Prepared in cooperation with the
ARIZONA DEPARTMENT OF WATER RESOURCES and YAVAPAI COUNTY

Hydrogeology of the Upper and Middle Verde River Watersheds, Central Arizona

Scientific Investigations Report 2005–5198

U.S. Department of the Interior
U.S. Geological Survey

USGS
science for a changing world

U.S. Geological Survey
Arizona Department of Water Resources
Yavapai County

Outline

Purpose and Scope
Report and Numerical Model
Surface-Water Flow Systems
Ground-Water Flow Systems
Conceptual Flow Systems
Water Quality

Purpose and Scope of Report

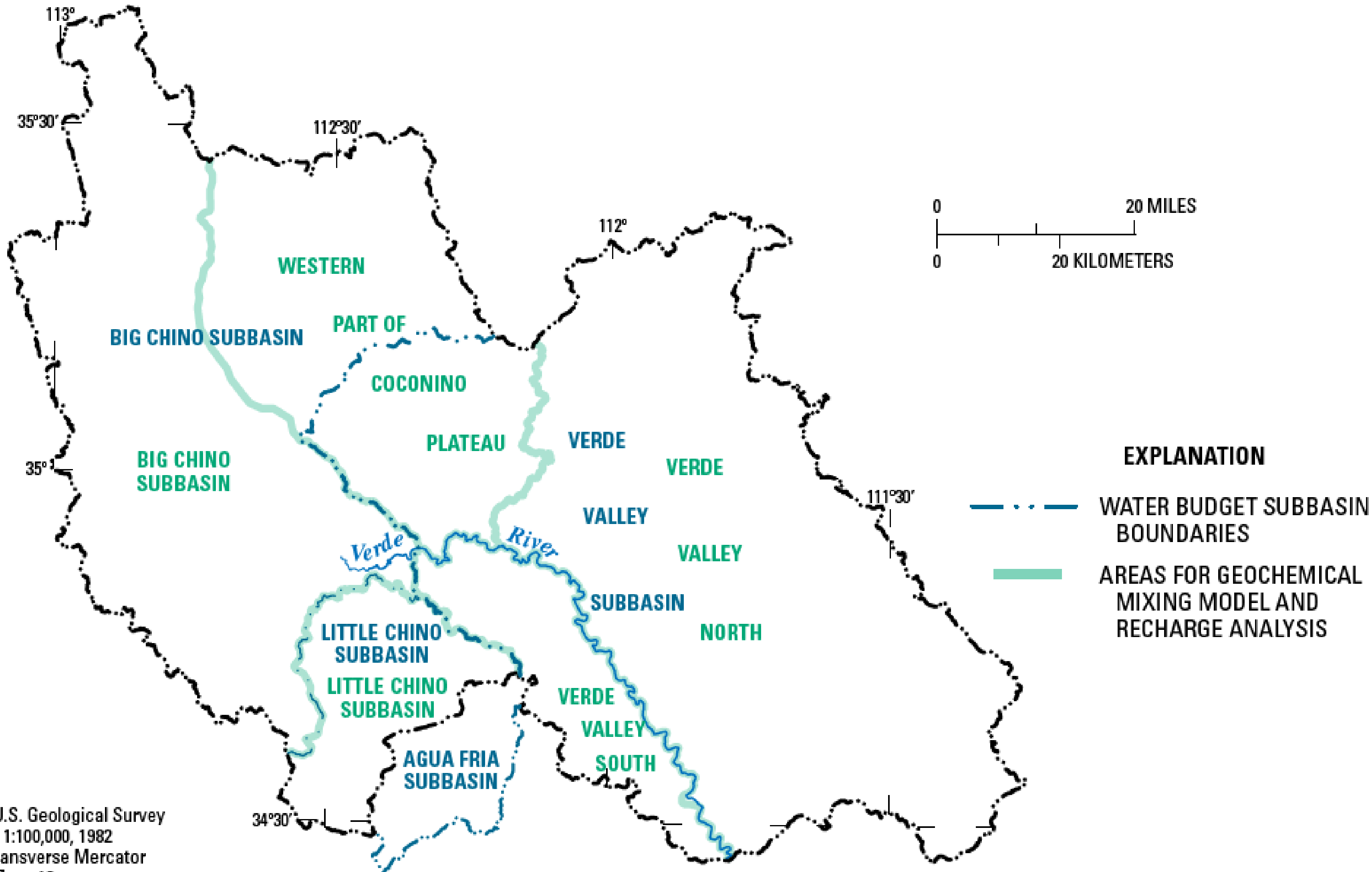
- Assimilate historical climatic, geologic, hydrologic, and water use data within the study area
- Describe the
  - Hydrogeologic Framework
  - Surface-water flow systems
  - Ground-water flow systems
  - Conceptual model of the occurrence and movement of water

The data and conceptual model contained within the report will be used to construct the numerical model

Purpose and Scope of the Numerical Model

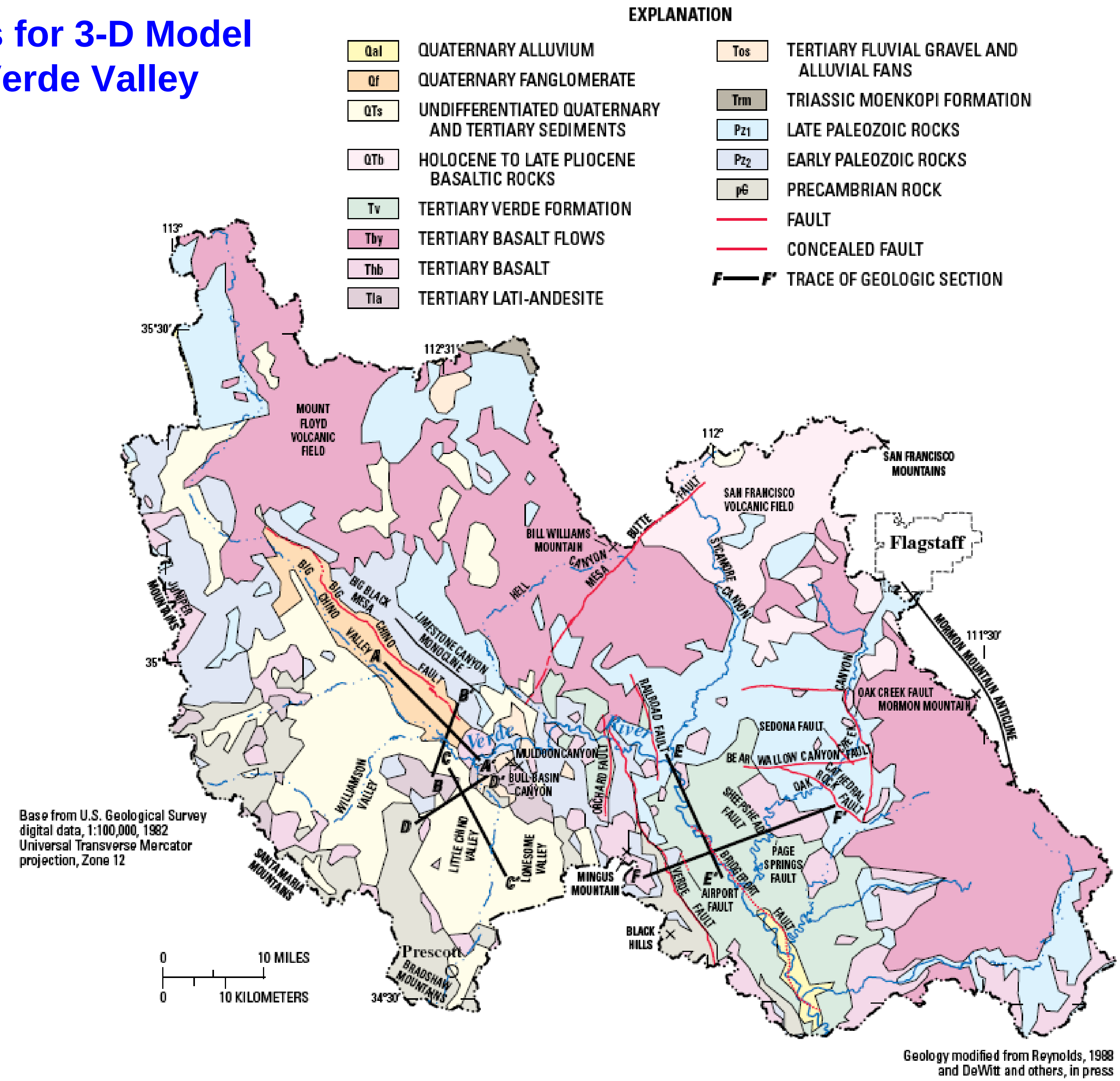
- The numerical model is an evaluation of the conceptual model and will provide numerical values for boundary conditions, ground-water flow rates, recharge rates and locations of ground-water flow
- It will describe flow patterns on a regional scale

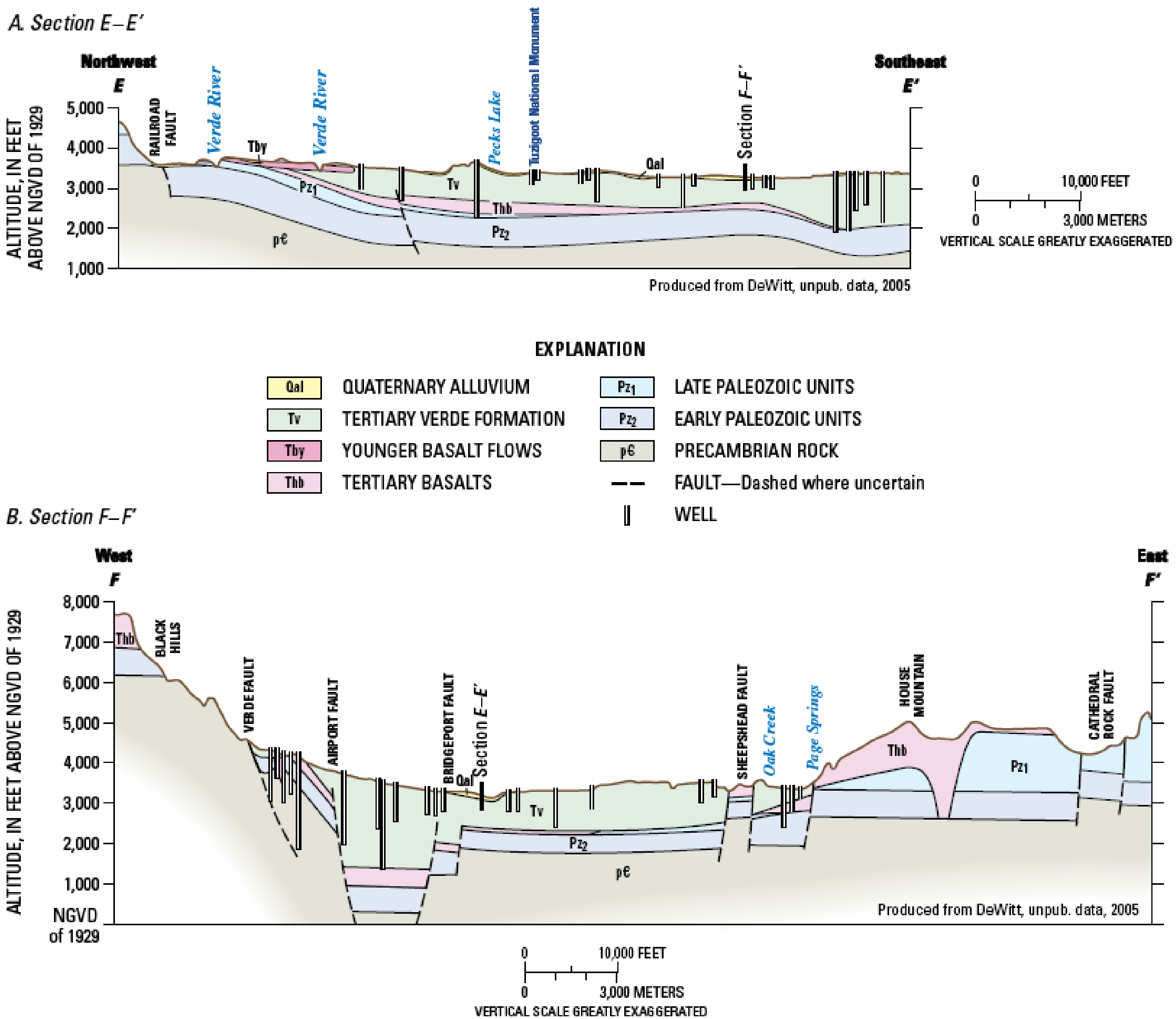
Legal Subbasin Boundaries and Chemistry Subbasin Boundaries



Base from U.S. Geological Survey digital data, 1:100,000, 1982
Universal Transverse Mercator projection, Zone 12

