How Pumping in the Big Chino Valley Affects the Flow in the Verde River

Summary

Ground water pumping in the Big Chino Valley reduces the base flow of the Verde River by intercepting and consuming ground water that would otherwise discharge from springs in the Verde River Canyon. Historical and current data support this idea. Several ADWR, USGS, USBR and private consultants' investigations have all pointed to the hydrologic connection between the ground water flowing through the Big Chino Valley Aquifer and the base flow of the Verde River. Increased pumping in the Big Chino Valley will further deplete the flow of the Verde River, will potentially harm critical habitat for endangered species, and will injure downstream water rights.

Hydrogeology of the Big Chino Sub-Basin

The Big Chino ground water sub-basin underlies the Big Chino Valley in Yavapai and Coconino Counties approximately 25 miles northwest of the city of Prescott, Arizona. The southern end of the basin is located near the town of Paulden and near Sullivan Lake. The northern boundary is south of the town of Seligman near Picacho Buttes where the Big Chino Valley narrows. The sub-basin contains Tertiary and Quaternary age sand, gravel, and clay sediments, basalt volcanic flows, and the underlying much older Paleozoic limestones and dolimites (Ewing et al, 1994). A detailed description of the geology can be found in Krieger, 1965 and Ewing et al, 1994.

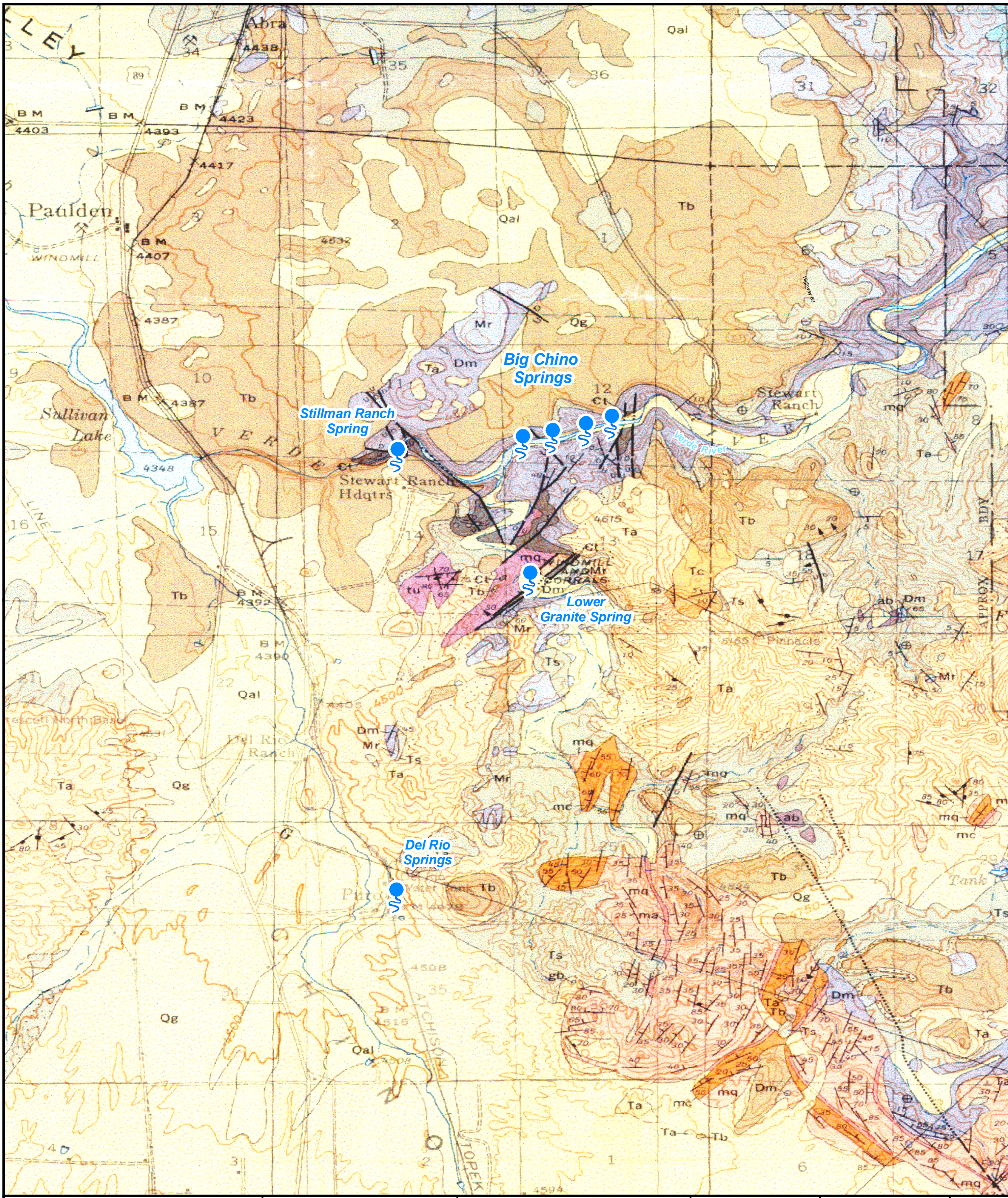
Plate 1 is a generalized cross section of the Big Chino Valley oriented along the axis of the sub-basin from the northwest to southeast. **Figure 1a** shows the geology of the Verde River Headwaters area and the location of significant springs that provide most of the base flow of the Verde River.

The Big Chino Basin can be thought of as a large, sediment and rock filled bathtub tilted toward the Verde River. The sediments and rock units filling the basin (bathtub) are, for the most part, permeable and allow ground water to flow through the basin. The basin sides and bottom are composed of low permeability basement rocks that transmit very little ground water.

The drain of the "bathtub" basin is not at the bottom of the tub but on the side near the top. Only relatively shallow ground water in the basin drains to the Verde River because low permeability basement rocks are shallow near the surface water outlets of the Big Chino Valley, (Wirt, 2000). Robertson (1991) determined through a ground water chemistry analysis that the deeper ground water does not mix with the recharge into the basin or is a significant component of the discharge from the basin.

Basic Ground Water Concepts

Water entering the basin is called "recharge" and the water leaving is called "discharge". Water flowing through the basin is said to be "in storage". Natural recharge occurs where precipitation (rain or snow) infiltrates into the ground. Recharge also occurs where a portion of the ground water pumped from wells and applied as irrigation water infiltrates into the ground and returns to the aquifer. This irrigation return flow differs from natural recharge in that it does not add new water to the aquifer, it just recycles it.



