CHAPTERS

CHAPTER 1:
INTRODUCTION

CHAPTER 1: INTRODUCTION

The Arizona Department of Water Resources ("Department" or "ADWR") prepared this technical report at the request of the Adjudication Court for the Gila River General Stream Adjudication ("Gila River Adjudication"), which includes several watersheds.[1] This report, entitled "Revised Subflow Zone Delineation Report for the San Pedro River Watershed" ("2014 Subflow Report"), presents information and a series of maps that delineate certain hydrogeologic features, known as subflow zones, for the San Pedro River, the Babocomari River, and Aravaipa Creek within the San Pedro River watershed, which is located within the Gila River Adjudication. See **Figure 1-1**.

Pursuant to A.R.S. §§ 45-251 to 264, the Adjudication Court must determine the nature, extent and relative priority of the rights of persons to use waters of the Gila River system and source, which includes appropriable water under state law and water subject to claims based on federal law. Appropriable water under state law includes surface water and certain subsurface water referred to as subflow, but does not include percolating groundwater. The right to use appropriable water depends on the priority of the appropriation. This 2014 Report is the fifth report prepared by the Department since 2002 related to the identification of subflow zones in the San Pedro River watershed.

This chapter includes a description of several court orders and decisions and previously issued ADWR reports to provide a historical context and understanding of the issues that have been addressed in the past and that continue to require analysis. Copies of court orders and decisions are provided in **Appendix A**. Copies of ADWR reports can be found at ADWR's web site.[2]

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[1] *In re the General Adjudication of All Rights to Use Water in the Gila River System and Source,* W-1, W-2, W-3, W-4 (Consolidated), Contested Case No. 103 (Maricopa County Superior Court).

[2] http://www.azwater.gov/AzDWR/SurfaceWater/Adjudications/default.htm

1.1 HISTORY OF PROCEEDINGS

The distinction between appropriable subflow and percolating groundwater has been an issue before the courts for decades. In the *Southwest Cotton* case, decided by the Arizona Supreme Court in 1931, the Arizona Supreme Court was faced with this issue.[3] In 1988, over 50 years after the *Southwest Cotton* decision, whether a well was pumping appropriable subflow became an issue in the Gila River Adjudication. The Adjudication Court developed a test to make that determination, which test was rejected five years later in 1993 by the Arizona Supreme Court in the *Gila River II* case.[4] Upon remand from the Arizona Supreme Court, the Adjudication Court applied the principles and criteria described in *Gila River II* and developed another subflow test in 1994 which turned on a well's location vis-à-vis a hydrogeologic area described as the subflow zone. Six years later in 2000, the Arizona Supreme Court in the *Gila River IV* case upheld the Adjudication Court's 1994 order.[5] These decisions and Adjudication Court orders are described more fully below.

1.1.1 *Southwest Cotton*

In the *Southwest Cotton* case, after noting that certain subterranean water is subject to appropriation under the same rule as surface streams, the Arizona Supreme Court defined appropriable "subflow" as follows:

> The underflow, <u>subflow</u> or undercurrent, as it is variously called, of a surface stream may be defined as those waters which slowly find their way through the sand and gravel constituting the bed of the stream, or the lands under or immediately adjacent to the stream, and are themselves a part of the surface stream. It is subject to the same rules of appropriation as the surface stream itself.

39 Ariz. at 82, 96, 4 P.2d at 376, 380 (emphasis added). To determine whether subsurface waters constitute subflow, the *Southwest Cotton* Court set forth the following test:

> Does drawing off the subsurface water tend to diminish appreciably and directly the flow of the surface stream? If it does, it is subflow, and subject to the same

[3] *Maricopa County Municipal Water Conservation Dist. No. 1 v. Southwest Cotton Co.,* 39 Ariz. 65, 96-97, 4 P.2d 369, 380-81 (1931), *modified and reh'g denied*, 39 Ariz. 367, 7 P.2d 254 (1932).
[4] *In re the General Adjudication of All Rights to Use Water in the Gila River System and Source,* 175 Ariz. 382, 391, 393, 857 P.2d 1236, 1245, 1247 (1993) (*Gila River II*).
[5] *In re the General Adjudication of All Rights to Use Water in the Gila River System and Source,* 198 Ariz. 330, 335-36, 9 P.3d 1069, 1074-75 (2000) (*Gila River IV*).

> rules of appropriation as the surface stream itself; if it does not, then, although it may originally come from the waters of such stream, it is not, strictly speaking, a part thereof, but is subject to the rules applying to percolating waters.

Id. at 96-97, 4 P.2d at 380-381.

1.1.2 *Gila River II*

In 1988, the Adjudication Court held that certain wells should be presumed to be pumping appropriable subflow if the volume of stream depletion was 50% or more as the result of 90 days of continuous pumping (50%/90-day test).[6] In 1993, the Arizona Supreme Court in *Gila River II* rejected the Adjudication Court's 50%/90-day test and remanded the matter to the Adjudication Court. The Court reaffirmed the rationale of *Southwest Cotton* that distinguished between subflow (which is subject to appropriation) and tributary groundwater (which is not).[7] The Court held:

> Whether a well is pumping subflow does not turn on whether it depletes a stream by some particular amount in a given period of time. As we stated above, it turns on whether the well is pumping water that is more closely associated with the stream than with the surrounding alluvium.

Gila River II, 175 Ariz. at 392-393, 857 P.2d at 1246-1247. The *Gila River II* Court described certain principles, such as elevation, gradient, chemical makeup, direction of flow, and differences in geology and hydrology that could be used by the Adjudication Court to develop criteria to separate appropriable subflow from percolating groundwater.[8]

1.1.3 1994 Subflow Order

On remand, the Adjudication Court applied the principles described in *Gila River II* and issued a detailed order dated June 30, 1994 ("1994 Subflow Order"), consisting of 66 pages of discussion and 36 additional pages of exhibits resulting from a ten-day evidentiary hearing during which the Adjudication Court heard testimony from ten experts in geology and

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[6] The Adjudication Court directed ADWR to use the 50%/90-day test in the final hydrographic survey report ("HSR") for the San Pedro River watershed in 1991 that relied upon the 50%/90-day test. An HSR is a comprehensive report required by A.R.S. § 45-256.

[7] 175 Ariz. at 390-392, 857 P.2d at 1244-1246.

[8] *Id.* at 392, 394, 857 P.2d at 1246, 1248.

hydrology.[9] The Adjudication Court also spent an additional two days traveling almost 600 miles and visiting 13 sites in the San Pedro River watershed, accompanied by counsel and experts, followed by a supplemental two-day hearing four months later.[10] The Adjudication Court held, *inter alia*, that certain wells located within the "subflow zone" of streams within the San Pedro River watershed were presumed to be pumping appropriable subflow, and as a result, were subject to the Gila River Adjudication. The Adjudication Court also held that the pumping of wells whose cones of depression reached the subflow zone and by continual pumping would cause loss of subflow affecting the quantity of the stream would be included in the Gila River Adjudication.[11] The Adjudication Court summarized its findings as follows:

1. A "subflow" zone is adjacent and beneath a perennial or intermittent stream and not an ephemeral stream.

2. There must be a hydraulic connection to the stream from the saturated "subflow" zone.

3. Even though there may be a hydraulic connection between the stream and its floodplain alluvium to an adjacent tributary aquifer or basin-fill aquifer, neither of the latter two or any part of them may be part of the "subflow" zone.

4. That part of the floodplain alluvium which qualifies as a "subflow," beneath and adjacent to the stream, must be that part of the geologic unit where the flow direction, the water level elevations, and gradations of the water level elevations and the chemical composition of the water in that particular reach of the stream are substantially the same as the water level, elevation and gradient of the stream.

5. That part of the floodplain alluvium which qualifies as a "subflow" zone must also be where the pressure of side recharge from adjacent tributary aquifers or basin fill is so reduced that it has no significant effect on the flow direction of the floodplain alluvium (i.e., a 200-foot setback from connecting tributary aquifers and a 100-foot setback from the basin-fill deposits).

6. Riparian vegetation may be useful in marking the lateral limits of the "subflow" zone particularly where there are observable seasonal and/or diurnal variations in stream flow caused by transpiration. However, riparian

[9] 1994 Subflow Order at page 3.
[10] *Id.* at 5-6.
[11] A "cone of depression" is a funnel-shaped area around a well where the water table has been lowered by the withdrawal of water through the well. *Id.* at 59.

vegetation on alluvium of a tributary aquifer or basin fill cannot extend the limits of the "subflow" zone outside of the lateral limits of the saturated floodplain Holocene alluvium.

7. All wells located in the lateral limits of the "subflow" zone are subject to the jurisdiction of this adjudication no matter how deep or where these perforations are located. However, if the well owners prove that perforations are below an impervious formation which precludes "drawdown" from the floodplain alluvium, then that well will be treated as outside the "subflow" zone.

8. No well located outside the lateral limits of the "subflow" zone will be included in the jurisdiction of the adjudication unless the "cone of depression" caused by its pumping has now extended to the point where it reaches an adjacent "subflow" zone, and by continual pumping will cause a loss of such "subflow" as to affect the quantity of the stream.

1994 Subflow Order at pages 64-66. The Adjudication Court concluded that the "weight of the evidence points to the saturated floodplain Holocene alluvium as the most credible 'subflow' zone. Its lateral and vertical limits have existed for some 10,000 or more years. It has far more stability of location than any other proposal …."[12]

Even so, the Adjudication Court noted that that there is a frequent lack of data and many assumptions which cannot be fully proven. The Adjudication Court stated:

> However, there are questions in the mind of this Court after hearing long periods of evidence over the last fourteen years. They are whether the quality of geologic or hydrologic opinion, the frequent lack of data, and the many assumptions which cannot be fully proven support a requirement that the property owner or objectors should have to overcome a clear and convincing level of burden of proof.

