CHAPTER 1: INTRODUCTION

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The Arizona Department of Water Resources ("Department" or "ADWR") prepared this supplemental report titled "Supplement to 2014 Subflow Zone Delineation Report" ("Supplemental Subflow Report") at the request of the Court for the Gila River General Stream Adjudication ("Gila River Adjudication").[1] Pursuant to A.R.S. §§ 45-251 to 264, the 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 all appropriable water under state law and water subject to claims based on federal law. Appropriable water includes surface water and certain subsurface water known as subflow.

1.1 2014 SUBFLOW REPORT

This report supplements a report filed by ADWR on April 1, 2014 entitled "Revised Subflow Zone Delineation Report for the San Pedro River Watershed" ("2014 Subflow Report"). In the 2014 Subflow Report, ADWR presented 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 system and source.

The 2014 Subflow Report is the fifth report that ADWR has prepared since 2002 related to the identification of subflow zones in the San Pedro River watershed. In the 2014 Subflow Report, ADWR described each of the preceding four reports as well as the Court decisions related to those reports and the 2014 Subflow Report. Copies of these

[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).

Court decisions were provided in Appendix A to the 2014 Subflow Report. Copies of ADWR's prior reports can be found at ADWR's web site.[2]

Both the 2014 Subflow Report and this Supplemental Subflow Report are based on the Court's October 12, 2012 Order ("2012 Order") in which the Court directed ADWR to revise a subflow zone delineation report that it issued in 2009 ("2009 Subflow Report"). In the 2014 Subflow Report, ADWR described its implementation of the Court's 2012 Order. That implementation is further explained in this Supplemental Subflow Report.

1.2 2012 COURT ORDER

In the 2012 Order, the Court directed ADWR to comply with certain requirements in the 2014 Subflow Report. Although the Court agreed with and adopted certain portions of the 2009 Subflow Report and found that the Arizona Geological Survey ("AZGS") had appropriately mapped the surficial geology along the San Pedro River, the Court also found that ADWR's analysis understated the extent of the floodplain because it did not take into account the existence of alluvial fans that cover much of the floodplain and adjacent basin fill. 2012 Order at p. 2, ¶¶ 6, 9; pp. 3-4 ¶ 19. The Court stated that the revised subflow zone delineation must have the following features:

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 [Floodplain Holocene Alluvium]; and

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

f. to the extent possible, interpret judicial pronouncements in a manner consistent with scientific fact.

2012 Order at p. 5, ¶ 2.

In determining what areas to include within the subflow zone, the Court 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;[3]

(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.

Id. at p. 5, ¶ 3. In order to comply with the 2012 Order, ADWR contracted with AZGS to consult on geologic settings and geomorphologic processes applicable to Holocene river alluvium, and to conduct investigations of sedimentary relationships at numerous sites along the San Pedro River, which ADWR used to delineate the lateral extent of the FHA. This process is described in Chapter 2 of the 2014 Subflow Report.

The Court also gave ADWR direction on the application of setbacks. The Court directed ADWR to apply them only in those instances where a hydraulic connection exists between the subflow zone and the surrounding material. *Id*. at p. 5, ¶ 4. The Court stated:

[3] "Pleistocene," "Tertiary," and "Holocene" are terms of art that refer to certain geologic periods of time.

> 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.

Id. at p. 4, ¶ 22.

> Two-hundred (200) foot setback 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 which have 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.

Id. at p. 4, ¶ 21. As described in Chapter 3 of the 2014 Subflow Report, ADWR developed a methodology for applying setbacks that was consistent with the 2012 Order and resulted in a continuous subflow zone.

1.3 SUPPLEMENTAL SUBFLOW REPORT

After ADWR issued the 2014 Subflow Report, several parties filed comments and/or objections, which were discussed at a hearing before the Court on November 6, 2014. During that hearing, ADWR indicated that it believed that providing additional information regarding the analyses presented in the 2014 Subflow Report would be of assistance to the Court and the parties.

This Supplemental Subflow Report further explains the analyses that ADWR used to implement the 2012 Order. Chapter 2 of this report describes ADWR's geomorphological inferences that ADWR used to determine the lateral extent of the FHA. Chapter 3 of this report presents segment-by-segment descriptions of procedures followed and information used to determine the lateral extent of the FHA, as well as the application of setbacks to determine the lateral extent of the subflow zone. The lateral extent of the subflow zone presented in the 2014 Subflow Report has been corrected to include the entire Historical Composite Active Floodplain.

As explained in Chapter 2 of this report, ADWR followed the directives of the 2012 Order by applying professional judgment to draw the necessary geomorphological inferences to determine the lateral extent of the FHA. "Professional Judgment" refers to judgment or opinion made in accordance with sound reasoning. The type of reasoning applied depends on the nature of the problem being solved. ADWR applied geomorphological reasoning based on the mapped geologic landforms of each watercourse's inner valley. In some locations, ADWR supplemented its geomorphological inferences by applying additional geologic or hydrologic reasoning based on other available information.

It is an accepted scientific principle that all geomorphological inferences have an inherent limit to their certainty. ADWR applied procedures intended to maximize certainty in determining the lateral extent of the FHA. ADWR's procedures are based on accepted principles of geology and geomorphology, and are supported by AZGS mapping as well as the other factors identified by the Court in the 2012 Order.