- **Cross-sections for 3-D Model**
- **Focus on the Verde Valley**





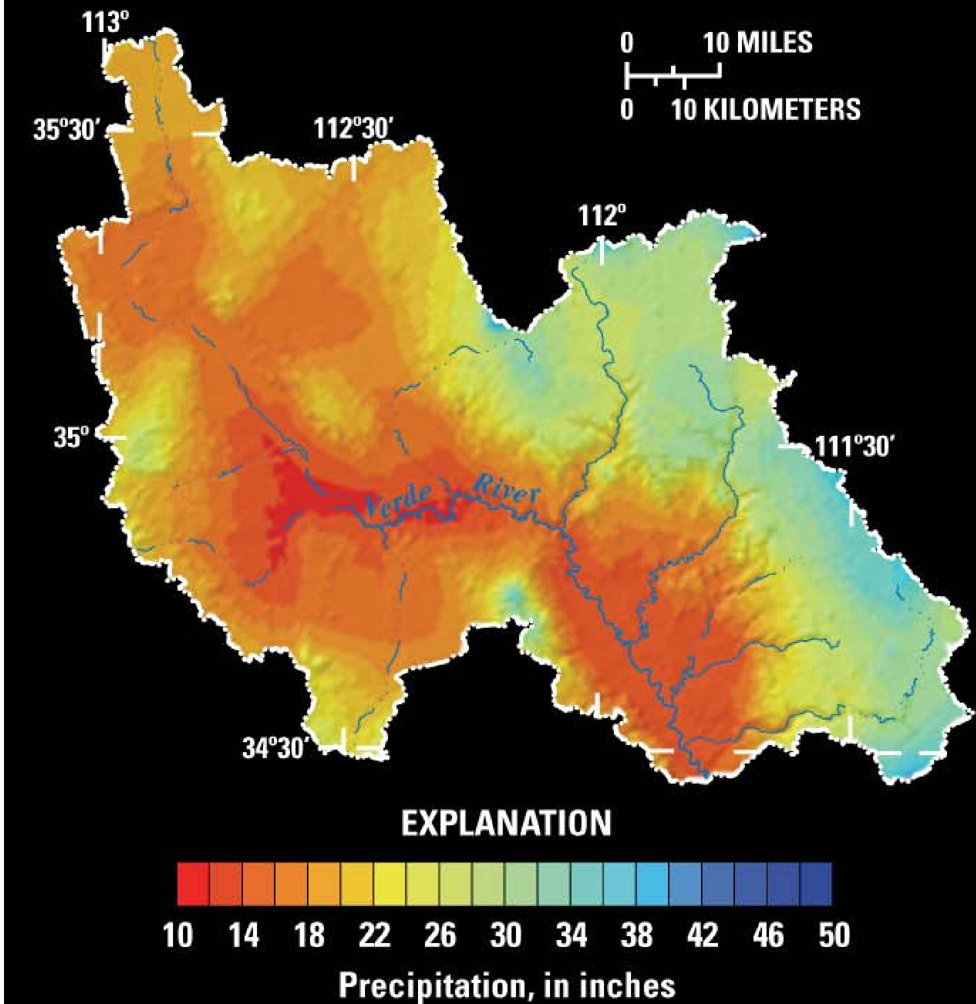
A. Section E–E′
Northwest
E
Southeast
E′
ALTITUDE, IN FEET ABOVE NGVD OF 1929
5,000
4,000
3,000
2,000
1,000
RAILROAD FAULT
Verde River
Tby
Verde River
Pecks Lake
Tuzigoot National Monument
Section F–F′
Qal
Pz1
Tv
Thb
Pz2
p€
0
10,000 FEET
0
3,000 METERS
VERTICAL SCALE GREATLY EXAGGERATED
Produced from DeWitt, unpub. data, 2005
EXPLANATION
Qal QUATERNARY ALLUVIUM
Tv TERTIARY VERDE FORMATION
Tby YOUNGER BASALT FLOWS
Thb TERTIARY BASALTS
Pz1 LATE PALEOZOIC UNITS
Pz2 EARLY PALEOZOIC UNITS
p€ PRECAMBRIAN ROCK
FAULT—Dashed where uncertain
WELL
B. Section F–F′
West
F
East
F′
ALTITUDE, IN FEET ABOVE NGVD OF 1929
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
NGVD of 1929
Thb
BLACK HILLS
VERDE FAULT
AIRPORT FAULT
BRIDGEPORT FAULT
Qal
Section E–E′
Tv
Pz2
p€
SHEEPSHEAD FAULT
Oak Creek
Page Springs
HOUSE MOUNTAIN
Thb
Pz1
CATHEDRAL ROCK FAULT
Produced from DeWitt, unpub. data, 2005
0
10,000 FEET
0
3,000 METERS
VERTICAL SCALE GREATLY EXAGGERATED

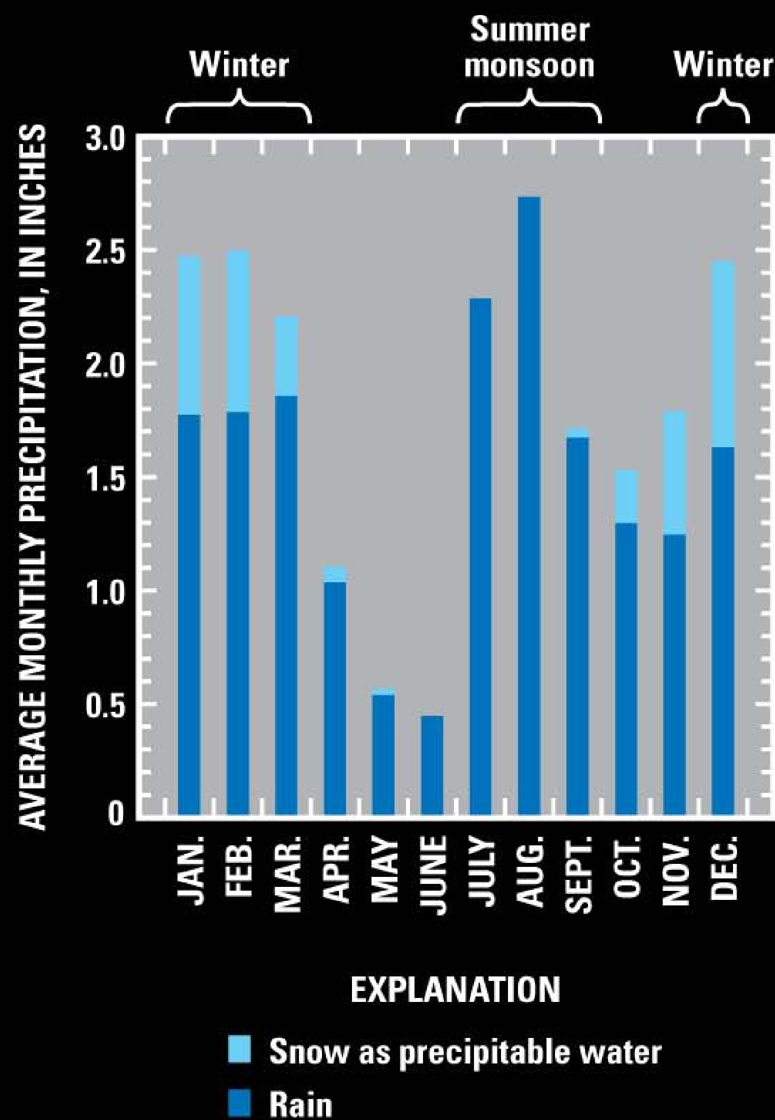
Surface-Water Flow Systems

- Middle Verde River watershed receives more precipitation at the same elevation than the upper Verde River Watershed
- Snowfall has been below average since the late 1950s
- The region including Chino Valley and Paulden is the most arid in the study area
- The Verde Valley has the highest potential evapotranspiration in the study area

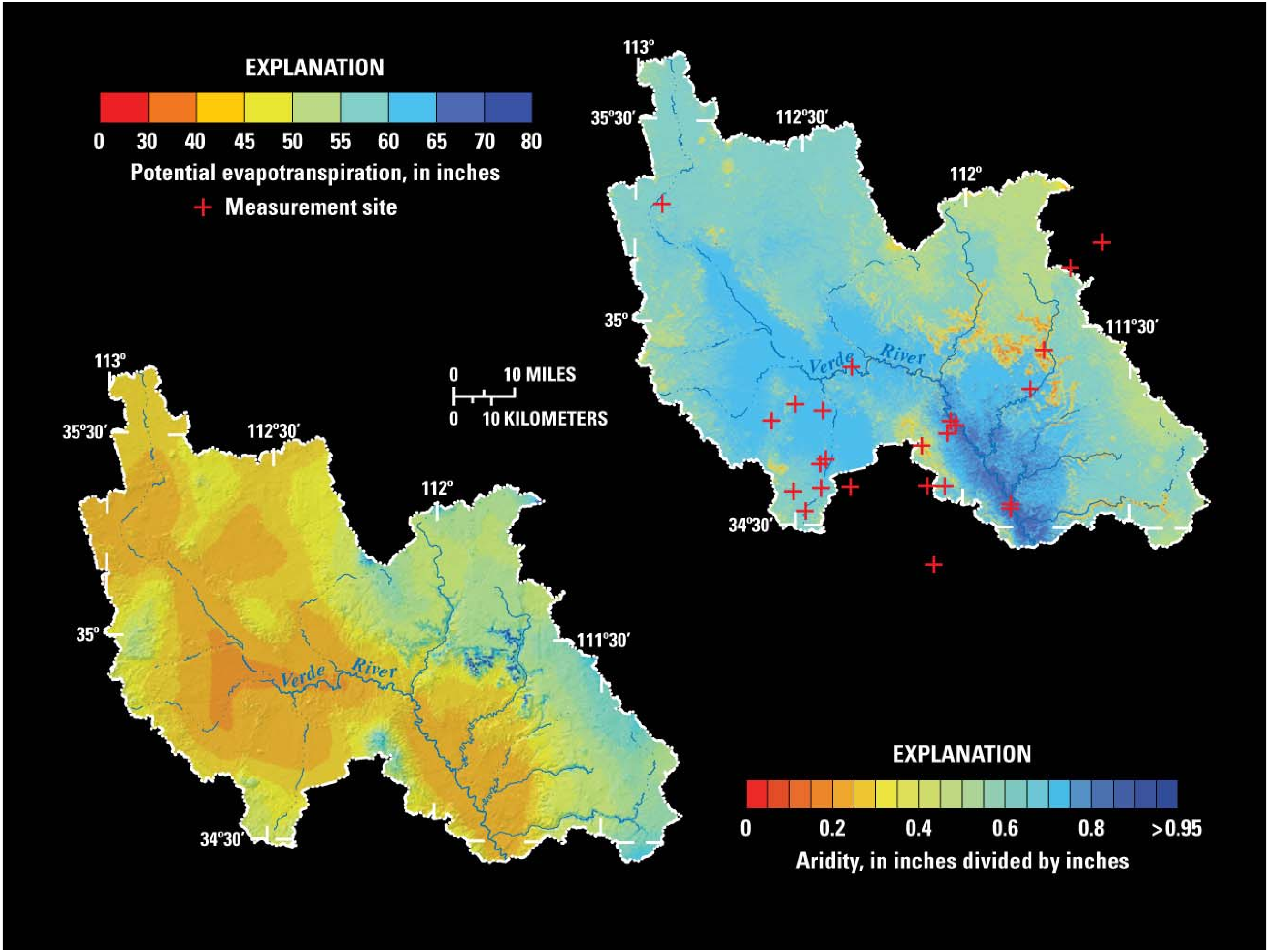
Climate Indices – Necessary for water resource projections

- Strong El Nino means more winter precipitation and variable summer precipitation
- Weak El Nino means less winter and summer precipitation
- La Nina means less winter precipitation but normal summer
- Pacific Decadal Oscillation (PDO) has a slight positive correlation with precipitation
    - Positive PDO means more precipitation and vice versa
- Atlantic Multi-decadal Oscillation (AMO) has a negative correlation with precipitation
    - Positive AMO means less precipitation