Id. at 63. The Adjudication Court concluded that a preponderance of the evidence burden of proof standard would be fairer.[13]

1.1.4 *Gila River IV*

In *Gila River IV* (decided September 22, 2000), the Arizona Supreme Court affirmed the Adjudication Court's 1994 Subflow Order including the findings set forth above.[14] The Court held:

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[12] *Id*. at 58.
[13] *Id*. at 64.
[14] 198 Ariz. at 340, 344, 9 P.3d at 1079, 1083.

> The criteria that the Adjudication Court articulated were elaborations of, but consistent with, the more general criteria set forth in *Gila River II*. The Adjudication Court properly applied those criteria to the San Pedro River basin in order to determine the most appropriate subflow zone, and the weight of the evidence supports the Adjudication Court's identification of that zone as the "saturated" floodplain Holocene alluvium.

Gila River IV, 198 Ariz. at 341-42, 9 P.3d at 1080-81. The Court cited *Gila River II* with approval and again reaffirmed the principles set forth in *Southwest Cotton*. However, because defining "subflow in any particular area is a relative endeavor," the Court cautioned that those cases should not serve as "straitjackets" that prevent conformance to hydrologic reality. The Court stated:

> As the groundwater users correctly observe, this court "adopted [Kinney's] narrow definition [of subflow] in *Southwest Cotton*," *Gila River II*, 175 Ariz. at 390, 857 P.2d at 1244, and again characterized subflow as "a narrow concept" in *Gila River II*. *Id*. at 391, 857 P.2d at 1245. Although those abstract, general statements hold true, we also observed in *Gila River II* that variations may affect where the line is drawn between subflow and nonappropriable percolating water, "depending on the volume of stream flow and other variables." *Id*. Thus, defining subflow in any particular area is a relative endeavor, "not an all-or-nothing proposition." *Id*. And, although "the line between surface and groundwater … is, to some extent, artificial and fluid," *id*. at 392, 857 P.2d at 1246, our various descriptions of subflow in *Gila River II* and *Southwest Cotton* should not serve as a straitjacket that restricts us from reaching in the direction of the facts and, so far as possible under those decisions, conforming to hydrological reality.

Gila River IV, 198 Ariz. at 340, 9 P.3d at 1079 (emphasis added, brackets and ellipses in original).

In its conclusion, the Arizona Supreme Court affirmed the Adjudication Court's 1994 Subflow Order "in all respects" and directed ADWR to determine the specific parameters of the subflow zone. The Court also indicated that additional analyses by ADWR would be required to determine a well's cone of depression and exclude wells that have a *de minimis* effect on the river system. The Court stated:

> We affirm the Adjudication Court's order after remand in all respects. The subflow zone is defined as the saturated floodplain Holocene alluvium. DWR, in turn, will determine the specific parameters of that zone in a particular area by evaluating all of the applicable and measurable criteria set forth in the Adjudication Court's order and any other relevant factors. See ¶¶ 33-35, *supra*. All wells located in the lateral limits of the subflow zone are subject to this

> adjudication. In addition, all wells located outside the subflow zone that are pumping water from a stream or its subflow, as determined by DWR's analysis of the well's cone of depression, are included in this adjudication. Finally, wells that, though pumping subflow, have a de minimus [*sic*] effect on the river system may be excluded from the adjudication based on rational guidelines for such an exclusion as proposed by DWR and adopted by the Adjudication Court.

Id. at 344, 9 P.3d at 1083 (emphasis added.)

After the decision in *Gila River IV*, the Adjudication Court initiated proceedings to determine the extent of the subflow zone based on the Adjudication Court's 1994 Subflow Order, which was affirmed by the Arizona Supreme Court in 2000 in *Gila River IV*. Over 10 years later, these proceedings have not yet concluded.

1.2 ADWR'S PRIOR REPORTS

As requested by the Adjudication Court, ADWR issued four reports between 2002 and 2012 that proposed methodologies for mapping the saturated floodplain Holocene alluvium in the San Pedro River watershed. Objections and comments on these reports were filed and hearings were held before the Special Master and the Adjudication Court, which resulted in further direction to ADWR from the Adjudication Court. These proceedings are described below for each of the prior reports issued by ADWR.

1.2.1 2002 Subflow Report

Pursuant to Minute Entry of the Adjudication Court dated January 9, 2002, ADWR filed a report entitled "Subflow Technical Report, San Pedro River Watershed" on March 29, 2002 ("2002 Subflow Report"). This report identified and described the procedures that ADWR proposed to use to establish the limits of the subflow zone within the San Pedro River watershed. ADWR also proposed a cone of depression test for wells located outside of the subflow zone, and guidelines for excluding wells whose pumping has a *de minimis* effect. On June 17, 2002, comments, objections, and joinders were filed by several parties, and sworn declarations were filed by expert witnesses.

The Adjudication Court referred the matter to the Special Master who conducted a two-day hearing, received written testimony both before and after the hearing, and heard oral argument. On July 16, 2004, the Special Master issued a report to the Adjudication Court including 39 recommendations that adopted most of the procedures described in ADWR's 2002 Subflow Report with certain modifications. Objections followed and the matter was briefed and argued to the Adjudication Court.

The Adjudication Court issued a detailed order dated September 28, 2005, that accepted the Special Master's recommendations in large part with certain exceptions.[15] The Adjudication Court held, *inter alia*, that the entire saturated floodplain Holocene alluvium comprised the subflow zone, but if ADWR determined, with respect to any specific area, that it could not delineate a reasonably accurate and reliable subflow zone, then it could use criteria specified in *Gila River IV*, and any other criteria that would be geologically and hydrologically appropriate. The Adjudication Court further held that the entire floodplain Holocene alluvium would be assumed to be saturated for jurisdictional purposes.[16] The Adjudication Court directed ADWR to prepare a map delineating the subflow zone, and submit the map and related information in a technical report.

1.2.2 2009 Subflow Report

As requested by the Adjudication Court, ADWR issued a report in 2009 entitled "Subflow Zone Delineation Report for the San Pedro River Watershed" ("2009 Subflow Report") in which ADWR set forth detailed hydrologic, geologic, and hydrogeologic criteria for delineating subflow zones within the San Pedro River watershed. Using these criteria, ADWR presented a series of hydrogeologic maps that delineated the subflow zones for the San Pedro River, the Babocomari River and Aravaipa Creek, together with related information. These maps were based on floodplain Holocene alluvium ("FHA") boundaries delineated at surficial geologic contacts between Holocene river alluvium and bounding geologic units mapped and reported by the Arizona Geological Survey ("AZGS"), which was under contract with ADWR.[17]

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[15] Petitions for interlocutory review of the 2005 Order were denied by the Arizona Supreme Court in May 2007.

[16] The Adjudication Court also addressed issues concerning ADWR's development of a cone of depression test, and the *de minimis* exclusion. Those issues do not fall within the scope of this report.

[17] ADWR's contract with the AZGS did not include mountain front streams, which are in remote locations and have limited access.

However, ADWR noted that these maps did not include buried FHA that ADWR understood to exist. Also, the application of the setbacks described in the Adjudication Court's 1994 Subflow Order resulted in gaps in the subflow zone.

1.2.3 2011 Response to Comments

Written objections or comments to the 2009 Subflow Report were filed by 26 parties. On August 25, 2010, the Adjudication Court entered an order that directed ADWR to respond to substantive legal and technical issues. On January 31, 2011, ADWR filed a report entitled "Response to Comments and Objections filed on ADWR's June 2009 Subflow Zone Delineation Report for the San Pedro River Watershed" ("2011 Response to Comments").[18] In this report, ADWR suggested alternative approaches to identify buried FHA. The Adjudication Court conducted a three-day hearing from January 24, 2012, through January 26, 2012 during which expert testimony was presented by several parties, ADWR and AZGS. At the close of the hearing, the Adjudication Court directed ADWR to develop a work plan for supplementing the 2009 Subflow Report.

1.2.4 2012 Work Plan

On April 20, 2012, ADWR filed a work plan for supplementing its 2009 Subflow Report ("2012 Work Plan") in a report entitled "Subflow Zone Delineation Methodology for the San Pedro River Watershed." In this report, ADWR developed a methodology to evaluate potential indicators of the presence of buried FHA that previously had not been identified by the surficial mapping conducted by the AZGS, and reexamined the application of setbacks to account for tributary groundwater.

Several parties filed comments, objections and motions relating to ADWR's 2012 Work Plan, as well as proposed findings of fact and conclusions of law. By Minute Entry filed August 23, 2012, the Adjudication Court set a hearing for November 8, 2012. In advance of the scheduled hearing, the Adjudication Court sustained in part and overruled in part the parties'

[18] Table 1-1 of the 2011 Response to Comments listed all of the parties that filed comments and objections, and identifies nine parties that raised substantive technical comments and objections. Table 2-2 summarized the substantive comments that agreed with the report, and Table 2-3 summarized the substantive comments and objections that disagreed with the report. The non-substantive comments and objections were referred to the Special Master.

objections to ADWR's 2009 Subflow Report consistent with findings of fact and conclusions of law set forth in Minute Entry Order filed October 12, 2012 ("2012 Order"). The Adjudication Court did not rule on the 2012 Work Plan, but it did deny certain motions that had been filed as moot.

A short time after the October 2012 Order was filed, the presiding judge for the Gila River Adjudication resigned and the case was reassigned. By Minute Entry filed October 24, 2013, the new presiding judge vacated and reset the November 8, 2012 hearing to January 10, 2013. By Minute Entry filed January 15, 2013, the Adjudication Court directed ADWR to submit a revised subflow zone delineation report by April 1, 2014, consistent with the 2012 Order.[19]

1.3 2014 SUBFLOW REPORT

ADWR is filing the 2014 Subflow Report to comply with the Adjudication Court's 2012 Order. Many of these issues were previously addressed in ADWR's 2012 Work Plan concerning the identification of buried FHA and the application of setbacks. The 2014 Subflow Report revises the 2009 Subflow Report as well as the 2012 Work Plan, and is consistent with the findings of fact and conclusions of law set forth in the 2012 Order. It also complies with the Adjudication Court's directives concerning the delineation of the revised subflow zone, the areas to be included within the revised subflow zone, and the applications of setbacks, which are described below.