The inherent limit in the certainty of predictions made using the geomorphological inferences required to delineate the subflow zones in the San Pedro River watershed have been recognized by both the trial court for the Gila River Adjudication and Arizona Supreme Court. Even in 1994, when the trial court first concluded that the "weight of the evidence points to the saturated floodplain Holocene alluvium as the most credible 'subflow' zone," the trial court also noted that there is a frequent lack of data and many assumptions which cannot be fully proven. See June 30, 1994 Order at p. 58. The trial 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 pp. 63-64 (emphasis added).[4]

Upon review of the trial court's 1994 Order, the Arizona Supreme Court also acknowledged that "defining subflow in any particular area is a relative endeavor." The Court cautioned that prior court decisions defining subflow should not serve as straitjackets that prevent conformance to hydrologic reality, and that the line between surface and groundwater is to some extent, artificial and fluid. 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.**

[4] The trial court's order followed a ten-day evidentiary hearing with testimony from ten experts in geology and hydrology, two days traveling almost 600 miles and visiting 13 sites in the San Pedro River watershed, accompanied by counsel and experts, with a supplemental two-day hearing four months later. And yet, there remained limitations due to lack of data that could not be overcome.

In re the General Adjudication of All Rights to Use Water in the Gila River System and Source, 198 Ariz. 330, 340, 9 P.3d 1069, 1079 (emphasis added, brackets and ellipses in original).

In remarks made at the close of the three-day evidentiary hearing preceding the 2012 Order, the trial court acknowledged the inherent uncertainty in delineating the lateral extents of the FHA and the subflow zones. The Court stated:

> **Uncertainty in the delineated lateral extents of the FHA and the subflow zone cannot be avoided**, but they must be defensible at each location.

Transcript of proceedings at pp. 10-17 (emphasis added). In recognition of these limitations, the trial court directed ADWR to use its professional judgment to delineate the subflow zones in the San Pedro River watershed.

In order to delineate the FHA and the subflow zones of the San Pedro River, Babocomari River and Aravaipa Creek, ADWR made geomorphologic inferences based on scientific reality and professional judgment, which both the trial court and the Arizona Supreme Court have recognized are necessary parts of the process. This Supplemental Subflow Report explains in more detail the basis for the inferences that were made. Objections to the Supplement Subflow Report are due by April 2, 2015.

CHAPTER 2:
ANALYSES USED TO DETERMINE THE LATERAL EXTENT OF THE FHA AND SUBFLOW ZONE

CHAPTER 2: ANALYSES USED TO DETERMINE THE LATERAL EXTENT OF THE FHA AND SUBFLOW ZONE

2.1 INTRODUCTION

This chapter expands on descriptions provided in Chapters 2 and 3 of the 2014 Subflow Report and provides greater explanation of the analyses used by ADWR. In order to comply with the 2012 Order, ADWR determined the lateral extent of the FHA using the AZGS geology mapping, applying professional judgment in the form of geomorphological reasoning, and to the extent appropriate, considering the factors identified in the 2012 Order.

2.2 GEOMORPHOLOGICAL REASONING AND INFERENCE

ADWR contracted with the Arizona Geological Survey ("AZGS") to obtain information that ADWR could use as a basis for applying geomorphological reasoning to infer the lateral extent of the FHA. The information produced by the AZGS is contained in a report entitled, *Geology and Geomorphology of the San Pedro River.* In this report, the AZGS discusses the geologic setting and the geomorphological development and evolution within the San Pedro River watershed during the Holocene and Pleistocene epochs, including the physical setting of Holocene river deposits within the inner river valleys. This report is summarized in Chapter 2 of the 2014 Subflow Report, and the full document is included in Appendix B to the 2014 Subflow Report.

Based on the AZGS mapping and other factors described in the 2012 Order, ADWR used geomorphological reasoning and inference to delineate the lateral extent of the FHA. Such reasoning and inference was necessary due to the scale and complexity of the landforms characteristic of the inner river valleys of the San Pedro River watershed.

Victor R. Baker,[1] renowned geomorphologist and University of Arizona Regents' Professor of Hydrology and Water Resources, explained that geomorphological reasoning relies heavily on inference, which reasons from real effects to real causes, eventually bringing together facts under a conceptual scheme (hypothesis). Causative processes are inferred retroductively for geomorphological indices, such as landforms and sediments. Baker observed that controlled experiments are not possible in much of the Earth sciences, including geomorphology, due to the complexity of the system.

> Shamos (1995, p. 96) makes the point this way: ... In general, as a science matures, it passes first through a purely descriptive stage, then proceeds to an experimental stage, and finally, as meaningful patterns are seen to emerge, to a theoretical stage, where one usually finds it highly productive to use the language of science (mathematics) to describe natural phenomena and uncover new knowledge. Physics and chemistry are already at this final stage; biology and Earth science, involving as they do far more **complex systems**, have been slower to mature to this level.
>
> ***
>
> Controlled experiments, at least for the most interesting phenomena, are not possible in much of the Earth sciences, including geomorphology. Instead of the detached objectivity of sterile laboratories, **the geomorphologist must be concerned with the open problem of the field, in which nature is 'taken as it is**.'

Baker (1996, pp. 59, 80) (emphasis added, ellipses supplied.) The development and evolution of differing geologic landforms over long periods of time are examples of these "far more complex systems," and it is those systems, taken as they are, that ADWR was required to analyze to determine the lateral extent of the FHA.

