

Figure 2. Annual GWQI Boxplot, All Long-term Reaches/Sites

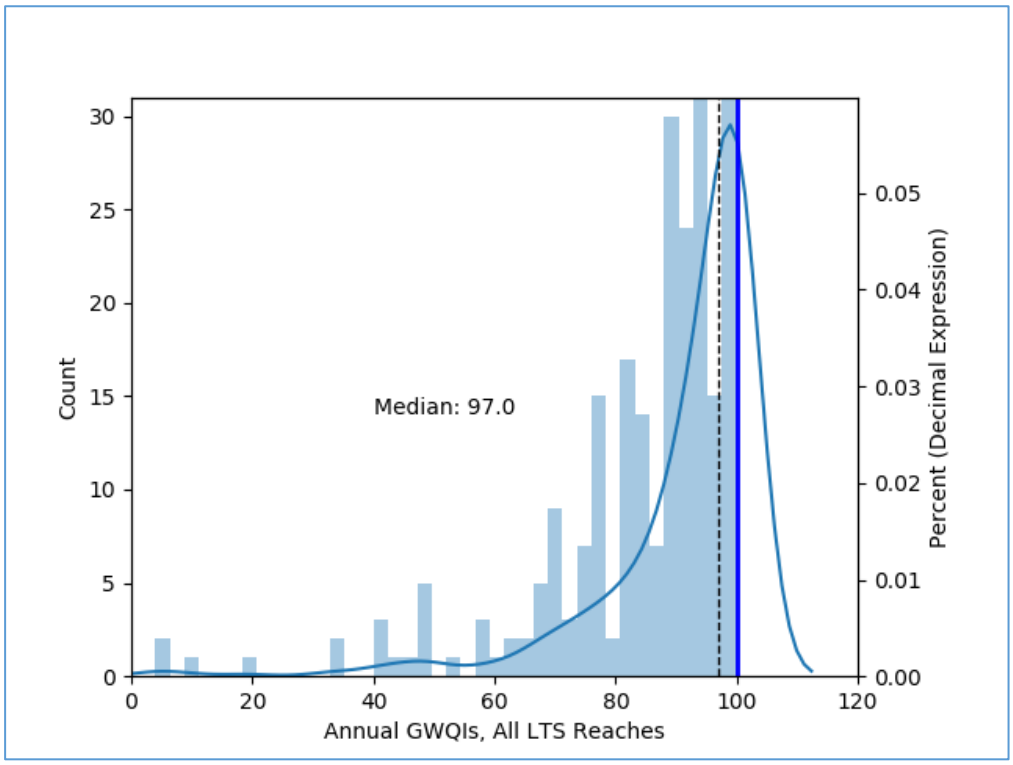

Figure 3. Annual GWQI Histogram/Kernel Density Estimation with median, Long-term Reaches/Sites

Histogram Bin	Count	Percentage	Histogram Bin	Count	Percentage
100	241	49.4	50	5	1
97.5	15	3.1	47.5	1	0.2
95	74	15.2	45	1	0.2
92.5	24	4.9	42.5	3	0.6
90	30	6.1	40	0	0
87.5	7	1.4	37.5	0	0
85	19	3.9	35	2	0.4
82.5	12	2.5	32.5	0	0
80	10	2.0	30	0	0
77.5	7	1.4	27.5	0	0
75	9	1.8	25	0	0
72.5	4	0.8	22.5	0	0
70	8	1.6	20	1	0.2
67.5	3	0.6	17.5	0	0
65	4	0.8	15	0	0
62.5	0	0.0	12.5	0	0
60	3	0.6	10	1	0.2
57.5	1	0.2	7.5	0	0
55	0	0.0	5	2	0.4
52.5	1	0.2	2.5	0	0

Table 5. Percentages and Counts by Histogram Bin, Figure 2

Waterbody ID	Maximum	Mean	Minimum	Geomean	SD	SEM	MAD/0.675	Skewness	CV
14070006-001	100	96.32	71	96.05	6.815	1.564	0	-3.11	0.0708
15020001-009	100	96.04	78	95.82	6.383	1.303	0	-1.64	0.0665
15020001-013B	100	92.39	67	91.85	9.75	2.033	7.413	-1.341	0.106
15020002-004	100	**69**	**4**	49.59	35.7	8.19	32.62	-0.929	0.517
15040004-001	100	95.29	49	94.51	10.43	2.129	0	-4.094	0.109
15040004-003	100	94.4	78	94.07	7.854	2.028	0	-1.345	0.0832
15040004-023	100	94.4	82	94.19	6.379	1.647	7.413	-0.791	0.0676
15040004-025B	100	98.12	88	98.05	3.706	0.899	0	-1.833	0.0378
15040005-022	94	82.87	68	82.45	8.535	2.204	8.895	-0.109	0.103
15050202-008	100	87.88	49	86.78	13.01	2.551	10.38	-1.408	0.148
15050203-001	100	87.47	34	84.7	19.08	4.926	0	-1.809	0.218
15050301-011	100	69.35	33	65.71	22.37	5.003	30.39	0.0338	0.323
15060103-004	100	89.81	42	87.56	17.56	4.391	3.706	-2.177	0.196
15060103-018C	100	96.05	87	95.92	5.148	1.181	0	-0.755	0.0536
15060103-280E	100	91.74	75	91.29	9.061	2.079	14.83	-0.59	0.0988
15060105-008	100	**99.29**	**92**	99.27	2.114	0.513	0	-3.136	0.0213
15060105-013A	100	92.76	60	92.09	10.49	2.543	7.413	-2.287	0.113
15060106A-003	100	97.93	91	97.89	3.058	0.79	0	-1.38	0.0312
15060202-025	100	98.56	88	98.5	3.355	0.671	0	-2.483	0.034
15060202-037	100	96.07	70	95.7	8.093	2.09	0	-2.752	0.0842
15060203-004	95	93.21	92	93.21	0.699	0.187	0	1.253	0.0075
15060203-022B	100	97.13	81	96.95	5.726	1.431	0	-2.183	0.059
15060203-022C	100	89.06	65	88.16	12.48	3.12	12.6	-0.973	0.14
15060203-025	100	97.17	82	97.02	5.424	1.566	0	-2.357	0.0558
15070101-008	**85**	75.17	48	74.39	10.29	2.969	7.413	-1.868	0.137
15070103-004	100	97.6	76	97.38	6.334	1.635	0	-3.246	0.0649
15070103-007B	100	93.92	77	93.67	6.922	1.92	8.895	-1.399	0.0737
15070201-003B	100	93.6	84	93.42	5.877	1.518	8.895	-0.436	0.0628

Table 6. Summary statistics, GWQI by WBID

Waterbody ID	Percentiles								
	99th	95th	90th	80th	75th (Q3)	50th (Q2)	25th (Q1)	20th	10th
14070006-001	100	100	100	100	100	100	95	94.6	93.4
15020001-009	100	100	100	100	100	100	94.25	92	86.2
15020001-013B	100	100	100	100	100	95	87	85.4	83.2
15020002-004	100	100	100	100	100	78	53	33.4	8
15040004-001	100	100	100	100	100	100	93	93	92.3
15040004-003	100	100	100	100	100	100	92	89.4	81.6
15040004-023	100	100	100	100	100	95	91.5	90.4	85
15040004-025B	100	100	100	100	100	100	100	95.2	93.2
15040005-022	94	94	94	93.2	90.5	82	78.5	77	71.8
15050202-008	100	100	100	100	98.75	93	83.25	78	72.5
15050203-001	100	100	100	100	100	100	77.5	75.4	68.4
15050301-011	100	100	100	92	89.25	71	49	48.4	41
15060103-004	100	100	100	100	100	97.5	89.5	88	68.5
15060103-018C	100	100	100	100	100	100	91.5	89	88.8
15060103-280E	100	100	100	100	100	90	87	84.6	79.8
15060105-008	100	100	100	100	100	100	100	100	98.4
15060105-013A	100	100	100	100	100	95	91	91	84.4
15060106A-003	100	100	100	100	100	100	96.5	96	93.6
15060202-025	100	100	100	100	100	100	100	99.2	95.4
15060202-037	100	100	100	100	100	100	95.5	94.4	89.6
15060203-004	94.87	94.35	94	93.4	93	93	93	93	93
15060203-022B	100	100	100	100	100	100	97	97	89.5
15060203-022C	100	100	100	100	100	91.5	83.5	82	68
15060203-025	100	100	100	100	100	100	96	96	92.4
15070101-008	84.89	84.45	83.8	82	82	77	73.5	72.4	65.7
15070103-004	100	100	100	100	100	100	100	98.8	94
15070103-007B	100	100	100	100	100	94	93	92.4	85.6
15070201-003B	100	100	100	100	100	94	90	87.6	84.8

Table 7. Percentiles summary, GWQI by WBID

GWQI ranges by WBID as displayed in Table 6 are presented graphically by boxplots in Figure 4-9:

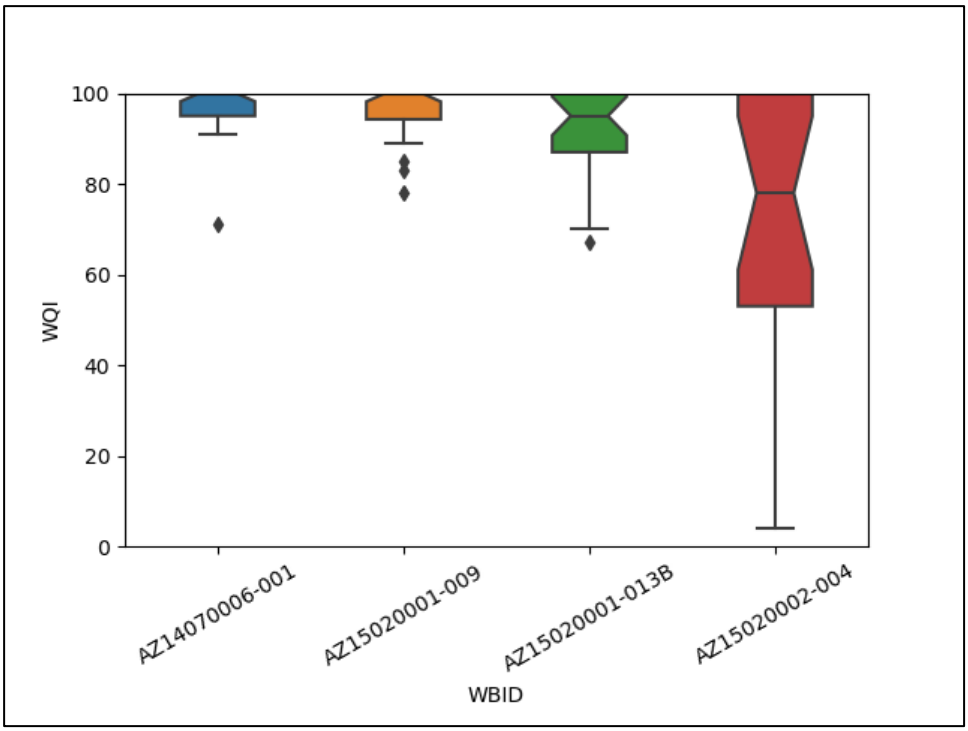

Figure 4. Annual GWQIs by WBID, Group 1 boxplots

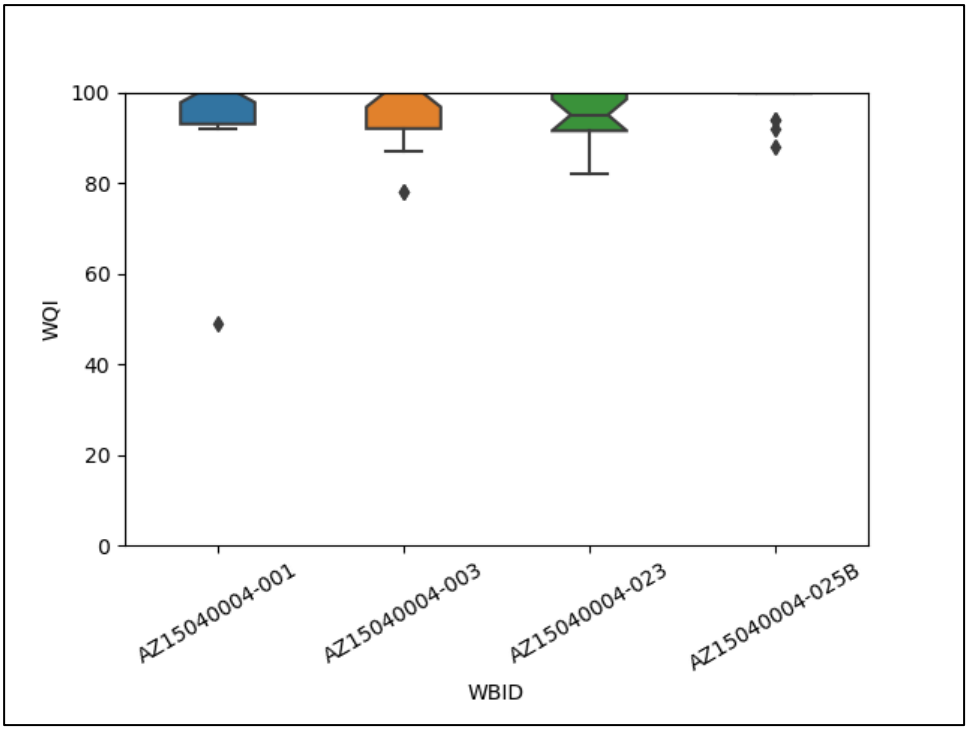

Figure 5. Annual GWQIs by WBID, Group 2 boxplots

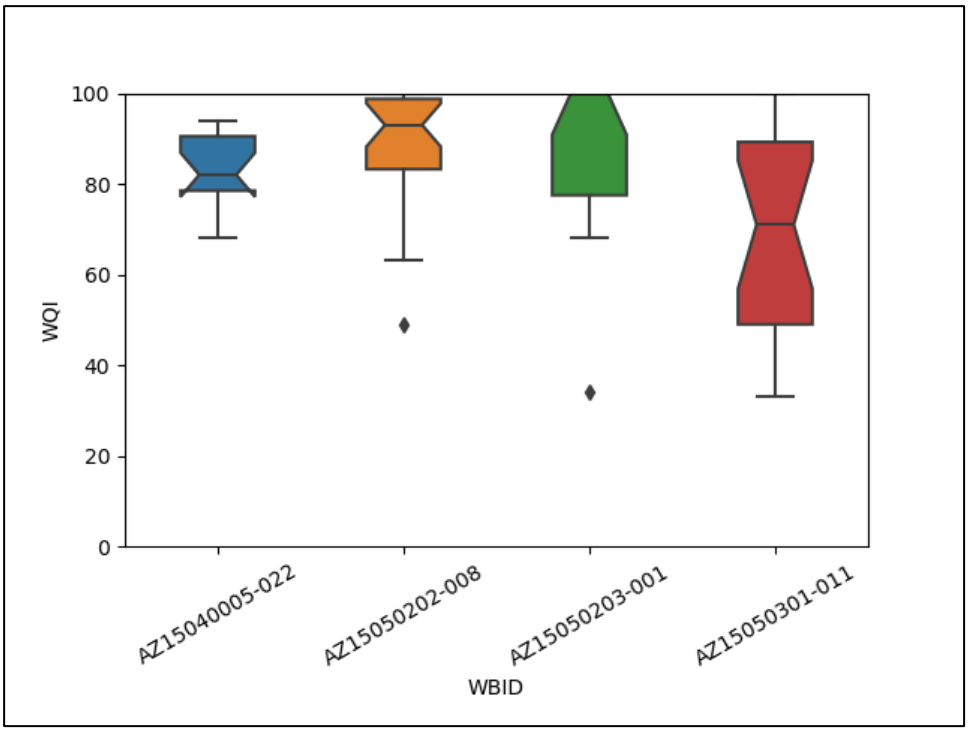

Figure 6. Annual GWQIs by WBID, Group 3 boxplots

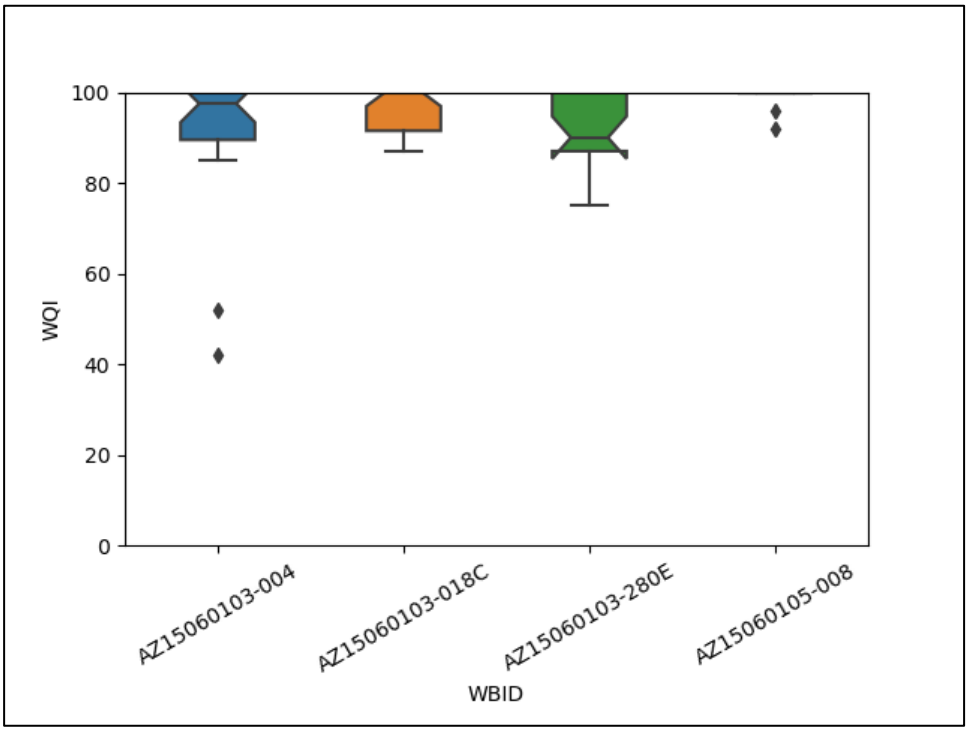

Figure 7. Annual GWQIs by WBID, Group 4 boxplots

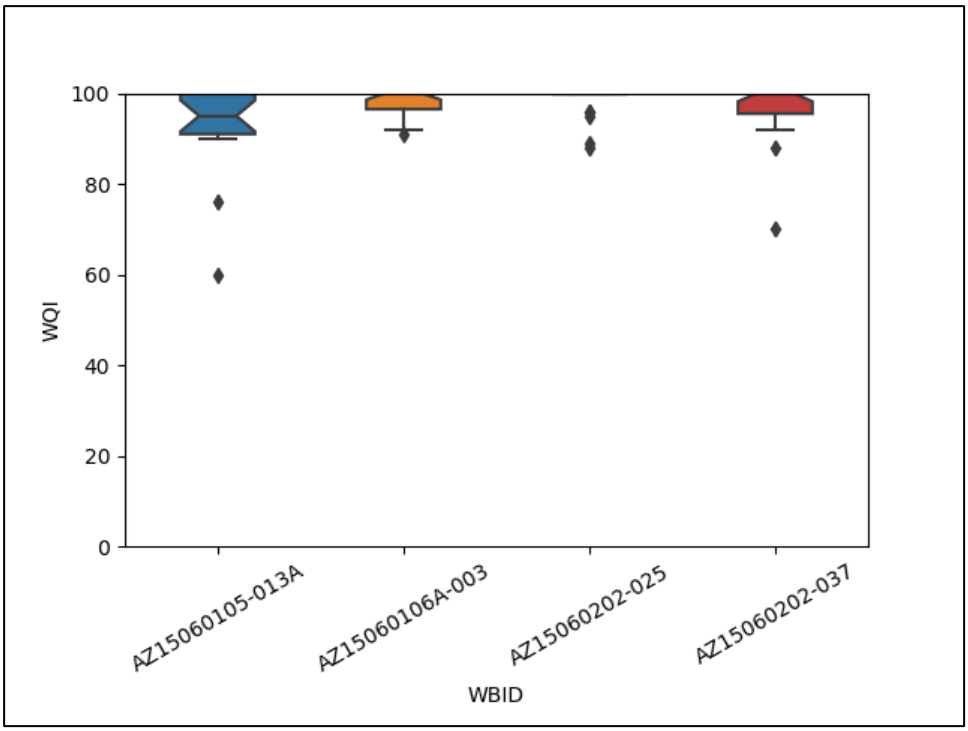

Figure 8. Annual GWQIs by WBID, Group 5 boxplots

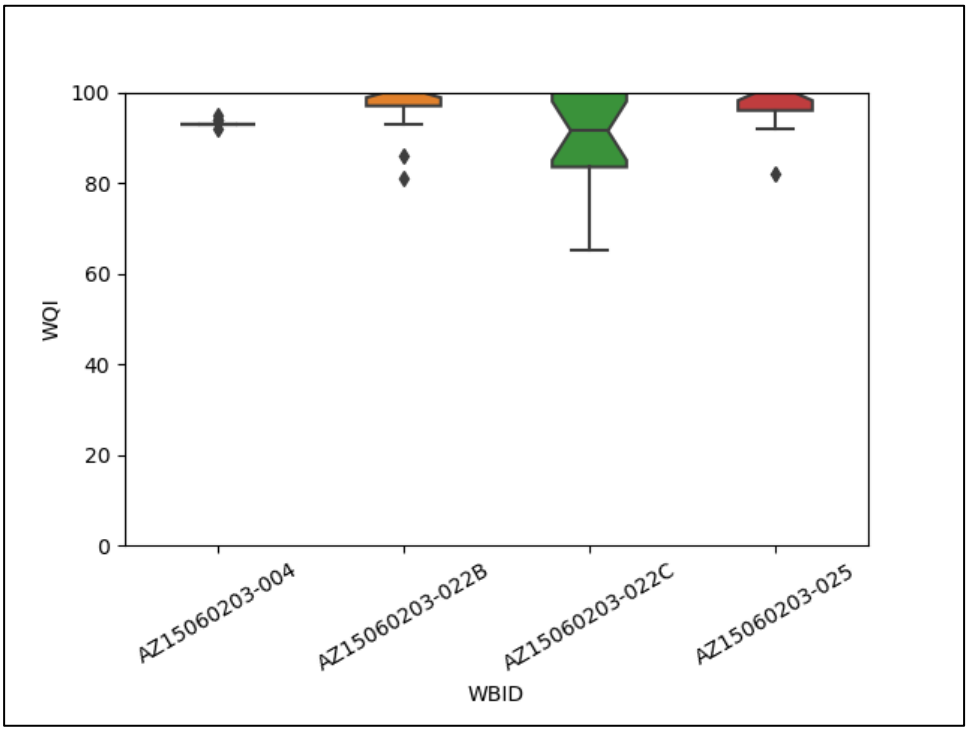

Figure 9. Annual GWQIs by WBID, Group 6 boxplots

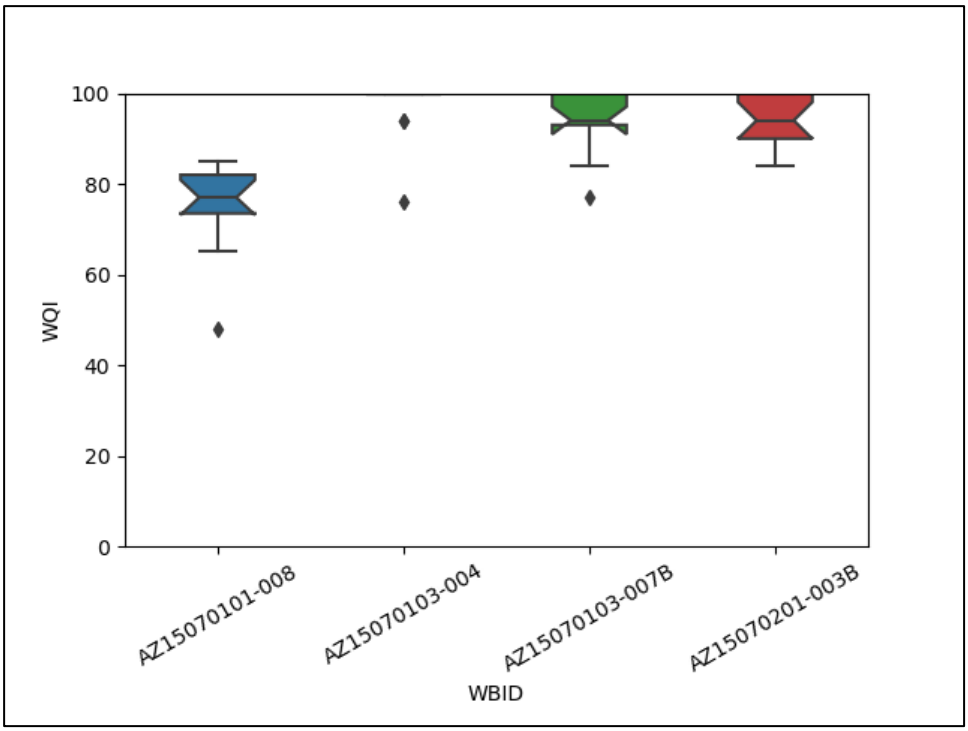

Figure 10. Annual GWQIs by WBID, Group 7 boxplots

2.1.2 Discussion – LTS Annual General WQI Summary Statistics

The data show consistently scoring quality annual indices for long-term sites across the state of Arizona with a handful of exceptions. For the data set considered as a whole (*n = 488*), the median annual water quality index of 97 on a 0-100 scale scored near the maximum possible. The 75th through 99th percentiles uniformly scored 100 for the set, while the 25th percentile was still a robust 89. The mean for the entire set was 91.5. The histogram analysis exhibited more than 49% (*n=241*) of all annual indices in the uppermost bin defined for the range 97.5-100, with another 15 percent (*n=74*) logged in the 92.5-95 range and six percent (*n=30*) in the 87.5-90 range (Figure 3, Table 5). The histogram displayed a slight left skew when considering that the plot is essentially a one-sided graph with a hard right limit of 100 (calculated skew -2.9). The raw standard deviation for the set was 14.22, while the outlier-resistant measure of median absolute deviation (MAD)/0.675 showed a value of 4.45, indicating a comparatively narrow dispersion of the set. The latter measure is the non-parametric approximation of the parametric standard deviation for large normal data sets.

While the median for the entire annual GWQI series is high, it is important to remember that the sites selected for the FSN network were reliably-flowing sites (i.e., perennial waters for the most part) on main-stem rivers and major tributaries in generally remote and dispersed parts of Arizona (Figure 1). Only seven of the 38 reaches considered were impaired for any analytes in historical water quality assessments; water quality thus reported as generally good to begin with. Additionally, the screening process, necessary to ensure largely continuous runs in the annual series, dropped out certain years that had exceedances logged; period of record indices (Section 4.0) pick up these exceedances that were missed for the trend analysis. It is also well to remember that the index only considers water chemistry.

Other indicators of water quality, such as the health of aquatic macroinvertebrate communities and fish populations, or physical indicators like measures of sedimentation in river channels, median sediment size class, or riparian cover are not considered in the GWQI. Some of these alternative measures indicate that Arizona has several areas of degraded water quality.

When annual GWQIs are considered by individual Waterbody IDs (WBIDs), other patterns and noteworthy features become apparent. Half of the evaluated reaches scored with medians at the uppermost limit of the WQI scale at 100. Reach 15060105-008 on Tonto Creek scored the highest overall, with a 10th percentile value of 98.4 (i.e., 90 percent of annual values exceeded this threshold). The reach's mean is 99.3, and its minimum is 92, indicating overall excellent water quality with rare exceedances of standards. Reach 15020002-004 on the Little Colorado River exhibited the broadest dispersion of the data set with a standard deviation of 35.7 and a MAD/0.675 of 32.42, indicating that water quality was widely-variable over time for this location. It also logged the minimum GWQI value of four for the entire data set, and its mean of 69 was the lowest annual GWQI mean determined for a reach in the set. The reach with the narrowest dispersion was Reach 15060203-004 below Bartlett Dam on the Verde River (Bartlett Lake Dam-Camp Creek), with a maximum annual GWQI of 95 and a minimum value of 92. The standard deviation for this reach was 0.699, while the MAD/0.675 was zero. Consistent water quality indices are expected below dams, as in this case, since water released from reservoirs benefits from residence time in reservoirs long enough to ensure thorough mixing and homogenization.

One additional site below a dam, Reach 14070006-001 on the Colorado River (Glen Canyon Dam - Lee's Ferry) also exhibits similar characteristics, though its dispersion is somewhat wider with a standard deviation of 6.8 and a MAD/0.675 of zero. This wider dispersion is due to purported selenium exceedances in the early years of the set record when detection limits were relatively high and analytical methods were not refined as much as in later years. With better lab technology and more accurate reporting in the 21st century, these exceedances have largely disappeared in recent years.

The reach with the lowest maximum score in the data set is Reach 15070101-008 on the Gila River (Hassayampa River- Gillespie Dam) with a maximum annual index of 85. This reach is an area with extensive and known impacts from agricultural discharges; it is currently impaired (with TMDLs developed) for total boron and total selenium with a long-running history of standards exceedances. It is noteworthy that though the maximum annual score for Reach 008 is the lowest of the set, the index variation for this reach is not the broadest (though it does score in the upper tier), nor does it score the lowest minimum for the set. It is surmised that while the water quality here is moderately degraded, the agricultural discharges are consistent from year to year and tend to have similar chemical make-up over time. These constant discharges in effect protect the reach from impulses of worse water quality, as may occasionally be seen with major storm water pulses from feeding desert washes.

2.2 Priority Impaired Reaches (PIR)

Annual analyte WQIs (AWQIs) were run for 38 priority-impaired reaches/sites and analyte combinations over a 31-year period from 1989 to 2019. Summary statistics by WBID and for the entire data set were compiled, including boxplots for each type, histograms, medians, means, frequency distributions, and percentiles. All annual AWQIs for PIRs are presented in Appendix D.

2.2.1 PIR Summary Statistics

Summary statistics were run in EPA's ProUCL program. Data was imported in spreadsheet form and run, both as a complete set, and when grouped by Waterbody ID. Boxplots and histogram graphs were generated using Python's Seaborn library after importation into a Python Pandas data frame from ProUCL. Table 8, Table 10, and Table 11 present values from the summary statistics for AWQIs. Table 9 breaks down the frequency and percentage of indices per histogram bin. Figure 11 and Figure 12 present a boxplot and histogram summarizing all yearly AWQIs generated for the data set.