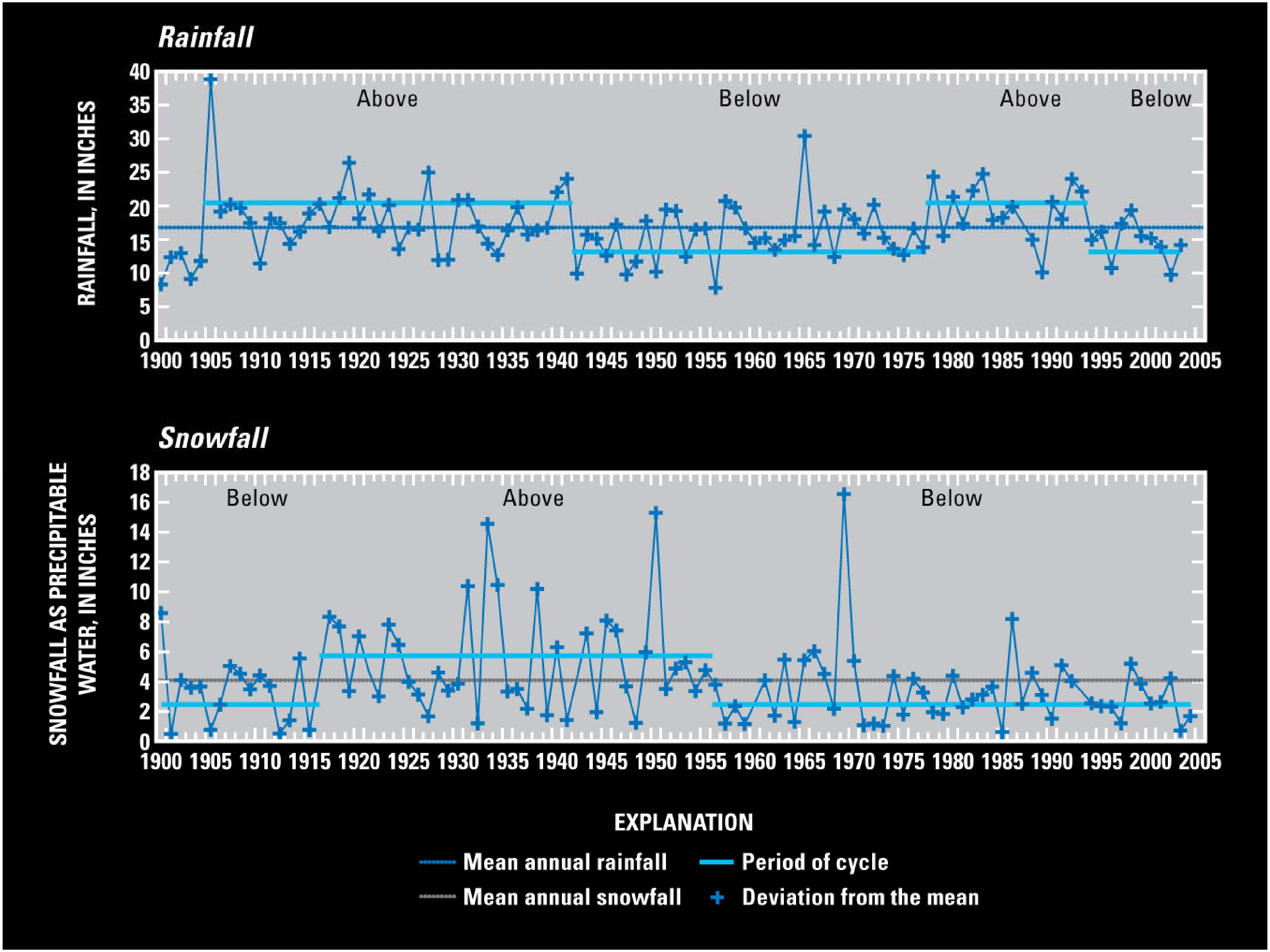


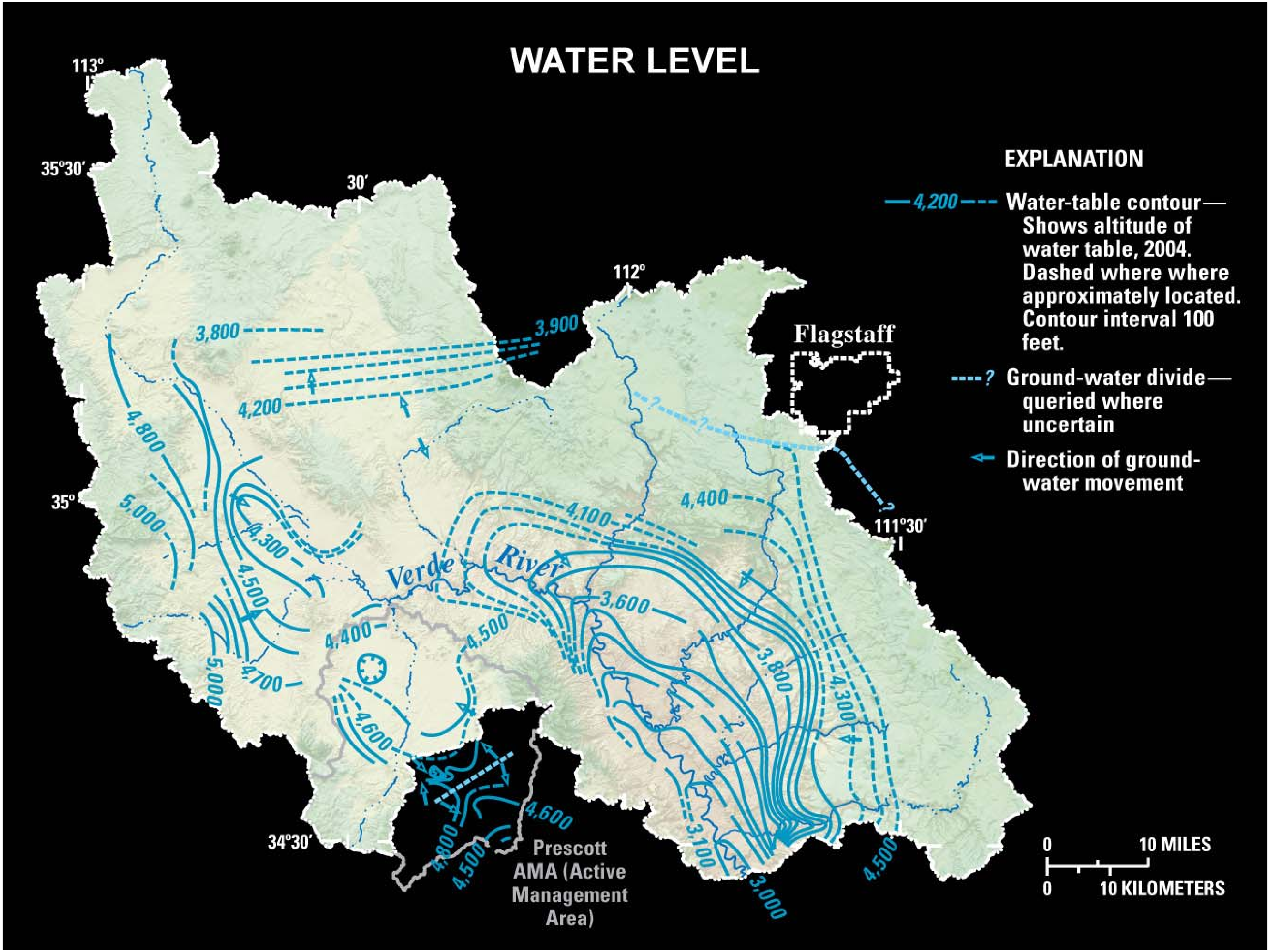


AREAL AND MONTHLY PRECIPITATION IN THE STUDY AREA



EXPLANATION
0
30
40
45
50
55
60
65
70
80
Potential evapotranspiration, in inches
Measurement site
113°
35°30′
112°30′
112°
35°
111°30′
34°30′
Verde River
0 10 MILES
0 10 KILOMETERS
EXPLANATION
0
0.2
0.4
0.6
0.8
>0.95
Aridity, in inches divided by inches

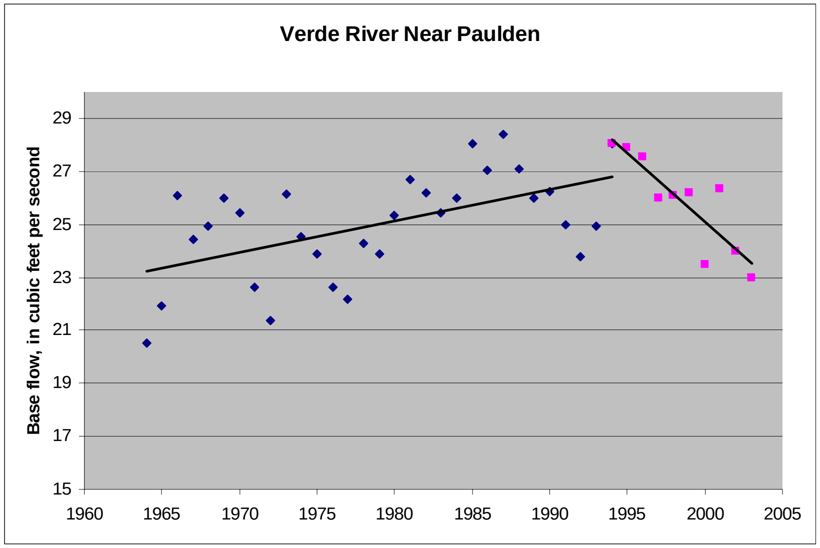

Rainfall
RAINFALL, IN INCHES
Above
Below
Above
Below
0
5
10
15
20
25
30
35
40
1900 1905 1910 1915 1920 1925 1930 1935 1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
Snowfall
SNOWFALL AS PRECIPITABLE WATER, IN INCHES
Below
Above
Below
0
2
4
6
8
10
12
14
16
18
1900 1905 1910 1915 1920 1925 1930 1935 1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
EXPLANATION
Mean annual rainfall
Mean annual snowfall
Period of cycle
Deviation from the mean



WATER LEVEL
113°
35°30′
30′
112°
35°
111°30′
34°30′
EXPLANATION
4,200 Water-table contour—Shows altitude of water table, 2004. Dashed where where approximately located. Contour interval 100 feet.
? Ground-water divide—queried where uncertain
Direction of ground-water movement
Flagstaff
Verde River
Prescott AMA (Active Management Area)
0 10 MILES
0 10 KILOMETERS
3,800
3,900
4,200
4,800
5,000
4,300
4,500
4,400
4,700
4,600
4,100
3,600
3,100
3,000

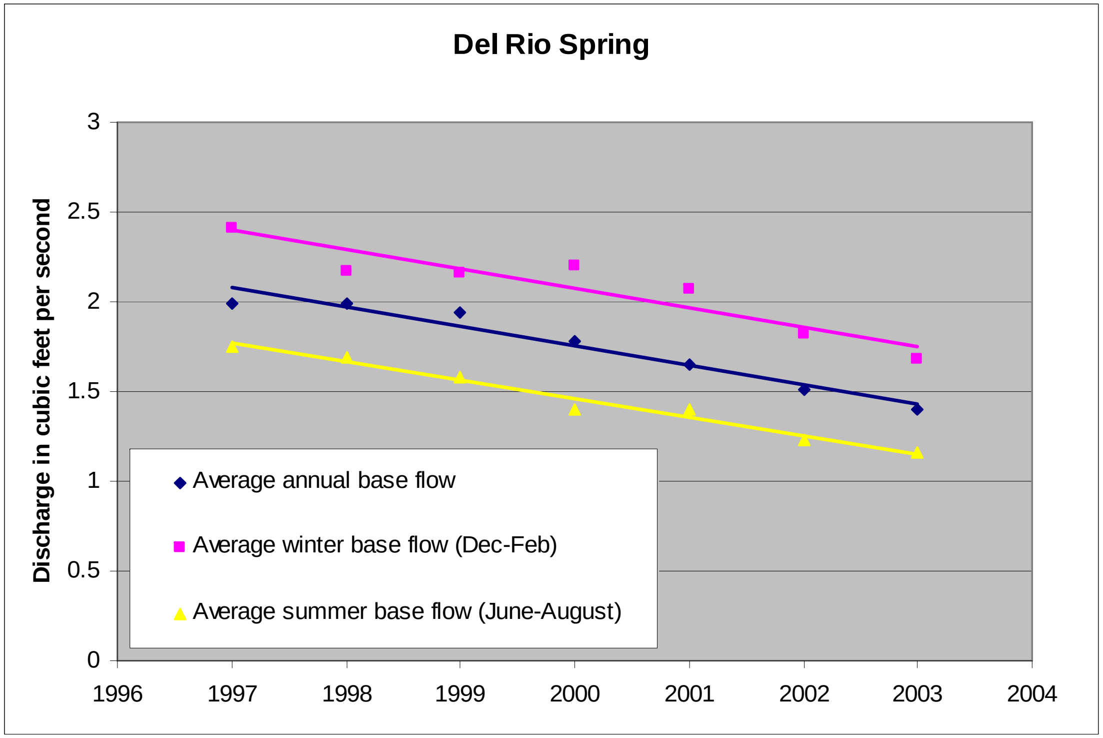
Surface-Water Flow Systems – Big Chino Subbasin

