Chapters

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

The Arizona Department of Water Resources (Department or ADWR) prepared this technical report titled "Delineation of Subflow Zones in the San Pedro River Watershed" (Subflow Zone Delineation Report) at the request of the adjudication court in a judicial proceeding known as the Gila River Adjudication, *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. W1-103. This judicial proceeding is pending in the Superior Court for Maricopa County.

As part of the Gila River Adjudication, ADWR provides both administrative and technical assistance to the adjudication court. ADWR provides administrative assistance on an ongoing basis by: (1) notifying existing and potential water right claimants of judicial proceedings, (2) maintaining a central repository of information, including an electronic database, concerning water right claims and other documents filed with the adjudication court, (3) transmitting water right claims and fees to the adjudication court, and (4) responding to public inquiries. ADWR provides technical assistance to the adjudication court at the court's request by: (1) gathering records and data, (2) investigating water uses and claims, and (3) preparing technical reports on a variety of matters, including hydrographic survey reports (HSRs) for watersheds and Indian reservations. ADWR's administrative and technical assistance is provided pursuant to statute and court order.

The Subflow Zone Delineation Report presents a series of maps that delineate the subflow zones for the San Pedro and Babocomari Rivers, and Aravaipa Creek, together with related information. **Figure 1-1** is a general location map that depicts the San Pedro River Watershed and the location of major streams, towns and roads in the area.

1.2 HISTORY OF PROCEEDINGS

Pursuant to A.R.S. §§ 45-251 to 264, the adjudication court must determine the extent and priority of the rights of persons to use waters of the Gila River system and source, which includes all appropriable water and water subject to claims based on federal law. Appropriable water includes surface water and certain subsurface water referred to as subflow. This technical report is part of the litigation to identify those wells in the San Pedro River Watershed that are subject to the adjudication.

1.2.1 *Southwest Cotton*

In a seminal case decided in 1931, the Arizona Supreme Court defined subflow 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." The Arizona Supreme Court further held that underground water withdrawn from a well is presumed to be percolating groundwater, and one who asserts that it is subflow must demonstrate that assertion by clear and convincing evidence. *See Maricopa County Municipal Water Conservation Dist. No. 1 v. Southwest Cotton Co.*, 39 Ariz. 65, 85, 96, 4 P.2d 369, 376, 380 (1931), *modified and reh'g denied*, 39 Ariz. 367, 7 P.2d 254 (1932) (*Southwest Cotton*).

As for a legal test to determine whether subsurface waters constitute subflow, the *Southwest Cotton* court stated:

> The best test which can be applied to determine whether underground waters are as a matter of fact and law part of the surface stream is that there cannot be any abstraction of the water of the underflow without abstracting a corresponding amount from the surface stream, for the reason that the water from the surface stream must necessarily fill the loose, porous material of its bed to the point of complete saturation before there can be any surface flow. Therefore the river bed must continue holding sufficient surface water to support the surface stream, as it were, for otherwise in drawing on the underground flow of the stream it will necessarily draw upon the waters flowing on the surface.
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> But considered as strictly a part of the stream, the test is always the same: 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 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 380-81. This test is often referred to as the Direct and Appreciable Test.

Many years after the *Southwest Cotton* decision, subflow was identified as an issue in the Gila River Adjudication. In 1987, the adjudication court held hearings on the relationship between surface water and groundwater, after which several parties filed motions to exclude certain wells from the adjudication arguing that they pumped percolating groundwater rather than subflow. In 1988, after hearing argument on the motions, the adjudication court held that certain wells withdrawing water from the younger alluvium of a stream 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). In 1991, as directed by the adjudication court, ADWR relied upon the 50%/90-day test for the preparation of the final San Pedro River Watershed HSR.

1.2.2 *Gila II*

In 1993, the Arizona Supreme Court rejected the 50%/90-day test in a case known as *Gila II*. *See In re the General Adjudication of all Rights to Use Water in the Gila River System and Source*, 175 Ariz. 382, 857 P.2d 1236 (1993). The adjudication court held that the 50%/90-day test was arbitrary and inconsistent with *Southwest Cotton's* narrow definition of subflow. The Arizona Supreme Court held that whether a well is pumping subflow "turns on whether the well is pumping water that is more closely associated with the stream than the surrounding alluvium." *Id.* at 392, 393, 857 P.2d at 1246, 1247. The Court also reaffirmed *Southwest Cotton's* distinction between subflow, which is subject to appropriation, and tributary groundwater, which is not, and set forth certain criteria that could be used to make this distinction. *Id.* at 391-92, 857 P.2d at 1245-46. The Court remanded the case to the adjudication court to "take evidence and, by applying the principles contained in this opinion, determine the criteria for separating appropriable subflow from percolating groundwater." *Id.* at 394, 857 P.2d at 1248.

1.2.3 1994 Subflow Order

After remand, the adjudication court developed a new subflow test described in an order dated June 30, 2004 ("1994 Subflow Order"), which was 66 pages long with 36 additional pages of exhibits. (**Appendix A-1**). The order was based on evidence presented at a ten-day hearing, during which the adjudication court heard testimony from ten geology and hydrology experts. 1994 Subflow Order, p. 3. 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. *Id.* at pp. 5-6. Based on the evidence presented, and applying the criteria listed in *Gila II,* the adjudication court formulated a new subflow test that turned on the location of a well vis-à-vis an area referred to as the "subflow" zone, which the adjudication court defined as the saturated floodplain Holocene alluvium. *Id.* at p. 56. The adjudication court summarized its conclusions 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, the 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 is observable seasonal and/or diurnal variations in stream flow caused by transpiration. However, riparian 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.

Id. at pp. 64-66.

1.2.4 *Gila IV*

On appeal, the Arizona Supreme Court affirmed "the adjudication court's order after remand in all respects," including the conclusions listed above. *In re the General Adjudication of all Rights to Use Water in the Gila River System and Source*, 198 Ariz. 330, 338, 344, 9 P.3d 1069, 1077, 1083 (2000) ("*Gila IV*"). Citing *Gila II*, the Arizona Supreme Court again reaffirmed the principles set forth in *Southwest Cotton* regarding the definition of subflow and the related Direct and Appreciable Test for determining whether a particular well is actually withdrawing subflow. *Id.* at 341, 9 P.3d at 1080. The Court also held that the new subflow test proposed by the adjudication court "properly applied [the criteria listed in *Gila II*] to the San Pedro River Watershed 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." *Id.* at pp. 341-42, 1080-81. **(Appendix A-2)**.

1.2.5 Post *Gila IV*

After the decision in *Gila IV*, the adjudication court issued a minute entry dated January 9, 2002 that directed ADWR to propose steps for implementing the 1994 Subflow Order as confirmed by the Arizona Supreme Court. As directed, in March 2002 ADWR issued a subflow report for the San Pedro River Watershed ("2002 Subflow Report"), and the adjudication parties filed objections thereto. The issues were briefed and argued before the Special Master, who subsequently issued 39 recommendations to the adjudication court for its review in July 2004 ("2004 Subflow Decision"). The 2004 Subflow Decision adopted ADWR's 2002 Subflow Report in large part with certain modifications. **(Appendix A-3)**. Following another round of briefing and oral argument, the adjudication court issued an order dated September 28, 2005 ("2005 Subflow Order"), which adopted the 2004 Subflow Decision with certain exceptions. The adjudication court directed ADWR to follow certain procedures to determine the limits of the subflow zone within the San Pedro River Watershed, prepare a map delineating the subflow zone, and submit the map and related information in a technical report (**Appendix A-4**). Two separate petitions were filed with the Arizona Supreme Court seeking review of portions of the 2005 Subflow Order that were subsequently denied.

1.3 SCOPE OF REPORT

As directed by the adjudication court, the scope of this report is limited to delineating the subflow zone, and it does not set forth proposed water right attributes for any individual water right claim or use. (2005 Subflow Order p. 42, ¶ 6 adopting 2004 Subflow Decision, Rec. No. 36.A) The adjudication court directed ADWR to delineate subflow zones within the San Pedro River Watershed by using certain procedures, which are described in detail in **Chapter 2.** ADWR followed these procedures to create a series of hydrologic maps, which were used in conjunction with geologic maps developed by the Arizona Geologic Survey (AZGS), to delineate subflow zones for the San Pedro and Babocomari Rivers and Aravaipa Creek.

Mountain front streams, which include the effluent-dominated streams within the San Pedro River Watershed, are not included in this report. These stream reaches are relatively short and often isolated from the major streams in the alluvial valleys. See **Figure 1-2**. Because these streams are located within and/or at the base of mountains, access is often difficult or restricted and significant resources would be required to research and map their locations. These streams were not included in the geologic mapping conducted by the AZGS.

1.4 NOTICE AND OBJECTIONS

Pursuant to the 2005 Subflow Order, upon filing this Subflow Zone Delineation Report with the adjudication court, ADWR must send a notice to all claimants in the San Pedro River Watershed and to persons listed on the Gila River Adjudication Court-Approved Mailing List informing them of the scope and availability of the report. Also, ADWR must inform each claimant of the right to file written objections to the report with the adjudication court and of the deadline for filing objections, which is within 180 days of the date that the report is filed. Objections must be limited to ADWR's findings regarding the lateral extent of the subflow zone. After considering the objections, the adjudication court will approve a map that delineates the subflow zones within the San Pedro River Watershed. (2005 Subflow Order p. 42, ¶ 6 and below, modifying and adopting 2004 Subflow Decision, Rec. Nos. 36.A-D)

Once the subflow zone map has been approved, ADWR will apply the adjudication court's cone of depression test to wells located outside the lateral limits of the subflow zone and examine all water right claims to determine *de minimis* water rights in the San Pedro River Watershed. ADWR will publish a Supplemental Final San Pedro River Watershed HSR containing its findings and proposed water right attributes on a claim by claim basis, including wells withdrawing subflow, cone of depression analyses, *de minimis* water rights, and all other new or updated information. ADWR will send notice of the filing of the Supplemental Final San Pedro River Watershed HSR to all claimants in the Gila River Adjudication, who may file objections within 180 days of the date on which the report is filed. (2005 Subflow Order p. 42, ¶ 6 adopting 2004 Subflow Decision Rec. Nos., 36.E-G)

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CHAPTER 2: SUBFLOW ZONE CRITERIA

As directed by the adjudication court, ADWR applied the procedures outlined in the 2005 Subflow Order to delineate the subflow zone for the San Pedro and Babocomari Rivers and Aravaipa Creek. The subflow zone is defined as the saturated floodplain Holocene alluvium. For purposes of this report, ADWR categorized these procedures as hydrologic, geologic and hydrogeologic criteria, which are described below. Also, ADWR followed the procedures described in Chapter 2 of ADWR's 2002 Subflow Report to determine the location of perennial and intermittent streams; the lateral extent of the floodplain Holocene alluvium; and the saturated portion of the floodplain Holocene alluvium, to the extent that they were consistent with the 2005 Subflow Order. (2005 Subflow Order, p. 42, ¶ 6 adopting 2004 Subflow Decision, Rec. No. 19)

2.1 HYDROLOGIC CRITERIA

As directed by the adjudication court, ADWR utilized the following procedures concerning streamflow conditions to delineate subflow zones within the San Pedro River Watershed.