In its 2012 Order, the Adjudication Court indicated that the revised subflow zone delineation must have the following features:

> The revised subflow zone delineation must (a) result in a continuous subflow zone; (b) result in a stable geologic feature; (c) include the entire current active channel of each watercourse; (d) include the Historical Composite Active Floodplain (1935-2007) for each watercourse; (e) accurately reflect the full extent of the FHA; and (f) to the extent possible, interpret judicial pronouncements in a manner consistent with scientific fact.

2012 Order at 5, ¶ 2.

[19] The 2013 Minute Entry acknowledged that ADWR may not have sufficient information to include mountain front streams in its report in the time allotted. Minute Entry at 3.

The Adjudication Court also directed ADWR to "use its professional judgment" and consider "as and to the extent appropriate, a combination of the following:"

(a) Arizona Geological Survey mapping to identify the surface exposure of the boundary between either bedrock or Pleistocene and Tertiary basin fill and Holocene alluvium;[20]
(b) topographic slope breaks (which may be considered, when appropriate, the edge of the subflow zone);
(c) vegetation patterns; and
(d) aerial photographs to determine the boundary between basin fill or bedrock and Holocene alluvium where alluvial fans and channel deposits are deposited on the floodplain.

The Adjudication Court cautioned ADWR not to rely solely upon surface data. *Id.* at ¶ 3.

Regarding setbacks, the Adjudication Court directed ADWR to apply them "only in those instances where a hydraulic connection exists between the subflow zone and the surrounding material. ADWR need not apply setbacks in instances in which it reasonably finds that no such hydraulic connection exists." *Id*. at ¶ 4.

In order to comply with the 2012 Order, ADWR contracted with the AZGS for consultation on geologic settings and geomorphologic processes applicable to Holocene river alluvium and investigations of sedimentary relationships at numerous sites along the San Pedro River that ADWR used to delineate the lateral extent of FHA, as described in Chapter 2 of this report. ADWR also developed a methodology for applying setbacks that resulted in a continuous subflow zone, as described in Chapter 3 of this report.[21]

[20] "Pleistocene," "Tertiary," and "Holocene" are terms of art that refer to certain geologic epochs.
[21] Subflow zones were not delineated for mountain front streams within the San Pedro River watershed due to time and other resource limitations.

CHAPTER 2:
DELINEATION OF THE LATERAL EXTENT OF THE FLOODPLAIN HOLOCENE ALLUVIUM

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2.1 INTRODUCTION

Pursuant to the Adjudication Court's 2012 Order, this report revises the conclusions presented in ADWR's 2009 Subflow Report regarding the delineation of the subflow zone within the San Pedro River watershed. In this chapter, ADWR describes the delineation of the lateral extent of the FHA for the San Pedro River, Babocomari River and Aravaipa Creek. In Chapter Three of this report, ADWR describes the application of certain setbacks to the delineation of FHA as directed by the Adjudication Court in order to delineate the subflow zone.

In the 2012 Order, the Adjudication Court found that ADWR's proposed delineation of the subflow zone in its 2009 Report was too narrow because it excluded portions of FHA that were overlain by alluvial fans and other deposits of tributary Holocene alluvium ("THA"). Although the Adjudication Court indicated that AZGS had appropriately mapped the surficial geology along the San Pedro River, the Adjudication Court found that this mapping was not dispositive, and it directed ADWR to use its technical expertise to delineate the subflow zone based on other available tools.[1] The Adjudication Court stated:

> ADWR's 2009 subflow zone delineation proposal for the San Pedro River is too narrow, as would be any mapping that relies too heavily on surface mapping. ADWR must have at its discretion use of a number of several tools in delineating the lateral extent of the FHA at a given location. Not every tool can or necessarily should be used at each location. ADWR must use its technical expertise to utilize all of the resources available to it in delineating the subflow zone.

2012 Order at 3, ¶ 18.

The Adjudication Court identified the existence of riparian vegetation, lithology data (soil borings), water level data, and aerial photography as potentially useful tools.[2] The Adjudication

[1] 2012 Order at 2-4, ¶¶ 6-12, 15, 20.
[2] *Id*. at 3, ¶¶ 13-14, 17; *Id*. at 5, ¶ 3.

Court also emphasized that ADWR should use its professional judgment when determining what areas to include within the subflow zone.[3]

As described in this chapter, delineation of the lateral extent of FHA is based on geological settings of the San Pedro River, Babocomari River and Aravaipa Creek; geomorphological processes of the streams and tributary drainages; and exposed bounding topography of the inner stream valleys. Where available and appropriate, ADWR also utilized riparian vegetation patterns, satellite imagery, soil lithology logs and water levels in shallow wells.

2.2 GEOLOGY AND GEOMORPHOLOGY OF THE SAN PEDRO RIVER VALLEY

In November 2013, ADWR executed an inter-agency agreement with the AZGS regarding the geology and geomorphology of the San Pedro River watershed, particularly the identification of Holocene river alluvium, and joint-investigations of sedimentary relationships at numerous sites along the San Pedro River and within tributary channels to the San Pedro River. In March 2014, AZGS produced two documents entitled, *Geology and Geomorphology of the San Pedro River* (“AZGS San Pedro Report”) and *Site Investigation of Tributary Drainages to the San Pedro River* (“AZGS Tributary Site Report”). Copies of these documents as well as the inter-agency agreement are provided in **Appendix B** to this report.

The Adjudication Court’s 2012 Order found that AZGS had appropriately mapped the surficial geology of the river alluvium and other deposits along the San Pedro River, Babocomari River, and Aravaipa Creek in March 2009. This mapping, together with an understanding of the physical setting and geomorphological processes at work in the San Pedro River valley, provide clues to the locations of buried FHA. The following sections summarize portions of the AZGS San Pedro Report describing the river’s geologic setting, geomorphic processes, and the pre-Holocene boundary topography.

[3] *Id*. at 5, ¶ 3.

2.2.1 Geologic Setting

The general trend of the San Pedro River Valley is governed by strong north to northwest structural and topographic alignments of adjacent mountain ranges formed during basin and range faulting about 8 to 25 million years ago. The uppermost reach of the river valley is flanked by the Huachuca and Mule Mountains; the next reach downstream is flanked by the Whetstone, Dragoon, Little Rincon, and Rincon Mountains; and the lower river valley by the Rincon, Santa Catalina, and Tortilla Mountains on the west and the Galiuro Mountains on the east. Bedrock bounds several miles of the river channel at the Tombstone Hills in the Fairbank-Charleston area; a location known as the Narrows, approximately 16 river miles north of Benson between the Rincon and Little Rincon Mountains; more than a mile of the river channel in the Redington area; and a short reach near Dudleyville above the Gila confluence.

Deposits of basin fill are called the St. David Formation in the upper basin (south of the Narrows) and the Quiburis Formation in the lower basin. St. David Formation deposits range from playa-like to river floodplain and channel deposits that were deposited from prior to 3.5 million years to less than 770,000 years ago. Quiburis Formation deposits are generally formed in playa environments and originated approximately 6 million years ago.

Basin fill deposits pre-date any incision of the San Pedro River, which occurred during the Pleistocene and Holocene (collectively Quaternary) epochs. The basin fill sediments transition from coarse gravel near the mountains to much finer-grained sand, silts, and clays in the valley center. Lake-like playa environments produce the finest-grained deposits. The coarser-grained deposits found at the valley margins are substantially more resistant to erosion than the finer-grained deposits at the valley center.

The topographically lowest part of the San Pedro Valley (the inner valley), which contains the modern river channel and all of the FHA of the San Pedro River, began to form in the late Pleistocene (pre-Holocene). As the river has incised, it has carved an erosional trough in older basin-fill deposits and bedrock, and has left behind remnants of older river deposits (river terraces) that record previous levels of the river. Old river terrace deposits perched high above the modern river record past levels of the river since river incision began in the early or middle Quaternary. The oldest of these Pleistocene terrace deposits (geologic map unit Qi1r) are found high above the modern river and thus predate most of the river incision. Progressively lower and younger Pleistocene river terrace deposits (geologic map units Qi2r, Qi3r) are more common and record past river levels during the long-term trend of down-cutting by the river.

Stratigraphic evidence from tributary drainages to the San Pedro River suggests that the ages of the youngest Pleistocene river deposits (Qi3r) are 15,000 to 50,000 years ago. After thousands of years of river aggradation, the San Pedro River incised into the Qi3r deposits resulting in the formation of the Qi3r terraces which are nearly always 10 feet or more higher than the adjacent Holocene river deposits. Evidence found in local tributaries suggests that this incision occurred in the youngest Pleistocene, approximately 13,000 to 15,000 years ago. During the youngest Pleistocene and the Holocene, the river has operated within a relatively narrow inner valley bounded by eroded basin deposits, older river terrace deposits, tributary deposits, and bedrock. In the subsurface, the inner valley presumably is cut into basin-fill deposits and bedrock. Evidence from tributary deposits indicates that there have been at least five (5) periods of incision during the Holocene, beginning approximately 7,500 years ago. The geologic map units for the Holocene river alluvium from youngest to oldest are denoted by Qycr, Qy4r, Qy3r, Qy2r and Qy1r.

2.2.2 Geomorphic Processes

The form of the inner valley of the San Pedro River has been shaped by various processes of geomorphology. Processes of primary importance are vertical incision, river aggradation[4], lateral erosion of the river and its tributaries, and erosion of adjacent hillslopes. Some of these processes are closely linked, such as river and tributary erosion. Other processes tend to operate in opposition to one another, such as river and tributary erosion versus river and tributary aggradation. Deposition of sediments in the inner valley involves interactions between tributary and river sediment supply, transportation of sediment, and changing river channel morphology and position in the inner valley. Tributaries of all sizes have deposited sediment, forming alluvial fans in the inner river valley, and there is abundant evidence in the historical aerial photo record for the past 80 years that interactions between these fans, river erosion and river aggradation are dynamic. **Figure 2-1** shows an example of an area of the San Pedro River eight miles north of Benson where the effects of several processes are apparent.

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[4] "Aggradation" is the term for the increase in land elevation due to the deposition of sediment.