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Explanation

Springs

Miles

0 0.5 1

Notes

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See Figure 1B for Geologic explanations

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Verde River Headwaters Big Chino Valley Geology

Figure 1a

Recent

Qal

Gravel and alluvium

Omitted from sections except where they effectively conceal large areas of older rocks

Pleistocene

Qg

Pediment and terrace gravel

Includes some unmapped sedimentary rocks of late Tertiary(?) age and Recent gravel and alluvium. Largely conceals the upper Tertiary(?) rocks

QUATERNARY

UNCONFORMITY

Pliocene(?)

Tb | Tc | Td | Ta | Ts

Volcanic and sedimentary rocks

Tb, *basaltic flow*
Tc, *basaltic cinder cone*
Td, *basaltic dike*
Ta, *andesitic rocks, including plug, dome, flow, breccia, mud flow, andesitic and rhyolitic tuff, and gravel composed largely of andesitic fragments. Stippled areas indicate andesitic mud flow or gravel composed largely of andesite*
Ts, *gravel and thin beds of fresh-water limestone. Stippled where composed largely of andesite*
Some of the upper flows and sedimentary rocks may be Pleistocene in age

TERTIARY(?)

UNCONFORMITY

Lower Permian

Pc

Coconino Sandstone

PERMIAN

Pennsylvanian and Lower Permian

Psu | Psm | PIPsl

Supai Formation

Psu, *upper member*
Psm, *middle member*
PIPsl, *lower member, which may include Pennsylvanian equivalents of the Naco or Callville Limestones*

PENNSYLVANIAN AND PERMIAN

UNCONFORMITY

Lower Mississippian

Mr

Redwall Limestone

MISSISSIPPIAN

CARBONIFEROUS

UNCONFORMITY

Middle(?) and Upper Devonian

Dm

Martin Limestone

DEVONIAN

UNCONFORMITY

Ct

Tapeats Sandstone

UNCONFORMITY

INTRUSIVE ROCKS

al

Alaskite

Stippled where contaminated with unnamed tuffaceous rocks of the Alder(?) Group

pg

Prescott Granodiorite

gb | qd

Gabbro and related rocks

gb, *gabbro*
qd, *quartz diorite*

VOLCANIC AND SEDIMENTARY ROCKS

mq | mc | ma

Mazatzal Quartzite

mq, *quartzite*
mc, *conglomerate*
ma, *argillite*
See figure 5 for stratigraphic relations of conglomerate and argillite

FAULT CONTACT

Stratigraphic position unknown

ab | at

Unnamed volcanic rocks of the Alder(?) Group

ab, *basaltic flows*
at, *tuffaceous rocks. Stippled where contaminated with alaskite*

SEPARATED BY INTRUSIVE ROCKS

Probable stratigraphic position

iu

Indian Hills Volcanics, undifferentiated

Stippled where contaminated with intrusive rocks

FAULT CONTACT(?)

tu

Texas Gulch Formation, undifferentiated

Alder Group

Yavapai Series

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Figure 1a and 1b originated from Geological Survey Geologic Map and Sections of the Paulden Quadrangle, Arizona Professional Paper 467, Plate 2

Notes

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Verde River Headwaters Big Chino Valley Geology

Figure 1b

Unless disturbed by man's activities, all ground water must eventually discharge to surface water. However, the path may be complicated and long. It may take many life times for the ground water to discharge. Sometimes, ground water discharges from one basin into another. For example, a portion of the ground water discharging from the Little Chino sub-basin enters the Big Chino sub-basin as ground water (Wirt, 2000). A common method of discharge is springs like Del Rio Springs in the Little Chino Sub-basin and in the Verde River Canyon that serve as the discharge area for ground water from the Big Chino sub-basin. **Figure 2** shows the conceptualized movement of ground water near the headwaters of the Verde River.

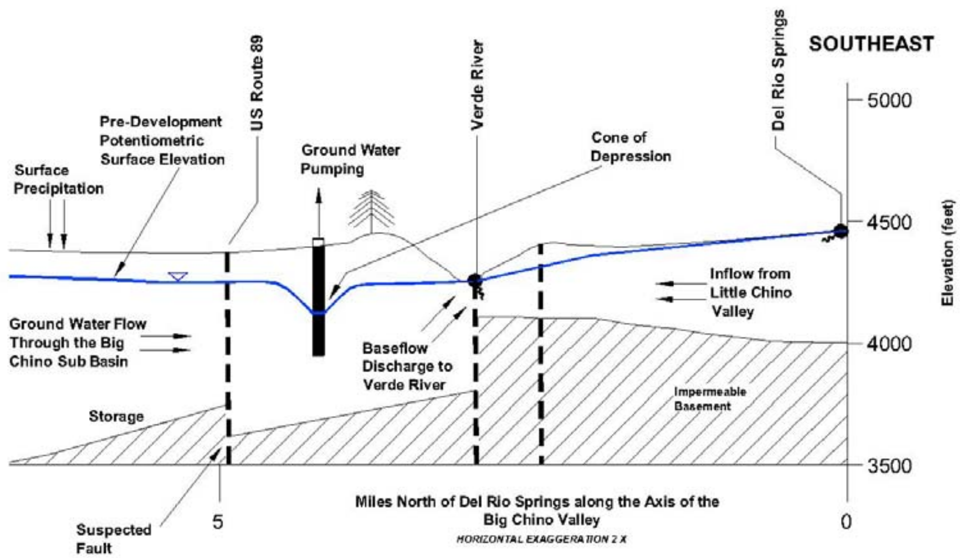

FIGURE 2 - Ground Water Flow in the Vicinity of the Verde River Headwaters

The direction of ground water flow can be determined by measuring the elevation of the water surface in wells and then preparing a map that shows contours of equal water elevation. Ground water flows from higher elevation to lower elevation perpendicular to the contours. The technical term for a map of ground water elevation is a "potentiometric surface map".

When the potentiometric surface is above the top of the aquifer, the aquifer is confined under pressure by an overlying layer of low permeability sediment or rock. A common term used in this situation is "artesian". When the potentiometric surface is higher than the ground level, wells naturally flow. When the potentiometric surface is below the top of the aquifer or there is no overlying low permeability zone, the common term for the potentiometric surface is the "water table".

When ground water is pumped from a well, the water level drops around the well and a cone of depression is created, as shown on **Figure 3**. As other wells are pumped, their cones of depression expand and connect together to form a larger cone of depression. When a cone of depression expands and intersects an impervious boundary like the sides of the basin, the drawdown increases (water level in the well drops) to meet the well's demand. When a cone of depression intersects a stream, the rate of the cone's expansion slows or even stops as the well induces flow from the stream into the aquifer and it uses it to meet a portion or all of its demand.