1. Use the definitions of perennial, intermittent, and ephemeral streams set forth in the adjudication court's June 30, 1994 order. (2005 Subflow Order, p. 41, ¶ 1 approving 2004 Subflow Decision, Rec. No. 1)
2. Investigate additional sources, including historical and current documents, scientific reports, mapping projects, aerial photography, and field investigations to locate perennial, intermittent, and effluent-fed streams with as much accuracy and reliability as possible. (2005 Subflow Order, p. 41, ¶ 1, approving 2004 Subflow Decision, Rec. No. 2)
3. Use predevelopment streamflow conditions for the subflow analysis. (2005 Subflow Order, p. 41, ¶ 1 approving 2004 Subflow Decision, Rec. No. 13)

4. For predevelopment streamflow conditions, use those existing during an identifiable chronological year or range of years immediately prior to regular, discernable diversion or depletion of streamflows resulting from human activity. However, ADWR should take a practical approach and adopt the earliest predevelopment timeframe for which accurate and reliable data is available. Appropriate predevelopment periods may differ even within various watersheds due to the quantity and quality of available data. ADWR may use its discretion in excluding from its analysis human generated depletions or diversions it concludes were minimal, localized, or sporadic. (2005 Subflow Order, p. 42, ¶ 4, clarifying 2004 Subflow Decision, Rec. No. 15)

Regarding the definitions of perennial, intermittent and ephemeral streams, these were set forth by the adjudication court in the 1994 Subflow Order as follows:

- Perennial streams discharge water continuously throughout the year. Their source of supply is normally comprised of both direct runoff from precipitation events or snow melt, and baseflow derived from the discharge of groundwater into the stream.

- Intermittent streams discharge water for long periods of time, but seasonally. For example, an intermittent stream may flow all winter, every winter, but never flow continuously during the summer. During seasons when baseflow is maintained, groundwater is contributing to the stream. During seasons of discontinuous streamflow, natural and cultural losses may be greater than the contribution from groundwater, resulting in a losing stream. Or, the amount of groundwater discharge itself may have decreased due to natural or cultural uses.

- Ephemeral streams discharge water only in response to precipitation events or snowmelt, and do not have a baseflow component at any time of the year; they flow out sporadically. The groundwater system and surface water system do not establish a hydraulic connection in these systems.

1994 Subflow Order, pp. 23-24. See **Figure 2-1** for a graphical representation of perennial and intermittent streams.

In the 1994 Subflow Order, the adjudication court held that the subflow zone must be adjacent and beneath a perennial or intermittent stream; but not an ephemeral stream, unless there is a saturated zone beneath connected to similar zones beneath upper and lower stream segments (ephemeral stream exception). 1994 Subflow Order, p. 35. Pursuant to the 2005 Subflow Order these stream conditions must be determined at "predevelopment" times as described above.

In addition, ADWR is to exclude from the subflow analysis the ephemeral streams shown on the Natural Resources Conservation Service (NRCS) soil survey maps, but include as part of the subflow zone any areas determined to fall within the ephemeral stream exception discussed above. (2005 Subflow Order, p. 41, ¶ 2, modifying 2004 Subflow Decision, Rec. No. 6) Although not undertaken as part of this report, ADWR will ultimately be tasked with investigating and tabulating all wells subject to the ephemeral stream exception. (2005 Subflow Order, p. 41, approving 2004 Subflow Decision, Rec. No. 14)

Also not part of this report is an analysis of effluent-dependent reaches, which are relatively short and often isolated from the major streams in the alluvial valleys. When these streams are addressed, for those that were not previously perennial, or recently perennial or intermittent, ADWR may not assume that the sediments immediately beneath these reaches are unsaturated due to clogging layers. (2005 Subflow Order, p. 41, approving 2004 Subflow Decision, Rec. No. 3)

2.2 GEOLOGIC CRITERIA

As directed by the adjudication court, ADWR utilized the following procedures concerning geologic conditions to delineate subflow zones within the San Pedro River Watershed.

1. Use the NRCS soil survey maps to delineate the lateral extent of the floodplain Holocene alluvium as one source or indicator, but not the exclusive means to delineate the lateral limits of the subflow zone. (2005 Subflow Order, p. 41, ¶ 1; 2004 Subflow Decision, Rec. No. 4)
2. Limit its subflow analysis to the floodplain Holocene alluvium. If other deposits or materials (such as Pleistocene) are found within the floodplain

alluvium of a stream, the presence and extent of those deposits shall be reported, but the criterion is the floodplain Holocene alluvium. (2005 Subflow Order, p. 41, ¶ 1, approving 2004 Subflow Decision, Rec. No. 5)

3. Use NRCS Survey AZ671 as a source of information to determine the lateral extent of the floodplain Holocene alluvium in the San Pedro River and its reaches between the International Border and St. David, Arizona. (2005 Subflow Order, p. 41, ¶ 1, approving 2004 Subflow Decision, Rec. No. 7)
4. Consider mapping methods as a criterion to evaluate the adequacy of a surficial map which depicts floodplain Holocene alluvium. (2005 Subflow Order, p. 41, ¶ 1 approving 2004 Subflow Decision, Rec. No. 8)
5. Obtain the largest scale version of a map whenever possible. (2005 Subflow Order, p. 41, ¶ 1 approving 2004 Subflow Decision, Rec. No. 9)
6. Take special care in transferring or re-projecting any depiction on a surficial map to a base map. (2005 Subflow Order, p. 41, ¶ 1 approving 2004 Subflow Decision, Rec. No. 10)

These procedures enabled ADWR to determine the lateral extent of the floodplain Holocene alluvium.

2.3 HYDROGEOLOGIC CRITERIA

As directed by the adjudication court, ADWR utilized the following procedures concerning hydrogeologic conditions to delineate subflow zones within the San Pedro River Watershed.

1. Assume the entire lateral extent of the floodplain Holocene alluvium is saturated for the purpose of delineating the subflow zone. (2005 Subflow Order, p. 41, ¶ 5, disapproving 2004 Subflow Decision, Rec. No. 16 and 17)
2. Exclude tributary aquifers, areas of basin fill recharge, and the alluvial plains of ephemeral streams from the subflow zone. (2005 Subflow Order, p. 42, ¶ 6, approving 2004 Subflow Decision, Rec. No. 18)

Regarding the saturation assumption, the adjudication court noted that "[t]he Supreme Court has made clear that the adjudication court is authorized to adopt reasonable assumptions in order to permit the adjudication to fulfill its functions." (2005 Subflow Order, p. 17) As noted in the 1994 Subflow Order, "in order to fulfill the definition of 'subflow,' the geologic unit must be saturated because of the need for a hydraulic connection between the stream and the 'subflow.'" 1994 Subflow Order, p. 56.

Regarding the exclusions from the subflow zone, the 1994 Subflow Order states that "where there are connecting tributary aquifers or floodplain alluvium of ephemeral streams, the boundary of the 'subflow' zone must be at least 200 feet inside of that connecting zone so that the hydrostatic pressure effect of the side recharge of this tributary aquifer is negligible and the dominant direction of flow is the stream direction." 1994 Subflow Order, pp 57-58. Additionally, "where there is a basin-fill connection between saturated zones of the floodplain Holocene alluvium and a saturated zone of basin fill, the boundary of the 'subflow' zone must be 100 feet inside of the connecting zone so that the hydrostatic pressure effect of the basin-fill's side discharge is overcome and the predominant direction of flow of all of the 'subflow' zone is the same as the stream's directional flow." *Id.* at 58.

Finally, the adjudication court directed ADWR to use the criteria specified in *Gila IV* following the procedures approved by the adjudication court. If ADWR determines, with respect to any specific area, it cannot delineate a reasonably accurate and reliable subflow zone then it should use any other criteria that are geologically and hydrologically appropriate for the particular location and report the reasons for selecting any other criteria it found appropriate for the location. (2005 Subflow Order, p. 41, ¶ 3 approving 2004 Subflow Decision, Rec. No. 12) As described in the chapters that follow, ADWR either developed other criteria or required further direction from the adjudication court in a few select instances in order to delineate the subflow zones within the San Pedro River Watershed.

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CHAPTER 3: HYDROLOGIC ANALYSIS

This chapter describes ADWR's analysis of hydrologic conditions in the San Pedro River Watershed. **Section 3.1** summarizes the hydrologic setting of the major streams in the watershed. **Section 3.2** describes early evidence of predevelopment flows in the streams and **Section 3.3** describes more recent evidence. Based on these lines of evidence, **Section 3.4** presents the major stream reaches that ADWR believes were perennial or intermittent before development occurred in the watershed. The geographic features mentioned in the chapter are shown in **Figure 3-1**.

3.1 HYDROLOGIC SETTING

This section describes the hydrologic setting of the San Pedro and Babocomari Rivers and Aravaipa Creek. Included is a discussion of the topography of each stream, streamflow patterns, and natural and cultural streamflow diversions. The section focuses on the occurrence of perennial and intermittent stream reaches and the factors affecting the baseflow that maintains water in these reaches.

3.1.1 Topography

<u>San Pedro River</u>

The headwaters of the San Pedro River lie about 30 miles south of the international border near Cananea, in Sonora, Mexico. North of the border, the river flows to the north-northwest for approximately 157 miles before joining the Gila River near the town of Winkelman. From an elevation of 4,278 feet at the border, the San Pedro River drops to an elevation of 1,919 feet at its confluence with the Gila River.

The San Pedro River drains an area of nearly 4,500 square miles (mi^2) (USGS, 2008) including parts of five counties (Cochise, Graham, Pima, Pinal, and Santa Cruz). It is fed by several tributaries, most which drain relatively short and steep catchments and are oriented roughly perpendicular to the river.

Babocomari River

The Babocomari River is a major tributary of the San Pedro River that joins the San Pedro near the abandoned town of Fairbank. It flows from west to east for approximately 29 miles, dropping in elevation from 4,801 feet east of the town of Elgin to 3,827 feet at its confluence with the San Pedro River. Its drainage covers an area of approximately 310 mi^2 (ADWR, 1991) and includes parts of Cochise and Santa Cruz Counties. Its two major tributaries, O'Donnell and Lyle Canyons, originate in the Canelo Hills and Huachuca Mountains, respectively, and join the river from the south, near Babocomari Ranch.

Aravaipa Creek

Aravaipa Creek is the second major tributary of the San Pedro River, joining the river between the towns of Mammoth and Dudleyville. From its headwaters 30 miles northwest of the town of Willcox, the creek flows northwest through Aravaipa Valley for about 31 miles before turning west through Aravaipa Canyon and reaching the San Pedro River 32 miles downstream. It drops from an elevation of 4,841 feet near the drainage divide with Sulphur Springs Valley to 2,155 feet at its confluence with the San Pedro River. The creek drains an area of nearly 600 mi^2 including parts of Graham and Pinal Counties (USGS, 2008).

3.1.2 Streamflow Patterns

When first encountered by Europeans in the late 1600s, the major streams in the watershed were dominated by cienegas (marsh or wetland) and generally were unincised, without a distinct channel (Hendrickson and Minckley, 1984; Hereford, 1993; and Huckleberry, 1996). Where a channel was present, it was often weakly incised allowing floodwaters to spread out and infiltrate.