- Base flow in the Verde River is directly linked to precipitation and changes in ground-water storage
  - Model will help enumerate the link
- Channel recharge occurs on an event basis
  - Model will help test the importance of channel recharge
- Peak streamflow and base flow is during the winter in the Verde River near Paulden
- Tributaries have peak streamflow in Feb-Mar and Aug
- Standard error at the Paulden gage for low flows is about 0.057 ft^3/s
- Base flow has declined about 380 acre-ft per year at Paulden since 1993
- Ground water from Big Chino Valley, Little Chino Valley, and Western Coconino Plateau contribute to the upper Verde River



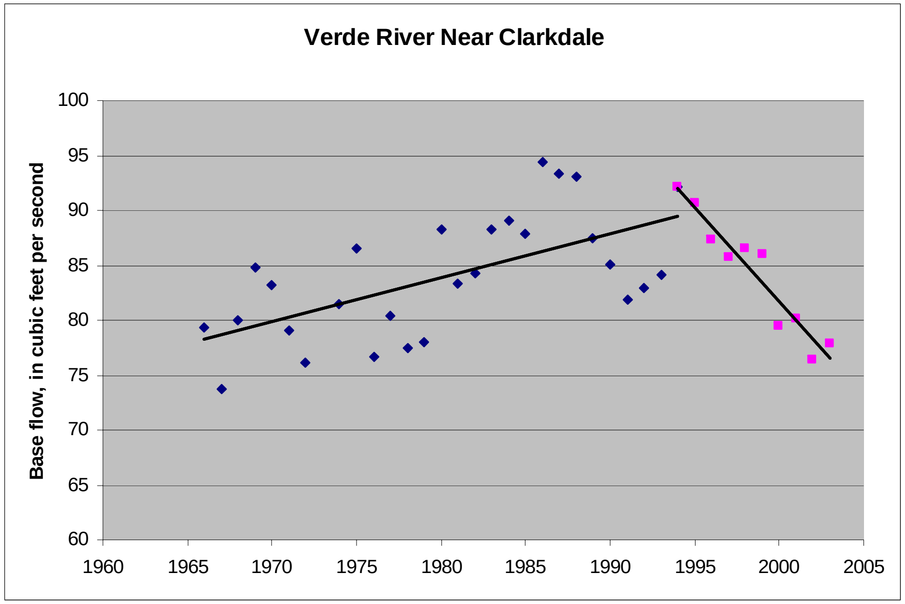
Surface-Water Flow Systems – Little Chino Subbasin

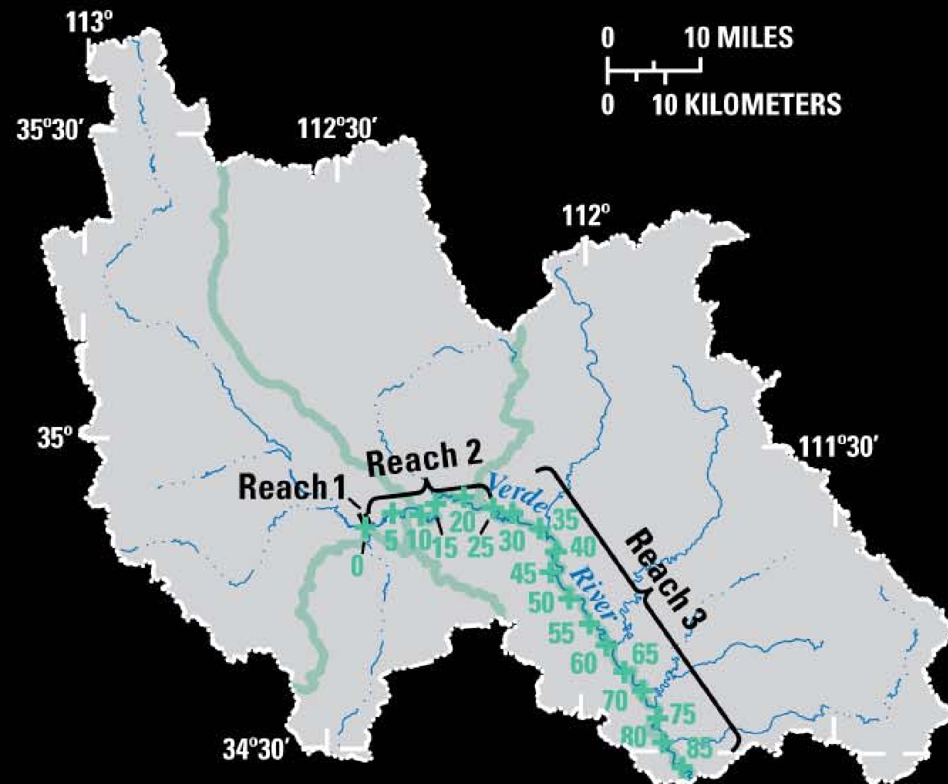
- Del Rio Springs and Granite Creek are the major features with flow leaving the subbasin
- Impoundment of surface water has likely reduced channel recharge
- Streamflow in Del Rio Springs is almost entirely base flow
    - Streamflow in Del Rio Springs is directly linked to ground-water pumping
- Base flow in Del Rio Springs decreased from 1,450 acre-ft per year in 1997 to 1,000 acre-ft per year in 2003
- Flow of water through the channel alluvium adjacent to Granite Creek and the Verde river is on the order of 0.25 ft^3/s



Surface-Water Flow Systems – Verde Valley Subbasin

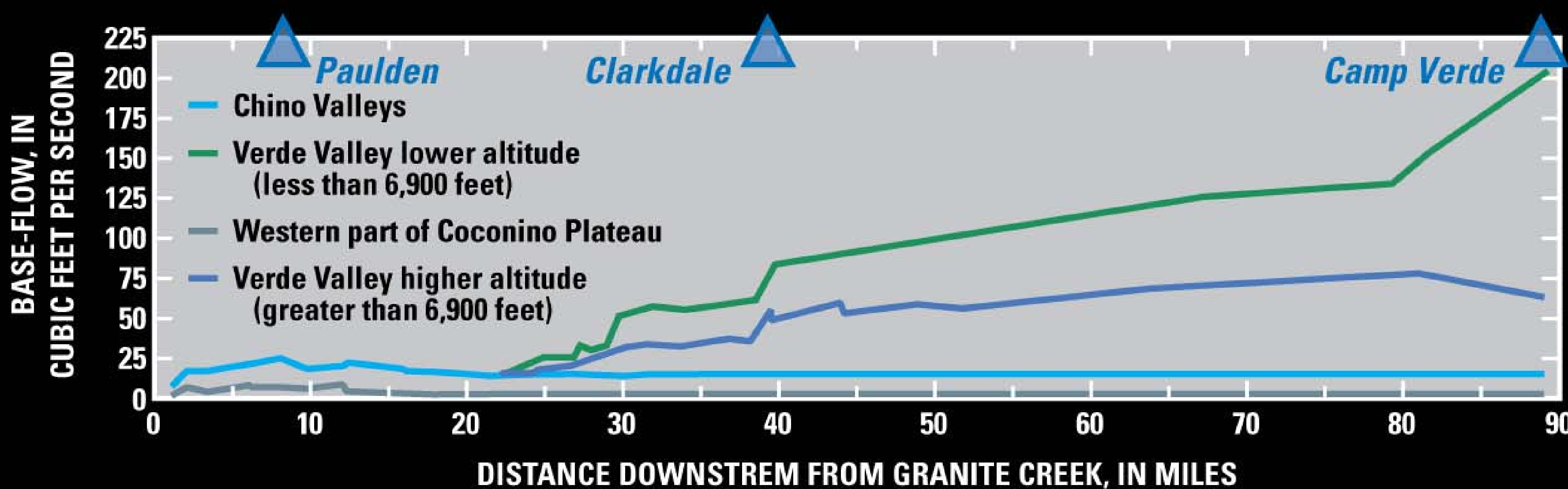
- The Verde River is the only surface water source entering and leaving the subbasin
- Base flow in tributaries is supported by recharge of water on the Mogollon escarpment (Rim)
- Base flow declines by 10 ft^3/s from the Paulden gage to Perkinsville (ET)
- Streamflow and base flow both peak in the winter months for the Verde River and tributaries
- The standard error in low flows is 0.12 ft^3/s for the Verde River measured at Clarkdale
- Declines in base flow average about 1,000 acre-ft per year at Clarkdale and 2,000 acre-ft per year at Camp Verde since 1994.
- Annual and winter base flow measured at Oak Creek near Sedona has declined since the mid-1980s
- Historical winter base flow in Wet Beaver Creek has a different trend than other tributaries





•Evaporative reach from about mile 12 (8) -22
•Chino Valleys contribute about 10% of base flow as recorded at Camp Verde