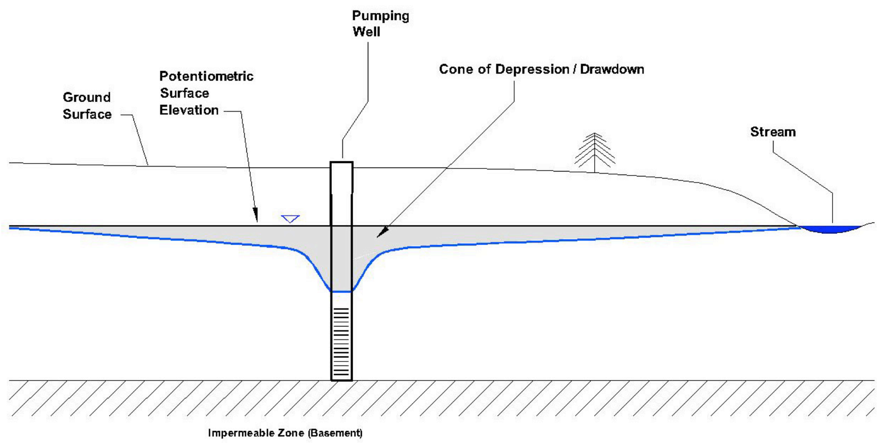

FIGURE 3 - Cone of Depression Intersecting a Stream

Source of Verde River Base Flow

Flow in the Verde River originates from springs in the headwaters area two miles southeast of Paulden. The springs are supplied by ground water discharge from the Big Chino Valley, Big Black Mesa, and the Little Chino Valley. The Big Black Mesa and Little Chino Valley contributes a small portion of the base flow, while the Big Chino Valley contributes at least 80 percent of the base flow of the Verde River above the Paulden stream gage, (Ford, 2002; Wirt, 2000). At the southern end of the Big Chino Valley, the only outlets for ground water moving through the aquifer are fractures and solution cavities in the limestone that underlies the basalt flows (Wirt, 2000). These solution features and fractures provide the hydrologic connection between the aquifer and the Verde River, as shown on **Figures 1 and 4** (Wirt, 2005).

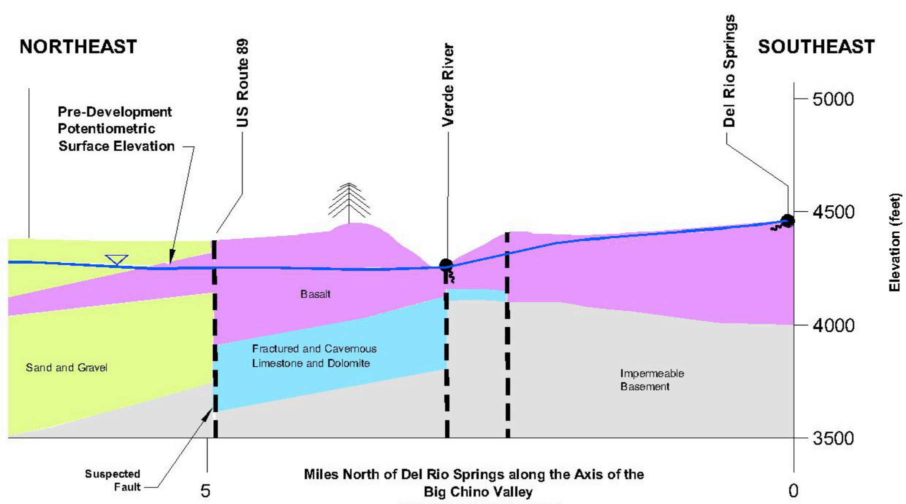

FIGURE 4 - Generalized Cross Section in the Vicinity of the Verde River Headwaters

Ground Water Use in the Big Chino Valley

The primary use of ground water in the Big Chino Valley is for crop irrigation. Ranching and irrigated agriculture in the Big Chino Valley, Williamson Valley, and Walnut Creek began in the 1860s and peaked in the 1950s and 1960s, (Wirt, 2005). Estimates of the amount of irrigation vary considerably prior to 1967 because there were very few direct measurements. Yavapai County Water Advisory Committee estimated historical land irrigated in the Big Chino Valley, as shown on Table 1. Their estimates show that irrigated acreage peaked in the 1950s through the 1970s, declined in the 1980s through the 1990s, and increased in 2000 through 2003 (Yavapai County Water Advisory Committee, 2004). Arizona Department of Water Resources (ADWR) reports that since 1998, the irrigated acreage in the upper Big Chino Valley has increased by 1,350 acres (ADWR, 2000), so that the irrigated acreage today is approximately 2,480 acres.

Table 1
Land Irrigated in the Big Chino Sub-basin
Average Value by Decade (Acres Irrigated)

Decade	Upper Big Chino	Williamson Valley	Paulden	Walnut Creek	Total
1940s	866.1	611.9	244.9	114.6	1837.5
1950s	1656.5	780.9	820.2	115.7	3373.3
1960s	1830.6	805.0	1017.9	131.8	3785.4
1970s	2383.4	561.1	288.7	130.7	3363.9
1980s	1688.6	615.3	184.7	114.1	2602.7
1990s	1292.9	532.8	146.1	89.4	2061.3
′00 - ′03	1399.6	581.1	338.0	107.7	2426.5

Changes in the Headwaters of the Verde River over Time

Prior to 1950, Big Chino Wash was perennial (flowed continually) or intermittent (flowed seasonally) in segments between Partridge Creek and Antelope Wash and perennial flow in the Big Chino Wash began above Sullivan Lake (Wirt, 2005). During this period, fish were reported in the Big Chino Wash. The Bureau of Reclamation described the Big Chino Valley in 1946 at the confluence of Williamson Valley and Big Chino Wash as "the head of the Verde, formed by the junction of Chino Creek and Williamson Valley Wash as fed by permanent ground water." This segment described by the Bureau of Reclamation is now ephemeral, which means that the creek only flows briefly in direct response to precipitation and its channel is always above the water table (Wirt, 2005). The change from perennial to ephemeral flow is an indication that ground water levels have dropped in the Big Chino sub-basin since 1946.

Today, the combination of pumping and drought conditions has negatively affected the head waters of the Verde River. Sections of the Big Chino Wash, Williamson Valley Wash, and the first mile of the Verde River south of Sullivan Lakes that were once perennial are now ephemeral (Wirt, 2000). As more pumping from the aquifer occurs, it is only reasonable to expect that the base flow of the Verde River will be further depleted and longer stretches of the Verde River will become ephemeral. This will detrimentally affect critical habitat for wildlife and will also injure downstream Verde River water users.

