ADEQ Arizona Department of Environmental Quality

WATER QUALITY DIVISION

White Paper: Analysis of depth to groundwater for estimating flow regimes in Arizona

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Background

The State of Arizona has over 100,000 known miles of surface water at medium resolution hydrography (USGS, n.d.). These surface waters are divided into segments, known individually as a reach. According to the U.S. Geological Survey (USGS), a reach is a section of a stream or river along which similar hydrologic conditions exist. These hydrologic conditions are described as flow regimes in the Arizona Revised Statutes § 49-201 as follows:

- Perennial means a surface water or portion of surface water that flows continuously throughout the year.
- Intermittent means a surface water or portion of surface water that flows continuously during certain times of the year and more than in direct response to precipitation, such as when it receives water from a spring, elevated groundwater table or another surface source, such as melting snowpack.
- Ephemeral means a surface water or portion of surface water that flows or pools only in direct response to precipitation.

ADEQ assigns each surface water reach, lake, pond or other type of surface water an identification number known as a Waterbody Identification Number or WBID. Through analysis of available and credible data, the Arizona Department of Environmental Quality (ADEQ) assigns each WBID one of the flow regimes. A WBID with insufficient data to determine flow regime is assigned an “Undetermined” flow regime. If there is no flow regime data for the WBID, it is assigned as “Null’. As of October 2021, approximately 23 percent of WBIDs in Arizona are assigned a perennial, intermittent or ephemeral flow regime.

With about 77 percent of Arizona WBIDs with an “Undetermined” or “Null” flow regime, ADEQ recognized that additional analysis of available and credible data could be critical to assigning additional flow regimes and verifying the others[1]. After a thorough review of peer-reviewed research and an analysis of readily available data specific to Arizona, ADEQ established a

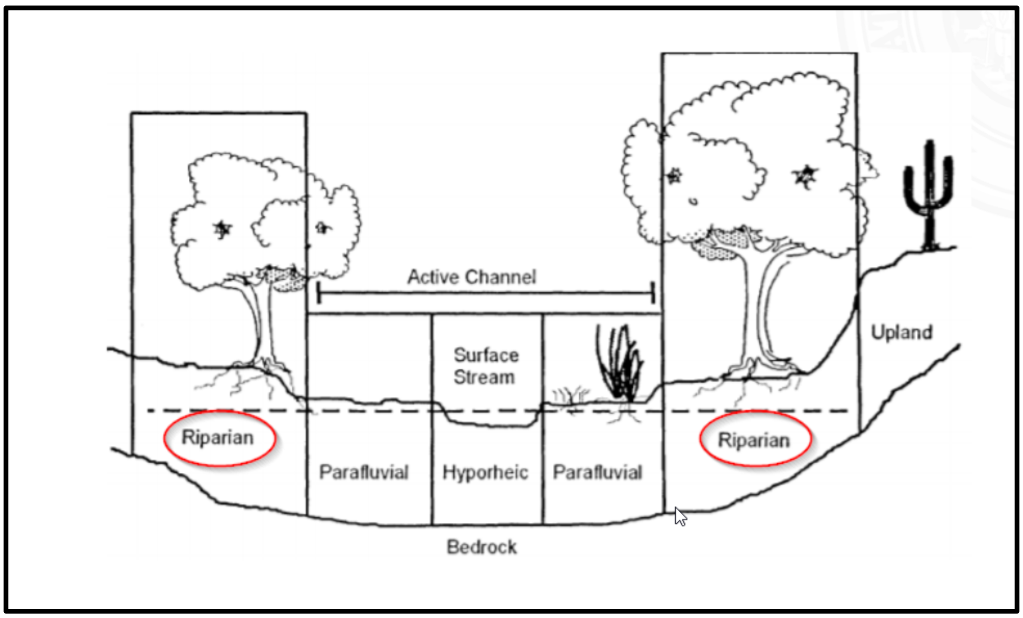
[1] Flow regimes are not static and can change based on, but not limited to, analysis of additional credible data, shifts in climate, and changes in water use, such as diversion or new discharges to a WBID. The WBIDs in this white paper were assigned the referenced flow regime as of March 2021.

methodology for estimating intermittent or ephemeral flow regimes through a review of groundwater well depth. This methodology is applied in the Groundwater Tool.