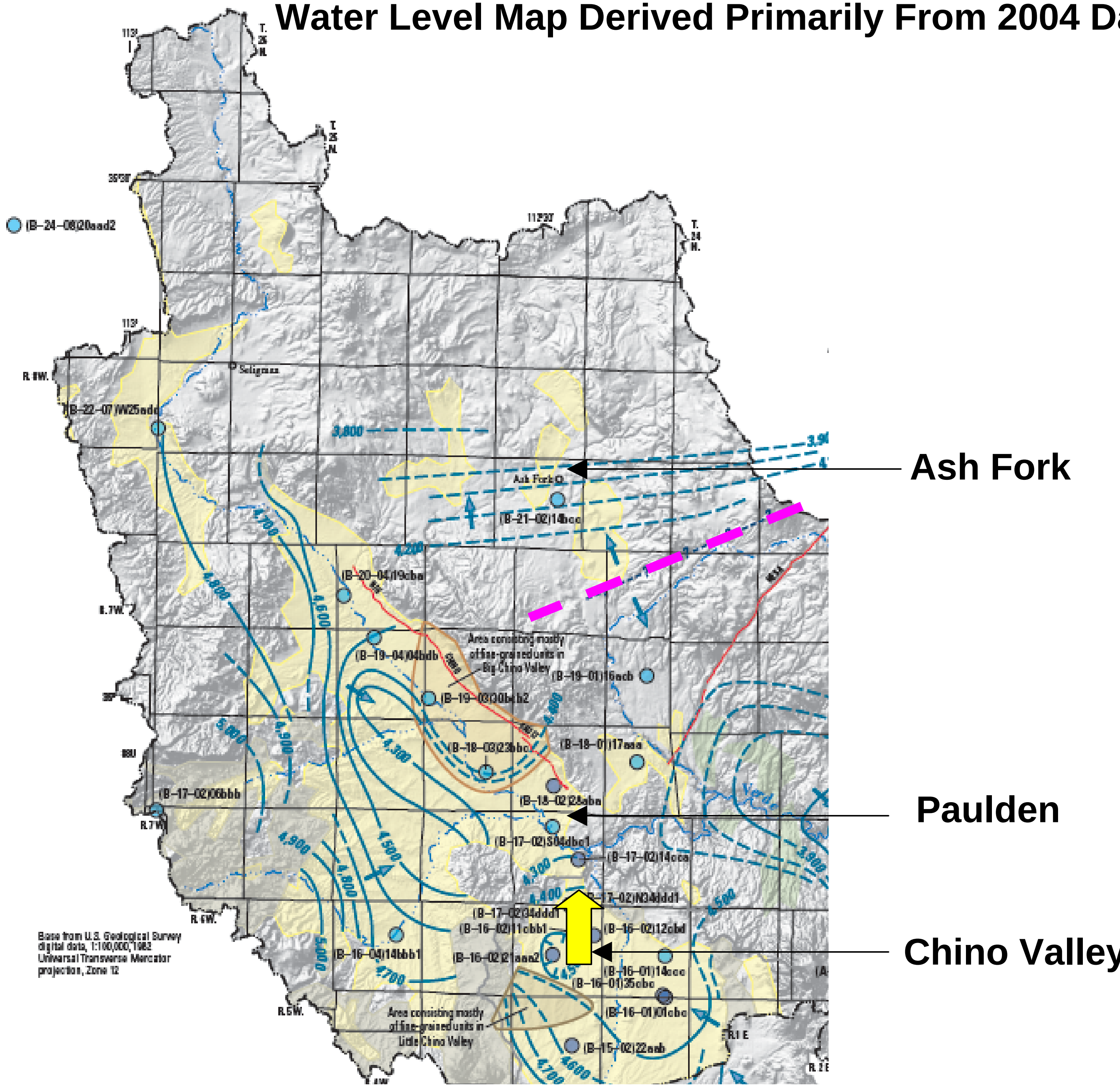
Base-flow contributions



Ground-Water Flow Systems – Big Chino Subbasin

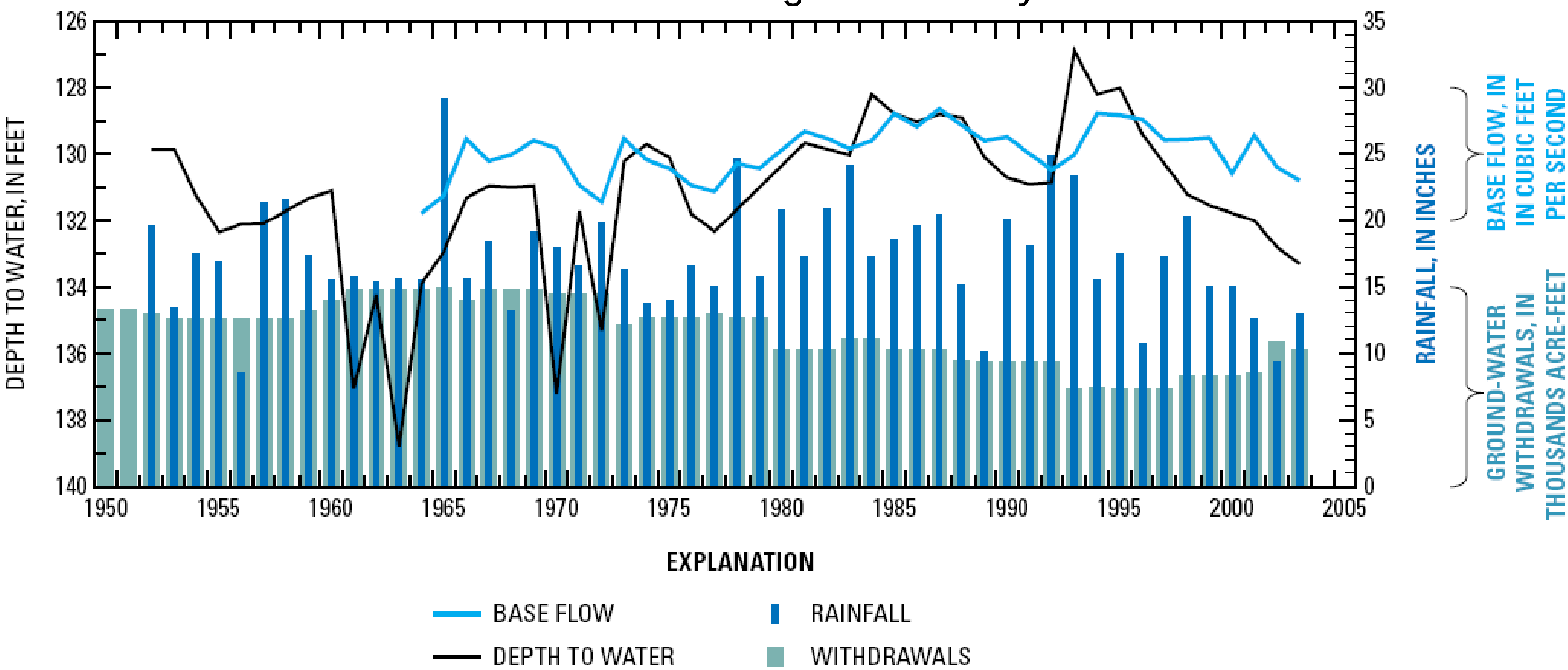
- Ground-water inflow from Little Chino subbasin has declined from pre-development time periods from about 3,000 acre-ft per year to 1,800 acre-ft per year presently
- A ground-water divide is located to the north of Big Black Mesa
    - The absence of data prohibits a definitive location but our initial hypothesis is that it originates near Bill Williams mountain and heads southwest to Big Black mesa
    - The numerical model will provide a better sense of the location
- Groundwater inflow and outflow in the vicinity of the northern border has not been quantified on the basis of limited data
    - The numerical model will estimate this quantity
- Verde River is the only ground-water discharge point for the Big Chino Valley
- Geologic data and 2004 water level altitudes indicate the presence of a fine-grained playa in Big Chino Valley
- Average ground-water residence times is between 1,000 to 10,000 years
    - 6,000 years is the best estimate
    - Numerical model will identify travel times through the system

Water Level Map Derived Primarily From 2004 Data



Ground-Water Flow Systems – Big Chino Subbasin – Cont

- •Base flow in the Verde River near Paulden stream gage is directly linked to precipitation and storage changes in the Big Chino Valley
  - •Numerical model will help determine the relationship between recharge and pumpage on base flow
- •Water level altitudes in the middle and eastern part of the Big Chino Valley rose from the early 1950s through the early 1990s. This period is succeeded by a decline through 2003 of about 0.5 to 0.75 ft/yr
- •Seasonal fluctuations in WLA eastern Big Chino valley varied from 1 to 3 ft

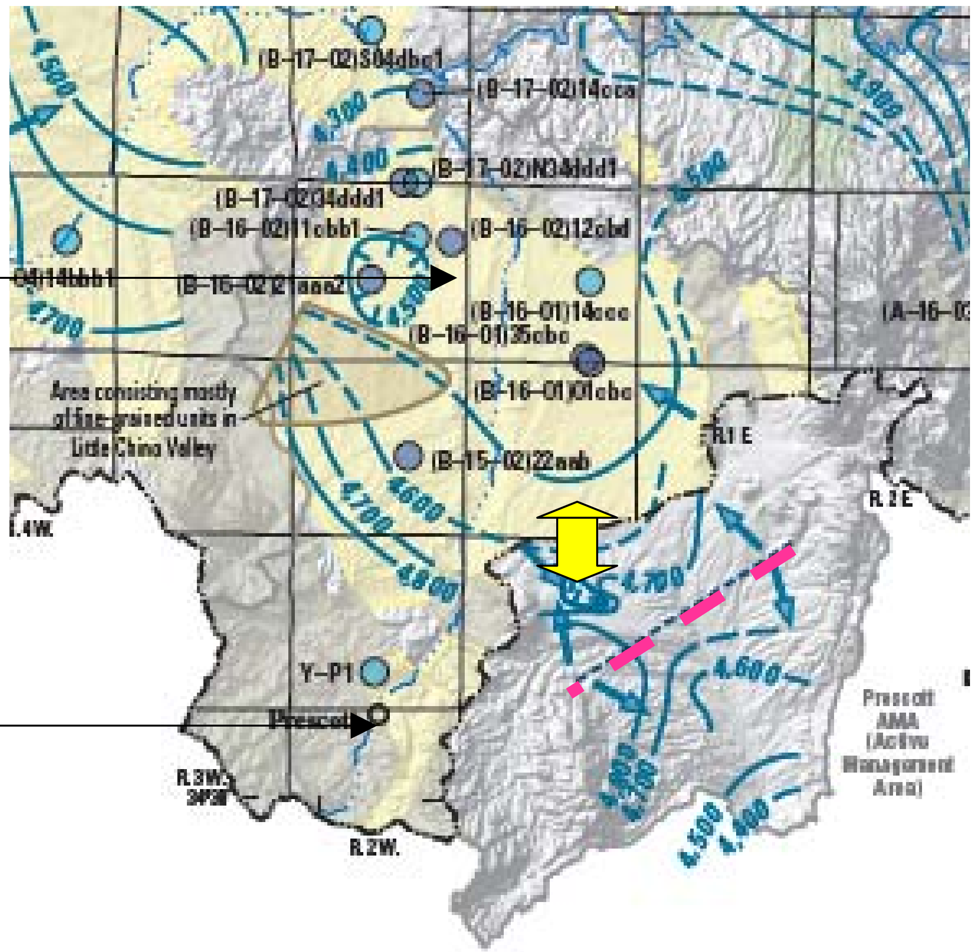


Ground-Water Flow Systems – Little Chino subbasin

- Ground-water outflow from Little Chino subbasin to the Big Chino subbasin has declined from pre-development time periods (3,000 to 1,800 acre-ft per year)
- A ground-water divide is located to the south of the surface water boundary of the Little Chino subbasin. Direction of flow has reversed direction from pre-development time periods caused by ground-water withdrawals
- Geologic data and 2004 Water level altitudes indicate the presence of a fine-grained units in the Little Chino Valley
- Base flow in Del Rio Springs is directly linked to ground-water recharge and storage changes in the Little Chino Valley
- Water level altitudes have declined since the mid 1930s however some areas have shown an increase as lands were removed from irrigation and recharge increased
- Water level altitudes dropped in 73 of 84 wells from 2001 to 2002 (average 4 ft)
- Water level altitudes dropped in 65 of 85 wells from 2002 to 2003 (average 2.5 ft)
- Seasonal fluctuations in water level altitudes are as high as 20 ft near the town of Chino Valley. Smaller variations (0-10 ft) in other parts of the basin