Stratigraphic exposures along incised tributary channels in areas that formerly were active tributary alluvial fans provide abundant evidence for interaction between tributary and river deposition through the middle and late Holocene. Beds of tributary gravel deposits are commonly found between beds of finer-grained deposits, which are probably river floodplain deposits. For example, exposures along Palominas arroyo[5] reveal that the river channel occupied a position near the eastern margin of the inner valley, about 0.5 miles east of the modern river channel, in the middle Holocene. This area is shown as site No. 1 on **Figure 2-2**. At this location, almost the entire area between the edge of the inner valley and the river channel is covered by the young Palominas alluvial fan. The San Pedro River channel was at the eastern margin of the inner valley a few thousand years ago, and the Palominas fan has encroached substantially onto the floodplain since that time. The portion of the inner valley that is currently covered by Palominas fan deposits was occupied by the San Pedro River sometime in the past few thousand years. In these areas, tributary sand and gravel deposits that were deposited along the margin of the river floodplain prior to historical river and tributary incision cap exposures of Holocene river alluvium.[6]

Vertical incision lowers the base-level of the river which, in turn, results in vertical incision of the tributaries. This process increases erosion and available downstream sediment supply. If the river flow does not have enough energy flow to transport the increased sediment supply downstream, then sediment deposition occurs resulting in a period of aggradation. Deposition of finer grained sediments can also occur as the result of floods which spill sediment-laden water over the banks of the river into adjacent floodplains with lower flow velocities and sediment carrying capacity. As the flood recedes, flow velocities and sediment carrying capacity in the river channel decrease and water is trapped outside the river banks where it forms still pools that deposit the sediment load. Evidence indicates a complex history of vertical incision and aggradation has occurred along the San Pedro River and some of its tributaries.

Lateral river erosion has been the dominant process establishing the form of the inner valley. As lateral erosion of the riverbanks widens the newly-incised channel, the perimeter length along which erosive forces act increases. This results in a gradual decreasing in the rate

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[5] "Arroyo" is a Spanish term commonly used to describe a desert ephemeral wash, often a small, narrow canyon with steep walls and flat floor.

[6] See AZGS San Pedro Report at page 8.

of lateral erosion over time, although lateral erosion will continue to occur on the outside bends of the channel. There are numerous places along the boundaries of the current inner river valley where lateral erosion over time has removed all of the older sediments so that Holocene river floodplain alluvium has been deposited directly against the older bounding basin fill geologic units.[7] As the active channel migrated back and forth within the valley floor over thousands of years, the bounding units were eroded to form a fairly well-defined inner valley.

As with the main stem of the river, tributaries also experienced both vertical incision and lateral erosion. While vertical incision is likely more predominant on smaller tributaries of the San Pedro River, lateral erosion can potentially occur on any sizeable tributary. Sediment deposition by tributaries occurs predominantly at the mouth of the tributary when the tributary stream loses power as its base level approaches the base level of the main stem. The sediments are deposited in a fan-shaped manner and the resulting land form is known as an alluvial fan. The fate of the alluvial fan is dependent on its interaction with the main stem of the river system. Fans that are deposited where the inner river valley is narrow and bounded by erosion-resistant geologic units can themselves be eroded by the lateral movement of the main stem river channel. Multiple fans deposited into the inner valley can overlap forming a broad plain commonly referred as a "bajada" sloping toward the main stem of the river.

Hillslopes and very small catchments feed water and sediment directly to the inner valley where the bounding topography is well-defined and close to the river. In these areas, tributary deposits commonly form narrow fringes or "aprons" along the margins of the inner valley, either as very small, steep alluvial fans or fairly planar aprons of young sediment at the toes of bounding hillslopes. These tributary deposits typically have been eroded from basin-fill deposits immediately upslope. Because the inner valley is narrow and the bounding topography is well-defined, young tributary deposits are quite vulnerable to removal by lateral river erosion. These narrow tributary aprons are not stable geologic features. Following periodic removal by lateral river erosion, they begin to accumulate again on top of river deposits when the river migrates away from the bounding topography. As previously discussed, there are many examples where

[7] There are multiple geologic mapping units that bound the inner valley of FHA and THA in various locations. These units include deposits from the Pleistocene epoch (Qi1r, Qi2r and Qi3r) as well as older basin fill deposits and bedrock.

essentially no tributary deposits are preserved at the junction of the inner valley and the bounding topography, indicating that river erosion has removed them.

Small tributaries that flow only in response to storm events may produce fans that are short-lived and rapidly eroded by flows in the main stem of the river. Larger tributaries with more frequent flows can produce larger fans that can alter the course of the main stem of the river. Small tributaries have deposited relatively small alluvial fans on the margins of the river floodplain, and the floors of tributary valleys commonly are covered with young tributary deposits that mantle some amount of erosional topography on the bounding geologic units. Because small tributary fans have formed all along the river corridor, the potential for them to be removed by river erosion depends on the form and width of the inner valley. In areas where the bounding topography is linear and the inner valley is narrow, it is likely that river flows of sufficient magnitude have occurred and the small tributary fans have been subject to periodic removal by lateral river erosion during the past 10,000 years. After they are eroded away, tributaries soon begin to build new fans atop young river deposits when the river migrates away from the tributary mouth. In areas where the bounding topography is eroded well back from the river and is crenulated,[8] tributary deposits in the inner valley are far less likely to have been removed by river erosion.

Larger tributaries have more erosive power and so can potentially erode the bounding geology of their valleys laterally. In locations where the San Pedro River has not eroded laterally up to the mouth of a tributary for a long period of time, the lateral erosion of the tributary can create an embayment[9] in the bounding geology of the inner valley. Where the bounding geology is resistant to erosion, the embayment at the mouth of the tributary can be narrow or non-existent. Where the bounding geology is readily eroded, the embayment can be large and extend some distance away from the river.

Larger tributaries also transport larger amounts of sediment, and many have deposited large, well-defined individual alluvial fans and fan complexes into the inner valley. Because they are large features, substantial lateral river erosion is required to significantly alter or remove them. For that reason, they might be considered to be more permanent features in the inner

[8] A "crenulated" boundary is one having a serrated pattern with small wavy edges.
[9] An "embayment" is an area having a bay or bay-like shape.

valley. However, because these fans are large features, they typically protrude well out into the inner valley, which renders them more susceptible to river erosion. The historic record demonstrates that large fans are also dynamic features, as they occasionally experience large floods and transport abundant sediment in these floods. In areas where the inner valley is relatively narrow and well-defined topographically, it is likely that even large tributary fans can be eroded and those areas temporarily incorporated into the river channel or floodplain.

In areas where the inner valley is very wide, it is likely that large tributary fans are more permanent features and only subject to some modification near the river. Fans in these settings are relatively large, and their apexes are located far from and substantially higher than the river. Prior to historical river incision, the slopes of these large fans typically transitioned almost imperceptibly onto the river floodplain. There is some unknown amount of interfingering of fan and river deposits in the subsurface in these areas, but the lateral extent cannot be readily determined from the observable geomorphic record.

2.2.3 Pre-Holocene Bounding Topography

The landforms found in the inner valley of the San Pedro River result from a combination of the erosional and depositional processes described above and the interaction of those processes with the bounding geologic units. The characteristic of the bounding pre-Holocene geologic units most relevant to landform creation is their resistance to erosion.

Where the bounding geologic units are more resistant to erosion, the inner valley is relatively narrow, and its lateral boundaries are more or less continuous with generally small and narrow embayments created by the confluence with tributaries. Where the inner valley is narrow or linear, it is highly likely that lateral erosion of the San Pedro River has impacted the bounding geology during the Holocene and that the river has deposited sediments from one side of the inner valley to the other. Though tributaries may deposit sediments that cover the river's sediments, it is very likely that floodplain Holocene alluvium lies beneath the tributary sediments where the inner valley is narrow or linear.

Where the bounding geologic units are less resistant to erosion, the inner valley is wide and its sides are notable for large embayments resulting from the lateral erosion of tributaries near their confluence with the San Pedro River into the softer bounding geology. Tributaries produce more sediment from the softer bounding geology and this increased sediment load can bury both the river deposits and potentially even remnants of the bounding geologic units that are closer to the river. Though floodplain Holocene alluvium likely extends from the modern river floodplain laterally beneath the tributary sediments, it is unlikely to extend all the way to the visible older geologic units bounding the embayments. The mapping of the lateral extent of the floodplain Holocene alluvium into the tributary embayments where the inner valley is very wide and bounded by geologic units less resistant to erosion requires the consideration of factors other than the existing geomorphology.

2.2.4 Site Investigations of Tributary Drainages

During December 2013 and January 2014, AZGS and ADWR staff visited sites of exposed tributary channel deposits along the boundary with the active San Pedro River. A list was developed of 39 candidate sites along the San Pedro River from near the U.S./Mexico border to near the confluence with the Gila River at Winkleman, AZ. Most of these sites are located in incised tributary drainages to the San Pedro River while others are in the active channel of the San Pedro River.

The AZGS Tributary Site Report includes map figures showing the 39 site locations marked as red dots and denoted by approximate river mile and directional information. For example "SPR 69.5E" denotes a site located on the east side of the San Pedro River at approximately river mile 69.5. If observations were made at a site, then annotated photographs and brief descriptions of the exposed sediment and a stratigraphic interpretation of the exposed sedimentary relationships were provided in the AZGS report.

Of the 39 sites, eight were inaccessible due to private property or other access issues, and nine were not useful because they were not incised deeply enough to provide exposures of sedimentary relationships between Holocene river and tributary alluvium. Exposures at 22 sites demonstrated overlapping, interfingering sedimentary alluvium relationships. Of these sites, five provided exposures along the San Pedro River and 17 were located within incised tributary channels. Of the 17 sites, four showed deposits potentially consistent with either Holocene San Pedro River floodplain deposition or tributary reworking of fine grained basin fill alluvium. One site was disturbed by human activity. The remaining twelve sites provide direct evidence that buried FHA extends farther away from the modern river channel than is depicted on AZGS 2009 surficial geologic maps. Locations of the twelve AZGS sites showing FHA extending outside surface mapped exposures are marked with red stars on **Figure 2-2**.