ADWR applied geomorphological reasoning based on well-understood cause-effect relationships and designed certain procedures intended to maximize certainty

[1] Baker, V.R., 1996, Chapter 4 - Hypotheses and Geomorphological Reasoning, *The Scientific Nature of Geomorphology: Proceedings of the 27th Binghamton Symposium in Geomorphology*, edited by Bruce L. Rhoads and Colin E. Thorn, pp. 57-85.

in determining the lateral extent of the FHA. ADWR's approach is rooted in fundamental physical processes and allows depositional patterns of the FHA to be efficiently inferred at the spatial scale of the landforms shaped by these processes.

The geomorphological principle of "equifinality" suggests that similar landforms might have evolved or developed from different initial conditions in different ways by possibly different processes. A consequence of this principle is that some unavoidable limitation in inference and prediction is common to all geomorphological hypotheses (Beven, 1996).[2] For example, the locations of the lines of contact shown on the geologic mapping are limited in accuracy by the AZGS to plus or minus 25, 50, or 250 feet, depending on how distinct, gradual or obscured the topographic feature marking the transition. In addition, delineating the lateral extent of the FHA is limited by the prevalence of mapped non-FHA alluvium at certain locations. Inference of the extent of this non-FHA alluvium is unavoidable due to lack of information regarding the number of potential facts that Baker (1996) described as "presumed to be endless in number and bewildering in complexity."[3] These limitations are inherent and cannot be eliminated, although they can be reduced through use of geomorphological inferences drawn from certain well-conceived cause-effect relationships.

As directed by the 2012 Order, ADWR exercised professional judgment and drew geomorphological inferences from the depositional history of the alluvial deposits in the San Pedro River watershed based on accepted principles of geology and geomorphology. ADWR delineated the lateral extent of the FHA as a stable geologic feature that includes the full extent of known or inferred deposits of FHA.

[2] Beven, K., Chapter 12 - Equifinality and Uncertainty in Geomorphological Modelling, *The Scientific Nature of Geomorphology: Proceedings of the 27th Binghamton Symposium in Geomorphology,* edited by Bruce L. Rhoads and Colin E. Thorn, pp. 289-313.

[3] Baker (1996, p. 58).

2.3 DETERMINING THE LATERAL EXTENT OF THE FHA

ADWR determined the lateral extent of the FHA using the AZGS surface geology mapping, geomorphological reasoning based on the eroded form of the pre-Holocene bounding topography, and to the extent appropriate, considering certain factors identified by the Court in the 2012 Order. ADWR determined the lateral extent of the FHA in three steps, as follows:

Step 1. *Identification of FHA where observed to be deposited directly against pre-Holocene bounding topography (Section 2.3.1).* This step applies to locations where surface exposures of the FHA are deposited directly against pre-Holocene bounding topography and no tributary Holocene alluvium ("THA") deposits are present. At these locations, ADWR determined the lateral extent of the FHA using the AZGS geology mapping alone.

Step 2. *Identification of FHA where river erosion and deposition predominates (Section 2.3.2).* This step applies to locations where the lateral extent of the FHA is obscured by THA, lateral river erosion and deposition have been the predominant processes shaping the pre-Holocene bounding topography, and effects of tributary erosion and deposition have been relatively minor. At these locations, ADWR determined the lateral extent of the FHA using the AZGS geology mapping coupled with geomorphological reasoning based on the width, linearity and degree of crenulation of the pre-Holocene bounding topography.

Step 3. *Identification of FHA where tributary erosion and deposition is significant (Section 2.3.3).* This step applies to locations where the lateral extent of the FHA is obscured by THA, and tributary erosion and deposition have significantly shaped the evolved landforms. At these locations, ADWR determined the lateral extent of the FHA using the AZGS geology mapping coupled with geomorphological reasoning based on the form and character of the pre-Holocene bounding topography and supplemented with geologic and/or hydrologic reasoning based on factors identified by the Court in the 2012 Order.

The delineation of the FHA using these three steps is depicted on map sheets in **Appendix A** to this report.

2.3.1 Step 1 - FHA Deposited Against Pre-Holocene Topography

In this first step, ADWR determined the lateral extent of the FHA at locations where surface exposures of the FHA are deposited directly against pre-Holocene bounding topography and no THA deposits are present.

A. ADWR determined that the lateral extent of the FHA coincides with mapped lines of contact between FHA and bounding topography; or where the historic composite active floodplain (1935-2007) establishes such contact during recent history.

B. These delineations are commonly associated with a distinct topographic feature for which the mapped location is estimated to be accurate by the AZGS to within 50 feet (+/- 25 feet).

2.3.2 Step 2 - Lateral River Erosion and Deposition Predominates

In this second step, ADWR determined the lateral extent of the FHA at locations where lateral erosion and deposition by the river has been the predominant process while tributary erosion and deposition have played a relatively minor role in shaping the bounding topography. These locations commonly exhibit one, both or some combination of the following characteristics:

A. Narrow, well-defined inner valley with linear to curvilinear alignment that parallels the general trend of the river course; steep topographic slope breaks form the margins of the inner valley with small and narrow tributary valleys; and fringes of THA deposits and visible alluvial fans along the margins of the inner valley.

(1) ADWR reasoned that during the past 10,000 years of the Holocene epoch, the river has shaped the bounding topography and deposited FHA directly against it. THA has since been deposited on top and buried the FHA.

(2) ADWR determined that the lateral extent of the FHA coincides with AZGS mapped lines of contact between THA and pre-Holocene bounding topography.

(3) ADWR expected some deviations in form and character of the bounding topography and determined that the FHA delineation smoothly bridges these deviations, when they do occur. These delineations are commonly associated with a distinct topographic feature for which the mapped location is estimated to be accurate by the AZGS to within 50 feet (+/- 25 feet).