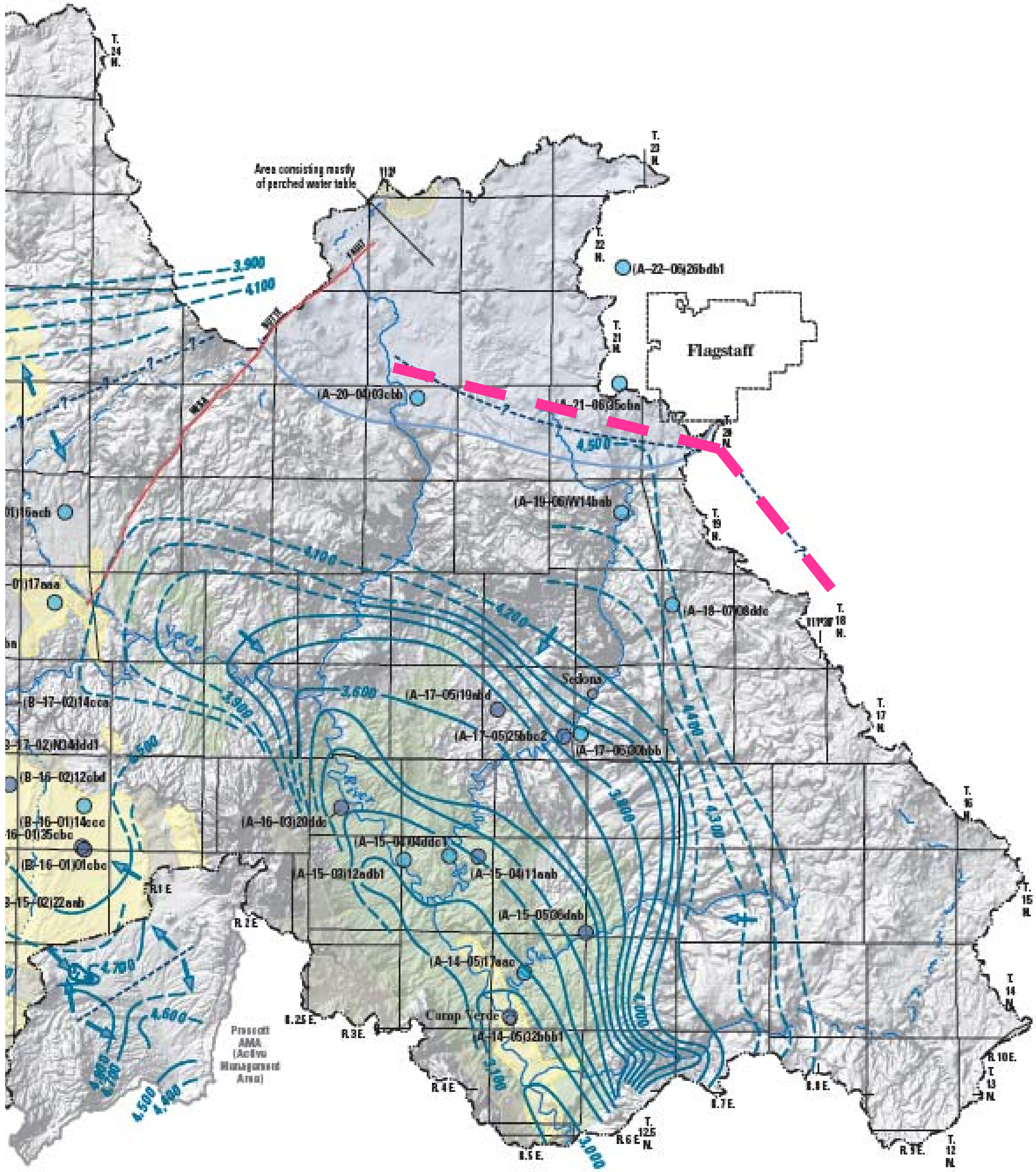
Chino Valley

Prescott

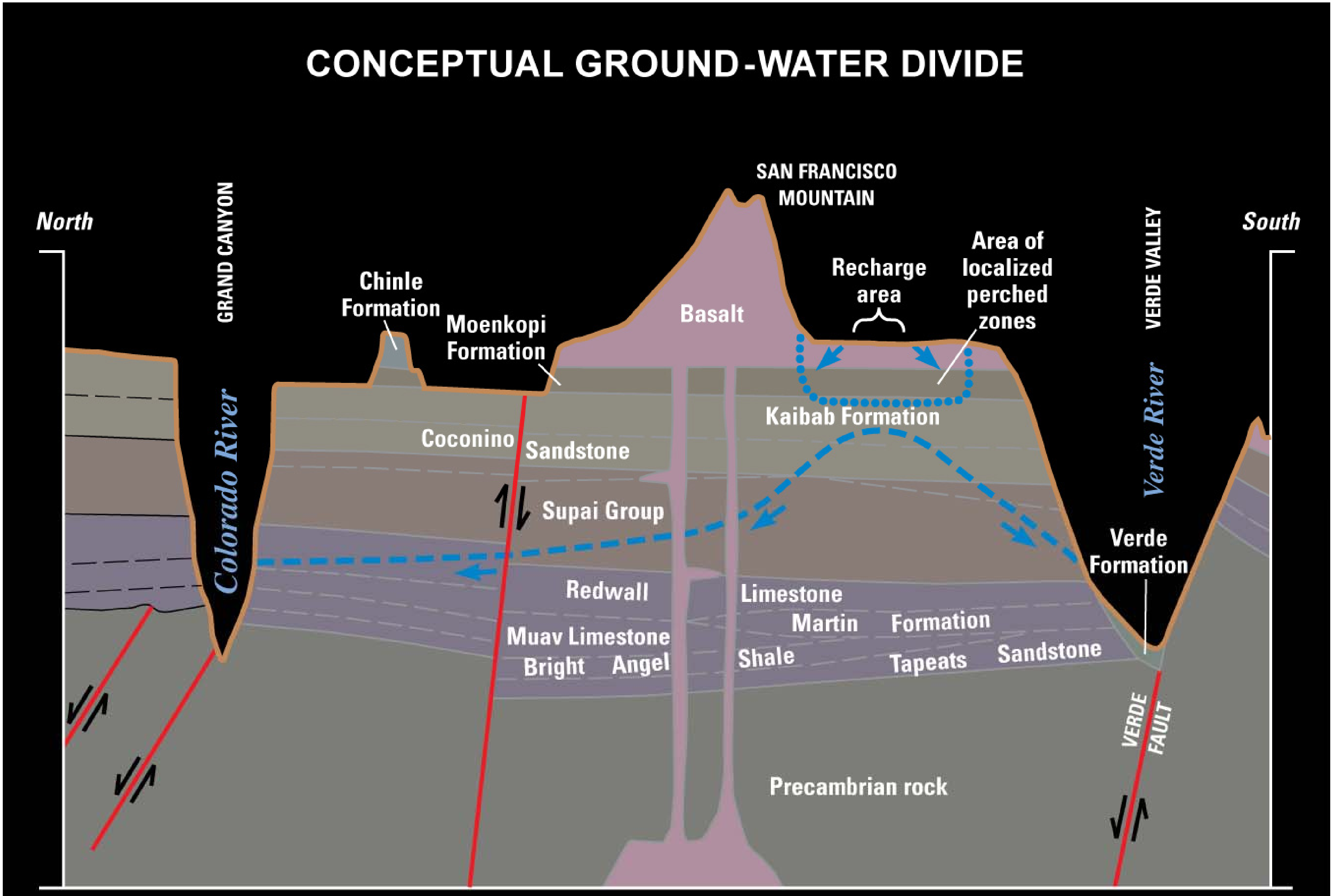


Ground-Water Flow Systems – Verde Valley subbasin

- Ground-water inflow from the Big Chino subbasin is only as base flow in the Verde River
- A ground-water divide is located to the north and east of Mogollon escarpment
  - The absence of data prohibits a definitive location but our initial hypothesis is that the it parallels Mormon mountain and then heads west south of Flagstaff
  - The numerical model will provide a better sense of the location
- Verde River is the only discharge point for the Verde Valley
- Ground-water inflow and outflow in the vicinity of the northern and eastern border has not been quantified on the basis of limited data
  - The numerical model will estimate this quantity
- Base flow in the Verde River is directly linked to ground-water recharge and storage changes in the Verde River Valley
- Water level altitude declines are as high as 30 - 40 ft in the Verde Formation over the past 40 years
- Seasonal fluctuations in wells varied between 0 and 30 ft

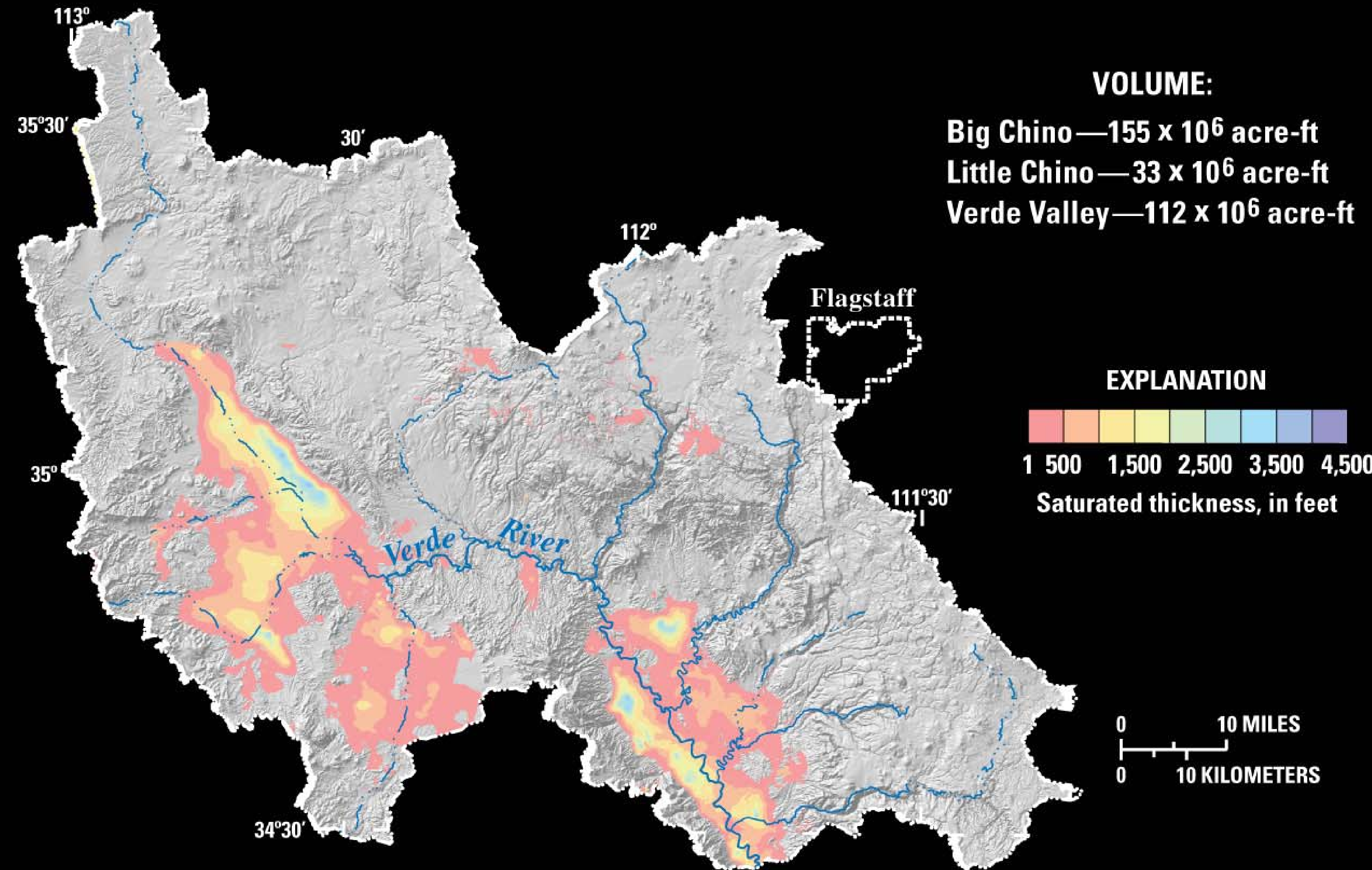


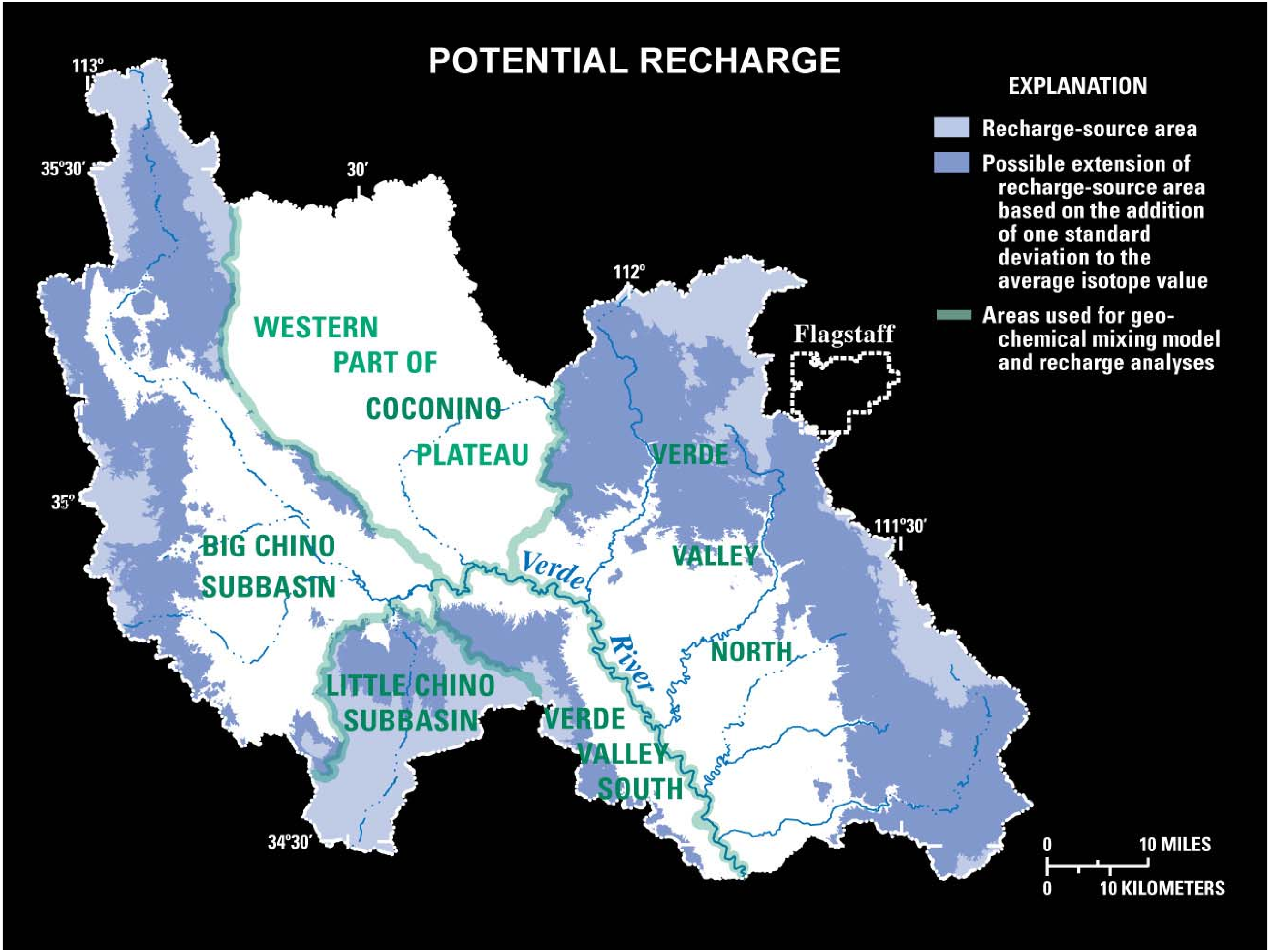
Area consisting mostly of perched water table
Flagstaff
Sedona
Camp Verde
Verde River
Prescott AMA (Active Management Area)
(A-22-06)26bdb1
(A-21-06)35cba
(A-20-04)03cbb
(A-19-06)W14bab
(A-18-07)08ddc
(A-17-05)19abd
(A-17-05)25bbc2
(A-17-06)30bbb
(A-16-03)20ddc
(A-15-04)04ddc1
(A-15-04)11aab
(A-15-03)12adb1
(A-15-05)06dab
(A-14-05)17aac
(A-14-05)32bbb1
(B-17-02)14cca
(B-16-02)12cbd
(B-16-01)14ccc
(B-16-01)01cbc
3,900
4,100
4,500
3,600
3,800
4,700
4,600
4,400
3,100
3,000
T. 24 N.
T. 23 N.
T. 22 N.
T. 21 N.
T. 20 N.
T. 19 N.
T. 18 N.
T. 17 N.
T. 16 N.
T. 15 N.
T. 14 N.
T. 13 N.
T. 12.5 N.
T. 12 N.
R. 1 E.
R. 2 E.
R. 2.5 E.
R. 3 E.
R. 4 E.
R. 5 E.
R. 6 E.
R. 7 E.
R. 8 E.
R. 9 E.
R. 10 E.