Entrenchment, the downcutting of a stream channel, began along the San Pedro River in the 1870s and, by the early 1900s, had begun to affect the Babocomari River and Aravaipa Creek. As described in **Section 4.1**, a combination of natural and anthropogenic factors likely explains this change. By the 1930s, entrenchment of the San Pedro and Babocomari Rivers was largely completed, although channel widening continued until the 1950s (Hereford, 1993; Huckleberry, 1996; and Wood, 1997). Entrenchment and channel widening appear to be still affecting the upper reaches of Aravaipa Creek (AZGS, 2009).

During entrenchment, the water table in saturated alluvium adjacent to a stream channel may be lowered and, for a brief period, increase the baseflow of the stream (Pool and Dickinson, 2007). Over time, the water table will reach a new equilibrium.

Streamflow data for the San Pedro River indicate that baseflows in the stream have decreased since the 1920s when entrenchment was still ongoing. **Figure 3-2** shows the frequency of streamflow (percentage of days each year with measureable flow) at four stream gages along the river. The Palominas gage is located near the International Border and measures streamflow entering the United States from the river's headwaters in Sonora. The gage near Redington is located in the middle San Pedro Valley, downstream of the confluence with the Babocomari River but upstream of Aravaipa Creek. The two Winkelman gages are located at the mouth of the San Pedro River (**Figure 3-8**).

Review of **Figure 3-2** suggests that the number of days each year with measureable flow has decreased in the San Pedro River over the 20th century. For example, streamflow was perennial at Palominas in the 1930s and at Winkelman in the 1920s, but has since become intermittent at both places. Near Redington, streamflow has been intermittent throughout the period of record but overall streamflow frequencies have decreased since the 1960s. Three factors may explain this decrease in streamflow frequency, including an increase in natural and cultural streamflow diversions (**Sections 3.1.3** and **3.1.4**) as well as a decrease in the amount and frequency of monsoon floods. The latter can recharge the floodplain aquifer that borders the river via bank storage and later discharge back to the stream as baseflow (Goodrich and others, 2008 and Thomas and Pool, 2006). A decrease in the frequency, magnitude, and duration of storms across the watershed may also explain the decline in annual river flows over the period.

Changes in the amount and frequency of flow in the Babocomari River and Aravaipa Creek during the 20th century are less well known due to a lack of long-term stream records. Nevertheless, the same factors that may explain changes in streamflow along the San Pedro River would have affected its major tributaries.

3.1.3 Natural Streamflow Depletions

The growth of riparian vegetation can affect the baseflow of perennial and intermittent streams by intercepting shallow underground water that would otherwise discharge to the channel and by increasing the infiltration of surface flows. Other factors being equal, the water needs of riparian vegetation will increase as its aerial extent and density increase. Comparison of early ground photographs of Aravaipa Creek in 1867 and the San Pedro and Babocomari Rivers in the 1880s to more recent photographs shows that the extent and density of woody riparian vegetation along the floodplain of these streams increased substantially during the 20th century (Webb and Leake, 2006 and Webb and others, 2007). Prior to entrenchment, many reaches of the San Pedro and Babocomari Rivers supported grasslands associated with cienegas, and riparian forests were uncommon. Early photographs of Aravaipa Creek show riparian forests in places, but these have since expanded.

Development of dense stands of woody riparian vegetation during the 20th century has increased natural water use in the San Pedro River Watershed and, during the growing season, likely decreased the baseflow of its major streams (Thomas and Pool, 2006). In the Sierra Vista Subwatershed, Pool and Dickinson (2007) estimated that pre-1940s water loss by riparian vegetation through evapotranspiration (ET) may have been as little as 40% of post-1970s ET rates. Across the watershed, ADWR (1991) estimated that water use by riparian vegetation in 1990 was substantial and totaled 52,600 acre-feet or almost 44% of the overall natural and cultural water uses that year.

In addition to decreasing baseflow, the increase in riparian vegetation may have also contributed to a loss in flood flows. Where the water level in floodplain aquifers is lowered by riparian water use, more flood flows may infiltrate into the channel and result in greater transmission losses. This effect in combination with climate change and changes in upland vegetation during the 20th century (Tuner and others, 2007) may largely explain the observed decrease in annual streamflows of the San Pedro River.

3.1.4 Cultural Streamflow Depletions

Cultural water use in the San Pedro River Watershed has generally increased since the mid-19th century. Before that time, indigenous people (Sobaipuris and

Apaches) and later Spanish and Mexican settlers diverted streamflow for irrigation (ADWR, 1991 and Rodgers, 2007), but the extent of their diversions are not well known. Stream diversions by American settlers began in the 1860s and increased afterward until channel entrenchment during the early 20th century rendered many diversion structures inoperable (Bryan and others, 1934; Muffley, 1938; and Rogers, 2007). **Figure 3-3** shows the approximate number of new irrigation diversions in the watershed between 1866 and 1912 based on available ditch records. As discussed in **Section 3.2**, these diversions had a direct effect on baseflows.

Over the course of the 20th century, well pumpage largely replaced surface water diversions. Although the effect of well pumpage on streamflows may be less direct than surface water diversions, it can also be important.

Along the San Pedro River, measured surface water diversions for irrigation decreased from 118 cubic feet per second (cfs) in 1899 (Walcott, 1901) and 86 cfs in 1921 (Schwalen, 1921) to less than 15 cfs in the 1970s and 1980s (ADWR, 1991). Artesian wells had been used locally since 1887 (Lee, 1905), but well development in the watershed was less important before the 1940s (Pool and Dickinson, 2007 and Putman and others, 1988). As electricity and high power pumps became more available, irrigated acreage in the watershed rose, from less than 500 acres during the 1940s to over 5,000 acres during the 1970s (**Figure 3-4**).

In addition to irrigation, water demands for municipal and industrial uses also rose during the 20th century. **Figure 3-5** shows how the quantity of underground water withdrawn from wells and mines within the Sierra Vista and Sonoran portions of the Upper San Pedro Basin increased from 1903 to 2002. In 2002, ADWR (2005) estimated that about 92% of cultural water demands within the upper basin were being met by well pumpage with the remainder met by surface water diversions and effluent reuse.

3.2 EARLY EVIDENCE OF PREDEVELOPMENT STREAMFLOWS

As described in **Chapter 2**, the adjudication court directed ADWR to use predevelopment streamflows in its subflow analysis. The court defined predevelopment conditions as those that existed immediately prior to regular, discernable diversion or depletion of streamflows by human activity. The court recognized that predevelopment periods may differ across the watershed due to the quality and availability of data and instructed ADWR to take a practical approach using the best available data.

The court further directed ADWR to locate perennial and intermittent streams in the watershed with as much accuracy and reliability as possible. Accordingly, a variety of data sources were used in this report including historic and recent documents, scientific reports, mapping projects, aerial photography and field investigations.

This section presents early evidence (generally collected before the 1940s) of streamflows in the watershed which suggest predevelopment conditions. By the time much of this evidence had been collected, some degree of development had already occurred. However, the fact that development had occurred itself provides evidence of predevelopment perennial and intermittent flows. Most early development would not have been possible without a reliable source of surface water.

ADWR identified several early lines of evidence of streamflows in the watershed. Historic accounts, records of historic ditch and ore mill diversions, historic streamflow and diversion measurements, and early (1935) aerial photographs all provide evidence of perennial and/or intermittent reaches along the major streams. ADWR also identified three published maps that show predevelopment streamflow conditions. Each line of evidence is discussed below. ADWR's geographic analysis of these data sources is described in **Appendix B-1**.

3.2.1 Historic Accounts

Prior to development by Europeans, the major streams in the San Pedro River Watershed were described generally as perennial with numerous cienegas (Di Peso, 1953; Lee, 1905; Newell, c1900; Rodgers, 1965; and Web and others, 2007). American explorers and early settlers noted the size and abundance of fish in the San Pedro River, and their importance as a food source indicates regular flows (Hendrickson and Minckley, 1984; Rogers, 1965; and, Tevis, 1954). Beaver, which require regular streamflows, were apparently also abundant in the watershed and economically important before stream development (Tellman and others, 1997).

By the late 19th century, cultural demands exceeded surface water availability in some areas and resulted in reduced streamflows and/or dry reaches (Newell, c1900 and CH2M Hill, 1997). This, in turn, led to litigation of water uses along portions of the San Pedro and Babocomari Rivers (Clifford, 1886; Douglas, 1898; Dyke, 1887; Grijalba, 1889; Hill, 1888 and 1889; and Miller, 1900). Describing the San Pedro River, Walcott (1901) noted that "in the lower portion of its course the river is in places dry, owing to the diversions made by a large number of small canals." Bryan and others (1934) stated that "the San Pedro usually becomes dry along portions of its lower course during the dry season as its water is diverted into irrigation ditches" with intermittent or ephemeral reaches resulting from streamflow diversions occurring "for several miles below Mammoth" and "for considerable distances below Redington." Regarding Aravaipa Creek and the Babocomari River, Bryan and others (1934) stated that "the dry-season discharge of each stream is fully used for irrigation" causing them to "become almost dry in the latter portions of dry seasons."

Table 3-1 lists 29 historic accounts of streamflow in the watershed that ADWR could locate on current maps. **Figure 3-6** shows the location of the historic accounts which describe the occurrence of cienegas, flow downstream of diversions, and perennial, intermittent, and ephemeral reaches. These accounts were identified by Rogers (2007) and taken from maps and survey notes, government reports, court documents and diaries. Taken together, they suggest that relatively long stretches of the San Pedro and Babocomari Rivers and Aravaipa Creek were likely perennial or intermittent prior to development.

3.2.2 Historic Irrigation Ditch and Ore Mill Diversions

Although the first streamflow diversions in the San Pedro River Watershed occurred by indigenous people and later by Spanish and Mexican settlers for agriculture, the earliest precise records date from Arizona's Territorial Period (1863-1912) and shortly after statehood. Using the data sources described above as well as county records from the Arizona State Archives (ASA) and Notices of Appropriation (NOAs) from ADWR's files, Rogers (2007) identified over 150 irrigation ditches and ore mills on the major streams in the watershed before statehood.

Prior to the 1919 Public Water Code, a person could appropriate water either by application of water to beneficial use or by posting a notice of intent to appropriate at the point of diversion and recording the notice with the county. In 1893, the Territorial Legislature enacted a recording system that remained in effect until the 1919 Public Water Code and required an appropriator to identify the source and amount of water appropriated, point of diversion, location of any storage reservoir, the means of diversion or conveyance, and place of use. The notice was required to be recorded with the county and a copy recorded with the Secretary of the Territory. The date of priority was the date of recording the notice if the water was applied to beneficial use within a reasonable time thereafter. Failure to appropriate and beneficially use the water within a reasonable time after posting and filing could result in a forfeiture of the right (ADWR, 1991). Some early diversions identified in the San Pedro River Watershed were only specified in NOAs and may not have actually been constructed. For the purpose of this report, ADWR did not attempt to verify that all appropriators who filed notices actually constructed diversions and put water to beneficial use.

According to Rogers (2007), early diversions in the San Pedro River Watershed included:

- 119 irrigation ditches and 9 ore mills on the San Pedro River;
- 13 irrigation ditches and 1 ore mill on Aravaipa Creek; and
- 12 irrigation ditches on the Babocomari River.