B. Less narrow and defined inner valley formed by exposures of eroded ridges, spines or knobs with linear to curvilinear alignment that parallels the general trend of the river course; less steep topographic slope breaks set back in places from the margins of the inner valley forming relatively small tributary valleys and making the bounding somewhat crenulated.

(1) ADWR reasoned that during the past 10,000 years of the Holocene epoch, the river has shaped and deposited FHA directly against much if not all of the bounding topography.

(2) ADWR reasoned that tributary erosion and deposition has contributed to widening the inner valley and eroding pre-Holocene bounding topography thereby creating ridges, spines or knobs in the bounding deposits.

(3) ADWR reasoned that during the past 10,000 years of the Holocene epoch, alluvium deposited along the margins of the inner valley are formed by dynamic interaction between river and tributary processes and likely consist of a complex inter-fingering of FHA and THA.

(4) ADWR reasoned that there is a potential for a limited extent of bounding topography to be buried by only a thin mantle of THA deposits along the outer edge of the widened inner valley.

(5) ADWR reasoned that if tributary erosion and deposition has contributed to widening the inner valley and there are eroding ridges, spines or knobs in the bounding deposits, then there is a potential that a limited extent of bounding topography is buried beneath a thin mantle of THA deposits at the outer edge of the widened inner valley.

(6) In order to account for the potential of a limited extent of bounding topography buried beneath a thin mantle of THA deposits at the outer edge of the widened inner valley, ADWR determined that the lateral extent of the FHA should be limited to coincide with a smooth line drawn tangent to mapped inward-leading exposures of ridges, spines or knobs of the pre-Holocene bounding topography.

(7) These delineations are most commonly associated with a distinct topographic feature for which the mapped location is estimated to be accurate by the AZGS to within 50 feet (+/- 25 feet), but in some locations the feature may be more gradual for which the mapped location is estimated to be accurate by the AZGS to within 100 feet (+/- 50 feet).

2.3.3 Step 3 – Tributary Erosion and Deposition is Significant

In this third and final step, ADWR determined the lateral extent of the FHA at the remaining locations where tributary erosion and deposition have significantly contributed to the form and character of the inner valley. At these locations, in addition to the AZGS geology mapping coupled with geomorphological reasoning, ADWR reviewed and analyzed other available information to supplement ADWR's determination of the lateral extent of the FHA with additional geologic and hydrologic reasoning. These locations commonly exhibit one, both or some combination of the following characteristics:

A. The bounding topography has been carved back or embayed from the inner valley forming relatively wide tributary valleys and large crenulations in the bounding topography surrounded by mantles of THA deposits. For much of the watershed, these locations are minor river segments appearing as small gaps in the delineations already completed in the first two steps.

(1) ADWR reasoned that during the past 10,000 years of the Holocene epoch, the river has made substantial lateral incursions and deposited FHA into these areas.

(2) ADWR reasoned that a combination of river and tributary processes has embayed or carved the bounding topography back from the inner valley and has formed eroded ridges, spines or knobs in the geologic deposits that may not be exposed.

(3) ADWR reasoned that tributary erosion and deposition has incised tributary valleys into bounding deposits making the topography more crenulated and that deposits within these tributary valleys are predominately THA.

(4) ADWR reasoned that during the past 10,000 years of the Holocene epoch, alluvium deposited along the margins of the inner valley are formed by dynamic interaction between river and tributary processes and likely consist of a complex inter-fingering of FHA and THA.

(5) ADWR determined that the lateral extent of the FHA extends beyond the inner valley but may not fully extend to a smooth line drawn tangent to mapped inward-leading exposures of ridges, spines or knobs of the pre-Holocene bounding topography.

(6) ADWR determined that the lateral extent of the FHA transverses THA deposits between fixed end-points established by adjacent

delineations in Steps 1 and 2. The lateral extent of the FHA follows a path inferred from: (1) location-specific width, linearity and crenulation of the bounding deposits; (2) findings of site-investigations in tributary drainages; (3) width, orientation and pattern of adjacent delineations; (4) review of photo-imagery and riparian vegetation growth patterns; and (5) analysis of soil lithology logs, if available.

(7) These delineations are most commonly associated with a gradual topographic feature for which the mapped location is estimated to be accurate by the AZGS to within 100 feet (+/- 50 feet), but in some locations the feature may be more obscured for which the mapped location is estimated to be accurate by the AZGS to within 500 feet (+/- 250 feet).

B. The bounding topography has been eroded or embayed far back from the inner valley and is separated from the FHA deposits by a wide, spatially-complex mantle of THA deposits. These locations cover extensive reaches of the river near the Towns of Benson and St. David.

(1) ADWR reasoned that during the past 10,000 years of the Holocene epoch, the river did not directly shape the bounding topography by lateral erosion in these areas.

(2) ADWR reasoned that tributary processes were predominant, eroding or embaying the bounding topography far back from the inner valley, and forming eroded ridges, spines or knobs in the geologic deposits, if any deposits are exposed above the mantle of THA deposits.

(3) ADWR reasoned that tributary erosion and deposition has incised wide tributary valleys into bounding deposits making the topography more crenulated and that deposits within these tributary valleys are predominately THA.

(4) ADWR determined that the lateral extent of the FHA extends beyond the inner valley but almost certainly does not fully extend to a smooth line drawn tangent to mapped inward-leading exposures of ridges, spines or knobs of the pre-Holocene bounding topography.