Potentiometric Surface Maps of the Big Chino Sub-Basin

To confirm that ground water levels had dropped following well development in the Big Chino Sub-basin, Leonard Rice Engineers, Inc. (LRE) developed a series of maps using water level measurement data obtained from the Arizona Department of Water Resources (ADWR). LRE prepared the following maps:

- Pre-development Big Chino Valley Potentiometric Surface (Plate2)
- Current Big Chino Valley Potentiometric Surface (Plate 3)
- Pre-development Depth to Potentiometric Surface (Plate 4)
- Current Depth to Potentiometric Surface (Plate 5)
- Change in the Potentiometric Surface (Drawdown) from Pre-development to Current (Plate 6)

The area mapped includes the Big Chino Sub-basin, Williamson Valley, and the area around Del Rio Springs in the Little Chino Sub-basin.

The Pre-development Potentiometric Surface map cannot exactly portray pre-well development conditions, because hydrogeologic data was not collected until well pumping for irrigated agriculture and cones of depression had already begun to develop. However, LRE believes that **Plate 2** is the best representation of the pre-development potentiometric surface.

Plates 2 and 3 show that ground water in the Big Chino sub-basin flows southeastward through the aquifer. This is consistent with other potentiometric surface maps (Wallace & Laney, 1976; Schwab, 1995). They also show that ground water flows from the basin fill aquifer through the basalt flows into the Paleozoic limestone and dolomite rocks, and then it moves southeastward past Paulden and discharges as base flow into the Verde River through springs, as described by Wirt, 2005 and Blasch, 2005.

Plates 4 and 5 show the depth to the Pre-development and Current potentiometric surface in the Big Chino Valley and Williamson Valley. These maps were created by subtracting the water elevation from the ground elevation at each data point. The depths to the potentiometric surface as shown on Plates 4 and 5 range from 0 to 350 feet.

Plate 6 shows the change in the elevation (drawdown) of the potentiometric surface from pre-development conditions to current conditions. The drawdown map shows that water levels have declined 20 to at least 40 feet in the Upper Big Chino Valley near the Big Chino Ranch and around the Verde River headwaters. Because the pre-development potentiometric surface is based upon water level data already affected by pumping, as described above, the actual pre-development surface was likely higher than mapped. This means that the drawdown shown on Plate 6 is likely less than what has actually occurred. Regardless, Plate 6 confirms that water levels have declined in the Big Chino Basin as suggested by Wirt (2004) who stated that

> *"Water levels near Sullivan Lake appear to have declined more than 80 feet since 1947 and are presently about 20 feet higher than the maximum elevation for the Upper Verde River Springs. Since 1950, about 6 miles of perennial stream segments surrounding Sullivan Lake became ephemeral – at least 4 miles in Little Chino Creek, 1 mile in Lower Big Chino Wash, and 1 mile of Verde River between Sullivan and Stillman Lakes."*

The drawdown is also consistent with Wirt (2004), who stated that "the Big Chino Valley has not experienced large water level declines, although pumping for irrigated agriculture has at times had an effect on water levels in some parts of the basin" and with a comparison of Wallace and Laney's (1976) and Schwab's (1995) potentiometric surface maps. Comparing these maps shows that although water levels were near the ground surface in the 1950s in the upper Big Chino Valley near Partridge Creek and the Big Chino Ranch (Wirt, 2005), water levels in this area were approximately 30 to 100 feet below the ground surface by 1975.

Stream Depletion Concepts

When a well pumps, the water produced must come from one or a combination of three sources:

1) storage in the aquifer,
2) interception of water flowing through the aquifer, and/or
3) induced recharge from a stream or lake.

The relative contribution from each source changes over time. Initially, all of the water comes from storage, then the portion that is intercepted recharge increases, and finally the portion that is induced stream recharge increases. The proportion that is not taken from storage reduces (depletes) the surface water system by either capturing the ground water flow that would eventually otherwise discharge to surface water or by directly reducing the stream flow by inducing recharge from the stream, or both. Eventually, the amount taken from storage becomes zero and all of the water produced depletes the surface water system by an amount equal to the pumping rate. The time frame for this full (100%) depletion to occur depends on the physical setting and the properties of the aquifer, and it can range from a matter of days to centuries.

When a well stops pumping, the cone of depression begins to refill in the same order as described above for a pumping well. Eventually, the stream depletion decreases and, given enough time, it returns to zero.

The following observation demonstrates pumping in the Big Chino Valley affects base flow of the Verde River:

> *"While collecting hydrologic data in the Little and Big Chino Valleys during the 1960s and early 1970s for the USGS, Hjalmarson witnessed the apparent effects of the ground water pumping in the lower Big Chino Valley on the base flow of the Verde River. At that time there was a land sales operation in the east part of Big Chino Valley known as "Holiday Lakes Estate." The lakes were about three miles south of the tail end of Big Chino Fault. During the late spring of 1964 at least three recreation lakes in the development were filled with ground water from the Big Chino aquifer. The volume and pattern of ground water pumped is unknown but given the estimated size of the lakes, the total volume probably exceeded 100 acre-feet during a several week time period. During this time period of heavy pumping the base flow of the Verde River (20 ft^3/s) decreased by 5 ft^3/s. For 11 days the mean daily discharge at the Paulden gage was 15ft^3/s. The lowest daily discharge recorded since the gage began operation in 1963. When the lakes were filled and pumping decreased, the base flow in the Verde River recovered to between 22 and 23 ft^3/s, despite the dry summer conditions, (Wirt, 2005).*

Depletions to the Base Flow of the Verde River

A local example of stream depletion caused by well pumping is Del Rio Springs in the Little Chino Sub-basin. Many (Wirt, Schwalen, Corkhill, and Mason) believe that prior to well development, ground water discharge from Del Rio Springs caused perennial flow to the Verde River (Wirt, 2000). Because water levels in the Little Chino Valley have declined as much as 75 feet (ADWR 1998; Corkhill and Mason, 1995; Remick, 1983) the flow of Del Rio Springs has decreased by 50 percent and water from Del Rio Springs no longer reaches the Verde River (Wirt, 2000; Schwalen, 1967; Matlock et al, 1973; Corkhill and Mason, 1995; USGS Annual Water Resources Data Reports, 1997-1998).