Detailed location maps and a list of ditch and mill names and apparent dates of first use are presented in **Appendix B-2**.

After statehood, between 1920 and 1923, the Arizona State Water Commission surveyed irrigated lands in the upper Gila River watershed and mapped a total of 90 ditches along the San Pedro River and Aravaipa Creek. **Figure 3-7** shows the location of these diversions as well as the earlier irrigation ditch diversions and ore mills identified by Rogers (2007). Several diversions were located along each stream with the greatest density along the San Pedro River downstream of Mammoth and along Aravaipa Creek below Aravaipa Canyon.

The location of historic irrigation ditches and ore mills do not provide direct evidence of perennial and intermittent streamflows, but they do suggest a reliable water source. For early ore mills in the watershed, streamflow was necessary for ore crushing and processing. For early farms, streamflow provided water for irrigation. In a report to the U.S. House of Representatives, Greely and Glassford (1891) stated that the valleys of the San Pedro and Babocomari Rivers had "crops of fruit, vegetables, grain, and hay…all under and dependent upon irrigation, for which the water supply is ample."

As described further in **Section 3.2.3**, measurement of ditch diversions suggests that perennial or intermittent flow occurred along much of the San Pedro River during the late 1800s and early 1900s. In 1890, 52 irrigated farms were counted in Cochise County covering a total area of 2,372 acres with an average size of 46 acres (Newell, c1900). Most of these relatively small farms were located along the San Pedro River with larger farms becoming more common in the area during subsequent decades (Muffley, 1938). Irrigation practices at the time required minimum applications of 4-6 inches of water to crop lands with periodic, more thorough applications of 9-11 inches (Buffum, 1909). For a 46-acre farm, this equates to 15 to 42 acre-feet of water during each application. Early diversions measured along the San Pedro River suggest that the minimum irrigation requirements could have reasonably been met by existing ditches with a 2- to 3-day application period. In March 1899, diversions at 41 ditches on the San Pedro River averaged 2.9 cfs or 5.8 acre-feet per day (afd), and in March 1921, diversions at 21 ditches on the river averaged 4.1 cfs or 8.1 afd.

Since most crops in arid climates require multiple irrigations, early farmers in the watershed would have needed a regular source of water at least until the monsoon season began in July. In describing flow in the San Pedro River, Newell (c1900) stated:

> The lowest stage of water in this river is usually reached in June, when there is the greatest demand, and the rise begins again after the commencement of the summer rains, during which time the flood water runs largely to waste. All the land which the ordinary unregulated flow of the river will supply, and probably more than can be supplied in certain seasons, is now under cultivation, and yet the demand for agricultural products far exceeds the amount that can be raised.

It is unlikely that flood flows were successfully utilized in the area since diversion dams and head gates were frequently destroyed by floods (Lee, 1905 and Bryan and others, 1934). The fact that diversion works were routinely lost to flooding suggests that they were designed to accommodate a more moderate, regular flow (baseflow) in the channel.

3.2.3 Historic Streamflow and Diversion Measurements

Several streamflow and diversion measurements were taken in the San Pedro River Watershed prior to the 1940s and provide more direct evidence of predevelopment flow conditions. During this period, flow data were routinely collected at the following stations:

- 6 streamflow gages, 2 diversion canals, and 1 diversion dam on the San Pedro River;
- 2 streamflow gages on Aravaipa Creek; and
- 1 streamflow gage on the Babocomari River.

The location of the dam and early streamflow gages and diversion canals is shown in **Figure 3-8**. Associated flow data are presented in **Appendix B-3**.

Streamflow regimes (perennial, intermittent, and ephemeral) were interpreted by ADWR based on the duration of flow measured at these stations. At streamflow gages with daily or weekly records, a stream was considered perennial if its flow duration was typically 100% (the median daily or weekly flow was greater than 0 cfs for the entire year) and intermittent if its flow duration was less than 100% but seasonal baseflow was apparent during the years of record. At the canals where only monthly records were available, a stream was considered perennial if there were typically diversions during each month and intermittent if diversions routinely occurred during the spring (April-June).

Based on published and unpublished (Schwalen, various dates) records for the stations and using the criteria described above, ADWR determined that prior to 1940, the San Pedro River was perennial at Palominas, Hereford, Charleston, and Fairbanks; intermittent near Mammoth; and perennial to intermittent at Winkelman. Aravaipa Creek was also determined to be perennial during this period near Mammoth and ephemeral downstream near Fieldman, and the Babocomari River ephemeral at Huachuca Siding. A summary of records from the early streamflow gages is provided in **Table 3-2**.

Early canal diversions are summarized in **Table 3-3** and suggest that flow in the San Pedro River during the 1920s was intermittent at the St. David Canal and perennial at the Benson Canal. Comparison of Benson Canal diversions during 1926 with flows upstream at the Charleston gage (**Figure 3-9**) show how canal diversions varied with the availability of river water. Daily stage data collected in 1912 at Boquillas Dam, located on the San Pedro River near Hereford, show how the quantity of water diverted into canals and sluiceways were also affected by river flows. As shown in **Figure 3-10**, the stage measured in the canals and sluiceways generally tracked the rise and fall in river stage although the relationship was complex and probably also reflected dam operations. The available stage data do suggest that flow in the river was perennial that year.

In addition to the early flow data collected at gaging stations, two seepage runs were conducted along the San Pedro River prior to 1940, the first in March 1899 and the second in March 1921. A seepage run can be defined as the technique of taking multiple flow measurements along a stream at the same time to identify gains and losses in flow. Depending on its purpose and local conditions, a seepage run can be designed to include mainstem flows, diversions, and/or inflows from tributaries and irrigation returns.

The March 1899 seepage run consisted of flow measurements at 39 diversion points located from St. David Canal downstream to the confluence with the Gila River. The March 1921 seepage run consisted of flow measurements at 21 diversion canals and 41 mainstem sites located from the International Border to the Gila confluence. **Figure 3-11** shows the location of the seepage run points. Precipitation may have occurred in the region during both seepage runs, but streamflow along the river appears to have been minimally affected by storm runoff and the seepage run data were interpreted by ADWR to represent baseflow (perennial or intermittent streamflow) conditions (**Appendix B-4**).

Figure 3-12 shows the cumulative diversions along the San Pedro River in March 1899. The distribution and quantity of these diversions, which ranged from 1 to 9 cfs and averaged 2.9 cfs, suggest that baseflow was present at that time along much of the middle and lower portions of the river. Relatively long reaches with no measured diversions, suggesting an absence of baseflow, occurred for 15 miles below the St. David Canal, 13 miles below the Lower Bayless & Berkalew Canal, and 9 miles below the Brown Ditch. A cumulative diversion of 118 cfs was measured from the St. David Canal to the river mouth and suggests that undepleted baseflow in the San Pedro River may have been continuous along much, if not all, of this reach.

Similar conclusions can be drawn from the March 1921 seepage run. Streamflow and cumulative diversion data for the San Pedro River from the International Border to its mouth are shown in **Figure 3-13**. Flow measured at 19 diversions along the river ranged from 0.5 to 11.9 cfs and averaged 4.1 cfs. Flow in the river was continuous across much of the watershed, but dry reaches occurred downstream of the St. David Canal, where all streamflow (11.9 cfs) was diverted, and also near Redington and Mammoth. Near Redington, only 0.3 cfs bypassed the Redington Canal and that flow also infiltrated within 0.5 miles downstream. Near Mammoth, only 0.5 cfs bypassed the Smith Canal and that also infiltrated 0.5 miles downstream. All streamflow was also diverted at the Zapata Canal (1.1 cfs) and Norton-Bernard Canal (0.5 cfs) and less than 1 cfs bypassed the Soza Canal. A cumulative diversion of 86 cfs suggests that, within the United States, undepleted baseflow in the San Pedro River may have been continuous from the International Border to its confluence with the Gila River.

3.2.4 1935 Aerial Photographs

Early aerial photographs also provide evidence of predevelopment streamflow conditions in the San Pedro River Watershed. In the 1930s, Fairchild Aerial Surveys Incorporated (Fairchild) flew and photographed the watershed under contract with the Soil Erosion Service (SES), predecessor to the Soil Conservation Service (SCS). The so-called Fairchild photographs are believed to be the earliest known aerial imagery for the region. Although ADWR was unable to determine precise flight dates, the following suggest that the aerial photographs were taken sometime between January and March 1935:

- Correspondence between SCS administrators and Fairchild indicate that their contract was finalized in November 1934 (Collier, 1934);

- In December 1934, newspapers reported that flights over the watershed would begin in January 1935 (Prescott Evening Courier, 1934 and The Deming Headlight, 1934);
- The pilot register from David-Monthan Airfield in Tucson, a regional aviation hub during the period, recorded the landing of Fairchild staff on January 26, 1935 (Hyatt, 2007);
- Negatives for selected aerial photographs of the watershed were ordered on March 13, 1935 (Schuch, 1935); and
- Vegetative cover and the angle and length of shadows on the photographs suggest to ADWR that they were taken during the winter.

Knowing the season when the Fairchild photographs were taken is important if they are to be used to infer early streamflow conditions. Although frontal storms occur periodically in the winter, baseflows are more common during the cooler months and better reflect the location of perennial and intermittent streams. Storms are less common in the watershed during the spring, but streamflow losses from irrigation diversions and riparian evapotranspiration are expected to be greater, and in the summer, floodflows are common in response to monsoon storms. ADWR's analysis of precipitation and streamflow records suggests that storm runoff may have occurred as much as 30 to 40% of the time during the period when the Fairchild photographs are believed to have been taken (**Appendix B-4**). However, the lack of visible overbank flows on the photographs and no visible flows where minor tributaries join the San Pedro River suggest that the photographs were taken during a period of baseflow conditions between storm runoff events. For this reason, they were used by ADWR to map the occurrence of perennial and intermittent streamflow.

ADWR used the tone, texture, and shape of features in the Fairchild photographs to identify stream reaches where flow was likely. This use of aerial photography is further described by Ray (1960) and Pandy (1987). Where a stream channel is believed to be dry, it often appears on aerial photographs in light tones in contrast to the dark, nearly black tones where water in the channel is believed to be relatively deep. Gray or medium tones suggest reaches where water in the channel is shallower or channel sediments are moist from recent streamflow or shallow subsurface water. The active channel can be distinguished from nearby riparian vegetation by its smoother texture and sinuous shape. **Figure 3-14** shows a Fairchild photograph of the San Pedro River near Redington where ADWR inferred a dry reach and reaches of relatively shallow and deep water. Shadows obscured some reaches of Aravaipa Creek and the Babocomari River which were deeply incised. An example of a deeply incised reach in Aravaipa Canyon is also shown in **Figure 3-14**.

A map that summarizes ADWR's analysis of the Fairchild photographs is presented in **Figure 3-15**. Along the San Pedro River, relatively deep water was inferred from the International Border to the Narrows, with interspersed reaches of shallow and deep water and dry channel from the Narrows to Redington. From Redington to the mouth of the San Pedro River, four reaches of apparently deep water were separated by shallow water or moist channel sediments. Along the Babocomari River, two reaches of deep water were inferred between Elgin and Huachuca City, an approximately 1-mile reach was obscured by shadows, and the lower 8 miles was apparently also deep water. Along Aravaipa Creek, deep or shallow water was inferred through much of Aravaipa Canyon to its mouth, except for two reaches obscured by shadows.