(5) ADWR further determined that the lateral extent of the FHA transverses THA deposits (between fixed end-points established by adjacent delineations) following a path inferred from: (1) location-specific width, linearity and crenulation of the bounding deposits; (2) findings of site-investigations in tributary drainages; (3) width, orientation and pattern of adjacent delineations; (4) review of photo-imagery and riparian vegetation growth patterns and (5) analysis of soil lithology logs, selected well driller logs and water levels in wells.

(6) These delineations are commonly associated with an obscured topographic feature for which the mapped location is estimated to be accurate by the AZGS to within 500 feet (+/- 250 feet).

2.4 VERIFICATION OF ADWR'S GEOMORPHOLOGICAL INFERENCES

The inferences drawn from ADWR's geomorphological reasoning are verified by findings of field geology investigations in the AZGS report entitled, *Site Investigation of Tributary Drainages to the San Pedro River* ("AZGA Site Investigation Report"). A copy of this report is provided in Appendix B-3 to the 2014 Subflow Report.

The AZGS Site Investigation Report, produced by the same experienced geologists who mapped the surface geology, presents stratigraphic interpretations of the exposed sedimentary relationships from sites of exposed tributary channel deposits along the boundary with the active river. The investigation included 25 sites located in both the upper and Lower San Pedro River valleys, with the majority located in the upper valley where the bounding topography of inner valley is, in general, less well-defined. ADWR accompanied the AZGS during the investigations of 12 sites. The locations of the sites investigated are depicted on the map sheets in **Appendix A**.

Tables 2-1A and **2-1B** in this Supplemental Subflow Report describe findings at the 25 sites investigated along the right and left margins (looking downstream) of the San Pedro River. The number of sites investigated was limited by time and difficulty of access in many places.

The far right column of each table analyzes whether the reported findings support or do not support the inferences drawn from ADWR's geomorphological reasoning. Results of the verification analysis can be summarized as follows:

- Support for ADWR's inferences is found at 12 sites where exposed alluvial deposits are identified as FHA.
- Consistency with ADWR's inferences is found at 4 sites where exposed alluvial deposits are identified as being consistent with FHA and/or THA.
- There were inconclusive findings at 9 sites where no observations were made due to lack of exposed alluvial deposits.

At every site where observations could be made, the findings of field investigations are consistent with the inferences drawn from ADWR's reasoning and three-quarters of those sites provide direct support for those inferences. None of the investigated site showed findings inconsistent with the geomorphological inferences made by ADWR.

2.5 ANALYSES OF SOIL LITHOLOGY AND DRILLER'S LOGS

In compliance with the 2012 Order, ADWR reviewed and analyzed soil lithology data from wells and other borings. The soil lithology data was used to further support ADWR's geomorphological inferences at locations where erosion and deposition by the river has predominately shaped the bounding topography (Step 2 from Section 2.3).

Where tributary deposition and erosion has been more significant in shaping the bounding topography (Step 3 from Section 2.3), available data supplemented geology mapping and geomorphological reasoning. To a limited extent, in the vicinity of four river segments, ADWR also analyzed driller's logs.

2.5.1. Professional-level Lithology Logs

As described in the 2014 Subflow Report, ADWR utilized information from soil lithology logs prepared by individuals trained in soil identification and classification techniques. ADWR distinguished these "professional-level lithology logs" from generally less-reliable "driller's logs" based on either (1) statements of qualification or (2) the logged entries indicative of trained individuals. A listing of 167 professional-level lithology logs reviewed by ADWR is provided in Appendix D-1 to the 2014 Subflow Report.

ADWR divided the lithology logs into three groupings based on location and mapped geologic deposits, as follows:

- One-hundred and twenty-four (124) lithology logs at locations mapped as FHA ("FHA-Logs");
- Twenty-nine (29) lithology logs at locations mapped as THA within the inner river valley ("THA-Logs"); and
- Fourteen (14) lithology logs at locations outside the inner river valley.

ADWR limited its analysis to the groupings of FHA-Logs and THA-Logs, which describe similar lithologies common to alluvial deposits that are characterized by inter-bedded layers of sands, gravels, silts and clays. However, both sets of logs lacked detailed information regarding changes in soil particle angularity and degree of carbonate cementation, and therefore could not be used to directly distinguish FHA from THA nor Holocene from latest Pleistocene river alluvium at depth. Typically, basin-fill deposits, when encountered were logged as thick deposits of clay described by their red color, dense hardness and high plasticity.

Tables 2-2A and **2-2B** in this Supplemental Subflow Report show results of ADWR's analysis of FHA-Logs for wells drilled in the upper and lower San Pedro River valleys, respectively. In the upper San Pedro River valley, **Table 2-2A** lists a total of 93 logs. Of those, 55 logs show alluvial deposits between 25 and 70 feet thick, 27 logs with less than 25 feet, and 11 logs show 70 feet or more. Only three of the drillings, each with more than 70 feet of alluvium, logged the contact with basin-fill deposits. The remaining 90 FHA-Logs for wells drilled in the upper San Pedro River valley were stopped short of reaching basin-fill and represent minimum thicknesses of alluvium.

In the lower San Pedro River valley, **Table 2-2B** lists a total of 31 logs. Of those, 16 logs show alluvial deposits less than 25 feet, 9 logs between 25 and 70 feet thick, and 6 logs with 70 feet or more. Only two of the drillings, each with more than 70 feet of alluvium, logged the contact with basin-fill deposits. The remaining 29 FHA-Logs for wells drilled in the lower San Pedro River valley were stopped short of reaching basin-fill and therefore represent minimum alluvial thicknesses.