2.3 TOOLS FOR DELINEATING THE LATERAL EXTENT OF FHA

A 33-sheet set of work maps covering the San Pedro River, Babocomari River and Aravaipa Creek is included as **Appendix C** to this report, and their underlying datasets are described in **Appendix D**. The work maps display the lateral extent of the FHA, as delineated by ADWR, based on geology, geomorphology and other information that helped to inform the professional judgment applied in the delineation as directed by the Adjudication Court's 2012 Order. This information is described below. [10]

2.3.1 Geology and Geomorphology

Based on the reports prepared by the AZGS and its 2009 mapping, FHA first was delineated along mapped contacts between surface exposures of pre-Holocene bounding topography and Holocene river alluvium. As directed by the Adjudication Court's 2012 Order, the FHA delineation then was adjusted where necessary to include the historical composite active floodplain, ("HCAF"), which is depicted on each of the work maps.[11] Next, FHA was delineated along mapped contacts between THA and exposures of relatively linear scarps of pre-Holocene bounding topography with smaller crenulations.

In the remaining areas, exposures of bounding topography display less uniformity and are farther away from the recent river deposits in the inner valley. It is in these areas that the AZGS concluded it is likely the river may not have actively eroded some of the exposed bounding geologic units. In completing delineation of the FHA in such areas, ADWR utilized certain data and information from riparian vegetation patterns, satellite imagery, soil lithology logs and water levels measured in shallow wells while maintaining continuity with the lateral extent and orientation of the FHA as delineated in the first two steps. The information obtained from

[10] Additional information relating to the application of setbacks is also depicted on the work maps. This process is discussed in Chapter 3.
[11] The HCAF is based on aerial photography from 1935 to 2007. For additional information, see ADWR 2011 Response to Comments, Section 5.1, Appendix D.

review of these other tools was considered together with all other available information. Intermediate conclusions were not derived from review of the individual tools, instead each piece of information was considered in the context of all other available and appropriate information enabling the application of professional judgment in delineating the lateral extent of FHA in accordance with directions from the Adjudication Court.

2.3.2 Riparian Vegetation Patterns

ADWR examined riparian vegetation growth data along the San Pedro River downloaded from the United States Fish and Wildlife Service National Wetlands Mapping website.[12] Information was derived from the data in two categories: (1) cottonwood and willow trees and (2) mesquite and salt cedar trees. Cottonwoods and willows grow on the active floodplains of perennial and intermittent rivers and are commonly classified as obligate phreatophytes, meaning that shallow subsurface water is essential for their survival. Mesquites and salt cedars can be found growing in upland areas, but dense stands of mesquite and salt cedar are most common on river floodplains and low river terraces. They are commonly classified as facultative phreatophytes, meaning that while they can use relatively shallow or deep subsurface water, they can also survive solely on rainfall. Areas where riparian vegetation has been planted and cultivated by man for mitigation and re-establishment projects were also identified.

Nearly all mapped growth of cottonwood and willow trees was limited to areas along the current active channel of the San Pedro River, which was well within the mapped exposures of Holocene river alluvium and therefore not useful for identifying buried FHA. Growth of mesquite and salt cedar trees was mapped within the FHA and THA of the inner valley as well as along some tributaries. Patterns and densities of mesquite and salt cedar trees were identified and compared to the lateral width and orientation of the FHA based on geology and geomorphology.

[12] http://www.fws.gov/wetlands/Data/Mapper.html

2.3.3 Remote Sensing Imagery

ADWR utilized aerial photography from the 2010 National Agriculture Imagery Program (NAIP)[13] by the United States Department of Agriculture, as well as satellite imagery from 2013 World Imagery by the ESRI Corporation.[14] Imagery was used to: (1) identify riparian vegetation along the San Pedro River, Babocomari River and Aravaipa Creek; (2) interpret areas mapped as having been disturbed by human activity; and (3) identify ground markers associated with location of the active channel and floodplain in areas where minor overlapping may exist along edges of the HCAF, Holocene alluvium and bedrock outcrops or other pre-Holocene geologic deposits.

2.3.4 Soil Lithology Logs

Along the San Pedro River, ADWR utilized information from 167 soil boring logs prepared by geologists or other trained professionals.[15] The majority of these professional-level lithology logs were from wells drilled within or in close proximity to mapped surface exposures of FHA and used for identification of characteristic descriptions of soil lithology. These lithology logs generally indicated the presence of inter-bedded layers of sands, gravels, silty sands, clayey sands, sandy clay etc. Due to the presence of a wide inner valley and limited available information overall, an additional 273 driller logs were reviewed for lithologic trends in the vicinities of river miles 112–109, 106–104, 99–96 and 89–86 of the San Pedro River.

Descriptions of soil lithology from borings drilled within the mapped THA were compared to the common characteristics identified from borings drilled within the mapped FHA and used for identifying trends in similarities or differences. Differences generally took the form of descriptions of shallow and thick clay deposits having moderate or high plasticity. Review of soil lithology was considered in context with all other available information used for delineation of the FHA.

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[13] https://www.fsa.usda.gov/FSA/apfoapp?area=home&subject=prog&topic=nai
[14] http://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9
[15] Soil boring lithology logs are described in two tables in **Appendix D** to this report.

2.3.5 Water Elevations in Shallow Wells

Water elevation measurements from shallow wells were used for completing delineation of the FHA along the San Pedro River between river miles 114 and 82. These 32 river miles have exposed bounding topography relatively far back from the river and therefore providing less constraint on the width of the FHA. Water elevation measurements for shallow wells less than 200 feet deep were obtained from ADWR's main repository for state-wide groundwater data, the Groundwater Site Inventory database (GWSI).[16] The GWSI consists of field-verified well data collected by ADWR personnel, the USGS, and other co-operating agencies. **Figure 2-3** shows the location of the wells used in the analysis based on the best available information for the latitude and longitude of each well.

The three best available datasets of water elevation measurements, collected during the years 1968, 1990 and 2006, were used in this analysis. These datasets include 397 water elevation measurements, which are described in three tables in **Appendix D**. ADWR also used the general direction of the river and inner valley as the directional line of subflow. In its 1994 Subflow Order, the Adjudication Court indicated that the flow direction in the subflow zone must be in the general overall direction of the stream. The Adjudication Court stated:

> Because low-flow streams like the San Pedro meander back and forth in a series of "S" curves within a wider principal or dynamic channel, flow direction must be the general overall direction of the stream.

1994 Subflow Order at page 57.

Figures 2-4, 2-5 and 2-6 display results of simple linear regression[17] analyses of 1968, 1990 and 2006 water elevations measured for wells drilled within mapped surface exposures of FHA ("FHA-wells"). Seven lines derived from regression analysis are shown on each figure. The lines of "Best-Fit" are shown as blue lines. The vertical distances between the two solid black lines labeled "Upper 50%" and "Lower 50%," represent the ranges of water elevations encompassing the middle 50 percent of the FHA-well data points. The vertical distances between the dashed lines and dotted lines represent the ranges of elevations of the middle 75 and

[16] See http://gisweb.azwater.gov/waterresourcedata/gwsi.aspx.

[17] In statistics, simple linear regression fits a straight line through a data set in such a way that the sum of the squared residuals (i.e. the vertical distances between the points of the data set and the fitted line) is as small as possible. The fitted straight line derived from regression analysis is referred as the "best-fit."

95 percent of FHA-well data, respectively. The best-fit and the upper and lower 50, 75 and 95 percent lines characterize shallow subsurface water conditions within the mapped, known FHA at the selected points in time.

Also plotted on **Figures 2-4, 2-5 and 2-6** are individual data points showing measured water elevations for wells constructed within aprons of THA mapped between the FHA and pre-Holocene bounding topographies ("THA-wells"). The THA-well data points are divided into two groups depending on whether the well from which the data was measured is constructed to the west or east of the mapped FHA.

The figures were used for comparative purposes in identifying trends in similarities or differences between the shallow subsurface water conditions inside the mapped FHA versus individual measurements within the THA on both sides of the river. Results of the water elevation comparisons (discussed below in **Section 2.4.4**) were considered in context with all other available information used for delineation of the FHA between river miles 114 and 82.

2.4 SAN PEDRO RIVER FHA

Description of the delineation of the lateral extent of the FHA of the San Pedro River is presented below. ADWR has defined seven reaches stretching 157 river miles from the international border with Mexico to the San Pedro's confluence with the Gila River, as depicted on **Figure 2-7**.

In the Upper San Pedro River Valley, the 75-mile long river is divided into four reaches beginning with a 23-mile reach extending from the U.S./Mexico Border to the bedrock lined channel at the Tombstone Hills in the Fairbank-Charleston area. Below the five-mile long bedrock-lined channel, the remaining 47 miles of the upper river is divided into two reaches with lengths of 15 and 32 miles, respectively. In the Lower San Pedro River Valley, the 82-mile long river is divided into three reaches beginning with a 23-mile reach extending from The Narrows to the bedrock lined channel in the Redington area. Below the 1.5 mile-long bedrock-lined channel, the remaining 57.5 miles of the lower river is treated as a single reach.

2.4.1 Upper Valley Reach 1 (River Miles 157-134)

The 23-mile long reach of the San Pedro River between the U.S./Mexico Border and the bedrock-lined channel at Tombstone Hills extends from river mile 157 to river mile 134 ("Upper Valley Reach 1"). This reach is characterized by relatively linear scarps eroded into pre-Holocene bounding topography. Mapped surface exposures of Holocene river alluvium cover most of the inner valley. Lateral river erosion, meandering and eroding side-to-side across the inner valley, is the dominant process at work. Deviations in linearity of the bounding topography are due to variations in lateral river erosion and the number of sufficiently large flood events since the river eroded laterally at that particular place. In many locations the Holocene tributary apron is narrow and not geologically stable, having young deposits derived from geologic units immediately upslope from the river floodplain. Where tributaries join the river, dynamic alluvial fan depositional environments exist and the river periodically erodes laterally against the older units that bound the inner valley, trimming and removing the local tributary deposits.