3.2.5 Published Predevelopment Streamflow Maps

ADWR identified three published maps that depict predevelopment streamflow conditions in the San Pedro River Watershed. Brown and others (1981) compiled a map of perennial streams in Arizona that included previously perennial reaches and former marshes. Their map was based on selected references as well as information from the Arizona Game and Fish Department (AGFD), U.S. Geological Survey (USGS), U.S. Forest Service (USFS), National Park Service (NPS) and private citizens. Hendrickson and Minckley (1984) mapped the distribution of cienagas/riverine marshes and perennial streams in southeastern Arizona prior to 1890 based on accounts of American explorers and settlers, and from court records. As part of the Southwest Alluvial Basins Regional Aquifer System Analysis, Freethey and Anderson (1986) characterized predevelopment hydrologic conditions across much of the southern and western portions of the state and mapped the location perennial streams. Their determination was based on existing literature, including Brown and others (1981), numerical groundwater models, and water budget data compiled by the USGS and other agencies from the early 1900s to about 1940. Where predevelopment data were lacking, Freethey and Anderson (1986) used recent data for basins where "development is minor and long term changes in water levels can be assumed to be small and negligible."

Figure 3-16 shows the location of predevelopment stream reaches in the San Pedro River Watershed using data from the three published maps. ADWR assumed that the recent perennial stream reaches mapped by Brown and others also existed during predevelopment times, and streamflow was perennial in the area of historic cienegas mapped by Hendrickson and Minckley. The maps by Brown and others and Hendrickson and Minckley are in general agreement and show the Babocomari River as perennial from near Elgin to its mouth, and the San Pedro River as perennial from the International Border to Redington and interrupted by three non-perennial reaches between there and its confluence with the Gila River. These researchers differed more in their assessment of predevelopment conditions along Aravaipa Creek with Hendrickson and Minckley depicting a perennial reach beginning upstream of Klondyke and extending downstream to its mouth while Brown and others only show Aravaipa Creek to be perennial through Aravaipa Canyon. Freethey and Anderson generally agreed with the map of Brown and others for both Aravaipa Creek and the Babocomari River, but showed the full length of the San Pedro River to be perennial. Differences in the maps are likely the result of different data sources or different interpretations of the same sources. ADWR did not attempt to resolve these differences.

3.3 RECENT EVIDENCE OF PREDEVELOPMENT STREAMFLOWS

This section presents more recent evidence of streamflows in the watershed which suggest predevelopment conditions. As previously described in **Sections 3.1** and **3.2,** by the 1940s, natural changes and development by man had affected streamflow conditions and locally reduced the occurrence and quantity of baseflow in the major streams. ADWR assumes that any perennial and intermittent stream reaches still in existence after the 1940s would have also been perennial or intermittent during predevelopment. Recent streamflow data has an advantage over earlier data as its documentation is often better and more consistent data collection techniques were used.

ADWR identified several recent lines of evidence for predevelopment streamflows. Instream flow claims, wet/dry surveys, recent streamflow and diversion measurements, and published streamflow maps all provide evidence of perennial and/or intermittent reaches along the major streams. Each recent line of evidence is discussed below. ADWR's geographic analysis of these data sources is described in **Appendix B-1**.

3.3.1 Instream Flow Claims

Using its surface water rights registry, ADWR identified several instream flow claims for major streams in the watershed. Instream flow claims are filed for surface water that remains in-situ or instream, is not physically diverted, and is for maintaining the flow of water necessary to preserve wildlife, including fish, and/or recreation. The claims are summarized in **Table 3-4** and include one application for a permit to appropriate and one certificated water right for the San Pedro River, one application for a permit to appropriate for the Babocomari River, and five certificated water rights for Aravaipa Creek. The location of the claims is shown in **Figure 3-17**. Instream flow claims for floodwaters and those claims without supporting streamflow data were not considered in this report. At least one year of monthly or bimonthly streamflow measurements are required for applications and four additional years of data are required to perfect the claims for certificated water rights.

Certificated instream flow rights have been issued for most of Aravaipa Creek through Aravaipa Canyon and for a relatively long reach of the upper San Pedro River within the San Pedro Riparian National Conservation Area (SPRNCA).[1] Instream flow applications have also been filed in SPRNCA for the lower Babocomari River and for a short reach of the San Pedro River near the international border.

[1] Between 1989 and 1991, ADWR field investigators documented a total of 86 acres within Aravaipa Canyon irrigated by surface water diversions from Aravaipa Creek. The diversions included a ditch in Township 6 South, Range 19 East (T6S, R19E), two ditches and several instream pumps in T6S, R17E, and one instream pump in T7S, R17E (ADWR, 1991).

3.3.2 Wet/Dry Surveys

During June 2007 and June 2008, the presence of water in the San Pedro River and lower Babocomari River was surveyed by trained volunteers using handheld Global Positioning System (GPS) units (TNC, 2008a and 2008b). The surveys coincided with the *minimum* annual baseflow of the rivers since evapotranspiration rates are high in June, but runoff from monsoon storms has typically not begun (Thomas and Pool, 2006). The lower five miles of the Babocomari River was surveyed during both years and, access permitting, 101 miles (64%) of the San Pedro River was surveyed in 2007 and 106 miles (67%) was surveyed in 2008. Aravaipa Creek was not surveyed during either year.

Figure 3-18 is a composite map of the 2007 and 2008 'wet/dry' surveys. Reaches depicted on the map as wet were found to be wet during at least one of the two surveys. Most, but not all, of the San Pedro River and lower Babocomari River within SPRNCA were mapped as wet during the surveys and several interspersed wet and dry reaches were identified north of the city of Benson.

3.3.3 Recent Streamflow and Diversion Measurements

Since the 1940s, daily flow data have been collected at the following stations in the watershed:

- 12 streamflow gages and 2 diversion canals on the San Pedro River;
- 2 streamflow gages on the Babocomari River; and
- 1 streamflow gage on Aravaipa Creek.

Figure 3-8 shows the location of the gages and diversion canals, and associated flow data are presented in **Appendix B-3**. As described in **Section 3.2.3**, ADWR used flow duration to determine streamflow regimes at the stations. Using published records, ADWR determined that flow was perennial or intermittent at all recent stations except for the gages on the San Pedro River near Benson (9471800) and at the Redington Bridge (9472050). A summary of the recent streamflow records is provided in **Table 3-5**.

3.3.4 Published Recent Streamflow Maps

ADWR identified three published maps that depict recent streamflow conditions in the San Pedro River Watershed. Valencia and others (1993) compiled a map of perennial stream reaches in Arizona as part of the Statewide Riparian Inventory and Mapping Project (SRIMP). Their map, which is limited to reaches 0.5 miles and longer, integrated previous data from Brown and others (1981) and Silvey and others (1984) with more recent riparian mapping by AGFD. Perennial streams were located in consultation with USFS, Bureau of Land Management (BLM), Arizona Department of Environmental Quality (ADEQ), ADWR, private sector hydrologists, and academicians. Wahl and others (1997), in a later phase of SRIMP, mapped the intermittent stream reaches across the state based on consultation with BLM, USFS, NPS, and AGFD. The Sonoran Desert Conservation Plan (2000) shows the location of perennial and intermittent stream reaches within Pima County based on existing reports, maps, and aerial photographs; input from the public, USFS and BLM; and, the recommendations of a technical advisory committee that included representatives from the Pima County Flood Control District, University of Arizona, U.S. Fish and Wildlife Service, Nature Conservancy, ADEQ, AGFD, and a private consultant.

Figure 3-19 shows the location of recent perennial and intermittent stream reaches in the watershed using data from the three published maps. ADWR assumes that the recent perennial and intermittent reaches mapped would have existed during predevelopment times. Taken together, the maps indicate that nearly the entire length of the San Pedro and Babocomari Rivers and Aravaipa Creek from Aravaipa Canyon to its confluence were recently either perennial or intermittent.

3.4 PREDEVELOPMENT PERENNIAL AND INTERMITTENT STREAM REACHES

This section consolidates the various early and recent lines of evidence for predevelopment streamflow presented in **Sections 3.2** and **3.3**. Since multiple lines of evidence were identified for the major streams in the watershed, ADWR prepared a series of graphs whereby data are plotted by stream mile and data sources are grouped for comparison.

To show the relatively large number of data points, the lines of evidence for the San Pedro River are plotted on four separate graphs, one for each subwatershed that the river crosses through (Sierra Vista, Benson, Redington, and Winkelman). When added to the graphs for the Babocomari River and Aravaipa Creek, this results in a total of six graphs that compare evidence of predevelopment streamflows (**Figures 3-21a** through **3-21d**, **3-22** and **3-23**). The following data sources are plotted on each graph:

- Historic accounts of streamflow conditions;
- Location of historic irrigation ditch diversions and ore mills;
- Early streamflow data;
- Analysis of 1935 aerial photographs; and
- Recent streamflow data.

Figure 3-20 provides a key to these data sources and also the legend for the graphs.

Early streamflow data were collected before the 1940s and include routine flow measurements at stream gages, diversion canals and a dam as well as results from seepage runs completed in March 1899 and March 1921. Recent streamflow data include the location of instream flow claims, wet/dry surveys, and daily flow measurements at several gage and canal stations. Note that published predevelopment and recent streamflow maps identified for the watershed are not included on the graphs. It was not clear to ADWR after reviewing these maps how the authors concluded that a given reach was perennial or intermittent based on the supporting data provided. Nonetheless, the maps are generally consistent with the conclusions drawn below.

3.4.1 San Pedro River

The lines of evidence presented in **Figures 3-21a** through **3-21d** suggest that prior to development, the San Pedro River was perennial or intermittent from the International Border (Stream Mile 157) to its confluence with the Gila River (Stream Mile 0). This conclusion is supported by the following evidence from each subwatershed:

<u>Sierra Vista Subwatershed</u>

- 1935 aerial photographs that span the subwatershed and recent streamflow data collected throughout the area;

- Historic irrigation diversions located along the upper and lower reaches of the subwatershed, and early streamflow data collected from these reaches;
- Historic accounts that describe streamflow conditions in portions of the upper and middle reaches; and
- Historic ore mills in the lower subwatershed that were probably supplied with water via one or more upstream diversions.

Benson Subwatershed

- Historic irrigation diversions located across the subwatershed as well as early streamflow data collected throughout this area;
- 1935 aerial photographs of the upper reach and most of the middle and lower reaches of the subwatershed;
- Historic accounts that describe streamflow conditions along the middle and lower reaches;
- Recent streamflow data collected from the upper reach and portions of the middle reach; and,
- Historic ore mills in the upper subwatershed that were probably supplied with water via one or more upstream diversions.

Redington Subwatershed

- Historic irrigation diversions located across the upper, lower, and much of the middle reaches of the subwatershed as well as early streamflow data collected throughout this area;
- Historic accounts that describe streamflow conditions along the upper reach and portions of the middle and lower reaches;
- 1935 aerial photographs of the lower reach and portions of the upper and middle reaches;
- Recent streamflow data collected from portions of all reaches in the subwatershed; and,
- A historic ore mill in the lower subwatershed that was probably supplied with water via an upstream diversion.