Tables 2-3A and **2-3B** in this Supplemental Subflow Report show results of ADWR's analysis of THA-Logs drilled in the upper and lower San Pedro River valleys, respectively. In the upper San Pedro River valley, **Table 2-3A** lists a total of 10 logs. Of these, 5 logs show alluvial deposits between 25 and 70 feet thick, 3 logs with 70 feet or more, and 2 logs show less than 25 feet. Only three of the drillings, two with more than 70 feet of alluvium and one with 47 feet, logged the contact with basin-fill deposits. The remaining seven THA-Logs for wells drilled in the upper San Pedro River valley were stopped short of reaching basin-fill and represent minimum thicknesses of alluvium.

In the lower San Pedro River valley, **Table 2-3B** lists a total of 19 logs. Of these, 9 logs show alluvial deposits with more than 70 feet of alluvium, 6 logs show between 25 and 70 feet, and 4 logs less than 25 feet. Only three of the drillings, each with more than 70 feet of alluvium, logged the contact with basin-fill deposits. The remaining 16 lithology logs in the lower San Pedro River valley were stopped short of reaching basin-fill and therefore represent minimum alluvial thicknesses.[4]

The locations of the wells where ADWR analyzed professional-level FHA-Logs and THA-Logs are depicted on the map sheets in **Appendix A**. Copies of the FHA-Logs and THA-Logs are provided in **Appendix B**.

2.5.2. Well Driller's Logs

As described in the 2014 Subflow Report, ADWR also analyzed data from selected driller's logs for wells completed in locations mapped as THA deposits near four short segments of the river where the bounding topography is far back from the inner valley and separated from the FHA by a wide mantle of THA deposits. These segments are located in the vicinity of river miles 112 to 109, 106 to 104, 99 to 96, and 89 to 86. Although the reliability of driller's logs generally is less than that of professional-level lithology logs in determining the lateral extent of the FHA, well driller's logs are useful in certain locations. A listing of 273 driller logs reviewed by ADWR is provided in Appendix D-2 to the 2014 Subflow Report.

Tables 2-4A through **2-4D** in this Supplemental Subflow Report show results of ADWR's analysis of driller's logs for wells completed in mapped THA deposits in the vicinities of river miles 112 to 109, 106 to 104, 99 to 96, and 89 to 86, respectively.

For river miles 112 to 109, a total of 14 driller logs were identified for wells completed in locations mapped as THA. **Table 2-4A** lists 13 logs showing 70 feet or more, one log with less than 25 feet, and no logs showing alluvial deposits between 25 and 70 feet thick. Ten of the drillings, 9 of which had more than 70 feet of alluvium, logged the contact with basin-fill deposits. The remaining 4 logs were stopped short of reaching basin-fill and represent minimum thicknesses of alluvium.

[4] For example, THA-Log No. 124 drilled near River Mile 29 shows alluvial deposits to a drilled depth of 1,410 feet and no contact with basin-fill deposits.

For river miles 106 to 104, a total of 100 driller logs were identified for wells completed in locations mapped as THA. **Table 2-4B** lists 49 logs showing 70 feet or more, 29 logs showing alluvial deposits between 25 and 70 feet thick, and 20 logs with less than 25 feet. Two of these driller logs were not legible so the thickness of alluvium could not be determined. A total of 90 of the drillings logged the contact with basin-fill deposits. The remaining eight logs were stopped short of reaching basin-fill and represent minimum thicknesses of alluvium.

For river miles 99 to 96, a total of 40 driller logs were identified for wells completed in locations mapped as THA. **Table 2-4C** lists 18 logs showing alluvial deposits between 25 and 70 feet thick, 14 logs showing 70 feet or more, and 7 logs with less than 25 feet. One of these driller logs was not legible so the thickness of alluvium could not be determined. A total of 25 of the drillings logged the contact with basin-fill deposits. The remaining 14 logs were stopped short of reaching basin-fill and represent minimum thicknesses of alluvium.

For river miles 89 to 86, a total of 21 driller logs were identified for wells completed in locations mapped as THA. **Table 2-4D** lists 10 logs showing 70 feet or more, 6 logs showing alluvial deposits between 25 and 70 feet thick, and 5 logs with less than 25 feet. A total of 18 of the drillings logged the contact with basin-fill deposits. The remaining three logs were stopped short of reaching basin-fill and represent minimum thicknesses of alluvium.

The locations of the wells where ADWR analyzed well driller logs are depicted on the map sheets in **Appendix C**.[5] Copies of these logs are provided in **Appendix D**.

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[5] Well locations in ADWR's wells registry are described as centroids of 10-acre squares. If more than one well is drilled within the same 10-acre area, they will plot at the same location when mapped. Wells shown on these figures are identified by "Location ID Nos." listed in **Tables 2-4A through 2-4D**, which in some cases identify more than one well.

2.6 ANALYSES OF WATER LEVELS IN WELLS

The depositional history of alluvial deposits can be evaluated through consideration of the hydrologic properties for alluvium having different depositional histories. The direction and magnitude of flowing water is related to the gradient in potential energy and the resistance to flow provided by the aquifers of porous media.

