A Proposed Approach to Sustainable Groundwater Extraction Based on Surface-Groundwater Interaction

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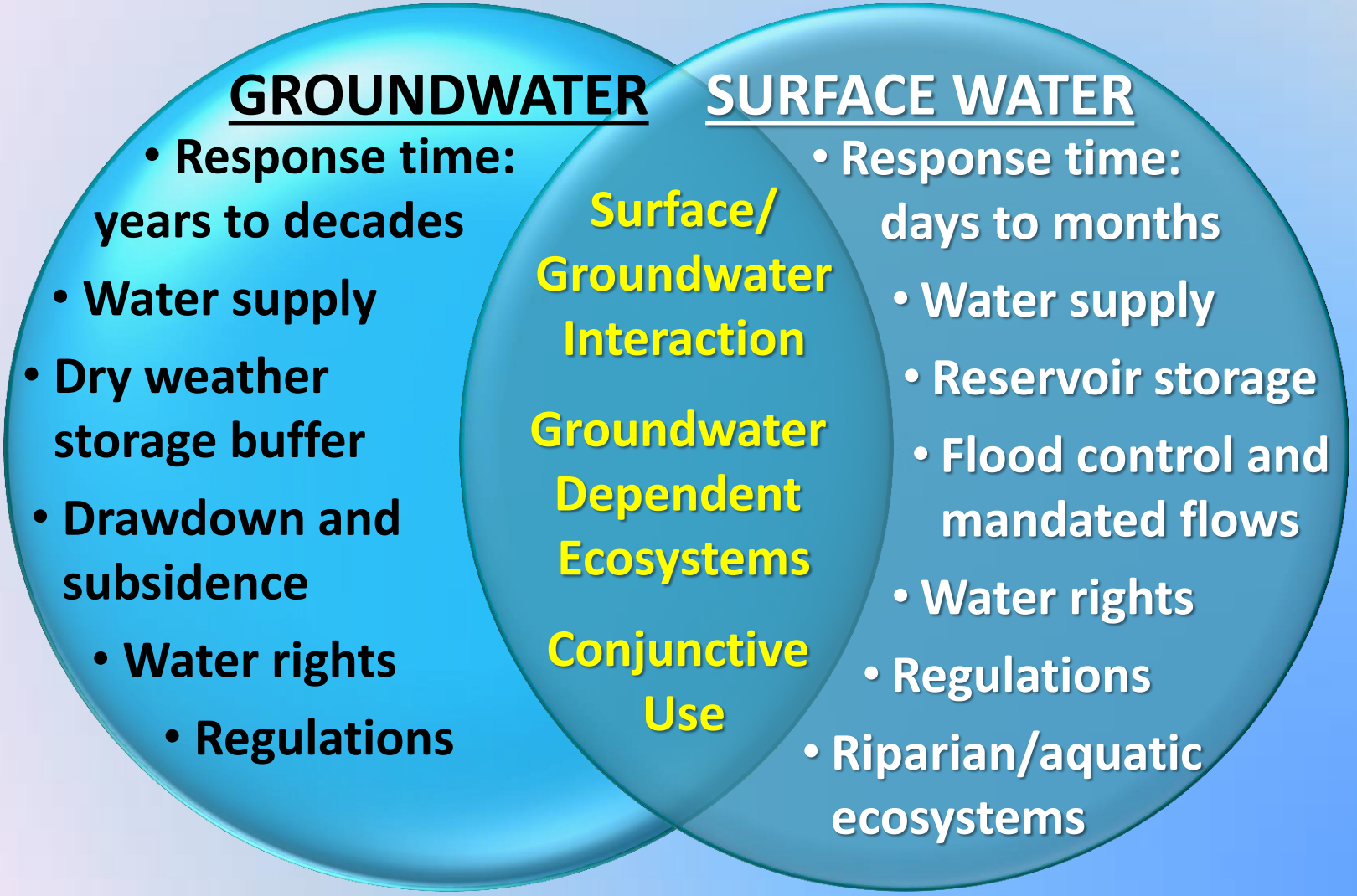
Overview

- Background and Key Concepts
- Stanislaus and Tuolumne River Surface Water depletion studies for implementation of a County Groundwater Ordinance
- The Proposed Colorado River Accounting Surface and a proposed alternative method using Groundwater Management Zones in the Colorado River Aquifer

One Resource?

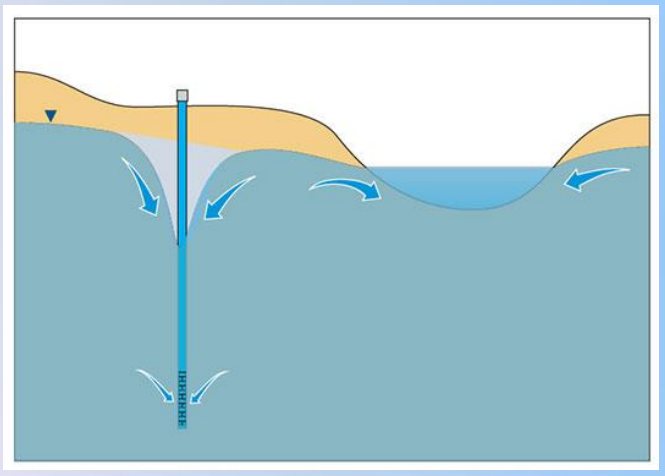


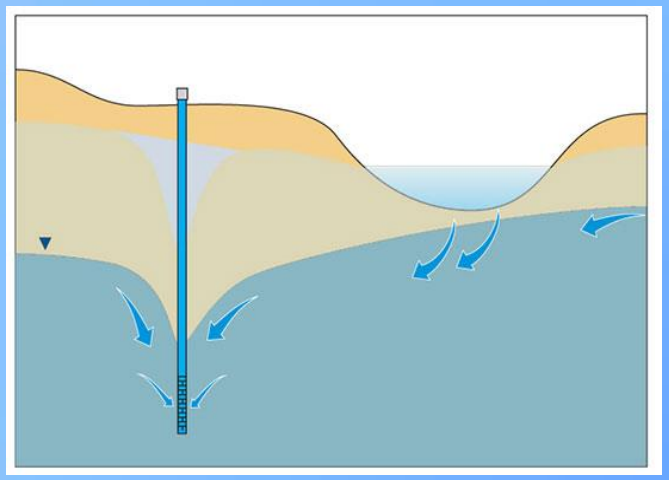
Key Concepts

- **Alley & Leake (2004):** ***Water resources cannot be developed without altering the natural environment; thus, one should not define basin yields, either as safe or sustainable, without carefully explaining the assumptions that have been made about the acceptable effects of ground water development on the environment.***

Key Concepts

Groundwater Extraction	=	Intercepted Discharge
Sustainable Yield	≠	Natural Recharge





Pictures taken from "Water Supply Protection for Rural Communities in Washington State," by Horsley Witten (http://www.horsleywitten.com/evergreen/index.html)

Surface Water Depletion

Controlling factors:

- Aquifer characteristics (especially Diffusivity)
- Distance between well and surface water
- Depth of well below surface water (similar to distance)
- Proximity to other recharge sources