Winkelman Subwatershed

- 1935 aerial photographs that span the subwatershed;
- Historic irrigation diversions located across the subwatershed as well as early streamflow data collected throughout this area;
- Historic accounts that describe streamflow conditions along portions of the upper and lower reaches of the subwatershed; and
- Recent streamflow data collected from portions of the middle and lower reaches.

It is important to remember when reviewing these lines of evidence the likely effect that upstream diversions had on downstream streamflows. In March 1899, a cumulative diversion of nearly 120 cfs was measured between St. David Canal located near Stream Mile 113 and the river's mouth (**Figure 3-12**). Similarly, in March 1921, a cumulative diversion of over 85 cfs was measured between Stream Mile 150 located near the International Border and the river's mouth (**Figure 3-13**). In both years, total diversions rose steadily from the Sierra Vista Subwatershed downstream through the Winkelman Subwatershed. Available data indicate that most, if not all, of these diversions consisted of baseflow from the river and not storm runoff. This information alone suggests that, had the diversions not occurred, the San Pedro River would likely have flowed at that time at least intermittently along its entire reach within the United States.

3.4.2 Babocomari River

The lines of evidence presented in **Figure 3-22** suggest that prior to development, the Babocomari River was perennial or intermittent downstream of Elgin at Babocomari Ranch (Stream Mile 21) to its confluence with the San Pedro River (Stream Mile 0). This conclusion is supported by:

- Historic accounts that describe streamflow conditions across this section of the river and historic irrigation diversions located in the area;
- 1935 aerial photographs of the upper and lower reaches of the section; and
- Recent streamflow data collected from the upper and lower reaches.

There was also some evidence of perennial or intermittent flow upstream of Stream Mile 21 including a NOA filed for an irrigation diversion near Stream Mile 24 and, based on interpretation of a 1935 aerial photograph, a 1.3-mile reach identified as perennial between Stream Miles 22 and 25. However, lacking other supporting data, ADWR concluded that prior to development it was less likely that the Babocomari River was perennial or intermittent above Stream Mile 21.[2]

3.4.3 Aravaipa Creek

The lines of evidence presented in **Figure 3-23** suggest that Aravaipa Creek was perennial or intermittent at predevelopment from about six miles upstream of Klondyke at Stream Mile 36 to its confluence with the San Pedro River at Stream Mile 0. This conclusion is supported by:

- Historic accounts that describe streamflow conditions across this section of the creek;
- Historic irrigation diversions located along the upper and lower reaches of the section;
- Recent streamflow data collected from the middle reach and portions of the lower reach;
- 1935 aerial photographs of the lower reach and portions of the middle reach; and
- A historic ore mill located downstream of Klondyke that probably was supplied with water via an upstream diversion.

There was also some evidence of perennial or intermittent flow upstream of Stream Mile 36 including four irrigation diversions mapped in 1921 between Stream Miles 42 and 46 by the Arizona Water Commissioner. However, lacking other supporting data, ADWR determined that prior to development it was less likely that Aravaipa Creek was perennial or intermittent above Stream Mile 36.

[2] In their comments to the San Pedro River Watershed Preliminary Hydrographic Survey Report, the Babocomari Ranch Company Limited Partnership noted that "The Department has a 1936 aerial photo which shows a field at this same general location [Section 6 of T21S, R19E] which means that prior to the existing dam and reservoir, there must have been a direct diversion from the Babocomari Creek to this field [near the ranch headquarters]" (Brophy, 1990).

CHAPTER 4: GEOLOGIC ANALYSIS

This chapter describes ADWR's analysis of geologic conditions in the San Pedro River Watershed. **Section 4.1** summarizes the geologic setting of the three major streams in the watershed. **Section 4.2** explains methods used by the AZGS to recently map the surface geology adjacent to these streams. Based on AZGS' work, **Section 4.3** presents detailed maps that show the extent of Holocene floodplain alluvium in the watershed.

4.1 GEOLOGIC SETTING

This section summarizes the geologic setting of the San Pedro and Babocomari Rivers and Aravaipa Creek. Unless otherwise noted, the discussion that follows was taken from AZGS (2009). The geographic features mentioned in the section are shown in **Figure 3-1**.

4.1.1 San Pedro River

Geologic History

The San Pedro River crosses deep sedimentary basins flanked by generally north-northwest trending mountain ranges. The ranges have diverse lithology and formed during basin and range faulting about 8 to 25 million years ago. They include, from south to north, the Mule, Dragoon, Winchester, and Galiuro Mountains on the east side of the river and the Huachuca, Whetstone, Rincon, Santa Catalina, and Tortilla Mountains on the west.

As these mountains rose, sediments were shed and deposited in adjacent basins. The basin-fill deposits typically consist of coarse sediments (boulders, cobbles and gravels) near the basin margins that grade into finer sediments (pebbles, sands, silts, clays, and evaporates) along the valley floor. Initially, these sediments were deposited in a closed basin where lakes and playas formed. In the late Pliocene to early Pleistocene (roughly 2 million years ago), the drainage system of the San Pedro Valley joined the

Gila River to the north. In response, the lakes and playas eventually drained and streams in the valley became more incised exposing the older (Tertiary-age) basin-fill deposits.

Since joining the Gila River, the San Pedro River has undergone repeated cycles of channel downcutting (entrenchment) and channel filling (aggradation). As a result, the channel is currently flanked by a series of river terraces. The terraces lie above the active floodplain and formed during the Pleistocene (10,000 to 2 million years ago) and Holocene (10,000 years ago to present). See **Figure 4-1**.

Historic Channel Conditions

Prior to the late 1800s, the San Pedro River that European explorers and settlers encountered was a relatively low-energy, unentrenched stream with frequent marshy reaches. The floodplain of the river at that time was bound by hills and bluffs of basin-fill deposits shaped by the river's long-term downcutting and lateral erosion and by younger river terraces. In many places, a distinct channel was absent and marsh grasses dominated. Where a channel was present, it was often weakly incised causing floodwaters to spread out and move slowly. These conditions promoted infiltration of streamflow rather than channel erosion.

In the 1870s, the river began to entrench. The active channel became more incised and its floodplain widened due to bank cutting and collapse. By the 1930s, most of the San Pedro River had been transformed into a high-energy and, in some places, deeply entrenched stream.

Several factors have been cited to explain this recent entrenchment of the San Pedro River. The factors fall into two groups:

Anthropogenic –

- Increased runoff from the introduction of livestock in the watershed and subsequent overgrazing of rangelands;
- Increased runoff from logging of forest lands to support mines in the region;
- Drainage of beaver ponds and cienegas to reduce the mosquito population and prevent the spread of malaria; and
- Channel disturbance from construction of railroads and diversion ditches.

Natural –

- Climate change resulting in flood flows of greater magnitude and frequency (Thomas and Pool, 2006);
- Drought and accompanying wild fires; and
- An estimated 7.2 magnitude earthquake centered in Sonora, Mexico during May 1877 that resulted in land disturbance, changes in spring flow and water table levels, and more wildfires (DuBois and Smith, 1980).

As indicated above, repeated cycles of channel entrenchment and aggradation occurred along the San Pedro River prior to substantial human activity. This suggests that, although one or more of the anthropogenic factors listed may have contributed to the recent entrenchment of the San Pedro River, natural factors probably also played some role and will do so again in the future.

Recent Channel Conditions

Since the 1950s, the width of the active floodplain of the San Pedro River has been relatively stable. Establishment of vegetation along and within the channel has apparently slowed or stopped channel incision and floodplain widening. Areas that were once part of the river's active floodplain now consist of Pleistocene- and Holocene-age terraces flanking the entrenched channel. The overall width of floodplain Holocene alluvium is often wider than the active floodplain, except where it is bound laterally by bedrock or consolidated basin-fill deposits. Where unbound, the width of floodplain Holocene alluvium along the San Pedro River is typically hundreds of feet wide and can reach almost one mile wide in some areas. Where bound, its width can be less than 100 feet. The latter occurs where the river narrows near Charleston and Fairbank, south of Cascabel, near Redington, and at Dudleyville.

The current channel of the San Pedro River migrates within the active floodplain in response to large storm events and through formation of point bars and meanders. Contributing to these migrations is the introduction of alluvium shed from tributaries that drain into the river. The Pleistocene and Holocene river deposits that border much of the active floodplain generally consist of fine sands, silts, and clays interspersed with pebble and gravel beds and organic-rich soils. Deposits in the active channel are usually coarser (cobbles, pebbles, and coarse sands), particularly downstream of tributaries. Where the introduction of tributary alluvium is particularly large, the floodplain may narrow and the river changes its course, at least temporarily, to accommodate the additional sediment. Eventually, a large flood may remove this material and allow the river to return to its prior course. As a result, tributary alluvium may temporarily cover floodplain Holocene alluvium at the surface and, overtime, interfinger with it in the subsurface (**Figure 4-1**). Where relatively large, low-gradient tributaries join the river, it can be difficult to delineate the contact between the Holocene stream and tributary alluvium. Ground photographs of the recent channel of the San Pedro River are shown in **Figure 4-2**.

4.1.2 Babocomari River

<u>Geologic History</u>

Along its lower reach, the Babocomari River crosses the sedimentary basin underlying the upper San Pedro River Valley. The geologic history of that basin is summarized in **Section 4.1.1**. Along its upper reach, the river crosses two other sedimentary basins flanked by northwest trending ranges. The Mustang Mountains to the north and the Canelo Hills and Huachuca Mountains to the south also formed during Basin and Range faulting. As these mountains and hills rose, fine and coarse sediments were shed and deposited in the adjacent basins. Deposition of the basin-fill sediments continued through the late Pliocene (2 to 3 millions years ago).

Since that time, the Babocomari River has undergone repeated cycles of channel entrenchment and aggradation. Eight Pleistocene and Holocene terraces have been mapped along the river and record these cycles.

<u>Historic Channel Conditions</u>

Like the San Pedro River, the Babocomari River first seen by Europeans was a relatively low energy, unincised stream with marshy reaches. It began to entrench in the early 1900s and by the 1930s had been transformed into a high energy and entrenched stream. The same factors that caused the recent entrenchment of the San Pedro River affected the Babocomari River.

Recent Channel Conditions

The current channel and floodplain of the Babocomari River is typically covered with coarse alluvium and entrenched from 3 to 20 feet below terraces formed by abandoned floodplains. Channel alluvium is thin to absent only along bedrock reaches in its headwaters near the Mustang Mountains and along a 1-mile bedrock canyon near its confluence with the San Pedro River where the Holocene floodplain alluvium narrows to less than a 100 feet. The channel is not entrenched for several miles upstream of a dam constructed near the Babocomari Ranch headquarters. The influence of the dam diminishes above the O'Donnell Canyon confluence. Ground photographs of the current channel of the Babocomari River are shown in **Figure 4-3**.