Pumping in the Big Chino Valley began in the 1940s and increased to a peak in the 1960s. Logically, this should have reduced the base flow of the Verde River. Unfortunately, gaging of the Verde River did not begin until the mid 1960s so the pre-development base flow was never measured.

Since the 1960s, the base flow in the Verde River has increased by an average of 110 af/yr (Wirt, 2005). The decrease in ground water pumping in the northern part of the valley between the 1980s and 1990s has contributed to the rising water levels in the southern portion of the aquifer near the headwaters and has helped increase the base flow to the Verde River (Wirt, 2005). This increase in base flow resulting from a decrease in pumping is predicable, as described in the Stream Concepts section above. The increase also shows that the Verde River base flow is related to pumping in the Big Chino Sub-basin. Therefore, if pumping increases in the future in the Big Chino Sub-basin, as proposed by the City of Prescott and others, the base flow will decrease over time so that the depletion will equal the increase in pumping. If the increase in pumping is on the order of 8000 af/yr, the eventual depletion to the base flow will be approximately 11 cfs, which is about forty percent of the Verde River base flow above the Paulden stream gage. This depletion will potentially impact endangered species habitat and it will also injure senior downstream surface water rights that rely on the Verde River.

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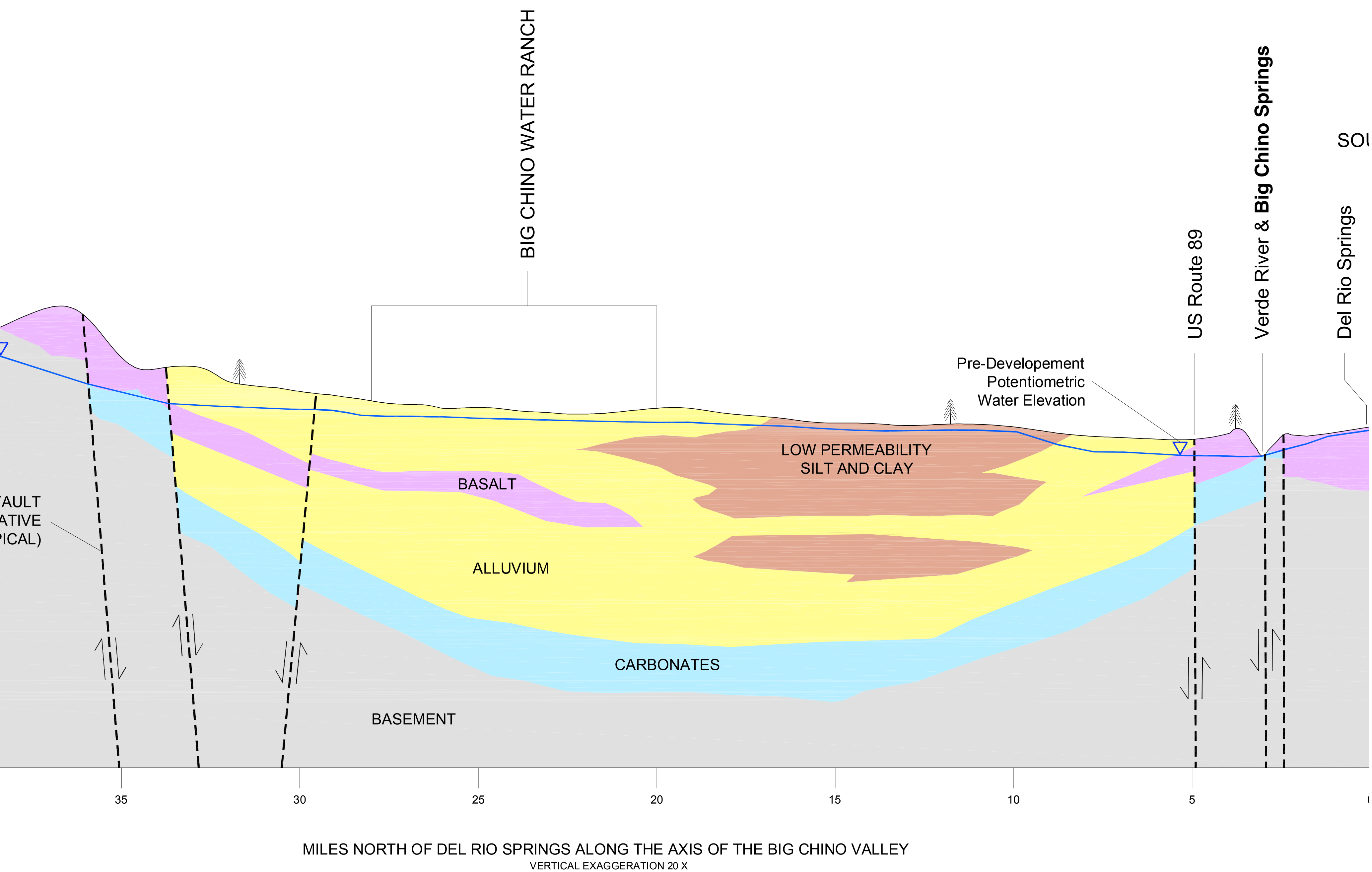
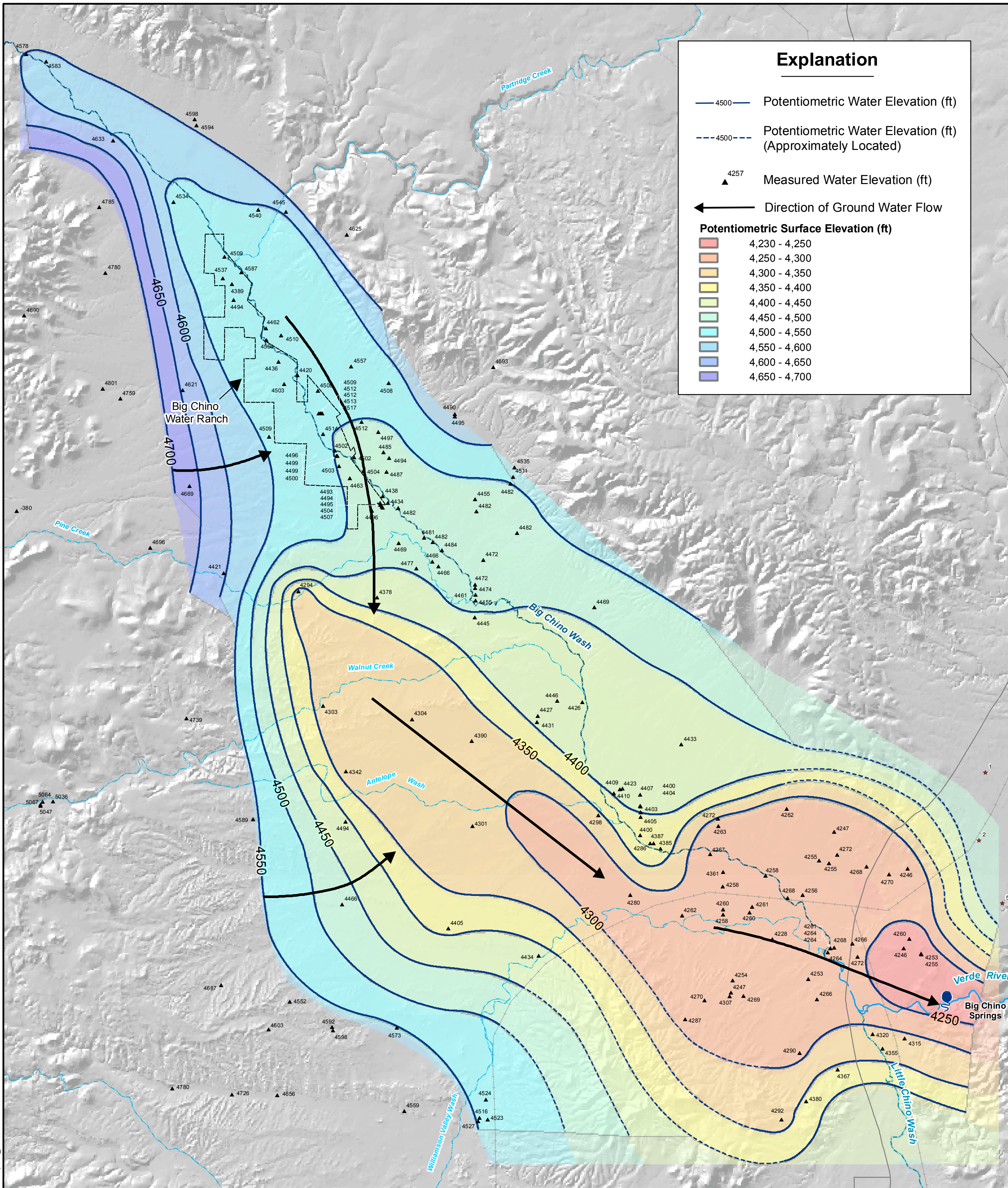
Plates