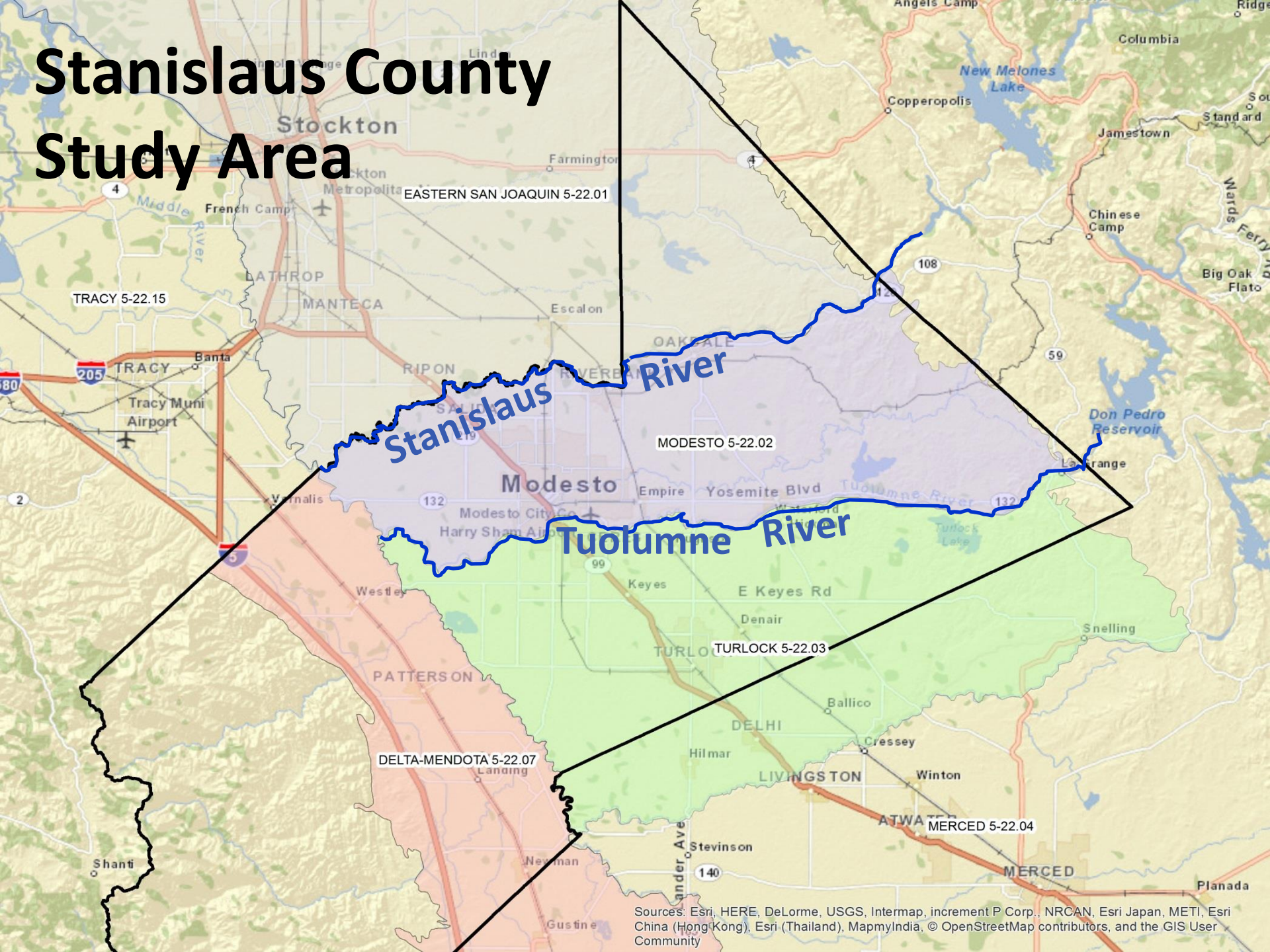
Common Misconceptions:

- Does not depend on whether a stream is gaining or losing
- Does not depend on groundwater flow direction
- Does not stop when pumping ceases
- Is not eliminated by pumping below aquitards

Example 1: Stanislaus & Tuolumne Rivers

- In 2014, Stanislaus County adopted a groundwater ordinance aligned with California's Sustainable Groundwater Management Act (SGMA).
- New wells must be demonstrated not to cause surface water depletion that has a significant and unreasonable impact on surface water resources.
- A modeling evaluation was conducted to establish a well permitting procedure that would be protective of surface water.

Stanislaus County Study Area



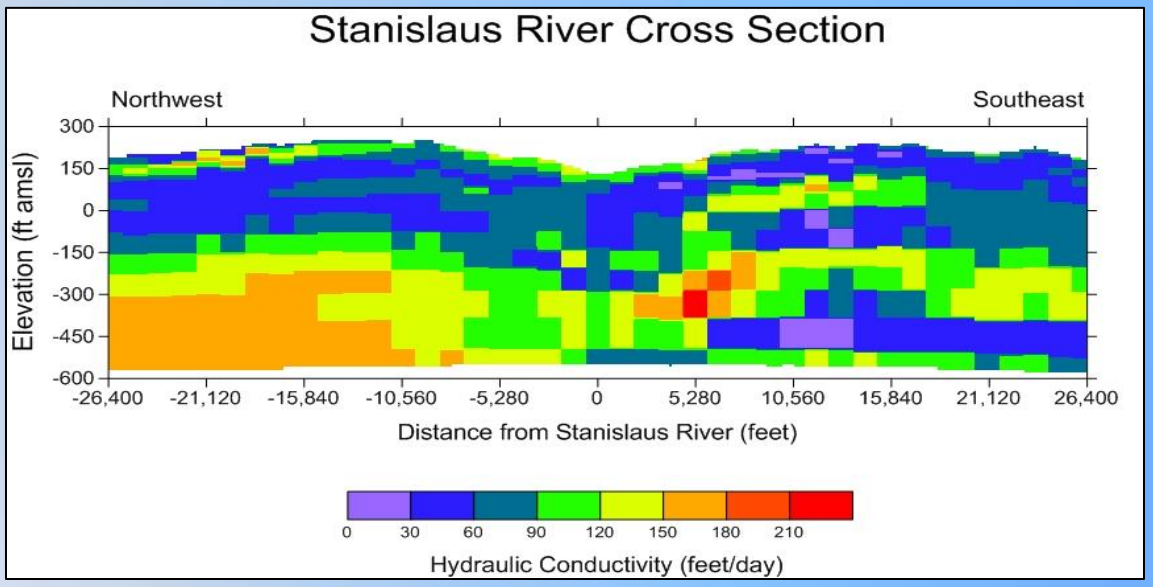
Framing the Study

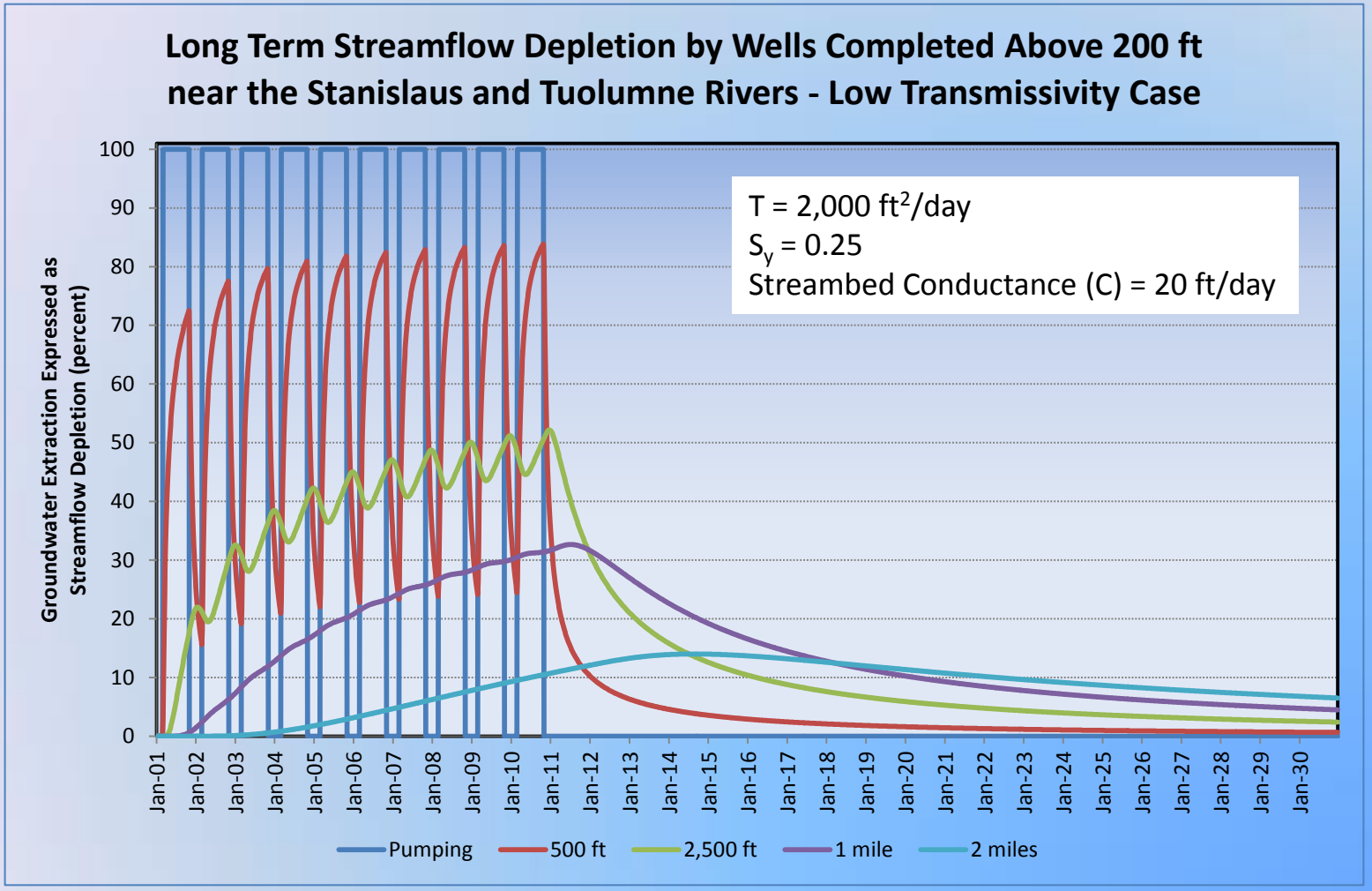
- Flow and water supply requirements are currently addressed by reservoir operations alone.
- Acceptable depletion will be established under Groundwater Sustainability Plans (GSPs) by 2022.
- Framing Question:

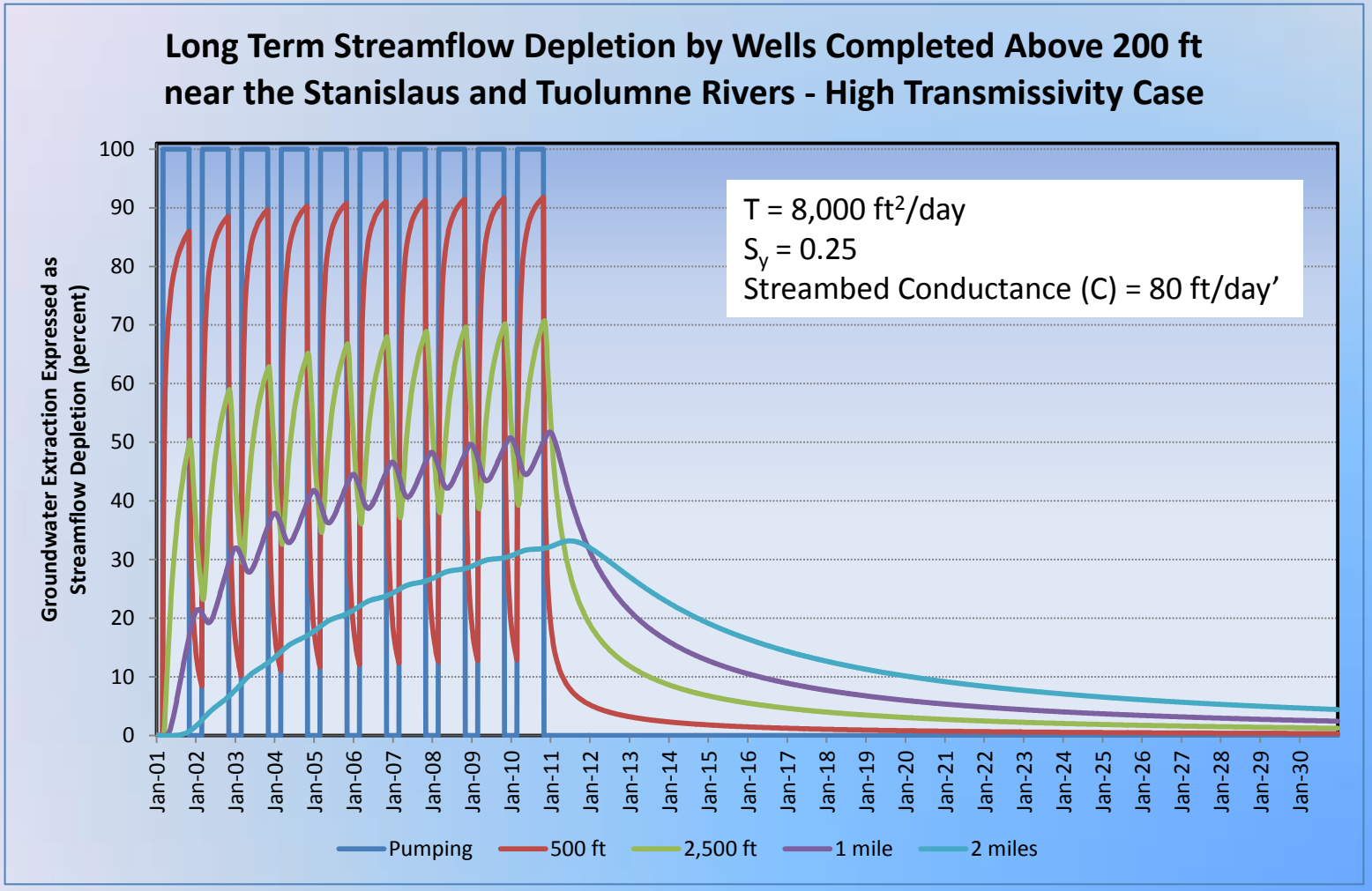
  "At what distance from the rivers will cumulative streamflow depletion be less than significant for pre-GSP new wells?"
- Based on current trends, up to 10 new wells expected.
- In absence of further data, up to 50% of gaging station error at low flow is acceptable depletion.