Summary Statistic	Value	Percentile	Value
Maximum	100	**99th**	100
Mean	68.66	**95th**	100
Minimum	0	**90th**	100
Geo-Mean	--	**80th**	100
Standard Deviation	37.18	**75th (Q3)**	100
Standard Error of Mean	1.96	**50th (Q2)**	91
Median Absolute Deviation / 0.675	17.79	**25th (Q1)**	31
Skewness	-0.729	**20th**	22.8
Coefficient of Variation	0.542	**10th**	5.7

Table 8. Summary statistics, Priority impaired reaches AWQI data set

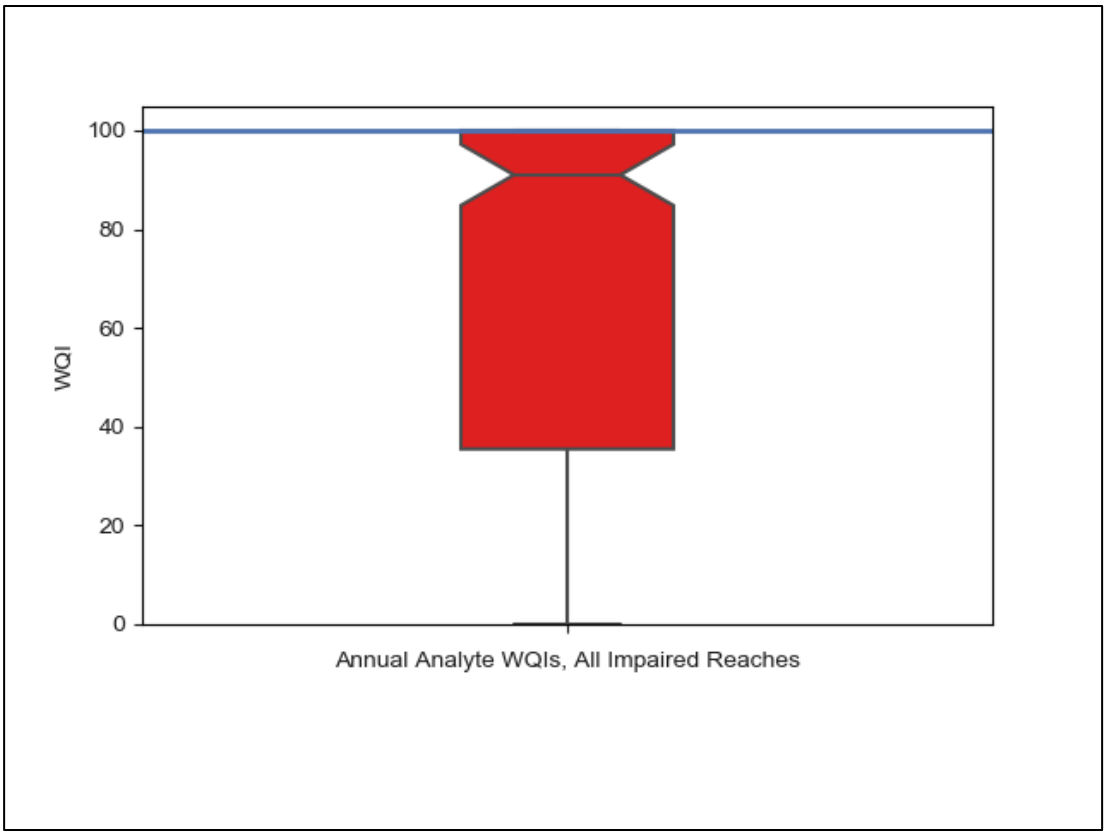

Figure 11. Annual AWQI Boxplot, All Impaired Reaches

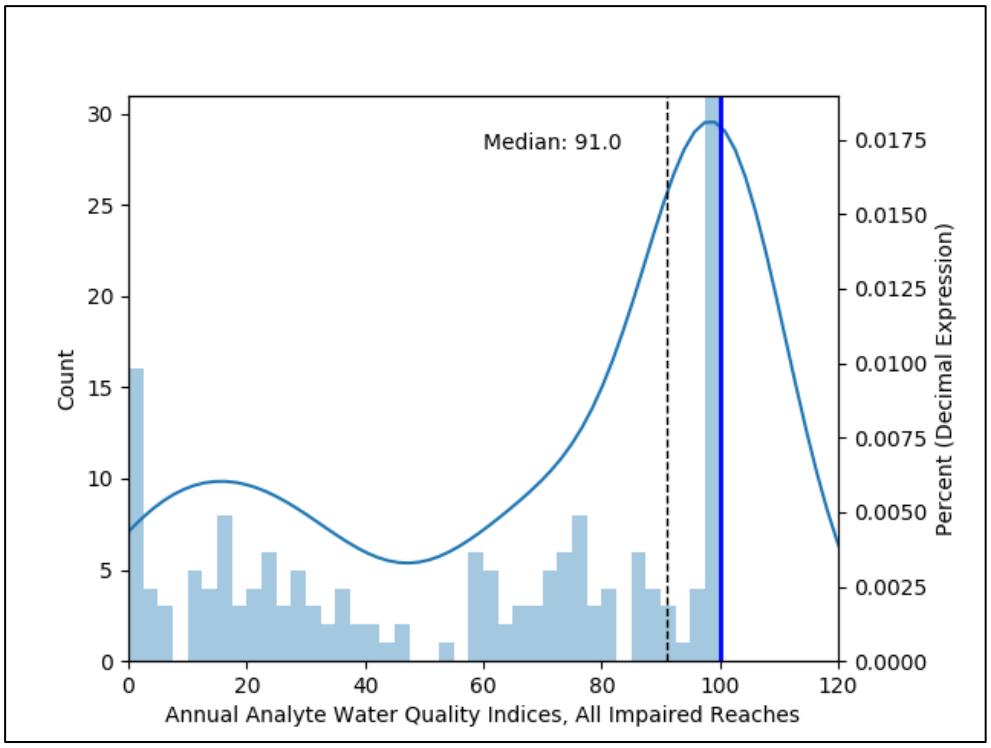

Figure 12. Annual AWQI Histogram/Kernel Density Estimate with median, All Impaired Reaches

Histogram Bin	Count	Percentage	Histogram Bin	Count	Percentage
100	163	45.3	50	3	0.8
97.5	4	1.1	47.5	4	1.1
95	4	1.1	45	1	0.3
92.5	5	1.4	42.5	2	0.6
90	6	1.7	40	3	0.8
87.5	6	1.7	37.5	3	0.8
85	2	0.6	35	4	1.1
82.5	5	1.4	32.5	3	0.8
80	3	0.8	30	5	1.4
77.5	7	1.9	27.5	4	1.1
75	11	3.1	25	8	2.2
72.5	3	0.8	22.5	5	1.4
70	6	1.7	20	6	1.7
67.5	2	0.6	17.5	3	0.8
65	8	2.2	15	12	3.3
62.5	4	1.1	12.5	5	1.4
60	8	2.2	10	2	0.6
57.5	0	0.0	7.5	3	0.8
55	1	0.3	5	7	1.9
52.5	0	0.0	2.5	29	8.1

Table 9. Percentages and Counts by Histogram Bin, Figure 11

WBID	Analyte	Maximum	Mean	Minimum	SD	SEM	MAD/0.675	Skewness	CV
AZ15030202-005A	ARSENIC-TOTAL-W	64	34	1	24.75	11.07	32.62	-0.292	0.728
AZ15030202-005A	COPPER-DISSOLVED-W	100	92.8	64	16.1	7.2	0	-2.236	0.173
AZ15030202-005A	MANGANESE-TOTAL-W	100	100	100	0	0	0	N/A	N/A
AZ15030202-005A	PH-TOTAL-W	100	91.36	58	14.81	4.465	0	-1.71	0.162
AZ15030202-005A	ZINC-DISSOLVED-W	100	71.2	15	37.89	16.95	11.86	-1.009	0.532
AZ15040005-022	LEAD-TOTAL-W	100	72	39	22.17	5.725	37.06	-0.0689	0.308
AZ15050100-012D	COPPER-DISSOLVED-W	100	65.57	22	23.8	8.997	16.31	-0.698	0.363
AZ15050100-012D	SELENIUM-TOTAL-W	100	82.14	39	23.35	8.825	19.27	-1.305	0.284
AZ15050100-014A	COPPER-DISSOLVED-W	100	60.83	33	23.5	9.593	17.79	0.817	0.386
AZ15050100-014A	SELENIUM-TOTAL-W	100	93.5	65	14.05	5.737	0	-2.382	0.15
AZ15050100-014B	COPPER-DISSOLVED-W	100	52.67	15	35.33	14.42	39.29	0.227	0.671
AZ15050202-003	ESCHERICHIA COLI-TOTAL-W	100	56.09	17	34.15	10.3	26.69	0.423	0.609
AZ15050202-006	COPPER-DISSOLVED-W	100	81.67	17	33.47	13.66	0	-1.972	0.41
AZ15050202-008	COPPER-DISSOLVED-W	100	84.59	15	26.62	6.457	0	-1.889	0.315
AZ15050202-008	ESCHERICHIA COLI-TOTAL-W	100	79.48	14	28.74	6.272	0	-1.21	0.362
AZ15050301-561B	CADMIUM-DISSOLVED-W	3	2.6	2	0.548	0.245	0	-0.609	0.211
AZ15050301-561B	COPPER-DISSOLVED-W	22	5.4	1	9.29	4.155	0	2.224	1.72
AZ15050301-561B	ZINC-DISSOLVED-W	1	0.667	0	0.516	0.211	0	-0.968	0.775
AZ15060103-018B	COPPER-DISSOLVED-W	33	12.08	0	9.224	2.558	2.965	0.751	0.764
AZ15060103-018C	COPPER-DISSOLVED-W	100	89.08	28	21.36	5.925	0	-2.312	0.24
AZ15060103-887	COPPER-DISSOLVED-W	2	0.273	0	0.647	0.195	0	2.42	2.371
AZ15060202-016	ESCHERICHIA COLI-TOTAL-W	100	92.2	61	17.44	7.8	0	-2.236	0.189
AZ15060202-017	ESCHERICHIA COLI-TOTAL-W	100	80.75	63	12.12	4.283	14.83	0.0913	0.15
AZ15060202-018A	ESCHERICHIA COLI-TOTAL-W	100	93.14	63	13.62	5.147	0	-2.406	0.146
AZ15060202-018B	ESCHERICHIA COLI-TOTAL-W	100	85.8	74	9.445	4.224	5.93	0.577	0.11
AZ15060202-018C	ESCHERICHIA COLI-TOTAL-W	100	94.96	60	9.787	1.957	0	-2.506	0.103
AZ15060202-019	ESCHERICHIA COLI-TOTAL-W	100	95.67	88	5.125	2.092	4.448	-0.58	0.0536
AZ15060202-022	ESCHERICHIA COLI-TOTAL-W	100	91.5	63	14.6	5.96	2.224	-2.04	0.16
AZ15060202-025	ESCHERICHIA COLI-TOTAL-W	100	96.53	74	9.149	2.362	0	-2.405	0.0948
AZ15070102-034B	ARSENIC-TOTAL-W	100	86.33	18	33.48	13.67	0	-2.449	0.388
AZ15070102-034B	LEAD-TOTAL-W	100	77.43	19	31.52	11.91	0	-1.204	0.407
AZ15070102-036B	COPPER-DISSOLVED-W	100	88.14	29	25.59	6.838	0	-2.025	0.29
AZ15070102-036B	LEAD-TOTAL-W	100	60.38	11	39.86	9.964	31.13	-0.216	0.66
AZ15070103-007A	CADMIUM-DISSOLVED-W	100	21.83	1	28.81	8.316	9.637	2.173	1.32
AZ15070103-007A	COPPER-DISSOLVED-W	100	55	2	41.95	12.11	54.11	0.106	0.763
AZ15070103-007A	PH-TOTAL-W	100	93.54	37	17.95	4.979	0	-3.078	0.192
AZ15070103-007A	ZINC-DISSOLVED-W	100	53.67	3	36.64	10.58	27.43	0.371	0.683
AZ15080301-337	COPPER-DISSOLVED-W	48	22.8	8	15.87	7.095	14.83	1.163	0.696

Table 10. Summary, AWQI Statistics by Reach and Impairment

Waterbody ID	Impaired Analyte	Percentiles								
		99th	95th	90th	80th	75th (Q3)	50th (Q2)	25th (Q1)	20th	10th
AZ15030202-005A	ARSENIC-TOTAL-W	63.32	60.6	57.2	50.4	47	40	18	14.6	7.8
AZ15030202-005A	COPPER-DISSOLVED-W	100	100	100	100	100	100	100	92.8	78.4
AZ15030202-005A	MANGANESE-TOTAL-W	100	100	100	100	100	100	100	100	100
AZ15030202-005A	PH-TOTAL-W	100	100	100	100	100	100	89.5	88	68
AZ15030202-005A	ZINC-DISSOLVED-W	100	100	100	100	100	92	49	42.2	28.6
AZ15040005-022	LEAD-TOTAL-W	100	100	100	100	91	75	53	46.8	43.6
AZ15050100-012D	COPPER-DISSOLVED-W	98.68	93.4	86.8	76.8	75	70	58.5	58.2	43.6
AZ15050100-012D	SELENIUM-TOTAL-W	100	100	100	100	100	87	74.5	67	52.8
AZ15050100-014A	COPPER-DISSOLVED-W	98.55	92.75	85.5	71	69.5	57	47.5	47	40
AZ15050100-014A	SELENIUM-TOTAL-W	100	100	100	100	100	100	97	96	80.5
AZ15050100-014B	COPPER-DISSOLVED-W	98.8	94	88	76	75.75	51	24	23	19
AZ15050202-003	ESCHERICHIA COLI-TOTAL-W	100	100	100	100	94	35	30	29	24
AZ15050202-006	COPPER-DISSOLVED-W	100	100	100	100	100	100	79.75	73	45
AZ15050202-008	COPPER-DISSOLVED-W	100	100	100	100	100	100	76	75.2	52.4
AZ15050202-008	ESCHERICHIA COLI-TOTAL-W	100	100	100	100	100	100	70	66	31
AZ15050301-561B	CADMIUM-DISSOLVED-W	3	3	3	3	3	3	2	2	2
AZ15050301-561B	COPPER-DISSOLVED-W	21.2	18	14	6	2	1	1	1	1
AZ15050301-561B	ZINC-DISSOLVED-W	1	1	1	1	1	1	0.25	0	0
AZ15060103-018B	COPPER-DISSOLVED-W	31.8	27	21.4	15	15	13	3	2.4	2
AZ15060103-018C	COPPER-DISSOLVED-W	100	100	100	100	100	100	88	79.6	69.2
AZ15060103-887	COPPER-DISSOLVED-W	1.9	1.5	1	0	0	0	0	0	0
AZ15060202-016	ESCHERICHIA COLI-TOTAL-W	100	100	100	100	100	100	100	92.2	76.6
AZ15060202-017	ESCHERICHIA COLI-TOTAL-W	99.37	96.85	93.7	89.8	88.75	79.5	74.75	71.6	66.5
AZ15060202-018A	ESCHERICHIA COLI-TOTAL-W	100	100	100	100	100	100	94.5	93	80.4
AZ15060202-018B	ESCHERICHIA COLI-TOTAL-W	99.48	97.4	94.8	89.6	87	86	82	80.4	77.2
AZ15060202-018C	ESCHERICHIA COLI-TOTAL-W	100	100	100	100	100	100	95	92.6	85.8
AZ15060202-019	ESCHERICHIA COLI-TOTAL-W	100	100	100	100	100	97	92.5	92	90
AZ15060202-022	ESCHERICHIA COLI-TOTAL-W	100	100	100	100	100	98.5	91	89	76
AZ15060202-025	ESCHERICHIA COLI-TOTAL-W	100	100	100	100	100	100	100	100	84.4
AZ15070102-034B	ARSENIC-TOTAL-W	100	100	100	100	100	100	100	100	59
AZ15070102-034B	LEAD-TOTAL-W	100	100	100	100	100	100	61.5	61.2	44.2
AZ15070102-036B	COPPER-DISSOLVED-W	100	100	100	100	100	100	100	89.6	43.9
AZ15070102-036B	LEAD-TOTAL-W	100	100	100	100	100	79	17.25	15	13
AZ15070103-007A	CADMIUM-DISSOLVED-W	94.94	74.7	51	24	24	8.5	5.25	3.6	3
AZ15070103-007A	COPPER-DISSOLVED-W	100	100	100	100	100	44.5	17.75	17.2	14.3
AZ15070103-007A	PH-TOTAL-W	100	100	100	100	100	100	100	100	83.2
AZ15070103-007A	ZINC-DISSOLVED-W	100	100	100	100	100	39	25	22.8	21.1
AZ15080301-337	COPPER-DISSOLVED-W	47.12	43.6	39.2	30.4	26	21	11	10.4	9.2

Table 11. Percentiles, AWQIs by WBID and analyte

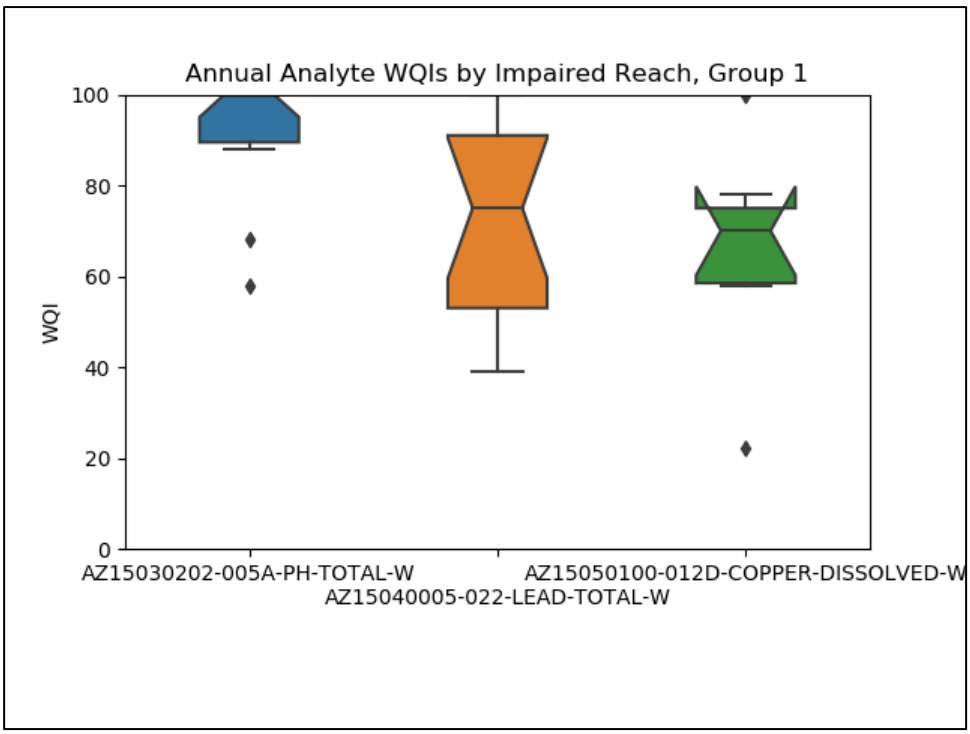

Figure 13. Annual AWQIs by WBID, Impaired Reaches Group 1 boxplots

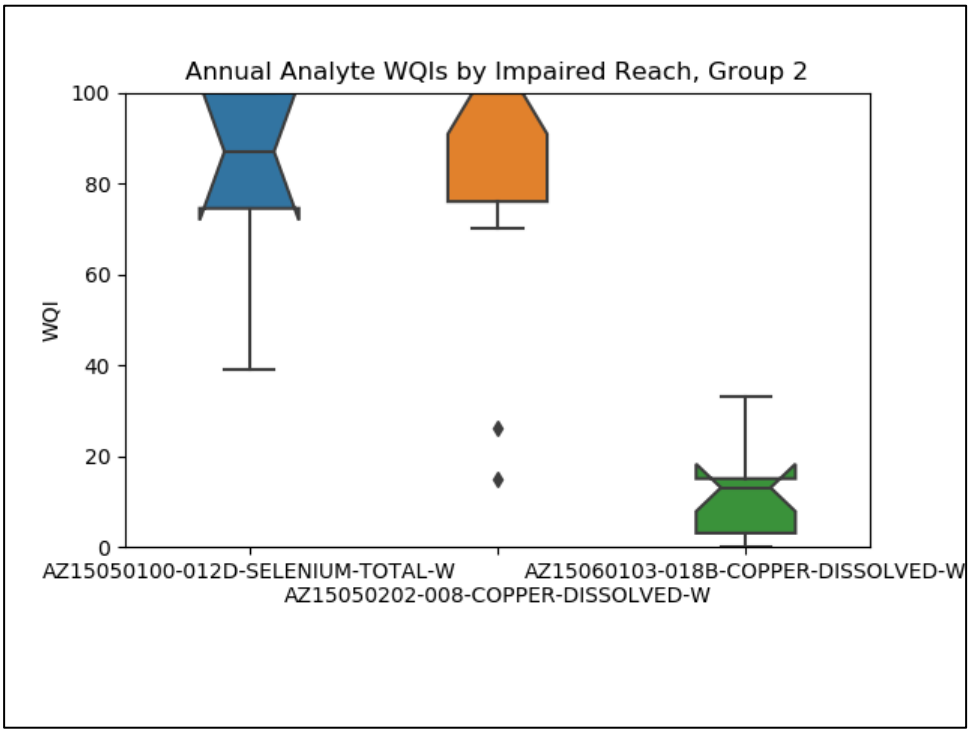

Figure 14. Annual AWQIs by WBID, Impaired Reaches Group 2 boxplots

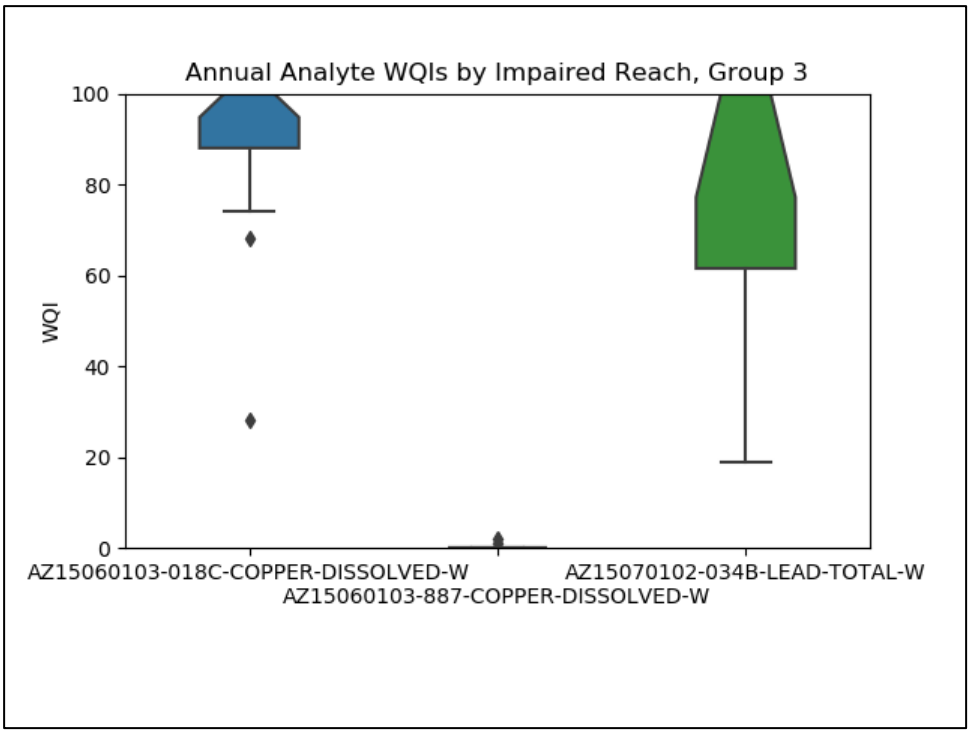

Figure 15. Annual AWQIs by WBID, Impaired Reaches Group 3 boxplots

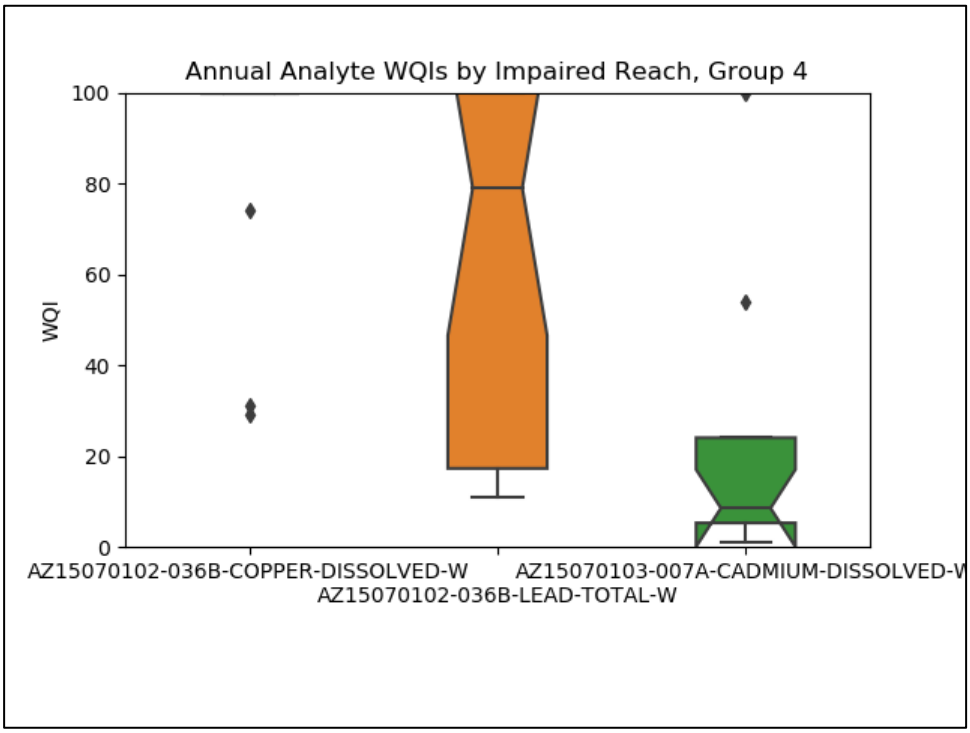

Figure 16. Annual AWQIs by WBID, Impaired Reaches Group 4 boxplots

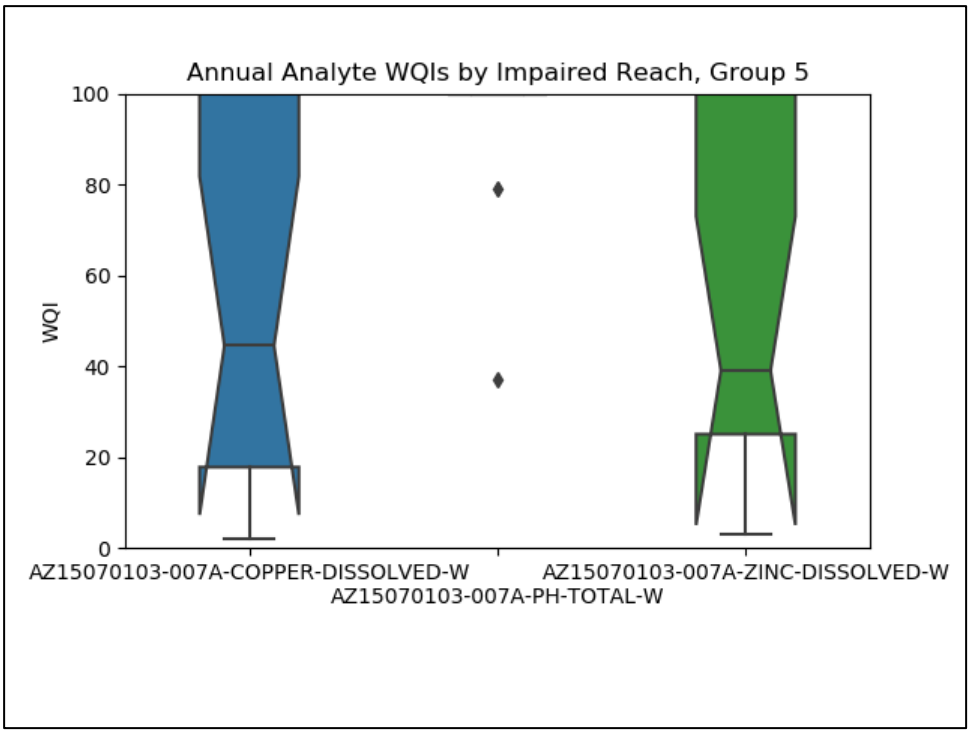

Figure 17. Annual AWQIs by WBID, Impaired Reaches Group 5 boxplots

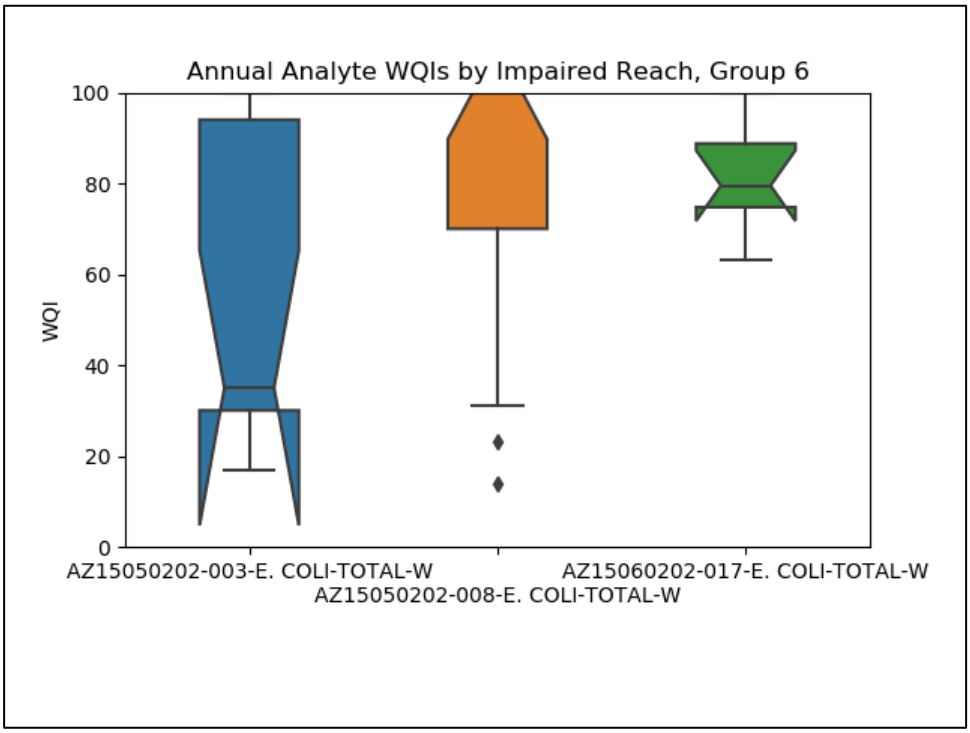

Figure 18. Annual AWQIs by WBID, Impaired Reaches Group 6 boxplots

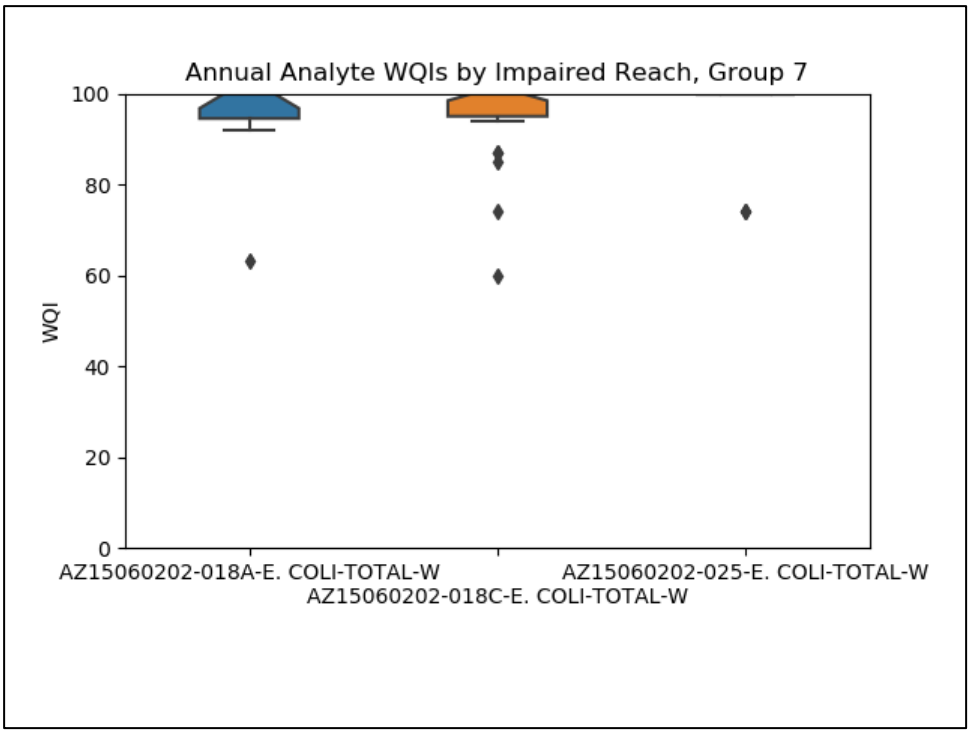

Figure 19. Annual AWQIs by WBID, Impaired Reaches Group 7 boxplots

2.2.2 Discussion – PIR Analyte WQI Summary Statistics

The annual statistics for the AWQIs of priority-impaired reaches demonstrated that in most cases, indices varied in a pronounced fashion through the period of record. The standard deviation for this data set was 37.2 (compare SD 14.2 for LTS GWQIs) and the coefficient of variation was 0.542 (compare 0.155 for LTS GWQIs). The histogram illustrates a pronounced bi-modal character (which might even be considered tri-modal given the high number/percentage of indices at three or below), with a clear plurality of indices clustered at or near the top possible score of 100 (Figure 12). Fully 45% (*n = 163 of 360*) of yearly indices achieved this distinction, with an additional 3.1 % (*n=11*) in histogram bin 72.5-75. On the other hand, 3.3% (*n=12*) clustered in bin 12.5-15, and 29 indices (8.1%) occupied the lowest bin 0-2.5, thereby demonstrating very poor water quality. The overall median for the set was 91 (compare median 97 for LTS GWQIs). As with the GWQI set, the PIR data set showed the 75th through 99th percentiles all registering at 100, the uppermost score possible. At the lower end of the scale, the 10th percentile value was 5.7 (compare 75.7 for the GWQI set), and an overall mean of 68.7 was noted for the PIR set (91.5 for LTS GWQIs).