Plates

GENERALIZED GEOLOGIC CROSS-SECTION OF THE BIG CHINO VALLEY YAVAPAI COUNTY, ARIZONA





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Notes

Definition: Potentiometric Surface – the total pressure surface of ground water. It is the level that water rises in a well. This may be above the top of the aquifer. The water table is the potentiometric surface where the water level is below the top of the aquifer.

Sources: ADWR, ADWR GWSI, USGS WRI Open File Report 76-78, American Geologic Institute's Dictionary of Geologic Terms, Remick Well Data, USGS 1/3 Arc Second National Elevation Dataset 10 meters Geographic NAD 83

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Predevelopment Big Chino Valley Potentiometric Surface Elevation Map

Plate 2

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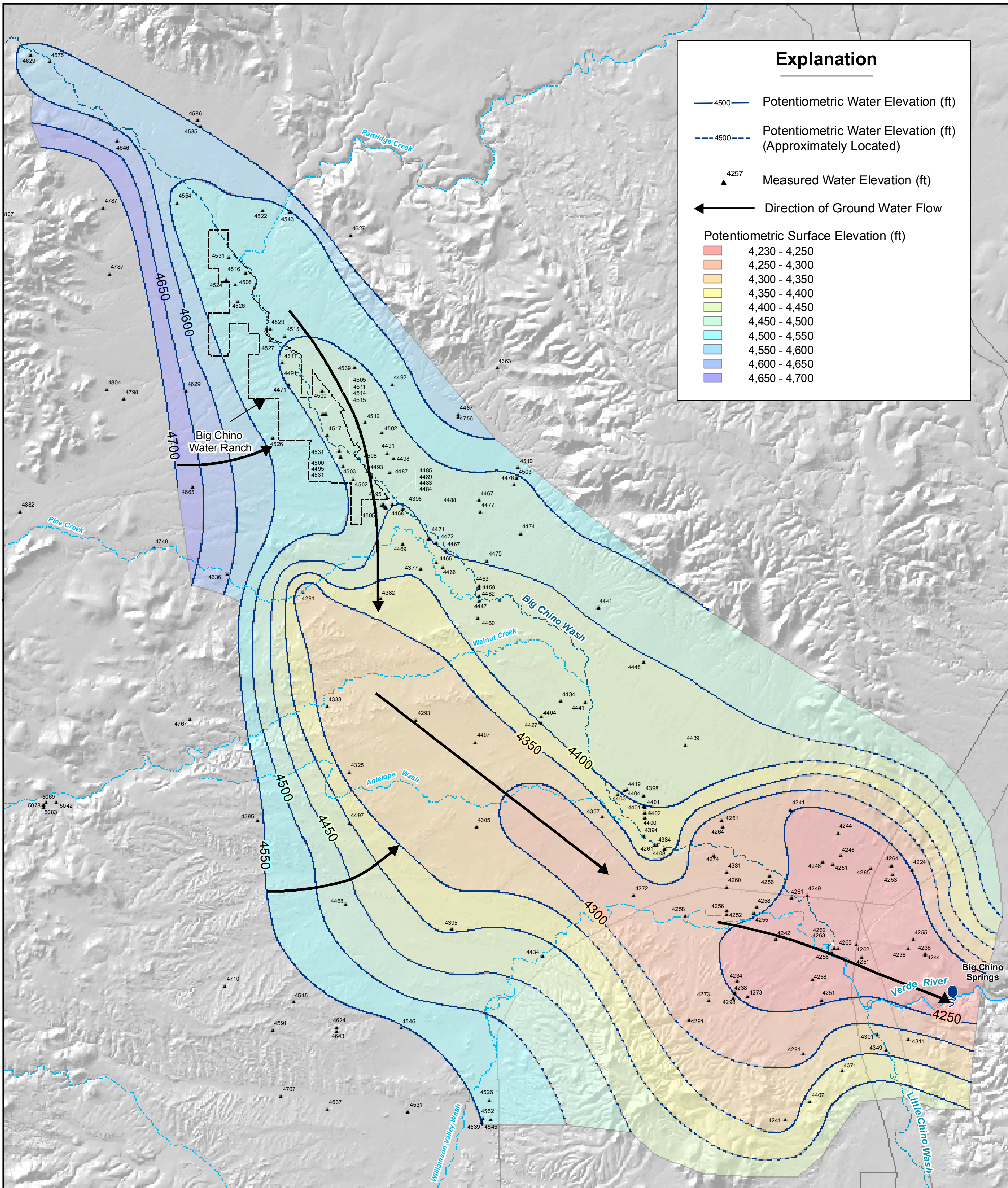