Within this reach, three AZGS investigation sites show exposures of otherwise buried FHA deposits outside of the mapped Holocene river alluvium channel:

- Near river mile 153, Palominas Arroyo exits the confinement of rolling basin fill hills to the east, flowing west to the San Pedro River. San Pedro River gravels and channel sediments are exposed in the arroyo as it cuts through a thin, broad, nearly semicircular fan with side walls exceeding 15 to 20 feet deep in places. This exposure may offer the best visible example of otherwise buried Holocene San Pedro River deposits adjacent to basin fill bluffs outside the modern channel. Exposures of buried FHA are located as much as 2,200 feet outside mapped Holocene river deposits on the AZGS 2009 surficial maps.
- Near river miles 143 and 141.5, small unnamed incised arroyos exit well-eroded basin fill deposits along the west side of the San Pedro River and have deposited broad splays of tributary alluvium dominantly composed of reworked basin fill sediment. Where the arroyos are sufficiently incised, interfingering depositional relationships between Holocene tributary and San

Pedro floodplain alluvium are exposed. The exposed fine-grained San Pedro River deposits are located up to 300 feet (river mile 143) and 175 feet (river mile 141.5) outside the mapped boundary of Holocene river alluvium on AZGS surficial maps. The exposures become buried short distances upstream and are no longer exposed in the arroyo wall, so the maximum lateral extents of the deposits are not visible.

Application of the geology and geomorphology tools described in **Section 2.3** allowed for delineation of the FHA along the vast majority of the reach. For the remaining areas, ADWR reviewed additional information while providing continuity of the FHA boundary. Between river miles 157 and 150 on the west side of the river, the delineation of FHA was completed by review of the site investigations listed above, photo-imagery, riparian vegetation patterns, and 18 of the 55 soil boring logs reviewed for the entire reach. In the area of river mile 136 on the east side of the river, delineation of FHA was completed by review of photo-imagery, and riparian vegetation patterns.

2.4.2 Upper Valley Reach 2 (River Miles 134-129)

Mapped surface exposures of Holocene river alluvium cover most of the inner valley within the five-mile long reach from river mile 134 to river mile 129, including the bedrock-lined channel at Tombstone Hills ("Upper Valley Reach 2"). Much of the length of the reach has mapped contacts between surface exposures of Holocene river alluvium or the HCAF and pre-Holocene bounding topography. In many locations the Holocene margin of the floodplain is narrow and comprised of temporary young deposits derived from adjacent hillslopes immediately upslope from the river floodplain.

Application of the geology and geomorphology tools described in **Section 2.3** allowed for delineation of FHA along most of the reach. In the remaining few locations where the bounding topography is less-uniform and farther away from the river, ADWR reviewed additional information while providing continuity of the FHA boundary. In the area of river mile 130 on the west side of the river, the delineation of FHA was completed by review of photo-imagery and riparian vegetation patterns. ADWR reviewed 12 lithology logs from soil borings drilled within the entire reach. A minor correction was made to the mapped location of the bedrock contact in the area of river miles 131 to 130 in order to include the active river channel within the delineation of FHA.

2.4.3 Upper Valley Reach 3 (River Miles 129-114)

The 15-mile long reach from river mile 129 to river mile 114 downstream of the bedrock-lined channel at Tombstone Hills is characterized by more crenulated scarps cut into pre-Holocene bounding topography ("Upper Valley Reach 3"). Eroded ridges or spines have formed, surrounded on three sides by, and extending toward (or into), the inner river valley. The orientations of the long axes of these ridges or spines tend to be perpendicular to the inner valley. In other locations eroded isolated pre-Holocene knobs have formed. In some cases, these landforms reflect complexities in the pattern of lateral river erosion, such as shorter-wavelength meanders scalloping out the bounding topography. In others, they simply indicate that the river has not actively eroded that part of the valley margin for thousands of years. It might be expected that some of the ridges, spines and knobs exposed at the surface extend farther toward the river in the subsurface (the iceberg phenomenon), and that the river may not have actively eroded the bounding topography as far away from the valley axis as some of the existing outcrops. Mapped surface exposures of Holocene river alluvium cover most of the inner valley.

Application of the geology and geomorphology tools described in **Section 2.3** allowed for delineation of FHA along much of the reach. In areas having more crenulated scarps, the remaining FHA was delineated tangent to the more-inward scarped exposures while providing continuity of the FHA boundary. ADWR reviewed 12 lithology logs from soil borings drilled within the entire reach. On the west side of the river, delineation of FHA was completed in the area of river mile 125 by review of photo-imagery, and riparian vegetation patterns. On the east side of the river, delineation of FHA was completed between river miles 122 and 120 and near river miles 117 and 115 by review of photo-imagery, riparian vegetation patterns, and four soil boring logs. Small mapped pre-Holocene exposures are encapsulated within the delineation of FHA in the area of river miles 119 to 118.

2.4.4 Upper Valley Reach 4 (River Miles 114-82)

The remaining 32 miles of the San Pedro River upstream of The Narrows, approximately 16 river miles north of Benson, from river mile 114 to river mile 82 are generally characterized by a wide inner valley with large embayments resulting from the lateral erosion of tributaries near their confluence with the river ("Upper Valley Reach 4"). In some segments of this reach, the exposed bounding topography is far back from the river and provides less constraint to the width of the FHA. The apron area between the exposed Holocene river deposits and the pre-Holocene bounding topography is covered with THA deposits. It is likely that substantial bounding topography has been buried by accumulation of young local deposits. Though FHA likely extends from the modern river floodplain laterally beneath the tributary sediments, it is unlikely to extend all the way to the visible older geologic units bounding the tributary embayments where the inner valley is very wide and bounded by geologic units less resistant to erosion.

Delineation of the FHA within this reach was ground-verified at six AZGS investigation sites showing exposures of otherwise buried FHA deposits outside of the mapped Holocene river alluvium channel:

- Near river mile 112, vertical channel walls of California Wash expose alternating beds of poorly sorted sandy to gravelly laminar and cross bedded sediment and well-sorted fine grained alluvium strongly resembling floodplain deposits exposed in the channel walls of the San Pedro to the east. The uppermost layer at the top of the sequence exhibits little to no soil development and appears to have been deposited recently, probably in historical times prior to widespread incision along the San Pedro River. Deposits exposed along California Wash record alternating deposition of Holocene tributary and San Pedro River alluvium prior to deposition of young tributary fan alluvium at the surface. These exposures of Holocene San Pedro River alluvium are located up to 275 feet outside mapped deposits of Holocene river alluvium on AZGS 2009 surficial geologic maps.
- Near river mile 108, a small unnamed tributary channel joins the San Pedro River from the east. The channel incises through broad, low-relief tributary alluvial fans and Holocene San Pedro deposits. Historically, agricultural fields straddled the boundary between tributary and river alluvium, obscuring the contact at the surface and some of these fields are still cultivated today. Fine-grained, alluvium with dark gray to black, organic-rich interbeds is

overlain by predominantly fine sandy alluvium with coarse sandy to pebbly interbeds. These deposits, in turn, are overlain by a thinning deposit of poorly sorted sandy to pebbly alluvium with angular to sub angular clasts.[18] The dark, organic-rich, banded fine-grained deposits are interpreted as low energy cienega-like[19] San Pedro River alluvium where springs have been known to sustain wetlands in the past. These dark layers could represent slow aggradation of organic-rich, swampy sediment prior to historical incision along this portion of the San Pedro River. This exposure is located at the mapped tributary fan/Holocene San Pedro alluvial boundary on the surface. Exposures of Holocene San Pedro deposits extend upstream in the arroyo for approximately 20 to 30 feet until becoming buried.

- Near river mile 107, Slavin Wash and other narrow incised arroyos cut through broad, coalescing Holocene tributary fan alluvium and San Pedro River deposits on the east side of the river. Poorly sorted sandy to pebbly alluvium is interbedded with well-sorted, fine-grained alluvium. This exposure is very close to the mapped surficial boundary of tributary alluvial fans on AZGS surficial geologic maps although an interfingering relationship between tributary and river alluvium appears to exist in the subsurface. The poorly sorted sandy to pebbly alluvium is interpreted as tributary alluvium while the well sorted fine-grained alluvium strongly resembles low energy San Pedro floodplain deposits exposed in river channel walls downstream.
- Near river mile 96, an unnamed tributary channel exposes interfingering fine grained San Pedro floodplain and coarser-grained, poorly sorted tributary fan alluvium. Very poorly sorted light brown sandy to gravelly beds with angular to sub angular clasts interfinger with finer-grained, well sorted, darker brown interbeds. The coarser beds strongly resemble tributary fan alluvium observed throughout the arroyo and in the modern tributary channel while the finer grained interbeds resemble San Pedro River floodplain deposits exposed in a

[18] "Clasts" are fragments of rock.
[19] A "cienega" is a wet, marshy area.

similar relationship in nearby arroyos and in modern channel walls of the San Pedro River. Probable Holocene river floodplain deposits are exposed in this arroyo up to 2,600 feet outside the mapped surficial boundary of Holocene river alluvium on AZGS 2009 geologic maps.

- Two sites, within several hundred feet of each other and near river mile 89.5 show exposures of interfingering Holocene tributary and San Pedro alluvium. Light brown, poorly sorted, sandy alluvium with angular to sub-angular pebble and gravel-dominated interbeds overlies more uniformly sorted, medium brown, fine sandy beds with darker brown fine sandy to silty buried soils. Isolated lenses of lithologically diverse, well-rounded pebbles and cobbles are present within the fine-grained layer. The poorly sorted alluvium with angular gravels exposed at the top of the arroyo wall is interpreted as tributary channel and fan deposits. These deposits overlie finer-grained, well-sorted sandy to silty alluvium with well-rounded cobble lenses representing Holocene San Pedro floodplain and channel deposits. The tributary sand to gravel cap becomes noticeably thinner near the modern San Pedro River channel, indicating thinning tributary fan deposition atop laterally extensive and thick Holocene San Pedro floodplain deposits. Holocene river floodplain deposits are exposed in this arroyo up to 820 feet outside the mapped surficial boundary of Holocene river alluvium on AZGS geologic maps. Most of the tributary alluvium evident at this location is the thinning alluvial deposit at the top of the exposure. The vast majority of sediment exposed in cross section here is interpreted as Holocene river deposits while surficial mapping shows this area as Holocene tributary deposits. The surface is dominated by tributary alluvium at this location which is depicted in surficial AZGS geologic mapping yet it seems clear Holocene river deposits extends farther from the river in the subsurface than the 2009 surficial maps indicate.