This highly variable character across the data set suggests that most impaired reaches demonstrate their impairments on an episodic basis, exhibiting more acceptable water quality in non-critical conditions and poorer water quality in critical conditions. The critical conditions may vary by reach and can be due to one of several factors, as outlined in Section 1.2.2. This variable character can be visually confirmed by the elongated nature of several of the boxplots (Figures 13-19). The histogram's bi-modal appearance also supports this interpretation.

When reaches with impairments are considered individually, Boulder Creek's (AZ15030202-005A) manganese impairment appears the least serious, with the 10th percentile recorded at 100 (i.e., no exceedances recorded). It should be noted that this reach had insufficient annual coverage in two of three sub-periods of the annual series that excluded these years from consideration in the trend analysis; in one of the omitted periods, there were some exceedances. A period of record analysis to follow gives a clearer picture of this reach's status. Oak Creek's uppermost reach (AZ15060202-019) also had a high AWQI score for *E. coli* with a 10th percentile of 90. Alum Gulch (AZ15050301-561B) at the other end of the scale showed bottom-tier 10th percentiles for dissolved cadmium, copper, and zinc (2, 1, and 0 respectively), while Pinal Creek, Brewery Gulch (both copper-impaired reaches), and the Hassayampa River (dissolved cadmium) also showed 10th percentiles in the bottom tier (2, 0, and 3 respectively). All of these metal impairments can be considered severe.

The dispersion characteristics of three of these most severe impairments (Alum Gulch Cd and Zn, Brewery Gulch Cu) is very narrow, with the standard deviation of each registering at less than 1. It should be noted that the mathematics behind the index calculation compress the lower end of the index scale by factors of 10 below a value of ten[2]. Even so, this narrow dispersion indicates these impairments have been consistent over many years and less prone to exhibiting the episodic variability other reaches do. This also suggests these impairments are more likely to be point-source impairments with consistent flow and loading causing the impairment. On the other end of the index scale, Boulder Creek's manganese impairment shows a standard deviation of zero, due to no exceedances reflected in AWQI calculations and all annual values registering at 100.

The broadest dispersion measures of the set were for the Hassayampa Reach 007A (Cu, D) with a standard deviation of 41.9 and a MAD/0.675 of 54.1. As previously mentioned, a high standard deviation indicates a reach with widely variable water quality and usually reflects periodic storm flow impacts alternating with stretches of time with better and more stable water quality.

The lowest maximum for a reach was one, logged by Alum Gulch's zinc-impaired reach. The lowest mean for a reach was 0.27, recorded by Brewery Gulch (Cu, D). The highest maximum of 100 was shared by 31 of the 38 reaches evaluated. The highest mean was, again, Boulder Creek (Mn, T) at 100. Verde River Reach 025 (*E. coli*) is also notable for a mean AWQI of 96.5.

[2] Index values between 10 and 100 exceed the standard by up to one order of magnitude; index values between 1 and 10 exceed by between one and two orders of magnitude, and index values of less than one exceed by more than two orders of magnitude.

3.0 Long-term Trends

3.1 Long-Term Sites/Reaches (LTS)

For both LTSs and priority-impaired reaches (PIRs), similar methods in testing for trends were employed. Mann-Kendall testing was performed on the runs to identify sites where monotonic trends were in evidence. Kendall tau coefficients were generated for each run, and Theil-Sen testing was done to identify the median trend for sites where monotonic trends existed. Testing for step trends was subsequently conducted on the sets by identifying changepoints in the data sequence (R, changepoints library) and testing the means before and after each identified changepoint with a Student's t test. Period of record indices were also generated over the entire period for both GWQIs and AWQIs to provide baseline indices for sites where no trends were detected.

Annual general WQIs were run for the 38 historical ADEQ Fixed Station Network monitoring sites over a 31-year period from 1989 to 2019.

3.1.1 LTS Monotonic Trends

Data was screened using a method recommended by Helsel & Hirsch for datasets that are not continuous. Broadly, the method recommends dividing the period of record into three equal periods and selecting only sub-periods that have at least 20% representation of the entire possible data set. For the purposes of this testing, data was split into an 11 and two ten year periods, and only periods with a minimum of six years' representation within a sub-period were selected for testing. Sites and reaches that had insufficient data to meet this criterion for any sub-period are grayed out and denoted with hyphens in the table.

Monotonic trend testing with the Mann-Kendall non-parametric test yielded the results displayed in Table 12. Three long-term reaches showed improving trends at a statistically significant level over the period tested; one reach showed declining water quality over the period tested. Generally, most reaches showed no monotonic trend in either improving or declining water quality over the periods tested.

The Colorado River Reach 14070006-001 showed an improvement in dissolved cadmium concentrations through the testing period. This improvement was likely driven by better analytical test methods with lower detection limits as time passed. Most cadmium standards are generally below 1 ug/L, depending upon accompanying hardness values, and many results in the 1990s reported to only the nearest unit in significant figures, with the majority of detectable results reporting a 1 ug/L. This improvement in cadmium reporting in recent years was sufficient to drive up the general WQI.

Little Colorado River reach AZ15020002-004 also showed monotonic improvement for the periods evaluated. This reach, while still impaired for *E. coli* and suspended sediment concentrations, had several records of extremely high suspended sediment exceedances in the 1989-1991 period. Later data indicated that exceedances, while still an ongoing problem for the reach, had moderated considerably from the earlier values, fostering an improving trend over the tested period. Due to insufficient data coverage, data after 2009 was not included in assessing any trends of this reach.

East Verde River reach 15060203-022C showed a disappearance in boron exceedances logged from 2002-2004. While this reach still has problems with arsenic and occasionally other analytes, the attainment of boron standards in recent years was sufficient to establish an improving general trend.

The only reach exhibiting a declining monotonic trend among long-term sites/reaches was Little Colorado River reach AZ15020001-009. This reach, below Springerville, consistently showed declining water quality in a number of different test scenarios including the primary Helsel/Hirsch scenario. Water quality was generally good to excellent through the 1990s and 2000s, with occasional SSC exceedances and isolated other analytes. After 2009, dissolved oxygen deficiencies appeared on a semi-regular basis, while SSC and *E. coli* exceedances persisted. Consequently, general water quality declined for this reach over the tested period. The reach origin is near wastewater treatment ponds for Springerville.

WBID	Waterbody	Reach Description	Trend Interpretation	P-Value
AZ15020001-009	LITTLE COLORADO RIVER	NUTRIOSO CREEK - TRIBUTARY	Declining	0.00206
AZ15060203-022C	EAST VERDE RIVER	AMERICAN GULCH - VERDE RIVER	Improving	--
AZ14070006-001	COLORADO RIVER	GLEN CANYON DAM - LEES FERRY	Improving	0.0243
AZ15020002-004	LITTLE COLORADO RIVER	SILVER CREEK - CARR L WASH	Improving	0.0306
AZ15070103-007B	HASSAYAMPA RIVER	UNNAMED TRIB – BLIND INDIAN CREEK	No trend	--
AZ15060105-008	TONTO CREEK	RYE CREEK - GUN CREEK	No trend	0.0266
AZ15050301-011	NOGALES WASH	MEXICAN BORDER - POTRERO CREEK	No trend	0.0626
AZ15060106A-003	SALT RIVER	STEWART MOUNTAIN DAM - VERDE RIVER	No trend	0.0713
AZ15020001-013B	LITTLE COLORADO RIVER WEST FORK	GOVERNMENT SPRING - LITTLE COLORADO EAST FORK	No trend	0.113
AZ15060203-025	VERDE RIVER	WEST CLEAR CREEK - FOSSIL CREEK	No trend	0.124
AZ15060202-037	VERDE RIVER	MUNDS DRAW - RAILROAD DRAW	No trend	0.129
AZ15070103-004	HASSAYAMPA RIVER	COTTONWOOD CREEK - MARTINEZ WASH	No trend	0.141
AZ15060103-018C	PINTO CREEK	WEST FORK PINTO CREEK - ROOSEVELT LAKE	No trend	0.183
AZ15050202-008	SAN PEDRO RIVER	U.S. MEXICO BORDER - CHARLESTON	No trend	0.198
AZ15060203-004	VERDE RIVER	BARTLETT LAKE DAM - CAMP CREEK	No trend	0.203
AZ15050203-001	SAN PEDRO RIVER	ARAVAIPA CREEK - GILA RIVER	No trend	0.209
AZ15040005-022	GILA RIVER	BONITA CREEK - YUMA WASH	No trend	0.227
AZ15060103-280E	PINAL CREEK	SEE RANCH CROSSING - UNNAMED TRIBUTARY	No trend	0.228
AZ15070101-008	GILA RIVER	HASSAYAMPA RIVER	No trend	0.246
AZ15040004-003	SAN FRANCISCO RIVER	BLUE RIVER - LIMESTONE GULCH	No trend	0.294
AZ15070201-003B	GILA RIVER	CASTLE DOME WASH - FORTUNA WASH	No trend	0.306
AZ15060103-004	SALT RIVER	PINAL CREEK - ROOSEVELT LAKE	No trend	0.331
AZ15040004-025B	BLUE RIVER	STRAYHORSE CREEK - SAN FRANCISCO RIVER	No trend	0.369
AZ15040004-023	SAN FRANCISCO RIVER	HEADWATERS - NM STATE LINE	No trend	0.417
AZ15060202-025	VERDE RIVER	SYCAMORE CREEK - OAK CREEK	No trend	0.446
AZ15060105-013A	TONTO CREEK	HEADWATERS - UNNAMED TRIBUTARY	No trend	0.466
AZ15060203-022B	EAST VERDE RIVER	ELLISON CREEK - AMERICAN GULCH	No trend	0.478
AZ15040004-001	SAN FRANCISCO RIVER	LIMESTONE GULCH - GILA RIVER	No trend	0.5
AZ15030107-001	COLORADO RIVER	MAIN CANAL - MEXICO BORDER	--	--

WBID	Waterbody	Reach Description	Trend Interpretation	P-Value
AZ15030201-004	BIG SANDY RIVER	BITTER CREEK - BURRO CREEK	--	--
AZ15030201-014	TROUT CREEK	COW CREEK - KNIGHT CREEK	--	--
AZ15030202-004	BURRO CREEK	BOULDER CREEK - BLACK CANYON	--	--
AZ15030203-009	SANTA MARIA RIVER	BRIDLE CREEK - ALAMO LAKE	--	--
AZ15040002-001	GILA RIVER	COTTONWOOD CREEK - SAN FRANCISCO RIVER	--	--
AZ15050203-011	SAN PEDRO RIVER	HOT SPRINGS CYN - REDFIELD CANYON	--	--
AZ15050301-010	SANTA CRUZ RIVER	MEXICAN BORDER - NOGALES WWTP OUTFALL	--	--
AZ15060203-018	VERDE RIVER	TANGLE CREEK - HORSESHOE LAKE	--	--
AZ15030104-020	COLORADO RIVER	BILL WILLIAMS RIVER - OSBORNE WASH	--	--

Table 12. Mann Kendall GWQI results, long term monitoring sites

3.1.2 LTS Kendall Tau Correlation Coefficients

Long-term sites/reaches GWQIs were subsequently tested for Kendall tau (KT) coefficients and significance. KT statistics were generated in the statistical software R. Results are presented in Table 13.

Only two reaches had statistically significant KT results at a p-value threshold of 0.05. The aforementioned Little Colorado reach AZ15020001-009 had a significant KT value of -0.468, indicating a moderate declining association of index scores over time. This result corroborates the Mann-Kendall test results presented previously.

Tonto Creek Reach 15060105-008 (Rye Creek to Gunn Creek) also exhibited a significant KT result, showing a moderate positive association of improving water quality over time. It yielded a positive KT coefficient of 0.416. Statistical testing is thus mixed; Mann-Kendall testing for this reach did not indicate sufficiently strong results to establish a trend for this reach. In part, the ambiguity regarding the trend may be due to the high baseline from which an improving trend could be determined; this reach has consistently exhibited high quality water, with 15 of the 17 years with records showed a general index score of 100 and the other two years showing index values in the 90s.

No other reaches of the set of 38 long-term sites/reaches showed statistically significant KT coefficients indicating trends over time for the GWQI.

Waterbody ID	Z-score	P-value	Estimated tau value
AZ14070006-001	1.498	0.134	0.254
AZ15020001-009	-2.898	0.004	-0.468
AZ15020001-013B	-1.236	0.216	-0.198
AZ15020002-004	1.463	0.144	0.246
AZ15030104-020	-0.987	0.324	-0.241
AZ15030107-001	0.115	0.909	0.024
AZ15030201-004	0.747	0.455	0.162
AZ15030201-014	-0.392	0.695	-0.080
AZ15030202-004	0.502	0.615	0.120
AZ15030203-009	-1.221	0.222	-0.327
AZ15040002-001	-1.057	0.291	-0.277
AZ15040004-001	0.028	0.978	0.005
AZ15040004-003	-1.390	0.165	-0.264
AZ15040004-023	-0.549	0.583	-0.099
AZ15040004-025B	0.204	0.839	0.037
AZ15040005-022	-1.065	0.287	-0.186
AZ15050202-008	-0.872	0.383	-0.126
AZ15050203-001	-0.489	0.625	-0.090
AZ15050203-011	-0.891	0.373	-0.243
AZ15050301-010	-0.308	0.758	-0.068
AZ15050301-011	-1.566	0.117	-0.258
AZ15060103-004	0.122	0.903	0.023
AZ15060103-018C	-0.591	0.554	-0.106
AZ15060103-280E	-0.782	0.434	-0.140
AZ15060105-008	2.007	0.045	0.416
AZ15060105-013A	0.935	0.350	0.160
AZ15060106A-003	1.808	0.071	0.367
AZ15060202-025	0.168	0.866	0.028
AZ15060202-037	0.631	0.528	0.124
AZ15060203-004	-0.707	0.480	-0.153
AZ15060203-018	0.097	0.923	0.019
AZ15060203-022B	0.085	0.932	0.016
AZ15060203-022C	1.836	0.066	0.320
AZ15060203-025	1.596	0.110	0.359
AZ15070101-008	-1.097	0.273	-0.221
AZ15070103-004	-1.040	0.298	-0.199
AZ15070103-007B	0.461	0.645	0.099
AZ15070201-003B	-1.036	0.300	-0.180

Table 13. Kendall Tau values, GWQI, long-term sampling sites

3.1.3 LTS Theil-Sen Median Slopes

For the four reaches identified by Mann-Kendall testing as exhibiting a trend, Theil-Sen testing was undertaken to identify the median slope associated with the trend. The Theil-Sen test is a non-parametric cousin to the parametric linear regression. It identifies the median slope in the population of all possible slopes connecting each possible pair of points in the data set. As with linear regressions, Theil Sen testing generates a best-fit line for the set. The slope of the line gives the reviewer information on whether the line is trending upward or downward, and the rate of change (slope) associated with the trend. Results are presented in Table 14. Figures 20-23 graphically portray results for the reaches. Theil-Sen slopes are indicated by red trend lines.

Reach	Theil Sen Median Slope	Theil Sen Intercept	Trend Interpretation
AZ14070006-001	0.49	-41.52	No SS* slope trend detected
AZ15020001-009	-0.397	53.9	Decreasing SS* slope trend detected
AZ15020002-004	0.0457	5.869	No SS* slope trend detected
AZ15060203-022C	0.258	-16.82	Increasing SS* slope trend detected

Table 14. Theil-Sen results of GWQI trend reaches

*SS – statistically significant

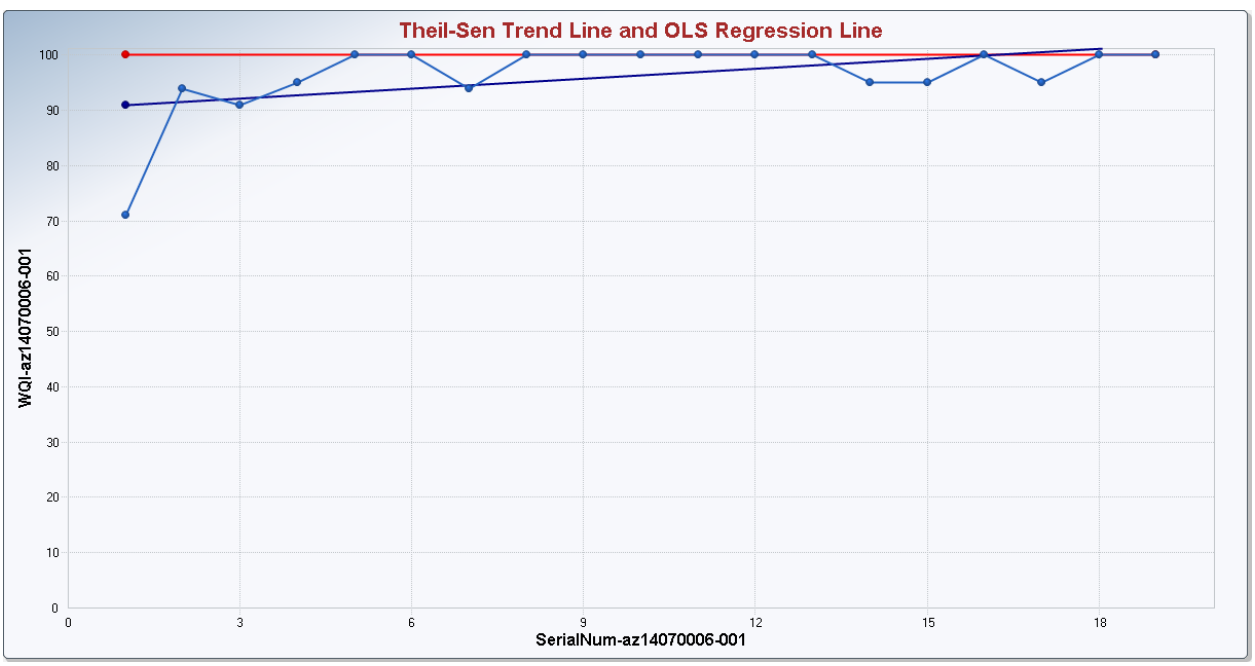

Figure 20. Reach 14070006-001 Theil Sen slope

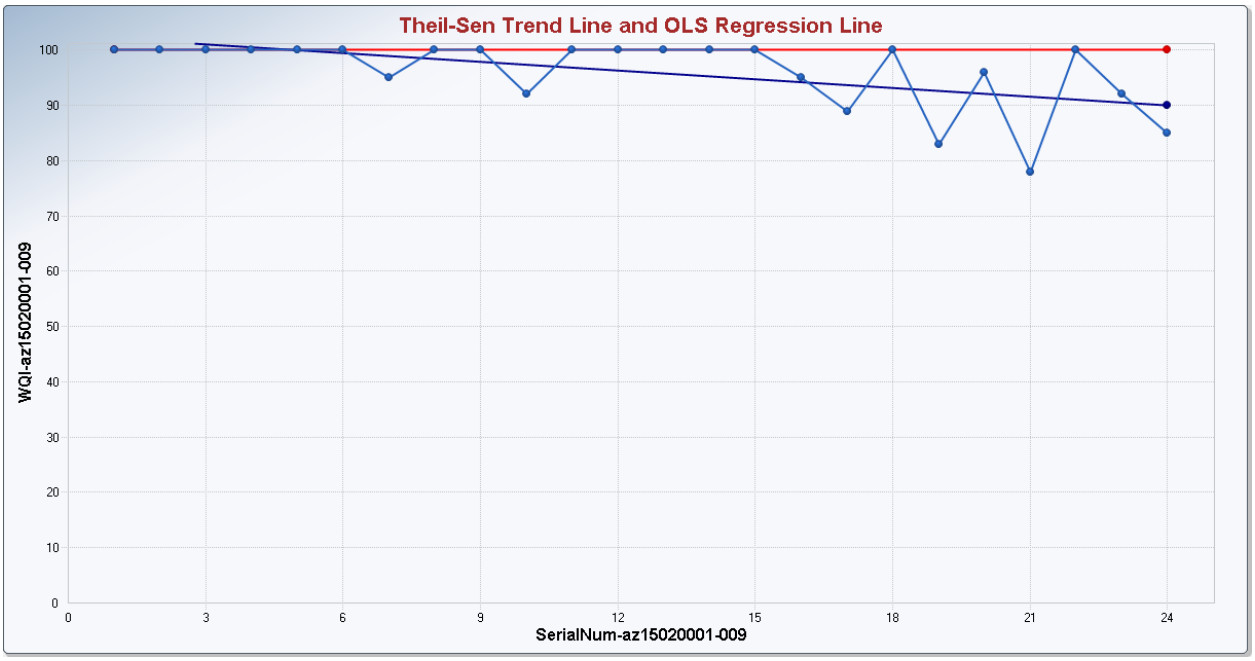

Figure 21. Reach 15020001-009 Theil Sen slope

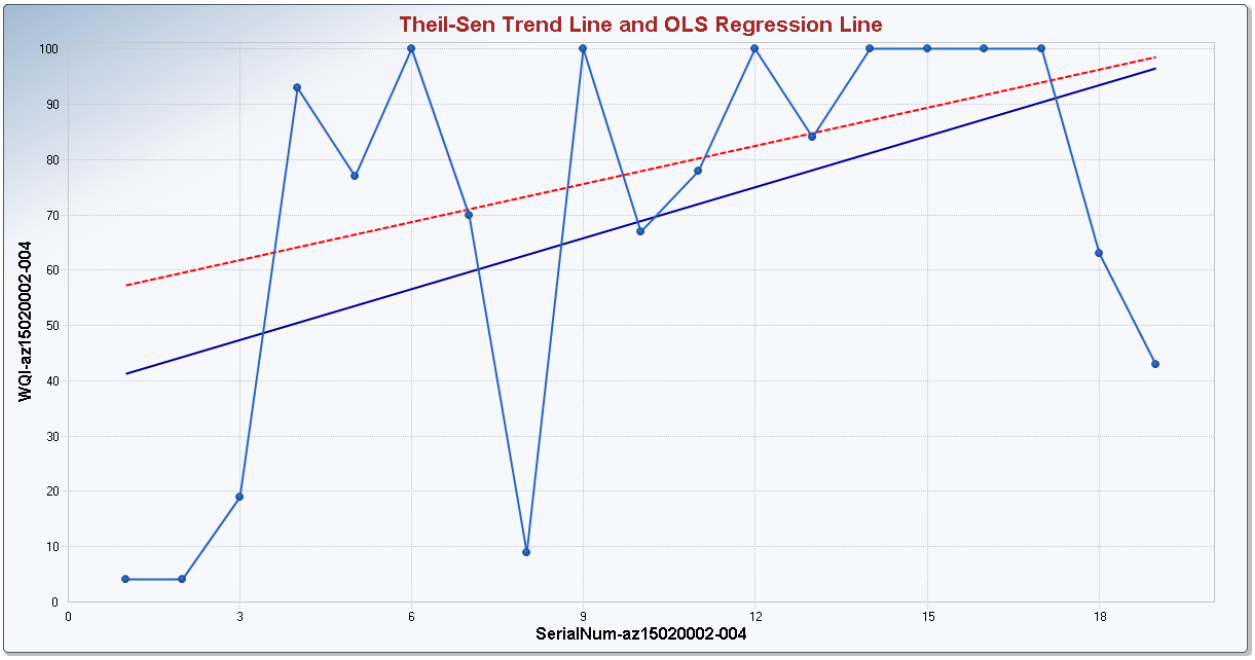

Figure 22. Reach 15020002-004 Theil Sen slope

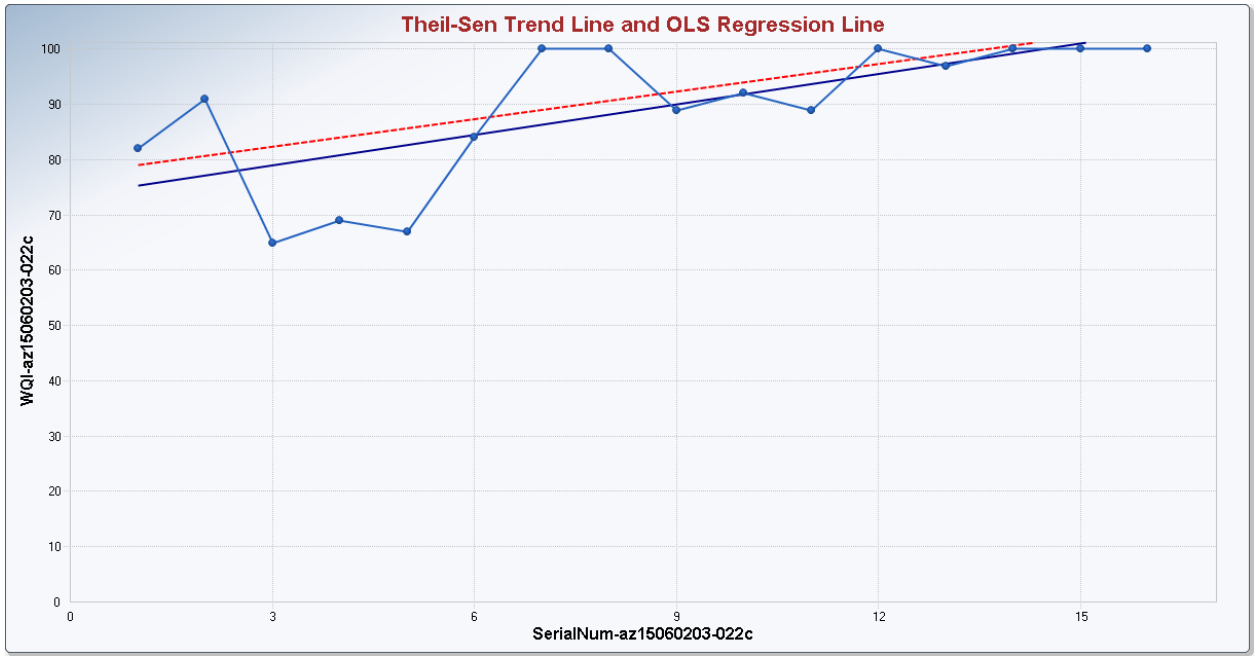

Figure 23. Reach 15060203-022C Theil Sen slope

3.1.4 LTS Changepoints and Step Trends

While monotonic trend analysis is one means of determining if a trend exists, it is designed to only identify and characterize trends that are consistent over an entire time frame. Step trends may also exist, particularly in data sets with gaps in the time series record, when a shift in baseline conditions, either up or down, can occur.

GWQI data sets were analyzed using the R package *changepoints* designed to identify points in a time series where an identifiable shift in mean takes place. Each vector of time series index values specific to a given reach was tested for changes in mean assigning a minimum segment length of three and looking for one identifiable changepoint in each series with a p-value confidence of 0.05. A subsequent step entailed running a Student's t-test on the step means identified by the package to confirm statistical significance of any reported step trends.

Results are summarized in Table 15. Graphs of reaches identified as having a step trend are aggregated in Figure 24. Graphs for reaches not having a confirmed step trend are presented in Appendix A.

Reach	Changepoint	Count	Mean 1	Mean2	P Value of T-test	Trend	Interpretation
AZ14070006-001	3	19	85.33	98.38	0.212	*	
AZ15020001-009	18	24	98.39	89.00	0.040	Step Trend exists	Declining
AZ15020001-013B	4	23	100.00	90.79	0.001	Step Trend exists	Declining
AZ15020002-004	3	19	9.00	80.25	0.000	Step Trend exists	Improving
AZ15040004-001	22	24	97.18	74.50	0.537	*	
AZ15040004-003	9	15	95.67	92.50	0.492	*	
AZ15040004-023	9	15	92.89	96.67	0.221	*	
AZ15040004-025B	12	17	98.83	96.40	0.381	*	
AZ15040005-022	4	15	88.00	81.00	0.314	*	
AZ15050202-008	22	26	90.36	74.25	0.220	*	
AZ15050203-001	10	15	83.50	95.40	0.172	*	
AZ15050301-011	6	20	93.50	59.00	0.000	Step Trend exists	Declining
AZ15060103-004	4	16	73.50	95.25	0.254	*	
AZ15060103-018C	10	19	98.30	93.56	0.048	Step Trend exists	Declining
AZ15060103-280E	4	19	100.00	89.53	0.000	Step Trend exists	Declining
AZ15060105-008	3	17	96.00	100.00	0.195	*	
AZ15060105-013A	6	17	96.00	91.00	0.255	*	
AZ15060106A-003	7	15	96.14	99.50	0.351	*	
AZ15060202-025	NA	25				No changepoint found	
AZ15060202-037	3	15	88.67	97.92	0.429	*	
AZ15060203-004	NA	14				No changepoint found	
AZ15060203-022B	8	16	98.75	95.50	0.282	*	
AZ15060203-022C	6	16	76.33	96.70	0.004	Step Trend exists	Improving
AZ15060203-025	3	12	92.67	98.67	0.386	*	
AZ15070101-008	8	12	77.88	69.75	0.408	*	
AZ15070103-004	6	15	100.00	96.00	0.169	*	
AZ15070103-007B	4	13	98.25	92.00	0.062	*	
AZ15070201-003B	7	15	96.14	91.38	0.120	*	
*** - Insufficient evidence of trend**							

Table 15. Changepoints and T-test results for step trends

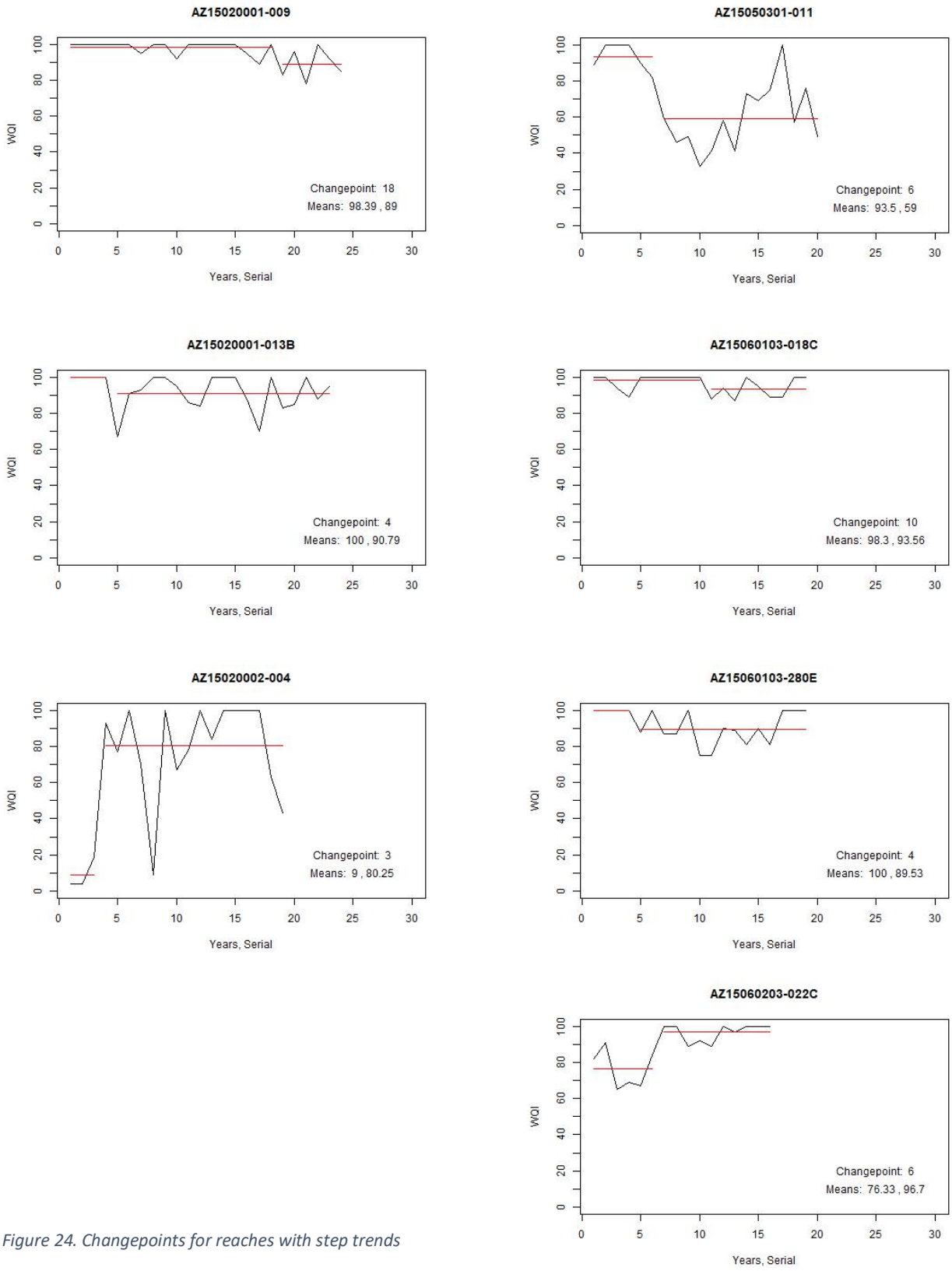

Figure 24. Changepoints for reaches with step trends

3.2 Priority Impaired Reaches (PIR)

Analyte WQIs were run for 46 ADEQ Priority Impaired Reaches over a 31-year period from 1989 to 2019. A total of 104 separate impairments involving 46 distinct reaches were considered. In most cases, the data record for these reaches only extended back to the mid-1990s. General trend detection methods for both LTSs and PIRs are outlined in Section 3.1.