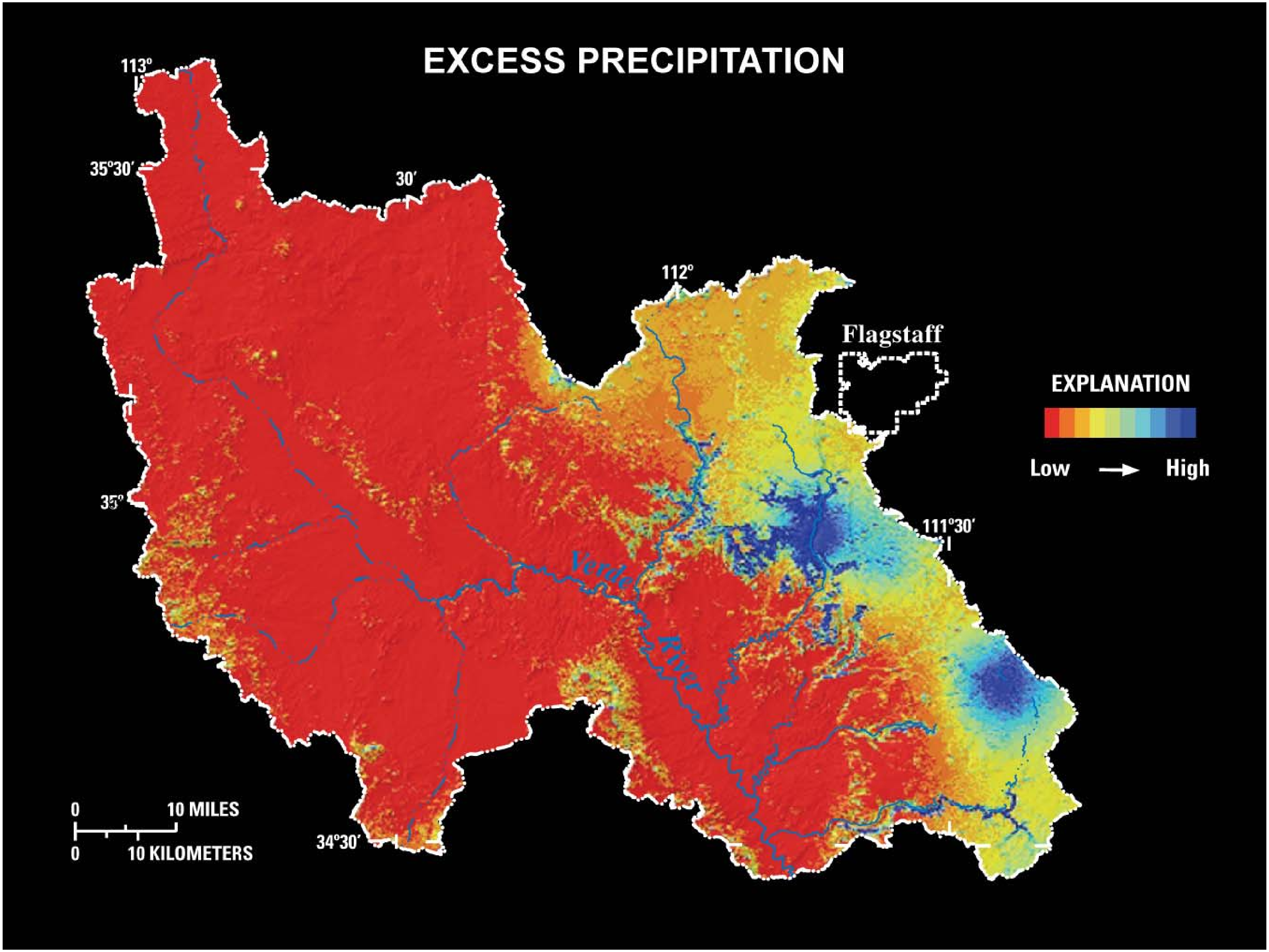


Modified from Flynn and Bills, 2002

THICKNESS AND VOLUME OF CENOZOIC SEDIMENTS AND VOLCANIC ROCKS




POTENTIAL RECHARGE
EXPLANATION
Recharge-source area
Possible extension of recharge-source area based on the addition of one standard deviation to the average isotope value
Areas used for geo-chemical mixing model and recharge analyses
113°
35°30′
30′
112°
35°
111°30′
34°30′
Flagstaff
WESTERN PART OF COCONINO PLATEAU
BIG CHINO SUBBASIN
LITTLE CHINO SUBBASIN
VERDE VALLEY NORTH
VERDE VALLEY SOUTH
Verde River
0 10 MILES
0 10 KILOMETERS

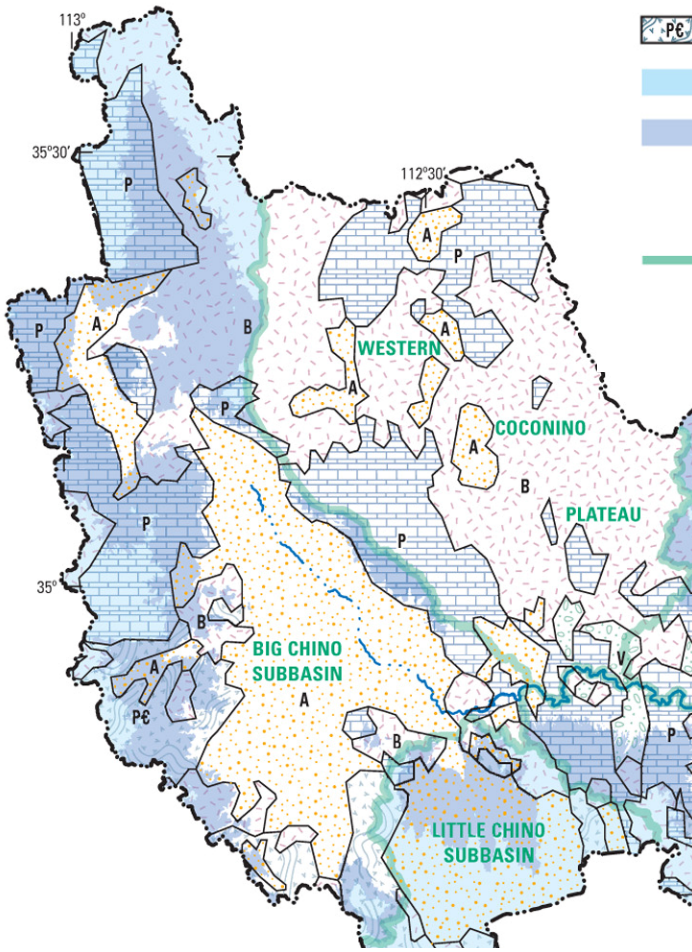

EXCESS PRECIPITATION
113°
35°30′
30′
112°
Flagstaff
EXPLANATION
Low
High
35°
111°30′
Verde
River
0
10 MILES
0
10 KILOMETERS
34°30′

Conceptual Flow Systems – Big Chino subbasin

- Recharge primarily occurs in the Paleozoics at the upper elevations in the Juniper Mountains and Big Black Mesa
- Recharge likely occurs along the Mogollon escarpment near fracture zones. There is significant excess precipitation near Bill Williams Mountain
- Excess water is low in the northwestern part of the subbasin suggesting recharge is not as high as near the Juniper mountains surrounding the Big Chino valley
- Channel recharge is probably an important contributor to recharge of the aquifer based on the type of channel sediments; however, there is limited data to verify this
- Ground-water flow within the aquifer system is towards the Verde River
- The depth of the saturated sediments within the Cenozoic sediment can range as high as several thousand feet

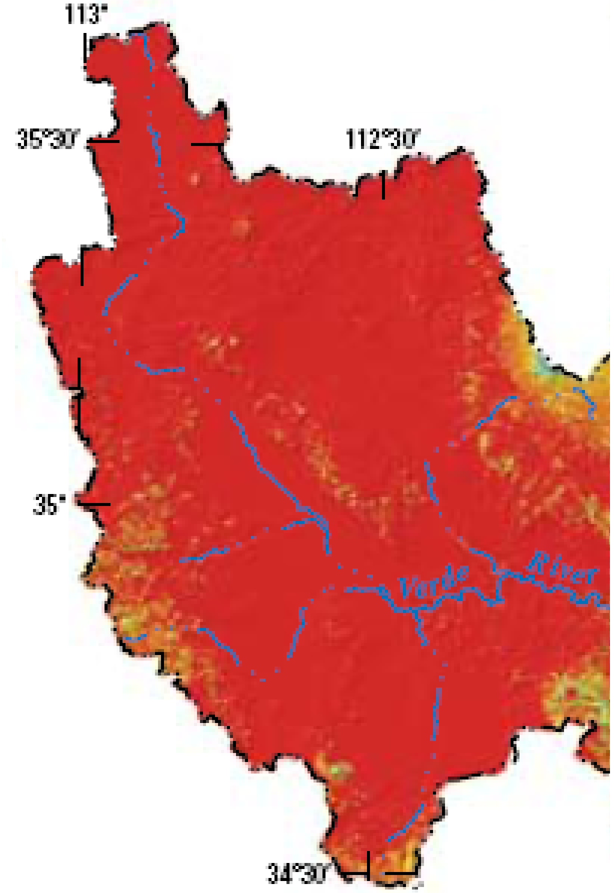
EXPLANATION

- A — ALLUVIUM
- V — VERDE FORMATION
- B — BASALTIC ROCK
- P — PALEOZOIC UNITS
- P€ — PRECAMBRIAN ROCK
- RECHARGE-SOURCE AREA
- UNCERTAINTY BOUNDS FOR THE RECHARGE SOURCE AREA
- CHEMISTRY SOURCE (RECHARGE) AREA BOUNDARY



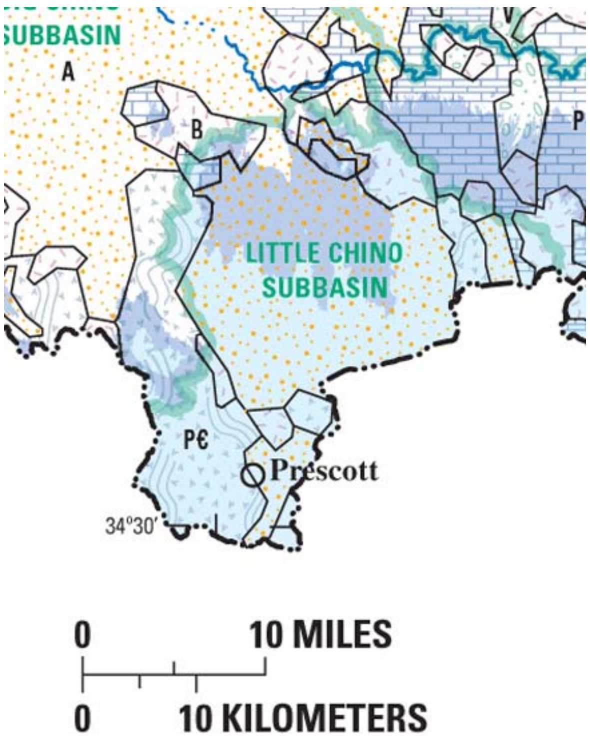
Recharge Potential

- High
- Medium
- Low



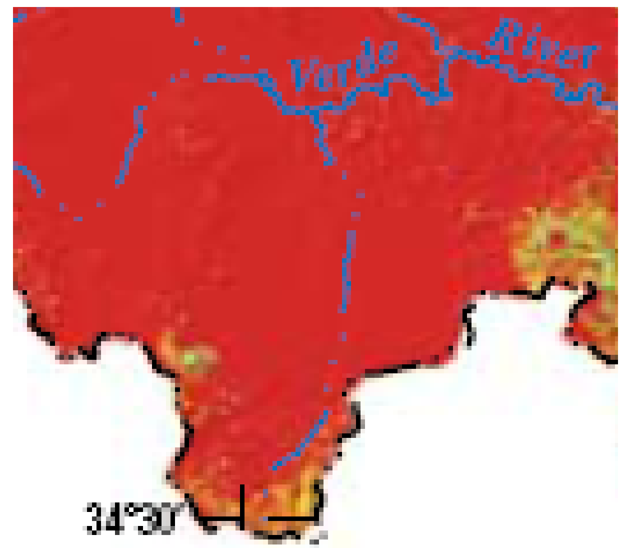
Conceptual Flow Systems – Little Chino Subbasin

- Mountain-block recharge in the subbasin is not as probable as other forms of recharge owing to impermeable geologic units
- Channel recharge and mountain front recharge are more probable
- Base flow in Del Rio Springs is directly connected to changes in aquifer storage