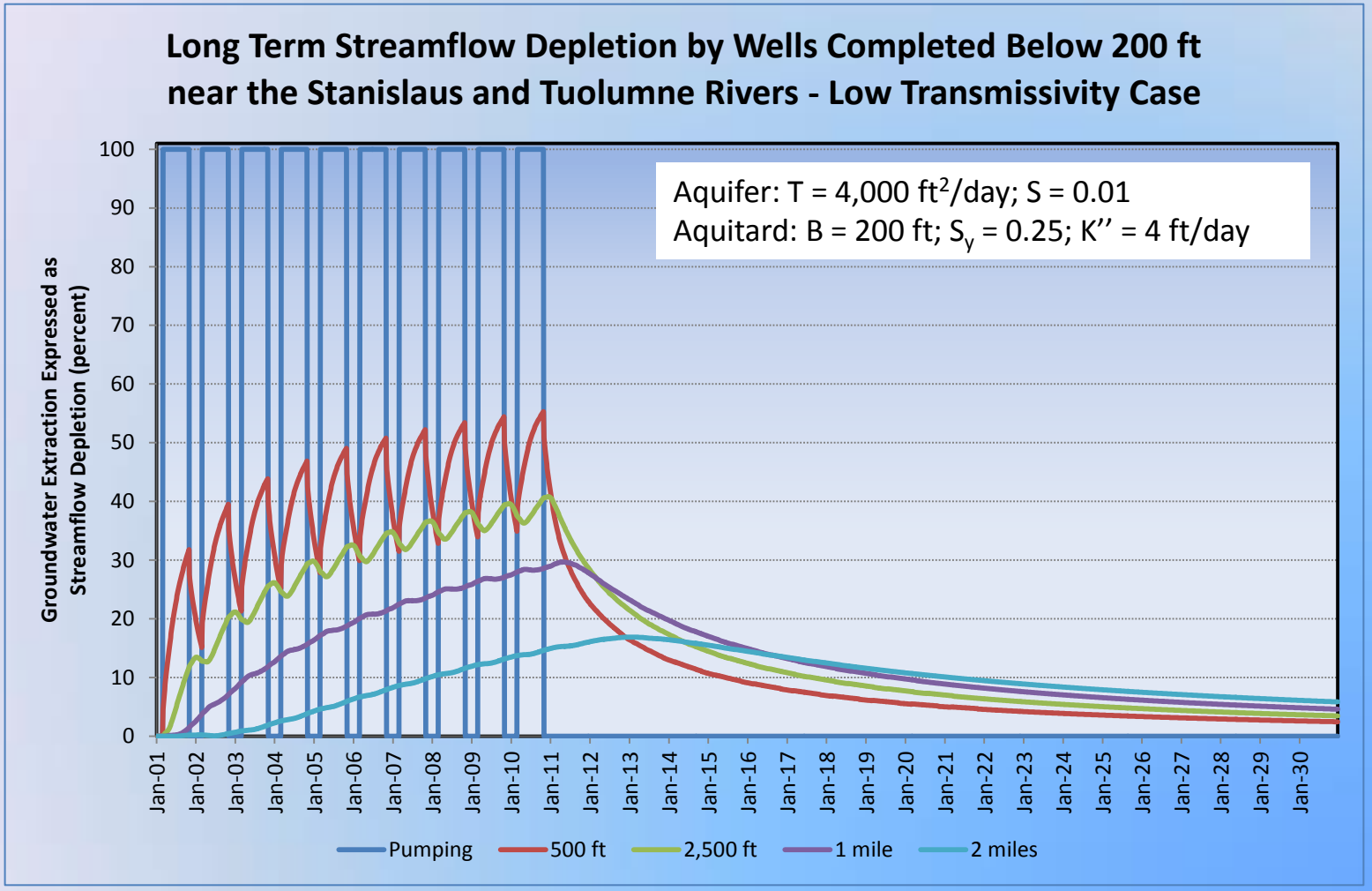
Approach

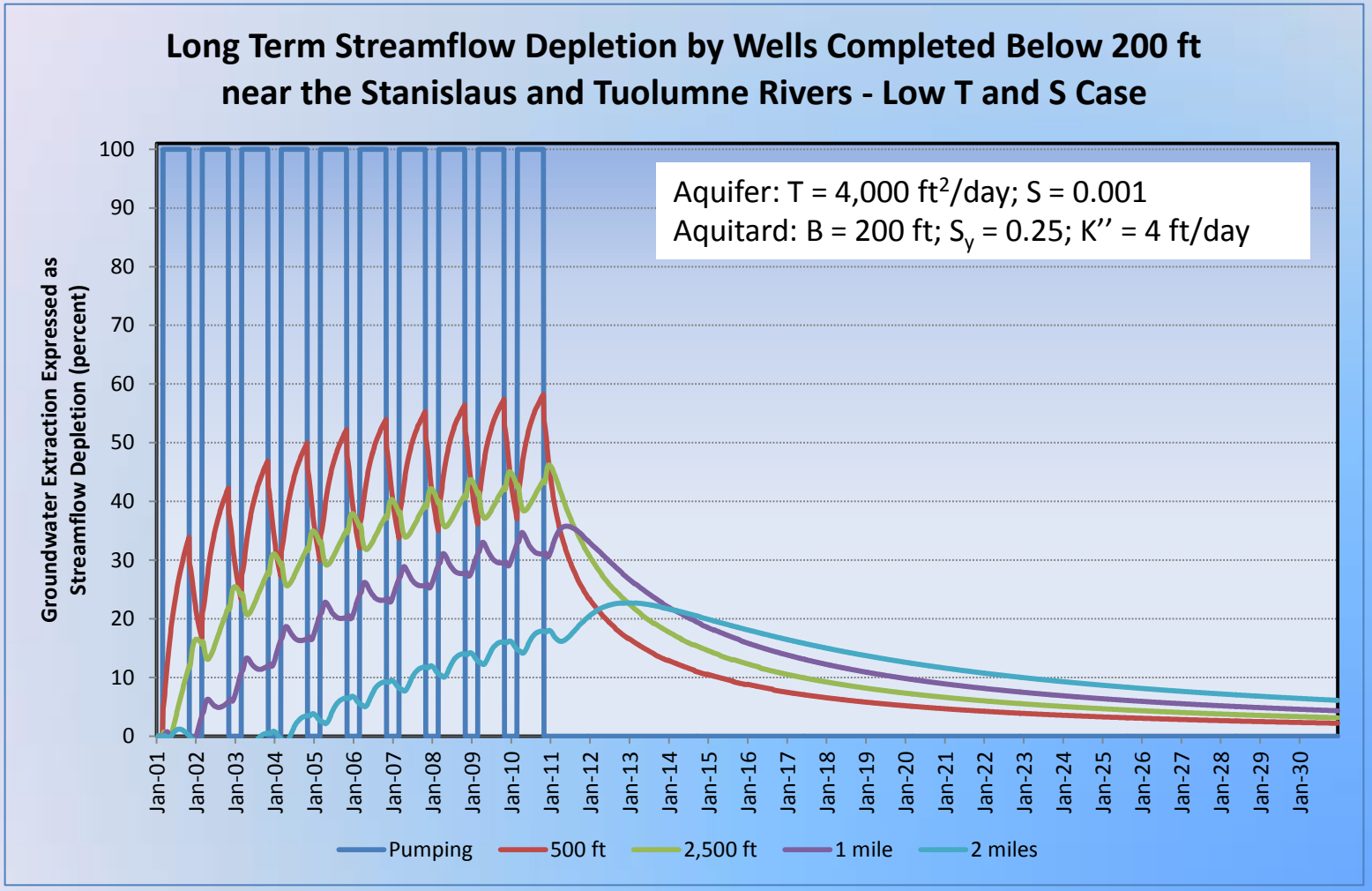
- Streamflow depletion was simulated using the USGS STRMDEPL08 analytical code.
- A conceptual model and aquifer parameters were developed based on the USGS MERSTAN model and data compiled from specific capacity tests.




Long Term Streamflow Depletion by Wells Completed Above 200 ft near the Stanislaus and Tuolumne Rivers - Low Transmissivity Case
Groundwater Extraction Expressed as Streamflow Depletion (percent)
100
90
80
70
60
50
40
30
20
10
0
T = 2,000 ft²/day
Sy = 0.25
Streambed Conductance (C) = 20 ft/day
Jan-01
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
Jan-08
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
Jan-14
Jan-15
Jan-16
Jan-17
Jan-18
Jan-19
Jan-20
Jan-21
Jan-22
Jan-23
Jan-24
Jan-25
Jan-26
Jan-27
Jan-28
Jan-29
Jan-30
Pumping
500 ft
2,500 ft
1 mile
2 miles


Long Term Streamflow Depletion by Wells Completed Above 200 ft near the Stanislaus and Tuolumne Rivers - High Transmissivity Case
Groundwater Extraction Expressed as Streamflow Depletion (percent)
100
90
80
70
60
50
40
30
20
10
0
Jan-01
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
Jan-08
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
Jan-14
Jan-15
Jan-16
Jan-17
Jan-18
Jan-19
Jan-20
Jan-21
Jan-22
Jan-23
Jan-24
Jan-25
Jan-26
Jan-27
Jan-28
Jan-29
Jan-30
T = 8,000 ft²/day
Sy = 0.25
Streambed Conductance (C) = 80 ft/day'
Pumping
500 ft
2,500 ft
1 mile
2 miles


Long Term Streamflow Depletion by Wells Completed Below 200 ft near the Stanislaus and Tuolumne Rivers - Low Transmissivity Case
Aquifer: T = 4,000 ft²/day; S = 0.01
Aquitard: B = 200 ft; Sy = 0.25; K'' = 4 ft/day
Groundwater Extraction Expressed as Streamflow Depletion (percent)
100
90
80
70
60
50
40
30
20
10
0
Jan-01
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
Jan-08
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
Jan-14
Jan-15
Jan-16
Jan-17
Jan-18
Jan-19
Jan-20
Jan-21
Jan-22
Jan-23
Jan-24
Jan-25
Jan-26
Jan-27
Jan-28
Jan-29
Jan-30
Pumping
500 ft
2,500 ft
1 mile
2 miles


Long Term Streamflow Depletion by Wells Completed Below 200 ft near the Stanislaus and Tuolumne Rivers - Low T and S Case
Aquifer: T = 4,000 ft²/day; S = 0.001
Aquitard: B = 200 ft; Sy = 0.25; K'' = 4 ft/day
Groundwater Extraction Expressed as Streamflow Depletion (percent)
100
90
80
70
60
50
40
30
20
10
0
Jan-01
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
Jan-08
Jan-09
Jan-10
Jan-11
Jan-12
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Jan-14
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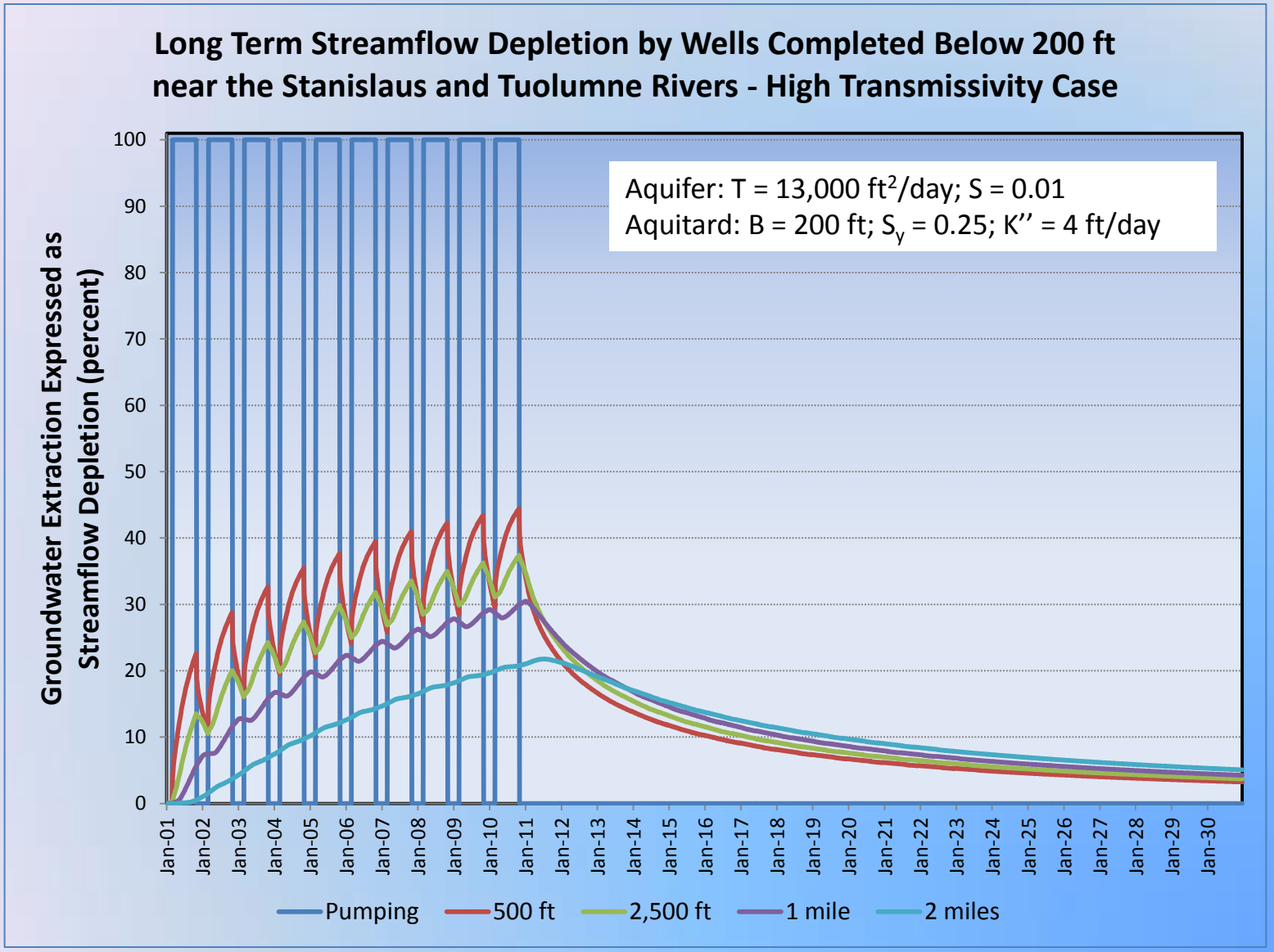
Jan-18
Jan-19
Jan-20
Jan-21
Jan-22
Jan-23
Jan-24
Jan-25
Jan-26
Jan-27
Jan-28
Jan-29
Jan-30
Pumping
500 ft
2,500 ft
1 mile
2 miles