3.2.1 PIR Monotonic Trends

Data was screened using a method recommended by Helsel & Hirsch for datasets that are not continuous. Generally, the method recommends dividing the period of record into three equal periods and selecting only sub-periods that have at least 20% representation of the entire possible data set. For the purposes of this testing, metals data was split into an 11 and two ten year periods, and only periods with a minimum of six years' representation were selected for testing. The period of record for *E. coli* reaches was not as extensive as the metals-impaired reaches; *E. coli* data was split into two periods of nine years and an eight-year period beginning in 1994. Thresholds of 6 years minimum (for nine-year sub-periods) or five years (for the eight-year period) were enforced in filtering the *E. coli* data sets.

Monotonic trend testing with the Mann-Kendall non-parametric test yielded the results displayed in Table 16 and Table 17. For metal impairments (Table 16), one reach (AZ15080301-337, Brewery Gulch in Bisbee) showed an improving trend for copper concentrations at a statistically significant level over the period tested; two additional reaches (AZ15030202-005A, Boulder Creek; AZ15070103-007A, Hassayampa River) showed improving tendencies for pH impairments at near-statistically significant levels over the period tested. Confidence levels in the H/H scenario for these two reaches, however, were not strong enough to assert definitive trends. Generally, most metal-impaired reaches did not show sufficient evidence in either improving or declining water quality over the periods tested to achieve statistical significance.

Of the ten reaches assessed for *E. coli* trends (Table 17), one reach (AZ15060202-018A, Oak Creek) showed a statistically significant improvement in *E. coli* concentrations over the period tested. No other reaches exhibited sufficient evidence of either declining or improving microbiological water quality to assert definitive trends. No *E. coli* reaches (besides 018A) were close enough to achieving statistical significance to warrant an evaluation of tendency, as performed for metals reaches.

Waterbody	Reach and Analyte	Time Frame	H/H Scenario	Std S score	Approx. p-Value	Tabulated p-value	Tendency
BREWERY GULCH	AZ15080301-337-COPPER-DISSOLVED-W	2000-2009	Improving	1.715	0.0432	0.042	
BOULDER CREEK	AZ15030202-005A-PH-TOTAL-W	2000-2019	No trend	1.73	0.0418	0.06	Upwards
HASSAYAMPA RIVER	AZ15070103-007A-PH-TOTAL-W	2000-2019	No trend	2.161	0.0154	0.102	Upwards
BOULDER CREEK	AZ15030202-005A-ARSENIC-TOTAL-W	2010-2019	No trend	0.735	0.231	0.242	
BOULDER CREEK	AZ15030202-005A-COPPER-DISSOLVED-W	2010-2019	No trend	N/A	N/A	0.592	
BOULDER CREEK	AZ15030202-005A-MANGANESE-TOTAL-W	2010-2019	No trend	N/A	N/A	0.592	
BOULDER CREEK	AZ15030202-005A-ZINC-DISSOLVED-W	2010-2019	No trend	1.516	0.0648	0.117	
GILA RIVER	AZ15040005-022-LEAD-TOTAL-W	2000-2019	No trend	-0.7	0.242	0.248	
MINERAL CREEK	AZ15050100-012D-COPPER-DISSOLVED-W	2000-2009	No trend	-0.901	0.184	0.191	
MINERAL CREEK	AZ15050100-012D-SELENIUM-TOTAL-W	2000-2009	No trend	0.953	0.17	0.191	
QUEEN CREEK	AZ15050100-014A-COPPER-DISSOLVED-W	2000-2009	No trend	-1.503	0.0664	0.068	
QUEEN CREEK	AZ15050100-014A-SELENIUM-TOTAL-W	2000-2009	No trend	-0.451	0.326	0.36	
QUEEN CREEK	AZ15050100-014B-COPPER-DISSOLVED-W	2000-2009	No trend	-0.376	0.354	0.36	
SAN PEDRO RIVER	AZ15050202-006-COPPER-DISSOLVED-W	2010-2019	No trend	-0.902	0.184	0.235	
SAN PEDRO RIVER	AZ15050202-008-COPPER-DISSOLVED-W	1989-1999, 2010-2019	No trend	-0.632	0.264	0.299	
ALUM GULCH	AZ15050301-561B-CADMIUM-DISSOLVED-W	2000-2009	No trend	1.443	0.0745	0.117	
ALUM GULCH	AZ15050301-561B-COPPER-DISSOLVED-W	2000-2009	No trend	-0.555	0.29	0.408	
ALUM GULCH	AZ15050301-561B-ZINC-DISSOLVED-W	2000-2009	No trend	1.62	0.0526	0.068	
PINTO CREEK	AZ15060103-018B-COPPER-DISSOLVED-W	2000-2019	No trend	-0.863	0.194	0.218	
PINTO CREEK	AZ15060103-018C-COPPER-DISSOLVED-W	1989-2009	No trend	-1.429	0.0764	0.126	
GIBSON MINE	AZ15060103-887-COPPER-DISSOLVED-W	2000-2019	No trend	0.234	0.407	0.44	
BIG BUG CREEK	AZ15070102-034B-ARSENIC-TOTAL-W	2010-2019	No trend	-0.586	0.279	0.36	
BIG BUG CREEK	AZ15070102-034B-LEAD-TOTAL-W	2010-2019	No trend	-0.67	0.252	0.281	
TURKEY CREEK	AZ15070102-036B-COPPER-DISSOLVED-W	2000-2019	No trend	-1.001	0.158	0.225	
TURKEY CREEK	AZ15070102-036B-LEAD-TOTAL-W	2000-2019	No trend	-1.394	0.0816	0.097	
HASSAYAMPA RIVER	AZ15070103-007A-CADMIUM-DISSOLVED-W	2000-2019	No trend	-1.105	0.135	0.155	
HASSAYAMPA RIVER	AZ15070103-007A-COPPER-DISSOLVED-W	2000-2019	No trend	N/A	N/A	0.527	
HASSAYAMPA RIVER	AZ15070103-007A-ZINC-DISSOLVED-W	2000-2019	No trend	0.702	0.241	0.273	

Table 16. PIR Metals Monotonic trends

Waterbody	Reach	Analyte	Time Frame	H/H Scenario	Std. S score	Approx. p-Value	Tabulated p-value
OAK CREEK	AZ15060202-018A	*Escherichia coli*	2003-2011	Improving	2.009	0.0223	0.035
SAN PEDRO RIVER	AZ15050202-003	*Escherichia coli*	2003-2019	No trend	-0.236	0.407	0.381
SAN PEDRO RIVER	AZ15050202-008	*Escherichia coli*	1994-2019	No trend	-0.774	0.22	0.246
OAK CREEK	AZ15060202-016	*Escherichia coli*	2003-2011	No trend	-1.061	0.144	0.242
OAK CREEK	AZ15060202-017	*Escherichia coli*	2003-2011	No trend	-0.619	0.268	0.274
OAK CREEK	AZ15060202-018B	*Escherichia coli*	2003-2011	No trend	0.245	0.403	0.408
OAK CREEK	AZ15060202-018C	*Escherichia coli*	1994-2019	No trend	-0.355	0.361	-1.645
OAK CREEK	AZ15060202-019	*Escherichia coli*	2003-2011	No trend	1.007	0.157	0.136
SPRING CREEK	AZ15060202-022	*Escherichia coli*	2003-2011	No trend	1.007	0.157	0.136
VERDE RIVER	AZ15060202-025	*Escherichia coli*	2003-2019	No trend	0.0849	0.466	0.461

Table 17. PIR E. coli Monotonic trends

3.2.2 PIR Kendall Tau Correlation Coefficients

Priority impaired reaches' AWQIs were subsequently tested for Kendall Tau (KT) coefficients and significance. KT statistics were generated in statistical software R. Results are presented in Table 18.

Only two priority-impaired reaches had statistically significant KT results at a p-value threshold of 0.05. In general, these results were similar to the Mann Kendall results. Oak Creek Reach 018B (*E. coli*) and Hassayampa River Reach 007A (pH) both displayed KT results indicating improving water quality for these reaches. The Oak Creek result confirmed MK testing for the same reach and analyte. The Hassayampa River KT result corroborated MK testing for Reach 007A, though MK testing for this combination exhibited only an improving tendency and did not achieve significance in the Helsel/Hirsch scenario. Boulder Creek Reach 005A (pH) and Brewery Gulch Reach 337 (Dissolved copper), both showing MK associations, failed to register in the KT results.

No other reaches of the set of 38 priority-impaired sites/reaches showed statistically significant KT coefficients indicating trends over time for the AWQI.

Waterbody	Reach and Analyte	Tau Z score	Tau p-value	Tau	Tau Trend	Significance
HASSAYAMPA RIVER	AZ15070103-007A-PH-TOTAL-W	2.259	0.024	0.543	Improving	Statistically significant
OAK CREEK	AZ15060202-018A-ESCHERICHIA COLI-TOTAL-W	2.177	0.029	0.732	Improving	Statistically significant
ALUM GULCH	AZ15050301-561B-CADMIUM-DISSOLVED-W	1.732	0.083	0.775	Improving	N.A.
ALUM GULCH	AZ15050301-561B-COPPER-DISSOLVED-W	-0.832	0.405	-0.359	Declining	N.A.
ALUM GULCH	AZ15050301-561B-ZINC-DISSOLVED-W	1.852	0.064	0.730	Improving	N.A.
BIG BUG CREEK	AZ15070102-034B-ARSENIC-TOTAL-W	-0.878	0.380	-0.346	Declining	N.A.
BIG BUG CREEK	AZ15070102-034B-LEAD-TOTAL-W	-0.837	0.402	-0.282	Declining	N.A.
BOULDER CREEK	AZ15030202-005A-ARSENIC-TOTAL-W	7.000	0.483	0.400	Improving	N.A.
BOULDER CREEK	AZ15030202-005A-COPPER-DISSOLVED-W	0.000	1.000	0.000	No trend	N.A.
BOULDER CREEK	AZ15030202-005A-MANGANESE-TOTAL-W	N.A.	N.A.	N.A.	N.A.	N.A.
BOULDER CREEK	AZ15030202-005A-PH-TOTAL-W	1.821	0.069	0.462	Improving	N.A.
BOULDER CREEK	AZ15030202-005A-ZINC-DISSOLVED-W	1.769	0.077	0.738	Improving	N.A.
BREWERY GULCH	AZ15080301-337-COPPER-DISSOLVED-W	9.000	0.083	0.800	Improving	N.A.
GIBSON MINE	AZ15060103-887-COPPER-DISSOLVED-W	0.351	0.725	0.093	Improving	N.A.
GILA RIVER	AZ15040005-022-LEAD-TOTAL-W	-0.750	0.453	-0.147	Declining	N.A.
HASSAYAMPA RIVER	AZ15070103-007A-CADMIUM-DISSOLVED-W	-1.174	0.240	-0.264	Declining	N.A.
HASSAYAMPA RIVER	AZ15070103-007A-COPPER-DISSOLVED-W	0.000	1.000	0.000	No trend	N.A.
HASSAYAMPA RIVER	AZ15070103-007A-ZINC-DISSOLVED-W	0.772	0.440	0.176	Improving	N.A.
MINERAL CREEK	AZ15050100-012D-COPPER-DISSOLVED-W	7.000	0.381	-0.333	Declining	N.A.
MINERAL CREEK	AZ15050100-012D-SELENIUM-TOTAL-W	1.111	0.266	0.370	Improving	N.A.
OAK CREEK	AZ15060202-016-ESCHERICHIA COLI-TOTAL-W	-1.414	0.157	-0.632	Declining	N.A.
OAK CREEK	AZ15060202-017-ESCHERICHIA COLI-TOTAL-W	11.000	0.548	-0.214	Declining	N.A.
OAK CREEK	AZ15060202-018B-ESCHERICHIA COLI-TOTAL-W	6.000	0.817	0.200	Improving	N.A.
OAK CREEK	AZ15060202-018C-ESCHERICHIA COLI-TOTAL-W	-0.383	0.702	-0.061	Declining	N.A.
OAK CREEK	AZ15060202-019-ESCHERICHIA COLI-TOTAL-W	1.208	0.227	0.447	Improving	N.A.
OAK CREEK	AZ15060202-022-ESCHERICHIA COLI-TOTAL-W	1.208	0.227	0.447	Improving	N.A.
OAK CREEK	AZ15060202-025-ESCHERICHIA COLI-TOTAL-W	0.170	0.865	0.038	Improving	N.A.

Waterbody	Reach and Analyte	Tau Z score	Tau p-value	Tau	Tau Trend	Significance
PINTO CREEK	AZ15060103-018B-COPPER-DISSOLVED-W	-0.925	0.355	-0.199	Declining	N.A.
PINTO CREEK	AZ15060103-018C-COPPER-DISSOLVED-W	-1.505	0.132	-0.349	Declining	N.A.
QUEEN CREEK	AZ15050100-014A-COPPER-DISSOLVED-W	3.000	0.136	-0.600	Declining	N.A.
QUEEN CREEK	AZ15050100-014A-SELENIUM-TOTAL-W	-0.676	0.499	-0.258	Declining	N.A.
QUEEN CREEK	AZ15050100-014B-COPPER-DISSOLVED-W	6.000	0.719	-0.200	Declining	N.A.
SAN PEDRO RIVER	AZ15050202-003-ESCHERICHIA COLI-TOTAL-W	-0.315	0.753	-0.075	Declining	N.A.
SAN PEDRO RIVER	AZ15050202-006-COPPER-DISSOLVED-W	-1.127	0.260	-0.430	Declining	N.A.
SAN PEDRO RIVER	AZ15050202-008-COPPER-DISSOLVED-W	-0.680	0.496	-0.134	Declining	N.A.
SAN PEDRO RIVER	AZ15050202-008-ESCHERICHIA COLI-TOTAL-W	-0.807	0.420	-0.138	Declining	N.A.
TURKEY CREEK	AZ15070102-036B-COPPER-DISSOLVED-W	-1.078	0.281	-0.245	Declining	N.A.
TURKEY CREEK	AZ15070102-036B-LEAD-TOTAL-W	-1.441	0.150	-0.279	Declining	N.A.

Table 18. Kendall Tau values, AWQI, priority-impaired reaches/ sites

3.2.3 PIR Theil-Sen Median Slopes

For the two reaches identified by Mann-Kendall testing as exhibiting a trend (15060202-018A *E. coli*, 15080301-337 Cu) and the two reaches achieving near-statistical significance (15030202-005A pH, 15070103-007A pH), Theil-Sen testing was undertaken to identify the median slope associated with the trend. Though Mann Kendall testing identified trends for these four reaches, no statistically significant Theil-Sen slopes were identified. Results are presented in Table 19. Figures 25-28 graphically portray results for the reaches. Theil-Sen slopes are indicated by red trend lines.

Reach -Analyte	Theil Sen Median Slope	Theil Sen Intercept	Trend Interpretation
AZ15030202-005A pH	0	100	No SS* slope trend detected
AZ15060202-018A *E. coli*	1.5	94	No SS* slope trend detected
AZ15070103-007A pH	0	100	No SS* slope trend detected
AZ15080301-337 Cu (D)	9.5	-7.5	No SS* slope trend detected

Table 19. Theil-Sen results of AWQI trend reaches

*SS – statistically significant

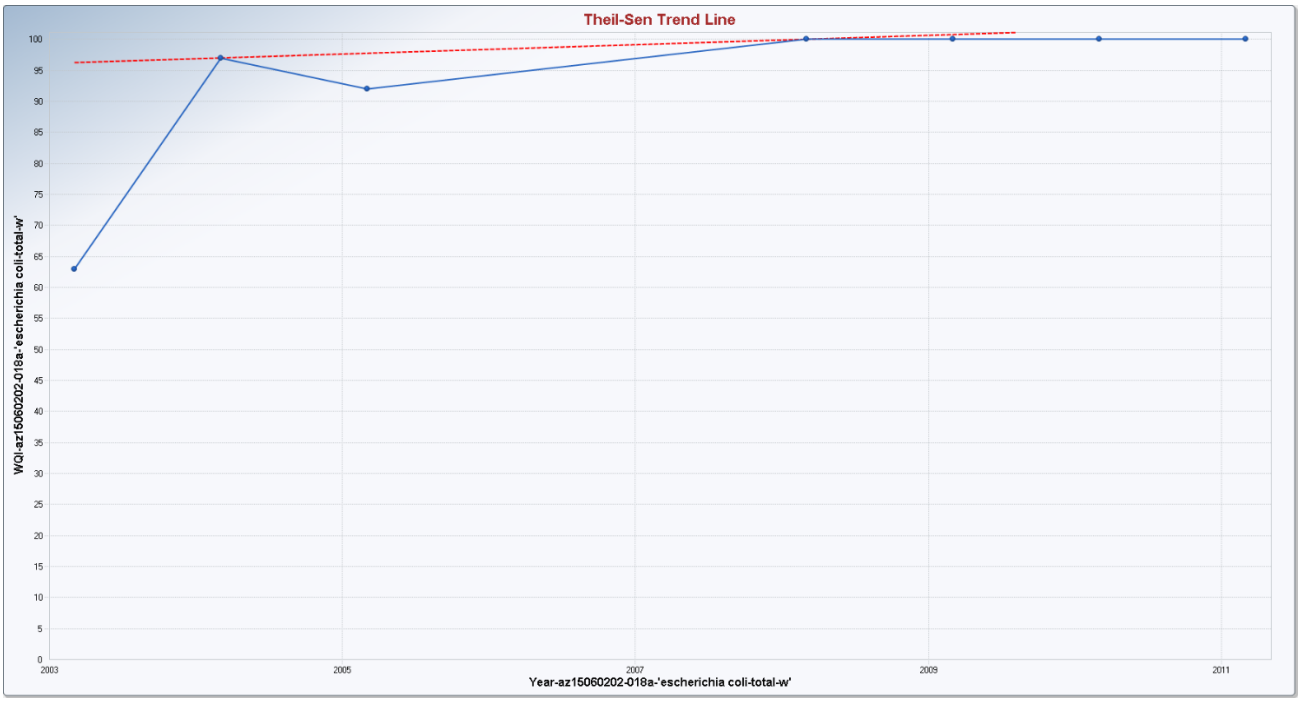

Figure 25. Reach 15060202-018A E. coli Theil Sen Slope

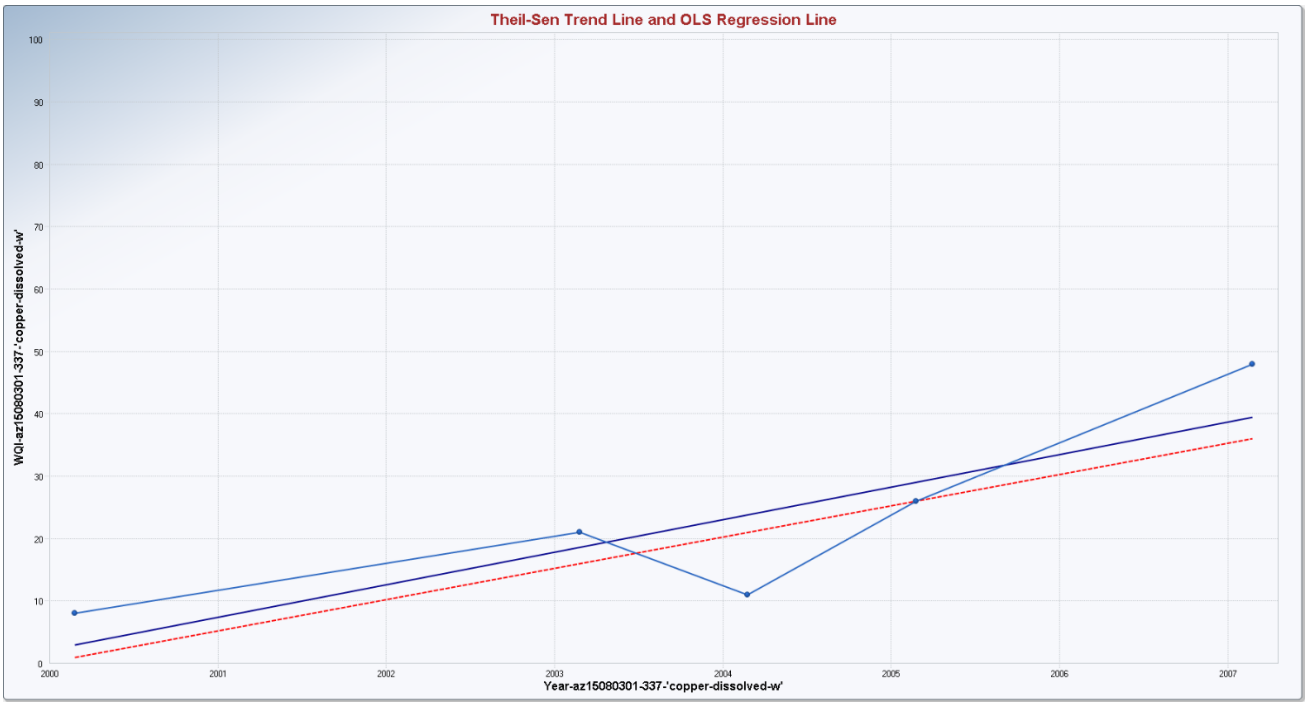

Figure 26. Reach 15080301-337 Copper Theil Sen slope

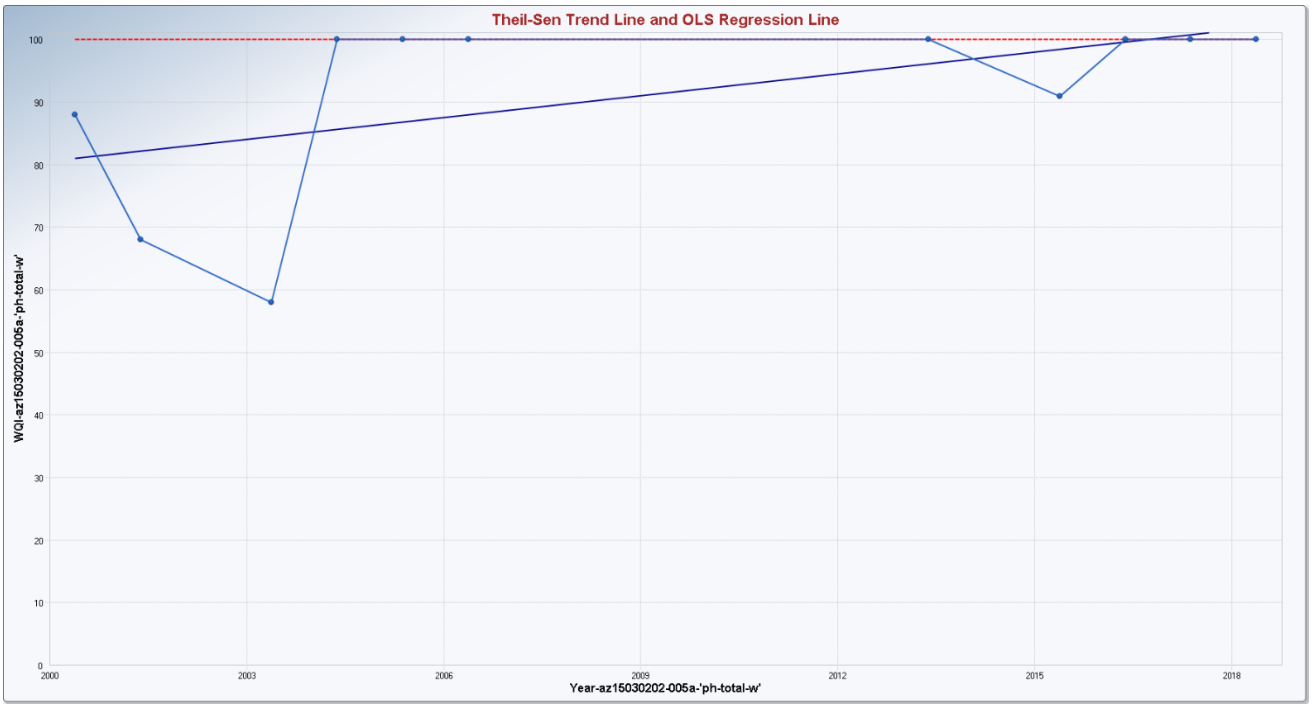

Figure 27. Reach 15030202-05A pH Theil Sen slope

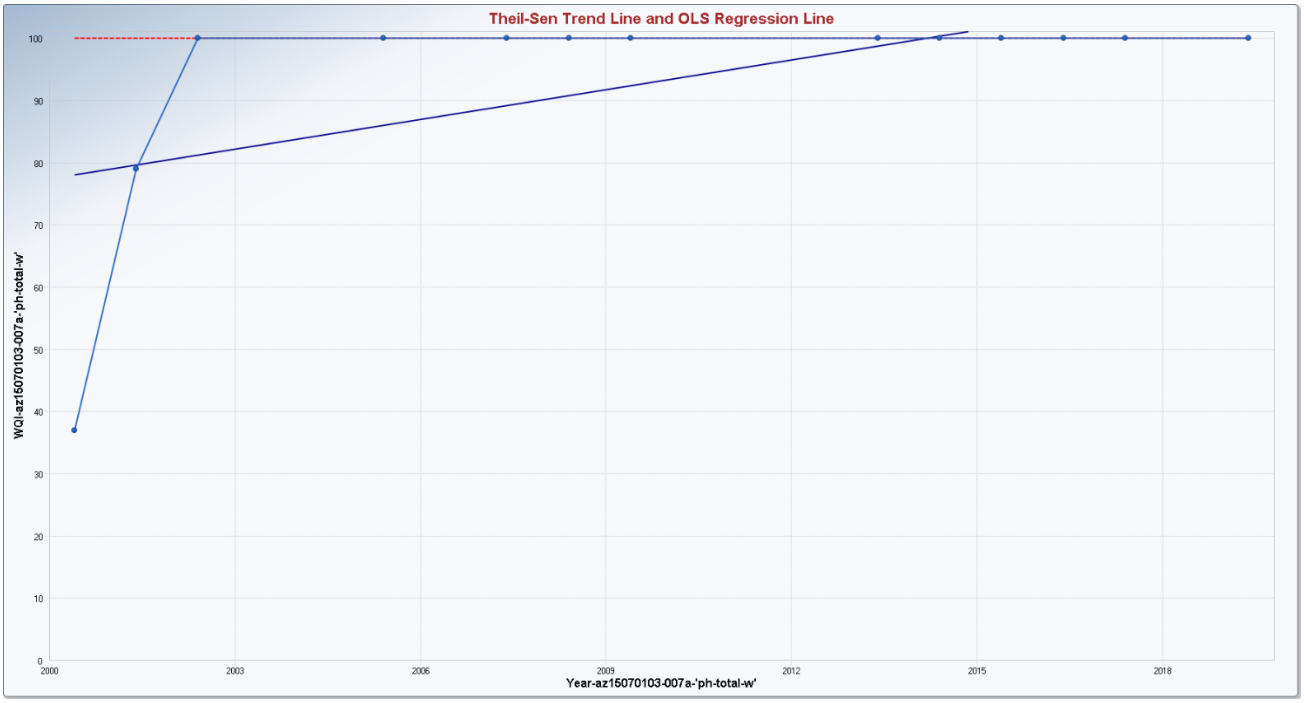

Figure 28. Reach 15070103-007A pH Theil Sen slope

3.2.4 PIR Changepoints and Step Trends

Analyte WQI data sets were analyzed using the R package *changepoints* designed to identify points in a time series where an identifiable shift in mean takes place. Each vector of time series index values specific to a given reach was tested for changes in mean assigning a minimum segment length of three and looking for one identifiable changepoint in each series with a p-value confidence of 0.05. A subsequent step entailed running a Student's t-test on the step means identified by the package to confirm statistical significance of any reported step trends.

Three reach-analyte combinations of the PIR data set were identified as having statistically significant step trends. These reaches are AZ15060202-018C (Oak Creek, *E. coli*), which exhibits a declining water quality trend; AZ15070102-036B (Turkey Creek, total lead), also exhibiting a declining trend; and AZ15070103-007A (Hassayampa River, dissolved zinc), which exhibits an improving trend.

Results are summarized in Table 20. Exported graphs of reaches identified as having a step trend are presented in Figure 29, Figure 30, and Figure 31. Graphs for reaches not having a confirmed step trend are presented in Appendix B.