In order to identify the flow gradients characteristic of the aquifer-units, ADWR analyzed water levels measured at wells along the lowest 32-mile reach of the upper San Pedro River valley. Between river miles 114 and 82, the inner valley is characterized by frequent and extensive reaches of the bounding topography separated from the FHA by a wide mantle of spatially-complex THA. In this area there are fewer locations available where the general trend of the inner valley and FHA deposits can be inferred directly from exposed geologic contacts and the form of the bounding topography (Steps 1 and 2 from Section 2.3). This section provides further description of the datasets selected and procedures followed by ADWR.

ADWR reviewed available data and considered several factors in selecting the input data, including:

- Number of wells;
- Spatial coverage of wells;
- Duration of time between measurements;
- Influence of seasonal pumping; and
- Selection of multiple time-frames.

Using these factors, ADWR selected the following three datasets based on data collected during 1990, 2006, and 1998:

1. 1990 Dataset: water levels measured at 75 wells between 11/26/1990 and 11/29/1990.
    a. 29 FHA-Wells.
    b. 13 THA-Wells on the west side of the river.
    c. 33 THA-Wells on the east side of the river.

2. 2006 Dataset: water levels measured at 53 wells between 11/27/2006 and 12/14/2006.
    a. 20 FHA-Wells.
    b. 9 THA-Wells on the west side of the river.
    c. 24 THA-Wells on the east side of the river.
3. 1998 Dataset: water levels measured at 33 wells between 03/01/1968 and 04/03/1968.
    a. 12 FHA-Wells.
    b. 3 THA-Wells on the west side of the river.
    c. 18 THA-Wells on the east side of the river.

In the subflow report prepared by ADWR in 2012, ADWR explains that in some locations there are too few measurements; the measurements that do exist are too widely spaced; and the flow properties of FHA, THA and latest Pleistocene river alluvium are too similar to discern locations of geologic contacts via calculation of flow gradients using measured water levels. For those areas, ADWR used a comparative analysis, which is described in the 2014 Subflow Report.

For each of the three datasets described above, ADWR first calculated the effective downstream gradient using best-fit linear regression on the water levels measured only in the FHA-Wells. Statistical measures of the 50, 75 and 95 percent confidence intervals were also computed for each regression. For each dataset, the FHA-Well data values were plotted with regression best-fit and confidence interval lines. Next, ADWR plotted the THA-Well data values on the best-fit and confidence intervals lines derived from the FHA-Wells. **Appendix E** to this Supplemental Subflow Report provides the following information for the 1990, 2006 and 1968 data analyses, respectively:

- Locations of FHA-Wells and THA-Wells;
- GWSI Site IDs for FHA-Wells and THA-Wells;
- Measured water level elevations for FHA-Wells and THA-Wells;

- Best-fit regression line with 50%, 75% and 95% confidence intervals based on FHA-Well data points, plotted separately with:
    - FHA-Well data points,
    - THA-Well data points on west side of river, and
    - THA-Well data point on east side of river.

The regression best-fit line represents the overall downstream gradient of the saturated FHA predicted using only measurements at wells completed in areas mapped as FHA. The confidence interval lines estimate expected variations in the accuracy of that prediction for statistical significance levels of 50, 25 and 5 percent. By comparing the FHA-Well and THA-Well data separately on the identical plots, ADWR was able to identify trends in similarities or differences between the frequency and magnitude of variation in flow gradients characteristic of the aquifer-units sampled independently by wells drilled in areas mapped as FHA versus those drilled in the THA on the west and east sides of the river. Copies of spreadsheets documenting the linear regression analyses are provided in **Appendix F** to this report.

2.7 APPLYING SETBACKS TO THE LATERAL EXTENT OF THE FHA TO DELINEATE THE LATERAL EXTENT OF THE SUBFLOW ZONE

In compliance with the 2012 Order, ADWR delineated the lateral extent of the subflow zone by applying certain setbacks to the lateral extent of the FHA using the analyses previously described. The 2014 Subflow Report describes the application of setbacks. ADWR did not apply setbacks at locations where the lateral extent of FHA shares a contact with mapped bedrock. At all other locations, ADWR performed the following series of steps:

1. Draw the 100-foot setback line;
2. Draw the 200-foot setback line;

3. At their confluences with the San Pedro River, project the lateral extents of the twelve largest ephemeral tributary drainages inward where they intersect both the 100-foot and 200-foot setback lines;
4. Draw the initial subflow line by following the transitions between the 100-foot and 200-foot setback lines projected in Step 3;
5. Truncate the initial subflow line as needed to include every part of the Historic Composite Active Floodplain (HCAF); and
6. Use straight-line transitions to close any gaps at bedrock-lined or truncated setbacks.

Figure 2-1 illustrates the process ADWR used to apply the 100-foot and 200-foot setbacks. Applications of setbacks to determine the lateral extent of the subflow zone are described in Chapter 3 of this report. The delineation of the lateral extent of the subflow zone is presented on the map sheets included in **Appendix G** to this report.

CHAPTER 3:
LATERAL EXTENT OF THE FHA AND SUBFLOW ZONE

CHAPTER 3: LATERAL EXTENT OF THE FHA AND SUBFLOW ZONE

3.1 INTRODUCTION

In Chapter 2, ADWR described the analyses that were used to determine the lateral extent of the FHA and subflow zone in the San Pedro River watershed. This chapter presents the results of those analyses.