Long Term Streamflow Depletion by Wells Completed Below 200 ft near the Stanislaus and Tuolumne Rivers - High Transmissivity Case
Groundwater Extraction Expressed as Streamflow Depletion (percent)
Aquifer: T = 13,000 ft²/day; S = 0.01
Aquitard: B = 200 ft; Sy = 0.25; K'' = 4 ft/day
100
90
80
70
60
50
40
30
20
10
0
Jan-01
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
Jan-08
Jan-09
Jan-10
Jan-11
Jan-12
Jan-13
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Jan-18
Jan-19
Jan-20
Jan-21
Jan-22
Jan-23
Jan-24
Jan-25
Jan-26
Jan-27
Jan-28
Jan-29
Jan-30
Pumping
500 ft
2,500 ft
1 mile
2 miles

Study Conclusions

- Surface Water Protection Zones were established 1 mile from the rivers for shallow wells and 2,500 feet for deeper wells.
- Applications for wells outside Surface Water Protection Zones do not require further evaluation of surface water depletion.
- Applications for wells in a Surface Water Protection Zone must include a site-specific Surface-Groundwater Interaction Study.

Example 2: Colorado River

- Supplies water to 7 western states and Mexico
- Subject to long-term drought and litigation
- In California, major water supply for PVID, IID, CVWD, MWD, (incl. SDCWA)

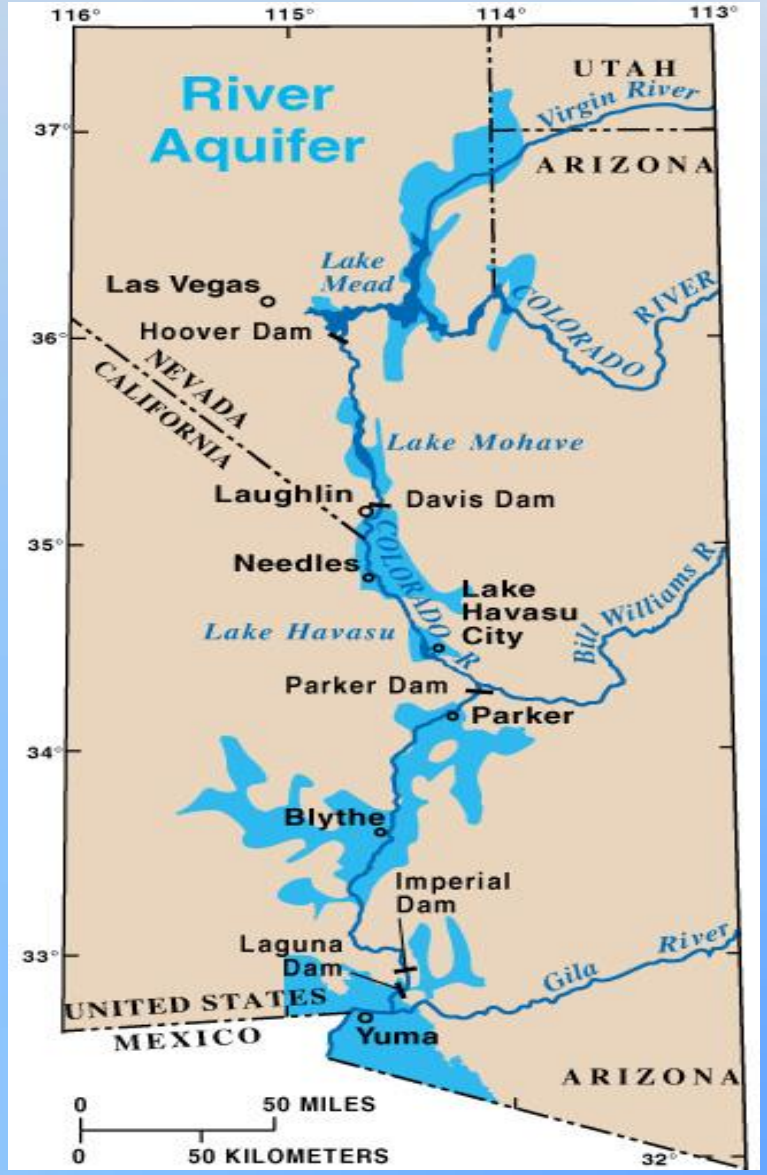
Consolidated Supreme Court Decree in Arizona v. California (2006)

- Specifies available water allocations to three Lower Colorado River Basin States, and extends role of the Bureau of Reclamation to conduct annual accounting of all consumptive water use in the LCR.

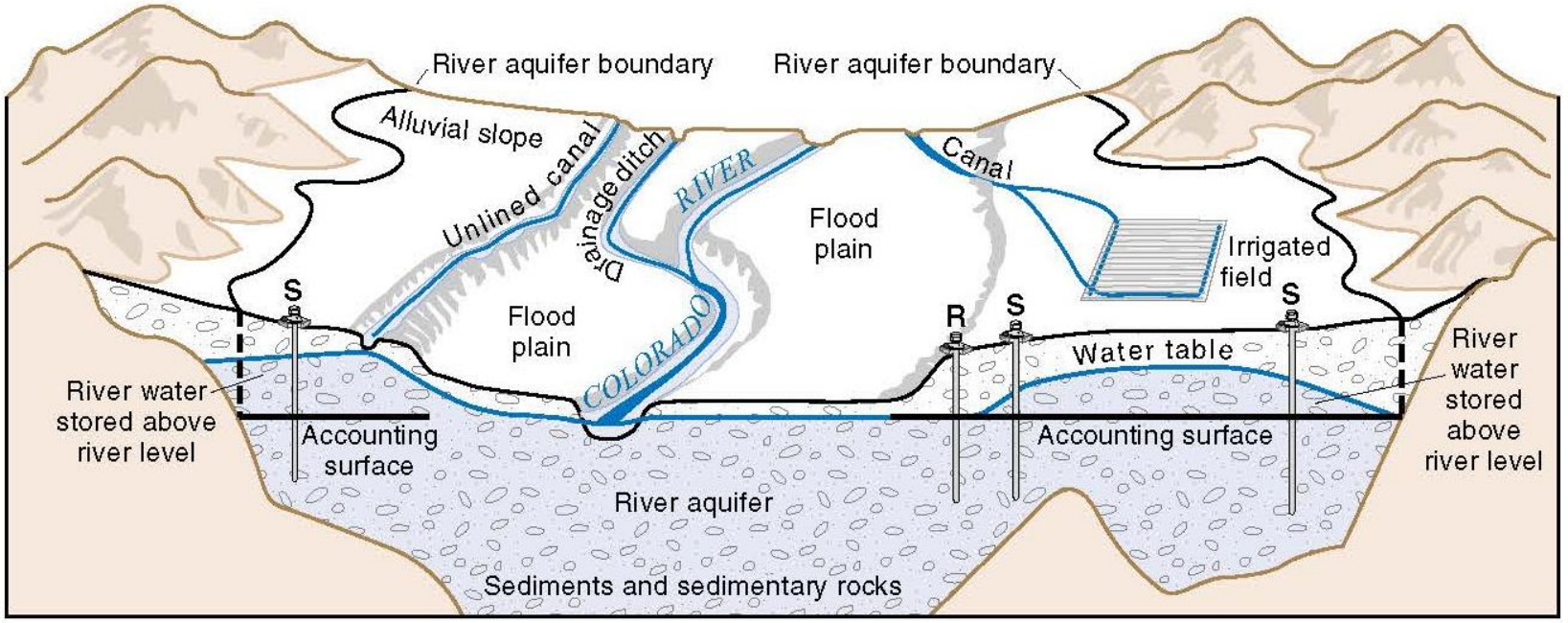
- Retains 1963 definition of consumptive use to include "… water drawn from the mainstream by underground pumping … ."