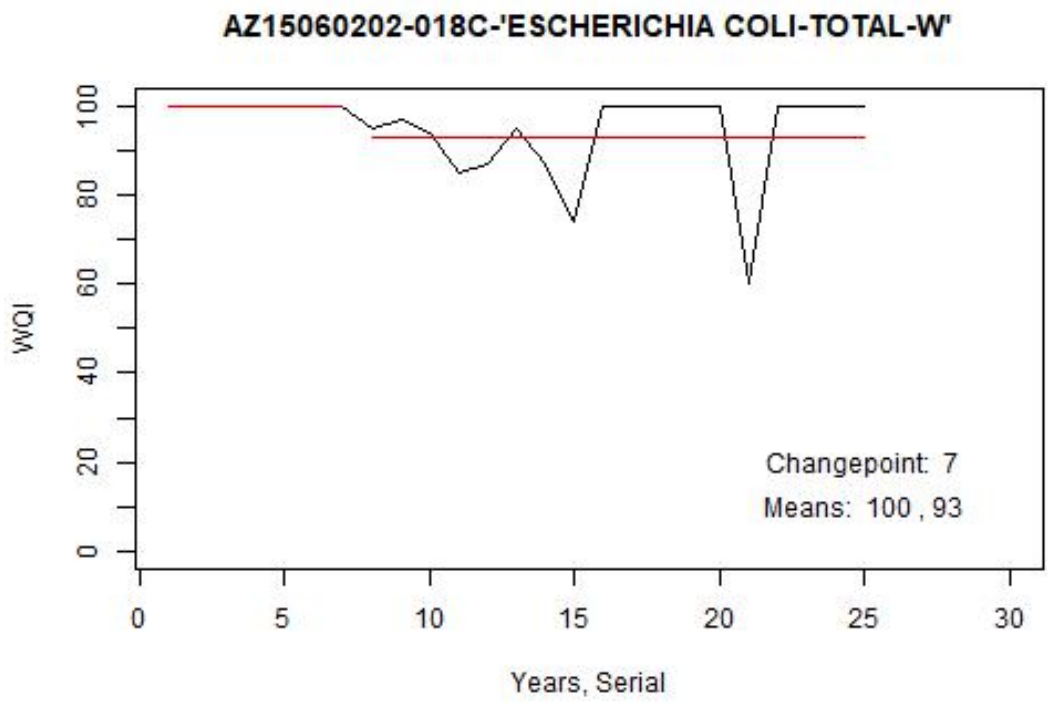

Figure 29. Changepoint, Oak Creek Reach 018C E. coli step trend

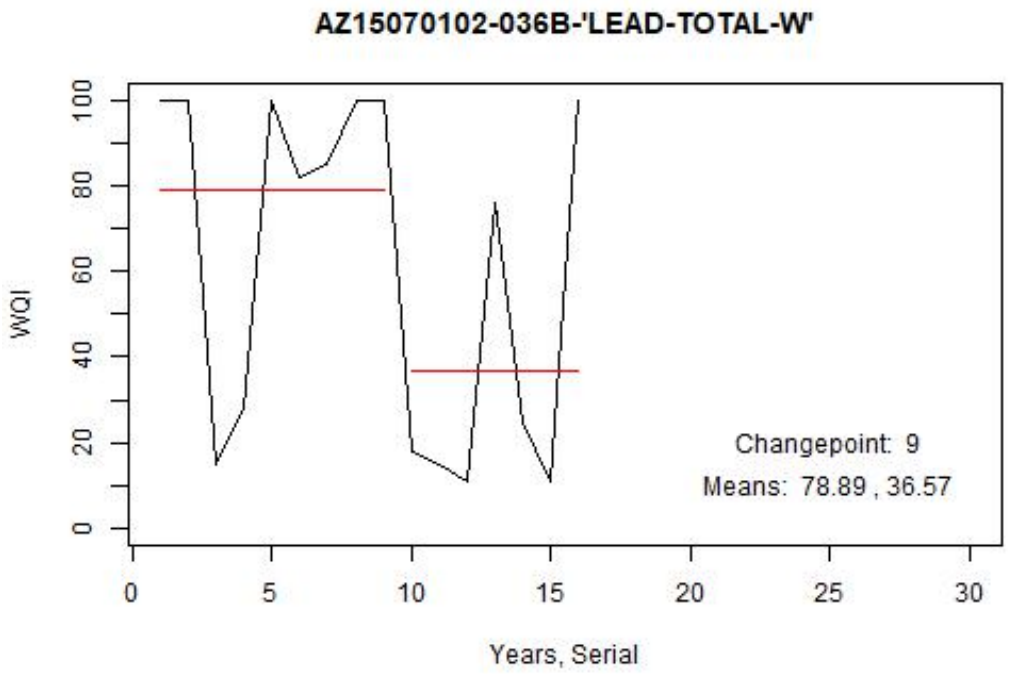

Figure 30. Changepoint, Turkey Creek Reach 036B total lead step trend

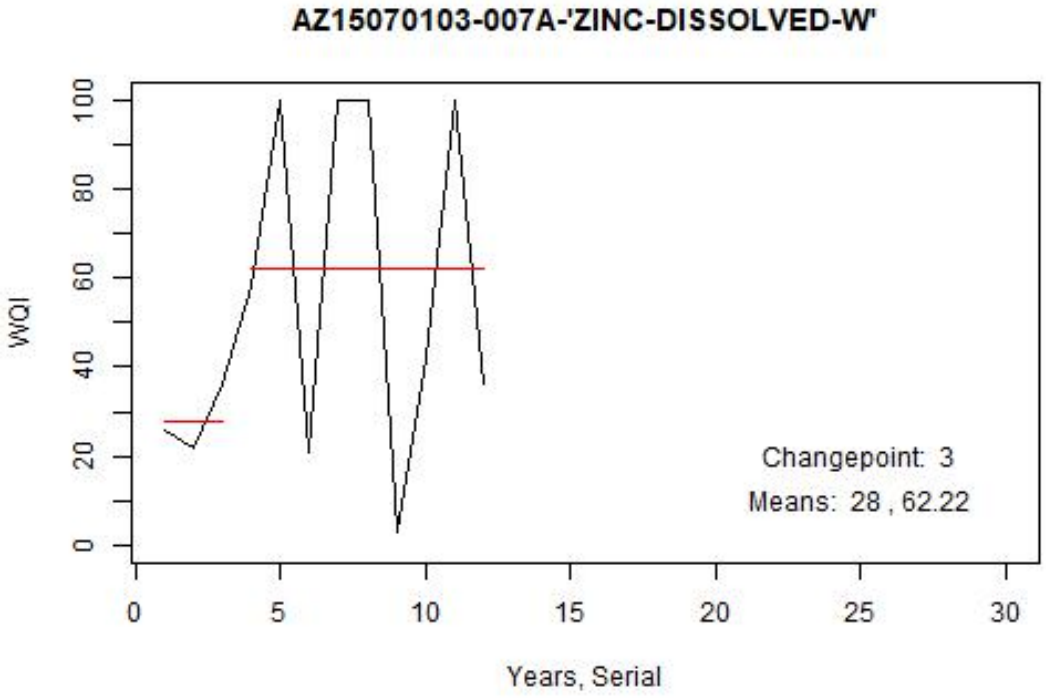

Figure 31. Changepoint, Hassayampa River Reach 007A dissolved zinc step trend

REACH-ANALYTE	CHANGE-POINT	MEAN 1	MEAN 2	T-TEST P-VALUE	INTERPRETATION	TREND
AZ15070103-007A-ZINC-DISSOLVED-W	3	28	62.22	**0.032**	**Significant**	Improving
AZ15060202-018C-ESCHERICHIA COLI-TOTAL-W	7	100	93	**0.015**	**Significant**	Declining
AZ15070102-036B-LEAD-TOTAL-W	9	78.89	36.57	**0.033**	**Significant**	Declining
AZ15030202-005A-PH-TOTAL-W	3	71.33	98.88	0.087	Insignificant	
AZ15040005-022-LEAD-TOTAL-W	6	83	64.67	0.140	Insignificant	
AZ15050100-012D-COPPER-DISSOLVED-W	5	73.4	46	0.447	Insignificant	
AZ15050100-012D-SELENIUM-TOTAL-W	5	77.6	93.5	0.294	Insignificant	
AZ15050202-003-ESCHERICHIA COLI-TOTAL-W	3	82.33	46.25	0.078	Insignificant	
AZ15050202-008-COPPER-DISSOLVED-W	13	90.54	65.25	0.258	Insignificant	
AZ15050202-008-ESCHERICHIA COLI-TOTAL-W	10	91.5	68.55	0.063	Insignificant	
AZ15060103-018B-COPPER-DISSOLVED-W	6	15.17	9.43	0.263	Insignificant	
AZ15060103-018C-COPPER-DISSOLVED-W	7	100	76.33	0.085	Insignificant	
AZ15060103-887-COPPER-DISSOLVED-W	None			NA	NA	
AZ15060202-017-ESCHERICHIA COLI-TOTAL-W	4	84.5	77	0.441	Insignificant	
AZ15060202-018A-ESCHERICHIA COLI-TOTAL-W	3	84	100	0.270	Insignificant	
AZ15060202-025-ESCHERICHIA COLI-TOTAL-W	8	93.5	100	0.170	Insignificant	
AZ15070102-034B-LEAD-TOTAL-W	5	92.4	40	0.211	Insignificant	
AZ15070102-036B-COPPER-DISSOLVED-W	11	93.73	67.67	0.335	Insignificant	
AZ15070103-007A-CADMIUM-DISSOLVED-W	8	30.25	5	0.065	Insignificant	
AZ15070103-007A-COPPER-DISSOLVED-W	8	63.88	37.25	0.348	Insignificant	
AZ15070103-007A-PH-TOTAL-W	3	72	100	0.270	Insignificant	

Table 20. AWQI Changepoints and T-test results for step trends

3.3 Trend Summaries

3.3.1 LTS/Reaches General Water Quality Index Trends

Over a 31-year period, few ADEQ long-term sites indicated a statistically significant GWQI trend in either direction. Study of the annual period of record series does indicate that in some cases water quality either declined or improved temporarily, then reverted to its former baseline. Overall, however, most long-term Arizona reaches were in a state of equilibrium when considered against statistical thresholds. Since water quality was generally of a high caliber to begin with, this is good news for the state.

Reaches exhibiting a long-term monotonic trend included AZ14070006-001 (Colorado River, ***Improving***), AZ15020001-009 (Little Colorado River, ***Declining***), AZ15020002-004 (Little Colorado River, ***Improving***), and AZ15060203-022C (East Verde River, ***Improving***). Three of these reaches (AZ15020001-009, AZ15020002-004, and AZ15060203-022C) also exhibited a corresponding step trend. This result is expected, since the same data sets used for monotonic trend analysis with a changepoint identified would likely exhibit a similar trend tendency in a step trend analysis. An additional four reaches exhibited step trends in their annual series. These include AZ15020001-013B (Little Colorado River, West Fork, ***Declining***), AZ15050301-011 (Nogales Wash, ***Declining***), AZ15060103-018C (Pinto Creek, ***Declining***), and AZ15060103-280E (Pinal Creek, ***Declining***).

Table 21 summarizes all long-term sites/reaches for general WQI trends.

3.3.2 PIR Analyte Water Quality Index Trends

The collection of priority impaired reaches suffered in comparison with the long-term sites/reaches when considering the length of the period of record and the regularity of sampling visits; consequently, the data set for summary is not as robust as the LTS set. With PIRs as well, relatively few reaches exhibited a statistically significant trend when reviewed for either monotonic or step trends.

The data set indicates modest progress on impaired reaches overall for the period of record (1989-2019), with three impaired reaches showing improving trends, and two reaches showing declining trends. Reaches AZ15060202-018A (Oak Creek, *E. coli*) and AZ15080301-337 (Brewery Gulch, dissolved copper) both exhibited ***improving*** long-term monotonic trends. Unlike the GWQI analysis, there was no duplication of reaches showing both types of trends (monotonic, step) in the analyte WQI analysis. PIR reaches exhibiting step trends included AZ15060202-018C (Oak Creek, *E. coli*, ***declining***), AZ15070102-036B (Turkey Creek, total lead, ***declining***), and AZ15070103-007A (Hassayampa River, dissolved zinc, ***improving***).

Table 22 summarizes all priority-impaired reaches for analyte WQI trends.

3.3.3 Trend Summaries Discussion

Most long-term sites/reaches have good to excellent water quality, and most have been in a state of equilibrium for the 31-year period examined (Table 21). Relatively few reaches exhibit a trend in either direction. Arizona has grown from approximately 4.7 million to its current 7.2 million residents over the 31-year period covered by this report, and relatively few of its bellwether reaches on major streams across the state suffered degraded water quality as a result. In part, this is likely due to the largely rural

character of the state and that population tends to be clustered in only a handful of metropolitan areas and small cities. Major lifelines including the Colorado River, the upper reaches of the Salt River, and the Verde River are all relatively untrammeled where overall water quality is concerned.

The same condition of equilibrium generally characterizes the priority impaired reaches as well, despite over 20 years of improvement efforts and in recent years, attempted remediation. Of the PIRs itemized in Table 22, only five (13%) exhibited a trend, and of these, and only three (8%) were improving trends. These conditions do have at least a possibility of turning around in index calculations in fairly short order, given the relative paucity of sampling data. Even so, water quality problems, particularly of the non-point source variety, can reasonably be expected to persist in some degree for a high percentage of PIRs.

It is important to note that all trend identifications in this report are based on statistical testing and rely on results of statistical significance for being reported as a trend. Rigorous statistically based criteria must have been met before a reach was identified as having a trend. This point cannot be emphasized enough. For monotonic trend analyses for both PIRs and LTSs, the Mann-Kendall test statistic generated for each reach was compared against tabulated probability thresholds (p-values) at a widely-accepted threshold (p= 0.05, i.e. 95% confidence) to either meet or fail to meet the null hypothesis, with the posited alternative hypothesis being that a monotonic trend was present. Likewise, in step trend analyses for both PIRs and LTSs, a Student's t- test statistic was generated by running the test and comparing the test statistic against p-values at the same probability threshold for the t-test, with a similar alternative hypothesis being the rejected null option for each reach in determining if a step trend was present.

One of the common misuses of the Arizona Water Quality Indices in its early years, in addition to reliance on data sets that were too small to exhibit stability, was the tendency to track indices from one quarter to the next, or one year to the next, as definitive evidence of either improving or declining water quality. Environmental data, particularly water quality data, is stochastic by nature and therefore can neither be determined nor predicted precisely in a deterministic fashion. As the GWQI and AWQI are both based on stochastic data, they, too, are stochastic in their behavior, and this must be accounted for by statistical testing, measures and characterizations in any attempt to ascertain a trend. In this report, both of the previous shortcomings of uses of the indices have been addressed. Trend identification has thorough statistical testing as its foundation, and period of record analyses (Section 4.0) employ supporting index stability scores to give adjunct information on how stable, and therefore reliable, a single index value may be.

REACH	WATERBODY	MONOTONIC	TREND CHARACTER	STEP TREND	TREND CHARACTER
AZ15020001-009	LITTLE COLORADO RIVER	Trend exists	Declining	Trend exists	Declining
AZ15020002-004	LITTLE COLORADO RIVER	Trend exists	Improving	Trend exists	Improving
AZ15060203-022C	EAST VERDE RIVER	Trend exists	Improving	Trend exists	Improving
AZ14070006-001	COLORADO RIVER	Trend exists	Improving	--	--
AZ15020001-013B	LITTLE COLORADO RIVER WEST FORK	--	--	Trend exists	Declining
AZ15050301-011	NOGALES WASH	--	--	Trend exists	Declining
AZ15060103-018C	PINTO CREEK	--	--	Trend exists	Declining
AZ15060103-280E	PINAL CREEK	--	--	Trend exists	Declining
AZ15030104-020	COLORADO RIVER	--	--	--	--
AZ15030107-001	COLORADO RIVER	--	--	--	--
AZ15030201-004	BIG SANDY RIVER	--	--	--	--
AZ15030201-014	TROUT CREEK	--	--	--	--
AZ15030202-004	BURRO CREEK	--	--	--	--
AZ15030203-009	SANTA MARIA RIVER	--	--	--	--
AZ15040002-001	GILA RIVER	--	--	--	--
AZ15040004-001	SAN FRANCISCO RIVER	--	--	--	--
AZ15040004-003	SAN FRANCISCO RIVER	--	--	--	--
AZ15040004-023	SAN FRANCISCO RIVER	--	--	--	--
AZ15040004-025B	BLUE RIVER	--	--	--	--
AZ15040005-022	GILA RIVER	--	--	--	--
AZ15050202-008	SAN PEDRO RIVER	--	--	--	--
AZ15050203-001	SAN PEDRO RIVER	--	--	--	--
AZ15050203-011	SAN PEDRO RIVER	--	--	--	--
AZ15050301-010	SANTA CRUZ RIVER	--	--	--	--
AZ15060103-004	SALT RIVER	--	--	--	--
AZ15060105-008	TONTO CREEK	--	--	--	--
AZ15060105-013A	TONTO CREEK	--	--	--	--
AZ15060106A-003	SALT RIVER	--	--	--	--
AZ15060202-025	VERDE RIVER	--	--	--	--
AZ15060202-037	VERDE RIVER	--	--	--	--
AZ15060203-004	VERDE RIVER	--	--	--	--
AZ15060203-018	VERDE RIVER	--	--	--	--
AZ15060203-022B	EAST VERDE RIVER	--	--	--	--
AZ15060203-025	VERDE RIVER	--	--	--	--
AZ15070101-008	GILA RIVER	--	--	--	--
AZ15070103-004	HASSAYAMPA RIVER	--	--	--	--
AZ15070103-007B	HASSAYAMPA RIVER	--	--	--	--
AZ15070201-003B	GILA RIVER	--	--	--	--

Table 21. Trend summary, Long Term Reaches, General WQIs

REACH	WATERBODY	IMPAIRED ANALYTE	MONOTONIC	TREND CHARACTER	STEP TREND	TREND CHARACTER
AZ15060202-018A	OAK CREEK	ESCHERICHIA COLI	Trend exists	Improving	--	--
AZ15080301-337	BREWERY GULCH	COPPER-DISSOLVED	Trend exists	Improving	--	--
AZ15060202-018C	OAK CREEK	ESCHERICHIA COLI	--	--	Trend exists	Declining
AZ15070102-036B	TURKEY CREEK	LEAD-TOTAL	--	--	Trend exists	Declining
AZ15070103-007A	HASSAYAMPA RIVER	ZINC-DISSOLVED	--	--	Trend exists	Improving
AZ15030202-005A	BOULDER CREEK	ARSENIC-TOTAL	--	--	--	--
AZ15030202-005A	BOULDER CREEK	COPPER-DISSOLVED	--	--	--	--
AZ15030202-005A	BOULDER CREEK	MANGANESE-TOTAL	--	--	--	--
AZ15030202-005A	BOULDER CREEK	PH-TOTAL	--	--	--	--
AZ15030202-005A	BOULDER CREEK	ZINC-DISSOLVED	--	--	--	--
AZ15030202-005B	BOULDER CREEK	ARSENIC-TOTAL	--	--	--	--
AZ15040005-022	GILA RIVER	LEAD-TOTAL	--	--	--	--
AZ15050100-012D	MINERAL CREEK	COPPER-DISSOLVED	--	--	--	--
AZ15050100-012D	MINERAL CREEK	SELENIUM-TOTAL	--	--	--	--
AZ15050100-014A	QUEEN CREEK	COPPER-DISSOLVED	--	--	--	--
AZ15050100-014A	QUEEN CREEK	SELENIUM-TOTAL	--	--	--	--
AZ15050100-014B	QUEEN CREEK	COPPER-DISSOLVED	--	--	--	--
AZ15050202-003	SAN PEDRO RIVER	ESCHERICHIA COLI	--	--	--	--
AZ15050202-006	SAN PEDRO RIVER	COPPER-DISSOLVED	--	--	--	--
AZ15050202-008	SAN PEDRO RIVER	ESCHERICHIA COLI	--	--	--	--
AZ15050202-008	SAN PEDRO RIVER	COPPER-DISSOLVED	--	--	--	--
AZ15050301-561B	ALUM GULCH	CADMIUM-DISSOLVED	--	--	--	--
AZ15050301-561B	ALUM GULCH	COPPER-DISSOLVED	--	--	--	--
AZ15050301-561B	ALUM GULCH	ZINC-DISSOLVED	--	--	--	--
AZ15060103-018B	PINTO CREEK	COPPER-DISSOLVED	--	--	--	--
AZ15060103-018C	PINTO CREEK	COPPER-DISSOLVED	--	--	--	--
AZ15060103-887	GIBSON MINE TRIBUTARY	COPPER-DISSOLVED	--	--	--	--
AZ15060202-016	OAK CREEK	ESCHERICHIA COLI	--	--	--	--
AZ15060202-017	OAK CREEK	ESCHERICHIA COLI	--	--	--	--

REACH	WATERBODY	IMPAIRED ANALYTE	MONOTONIC	TREND CHARACTER	STEP TREND	TREND CHARACTER
AZ15060202-018B	OAK CREEK	ESCHERICHIA COLI	--	--	--	--
AZ15060202-019	OAK CREEK	ESCHERICHIA COLI	--	--	--	--
AZ15060202-022	SPRING CREEK (SPN)	ESCHERICHIA COLI	--	--	--	--
AZ15060202-025	VERDE RIVER	ESCHERICHIA COLI	--	--	--	--
AZ15070102-034B	BIG BUG CREEK	ARSENIC-TOTAL	--	--	--	--
AZ15070102-034B	BIG BUG CREEK	LEAD-TOTAL	--	--	--	--
AZ15070102-036B	TURKEY CREEK	COPPER-DISSOLVED	--	--	--	--
AZ15070103-007A	HASSAYAMPA RIVER	CADMIUM-DISSOLVED	--	--	--	--
AZ15070103-007A	HASSAYAMPA RIVER	COPPER-DISSOLVED	--	--	--	--
AZ15070103-007A	HASSAYAMPA RIVER	PH-TOTAL	--	--	--	--

Table 22. Trend summary, Priority Impaired Reaches, Analyte WQIs

4.0 Period of Record Indices

While it is instructive to examine and characterize the annual time series for both general and analyte WQIs over a long period, a year's data for any given reach does not constitute a robust and stable set for index calculation. Previous work with both types of indices has led to a working rule of thumb that a year is the absolute minimum length of time that should be considered to cover the full span of annual hydrologic seasonality in Arizona. For GWQI sites and reaches, most were sampled on a quarterly basis during years they were sampled. Small annual sets like these used to generate WQIs are subject to wide measures of variability and an instable character, where the addition of subsequent samples to the set can cause rapid and dramatic climbs or declines in the calculated index value. This effect lessens as the data set size grows, and the index eventually approaches a value that can be considered stable.

Due to these small annual sets, the wide variability of annual reach score values can contribute to statistical "noise" that may obscure the "signal" of a slight trend. This effect may partially explain why relatively few Arizona reaches exhibited a trend relative to the size of the population considered. The Mann-Kendall and Kendall Tau tests do not conclude that no trend is present where there is no finding of statistical significance, but only that there is insufficient evidence from the data set to conclude that a trend exists at the stated level of confidence. Sometimes this may suggest a data set that may not be large enough to overcome a noisy background, or alternatively in the case of WQ scores, that there is amplified variability when considered from year to year that may hide or obscure a trend that may be present.

ADEQ has designed a corollary score to accompany indices. This score is termed an ***index stability score***. The index stability score (ISS) is a score also on a scale from 0-100 calculating how stable and consequently reliable an expressed index value is considered. The ISS considers three distinct categories in its calculation: the statistical sufficiency of the set (number of records in the set), the natural variability exhibited in the set, and the data representativeness of the set. Additionally, terms are included to govern the score in the case sample counts below a threshold, and for the general WQI, a term to grade the percentage of analytes represented in the core parameter set.

As a quality assurance measure, index values that are modified to reflect their ungoverned values and used without the consideration or context of their ISS scores lose their status as *water quality indices* and revert to consideration as *water quality scores*. As scores, their ISS values automatically revert to 0. With a score of 0, there can be no expectation of stability in the score and consequently, the value is not considered reliable. Further discussion on the background and calculation of the ISS is presented in the next section.

Where trend analysis is concerned in this report, all annual time series WQIs are actually water quality scores, as no reach achieved the minimum record count of ten in a year during any year considered. All scores considered in annual series statistics were modified by removing the governing terms before running the index calculations.

For these reasons, the most reliable measure of indices is one that spans the entire period of record being considered and includes every data point collected in that span. Period of record (POR) index values are generally extremely robust when the period is long enough and thus can give an accurate and

reliable read on the water quality for the period. When accompanied by the ISS, the POR index gives the most complete picture of the health of the reach and information on the robustness of the index as well for the user's consideration and benefit.

4.1 Index Stability Score

The Index Stability Score formula follows the general model of the GWQI formula:

$$\text{Index Stability Score} = L_c * p_G * \frac{\sqrt{C_1^2 + C_2^2 + C_3^2}}{1.732}$$

Where $C_1 = 100 * \frac{n}{30}$ *(Statistical sufficiency sub-score)*

And $C_2 = 100 * \left(1 - \left(\frac{CoV}{\sqrt{n}}\right)\right)$ *(Natural variability sub-score)*

And $C_3 = 100 * \left(\sum_{i=1}^{n} \frac{i}{n}\right) + \sum_{i=1}^{2} w_i * x_i$ *(Data representativeness sub-score)*

Each sub-score term can range from 0 to 100 before further operations. Squaring each term and summing all under the radical has a theoretical maximum of 30,000. Taking the root of the theoretical maximum yields a value of 173.2. A divisor of 1.732 then normalizes the vector length to a result no greater than 100, with 100 representing high confidence of a stable and reliable score, and 0 representing no confidence in the score stability.

4.1.1 First term – Mathematical/statistical sufficiency

The first term of the stability score addresses the data set's ***statistical sufficiency*** in evaluating whether the data set is large enough so that the central limit theorem begins to take effect. When the central limit theorem begins to be operative, data sets behave as normally distributed data sets, even if the data set is a distribution other than normal. This lends added reliability to measures such as the mean and standard deviation and thus provides an indication that sufficient data is present to reduce index variability when considered in sample-by-sample calculations. The term is a proration based on an ideal minimum set size. The *n* used as a threshold (denominator) for the term is 30, and proration for the term is normalized on a 0-100 scale. If more than 30 samples exist, the sample sub-score is maximized at 100 for all *n*'s over 30.

Mathematically, the term shall be represented as the percentage of samples relative to a set considered complete at 30 samples:

C_1

Where $C_1 = 100 * \frac{n}{30}$

And *n* = number of samples for consideration

In the GWQI with representation from several analytes, C_1 is the average of all individual parameter C_1s in the set.

4.1.2 Second term – Natural variability

The term for ***natural variability*** takes advantage of a *mathematical property* of the set: the maximum coefficient of variation (CoV) of the data set equals the square root of the number of values in the set. Consequently, the ratio between the CoV and √n will always be a value between 0 and 1. Multiplication of this value by 100 puts the sub-score on a 0-100 scale, and subtraction of the value from 100 re-orients the score so that a high score represents a dataset with less variability (more reliability), while a low score represents widely-fluctuating values in the reported range.

Mathematically, the term shall be presented as:

C_2

Where $C_2 = 100(1 - \frac{CoV}{\sqrt{n}})$

And CoV = $s / \overline{x}$

And $s = \sqrt{\frac{\sum(x - \bar{x})^2}{n - 1}}$

And $\overline{X} = \frac{\sum X}{N}$

As with the C_1 term in the GWQI ISS calculation, C_2 is the average of all individual parameter C_2s in the set.

4.1.3 Third term – Data representativeness

The third term, ***data representativeness***, represents a summation of various conditions intended to characterize whether the set covers enough different natural conditions to be truly representative in nature. These conditions include the following:

- Presence of events sampled in storm flow conditions
- Presence of events sampled in base flow conditions
- Seasonal distribution – at least one sample in each of three seasons (counting as one criterion)
- Percentage of results not exhibiting "greater than" values
- Duration of sampling record – percentage of year elapsed between first and last sample. At least one year is required to maximize this criterion sub-score. Durations beyond one year receive full credit.

The number of factors that are not percentage values outlined shall be summed as either being met (1 pt.) or not (0 pts) for a set, then divided by the total number of criteria applicable. The proportion of pass/fail scores to the entire list is then applied as a weight. The percentage criteria are averaged and weighted by the proportion of total criteria reporting as percentages and summed with the other weighted score. The final weighted value is multiplied by 100 for the third sub-score.

Mathematically, the term shall be presented as:

C_3

Where $C_3 =$ $$100 * (\sum_{i=1}^{n} \frac{i}{n}) + \sum_{i=1}^{2} w_i * x_i$$

w_i is the weight applied to *i*th term of the percentage sub-criteria

x_i is the percentage of the *i*th term expressed in decimal form

4.1.4 General Index ISS – Core parameter coefficient

The GWQI ISS has a coefficient equal to the percentage of core parameter analytes represented in the data set applied to the overall calculation to ensure incomplete data sets meeting all other criteria do not erroneously generate a high GWQI. Testing in early iterations of ISS development revealed that a single pass/fail item for core scope coverage originally included in the data representativeness term of the index was not sufficiently sensitive enough to penalize the stability score adequately when core parameter coverage was incomplete. The embedded criterion for core scope coverage was removed from the score and replaced by this coefficient. Since core parameter coverage considerations do not apply to analyte WQIs, the coefficient is not used in that context.

Mathematically, the term shall be presented as:

$$p_G$$

Where pG is the percentage of core parameter analytes represented for a member of the same designated use grouping

4.1.5 Lorenz coefficient

For analyte WQI data sets with fewer than ten records or GWQI data sets with an average of fewer than 10 records per analyte, a Lorenz coefficient based on a cubic curve between 0 and 1 is applied to penalize calculations made on small data sets. For more than ten records (or an average of more than ten), the coefficient is 1. This coefficient is intended to discourage use of the WQI where stability is lacking. For uses required when data set counts are fewer than the thresholds expressed above, QA disclaimers can be applied and the coefficient removed. In such a case, the reported value is no longer considered an ***index*** value with full QA assurance, but a ***score*** with no accompanying assurance of QA integrity.

Water quality scores, where Lorenz coefficients are removed, are considered to have stability scores of 0.

Mathematically, the term shall be presented as:

$$L_c$$

Lorenz coefficients are presented in Table 23.

Lorenz curve coefficients

0	0.000
1/10	0.001
2/10	0.008
3/10	0.027
4/10	0.064
5/10	0.125
6/10	0.216
7/10	0.343
8/10	0.512
9/10	0.729
10/10	1.000

Table 23. Lorenz coefficients for small data sets

4.2 Period of Record Indices and ISSs

Period of record (POR) index calculations were made on the entire set of both long-term sites and priority- impaired reaches. For priority-impaired reaches in particular, the run captured index calculations for reaches that did not have sufficient annual data to justify an annual WQI trend analysis. These reaches are indicated by the unmarked entries in the column for *Annual Series* in Table 2.

LTS POR indices and ISSs are presented in Table 26. Summary statistics for POR GWQIs are presented below in Table 24 and Table 25.

Priority impaired reaches and ISSs are presented in Table 27. Summary statistics for GWQI Index Stability Scores are presented afterwards in Table 28 and Table 29.

GWQI POR Summary Statistic	Value	Percentile	Value
Maximum	96	**99th**	96
Mean	77.5	**95th**	96
Minimum	38	**90th**	90.2
Geo-Mean	76.4	**80th**	87.6
Standard Deviation	12.4	**75th (Q3)**	84.75
Standard Error of Mean	2.015	**50th (Q2)**	80
Median Absolute Deviation / 0.675	11.12	**25th (Q1)**	70.25
Skewness	-1.034	**20th**	68
Coefficient of Variation	0.16	**10th**	65.5

Table 24. Period of Record General Water Quality Index Summary Statistics, LTSs

GWQI ISS POR Summary Statistic	Value	Percentile	Value
Maximum	96	**99th**	95.6
Mean	82.5	**95th**	94.2
Minimum	67	**90th**	93
Geo-Mean	82.1	**80th**	90.6
Standard Deviation	7.8	**75th (Q3)**	89.8
Standard Error of Mean	1.263	**50th (Q2)**	80.5
Median Absolute Deviation / 0.675	9.64	**25th (Q1)**	77
Skewness	0.096	**20th**	75
Coefficient of Variation	0.094	**10th**	73

Table 25. Period of Record GWQI Index Stability Score Summary Statistics, LTSs

WBID	Waterbody	Waterbody Description	Start Date	End Date	WQI	Index Stability (ISS)
AZ14070006-001	COLORADO RIVER	GLEN CANYON DAM - LEES FERRY	01/01/1989	12/31/2019	88	87
AZ15020001-009	LITTLE COLORADO RIVER	NUTRIOSO CREEK - TRIBUTARY	01/01/1989	12/31/2019	82	72
AZ15020001-013B	LITTLE COLORADO RIVER WEST FORK	GOVERNMENT SPRING - LITTLE COLORADO EAST FORK	01/01/1989	12/31/2019	82	75
AZ15020002-004	LITTLE COLORADO RIVER	SILVER CREEK - CARR L WASH	01/01/1989	12/31/2019	55	71
AZ15030104-020	COLORADO RIVER	BILL WILLIAMS RIVER - OSBORNE WASH	01/01/1989	12/31/2019	96	73
AZ15030107-001	COLORADO RIVER	MAIN CANAL - MEXICO BORDER	01/01/1989	12/31/2019	88	79
AZ15030201-004	BIG SANDY RIVER	BITTER CREEK - BURRO CREEK	01/01/1989	12/31/2019	67	84
AZ15030201-014	TROUT CREEK	COW CREEK - KNIGHT CREEK	01/01/1989	12/31/2019	81	91
AZ15030202-004	BURRO CREEK	BOULDER CREEK - BLACK CANYON	01/01/1989	12/31/2019	87	87
AZ15030203-009	SANTA MARIA RIVER	BRIDLE CREEK - ALAMO LAKE	01/01/1989	12/31/2019	84	95
AZ15040002-001	GILA RIVER	COTTONWOOD CREEK - SAN FRANCISCO RIVER	01/01/1989	12/31/2019	79	88
AZ15040004-001	SAN FRANCISCO RIVER	LIMESTONE GULCH - GILA RIVER	01/01/1989	12/31/2019	84	95
AZ15040004-003	SAN FRANCISCO RIVER	BLUE RIVER - LIMESTONE GULCH	01/01/1989	12/31/2019	84	93
AZ15040004-023	SAN FRANCISCO RIVER	HEADWATERS - NM STATE LINE -	01/01/1989	12/31/2019	89	84
AZ15040004-025B	BLUE RIVER	STRAYHORSE CREEK - SAN FRANCISCO RIVER	01/01/1989	12/31/2019	79	91
AZ15040005-022	GILA RIVER	BONITA CREEK - YUMA WASH	01/01/1989	12/31/2019	70	79
AZ15050202-008	SAN PEDRO RIVER	U.S. MEXICO BORDER - CHARLESTON	01/01/1989	12/31/2019	73	94
AZ15050203-001	SAN PEDRO RIVER	ARAVAIPA CREEK - GILA RIVER	01/01/1989	12/31/2019	71	89
AZ15050203-011	SAN PEDRO RIVER	HOT SPRINGS CYN - REDFIELD CANYON	01/01/1989	12/31/2019	68	78
AZ15050301-010	SANTA CRUZ RIVER	MEXICAN BORDER - NOGALES WWTP OUTFALL	01/01/1989	12/31/2019	81	81
AZ15050301-011	NOGALES WASH	MEXICAN BORDER - POTRERO CREEK	01/01/1989	12/31/2019	38	90
AZ15060103-004	SALT RIVER	PINAL CREEK - ROOSEVELT LAKE	01/01/1989	12/31/2019	62	67
AZ15060103-018C	PINTO CREEK	WEST FORK PINTO CREEK - ROOSEVELT LAKE	01/01/1989	12/31/2019	81	90
AZ15060103-280E	PINAL CREEK	SEE RANCH CROSSING - UNNAMED TRIBUTARY	01/01/1989	12/31/2019	52	77
AZ15060105-008	TONTO CREEK	RYE CREEK - GUN CREEK	01/01/1989	12/31/2019	96	79
AZ15060105-013A	TONTO CREEK	HEADWATERS - UNNAMED TRIBUTARY	01/01/1989	12/31/2019	80	79
AZ15060106A-003	SALT RIVER	STEWART MOUNTAIN DAM - VERDE RIVER	01/01/1989	12/31/2019	67	74
AZ15060202-025	VERDE RIVER	SYCAMORE CREEK - OAK CREEK	01/01/1989	12/31/2019	88	79
AZ15060202-037	VERDE RIVER	MUNDS DRAW - RAILROAD DRAW	01/01/1989	12/31/2019	73	75