Research and Analysis

In arid lands, riparian vegetation can be found where surface water or shallow groundwater provide a reliable water source for growth and propagation. Within the active channel, vegetation generally stands much taller and denser than the plant life seen in the surrounding landscape, creating a visible corridor of thriving plant life in another wise sparse desert landscape (Figure 1).

Figure 1. Riparian area cross-section view (Holmes et al. 1994)



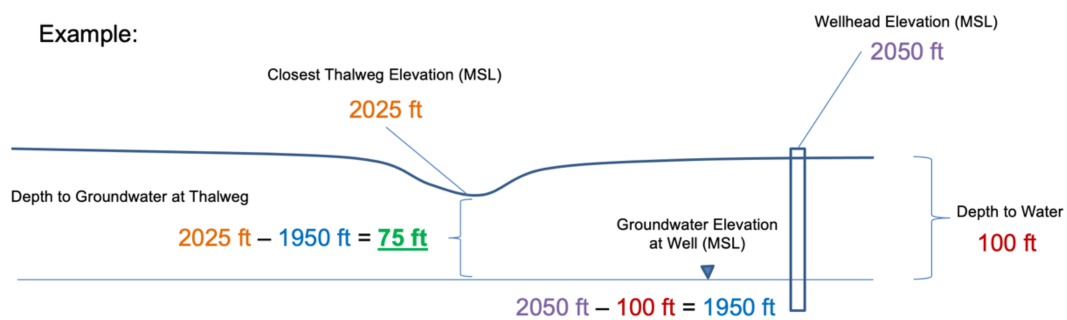
Typical riparian trees in Arizona consist of cottonwoods and willows at low elevations; and alder, willow, ash, box elder and other species at mid to upper elevations. Some desert streams also have distinct xeroriparian corridors, which consist of the same vegetation as the upland but with much denser growth. Generally, xeroriparian corridors consist of mesquite, Palo Verde and other desert tree species.

Research shows the presence of riparian or xeroriparian vegetation corridors in arid environments is indicative of shallow groundwater and signals an increased potential for above ground seasonal or intermittent flow in a surface water (Nadeau & Megdal, 2012; Stromberg & Merritt, 2016; Manning et al., 2020; Mazor et al., 2021). Specifically, Stromberg and Merritt (2016) found that riparian species have a maximum rooting depth to groundwater of approximately 10 meters (33 feet) in known Arizona intermittent desert streams.

To estimate probable intermittent or ephemeral flow regime based on riparian vegetation rooting depths identified in published research, ADEQ developed a methodology to determine the groundwater depth associated with a WBID by using the thalweg, which is the lowest elevation in the channel of a waterway. Data from the Arizona Department of Water Resources (ADWR) Groundwater Site Inventory (GWSI) and Wells55 database were imported into a Geographic Information System (GIS) (ADWR, n.d.). A GIS algorithm was then created to (1) identify groundwater elevation above mean sea level from a selected well; (2) determine the thalweg elevation above mean sea level; and (3) subtract groundwater elevation from thalweg elevation to approximate the depth to groundwater. An example of this process can be seen in Figure 2.

Figure 2. Depth to groundwater algorithm.

- Groundwater Elevation at well (MSL) = Wellhead elevation (MSL) – Depth to Water
- Depth to Groundwater at Thalweg = Thalweg Elevation (MSL) – Groundwater Elevation at Well (MSL)
- Use Thalweg Elevation (MSL) for the thalweg point closest to selected well (determined by GIS)



In the development of the methodology, ADEQ recognized there are uncertainties and limitations in the assumptions used to estimate flow regime. The issues were considered and countermeasures were identified to increase quality of the results; these are listed in Table 1.

Table 1. Groundwater Tool assumptions and countermeasures.

Assumption	Reality	Countermeasure
Groundwater gradient between the well(s) and thalweg is flat.	There is generally a gradient from the well to the thalweg that will magnify error the farther away from the WBID.	Well selection is constrained to a half-mile buffer on either side of the WBID. Only the closest wells are chosen for depth-to-groundwater calculation. If no wells are available within the half-mile buffer, this tool is not applied.