The Colorado River Aquifer

- Determined based solely on bedrock structure.
- Interpreted from geologic mapping and gravimetric survey data.



Proposed Accounting Surface Methodology



EXPLANATION

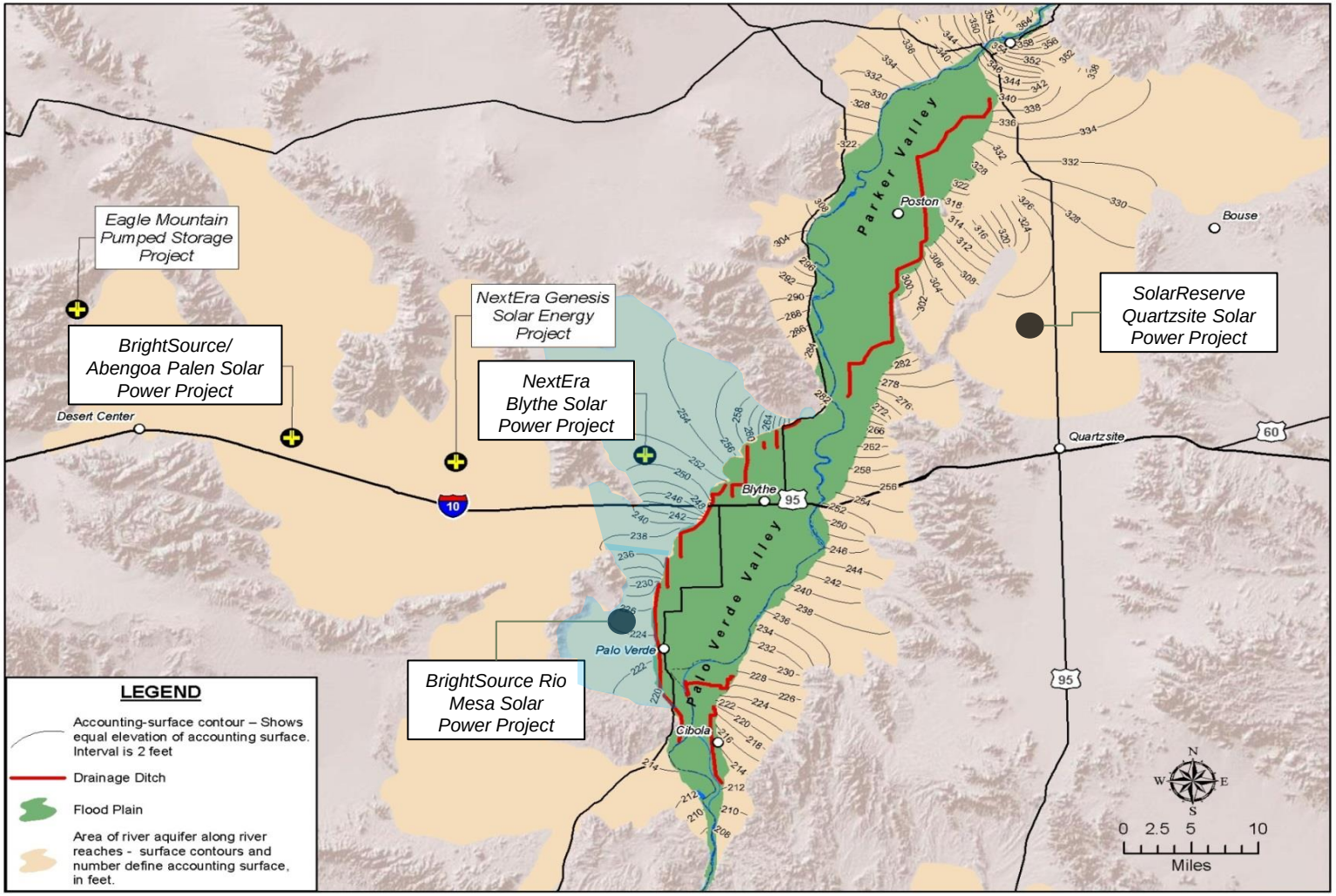
SEDIMENTS AND SEDIMENTARY ROCKS

BEDROCK

WELL—The symbol "**R**" denotes a well that has a static water-level elevation equal to or below the accounting surface and is presumed to yield water that will be replaced by water from the Colorado River. "**S**" denotes a well that has a static water-level elevation above the accounting surface and is presumed to yield river water stored above the river level.