WBID	Waterbody	Waterbody Description	Start Date	End Date	WQI	Index Stability (ISS)
AZ15060203-004	VERDE RIVER	BARTLETT LAKE DAM - CAMP CREEK	01/01/1989	12/31/2019	93	73
AZ15060203-018	VERDE RIVER	TANGLE CREEK - HORSESHOE LAKE	01/01/1989	12/31/2019	96	77
AZ15060203-022B	EAST VERDE RIVER	ELLISON CREEK - AMERICAN GULCH	01/01/1989	12/31/2019	79	81
AZ15060203-022C	EAST VERDE RIVER	AMERICAN GULCH - VERDE RIVER	01/01/1989	12/31/2019	80	80
AZ15060203-025	VERDE RIVER	WEST CLEAR CREEK - FOSSIL CREEK	01/01/1989	12/31/2019	85	78
AZ15070101-008	GILA RIVER	HASSAYAMPA RIVER – GILLESPIE DAM	01/01/1989	12/31/2019	73	72
AZ15070103-004	HASSAYAMPA RIVER	COTTONWOOD CREEK - MARTINEZ WASH	01/01/1989	12/31/2019	79	92
AZ15070103-007B	HASSAYAMPA RIVER	UNNAMED TRIB – BLIND INDIAN CREEK	01/01/1989	12/31/2019	68	93
AZ15070201-003B	GILA RIVER	CASTLE DOME WASH - FORTUNA WASH	01/01/1989	12/31/2019	68	96

Table 26. Period of Record General WQIs and Index Stability Scores for LTS Reaches

WBID	Waterbody	Analyte	Use	Comments	Start Date	End Date	AWQI	Index Stability
AZ15020007-007	PUERCO RIVER	COPPER-DISSOLVED-W	AWW	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	6	8
AZ15030202-006B	BOULDER CREEK	BERYLLIUM-DISSOLVED-W	AWW		1/1/1989	12/31/2019	64	69
AZ15040005-022	GILA RIVER	LEAD-TOTAL-W	FBC		1/1/1989	12/31/2019	67	92
AZ15050100-012B	MINERAL CREEK (MIN)	COPPER-DISSOLVED-W	AWW		1/1/1989	12/31/2019	83	91
AZ15050100-012B	MINERAL CREEK (MIN)	SELENIUM-TOTAL-W	AWW		1/1/1989	12/31/2019	98	93
AZ15050100-012D	MINERAL CREEK (MIN)	COPPER-DISSOLVED-W	AWW		1/1/1989	12/31/2019	39	92
AZ15050100-012D	MINERAL CREEK (MIN)	SELENIUM-TOTAL-W	AWW		1/1/1989	12/31/2019	74	92
AZ15050100-014A	QUEEN CREEK	COPPER-DISSOLVED-W	AWW		1/1/1989	12/31/2019	55	97
AZ15050100-014A	QUEEN CREEK	SELENIUM-TOTAL-W	AWW		1/1/1989	12/31/2019	96	93
AZ15050100-014A	QUEEN CREEK	LEAD-TOTAL-W	PBC		1/1/1989	12/31/2019	53	89
AZ15050100-014B	QUEEN CREEK	COPPER-DISSOLVED-W	AWW		1/1/1989	12/31/2019	60	76
AZ15050100-014C	QUEEN CREEK	COPPER-DISSOLVED-W	AWW	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	28	37
AZ15050100-1818	ARNETT CREEK	COPPER-DISSOLVED-W	AWW	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	60	57
AZ15050202-006	SAN PEDRO RIVER	COPPER-DISSOLVED-W	AWW		1/1/1989	12/31/2019	88	81
AZ15050202-008	SAN PEDRO RIVER	COPPER-DISSOLVED-W	AWW		1/1/1989	12/31/2019	85	96
AZ15050203-022A	COPPER CREEK	COPPER-DISSOLVED-W	AWW	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	5	3
AZ15050203-022A	COPPER CREEK	SELENIUM-TOTAL-W	AWW	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	60	54
AZ15050203-022A	COPPER CREEK	ZINC-DISSOLVED-W	AWW	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	3	2
AZ15050203-022A	COPPER CREEK	IRON-DISSOLVED-W	AWW	No data retrieved	1/1/1989	12/31/2019		
AZ15050203-022A	COPPER CREEK	CADMIUM-DISSOLVED-W	AWW	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	6	4
AZ15050301-025A	HARSHAW CREEK	COPPER-DISSOLVED-W	AWE	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	25	24
AZ15050301-025A	HARSHAW CREEK	PH-TOTAL-W	PBC	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	28	28

WBID	Waterbody	Analyte	Use	Comments	Start Date	End Date	AWQI	Index Stability
AZ15050301-558A	THREE R CANYON	COPPER-DISSOLVED-W	AWE	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	0	0
AZ15050301-558A	THREE R CANYON	CADMIUM-DISSOLVED-W	AWE	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	0	0
AZ15050301-558A	THREE R CANYON	ZINC-DISSOLVED-W	AWE	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	0	0
AZ15050301-558A	THREE R CANYON	PH-TOTAL-W	PBC	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	0	0
AZ15050301-558B	THREE R CANYON	COPPER-DISSOLVED-W	AWW	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	0	35
AZ15050301-558B	THREE R CANYON	CADMIUM-DISSOLVED-W	AWW	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	1	33
AZ15050301-558B	THREE R CANYON	ZINC-DISSOLVED-W	AWW	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	1	34
AZ15050301-558B	THREE R CANYON	PH-TOTAL-W	FBC	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	4	25
AZ15050301-558B	THREE R CANYON	BERYLLIUM-DISSOLVED-W	AWW	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	22	14
AZ15050301-558C	THREE R CANYON	COPPER-DISSOLVED-W	AWE	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	0	2
AZ15050301-558C	THREE R CANYON	CADMIUM-DISSOLVED-W	AWE	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	3	2
AZ15050301-558C	THREE R CANYON	ZINC-DISSOLVED-W	AWE	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	1	2
AZ15050301-558C	THREE R CANYON	PH-TOTAL-W	PBC	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	0	2
AZ15050301-560	COX GULCH	COPPER-DISSOLVED-W	AWW	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	0	1
AZ15050301-560	COX GULCH	CADMIUM-DISSOLVED-W	AWW	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	0	1
AZ15050301-560	COX GULCH	ZINC-DISSOLVED-W	AWW	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	0	1
AZ15050301-560	COX GULCH	PH-TOTAL-W	FBC	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	0	0
AZ15050301-560	COX GULCH	BERYLLIUM-DISSOLVED-W	AWW	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	1	1
AZ15050301-641	UNNAMED TRIB (UA2) TO ALUM GULCH	COPPER-DISSOLVED-W	AWE	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	0	0
AZ15050301-641	UNNAMED TRIB (UA2) TO ALUM GULCH	ZINC-DISSOLVED-W	AWE	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	0	0
AZ15050301-888	UNNAMED TRIB (ENDLESS MINE TRIBUTARY) TO HARSHAW CREEK	PH-TOTAL-W	PBC	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	1	2

WBID	Waterbody	Analyte	Use	Comments	Start Date	End Date	AWQI	Index Stability
AZ15050301-888	UNNAMED TRIB (ENDLESS MINE TRIBUTARY) TO HARSHAW CREEK	COPPER-DISSOLVED-W	AWE	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	1	0
AZ15050301-889	UNNAMED TRIB TO THREE R CYN	COPPER-DISSOLVED-W	AWE	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	0	0
AZ15050301-889	UNNAMED TRIB TO THREE R CYN	CADMIUM-DISSOLVED-W	AWE	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	0	0
AZ15050301-889	UNNAMED TRIB TO THREE R CYN	ZINC-DISSOLVED-W	AWE	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	0	0
AZ15050301-889	UNNAMED TRIB TO THREE R CYN	PH-TOTAL-W	PBC	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	0	0
AZ15050301-890	UNNAMED TRIB TO COX GULCH	COPPER-DISSOLVED-W	AWE	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	0	0
AZ15050301-890	UNNAMED TRIB TO COX GULCH	CADMIUM-DISSOLVED-W	AWE	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	0	0
AZ15050301-890	UNNAMED TRIB TO COX GULCH	ZINC-DISSOLVED-W	AWE	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	0	0
AZ15050301-890	UNNAMED TRIB TO COX GULCH	PH-TOTAL-W	PBC	No data retrieved	1/1/1989	12/31/2019		
AZ15070102-033A	LYNX CREEK	CADMIUM-DISSOLVED-W	AWC	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	2	15
AZ15070102-033A	LYNX CREEK	ZINC-DISSOLVED-W	AWC	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	4	13
AZ15070102-036B	TURKEY CREEK	COPPER-DISSOLVED-W	AWW		1/1/1989	12/31/2019	34	82
AZ15070102-036B	TURKEY CREEK	LEAD-TOTAL-W	FBC		1/1/1989	12/31/2019	28	84
AZ15070102-123	MONEY METALS TRIB	COPPER-DISSOLVED-W	AWE	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	7	50
AZ15070102-123	MONEY METALS TRIB	ZINC-DISSOLVED-W	AWE	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	14	50
AZ15070102-1994	UNNAMED TRIB TO EUGENE GULCH	COPPER-DISSOLVED-W	AWE	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	0	0
AZ15070102-234	UNNAMED TRIB TO BIG BUG CREEK	COPPER-DISSOLVED-W	AWC	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	0	2
AZ15070102-234	UNNAMED TRIB TO BIG BUG CREEK	ZINC-DISSOLVED-W	AWC	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	0	2
AZ15070102-234	UNNAMED TRIB TO BIG BUG CREEK	LEAD-DISSOLVED-W	AWC	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	3	2
AZ15070103-007A	HASSAYAMPA RIVER	COPPER-DISSOLVED-W	AWC		1/1/1989	12/31/2019	22	90
AZ15070103-007A	HASSAYAMPA RIVER	CADMIUM-DISSOLVED-W	AWC		1/1/1989	12/31/2019	19	94
AZ15070103-007A	HASSAYAMPA RIVER	ZINC-DISSOLVED-W	AWC		1/1/1989	12/31/2019	31	93

WBID	Waterbody	Analyte	Use	Comments	Start Date	End Date	AWQI	Index Stability
AZ15070103-007A	HASSAYAMPA RIVER	PH-TOTAL-W	FBC		1/1/1989	12/31/2019	82	100
AZ15070103-239	FRENCH GULCH	COPPER-DISSOLVED-W	AWW		1/1/1989	12/31/2019	38	88
AZ15070103-239	FRENCH GULCH	CADMIUM-DISSOLVED-W	AWW		1/1/1989	12/31/2019	95	88
AZ15070103-239	FRENCH GULCH	ZINC-DISSOLVED-W	AWW		1/1/1989	12/31/2019	96	88
AZ15070103-349	CASH MINE CREEK	COPPER-DISSOLVED-W	AWC	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	0	7
AZ15070103-349	CASH MINE CREEK	CADMIUM-DISSOLVED-W	AWC	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	3	7
AZ15070103-349	CASH MINE CREEK	ZINC-DISSOLVED-W	AWC	Insufficient data; index calculation constrained.	1/1/1989	12/31/2019	6	6
AZ15070103-415	UNNAMED TRIB TO CASH MINE CREEK	COPPER-DISSOLVED-W	AWC		1/1/1989	12/31/2019	1	67
AZ15070103-415	UNNAMED TRIB TO CASH MINE CREEK	CADMIUM-DISSOLVED-W	AWC		1/1/1989	12/31/2019	0	68
AZ15070103-415	UNNAMED TRIB TO CASH MINE CREEK	ZINC-DISSOLVED-W	AWC		1/1/1989	12/31/2019	2	68
AZ15080301-090A	MULE GULCH	COPPER-DISSOLVED-W	AWW		1/1/1989	12/31/2019	36	85
AZ15060202-025	VERDE RIVER	ESCHERICHIA COLI-TOTAL-W	FBC		1/1/1989	12/31/2019	97	92
AZ15060202-018C	OAK CREEK	ESCHERICHIA COLI-TOTAL-W	FBC		1/1/1989	12/31/2019	91	82
AZ15060202-018A	OAK CREEK	ESCHERICHIA COLI-TOTAL-W	FBC		1/1/1989	12/31/2019	93	90
AZ15060202-018B	OAK CREEK	ESCHERICHIA COLI-TOTAL-W	FBC		1/1/1989	12/31/2019	89	82
AZ15060202-017	OAK CREEK	ESCHERICHIA COLI-TOTAL-W	FBC		1/1/1989	12/31/2019	81	81
AZ15060202-016	OAK CREEK	ESCHERICHIA COLI-TOTAL-W	FBC		1/1/1989	12/31/2019	95	71
AZ15060202-019	OAK CREEK	ESCHERICHIA COLI-TOTAL-W	FBC		1/1/1989	12/31/2019	90	85
AZ15060202-022	SPRING CREEK (SPN)	ESCHERICHIA COLI-TOTAL-W	FBC		1/1/1989	12/31/2019	91	82
AZ15050202-008	SAN PEDRO RIVER	ESCHERICHIA COLI-TOTAL-W	FBC		1/1/1989	12/31/2019	63	81
AZ15050202-003	SAN PEDRO RIVER	ESCHERICHIA COLI-TOTAL-W	FBC		1/1/1989	12/31/2019	42	81
AZ15030202-005A	BOULDER CREEK	COPPER-DISSOLVED-W	AWW		1/1/1989	12/31/2019	30	86

WBID	Waterbody	Analyte	Use	Comments	Start Date	End Date	AWQI	Index Stability
AZ15030202-005A	BOULDER CREEK	ARSENIC-TOTAL-W	FBC		1/1/1989	12/31/2019	20	93
AZ15030202-005A	BOULDER CREEK	PH-TOTAL-W	FBC		1/1/1989	12/31/2019	84	100
AZ15030202-005A	BOULDER CREEK	ZINC-DISSOLVED-W	AWW		1/1/1989	12/31/2019	25	87
AZ15080301-337	BREWERY GULCH	COPPER-DISSOLVED-W	AWE		1/1/1989	12/31/2019	28	84
AZ15050301-561B	ALUM GULCH	COPPER-DISSOLVED-W	AWW		1/1/1989	12/31/2019	6	96
AZ15050301-561B	ALUM GULCH	CADMIUM-DISSOLVED-W	AWW		1/1/1989	12/31/2019	6	96
AZ15050301-561B	ALUM GULCH	ZINC-DISSOLVED-W	AWW		1/1/1989	12/31/2019	1	95
AZ15060103-018B	PINTO CREEK	COPPER-DISSOLVED-W	AWW		1/1/1989	12/31/2019	13	95
AZ15060103-018C	PINTO CREEK	COPPER-DISSOLVED-W	AWW		1/1/1989	12/31/2019	89	89
AZ15070102-034B	BIG BUG CREEK	ARSENIC-TOTAL-W	FBC		1/1/1989	12/31/2019	89	66
AZ15070102-034B	BIG BUG CREEK	LEAD-TOTAL-W	FBC		1/1/1989	12/31/2019	75	71
AZ15060103-887	GIBSON MINE TRIBUTARY	COPPER-DISSOLVED-W	AWE		1/1/1989	12/31/2019	0	96
AZ15030202-005A	BOULDER CREEK	MANGANESE-TOTAL-W	FBC		1/1/1989	12/31/2019	98	88

Table 27. Period of Record Analyte WQIs and Index Stability Scores for PIRs

Summary statistics for AWQIs and AWQI Index Stability Scores on priority-impaired reaches are presented below in Table 28 and Table 29.

AWQI POR Summary Statistic	Value	Percentile	Value
Maximum	98	**99th**	98
Mean	31.0	**95th**	95.15
Minimum	0	**90th**	90.3
Geo-Mean	--	**80th**	78.6
Standard Deviation	36.1	**75th (Q3)**	62.25
Standard Error of Mean	3.647	**50th (Q2)**	10
Median Absolute Deviation / 0.675	14.83	**25th (Q1)**	0
Skewness	0.762	**20th**	0
Coefficient of Variation	1.165	**10th**	0

Table 28. Period of Record Analyte Water Quality Index Summary Statistics, PIRs

AWQI ISS POR Summary Statistic	Value	Percentile	Value
Maximum	100	**99th**	100
Mean	48.5	**95th**	96
Minimum	0	**90th**	93.3
Geo-Mean	--	**80th**	90
Standard Deviation	40.21	**75th (Q3)**	88
Standard Error of Mean	4.061	**50th (Q2)**	61.5
Median Absolute Deviation / 0.675	49.67	**25th (Q1)**	2
Skewness	-0.119	**20th**	1.4
Coefficient of Variation	0.829	**10th**	0

Table 29. Period of Record AWQI Index Stability Score Summary Statistics, PIRs

Boxplots and histograms for period of record general indices and stability scores are provided below in Figure 32, Figure 33, and Figure 34. Likewise, boxplots and histograms for period of record analyte indices and stability scores are provided in Figure 35, Figure 36, and Figure 37.

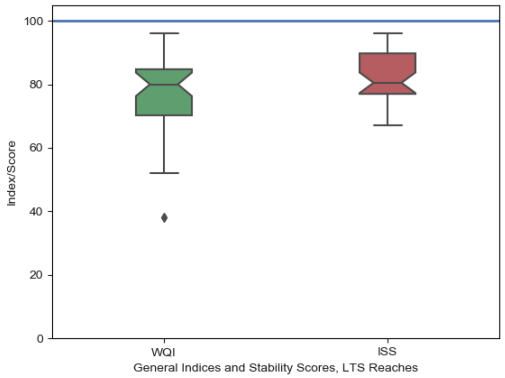

Figure 32. Boxplots, POR General Indices and ISSs

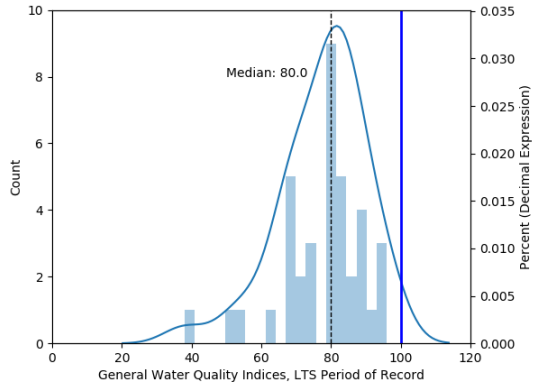

Figure 33. Histogram/KDE, POR GWQIs, LTSs

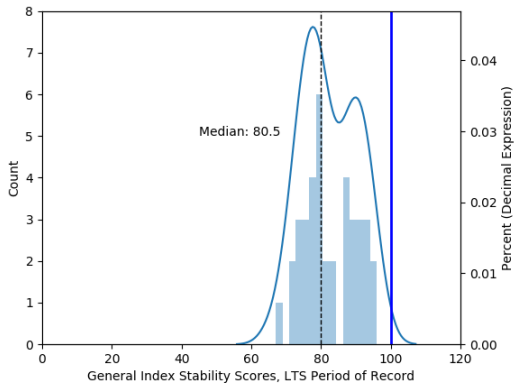

Figure 34. Histogram/KDE POR Stability Scores, LTSs

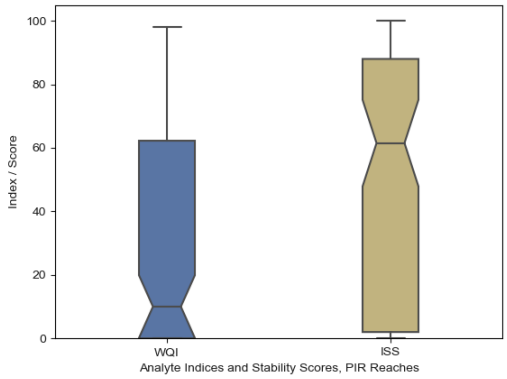

Figure 35. Boxplots, POR Analyte Indices and ISSs

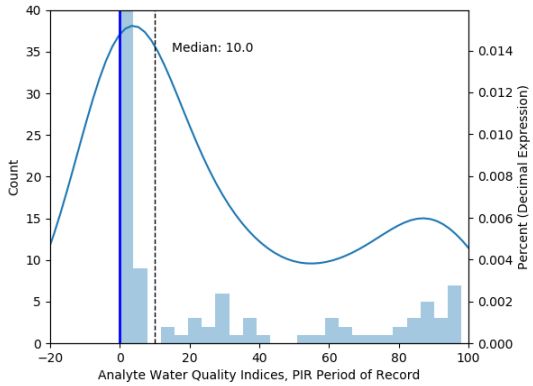

Figure 36. Histogram/KDE, POR AWQIs, PIRs

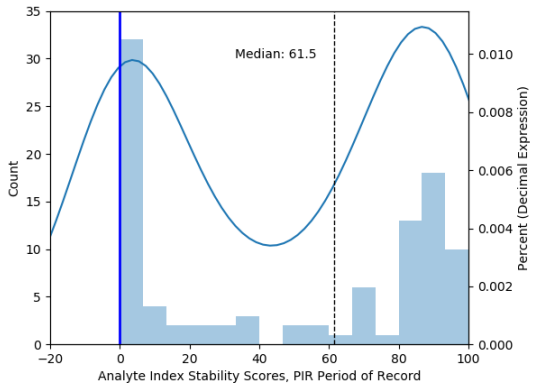

Figure 37. Histogram/KDE POR Stability Scores, PIRs

4.3 Discussion - Period of Record WQIs

As one might expect, the general and analyte population groups exhibited distinctly different characteristics as befits their statuses representing long-term reaches and impaired reaches respectively. The general WQIs characterizing long-term sites and reaches overall showed fair to good water quality, with corresponding fair to good index stability scores. The median general score was 80, and the median index stability score 81. The general index set exhibited a unimodal distribution with a slight left skew. The general index stability scores data set exhibited a bi-modal distribution with almost no skew; there was a pronounced break in grouping at ISS 85. For both the GWQIs and the general ISSs, the 99th, 95th, and 90th percentiles all were at 90 or above. The mean for the GWQIs was 77.5; the mean for the ISSs was similar at 82.5. These are respectable indices considering that a 31 year time frame was evaluated, and the solid accompanying ISSs indicates that a good deal of confidence can be placed in the reliability of the POR indices; index values are not likely to change with a few additional data points.

When looking at individual indices and scores from the GWQI set, the top scoring WQI reaches were:

- Colorado River (Bill Williams River – Osborne Wash, AZ15030104-020)
- Tonto Creek (Rye Creek – Gun Creek, AZ15060105-008)
- Verde River (Tangle Creek – Horseshoe Reservoir, AZ15060203-018)

All of these logged indices of 96 over the 31-year period. Honorable mentions go to the following:

- Verde River (Bartlett Lake Dam – Camp Creek, AZ15060203 -004) [93]
- San Francisco River (Headwaters – NM State Line, AZ15040004-023) [89]
- Verde River (Sycamore Creek – Oak Creek, AZ15060202-025) [88]
- Colorado River (Main Canal – Mexico border, AZ15030107-001) [88]

Overall, this is good news for Arizona citizens, as the Colorado and Verde Rivers are two of the major water lifelines for the state.

At the other end of the scale for general indices, Nogales Wash (Mexico Border – Potrero Creek) performed the most poorly with a GWQI of 38. This reach has exhibited poor water quality for many years and been known for persistent problems due to receiving poorly-treated or completely untreated storm water and sewage overflows from Nogales, Mexico. Faring better but still in the rear of the pack are Pinal Creek (See Ranch Crossing – Unnamed Tributary, AZ15060103-280E) with an index of 52 and the Little Colorado River (Silver Creek – Carr Lake Wash, AZ15020002-004) scoring 55. The latter reach has had TMDLs approved for suspended sediment concentration and *E. coli* impairments. All three reaches trailed the bulk of the set considerably, as there was a gap of seven points between the Little Colorado River reach and the next lowest scoring reach at 62. Above the mid-60s, index values cluster more closely together.

The general index stability scores demonstrated their utility in identifying reaches where data sets are extensive and consequently index values are reliable. There were ten GWQI reaches scoring 90 or higher. The best of the group for stability included the Gila River in the Yuma vicinity (Castle Dome Wash – Fortuna Wash, AZ15070201-003B) at 96, the San Francisco River near Clifton (Limestone Gulch – Gila River, AZ15040004-001) at 95, and the San Pedro River (Mexico border – Charleston, AZ15050202-008) scoring 94. Ironically, the Nogales Wash reach previously identified as poor in water quality scored in

this group with an ISS of 90. Salt River reach AZ15060103-004 (Pinal Creek – Roosevelt Lake) scored the weakest of the GWQI set for stability with a score of 67. All other reaches had scores higher than 70.

The AWQIs for the period of record, by contrast, showed much lower values and a much wider spread for the distribution indicating generally very poor water quality for the analyte(s) of concern and episodic water quality standard violations for each PIR[3]. The set comprised 100 distinct analyte –reach combinations. While the maximum score was 98, the median for the set was only ten (10). An index below ten indicates the waterbody's exceedances are more an order of magnitude beyond water quality standards, and an index lower than one indicates the waterbody's exceedances are two orders of magnitude removed from attaining water quality standards. The standard deviation for the set was 36.1 (compare SD 8.7 for LTS reaches). The 10th, 20th, and 25th percentiles for the set were all zero (0). The distribution exhibited a positive (right) skew. Index stability scores, in contrast to the LTS set, clearly indicated the PIRs were not sampled on as regular a basis as the LTS reaches. Scores were generally unstable and therefore indicate only limited confidence is warranted for the index values. ISSs spanned the entire score range with a maximum of 100 and a minimum of zero (0); the median ISS was 61.5. The 10th, 20th, and 25th percentiles were 0, 1.4, and 2 respectively. A somewhat less skewed distribution (than corresponding AWQIs) did log a 75th percentile of 88 and exhibited a negative (left) skew of -0.119. The AWQIs showed a bimodal distribution character, as did the ISSs (Figure 36, Figure 37), with the ISS scores more evenly balanced between extremes. However, for the index values, the AWQI modal presentation showed low values predominating at the peaks as opposed to the high values for GWQIs (compare Figure 33, Figure 36). The AWQI ISSs, like their GWQI ISS counterparts, also showed a bimodal character, but the spread of the peaks was much wider with approximately equal weights on both ends of the scale (compare Figure 34, Figure 37).

When considering metals-related individual PIRs, there are four reaches comprising five reach-analyte combinations that strongly suggest that impairment, if previously an issue is no longer one, and a reasonable expectation is that these PIRs will not be PIRs for much longer.

- French Gulch (AZ15070102-239) POR impairments for dissolved zinc and cadmium showed index values of 95 and 96 respectively.
- Likewise, the Queen Creek headwaters (AZ15050100-014A) selenium impairment showed an index value of 96.
- The top scorers and the final reaches scoring above 90 were Mineral Creek (Devils' Canyon – Diversion Tunnel, AZ15050100-012B) with its POR selenium impairment scoring 98 and Boulder Creek (Wilder Creek – Butte Creek, AZ15030202-005A) with a manganese impairment showing 98.

Unfortunately, these were some of the few bright spots for POR AWQIs. There were fully 26 of the 100 reach-analyte combinations that scored zeros (Table 27). Impaired waters scoring zeros included Three R Canyon, Cox Gulch, Cash Mine Creek, unnamed tributaries to Three R and Cox Gulch, and unnamed tributaries to Big Bug Creek, Eugene Creek, Alum Gulch, and Cash Mine Creek. An additional 23 impaired

[3] Constant WQ standards violations would present with a much narrower range of presentation, though the measure of central tendency might be similar. A wide range indicates water quality can on occasion be temporarily better for the analyte of concern.

reach-analyte combinations scored below ten. Notably, these are all mining-related impairments for metals, and they are all severe. The silver lining for metals PIR reaches scoring 0 is that most (23 of 26) stability scores were below 10, and 15 of the 26 were 0, indicating there are very limited data sets to evaluate. Indices, therefore, have the potential to rebound dramatically with additional data. With the recent fast-tracking and focused prioritization placed on monitoring and improving impaired waters, these reaches will likely be more intensively monitored in the future. Resources and the likelihood of remediation currently dictate where and how often ADEQ samples PIRs.

Nineteen (19) metals-related PIR reach-analyte combinations exhibited ISSs of 90 or better. These generally were logged on impaired main-stem rivers or major tributaries sampled on a regular basis. Waters scoring well in this ISS category for POR AWQI calculations included the Gila River, San Pedro River, and the Hassayampa River. Additionally, Mineral Creek, Alum Gulch, Boulder Creek and Queen Creek scored well on ISS calculations.

E. coli impairments showed considerably better overall results, with six of the ten impaired reaches scoring at 90 or above on their AWQIs. The highest scoring *E. coli* PIR was the Verde River (AZ15060202-025) at 97. Even Oak Creek's Reach 018B, the location of Slide Rock State Park and a long-standing impaired reach with more than its share of publicity for poor bacteriological water quality, scored a solid 89 AWQI over the period of record for this report. The poorest scoring members of the *E. coli* PIR group included two reaches of the upper San Pedro River (Mexico border – Charleston, Walnut Gulch – Dragoon Wash), which scored 63 and 42 respectively. In addition to the problems presented by grazing in the San Pedro watershed and a flashy, monsoon-based precipitation regime, it is suspected that the San Pedro's use as an immigration corridor as migrants trek northward along the river are contributing to the documented poor bacteriological water quality of the upper San Pedro River. These problems have created a persistent and evident water quality problem, as the AWQIs attest.

ISSs for the *E. coli* PIR group were strong overall, indicating reliable scores with little variability. Two reaches (Verde River, AZ15060202-025; Oak Creek, AZ15060202-018A) scored at 90 or higher with the Verde reach occupying the top spot at 92. The lowest-scoring ISS value for the *E. coli* group was Oak Creek Reach 016 (Spring Creek – Verde River) with a score of 71. Other *E. coli* reach ISSs clustered in the 80s. In contrast with mining-related PIRs, *E. coli* PIRs benefitted from being on major streams or tributaries with publicly recognized recreational value; these characteristics ensured that many sampling visits were made to monitor water quality over previous decades.

5.0 Conclusions

5.1 Summary of Key Findings for Arizona Water Quality, 1989-2019

5.1.1 Annual WQ Scores Series

5.1.1.1 LTS GWQ Scores

The data considered in this report show consistently scoring high annual general water quality scores for long-term sites across the state of Arizona with a handful of exceptions. For the data set considered as a whole, the median annual water quality index of 97 on a 0-100 scale scored near the maximum possible. Half of the evaluated reaches in the annual GWQI series scored with medians at the uppermost limit of the WQI scale at 100, indicating periods where no water quality standards exceedances occurred. Exceptional LTS reaches in annual trend series included the following (score, followed by reach identification):

- Median 100 – 10th percentile 98.3: **Tonto Creek** (Rye Creek – Gun Creek), AZ15060105-008
- Median 100 --10th percentile 95.4: **Verde River** (Sycamore Creek - Oak Creek), AZ15060202-025
- Median 100 – 10th percentile 94: **Hassayampa River** (Cottonwood Creek-Martinez Wash), AZ15070103-004

The lowest scoring reaches in the GWQ score annual series for LTS reaches were the following (score, reach identification):

- Median 71: **Nogales Wash** (Mexican border – Potrero Creek), AZ15050301-011
- Median 77: **Gila River** (Hassayampa River – Gillespie Dam), AZ15070101-008
- Median 78: **Little Colorado River** (Silver Creek – Carr Lake Draw), AZ15020002-004

5.1.1.2 PIR AWQ Scores

The annual statistics for the AWQIs of priority-impaired reaches demonstrated that in most cases, indices varied in a pronounced fashion through the period of record. The overall median for the AWQ set was 91. Reaches scoring high in the AWQ scores annual series included the following:

- Median 100 --- 10th percentile 100: **Boulder Creek** (Wilder Creek-Butte Creek), Manganese (T), AZ15030202-005A
- Median 100 –10th percentile 85.8: **Oak Creek** (Unnamed Tributary - Manzanita Campground), *E. coli*, AZ15060202-018C
- Median 100 –10th percentile 84.4: **Verde River** (Sycamore Creek - Oak Creek), *E. coli*, AZ15060202-025

On the other hand, PIRs scoring at the bottom of the list included the following. All are mining / metals impairments:

- Median 0 -- 99th percentile 1.9: **Gibson Mine Tributary**, (Headwaters – Pinto Creek), Copper (D), 15060103-887

- Median 1 – 99th percentile 1: **Alum Gulch** (31°28'20"/110°43'51" - 31°29'17"/110°44'25"), Zinc (D), AZ15050301-561B
- Median 1 – 99th percentile 21.2: **Alum Gulch** (31°28'20"/110°43'51" - 31°29'17"/110°44'25"), Copper (D), AZ15050301-561B

5.1.2 Trend Summaries

5.1.2.1 LTS GWQ Score Trends

There were relatively few trends either improving or declining for Arizona stream over the 31-year annual series. Trends were evaluated against statistical thresholds for both monotonic and step characters. The reasons for general trend improvements or declines are specific to the reaches identified; improvements or declines may have been caused by a variety of factors. Table 30 compiles LTS GWQ sites exhibiting ***statistically significant*** trends over the 31-year period:

REACH	WATERBODY	MONOTONIC TREND	TREND CHARACTER	STEP TREND	TREND CHARACTER
AZ14070006-001	COLORADO RIVER	Trend exists	Improving	--	--
AZ15020001-009	LITTLE COLORADO RIVER	Trend exists	Declining	Trend exists	Declining
AZ15020001-013B	LITTLE COLORADO RIVER WEST FORK	--	--	Trend exists	Declining
AZ15020002-004	LITTLE COLORADO RIVER	Trend exists	Improving	Trend exists	Improving
AZ15050301-011	NOGALES WASH	--	--	Trend exists	Declining
AZ15060103-018C	PINTO CREEK	--	--	Trend exists	Declining
AZ15060103-280E	PINAL CREEK	--	--	Trend exists	Declining
AZ15060203-022C	EAST VERDE RIVER	Trend exists	Improving	Trend exists	Improving

Table 30. Summary, Monotonic and Step Trends, LTS GWQ Scores

5.1.2.2 PIR AWQ Score Trends

With PIRs as well, relatively few reaches exhibited a statistically significant trend, when either evaluated for monotonic or step trends. The data set indicates modest progress on impaired reaches overall for the 31-year period of record when evaluated on an annual basis, with three impaired reaches showing improving trends, and two reaches showing declining trends. Table 31 compiles the results.