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Current Big Chino Valley Potentiometric Surface Elevation Map

Plate 3

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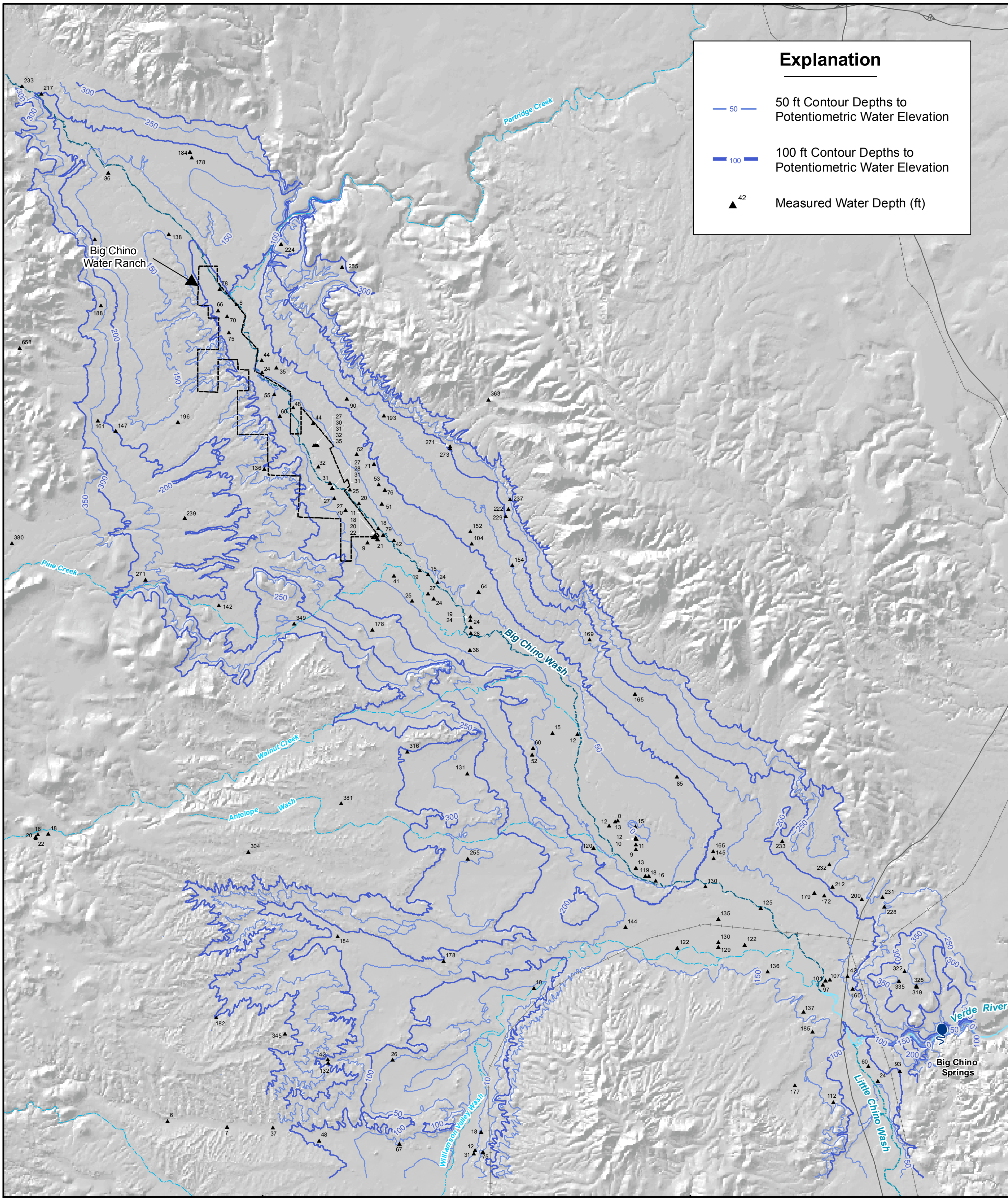

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Predevelopment Depth to Big Chino Valley Potentiometric Surface Elevation Map

Plate 4

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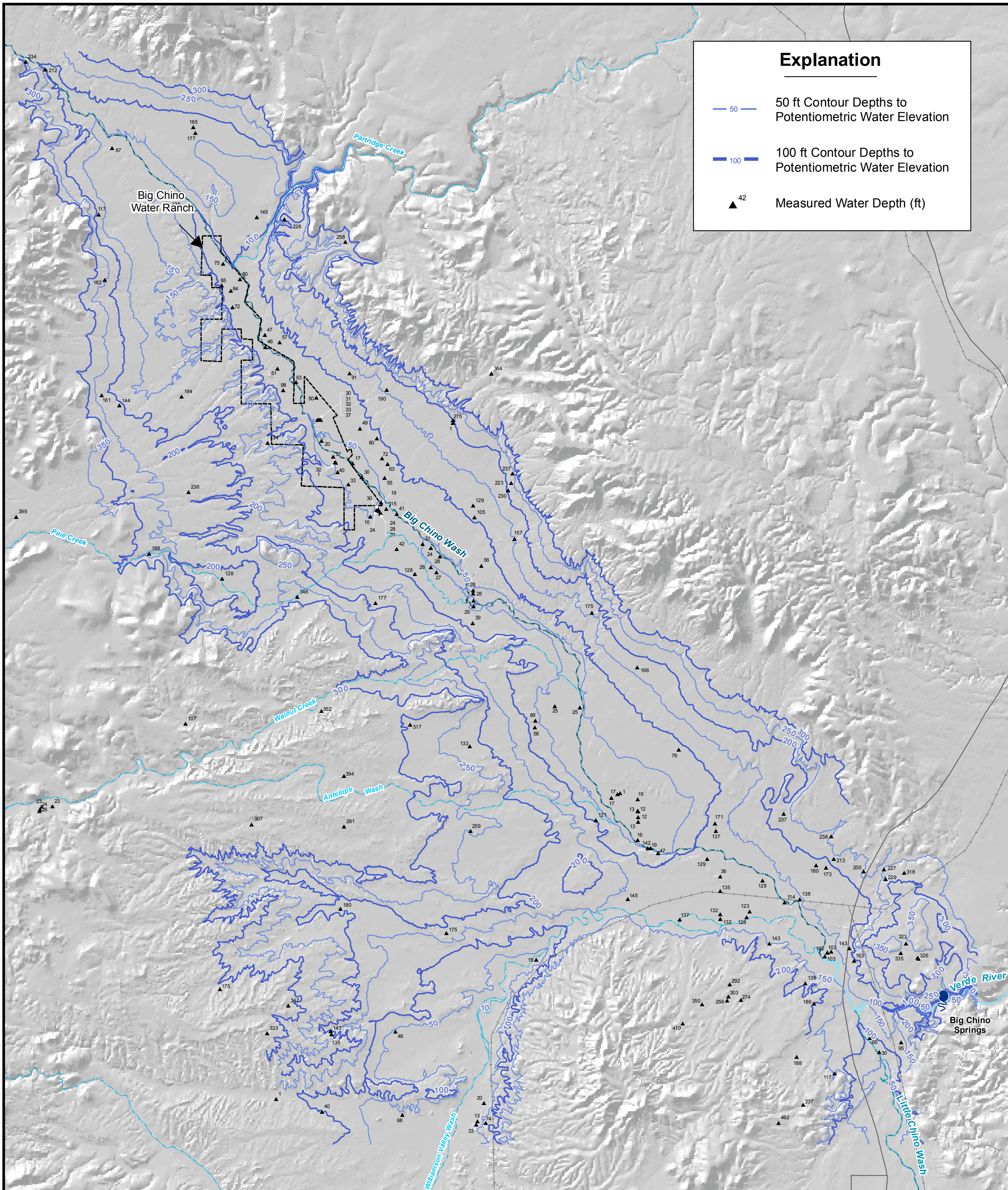