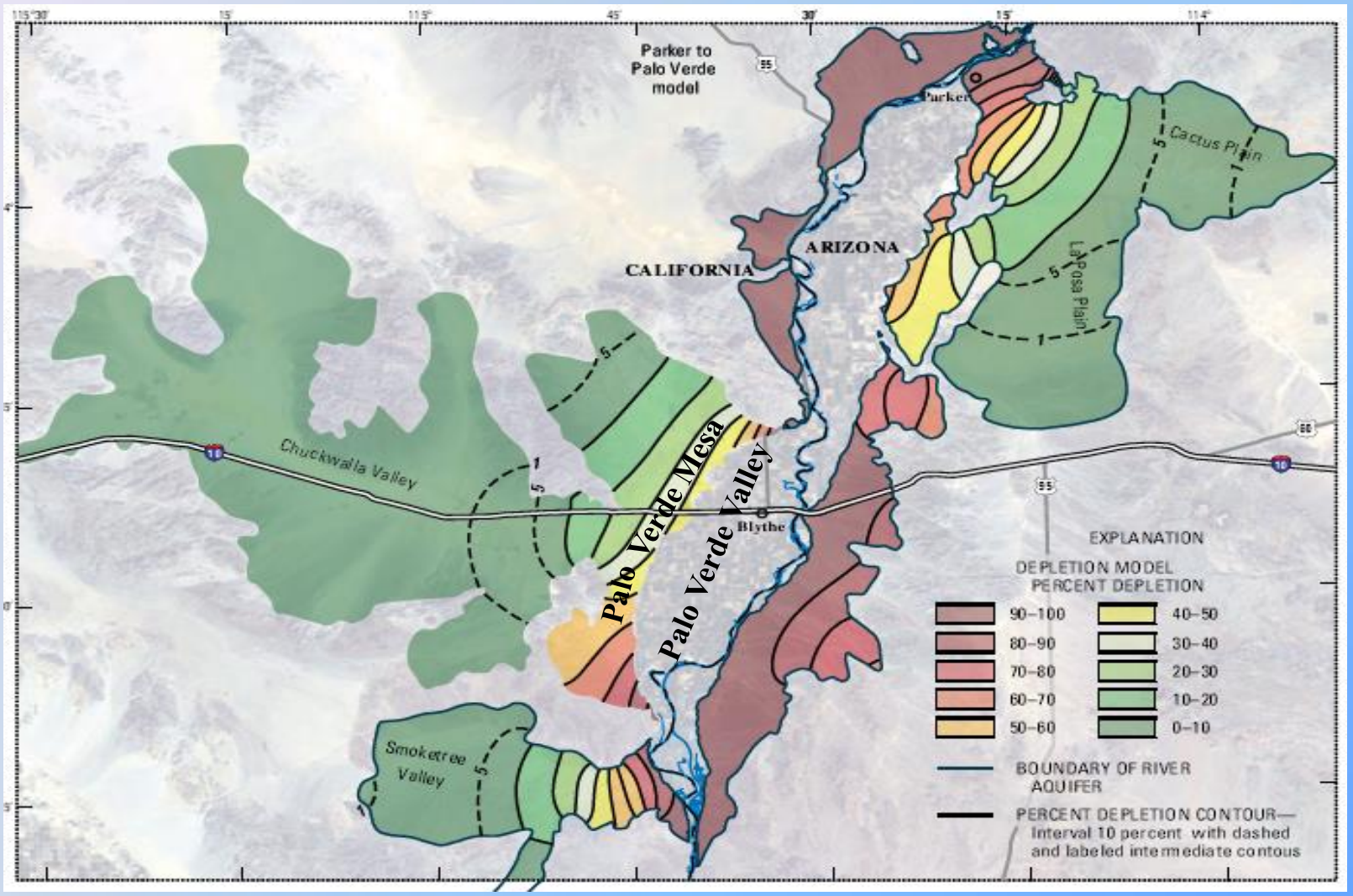
From USGS WRIR 00-4085

Proposed Accounting Surface



Adapted from USGS WRIR 00-4085

USGS Aquifer Depletion Model



From USGS SIR 2008-5189

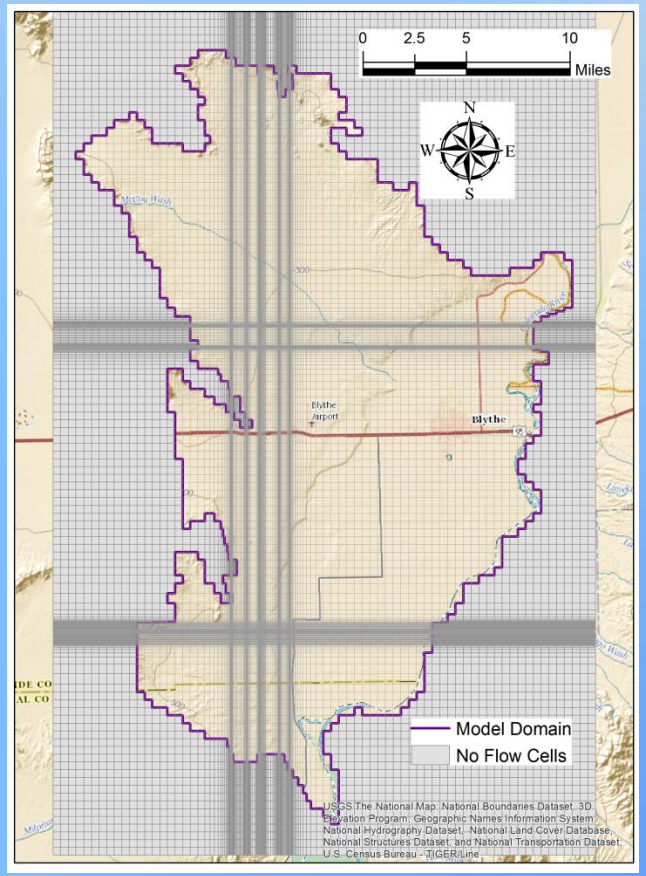
Framing the Study

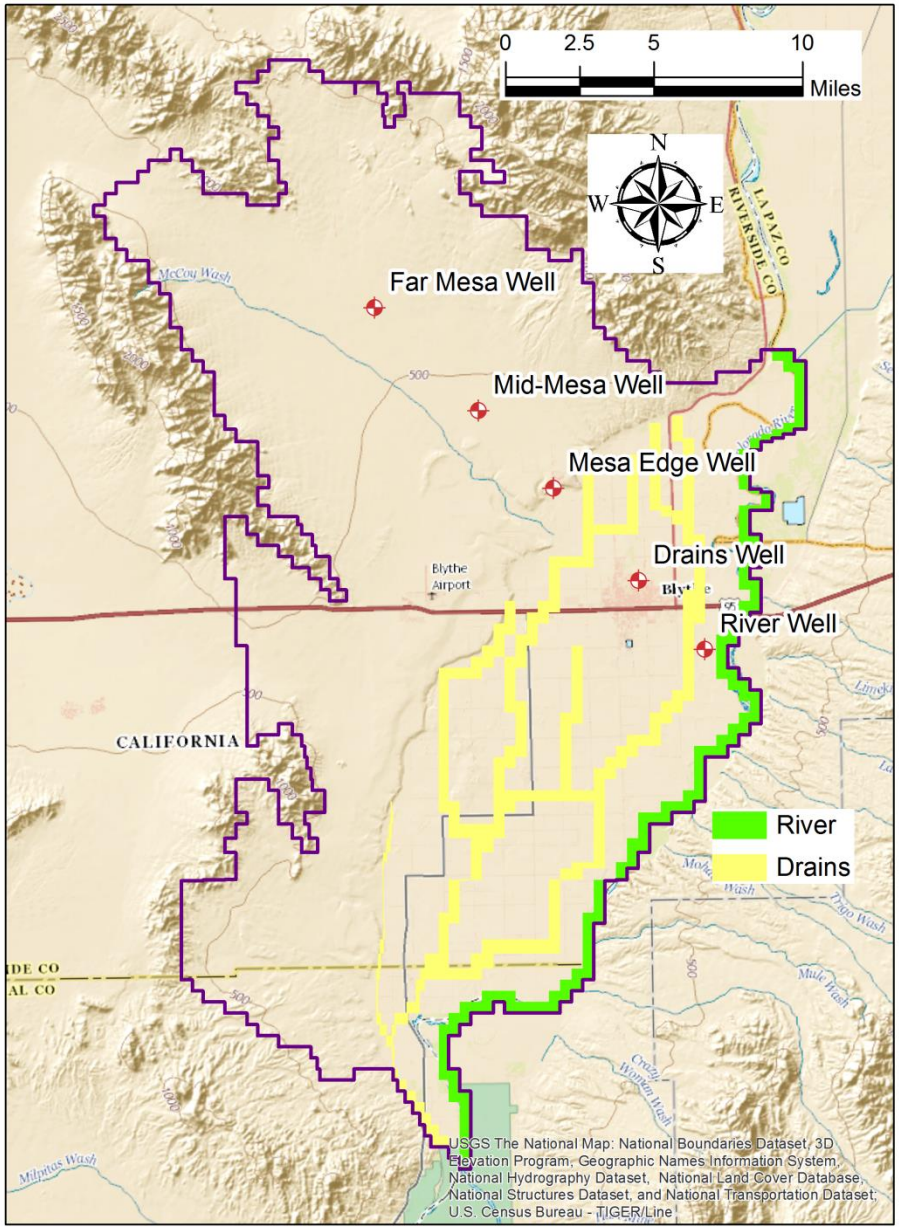
- Areas in Chuckwalla Valley and Palo Verde Mesa are 30 to 60 miles from the river in different hydrogeologic regimes and separated by areas of constricted flow and mounded groundwater
- Stable isotope data indicates a chemistry distinct from modern river water, suggesting tributary water.
- The measurement error in PVID drain return flow accounting is +/- 50,000 acre-feet/year.
- Framing Question:

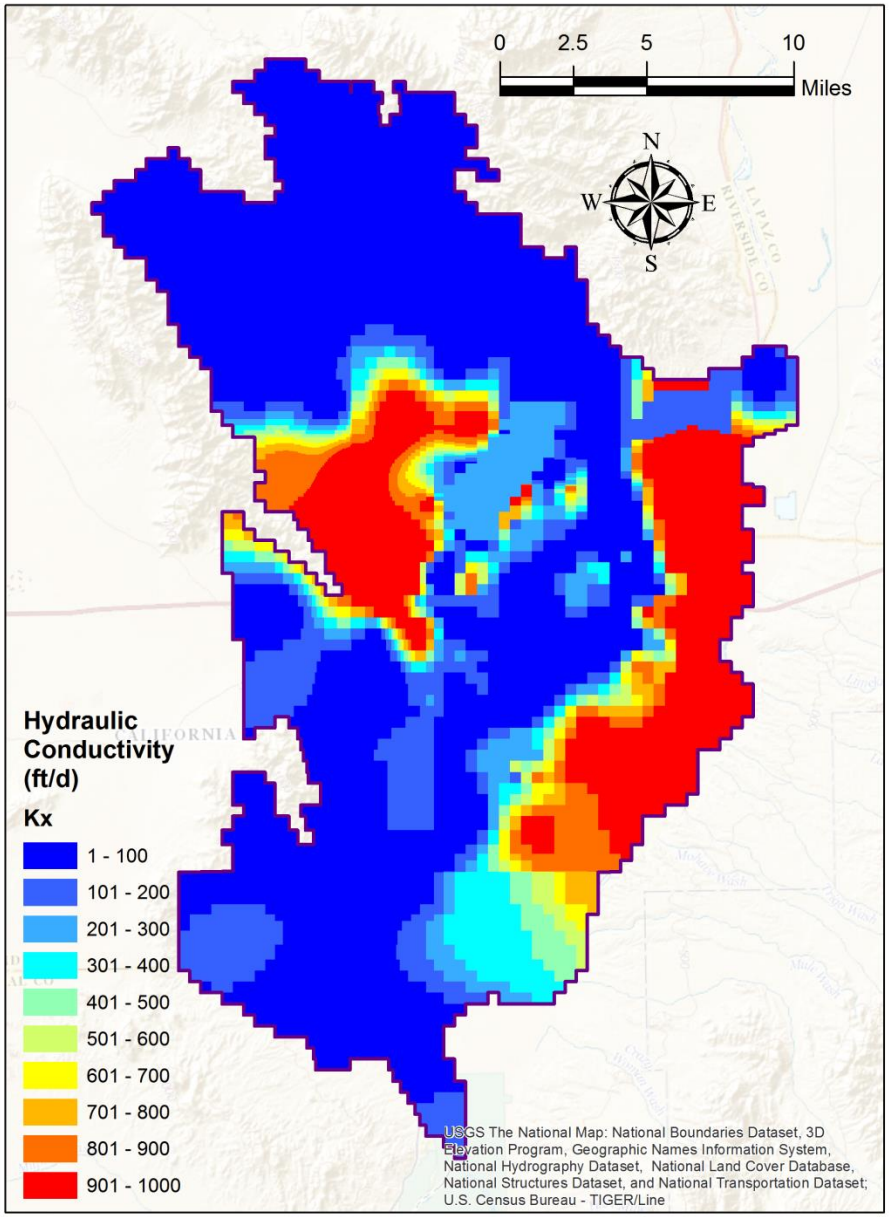
  "At what distance from the river and associated drains is groundwater extraction from individual wells no longer relevant to annual accounting requirements?"

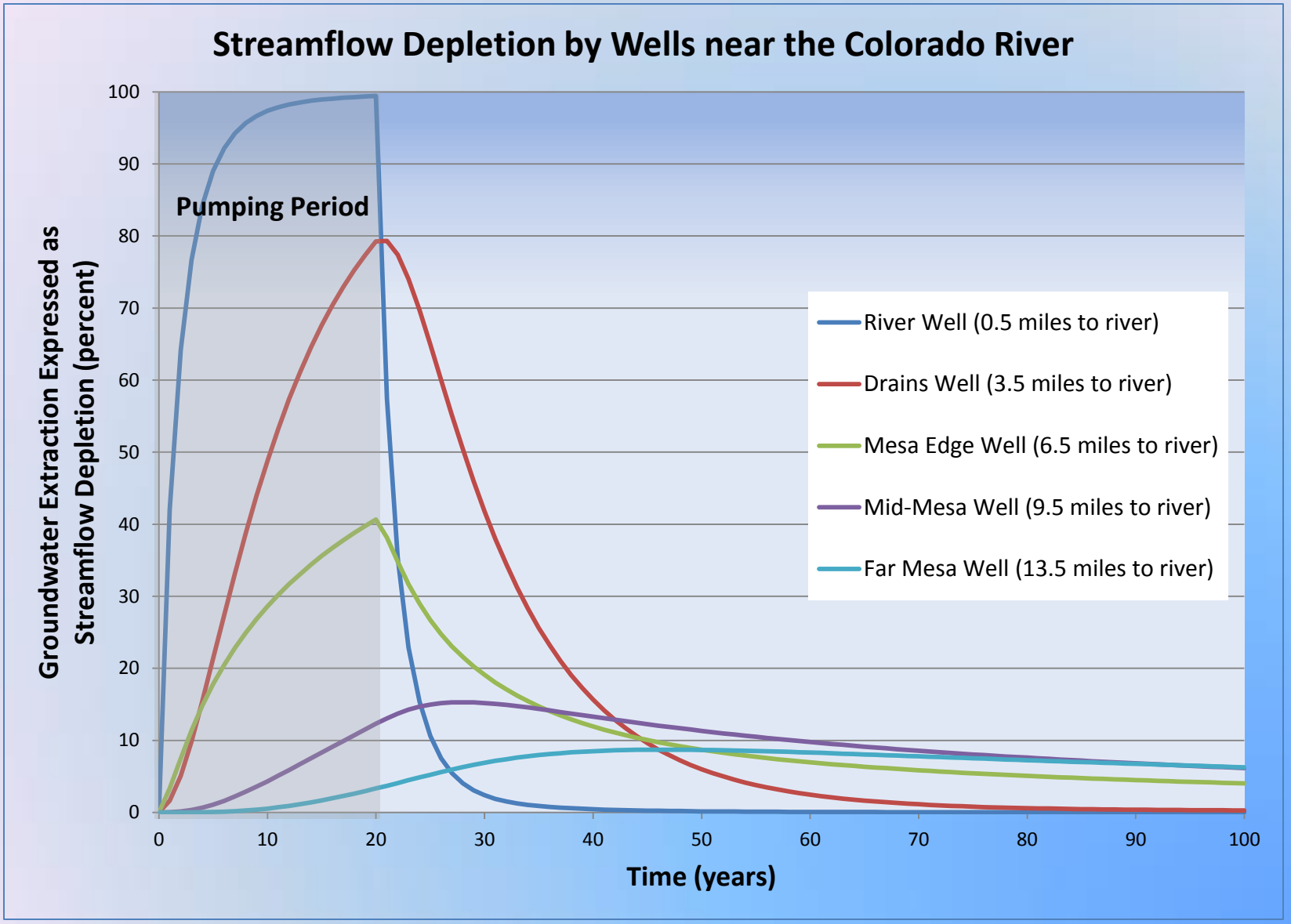
Approach

- Streamflow depletion was simulated with a model constructed using MODFLOW 2000.
- Updated and refined prior modeling by USGS and AECOM, and calibrated to over 100 PVID wells.
- Groundwater extraction was simulated near the river and drains in Palo Verde Valley, and at varying distances on Palo Verde Mesa.




0 2.5 5 10
Miles
N
W
E
S
Far Mesa Well
Mid-Mesa Well
Mesa Edge Well
Drains Well
River Well
Blythe Airport
CALIFORNIA
River
Drains
USGS The National Map: National Boundaries Dataset, 3D Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; U.S. Census Bureau - TIGER/Line


0 2.5 5 10
Miles
N
W
E
S
Hydraulic Conductivity (ft/d)
Kx
1 - 100
101 - 200
201 - 300
301 - 400
401 - 500
501 - 600
601 - 700
701 - 800
801 - 900
901 - 1000
USGS The National Map: National Boundaries Dataset, 3D Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; U.S. Census Bureau - TIGER/Line


Streamflow Depletion by Wells near the Colorado River
Groundwater Extraction Expressed as Streamflow Depletion (percent)
Pumping Period
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
Time (years)
River Well (0.5 miles to river)
Drains Well (3.5 miles to river)
Mesa Edge Well (6.5 miles to river)
Mid-Mesa Well (9.5 miles to river)
Far Mesa Well (13.5 miles to river)

Preliminary Conclusions

Palo Verde Valley Groundwater Basin

- Streamflow depletion from wells near the river or drains closely matches pumping and accounts for almost all of the pumped water within a relatively short time period.
- Streamflow depletion from wells more distant from drains or the river is delayed and attenuated, but still accounts for a majority of extraction after 10 to 20 years.
- It seems reasonable and feasible to us to account for water extracted from these wells as Colorado River water.

Preliminary Conclusions

Palo Verde Mesa Groundwater Basin

- Streamflow depletion from wells on the mesa is further delayed and attenuated in proportion to distance.
- At the edge of the mesa, pumping may still induce significant but more limited streamflow depletion after a period of time.
- Streamflow depletion from pumping within the mesa is much more muted, delayed, and persistent after the cessation of pumping, and does not resemble the response from pumping in the Palo Verde Valley Basin.

Preliminary Conclusions

Palo Verde Mesa Groundwater Basin (cont.)

- In our opinion, groundwater pumping in Palo Verde Mesa Basin should be managed on a basin scale.
- A management framework could be prepared that includes the following:
  - Quantification of tributary flows that are available for local use, considering both hydrogeology and the geochemical evidence for the source of the water; and
  - A monitoring program and measurable objectives for basin management.
- A potential avenue to prepare such a framework would be preparing a GSP under the California SGMA.