REACH	WATERBODY	IMPAIRED ANALYTE	MONOTONIC TREND	TREND CHARACTER	STEP TREND	TREND CHARACTER
AZ15060202-018A	OAK CREEK	ESCHERICHIA COLI	Trend exists	Improving	--	--
AZ15060202-018C	OAK CREEK	ESCHERICHIA COLI	--	--	Trend exists	Declining
AZ15070102-036B	TURKEY CREEK	LEAD-TOTAL	--	--	Trend exists	Declining
AZ15070103-007A	HASSAYAMPA RIVER	ZINC-DISSOLVED	--	--	Trend exists	Improving
AZ15080301-337	BREWERY GULCH	COPPER-DISSOLVED	Trend exists	Improving	--	--

Table 31. Summary, Monotonic and Step Trends, PIR AWQ Scores

5.1.3 Period of Record WQI Determinations

5.1.3.1 LTS Period of Record GWQIs

Overall, the general WQIs characterizing long-term sites and reaches showed fair to good water quality, with corresponding fair to good index stability scores. The median general score was 80, while the median index stability score logged 81. The top scoring WQI reaches for the period of record included the following:

- Index: 96 **Colorado River** (Bill Williams River – Osborne Wash, AZ15030104-020)
- Index: 96 **Tonto Creek** (Rye Creek – Gun Creek, AZ15060105-008)
- Index: 96 **Verde River** (Tangle Creek – Horseshoe Reservoir, AZ15060203-018)

The following reaches also scored well:

- Index: 93 **Verde River** (Bartlett Lake Dam – Camp Creek, AZ15060203 -004)
- Index: 89 **San Francisco River** (Headwaters – NM State Line, AZ15040004-023)
- Index: 88 **Colorado River** (Main Canal – Mexico border, AZ15030107-001)
- Index: 88 **Verde River** (Sycamore Creek – Oak Creek, AZ15060202-025)

Conversely, the following LTS GWQI reaches demonstrated the worst WQIs over the period of record:

- Index: 38 **Nogales Wash** (Mexico Border – Potrero Creek, AZ15050301-011)
- Index: 52 **Pinal Creek** (See Ranch Crossing – Unnamed Tributary, AZ15060103-280E)
- Index: 55 **Little Colorado River** (Silver Creek – Carr Lake Wash, AZ15020002-004)

5.1.3.2 PIR Period of Record AWQIs

The AWQIs for the period of record, by contrast with the GWQIs, showed much lower values and a much wider spread of data indicating generally very poor water quality for the analyte(s) of concern and episodic water quality standard violations for each PIR. As previously mentioned, 26 of the 100 reach-analyte combinations for mining-related impairments scored zeros for their period of records. Full details are provided in Table 27. Impaired waters scoring zero included the following:

- Three R Canyon (multiple reach-analyte combinations)
- Cox Gulch (multiple reach-analyte combinations)
- Cash Mine Creek (multiple reach-analyte combinations)
- Unnamed tributary to Three R
- Unnamed tributary to Cox Gulch
- Unnamed tributary to Big Bug Creek

- Unnamed tributary to Eugene Creek
- Unnamed tributary to Alum Gulch
- Unnamed tributary to Cash Mine Creek

Finally, a handful of PIRs performed well on AWQIs. Most of those scoring above 90 were *E. coli* impairments, but a few mining-related impairments also scored well. The top scoring PIRs for AWQIs in the period of record included the following:

- Index: 98 **Mineral Creek** (AZ15050100-012B), selenium (mining-related)
- Index: 98 **Boulder Creek** (AZ15030202-005A), manganese (mining-related)
- Index: 97 **Verde River** (AZ15060202-025), *E. coli* (recreational/grazing)
- Index: 96 **Queen Creek** headwaters (AZ15050100-014A), selenium (mining-related)
- Index: 96 **French Gulch** (AZ15070102-239), dissolved cadmium (mining-related)
- Index: 95 **Oak Creek** (AZ15060202-016), *E. coli* (recreational/grazing)
- Index: 95 **French Gulch** (AZ15070102-239), dissolved zinc (mining-related)
- Index: 93 **Oak Creek** (AZ15060202-018A), *E. coli* (recreational)

5.1.4 Program Status Goal Summary

In Section 1.0, discussion was presented concerning water quality program / policy goals and how trend analyses might cast illumination on progress towards achieving them. Table 32 and Table 33 present summaries of reach performance and comparison to the policy goals of restoring and/or maintaining (i.e., preventing degradation of) water quality for LTSs and PIRs respectively. Categories for characterizing program goal statuses in both tables include the following:

- **Maintained / Improved** - Reach is not impaired and shows trend improvement
- **Maintained** – Reach is not impaired and exhibits equilibrium
- **Deteriorating** – Reach is not impaired, but exhibits a declining water quality trend
- **Recovering** – Reach is impaired, but exhibits an improving trend
- **Persisting/Degraded** – Reach is impaired and exhibits equilibrium
- **Actively Degrading** – Reach is impaired and exhibits worsening water quality

For LTSs (Table 32), status counts broke out as follows:

- **Maintained / Improved** - 2
- **Maintained** – 27
- **Deteriorating** – 2
- **Recovering** – 1
- **Persisting/Degraded** – 3
- **Actively Degrading** – 3

The first three categories do not apply in consideration of impaired reaches. For PIRs (Table 33), status counts broke out as follows:

- **Recovering** – 3
- **Persisting/Degraded** – 34
- **Actively Degrading** – 2

The categories of *Maintained / Improved, Maintained,* and *Recovering* are considered as meeting program objectives. The remaining categories, with the exception of *Deteriorating*, are not meeting program objectives. The *Deteriorating* category is not considered, as it neither fully meets nor does not meet objectives. Grouped thusly, the breakdown is as follows:

LTSs

- **Meeting Program Objectives:** 30 reaches
- **Not Meeting Program Objectives**: 6 reaches

PIRs

- **Meeting Program Objectives:** 3 reaches
- **Not Meeting Program Objectives**: 36 reaches

Plainly evident, these status counts also confirm what the trend analyses on index values indicate - that most reaches are in a state of equilibrium when compared against their program status goals. One of the major conclusions for water quality monitoring and management, given the relative static trend character of most reaches whether unimpaired or impaired, is that planning efforts might better be directed towards protective and preventative actions before water quality suffers degradation than in trying to rehabilitate waters once degraded. This is not to suggest that attempts at remediation should be abandoned for impaired water bodies. It only suggests strongly by implication that it is easier, more effective and far less costly to maintain good water quality, as indices might reflect, than it is to attempt recovery of good water quality from poor water quality once a reach has suffered degradation. This conclusion can be considered the key finding of the trend analyses set forth in this report.

REACH	WATERBODY	303(D) STATUS	TREND	PROGRAM GOAL STATUS
AZ14070006-001	COLORADO RIVER		Improving	Maintained/Improved
AZ15020001-009	LITTLE COLORADO RIVER	Impaired	Declining	Actively Degrading
AZ15020001-013B	LITTLE COLORADO RIVER WEST FORK		Declining	Deteriorating
AZ15020002-004	LITTLE COLORADO RIVER	Impaired	Improving	Recovering
AZ15030104-020	COLORADO RIVER			Maintained
AZ15030107-001	COLORADO RIVER	Impaired		Persisting/Degraded
AZ15030201-004	BIG SANDY RIVER			Maintained
AZ15030201-014	TROUT CREEK			Maintained
AZ15030202-004	BURRO CREEK			Maintained
AZ15030203-009	SANTA MARIA RIVER			Maintained
AZ15040002-001	GILA RIVER			Maintained
AZ15040004-001	SAN FRANCISCO RIVER			Maintained
AZ15040004-003	SAN FRANCISCO RIVER			Maintained
AZ15040004-023	SAN FRANCISCO RIVER			Maintained
AZ15040004-025B	BLUE RIVER			Maintained
AZ15040005-022	GILA RIVER	Impaired		Persisting/Degraded
AZ15050202-008	SAN PEDRO RIVER			Maintained
AZ15050203-001	SAN PEDRO RIVER			Maintained
AZ15050203-011	SAN PEDRO RIVER			Maintained
AZ15050301-010	SANTA CRUZ RIVER			Maintained
AZ15050301-011	NOGALES WASH	Impaired	Declining	Actively Degrading
AZ15060103-004	SALT RIVER			Maintained
AZ15060103-018C	PINTO CREEK	Impaired	Declining	Actively Degrading
AZ15060103-280E	PINAL CREEK		Declining	Deteriorating
AZ15060105-008	TONTO CREEK			Maintained
AZ15060105-013A	TONTO CREEK			Maintained
AZ15060106A-003	SALT RIVER			Maintained
AZ15060202-025	VERDE RIVER			Maintained
AZ15060202-037	VERDE RIVER			Maintained
AZ15060203-004	VERDE RIVER			Maintained
AZ15060203-018	VERDE RIVER			Maintained
AZ15060203-022B	EAST VERDE RIVER			Maintained
AZ15060203-022C	EAST VERDE RIVER		Improving	Maintained/Improved
AZ15060203-025	VERDE RIVER			Maintained
AZ15070101-008	GILA RIVER	Impaired		Persisting/Degraded
AZ15070103-004	HASSAYAMPA RIVER			Maintained
AZ15070103-007B	HASSAYAMPA RIVER			Maintained
AZ15070201-003B	GILA RIVER			Maintained

Table 32. LTS Trends and Program Goal Status

REACH	WATERBODY	IMPAIRED ANALYTE	TREND	PROGRAM GOAL STATUS
AZ15030202-005A	BOULDER CREEK	ARSENIC-TOTAL		Persisting/Degraded
AZ15030202-005A	BOULDER CREEK	COPPER-DISSOLVED		Persisting/Degraded
AZ15030202-005A	BOULDER CREEK	MANGANESE-TOTAL		Persisting/Degraded
AZ15030202-005A	BOULDER CREEK	PH-TOTAL		Persisting/Degraded
AZ15030202-005A	BOULDER CREEK	ZINC-DISSOLVED		Persisting/Degraded
AZ15030202-005B	BOULDER CREEK	ARSENIC-TOTAL		Persisting/Degraded
AZ15040005-022	GILA RIVER	LEAD-TOTAL		Persisting/Degraded
AZ15050100-012D	MINERAL CREEK	COPPER-DISSOLVED		Persisting/Degraded
AZ15050100-012D	MINERAL CREEK	SELENIUM-TOTAL		Persisting/Degraded
AZ15050100-014A	QUEEN CREEK	COPPER-DISSOLVED		Persisting/Degraded
AZ15050100-014A	QUEEN CREEK	SELENIUM-TOTAL		Persisting/Degraded
AZ15050100-014B	QUEEN CREEK	COPPER-DISSOLVED		Persisting/Degraded
AZ15050202-003	SAN PEDRO RIVER	ESCHERICHIA COLI		Persisting/Degraded
AZ15050202-006	SAN PEDRO RIVER	COPPER-DISSOLVED		Persisting/Degraded
AZ15050202-008	SAN PEDRO RIVER	ESCHERICHIA COLI		Persisting/Degraded
AZ15050202-008	SAN PEDRO RIVER	COPPER-DISSOLVED		Persisting/Degraded
AZ15050301-561B	ALUM GULCH	CADMIUM-DISSOLVED		Persisting/Degraded
AZ15050301-561B	ALUM GULCH	COPPER-DISSOLVED		Persisting/Degraded
AZ15050301-561B	ALUM GULCH	ZINC-DISSOLVED		Persisting/Degraded
AZ15060103-018B	PINTO CREEK	COPPER-DISSOLVED		Persisting/Degraded
AZ15060103-018C	PINTO CREEK	COPPER-DISSOLVED		Persisting/Degraded
AZ15060103-887	GIBSON MINE TRIBUTARY	COPPER-DISSOLVED		Persisting/Degraded
AZ15060202-016	OAK CREEK	ESCHERICHIA COLI		Persisting/Degraded
AZ15060202-017	OAK CREEK	ESCHERICHIA COLI		Persisting/Degraded
AZ15060202-018A	OAK CREEK	ESCHERICHIA COLI	Improving	Recovering
AZ15060202-018B	OAK CREEK	ESCHERICHIA COLI		Persisting/Degraded
AZ15060202-018C	OAK CREEK	ESCHERICHIA COLI	Declining	Actively Degrading
AZ15060202-019	OAK CREEK	ESCHERICHIA COLI		Persisting/Degraded
AZ15060202-022	SPRING CREEK	ESCHERICHIA COLI		Persisting/Degraded
AZ15060202-025	VERDE RIVER	ESCHERICHIA COLI		Persisting/Degraded
AZ15070102-034B	BIG BUG CREEK	ARSENIC-TOTAL		Persisting/Degraded
AZ15070102-034B	BIG BUG CREEK	LEAD-TOTAL		Persisting/Degraded
AZ15070102-036B	TURKEY CREEK	COPPER-DISSOLVED		Persisting/Degraded
AZ15070102-036B	TURKEY CREEK	LEAD-TOTAL	Declining	Actively Degrading
AZ15070103-007A	HASSAYAMPA RIVER	CADMIUM-DISSOLVED		Persisting/Degraded
AZ15070103-007A	HASSAYAMPA RIVER	COPPER-DISSOLVED		Persisting/Degraded
AZ15070103-007A	HASSAYAMPA RIVER	PH-TOTAL		Persisting/Degraded
AZ15070103-007A	HASSAYAMPA RIVER	ZINC-DISSOLVED	Improving	Recovering
AZ15080301-337	BREWERY GULCH	COPPER-DISSOLVED	Improving	Recovering

Table 33. PIR Trends and Program Goal Status

5.2 Final Thoughts: Development and Utility of AZ Water Quality Index and Stability Score

The WQI has demonstrated that its promise as a metric to evaluate improvement in water quality over time was warranted, and with this report, its potential has now been realized. Trend analysis of indices as conducted in this report was one of the prime reasons to pursue development and implementation of the index. Other features and advantages of the index are numerous; the scale is simple and easily understandable, requiring only a general orientation as to what constitutes a top score. The index is readily scalable in terms of spatial application, whether to a single site, a stream reach (as in this report), or more broadly to an entire stream when designated uses are consistent across all reaches. The index also has great flexibility when considered temporally, as it can be calculated for any period of interest, provided enough data is available to generate indices that have sufficiently robust stability scores. Further development and adaptation of the index's conceptual basis has allowed for the creation and use of analyte-specific indices, with a modified mathematical basis, to assess the degree of severity of any individual parameter's impairment here in Arizona.

While an index evaluation is not a substitute for the more comprehensive and rigorous analysis of water quality that accompanies statewide assessments and other investigations, this tool allows for analysis in ways that were formerly beyond the reach of state water quality analysts and decision-makers. This report marks the first trend analysis study produced by state agencies for Arizona surface water quality covering a period of record of more than three decades. To be sure, there are limitations associated with the index; it does not faithfully duplicate state water quality standards in every detail, and an understanding of its conceptual basis is necessary to properly use and interpret the resulting numbers. But critically, the index has overcome previous hurdles that had previously prevented Arizona from conducting scientific trend analysis studies; among these were changes through time in analytical lab tests and method sensitivities, differing detection limits, varying scales of reporting, and varying characteristics of the data sets being considered (e.g., logarithmic responses, linear or factor-based responses). By shifting the focus from raw results and detection limits to a consistent consideration of the scope, frequency, and magnitude of standards exceedances, and placing all calculations on the same 0-100 scale, the index has opened the door to new horizons of scientific inquiry and analysis for Arizona water quality.

One of the most common misuses of the indices in years past was the recurrent practice of using data sets that were too small to generate reliable indices. Now there is an adjunct tool - the Index Stability Score - that penalizes and discourages that approach. Additionally, recognition of the stochastic behavior of index expression over time and the conducting of rigorous statistical testing to analyze this behavior guards against the improper interpretation of changes in index reporting, another weakness previously identified in its use. With both of these identified primary misuses of early versions of the index addressed and rectified, Arizona now has a strong scientific and communication tool in its arsenal.

In this report, the utility of Arizona's Water Quality Index and accompanying Index Stability Score has been demonstrated. These tools are extremely useful tools for analyzing water quality data in a concise and easily understandable way. They allow comparison of disparate sets of data from differing analytes, groups of analytes, detection limits and analytical methods over varying time frames and for long uninterrupted periods. The metrics achieve this in a way that puts all information in the same context and on the same scale for easy comparison and analysis. Additionally, the Index Stability Score provides

an easily digestible metric for the reliability (i.e. quality assurance) of its accompanying water quality index. Together, these tools provide Arizona water quality analysts, decision-makers, and the public both incisive and extensive insight into not only existing and recent past water quality conditions, but also on how water quality has varied over time for Arizona streams and rivers. Future follow-up studies using the indices as demonstrated here are warranted, and additional benefits will be realized when results based on index evaluations are shared widely with the public.

6.0 References

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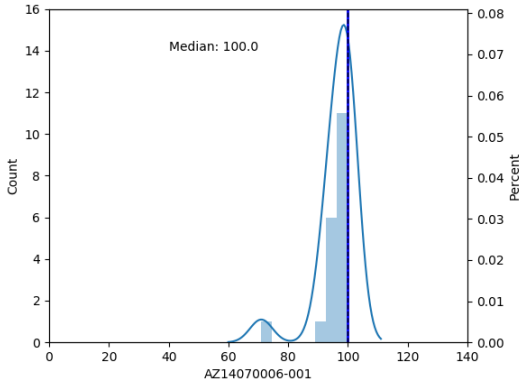
Appendix A. Long-term Sites/Reaches Histograms

Histogram/Kernel Density Estimate by WBID with median plots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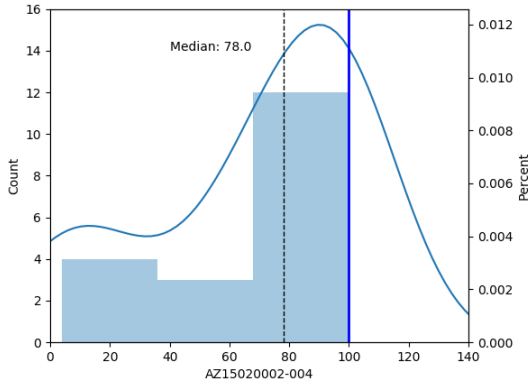
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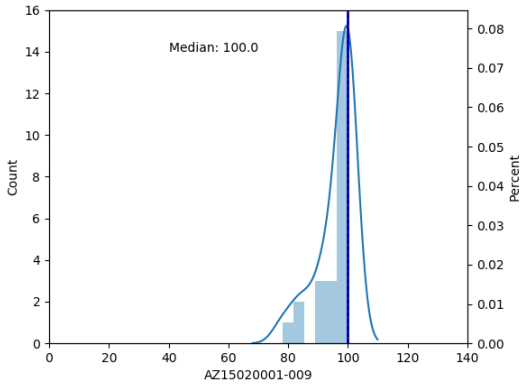
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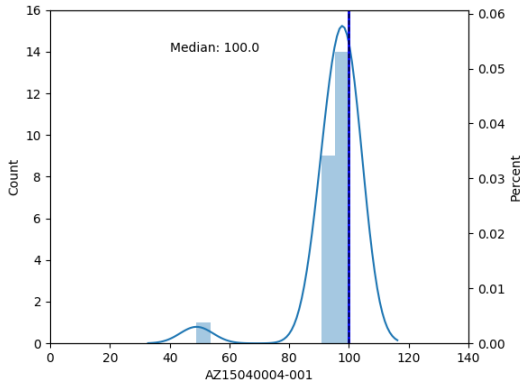
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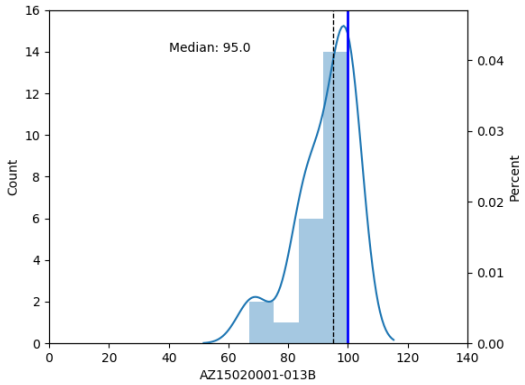
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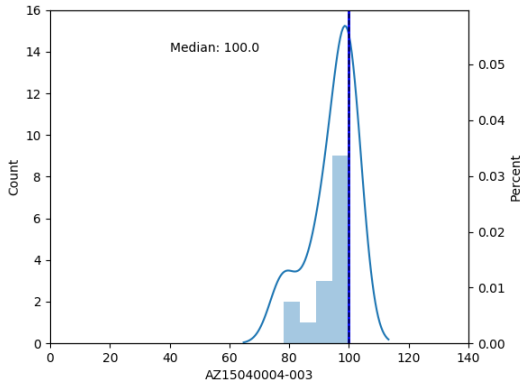
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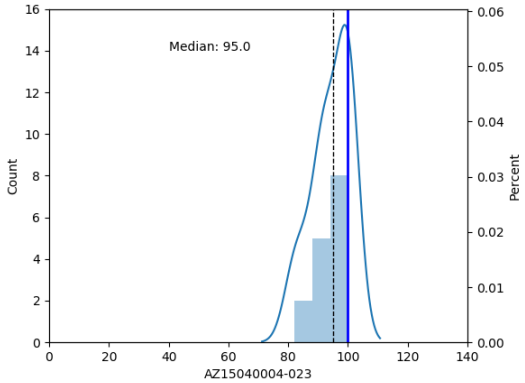
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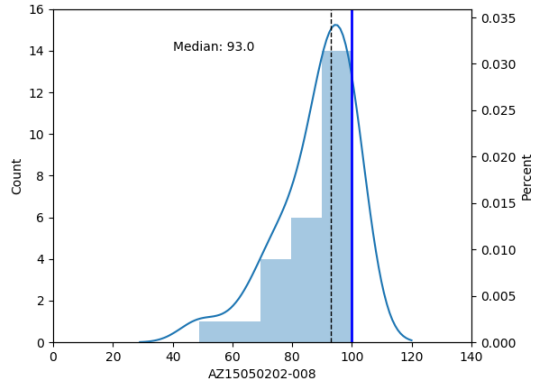
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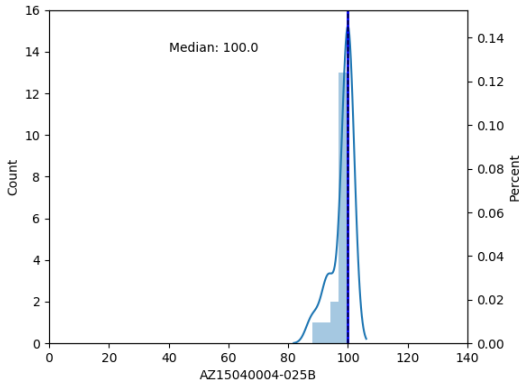
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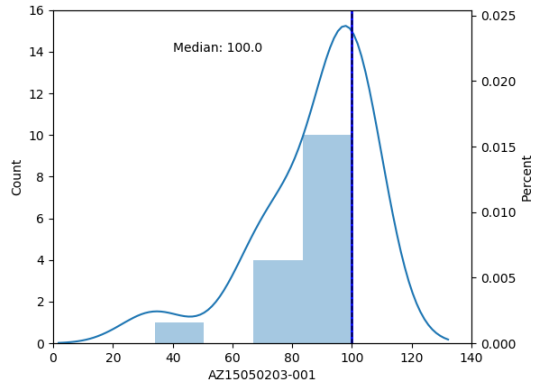
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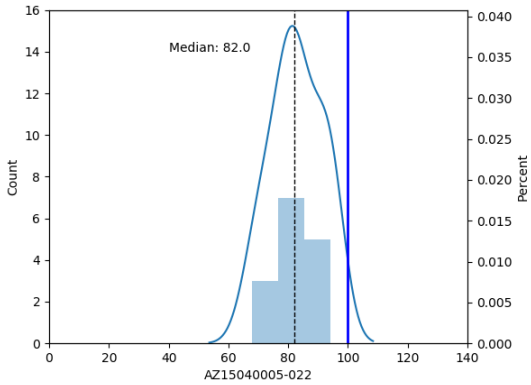
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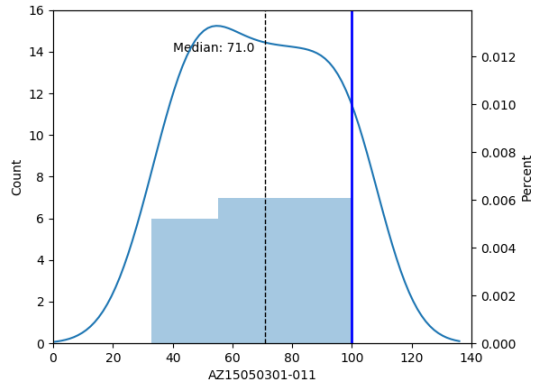
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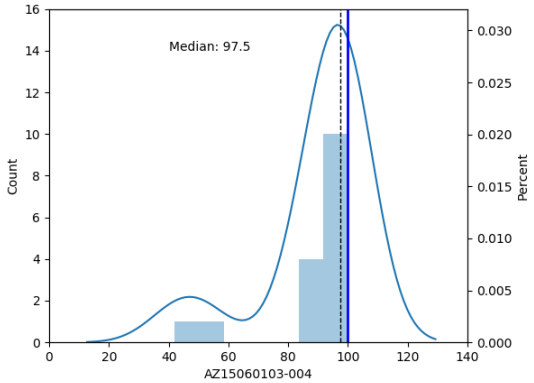
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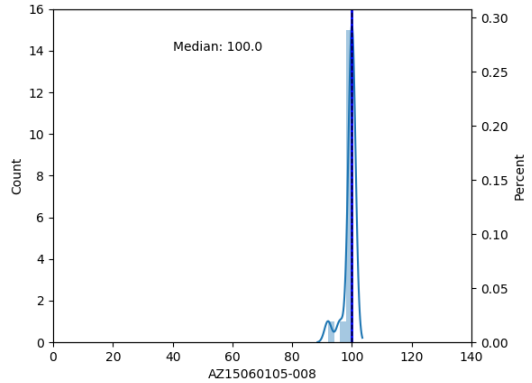
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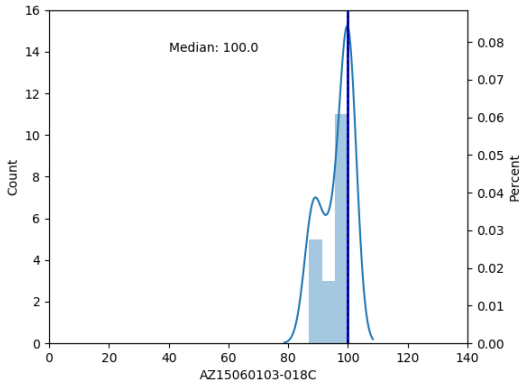
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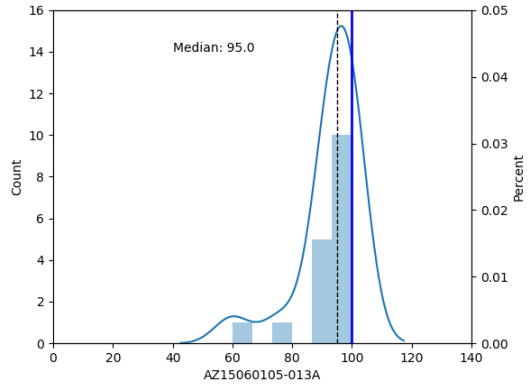
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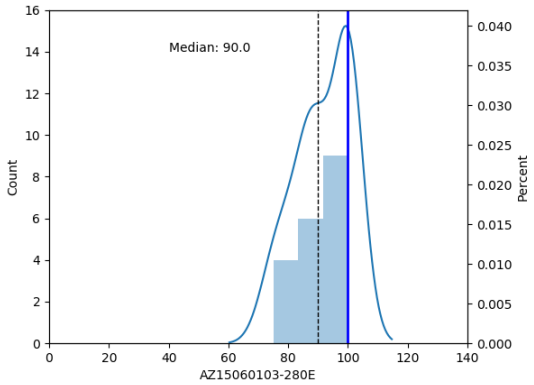
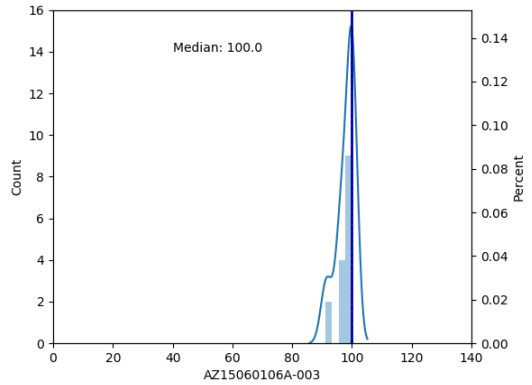

Median: 90.0
Count
Percent
AZ15060103-280E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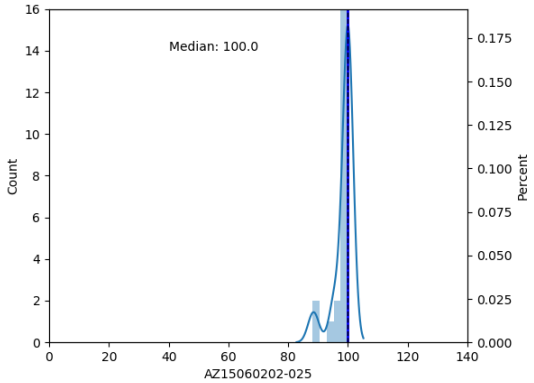
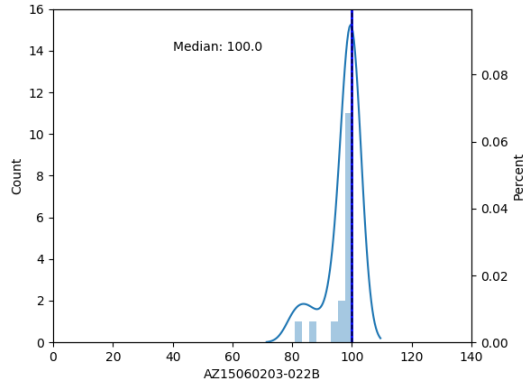
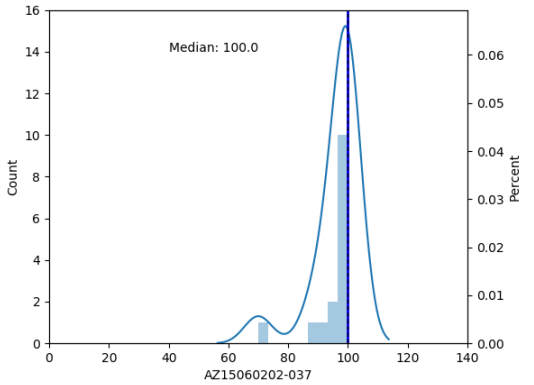
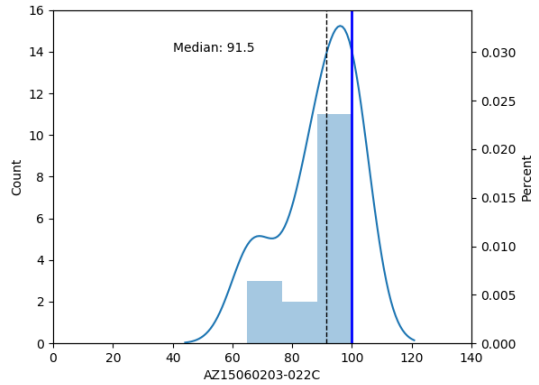
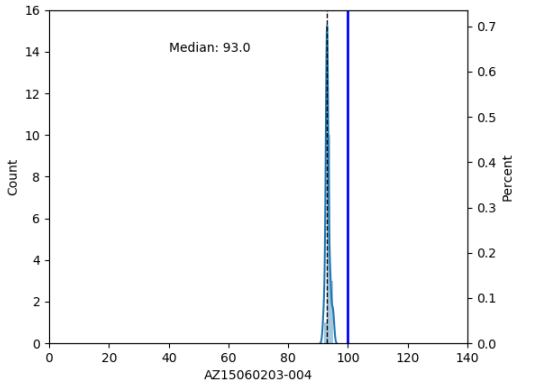
AZ15060106A-003

