Next Generation Verde Basin MIKE SHE Model

Yavapai-Apache Nation and The Nature Conservancy

Presented via Zoom
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Integrated Hydro Systems, LLC

Review of Verde MIKE SHE Development

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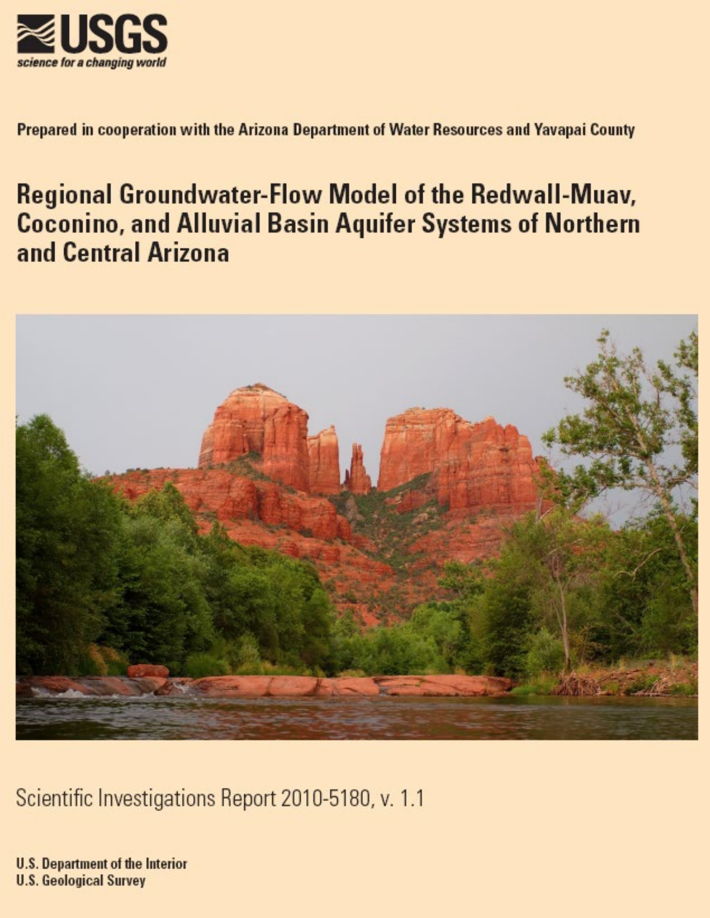
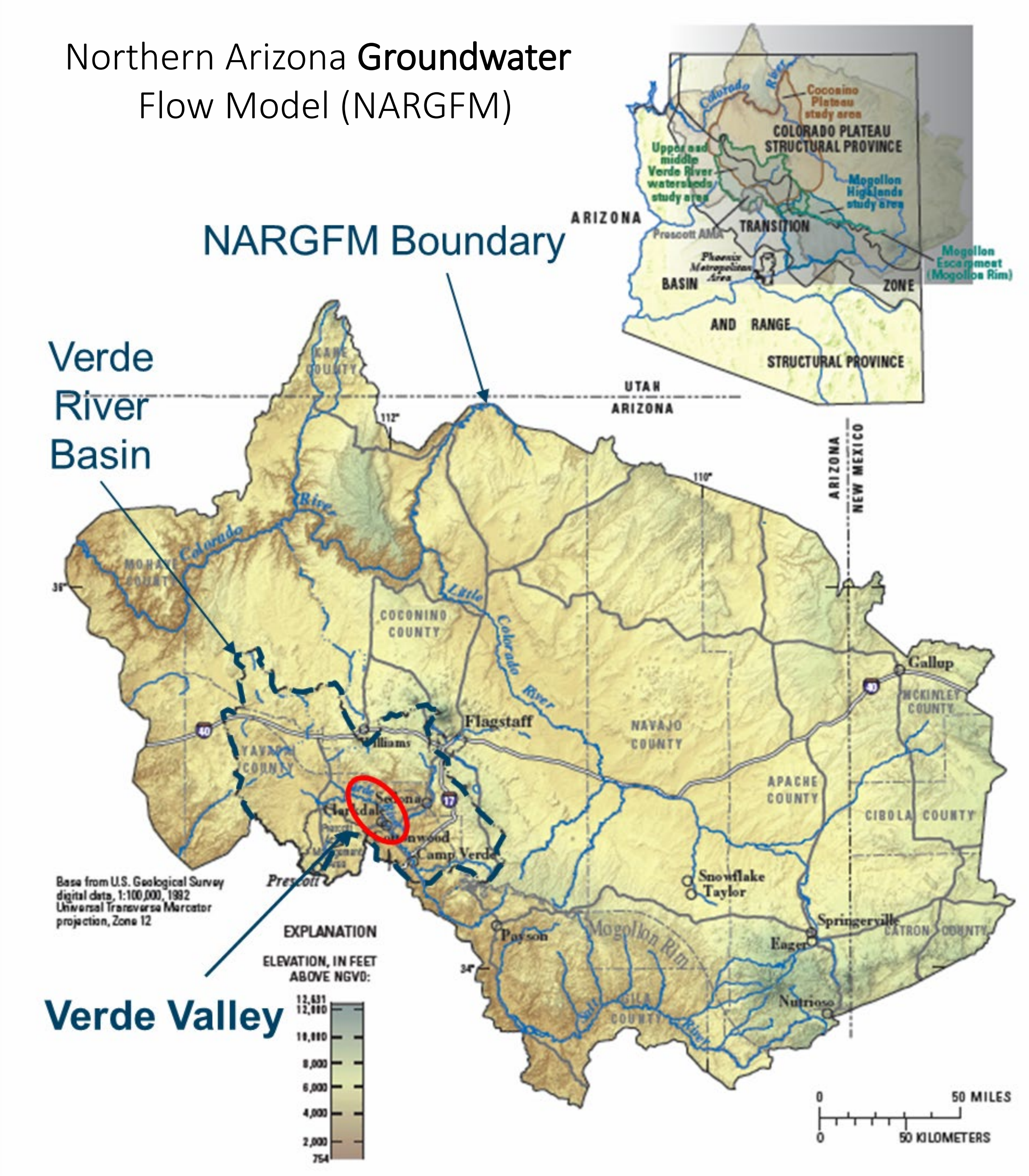
USGS Published NARGFM in 2011