One data point or well location is an accurate representation of the depth to groundwater.	The length of WBIDs vary, and one data point may not be representative of conditions on the entire length.	Ideally, 3 wells are selected near the top, middle, and bottom of the WBID. The mean groundwater depth is then calculated to estimate potential flow regime.
Well locations were assumed to be accurate.	The Wells55 database is recognized as having poor locational accuracy due to the original cadastral requirements for well registration. The GWSI database is an improvement on Wells55, but is not comprehensive of the original well registry.	GWSI data are prioritized over Wells55 data.
Well measurements were assumed to be representative of present-day conditions.	Water levels associated with Wells55 or GWSI reflect a point in time, typically when the well was first drilled. Current regional water levels may not be reflected in the data.	Data utilized is limited to the last 20 years.
Well measurement point elevations and thalweg elevations are coincident with ground elevation.	Wells55 data do not typically include a measurement point elevation relative to mean sea level. Furthermore, measurement points in both databases can be above ground level to accommodate pumps. Similarly, WBID line features are not specifically tied to elevation.	Thalweg and Wells 55 elevations were extrapolated from USGS 10-meter National Elevation Datasets to address data gaps.
The system acts as a sandbox with water levels representative of the same formation immediately underlying a stream.	Basin and Range hydrogeology is complex, not uniform. Therefore, conditions between the wells and WBID may not be representative of the geologic formation hosting riparian vegetation species. Changes in land use can also contribute to severe stream incision that can bias depth to water calculations.	Exclude negative values in average depth to groundwater, which can indicate artesian conditions encouraging riparian growth or other geomorphic heterogeneities, such as channel entrenchment.
Thalweg elevations are not significantly different from the present-day thalweg.	Some locations in Arizona are severely entrenched resulting in significant differences between depth to water under the thalweg and depth to water under the floodplain hosting vegetation.	Recognize associated uncertainties which may need addressed at a later date when weight of evidence is considered and/or further analysis is warranted.

ADEQ also developed a confidence factor rating to further refine application of results. A confidence factor rating of High, Moderate or Low was assigned based on a combination of well data type and spatial coverage for the WBID. A High confidence factor is assigned when data from three GWSI wells were used and the spatial coverage of the entire WBID was good (i.e. wells located near the top, middle and bottom of the WBID). A Moderate confidence factor is assigned when a combination of GWSI and Wells55 data were used or if spatial coverage of the WBID was less than 50 percent. A Low confidence factor is assigned when only Wells55 data were used and/or if only one well was located near the WBID. Results with a High or Moderate confidence factor were then utilized to estimate flow regime, while those with a Low confidence factor were not due to uncertainties.

To test the thresholds in the literature against the methodology, ADEQ conducted a sensitivity analysis on a range of rooting depths for riparian vegetation species as identified by Nadeau and Megdal (2012) along the San Pedro River in southeast Arizona. ADEQ tested the performance of these thresholds from 16 to 40 feet (5 to 12 meters) on WBIDs with confirmed ephemeral or intermittent flow regimes (Figure 3). A list of the WBIDs can be found in Appendix A and Appendix B. The sensitivity analysis indicates that the 16 to 28-foot groundwater depth did not predict the known intermittent streamflow conditions as accurately as the 29-foot threshold. For thresholds greater than 29 feet, the sensitivity result was the same for known intermittent streams up to the 40-foot threshold.

Figure 3. Sensitivity Analysis of the Groundwater Tool for WBIDs with known intermittent (top list) or ephemeral (bottom list) flow regimes; 1 = intermittent and 0 = ephemeral. The results of the methodology for each WBID can be found in Appendix A and Appendix B.

(ft)	Modeled Threshold @ Given Depth to Water (ft)																								
16	17	18	19	20	21	22	23	24	25	26	27	28	*29*	30	31	32	33	34	35	36	37	38	39	40	
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Green is good!
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	
0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	Yellow is good!
0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Further validation was conducted using a confusion matrix approach, whereby the flow regime estimates at the 16-foot and 29-foot thresholds were compared. At the 16-foot threshold, the methodology correctly identified known intermittent WBIDs 38 percent of the time and known ephemeral WBIDs 94 percent of the time, with an average accuracy of 67 percent (Table 1). While at the 16-foot threshold the Groundwater Tool functioned well at correctly predicting ephemeral flow regimes, it poorly predicted WBIDs with an intermittent flow regime.

Table 1. Confusion matrix of correct identifications of known intermittent and ephemeral flow regimes using the 16-foot threshold.