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Notes

Definition: Potentiometric Surface – the total pressure surface of ground water. It is the level that water rises in a well. This may be above the top of the aquifer. The water table is the potentiometric surface where the water level is below the top of the aquifer.

Sources: ADWR, ADWR GWSI, USGS WRI Open File Report 76-78, American Geologic Institute's Dictionary of Geologic Terms, Remick Well Data, USGS 1/3 Arc Second National Elevation Dataset 10 meters Geographic NAD 83

Substantial efforts have been made to accurately compile GIS data and documentation. Accuracy is not guaranteed. This product is for reference purposes only and is not to be construed as a legal document or survey instrument.

Current Depth to the Big Chino Valley Potentiometric Surface Elevation Map

Plate 5

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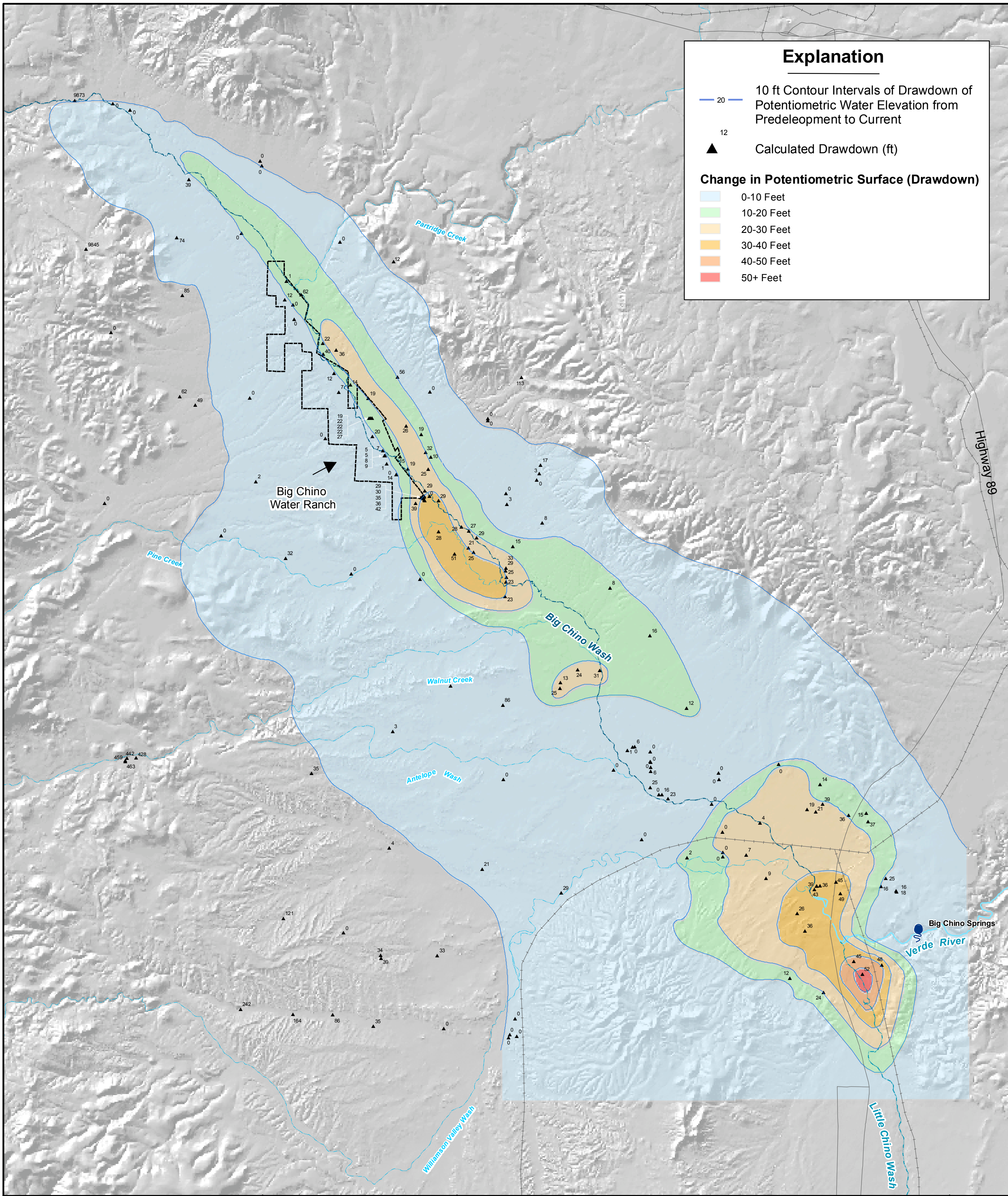

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Project Number: 695SLW07

April 19, 2007

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Change in Potentiometric Surface (Drawdown) from Predevelopment to Current

Plate 6