EXPLANATION

- A — ALLUVIUM
- V — VERDE FORMATION
- B — BASALTIC ROCK
- P — PALEOZOIC UNITS
- PЄ — PRECAMBRIAN ROCK
- RECHARGE-SOURCE AREA
- UNCERTAINTY BOUNDS FOR THE RECHARGE SOURCE AREA
- CHEMISTRY SOURCE (RECHARGE) AREA BOUNDARY

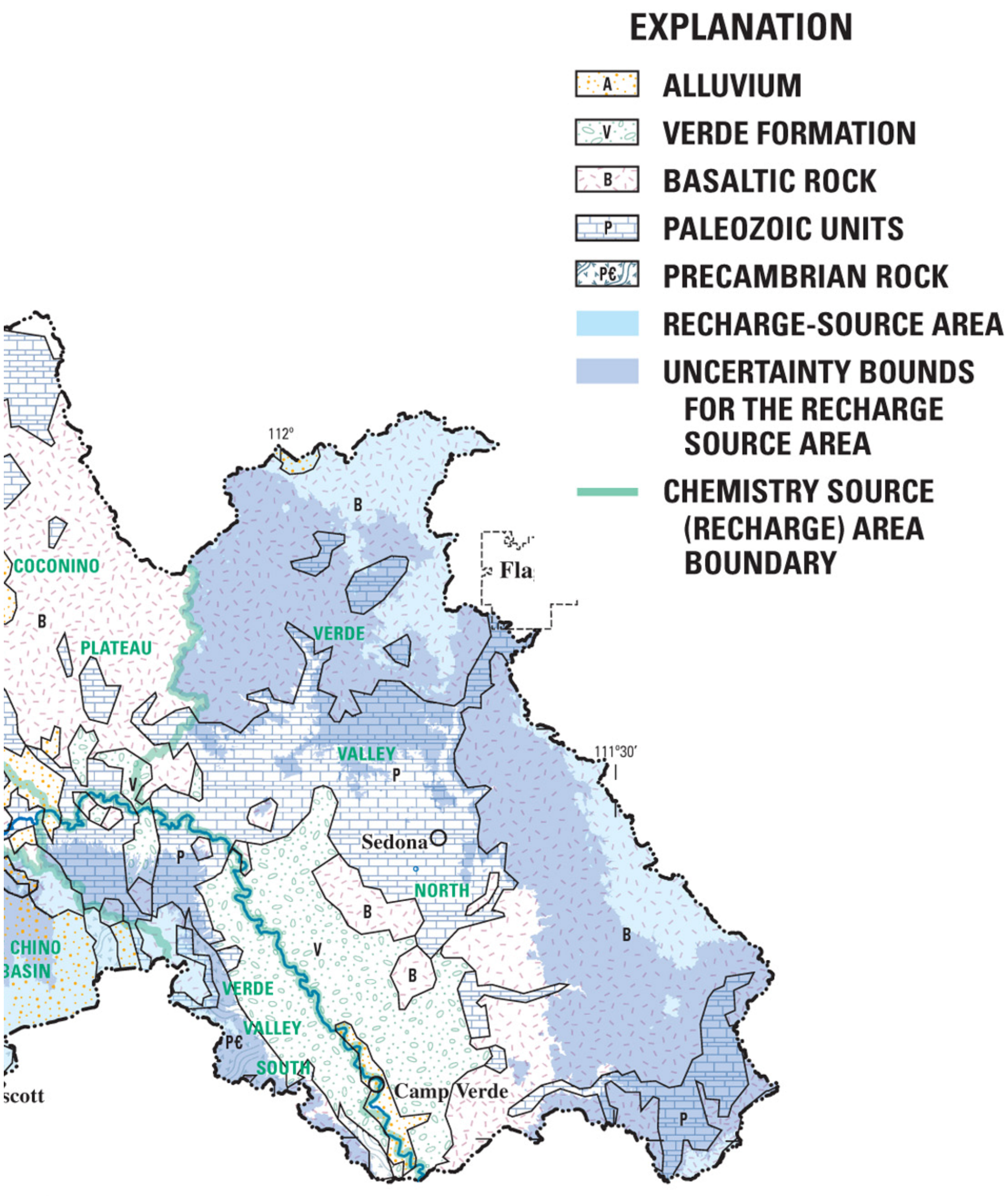


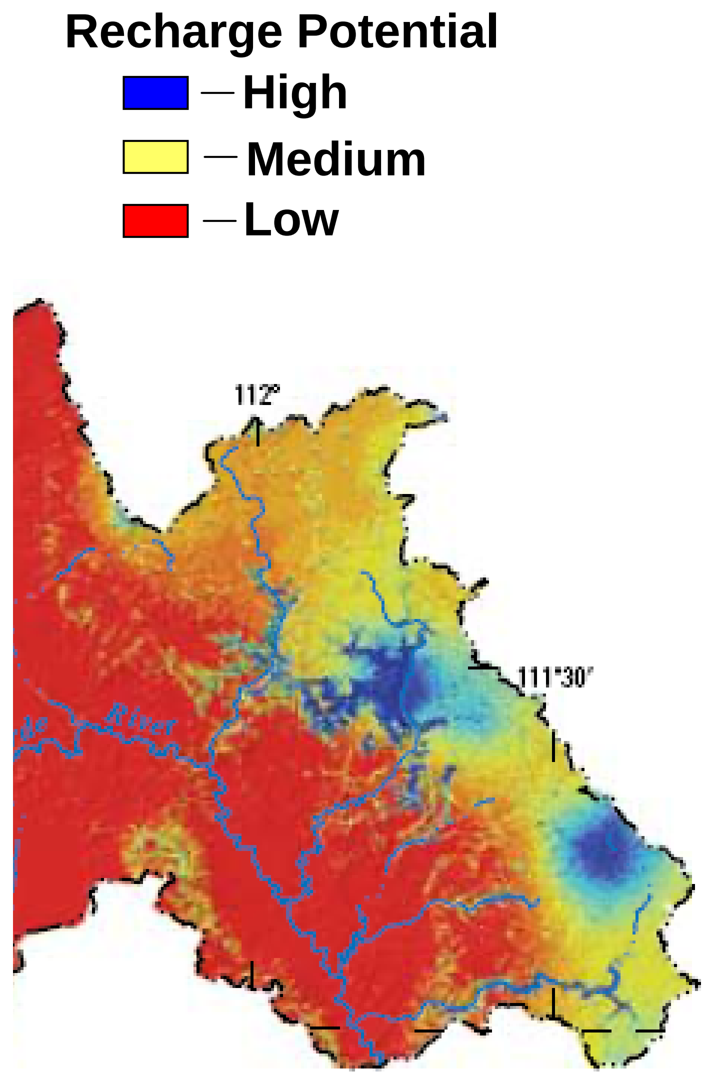
Recharge Potential

- High
- Medium
- Low

Conceptual Flow Systems – Verde Valley Subbasin

- Recharge in the Black Hills is primarily in the Paleozoics at upper elevations
- Springs at mid-slope occur where more permeable units overlie less permeable units
- Recharge is high along the Mogollon escarpment near fracture zones. Some of the volcanic rocks act as local perched aquifers. Areas near the San Francisco Peaks and Happy Jack are indicated as the probable sources of recharge
- Connectivity of the C aquifer and Redwall-Muav aquifer are likely through permeable fracture and fault zones
- The connectivity is not universal as less permeable units can act as aquitards
- Recharge along the Coconino Plateau contributes to base flow in tributaries originating along the Mogollon escarpment or as ground-water flow to the Verde Formation
- The depth of the saturated sediments within the Verde Formation can range as high as several thousand feet


EXPLANATION
A ALLUVIUM
V VERDE FORMATION
B BASALTIC ROCK
P PALEOZOIC UNITS
P€ PRECAMBRIAN ROCK
RECHARGE-SOURCE AREA
UNCERTAINTY BOUNDS FOR THE RECHARGE SOURCE AREA
CHEMISTRY SOURCE (RECHARGE) AREA BOUNDARY
112°
111°30′
COCONINO
PLATEAU
VERDE
VALLEY
NORTH
CHINO
BASIN
VERDE
VALLEY
SOUTH
Sedona
Camp Verde
Fla
scott


Recharge Potential
High
Medium
Low
112°
111°30′
River

Water Quality in the Study Area

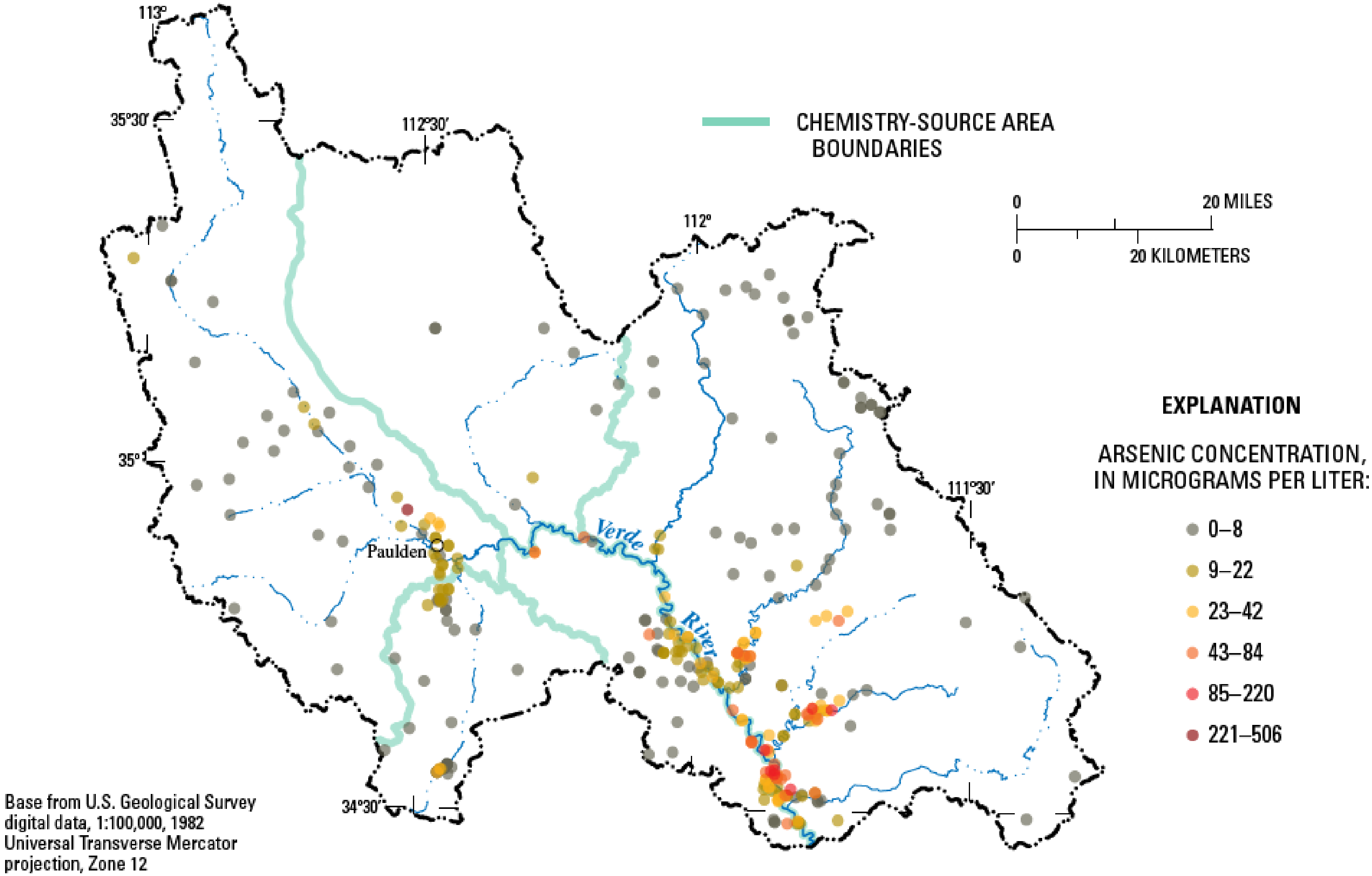
Surface Water

- Arsenic is the only compound of 143 compounds that exceeds surface water standards
  - Arsenic is naturally occurring
- The USEPA maximum contaminant level (MCL) for arsenic in drinking water will change to 10 micrograms per liter January 2006.
  - Verde River samples downstream of Clarkdale gage exceed this value

Ground Water

- Concentrations of antimony, arsenic, fluoride, lead, nitrate, and selenium exceeded the MCLs of the primary drinking water standards in some samples
  - Arsenic exceeded standards most frequently
- Secondary MCLs are not enforceable but are designed to improve the aesthetic quality of the water. Fluoride and sulfide exceeded standards (4-5 percent of samples) more frequently than any other factor evaluated.

Arsenic distribution in ground water




Questions?
USGS
science for a changing world