As described in **Section 2.3**, a wide inner valley has formed between river miles 114 and 82 including a number of segments where the exposed bounding topography provides less constraint on the width of the FHA. On the west side of the river, FHA was delineated along mapped contacts between surface exposures of pre-Holocene bounding topography and

Holocene river alluvium in areas of river miles 114, 110, 105, 104.5 and 82. FHA delineation then was adjusted where necessary to include the HCAF at river mile 95. Delineation of the FHA beyond these areas provided continuity in the lateral extent of FHA and used information from the site investigations listed above, lithology logs, water levels measured in shallow wells and imagery and vegetation growth patterns described below.

ADWR reviewed professional-level lithology logs from 33 soil borings in areas of river miles 114, 112, 107 (six borings), 106 (four borings), 105, 104 (eight borings), 101, 99 (ten borings) and 83. An additional 276 soil boring logs from drilled wells were reviewed in vicinities of river mile areas 112–109.5, 106–104, 99–96 and 89–86. ADWR also reviewed water level measurements for three sub-reaches:

- River Miles 114 to 104: A majority of wells are drilled to the east of the exposed FHA, and show water levels greater than the mean FHA-level and less than the upper 95 percent. Generally, these wells were considered to exhibit a trend in water levels being generally consistent with FHA. A smaller number of wells drilled to the east have water levels above the upper 95 percent of FHA wells, i.e. generally inconsistent with being drilled in FHA. One of three wells on the west side of the river shows levels above the upper 95 percent of FHA wells and the other two wells show water levels at or below the mean FHA-level.
- River Miles 100 to 95: Most of the wells are drilled to the east of the exposed FHA, i.e. exhibiting a trend generally consistent with FHA. Most fell within the middle 75 percent of FHA measurements, and all but one of these wells showed water levels within the middle 95 percent.
- River Miles 91 to 82: Most of the wells are drilled to the west of the exposed FHA, and show water levels greater than the mean FHA-level and less than the upper 95 percent, i.e. exhibiting a trend generally consistent with FHA. A few of these wells showed levels above the upper 95 percent of FHA wells, i.e. not consistent with FHA.

These water levels established several identified spatial trends of either being generally consistent or inconsistent with wells drilled in the FHA. These findings are not conclusive as to the extent of FHA but were considered in context of all other available information and used to inform the Department’s professional judgment as applied.

Satellite imagery and mapped growth of mesquite and salt cedar trees provided information within several tributary embayments, including river miles 85 and 82. The line of heavy vegetative growth in these areas generally followed the line of continuity of FHA. Like the lithology and water level data, these findings are not by themselves conclusive, but considered in the full context of available and appropriate information.

2.4.5 Lower Valley Reach 1 (River Miles 82-59)

The 23-mile long reach from river mile 82 at The Narrows to river mile 59 at the bedrock-line channel near Redington is characterized by more crenulated scarps cut into pre-Holocene bounding topography ("Lower Valley Reach 1"). Eroded ridges or spines have formed, surrounded on three sides by, and extending toward (or into), the inner river valley. In other locations eroded isolated pre-Holocene knobs have been formed. It is likely that some of the ridges, spines and knobs exposed at the surface extend farther toward the river in the subsurface, and the river may not have actively eroded the bounding topography as far out from the valley axis as the existing outcrops. Mapped surface exposures of Holocene river alluvium cover much of the inner valley.

Delineation of the FHA within this reach was ground-verified at two AZGS investigation sites showing exposures of otherwise buried FHA deposits outside of the mapped Holocene river alluvium channel:

- Near river mile 69.5, Lower Teran Wash has deposited a broad semi-circular alluvial fan where it becomes unconfined by high-standing, dissected, Quiburis basin fill bluffs. The modern Teran Wash channel has incised through interfingering Holocene tributary fan and San Pedro River deposits as it has kept pace with historical to latest Holocene base level drop of the San Pedro River to the south. Prior to basin incision it is likely the zone of confluence between these two channels was much more widespread and deposit dominance fluctuated laterally with river meandering and tributary floods. Although AZGS surficial mapping depicts tributary fan alluvium throughout this area at the surface, this exposure exhibits interfingering and concurrent deposition of Teran Wash and San Pedro River sediment in an aggrading distal fan/river floodplain environment up to 425 feet farther from the river than depicted on AZGS 2009 maps.

- Near river mile 66, Hot Springs Wash joins the San Pedro River from the east side. Hot Springs Wash becomes unconfined upon exiting Hot Springs Canyon to the north. Unconfined flow has resulted in deposition of a broad fan at the mouth of the canyon. Since the deposition of this tributary fan, the San Pedro River has incised and Hot Springs Wash has incised as well to the new base level, eroding through its own fan and Holocene San Pedro River floodplain deposits. Exposures of the relationship between these sedimentary packages are visible along outside erosional bends of Hot Springs Wash. The poorly sorted sand and gravel in the upper half of the exposure is interpreted as tributary Hot Springs Wash alluvium. The well sorted fine sandy to silty deposits overlain by the tributary alluvium is interpreted as San Pedro River floodplain deposits. The deposition and erosion cycle between Hot Springs Wash and the San Pedro River evident in the modern landscape is indicative of these same processes in the past. Holocene river alluvium is exposed in the banks of Hot Springs Wash up to 350 feet outside the boundary depicted on AZGS 2009 surficial geologic maps.

Application of the geology and geomorphology tools described in **Section 2.3** allowed for delineation of FHA along most of the reach, particularly north of river mile 72. Between river miles 82 and 72 on both sides of the river, 70 and 67 on the east side, and 66 to 64 on the west side, the delineation of FHA was completed by review of the site investigations listed above, photo-imagery and riparian vegetation patterns. In areas having more crenulated scarps, the delineation is mostly tangent to the more-inward scarped exposures while providing continuity of FHA. A mapped pre-Holocene exposure is encapsulated within the delineation of FHA in the area of river mile 78.

2.4.6 Lower Valley Reach 2 (River Miles 59-57.5)

Mapped surface exposures of Holocene river alluvium cover nearly all of the inner valley within the mile and a half long reach between river mile 59 and river mile 57.5, which is mostly bedrock-lined ("Lower Valley Reach 2"). Most of the length of the reach has mapped contacts between surface exposures of Holocene river alluvium or the HCAF and pre-Holocene bounding topography. In nearly all locations, the Holocene margin of the floodplain is narrow and comprised of temporary young deposits derived from adjacent hillslopes immediately upslope from the river floodplain.

Application of the geology and geomorphology tools described in **Section 2.3** allowed for delineation of the FHA along nearly the entire length of the reach. The delineation of FHA was completed by review of photo-imagery and riparian vegetation patterns, while providing continuity of FHA.

2.4.7 Lower Valley Reach 3 (River Miles 57.5-0)

The last 57.5-mile long reach of the San Pedro River to its confluence with the Gila River between river mile 57.5 and river mile 0 is characterized by relatively linear scarps cut into pre-Holocene bounding topography ("Lower Valley Reach 3"). Mapped surface exposures of Holocene river alluvium cover much of the inner valley. Lateral river erosion, eroding side-to-side across the inner valley, is the dominant process at work and deviations in linearity of the bounding topography is due to variations in lateral river erosion, and the length of time since the river eroded laterally at that particular place. Late Pleistocene river terrace bounding topography is mapped in many locations. The Holocene tributary apron is sometimes narrow and geologically ephemeral having young deposits derived from geologic units immediately upslope from the river floodplain. Where tributaries join the river, dynamic alluvial fan depositional environments exist and the river periodically erodes laterally against the older units that bound the inner valley, trimming or removing the local tributary deposits.

Delineation of the FHA within this reach was ground-verified at one AZGS investigation site, which shows exposures of otherwise buried FHA deposits outside of the mapped Holocene river alluvium channel:

- Near river mile 32, James Wash is a 150-foot wide tributary channel where it exits tall, well-dissected basin fill bluffs. A broad alluvial fan emanates from this drainage and the modern arroyo channel has incised through the tributary fan and underlying deposits. A small fan has been deposited onto historical San Pedro River deposits at the mouth of the arroyo. Local variations in dominance of sediment from one source of deposition over the other can be explained by meandering of the San Pedro River, floods along James Wash, and limited preservation and exposure of depositional relationships. Large

> pebbles and cobbles exposed in James Wash deposits exhibit cross-bedding and lie in erosional contact with underlying San Pedro deposits, indicating the coarser sediment was deposited by high energy flow, possibly during a flood event in the tributary channel. The fine-grained well-sorted composition of the lower deposit indicates steady, lower energy deposition such as that of a river floodplain or low energy channel. Similar fine grained deposits are encountered in Holocene to historical San Pedro River deposits to the west. Holocene river alluvium is exposed in channel walls up to 600 feet outside mapped boundaries of Holocene River alluvium on AZGS surficial geologic maps.

Application of the geology and geomorphology tools described in **Section 2.3** allowed for delineation of the FHA along the vast majority of the reach. The delineation of FHA in other areas of the reach was completed by review of the site investigation listed above, lithology logs from 55 soil borings drilled south of river mile 40, photo-imagery, and riparian vegetation patterns, while providing continuity of FHA. Specifically, for embayments in areas of tributaries near river miles 57 to 52, 51 to 50, 49, 46 and 41 to 40, the FHA was completed using photo-imagery, and riparian vegetation patterns.