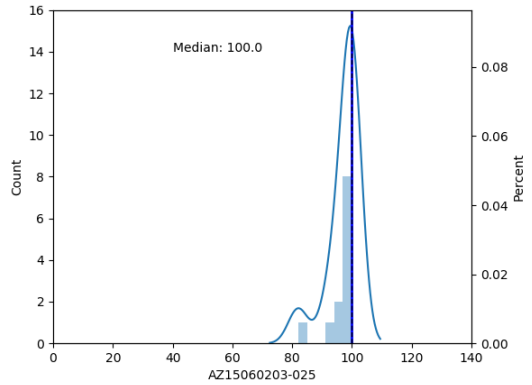

Median: 100.0
Count
Percent
AZ15060202-025

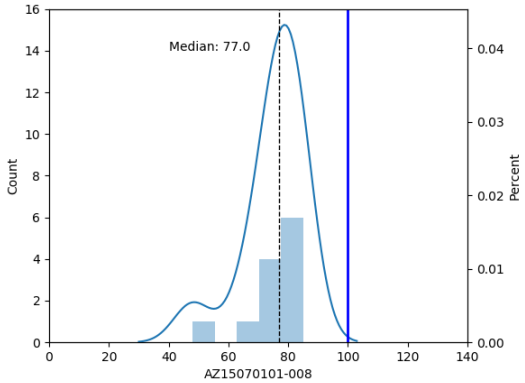

Median: 100.0
Count
Percent
AZ15060203-022B

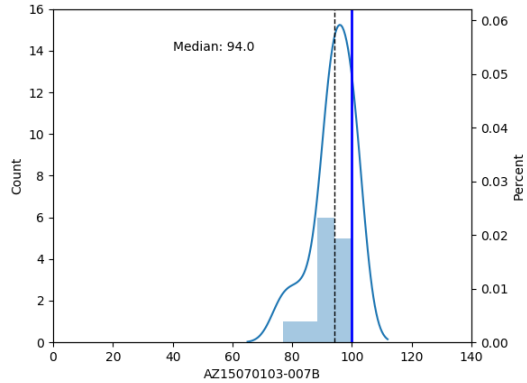

Median: 100.0
Count
Percent
AZ15060202-037

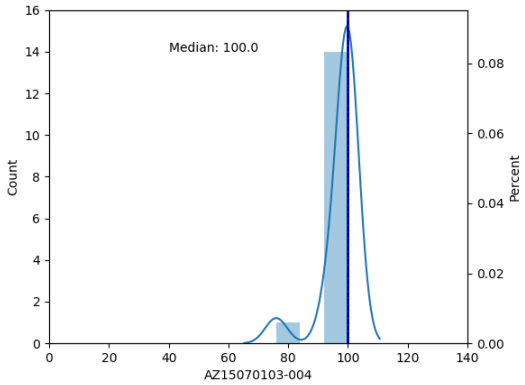

Median: 91.5
Count
Percent
AZ15060203-022C

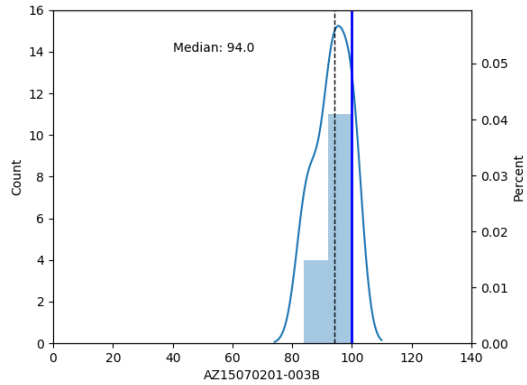

Median: 93.0
Count
Percent
AZ15060203-004


Median: 100.0
Count
Percent
AZ15060203-025


Median: 77.0
Count
Percent
AZ15070101-008

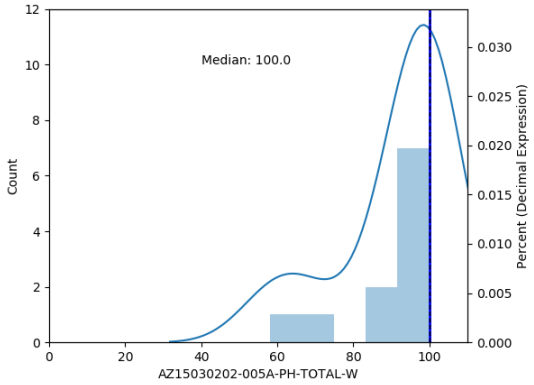

Median: 94.0
Count
Percent
AZ15070103-007B

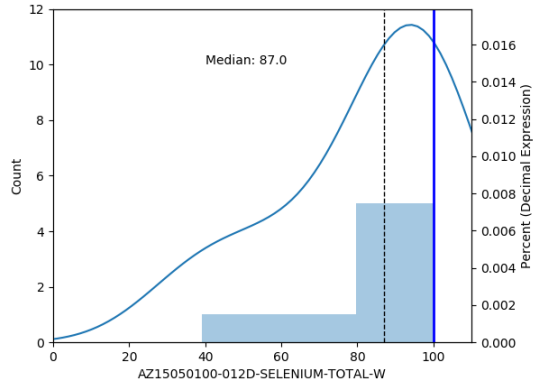

Median: 100.0
Count
Percent
AZ15070103-004

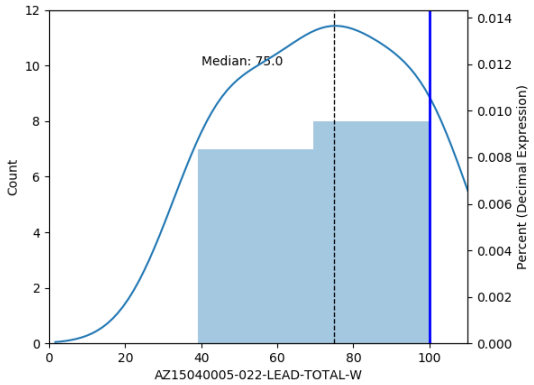

Median: 94.0
Count
Percent
AZ15070201-003B

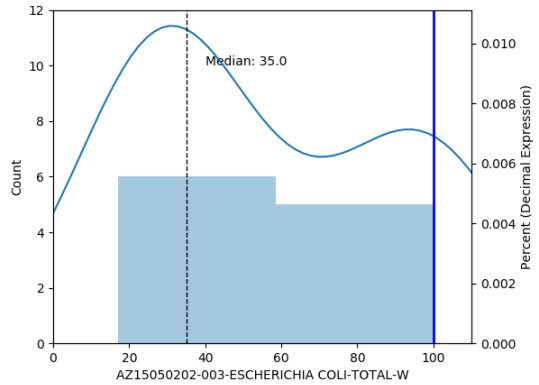
Appendix B. Priority Impaired Reaches Histograms

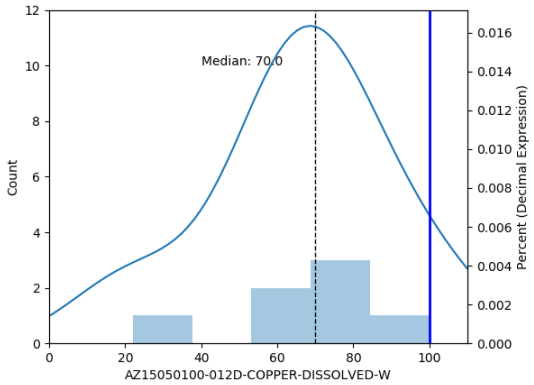
Histogram/Kernel Density Estimate by WBID with median plots

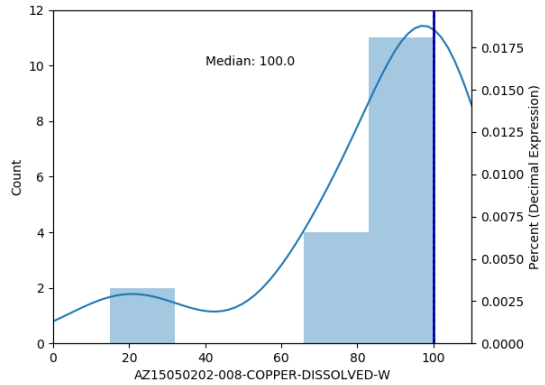

Median: 100.0
Count
Percent (Decimal Expression)
AZ15030202-005A-PH-TOTAL-W

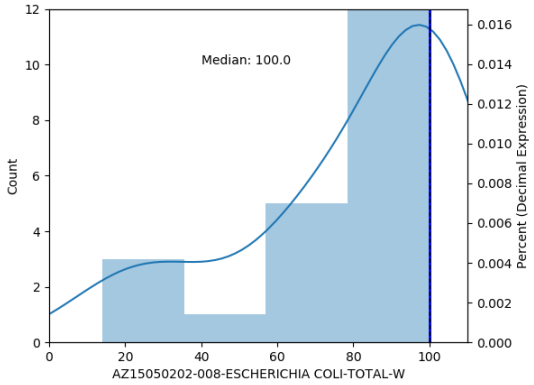

Median: 87.0
Count
Percent (Decimal Expression)
AZ15050100-012D-SELENIUM-TOTAL-W

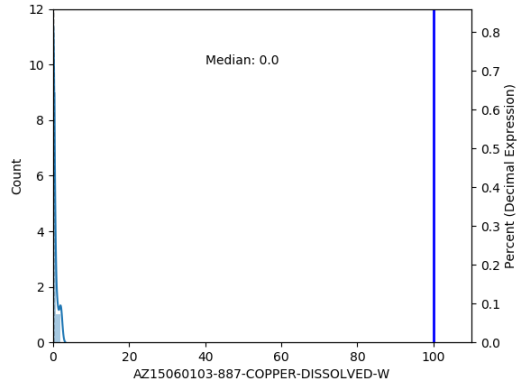

Median: 75.0
Count
Percent (Decimal Expression)
AZ15040005-022-LEAD-TOTAL-W

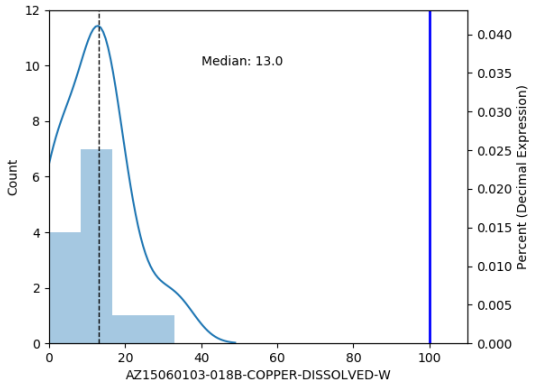

Median: 35.0
Count
Percent (Decimal Expression)
AZ15050202-003-ESCHERICHIA COLI-TOTAL-W

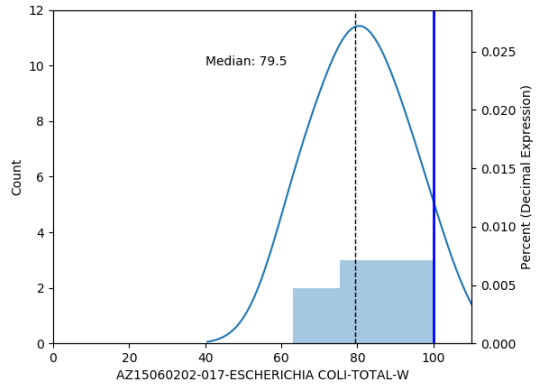

Median: 70.0
Count
Percent (Decimal Expression)
AZ15050100-012D-COPPER-DISSOLVED-W

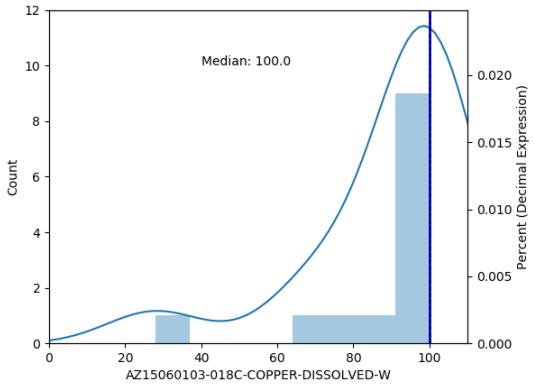

Median: 100.0
Count
Percent (Decimal Expression)
AZ15050202-008-COPPER-DISSOLVED-W

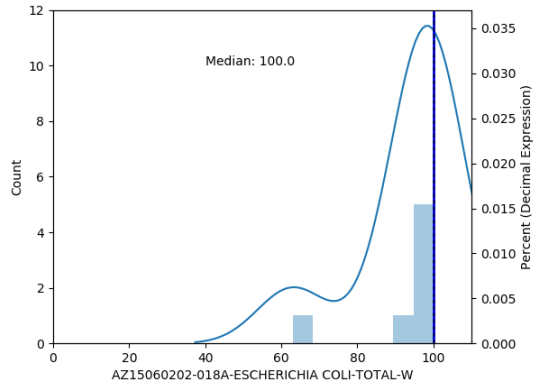

Median: 100.0
Count
Percent (Decimal Expression)
AZ15050202-008-ESCHERICHIA COLI-TOTAL-W

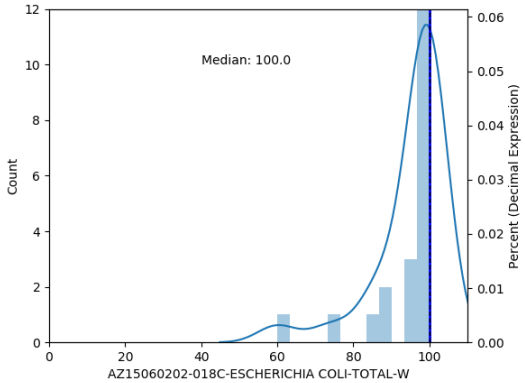

Median: 0.0
Count
Percent (Decimal Expression)
AZ15060103-887-COPPER-DISSOLVED-W

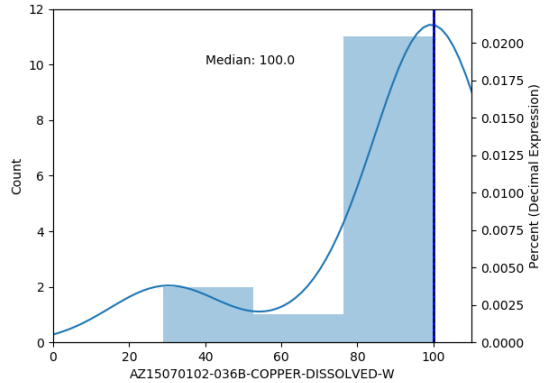

Median: 13.0
Count
Percent (Decimal Expression)
AZ15060103-018B-COPPER-DISSOLVED-W

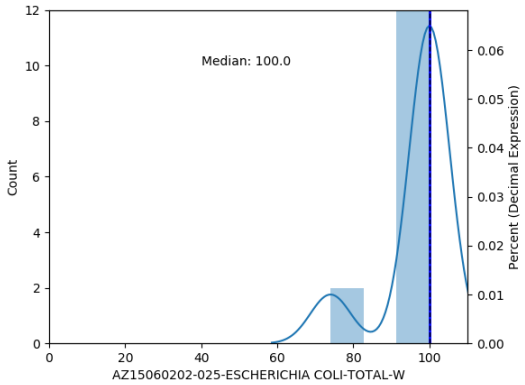

Median: 79.5
Count
Percent (Decimal Expression)
AZ15060202-017-ESCHERICHIA COLI-TOTAL-W

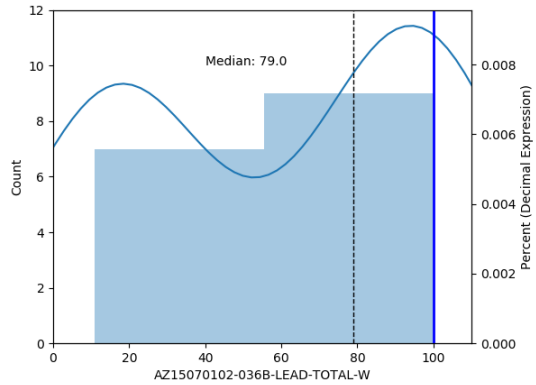

Median: 100.0
Count
Percent (Decimal Expression)
AZ15060103-018C-COPPER-DISSOLVED-W

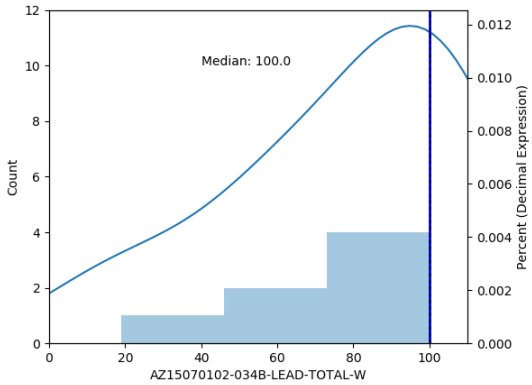

Median: 100.0
Count
Percent (Decimal Expression)
AZ15060202-018A-ESCHERICHIA COLI-TOTAL-W

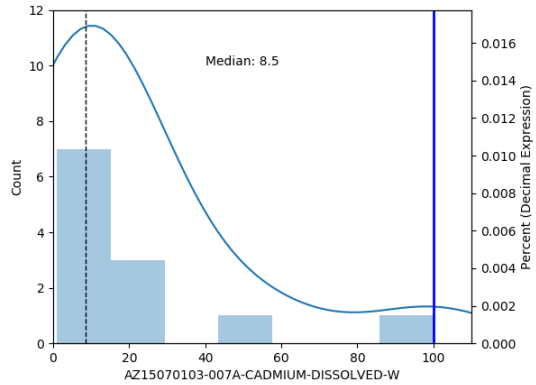

Median: 100.0
Count
Percent (Decimal Expression)
AZ15060202-018C-ESCHERICHIA COLI-TOTAL-W

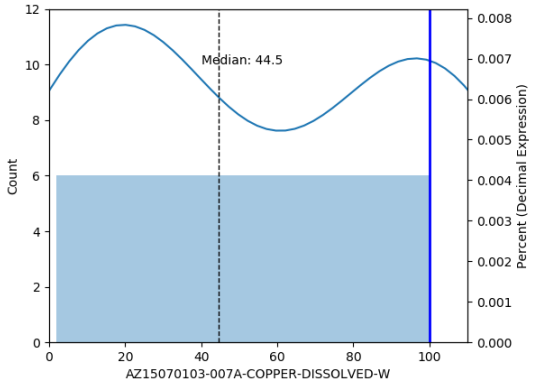

Median: 100.0
Count
Percent (Decimal Expression)
AZ15070102-036B-COPPER-DISSOLVED-W

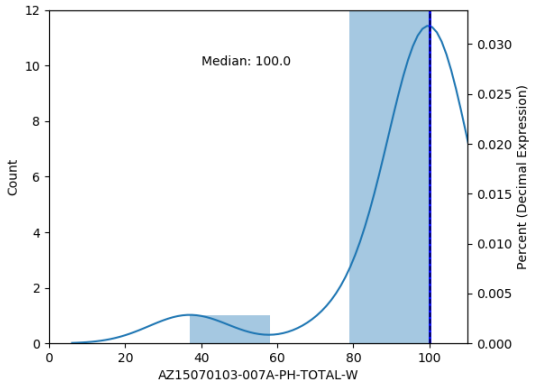

Median: 100.0
Count
Percent (Decimal Expression)
AZ15060202-025-ESCHERICHIA COLI-TOTAL-W

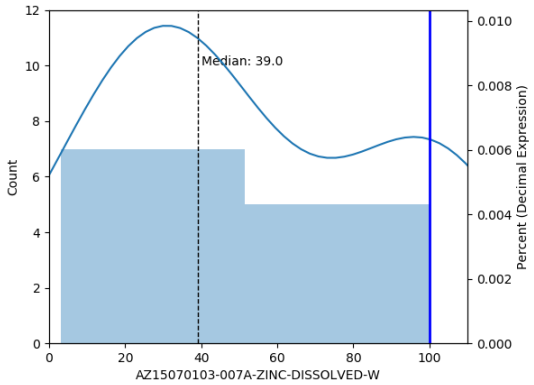

Median: 79.0
Count
Percent (Decimal Expression)
AZ15070102-036B-LEAD-TOTAL-W


Median: 100.0
Count
Percent (Decimal Expression)
AZ15070102-034B-LEAD-TOTAL-W


Median: 8.5
Count
Percent (Decimal Expression)
AZ15070103-007A-CADMIUM-DISSOLVED-W


Median: 44.5
Count
Percent (Decimal Expression)
AZ15070103-007A-COPPER-DISSOLVED-W


Median: 100.0
Count
Percent (Decimal Expression)
AZ15070103-007A-PH-TOTAL-W


Median: 39.0
Count
Percent (Decimal Expression)
AZ15070103-007A-ZINC-DISSOLVED-W

Appendix C. LTS Reaches Annual GWQIs

WBID	WATERBODY	YEAR 1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
AZ14070006-001	COLORADO RIVER	71	94	91	95	100	100	94	100	100	100	100	100	100	95	95	100	95	100	100				100				95	96			
AZ15020001-009	LITTLE COLORADO RIVER		100	100	100	100	100					100	95	100	100	92	100	100	100	100	100	95	89	100		83	96	78	100	92	85	
AZ15020001-013B	LITTLE COLORADO RIVER WEST FORK	100				100	100	100	67			91	93	100	100	95	86	84	100	100	100	88	70	100	83	85		100		88	95	
AZ15020002-004	LITTLE COLORADO RIVER	4	4	19		93	77	100	70		9	100	67	78	100	84	100	100	100	100	63	43	53									
AZ15030104-020	COLORADO RIVER										100	100	100	100	100	100	95	100	100	100				100				95	100			
AZ15030107-001	COLORADO RIVER										100	97	100	96	97	93	93	91	92	100				95			100	100	100			
AZ15030201-004	BIG SANDY RIVER	100	85	63							100	89	100	90	90	93	86	92				100	93									
AZ15030201-014	TROUT CREEK		100	84	100	100	100			100		100	100	100	100	87	100						100		93	93				100	100	
AZ15030202-004	BURRO CREEK	85										100	100	100	100	100	93	100	100	100										93	100	100
AZ15030203-009	SANTA MARIA RIVER	100	100	100								100	92	85	100	94	89	100														
AZ15040002-001	GILA RIVER									100		100	100	100	85	87	92	100	91	93												
AZ15040004-001	SAN FRANCISCO RIVER	94				100	100	100	92	100	93	92	100	100	93	100	100	100	93	94	93	100			100	100	100	94		49	100	
AZ15040004-003	SAN FRANCISCO RIVER				100					100		100	100	100	78	100	95	100	94		94	100		87	100			78	100	90	100	
AZ15040004-023	SAN FRANCISCO RIVER				100	91	83	100	100			92	100	88	82	100	93	95	100		100	92					94	94		77		
AZ15040004-025B	BLUE RIVER (BLR)	94			100	100	92	100	100		100	100	100	100	100	100	88	94	100		100	100		87	100					100	100	
AZ15040005-022	GILA RIVER									90	80	89	71	94	94	93	82	83	78	88				79	73	85	68	79	82	94		
AZ15050202-008	SAN PEDRO RIVER	94	100	83	94	100	84	89	95	94	89	89	93	85	93	94	71	100	78	100				63			100	100	74	49	74	100
AZ15050203-001	SAN PEDRO RIVER				100	100					100	100	93	78	100	93	68	100		100	69	100	34	100	100		77	100		100		
AZ15050203-011	SAN PEDRO RIVER			100	100							100	86	100	100	100	74	94				100										
AZ15050301-010	SANTA CRUZ RIVER	100	100	100	91	91	100	95		100	100	84	91	95							100	100										
AZ15050301-011	NOGALES WASH	89	100	100	100	90	82	59	46	49	33	41	58	41	73	69	75	100	57		76	49										
AZ15060103-004	SALT RIVER										96	100	100	100	52	42	100	85	90	100		100	100	90	100	88	95	95	100			
AZ15060103-018C	PINTO CREEK	100	100	94	89	100	100	100	100	100	100	88	94	87	100	95	89	89		100	100								100			
AZ15060103-280E	PINAL CREEK	100	100	100	100	88	100	87	87	100	75	75	90	89	81	90	81	100		100	100											
AZ15060105-008	TONTO CREEK (TON)	100	92	96	100	100	100	100	100	100	100	100	100	100	100	100	100	100														
AZ15060105-013A	TONTO CREEK (TON)						95		80			90	90	100	95	91	100	100	60	100	92	100	100	76		91	91	100			95	96
AZ15060106A-003	SALT RIVER											96	97	97	96	92	100	100	91	100				100	100	100	100	96	100	100		
AZ15060202-025	VERDE RIVER		89	100	100	100		100			100	100	96	100	100	100	100	100	100	100	100			95	88	96	100	100	100	100	100	100
AZ15060202-037	VERDE RIVER	96	70	100	100	95		100	100		100	88	100	100	92	100	100	100												75	100	
AZ15060203-004	VERDE RIVER											93	93	93	93	94	93	95	94	93				93	92	93	93	93	93			
AZ15060203-018	VERDE RIVER					86		100			96	100	96	100	100	100	100	90	100	100				100				100	100	78	95	
AZ15060203-022B	EAST VERDE RIVER	97	93	100	100	100	100	100			100	81	100	100	97	100	100	100				86		90	100	100						
AZ15060203-022C	EAST VERDE RIVER							100			96	90	82	91	65	69	67	84		100	100	89	92	89	100	97		100	100	100		
AZ15060203-025	VERDE RIVER	96	100	82				100			100	92	100	100	96	100	100	100							100						100	
AZ15070101-008	GILA RIVER										79	83	82	81	76	72	85	75						74	78	65	48				84	82
AZ15070103-004	HASSAYAMPA RIVER	100	100	100	100	100	100					76	100	100	100	100	94	100			94	100					100	100			92	100
AZ15070103-007B	HASSAYAMPA RIVER			93	100	100	100	93	92			77	94	84	94	100	100	94														100
AZ15070201-003B	GILA RIVER				100	86	100	93	100	94	100	92	84	84	94	95	94	88		100					87	92	81				100	

Appendix D. Priority Impaired Reaches Annual AWQIs

WBID	WATERBODY	ANALYTE	YEAR 1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
AZ15030202-005A	BOULDER CREEK	ARSENIC-TOTAL-W																									1		18	64	47	40	
AZ15030202-005A	BOULDER CREEK	COPPER-DISSOLVED-W																									100		100	64	100	100	
AZ15030202-005A	BOULDER CREEK	MANGANESE-TOTAL-W																									100		100	100	100	100	
AZ15030202-005A	BOULDER CREEK	PH-TOTAL-W												88	68		58	100	100	100							100		91	100	100	100	
AZ15030202-005A	BOULDER CREEK	ZINC-DISSOLVED-W																									15		49	100	92	100	
AZ15030202-005B	BOULDER CREEK	ARSENIC-TOTAL-W												21	49															13	15	18	
AZ15040005-022	GILA RIVER	LEAD-TOTAL-W												42	100	100	100	81	75	65	77				47	39	59	46	67	82	100		
AZ15050100-012D	MINERAL CREEK	COPPER-DISSOLVED-W												59	78	100	58	72	70			22											
AZ15050100-012D	MINERAL CREEK	SELENIUM-TOTAL-W												39	87	100	100	62	87			100											
AZ15050100-014A	QUEEN CREEK	COPPER-DISSOLVED-W															100	71	49		33	65	47										
AZ15050100-014A	QUEEN CREEK	SELENIUM-TOTAL-W															100	100	100	65	96	100											
AZ15050100-014B	QUEEN CREEK	COPPER-DISSOLVED-W														23	76		75	100	27	15											
AZ15050202-003	SAN PEDRO RIVER	*E. COLI*-TOTAL-W					100	49				100	48					100	59	88			24	29	31			100	34	35	17	100	
AZ15050202-006	SAN PEDRO RIVER	COPPER-DISSOLVED-W																							100	100			100	73	17	100	
AZ15050202-008	SAN PEDRO RIVER	COPPER-DISSOLVED-W	26	100	100	100	100	75	100	100	100	76	100															100	100	70	15	76	100
AZ15050202-008	SAN PEDRO RIVER	*E. COLI*-TOTAL-W					76	66	100	100	100	73	100	100	100	100	31	100	72	100				14			100	100	23	44	70	100	
AZ15050301-561B	ALUM GULCH	CADMIUM-DISSOLVED-W												2				2		3		3	3										
AZ15050301-561B	ALUM GULCH	COPPER-DISSOLVED-W												1				22		2		1	1										
AZ15050301-561B	ALUM GULCH	ZINC-DISSOLVED-W												0				0		1		1	1	1									
AZ15060103-018B	ALUM GULCH	COPPER-DISSOLVED-W												13	23		11	15	15		14	2						3	11	0	33	2	15
AZ15060103-018C	PINTO CREEK	COPPER-DISSOLVED-W	100	100	100	100	100		100					100	28		88	74	68		100	100											
AZ15060103-887	GIBSON MINE TRIBUTARY	COPPER-DISSOLVED-W												0	0		0	0			0						1	2	0	0		0	0
AZ15060202-016	OAK CREEK	*E. COLI*-TOTAL-W														100	100	100		100	61												
AZ15060202-017	OAK CREEK	*E. COLI*-TOTAL-W												86	92	78	88	81	91	77	68		100	63	63					100	100	100	
AZ15060202-018A	OAK CREEK	*E. COLI*-TOTAL-W														63	97	92			100	100	100	100						100	64		
AZ15060202-018B	OAK CREEK	*E. COLI*-TOTAL-W											92	90	90	82	87	86			74	100											
AZ15060202-018C	OAK CREEK	*E. COLI*-TOTAL-W					100	100	100	100	100	100	100	95	97	94	85	87	95	87	74	100	100	100	100	100		60	100	100	100	100	
AZ15060202-019	OAK CREEK	*E. COLI*-TOTAL-W									100					88	94	100		100	92	100									54	100	
AZ15060202-022	SPRING CREEK	*E. COLI*-TOTAL-W												92	77	89	97	100		63	100	100						100	100		100	100	
AZ15060202-025	VERDE RIVER	*E. COLI*-TOTAL-W									100	100	82	100	100	100	100	100	100	100	100			74	74	100	100	100	100	100	100	100	
AZ15070102-034B	BIG BUG CREEK	ARSENIC-TOTAL-W																									100		100	100	100	18	100
AZ15070102-034B	BIG BUG CREEK	LEAD-TOTAL-W																						62			100		100	100	100	19	61
AZ15070102-036B	TURKEY CREEK	COPPER-DISSOLVED-W												100	100	100	31				100	100	100	100				100	100	100	74	29	100
AZ15070102-036B	TURKEY CREEK	LEAD-TOTAL-W												100	100	15	28	100			82	85	100	100		18		15	11	76	25	11	100
AZ15070103-007A	HASSAYAMPA RIVER	CADMIUM-DISSOLVED-W												23	24	24					7	7	3				100	54	1	3	10		6
AZ15070103-007A	HASSAYAMPA RIVER	COPPER-DISSOLVED-W												17	20	100					60	100	14				100	100	18	29	100		2
AZ15070103-007A	HASSAYAMPA RIVER	PH-TOTAL-W												37	79	100			100		100	100	100				100	100	100	100	100		100
AZ15070103-007A	HASSAYAMPA RIVER	ZINC-DISSOLVED-W												26	22	36					58	100	21				100	100	3	42	100		36
AZ15080301-337	BREWERY GULCH	COPPER-DISSOLVED-W												8			21	11	26		48												