	Known Intermittent	Known Ephemeral
Estimated Intermittent	6	1
Estimated Ephemeral	10	16
Percent Accuracy	38%	94%
Overall Accuracy	67%	

At the 29-foot threshold, the methodology correctly identified known intermittent WBIDs 81 percent of the time and known ephemeral WBIDs 82 percent time, with an average accuracy of 82 percent (Table 2).

Table 2. Confusion matrix of correct identifications of known intermittent and ephemeral flow regimes using the 29-foot threshold with the Groundwater Tool.

	Known Intermittent	Known Ephemeral
Estimated Intermittent	13	3
Estimated Ephemeral	3	14
Percent Accuracy	81%	82%
Overall Accuracy	82%	

The results of the confusion matrix indicate higher accuracy of actual intermittency using the 29-foot threshold as compared to the 16-foot threshold. These results support the depth to groundwater literature value of 10 meters or 33 feet indicated by Stromberg and Merritt (2016). ADEQ therefore selected the 33-foot threshold as the value for differentiating a probable intermittent from ephemeral flow regime of a WBID.

Application of the Tool

ADEQ applies the Groundwater Tool to WBIDs with an unknown flow regime. If the calculated groundwater depth using the methodology is 33 feet or less, then the flow regime is estimated to be potentially intermittent; if calculated depth is greater than 33 feet, the flow regime is estimated to be potentially ephemeral.

Definitive flow regimes are not assigned using the tool, at this time. The Groundwater Tool is only an indicator of flow regime for a WBID. To assign a flow regime, ADEQ requires additional empirical data, including, but not limited to, flow gauge data, information from field visits, analysis of imagery (i.e. game cameras, satellite imagery, etc.), or results of a streamflow duration assessment methodology (SDAM) survey. Results of the tool can assist ADEQ with prioritization of additional data gathering efforts.

Conclusion

Knowledge of flow regimes is critical for federal and state jurisdictional evaluations of Arizona surface waters. With no flow regime assigned to about 77 percent of Arizona WBIDs, ADEQ needs tools to assist with these evaluations for purposes of assessing and permitting surface waters. Research and data indicate the methodology applied using the Groundwater Tool is effective for estimating flow regime of Arizona WBIDs. The Groundwater Tool is one of multiple tools ADEQ utilizes for this purpose.

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Appendix A. Stream reaches with a confirmed intermittent flow regime from Jones (2018).

WBID	Site Name	Depth to Groundwater
AZ15060105-023	Green Valley Creek (upstream location)	0.9
AZ15060105-023	Green Valley Creek (downstream location)	0.9
AZ15050203-003	San Pedro River	3.52
AZ15060201-019	Apache Creek	4.96
AZ15070102-022	Agua Fria	7.87
AZ15060203-003	Verde River	11.9
AZ15050202-003	San Pedro River	16.57
AZ15020002-014	Little Colorado River	19.7
AZ15060106B-001C	Salt River	21.79
AZ15050301-008B	Santa Cruz River	21.97
AZ15060105-455B	Barnhardt Canyon	23.41
AZ15060202-009	Rarick Canyon	27.39
AZ15070102-034B	Big Bug-Below Providence Mine	28.35
AZ15060106B-026A	Cave Creek-Spur Cross	51.04
AZ15050202-004	Babocomari River	82.7
AZ15020008-004	Jacks Canyon	110.4

Appendix B. WBIDs with an assigned flow regime of ephemeral as of March 2021.

WBID	Site Name	Depth to Groundwater
AZ15050100-002I-I	Gila River	9.4
AZ15070201-008	Gila River	16.8
AZ15070201-006	Gila River	20.8
AZ15050202-001	San Pedro River	35.7
AZ15070102-001B	Agua Fria River	42.2
AZ15050302-003	Rillito Creek	44.2
AZ15060202-483	Carroll Canyon Wash	45.2
AZ15070102-001A	Agua Fria River	84.6
AZ15050301-003A	Santa Cruz River	109.9
AZ15070102-234	Unnamed Trib to Big Bug Cr	180.5
AZ15070102-234	Unnamed Trib to Big Bug Creek	180.5
AZ15060106B-179	Indian Bend Wash	221.2
AZ15050100-003I-I	Gila River	238
AZ15070102-007B	Agua Fria River	273.5
AZ15070102-007A	Agua Fria River	326.3
AZ15060203-989A	Ashbrook Wash	348.5
AZ15070103-363	Star Wash	367.5