4.1.3 Aravaipa Creek

Geologic History

As with the San Pedro and Babocomari Rivers, Aravaipa Creek crosses deep sedimentary basins bounded by mountains formed during basin and range faulting. Along its lower reach, the creek crosses the sedimentary basin underlying the lower San Pedro River Valley. The geologic history of that basin is summarized in **Section 4.1.1**. Along its upper reach, the creek crosses a second basin bound by the Black Hills and Galiuro Mountains to the west and Pinaleno and Santa Teresa Mountains to the east. These mountains and hills rose from 5 to 13 million years ago and shed sediments into the adjacent basin. Between the basins, the creek has cut a path through the Galiuro Mountains by way of Aravaipa Canyon.

Historic Channel Conditions

When surveyed in 1875, the upper reach of Aravaipa Creek was described as a low energy, relatively unincised stream. By 1914, the area upstream of a historic wagon trail called the Globe to Willcox Road had become entrenched up to six feet. In addition to the potential causes of entrenchment listed in **Section 4.1.1**, use of the wagon trail may have initiated erosion along this portion of the creek.

Since that time, headward and bank erosion have continued upstream and are probably still occurring today. As evidence, modern fences can be found in places suspended over 10 feet above the active channel.

Recent Channel Conditions

The active floodplain of Aravaipa Creek is typically sandy, from 300 feet or more wide, and entrenched from 6 to 15 feet below older Holocene terraces and Tertiary basin-fill deposits. The current channel is largely unvegetated and can shift significantly within the floodplain in response to storm events. Tributaries are relatively steep and choked with coarse sediments that spill onto pre-entrenchment floodplain deposits and, in some areas, reach the current creek channel. This excess sediment suggests that the drainage system of Aravaipa Creek is less mature than the San Pedro River (i.e., sediment transport out of the basin began later than the San Pedro's integration with the Gila River).

In upper Aravaipa Valley, upstream from Black Canyon, the channel of Aravaipa Creek is weakly incised and difficult to follow in places. Construction of earthen and concrete dams and diversion structures across the creek probably contributed to channel aggradation in this area. Downstream of the valley, within Aravaipa Canyon, the creek narrows to a few hundred feet or less and is bound by steep bedrock walls that can reach nearly 1,000 feet high. Here the channel is covered with coarse flood deposits and stabilized by relatively dense riparian vegetation. Ground photographs of the current channel of Aravaipa Creek are shown in **Figure 4-4**.

4.2 MAPPING METHODS

This section explains the methods used to map the extent of Holocene channel, floodplain, and terrace deposits (together referred to as floodplain Holocene alluvium) along the San Pedro River and its two major tributaries, the Babocomari River and Aravaipa Creek. In support of efforts to map subflow zones in the San Pedro River Watershed, ADWR contracted AZGS in March 2007 to map the surface geology associated with these streams. A copy of AZGS' report of findings and their contract with ADWR are provided in **Appendices C-1** and **C-2**, respectively.

The discussion that follows includes AZGS' mapping strategy and criteria, review of existing data sources, field work, identification of geologic units and contacts between units, and determination and designation of unit ages.

4.2.1 Strategy

The following steps were taken by AZGS to produce surface geology maps for ADWR:

1 Compile existing geologic maps of the watershed;

2 Review the existing maps using aerial photographs and topographic data;

3 Conduct new mapping where no large-scale maps were available;

4 Collect field data (ground observations and photographs) at regular points along each stream to verify contacts between geologic units;

5 Revise existing geologic maps, as needed; and

6 Develop 1:24,000-scale strip maps that show the extent of floodplain Holocene alluvium associated with the streams.

4.2.2 Criteria

AZGS used several criteria to distinguish floodplain Holocene alluvium from other geologic units exposed in the area. The latter include Pleistocene stream terraces, tributary and Tertiary basin-fill deposits, and consolidated crystalline and sedimentary rocks (bedrock).

Surface slope was a useful criterion and readily determined from review of aerial photographs and topographic information. In general, floodplain Holocene alluvium and Pleistocene stream terraces form relatively gentle slopes that follow the stream gradient. Slopes of Holocene and older tributary deposits are typically steeper and perpendicular to the current channel. Slopes formed on Tertiary basin-fill deposits and older bedrock are often steeper yet and also perpendicular to the channel.

Sediment characteristics were used to further distinguish the floodplain alluvium and stream terraces from tributary deposits. Channel deposits within the floodplain and terraces typically consist of well-rounded, coarse sediments composed of diverse rock types. Tributary deposits, by comparison, are often more angular, have less diverse rock types, and form thinner and less extensive overbank deposits.

To distinguish floodplain Holocene alluvium from adjacent Pleistocene stream terraces, soil development and surface color were also used. In the southwestern United States, significant soil development usually only begins beneath an alluvial surface after it has become isolated from active flooding for thousands if not tens of thousands of years. Pleistocene stream terraces often appear reddish in color, a result of clay accumulation in near-surface soils and rock varnish, and may contain caliche (hardpan) layers. Holocene deposits, in contrast, are typically light gray to light brown in color and often still retain evidence of the depositional processes that formed them (channels, bars, and swales).

The degree of erosion was used to further distinguish floodplain Holocene alluvium from Pleistocene stream terraces. Since the Pleistocene terraces are higher and less subject to flooding than the floodplain Holocene alluvium, the former are often more deeply incised and eroded by tributaries.

4.2.3 Review of Existing Data Sources

AZGS identified several existing maps with detailed surface geology of the watershed. **Figure 4-5** shows the location of 7.5-minute quadrangles along the major streams that were either a) previously mapped by AZGS (blue boxes), b) previously mapped by others (red boxes), or c) mapped by AZGS specifically for this project (yellow boxes). AZGS reviewed the existing geology maps and, as necessary, revised them based on new field work, interpretation of aerial photography, and review of topographic data. The latter included LIDAR (satellite) imagery and USGS topographic maps and digital elevation model (DEM) data. AZGS conducted new geologic mapping where no large scale (1:24,000 scale or greater) maps were available of the floodplain Holocene alluvium.

Published NRCS soil survey maps were also reviewed and used to check map interpretations and assist in assigning age estimates (i.e., Holocene v. Pleistocene units). These surveys were particularly useful in delineating floodplain Holocene alluvium in areas disturbed by human activities. Soil maps of the lower (northern) portions of the watershed were under review by NRCS and not used.

4.2.4 Field Work

AZGS geologists took field notes and ground photographs for this project at approximately 1-mile intervals, and more frequently in many areas, along the boundary of the floodplain Holocene alluvium, even where suitable maps already existed. Global Positioning System (GPS) points were collected at the field sites and are presented along with AZGS field notes and ground photographs in **Appendix C-3**. Stream access was generally good, but private property limited field work in a few areas. Also, GPS reception was weak or non-existent in some canyons (e.g., Aravaipa Canyon) and control points were recorded where a signal was available.

ADWR staff joined AZGS geologists on two field trips to observe their mapping methodology first hand and further discuss with them how their geology maps would be used to delineate subflow zones in the watershed. The first field trip took place during November 14-15, 2007 and covered the upper and middle San Pedro River from the International Border to Redington. The second field trip took place during August 4-6, 2008 and covered the Babocomari River, Aravaipa Creek, and the lower San Pedro River from Redington to its confluence with the Gila River. A copy of the AZGS field trip guides is presented in **Appendix C-4**.

4.2.5 Identification of Geologic Units and Contacts

AZGS identified over 140 distinct geologic units within an approximately 1-mile strip mapped on both sides of the streams.   AZGS grouped the units into five categories and four subcategories based on their origin and age:

- San Pedro and Babocomari River and Aravaipa Creek alluvium
    - Holocene (5 units)
    - Pleistocene (8 units)
- Piedmont alluvium and surficial deposits
    - Holocene (14 units)
    - Pleistocene (16 units)

- Tertiary basin-fill alluvium (18 units)
- Bedrock (82 units)
- Other (4 units).

See **Figure 4-1**. Although an effort was made to standardize unit designations across the watershed, AZGS admits some redundancies in the units may exist, particularly for bedrock units previously mapped by non-AZGS geologists. The "Other" category includes disturbed ground and plowed areas, talus and colluvium.

The contact between floodplain Holocene alluvium and the other geologic units was not always well defined in the field. To depict this uncertainty on their geology maps, AZGS used three line types. A solid line was used where the contact was clear and well defined, with an estimated accuracy of ± 25 feet. Where the contact was subtle or gradational, a dashed line was used with an estimated accuracy of ± 50 feet. A dotted line was used where the contact has been disturbed by human activity and is approximate, with an estimated accuracy of ± 250 feet depending on the level of disturbance.

4.2.6 Determination and Designation of Unit Ages

As described in **Section 4.2.2**, AZGS used several criteria to distinguish floodplain Holocene alluvium from the other geologic units in the watershed. Soil characteristics (development and color) were particularly useful in distinguishing Holocene and Pleistocene deposits, as was their degree of erosion. Although these features do not provide exact ages, they provide a quantitative basis for estimating the age of deposits and alluvial surfaces. Uncertainty does exist in age estimates from soil characteristics, particularly for stream deposits dating from the early Holocene to late Pleistocene (approximately 5,000 to 20,000 years ago).

Paleontological and archeological sites can provide more exact ages where they exist and have been investigated. Paleontological sites in the Upper San Pedro Valley have identified remains of large mammals, including mammoth, with Clovis spear points and other human artifacts. Radiocarbon ages from these sites date from about 12,000 years ago (late Pleistocene). Unfortunately, many of these sites are located along small tributary washes far upslope of the San Pedro River and the deposits cannot be correlated directly to the deposits exposed along the river. Several archeological sites have, however, been recorded within the floodplain deposits of the San Pedro and Babocomari Rivers and along Aravaipa Creek. Data from these sites are summarized in **Table 4-1** and generally support the unit ages that AZGS estimated based on soil characteristics.

AZGS used the following naming conventions to differentiate the age of non-bedrock units:

- Qy – recent or young (y) Quaternary (Q) units of Holocene age;
- Qi – intermediate (i) Quaternary units of Pleistocene age;
- Qo – old (o) Quaternary units of early Pleistocene age;
- QT – early Quaternary/late Tertiary (T) units of late Pliocene-early Pleistocene age; and
- T – Tertiary units.

Numbers were used to further distinguish units of the same general age; the higher the number, the younger the unit relative to other units. For example, Qi3 units were deposited after Qi1 and Qi2 units, but before all Qy units. An "r" was added to specify that the unit was deposited by a major stream in the watershed and a "c" was used in place of numbers to indicate that the unit is currently being deposited. In this way, AZGS used Qycr to designate the active channel of the San Pedro and Babocomari Rivers and Aravaipa Creek. The active channel of these streams was mapped using aerial photographs taken in 2005 and 2007.

4.3 EXTENT OF FLOODPLAIN HOLOCENE ALLUVIUM

Results from AZGS' mapping effort are presented in a series of 6 maps sheets and 14 associated figures (**Figure 4-6**). The figures are strip maps that show the surface geology, mapped at a scale of 1:24,000, within an approximately 1-mile wide strip on either side of the streams and include the full extent of the floodplain Holocene alluvium. The strip maps overlap slightly to ensure complete coverage of the streams and are presented in **Appendix C-5**.

For the purpose of delineating subflow zones in the watershed, ADWR regrouped the various geologic units identified by AZGS and combined them into five new categories:

- Floodplain Holocene alluvium
- Tributary Holocene alluvium
- Basin fill
- Bedrock
- Disturbed area.