2.5 BABOCOMARI RIVER FHA

The lateral extent of FHA of the Babocomari River is presented in three reaches stretching 22 river miles from the upstream extent of perennial or intermittent flow as determined in the 2009 Subflow Report to the confluence with the San Pedro River. The uppermost 17 miles is treated as a single reach, followed by three miles of bedrock-lined channel and the remaining two-mile long reach. These reaches are depicted on **Figure 2.7**.

2.5.1 Babocomari Reach 1 (River Miles 22-5)

The uppermost 17-mile long reach of the Babocomari River from river mile 22 to river mile 5 is characterized by relatively linear scarps cut into pre-Holocene bounding topography ("Babocomari Reach 1"). Mapped surface exposures of Holocene river alluvium cover much of the inner valley. Lateral river erosion, eroding side-to-side across the inner valley, is the dominant process at work. Late Pleistocene river terrace bounding topography is mapped along most of the north side of the river. The Holocene tributary apron is in places narrow and geologically ephemeral having young deposits derived from geologic units immediately upslope from the river floodplain. Where tributaries join the river, dynamic alluvial fan depositional environments existing within the river's inner valley where the river periodically erodes laterally against the older units, trimming or removing the local tributary deposits. Application of the geology and geomorphology tools described in **Section 2.3** allowed for delineation of the FHA along most of the reach. At the mouths of tributary drainages near river miles 20, 19, 18 and 15, the FHA was completed using photo-imagery, and riparian vegetation patterns, while providing continuity of FHA. Small mapped pre-Holocene exposures are encapsulated within the delineation of FHA in the area of river miles 20 to 15.

2.5.2 Babocomari Reach 2 (River Miles 5-0)

Mapped surface exposures of Holocene river alluvium nearly cover the inner valley along the bottom five miles of the Babocomari River from river mile 5 to river mile 0 ("Babocomari Reach 2"). Where not covered by surface exposures of FHA, the Holocene tributary apron is narrow and geologically ephemeral. Application of the geology and geomorphology tools described in **Section 2.3** allowed for delineation of the FHA along nearly all of the reach. At the mouths of tributary drainages near river miles 5 and 1.5, the FHA was completed using photo-imagery, and riparian vegetation patterns, while providing continuity of FHA. A small portion of the HCAF mapped as moving a short distance up a tributary drainage was truncated and not included in the delineation of FHA.

2.6 ARAVAIPA CREEK FHA

The lateral extent of FHA of Aravaipa Creek is presented in three reaches stretching 37 river miles from the upstream extent of perennial or intermittent flow as determined in the 2009 Subflow Report to the confluence with the San Pedro River. The uppermost 8 miles is followed by the 22-mile long Aravaipa Canyon and the remaining seven mile long reach. These reaches are depicted on **Figure 2.7**.

2.6.1 Aravaipa Reach 1 (River Miles 37-29)

The upper most eight-mile long reach of Aravaipa Creek from river mile 37 to river mile 29 is characterized by crenulated scarps cut into pre-Holocene bounding topography ("Aravaipa Reach 1"). In some locations, particularly on the northeast side of the river, more linear scarps are cut into the bounding topography. It is likely that in the more crenulated areas, some of the ridges, spines and knobs exposed at the surface extend farther toward the river in the subsurface, and the river may not have actively eroded the bounding topography as far out from the valley axis as the existing outcrops. Application of the geology and geomorphology tools described in **Section 2.3** allowed for delineation of the FHA at locations near river miles 36, 35, 34, 33 and 32. In areas having more crenulated scarps, the FHA was delineated tangent to the more-inward scarped exposures while providing continuity of FHA. The remaining FHA delineation at the mouths of tributary drainages between river miles 36 and 35 on the north side, 35 and 34 on the south side and between 31.5 and 29.5 on both sides were completed with information reviewed from photo-imagery and riparian vegetation patterns.

2.6.2 Aravaipa Reach 2 (River Miles 29-7)

Mapped surface exposures of Holocene river alluvium almost completely cover the inner valley along the 22 miles of Aravaipa Canyon from river mile 29 to river mile 7 ("Aravaipa Reach 2"). Where not covered by surface exposures of FHA, the Holocene tributary apron is narrow and geologically ephemeral. Application of the geology and geomorphology tools described in **Section 2.3** allowed for delineation of the FHA along nearly all of the reach. At the mouths of small tributary drainages near river miles 27, 26 and 20, the FHA was completed using photo-imagery, and riparian vegetation patterns, while providing continuity of FHA. A minor correction was made for consistency of the FHA, HCAF and AZGS mapped geology in the areas of river mile 12.

2.6.3 Aravaipa Reach 3 (River Miles 7-0)

The lower seven-mile long reach of Aravaipa Creek from river mile 7 to river mile 0 is characterized by relatively linear scarps cut into pre-Holocene bounding topography ("Aravaipa Reach 3"). Mapped surface exposures of Holocene river alluvium cover most of the inner valley. Lateral river erosion is the dominant process at work. The Holocene tributary apron is in places narrow and geologically ephemeral having young deposits derived from geologic units immediately upslope from the river floodplain. Alluvial fan depositional environments exist in the areas of river miles 4 and 2. Application of the geology and geomorphology tools described in **Section 2.3** allowed for delineation of the FHA along most of the reach. At the mouths of tributary drainages near river mile 4.5 on both sides of the creek, and river miles 2 and 1 on the north side delineation was completed using photo-imagery, and riparian vegetation patterns, while providing continuity of FHA.

CHAPTER 3: DELINEATION OF THE LATERAL EXTENT OF THE SUBFLOW ZONE

CHAPTER 3: DELINEATION OF THE LATERAL EXTENT OF THE SUBFLOW ZONE

3.1 INTRODUCTION

In this chapter, ADWR describes the application of certain setbacks to the delineation of FHA as directed by the Adjudication Court in order to delineate the subflow zone for the San Pedro River, Babocomari River and Aravaipa Creek. In Chapter Two of this report, ADWR described the delineation of the lateral extent of FHA.

3.2 APPLICATION OF SETBACKS

In the 2012 Order, the Adjudication Court found that the parameters used by ADWR in the 2009 Report with respect to use of routine applications of setbacks improperly resulted in exclusion of areas within the subflow zone.[1] The Adjudication Court then provided direction to ADWR on the manner in which setbacks should be applied. The Adjudication Court stated:

> 21. Two-hundred (200) foot setbacks assumptions may not be used in locations where thin veneers of tributary alluvium overlie the FHA. Except at the mouths of larger ephemeral streams or washes (those with relatively frequent surface and underground flow), the setbacks shall be one hundred (100) feet from the edge of the FHA. Setback assumptions shall not be used in bedrock canyons.
>
> 22. When a hydraulic connection exists between the underground flow associated with tributary and surface flow of the primary watercourse, the following adjustments are permitted:
>
> a. Apply 100-foot setbacks everywhere except for large ephemeral streams that have relatively frequent surface and underground flow.
> b. Modify the setbacks to include the active river channel.
> c. When setbacks cross or where basin fill is adjacent to the active channel, continue the subflow zone using the active channel.
> d. Evaluate disturbed ground based upon the likely underlying geologic unit.

2012 Order at 4, ¶¶ 21-22.

[1] 2012 Order at 3, ¶ 16.

The Adjudication Court further held that the delineation of the subflow zone must satisfy the following:

a. result in a continuous zone;
b. result in a stable geologic feature;
c. include the entire current active channel of each watercourse;
d. include the Historical Composite Active Floodplain (1935-2007)[2] for each watercourse;
e. accurately reflect the full extent of the floodplain Holocene alluvium; and
f. to the extent possible, interpret judicial pronouncements in a manner consistent with scientific fact.

Id. at 5, ¶ 2.

ADWR implemented the Adjudication Court's direction by first identifying the ephemeral drainages that are tributary to the San Pedro River and those that have relatively frequent flows. **Figure 3-1** displays the sizes of 517 ephemeral drainages tributary to the San Pedro River having areas ranging from 0.02 to 138 square miles, plotted as a cumulative frequency curve. A cumulative frequency curve relates the area sizes to the cumulative percentage of the 517 drainages smaller than that size. As examples, the figure shows that fifty percent of tributaries have drainage areas of two square miles and ninety percent are lesser than or equal to 20 square miles. **Figure 3-2** plots the same data with arithmetic ordinate values (Y-axis) to identify 97.5 percent as the point of maximum curvature. The point of maximum curvatures is a natural break-point in the dataset by which to distinguish larger tributaries experiencing, on average, more frequent flows.

Twelve tributaries comprising the largest 2.5 percent are listed in **Table 3-1**. Included in the table are the two-year return-period peak flood runoff discharges for each of the tributaries as estimated using a regional regression equation for southern Arizona published by the United States Geological Survey.[3] Also included in the table is the median annual flood runoff volume recorded for the period of record 1957 through 2011 for Walnut Gulch by the United States

[2] The HCAF is based on aerial photograph from 1935 to 2007. ADWR understands that the HCAF must be included within the delineation of the FHA. Like other parts of the FHA (excluding the active channel) the application of setbacks resulted in some portions of the HCAF not being included within the delineated subflow zone.
[3] Thomas, B.E., Hjalmarson, H.W., and Waltemeyer, S.D., 1997, "Methods for Estimating Magnitude and Frequency of Floods in the Southwestern United States: U.S. Geological Survey Water-Supply Paper 2433," 195 p.

Department of Agriculture Agricultural Research Service. Based on area sizes and available flood runoff data, these tributaries were determined to satisfy the Adjudication Court's direction regarding application of two-hundred foot setbacks. ADWR applied setbacks of 200-feet at the mouths of these twelve large ephemeral streams where there would be side recharge from a tributary aquifer, and 100-foot setbacks at other locations where there would be side recharge from basin fill. However, as directed by the Adjudication Court, ADWR did not apply these setbacks to bedrock-lined reaches or where application would result in exclusion of parts of the current active channel from the subflow zone.

3.3 SUBFLOW ZONE

After ADWR applied setbacks, ADWR mapped the lateral extent of the subflow zone of the San Pedro River, and its two main tributaries, the Babocomari River and Aravaipa Creek. The subflow zone maps are included in **Appendix C**.