3.2 ANALYSES RESULTS FOR FHA DELINEATION

Using Steps 1, 2, and 3 described in Chapter 2, ADWR analyzed approximately 394 miles along the San Pedro River, the Babocomari River, and Aravaipa Creek. In **Table 3-1,** ADWR lists 17 river segments covering the San Pedro River watershed and the steps that were used to analyze those segments for the delineation of the lateral extent of FHA.

ADWR applied Step 1 of its analyses and identified [126.7] miles (32%) where FHA deposits touch the bounding pre-Holocene topography. These are the only locations in the watershed where the lateral extent of the FHA is observable on the surface and include both river valley sides.

ADWR applied Step 2 of its analyses and identified [198.9] miles (51%) where the lateral extent of the FHA is not observable on the surface, but where ADWR could infer the extent of FHA deposits from the development and evolution of landscapes represented on the geology maps.

ADWR applied Step 3 of its analyses and identified [68.1] miles (17%) where the lateral extent of the FHA is not observable on the surface, and where ADWR could not infer the extent of FHA deposits from the development and evolution of landscapes represented on the geology maps. As part of the Step 3 analysis, ADWR used the fixed end-points and end-slopes from adjacent locations of FHA deposits that were delineated in Steps 1 and 2 and examined other available data and information, which is described in Chapter 2.

3.3 PRESENTATION OF THE LATERAL EXTENT OF THE FHA

ADWR's delineations of the lateral extent of the FHA and subflow zone are presented in 17 segments covering the watershed as follows:

- San Pedro River Miles 157 to 143;
- San Pedro River Miles 143 to 131;
- San Pedro River Miles 131 to 118;
- San Pedro River Miles 118 to 104;
- San Pedro River Miles 104 to 91;
- San Pedro River Miles 91 to 77;
- San Pedro River Miles 77 to 63;
- San Pedro River Miles 63 to 50;
- San Pedro River Miles 50 to 37;
- San Pedro River Miles 37 to 24;
- San Pedro River Miles 24 to 11;
- San Pedro River Miles 11 to 0;
- Aravaipa Creek Miles 37 to 26;
- Aravaipa Creek Miles 26 to 8;
- Aravaipa Creek Miles 8 to 0;
- Babocomari River Miles 22 to 7; and
- Babocomari River Miles 0 to 7.

Table 3-1 demonstrates that overall, approximately 83% of the total river mile length of lateral extent of FHA determined in the watershed was determined by ADWR in Steps 1 and 2. Notably, by using Steps 1 and 2 alone, the lateral extent of the FHA was determined for over 98% of the Babocomari River. ADWR applied Step 3 to the remaining 17% of the locations.

Appendix A provides ANSI D[1] map sheets with information and data displayed at a resolution of 1:24,000 for each of the 17 segments used for presenting the data sets in this report. Each "FHA Sheet" displays the following information, as applicable:

- Different sub-segments of the FHA lines color-coded to identify locations where the FHA determinations were completed in Steps 1, 2 or 3. The upstream-and-downstream terminal points for each sub-segment are identified to the nearest tenth of a mile;
- Table for each side of the watercourse showing the length in feet of each sub-segment of the FHA lines for Steps 1, 2, and 3;
- 2010 National Agriculture Imagery Program (NAIP) photo-imagery;
- 2009 AZGS geology mapping;
- 2011 ADWR historical composite active floodplain (1935-2007);
- 2014 AZGS tributary investigation sites;
- U.S. Fish & Wildlife Service riparian vegetation growth data for cottonwood/willow trees and mesquite/salt cedar trees; and
- Professional-level soil lithology logs drilled in locations mapped as FHA or THA within the inner river valley.

An example of one of the FHA Sheets is presented in **Figure 3-1** for illustrative purposes.

Additional information is presented on map sheets in **Appendix C** and **Appendix E**. **Appendix C** provides ANSI D sheets with information and data for the driller logs mapped as THA within the inner valley between San Pedro River miles 112 to 86 as described in Section 2.5.2. **Appendix E** provides ANSI D sheets with information and data for water levels in wells between San Pedro River miles 114 to 82 as described in Section 2.6.

[1] 22 inches x 34 inches.

3.4 PRESENTATION OF THE LATERAL EXTENT OF THE SUBFLOW ZONE

The Subflow Sheets for each of the 17 segments display the following information, as applicable:

- Extent of the FHA based on the FHA Sheets;
- 2010 National Agriculture Imagery Program (NAIP) Photo-Imagery;
- 2009 AZGS geology mapping;
- 2011 ADWR historical composite active floodplain (1935-2007);
- Large tributary drainages where 200-foot setbacks were applied; and
- Extent of the subflow zone.

An example of one of the Subflow Sheets is presented in **Figure 3-2** for illustrative purposes. **Appendix G** provides ANSI D sheets with information and data for the subflow zone displayed at a resolution of 1:24,000 for each of the 17 segments.

The subflow zone presented on the Subflow Sheets reflects corrections made by ADWR at locations where certain areas of the HCAF were unintentionally excluded in the 2014 Subflow Report. This process, as well as the process of applying setbacks, resulted in some angular reaches in the subflow zone, which could be smoothed out in future mapping.

3.5 SUMMARY

In the majority of the locations, ADWR was able to rely solely on AZGS geology mapping and reasoning based on that mapping to identify FHA deposits (Steps 1 and 2). In the remaining areas, ADWR also relied on AZGS geology mapping and reasoning based on that mapping, and in addition used its professional judgment in interpreting other available information and data (Step 3). This process involved geomorphological reasoning and inference, which by their nature had inherent limitations due to the complexity of landforms in the San Pedro River watershed.