Figure 4-7 is schematic of the watershed that shows how the first four categories are related. ADWR used these generalized geologic units to distinguish floodplain Holocene alluvium from the other units AZGS mapped and, as described further in **Chapter 5**, to adjust the width of the floodplain Holocene alluvium inward to account for hydrostatic pressure from bordering tributary and basin-fill aquifers. The specific AZGS geologic units that ADWR combined to create the categories are listed in **Table 4-2**.

The location and extent of the generalized geologic units are presented in a set of quadrangle-size maps prepared by ADWR and presented in **Appendix D-1.** ADWR prepared these maps by obtaining the Geographic Information System (GIS) data that AZGS used to depict geologic units on its strip maps. After regrouping the units as described above, ADWR transferred the GIS data from AZGS directly to USGS quadrangles base maps. As shown on an example map in **Figure 4-8**, the generalized geologic units are each assigned a unique color and the geologic contact between the floodplain Holocene alluvium and other units is depicted as originally mapped by AZGS. Floodplain Holocene alluvium consists of five AZGS map units that ADWR combined (from youngest to oldest, Qycr + Qy4r + Qy3r + Qy2r + Qy1r).

The maps in **Appendix D-1** show that the width of floodplain Holocene alluvium in the watershed ranges from 0 feet to nearly 5,000 feet. It is generally narrowest where the streams are bound by bedrock canyons and narrows, and widest along the San Pedro River just north of the city of Benson.

The maps in **Appendix D-1** also show where tributaries have recently deposited alluvium on top of the floodplain. Although this tributary Holocene alluvium may eventually get washed away during a large flood, at the time of mapping, AZGS distinguished it from the floodplain deposits. Subsurface mapping to delineate the extent to which tributary Holocene alluvium overlies floodplain Holocene alluvium would be impractical and was considered beyond the scope of this project.

ADWR does not consider tributary Holocene alluvium to be part of the floodplain Holocene alluvium. This approach is consistent with the 1994 Subflow Order. Judge Goodfarb indicated that the subflow zone "must be outside of and not include those tributary alluvial deposits…" 1994 Subflow Order, p. 36. In the 2005 Subflow Order, the court directed ADWR to limit its subflow analysis to the floodplain Holocene alluvium and report the occurrence of other deposits or materials within the floodplain. Further direction from the court would be required to address other deposits or materials within the floodplain Holocene alluvium. A possible approach is presented in **Appendix D-4.**

The occurrence of tributary Holocene alluvium within and adjacent to the floodplain has also resulted in islands of floodplain Holocene alluvium adjacent to the floodplain. In the examples shown in **Figure 4-9**, recent tributary deposits appear to have cut off areas of floodplain Holocene alluvium and isolated them from the main floodplain. For purposes of delineating subflow zones in the watershed, these islands of floodplain Holocene alluvium adjacent to the floodplain were not considered by ADWR.[1]

[1] See **Appendix D-4** for a discussion of a possible approach that would address isolated floodplain Holocene alluvium.

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CHAPTER 5: HYDROGEOLOGIC ANALYSIS

In the San Pedro River Watershed, the court defined the subflow zone as the saturated floodplain Holocene alluvium. For purposes of delineating the subflow zone, the court instructed ADWR to assume that the entire lateral extent of the floodplain Holocene alluvium is saturated. The maps discussed in **Chapter 4** and presented in **Appendix D-1** show the extent of floodplain Holocene alluvium along the San Pedro and Babocomari Rivers and Aravaipa Creek based on geologic mapping by AZGS (2009).

In his 1994 Subflow Order, Judge Goodfarb recognized that the width of the subflow zone is potentially affected by hydrostatic pressure from saturated basin fill and tributary alluvium that border the floodplain.

> Where the alluvial plain of tributary aquifers or ephemeral streams connects to the floodplain Holocene alluvium of the stream itself and provides tributary or basin fill recharge, that tributary aquifer must also be excluded because its flow direction is different and often perpendicular to the stream-flow direction.
>
> * * *
>
> [W]here there are connecting tributary aquifers or floodplain alluvium of ephemeral streams, the boundary of the "subflow" zone must be at least 200 feet inside of that connecting zone so that the hydrostatic pressure effect of the side recharge of this tributary aquifer is negligible and the dominant direction of flow is the stream direction…[W]here there is a basin-fill connection between saturated zones of the floodplain Holocene alluvium and a saturated zone of basin fill, the boundary of the "subflow" zone must be 100 feet inside of the connecting zone so that the hydrostatic pressure effect of the basin-fill's side discharge is overcome and the predominant direction of flow of all of the "subflow" zone is the same as the stream's directional flow.
>
> * * *
>
> 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).

1994 Subflow Order, pp. 57-58, 65.

As indicated in **Chapter 4,** ADWR regrouped the geologic units mapped by AZGS to delineate the extent of floodplain Holocene alluvium. This also allows the 100- and 200-foot setbacks described in the 1994 Subflow Order to be applied. In addition to floodplain Holocene alluvium, the generalized surficial geology maps in **Appendix D-1** show the extent of basin fill, tributary Holocene alluvium, and bedrock. ADWR applied a 100-foot setback where the floodplain Holocene alluvium was bordered by basin fill and a 200-foot setback where it was bordered by tributary Holocene alluvium. The 1994 Subflow Order did not discuss hydrostatic pressure effects from bedrock bordering the floodplain.

Before ADWR could apply the 100- and 200-foot setbacks, it addressed some disturbed areas that AZGS mapped within and bordering the floodplain. In these areas, AZGS found man-made features covering the ground surface. The features included dam, road, and railroad embankments, a canal and diversion structures, and portions of a town. Using professional judgment, ADWR assumed which geologic unit or units likely underlie the disturbed areas based on the surface geology that AZGS mapped immediately adjacent to them. Maps that show both the disturbed areas within and bordering the floodplain and the geologic units that ADWR assumed underlie them are presented in **Appendix D-2.**

The maps presented in **Appendix D-3** show the extent of floodplain Holocene alluvium with and without the 100- and 200-foot setbacks applied. Green lines are used to show the original width of the floodplain deposits mapped by AZGS. Orange lines are used to show how the width of these deposits is reduced by the setbacks to account for side recharge from basin fill and tributary alluvium. Where no setbacks occur, only orange lines are shown on the maps. As directed by the court, other geologic units identified within the floodplain were not considered by ADWR in its subflow zone delineation. On the maps in **Appendix D-3**, the other units appear as islands within the floodplain and are outlined in black.

Along several reaches of the Babocomari River and Aravaipa Creek, and along a few reaches of the San Pedro River, the 100- and 200-foot setbacks are greater than the width of floodplain Holocene alluvium mapped by AZGS. These reaches are depicted on the maps in **Appendix D-3** with a light blue line. There is also a bedrock canyon reach along the Babocomari River (Fairbank quadrangle map) where AZGS did not delineate floodplain Holocene alluvium on the 1:24,000-scale map that it used. This reach is depicted in **Appendix D-3** with a dark blue line. **Figure 5-1** provides three examples of these conditions.

There are also five stream reaches where ADWR did not apply the setbacks. Two of the reaches are on the San Pedro River, two are on the Babocomari River, and one is on Aravaipa Creek. Along these reaches, the setbacks overlap with other geologic units in the floodplain. The reaches are bracketed on the maps in **Appendix D-3** and, for reference, the original width of the floodplain Holocene alluvium and the outline of other geologic units in the floodplain are shown. Close-ups of the five stream reaches where ADWR did not apply the setbacks are shown in **Figure 5-2**.

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CHAPTER 6: SUBFLOW ZONE DELINEATIONS

This chapter presents subflow zone delineation maps for the San Pedro and Babocomari Rivers and Aravaipa Creek. ADWR prepared these maps by combining its geology maps that show the extent of floodplain Holocene alluvium and setbacks for side recharge (**Appendix D-3**) with the graphs that compare evidence of predevelopment streamflow conditions (**Figures 3-21** through **3-23**). More specifically, ADWR delineated the subflow zones by first identifying those stream reaches that it determined had perennial or intermittent streamflow at predevelopment, and then applied the lateral extent of the floodplain Holocene alluvium. To map the subflow zone, the lateral extent of the floodplain Holocene alluvium was adjusted by 100- and 200-foot setbacks to account for side recharge from saturated basin fill and tributary alluvium, respectively, as described in **Chapter 5.**

Figure 6-1 shows the extent of the subflow zone for the major streams in the watershed and an index of the 1:24,000-scale quadrangle (quad) maps used to delineate the subflow zones in greater detail. A copy of the detailed subflow zone delineation maps is provided in **Appendix E**. Along the San Pedro River, ADWR delineated a subflow zone from the International Border downstream to the confluence with the Gila River. The subflow zone is depicted on 21 quad maps. Along the Babocomari River, ADWR delineated a subflow zone from a point east of Elgin at Babocomari Ranch downstream to the confluence with the San Pedro River. This subflow zone is depicted on three quad maps. And, along Aravaipa Creek, ADWR delineated a subflow zone from a point about six miles south of Klondyke downstream to the confluence with the San Pedro River. That subflow zone is depicted on six quad maps.

ADWR did <u>not</u> delineate subflow zones in four areas along the streams. These areas include:

1. Where predevelopment streamflows were determined to be ephemeral;
2. Where the floodplain Holocene alluvium was not mapped at the 1:24,000-scale used by AZGS;

3. Where the width of the setbacks for side recharge are greater than the width of the floodplain Holocene alluvium; and

4. Where the setbacks overlap with other geologic units in the floodplain.

The first area where ADWR did not delineate a subflow zone occurs along the upper section of the Babocomari River (see the Elgin and Mustang Mountains Quads) and the upper section of Aravaipa Creek (see the Buford Hill, Eureka Ranch, and Klondyke Quads). In these areas, ADWR determined that predevelopment streamflow conditions were ephemeral.

The second area where ADWR did not delineate a subflow zone only occurs along an approximately 0.5-mile reach of the lower Babocomari River (see the Fairbank Quad). In this area, AZGS did not map the floodplain Holocene alluvium.

The third area where ADWR did not delineate a subflow zone occurs along numerous reaches of each stream. One or more of these reaches is found on all quads except where: (1) Aravaipa Creek passes through the Oak Grove Canyon Quad, and (2) the San Pedro River passes through the Benson, Bob Thompson Peak, Buehman Canyon, Clark Ranch, Dudleyville, Hereford, Kielberg Canyon, Lookout Mountain, Peppersauce Wash, Mammoth, St. David, Stark, and Winkelman Quads. In these areas, the width of the setbacks for side recharge is greater than the width of the floodplain Holocene alluvium.

The fourth area that ADWR did not delineate a subflow zone occurs where the setbacks for side recharge overlap with other geologic units in the floodplain. These reaches are shown in **Figure 5-2** and found on the Fairbank and Hereford Quads for the San Pedro River, the Fairbank and Mustang Mountains Quads for the Babocomari River, and the Lookout Mountain Quad for Aravaipa Creek. In this area and the first area where ADWR determined that streamflows were ephemeral at predevelopment, the lateral extent of floodplain Holocene alluvium is shown for reference on the maps in **Appendix E**.