- First model of entire Verde Basin
- Covered all of N. AZ


Regional Groundwater-Flow Model of the Redwall-Muav, Coconino, and Alluvial Basin Aquifer Systems of Northern and Central Arizona



NARGFM- Groundbreaking Effort by USGS

STRENGTHS:

- interbasin flows
- major rivers
- pre-development to 2006
- time-varying recharge
- regional aquifers
- familiar MODFLOW code

WEAKNESSES:

- lumped approach to Verde Valley ET
- external, uncalibrated recharge estimates varied over multi-decadal periods
- multi-year time-steps
- simplified 3-layer representation of highly complex geology
- lack of explicit faulting
- no surface runoff
- 1-km grid scale

Why did YAN Choose MIKE SHE?

- Explicit simulation and calibration of **recharge** from **hourly** precipitation, temperature, and reference ET values
- Explicit simulation of Verde Valley **irrigation** and **robust ET** calculation
- Desire to better understand the **complex hydrologic connection** between the Upper and Middle Verde Basin areas
- Full surface water- groundwater interaction with TOTAL streamflow
- Ability to **test subsurface hydrologic characterization** in integrated hydrologic space
- ET calibration
- Snow pack calibration
- Climate predictions

Regional Verde Basin MIKESHE – 1 km grid

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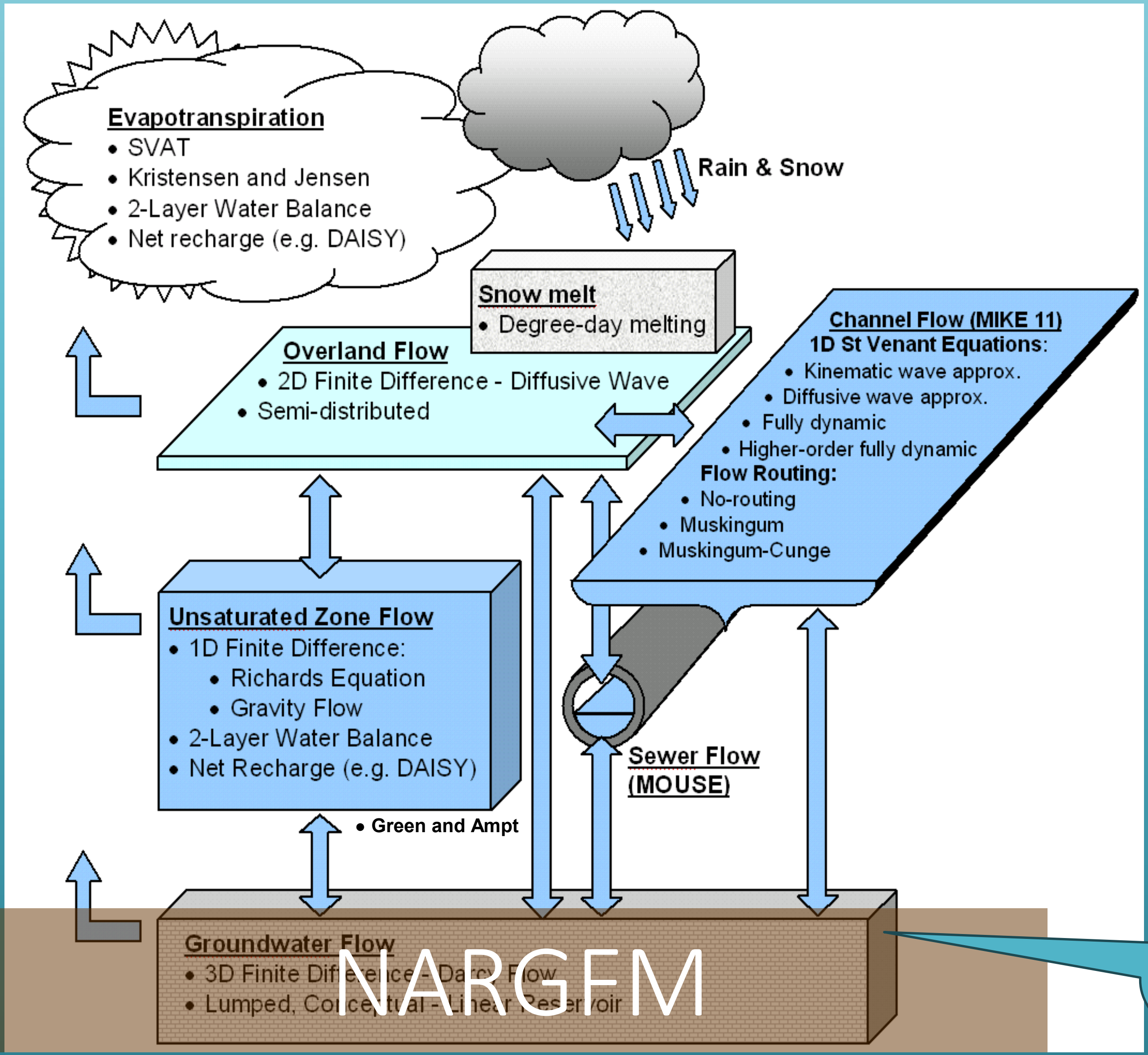
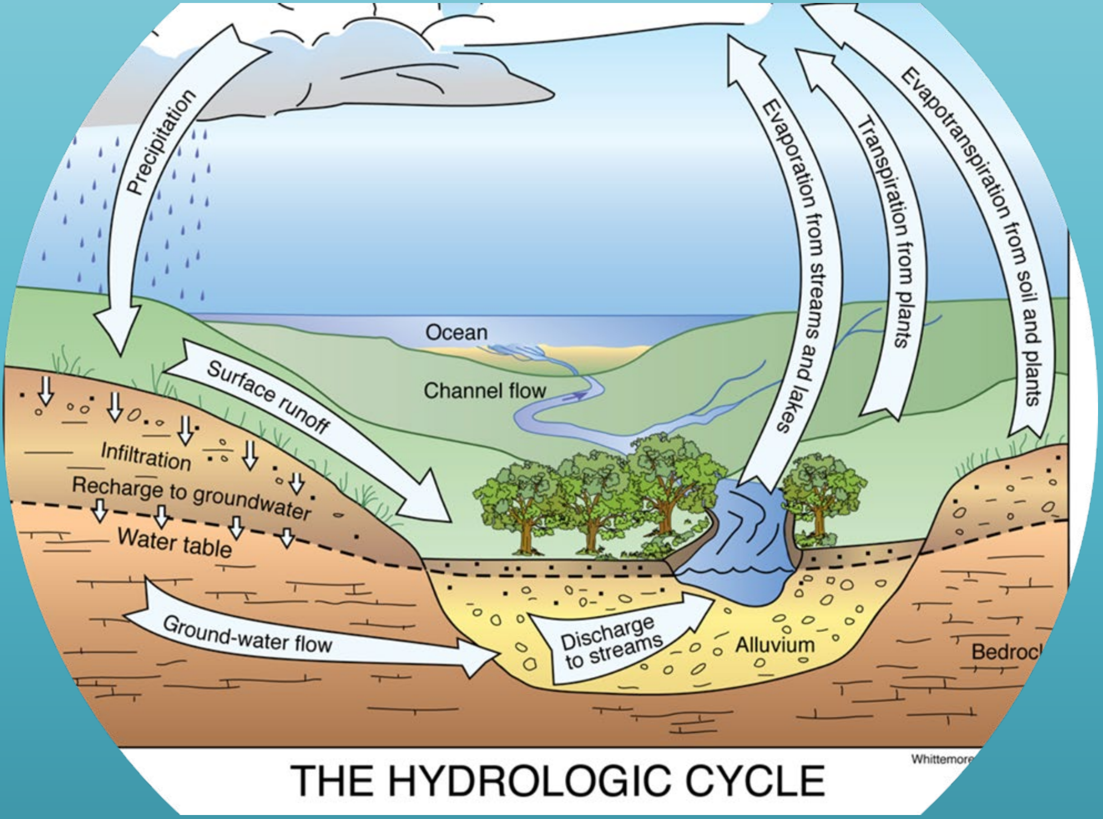
MIKESHE Model

Represents Entire Hydrologic Cycle





Groundwater Model

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NARGFM Hydraulic Property Distribution

Discontinuous layers

Hydraulic property distributions

- *Not directly tied to hydrostratigraphy*
- *Anisotropy vs Faults*

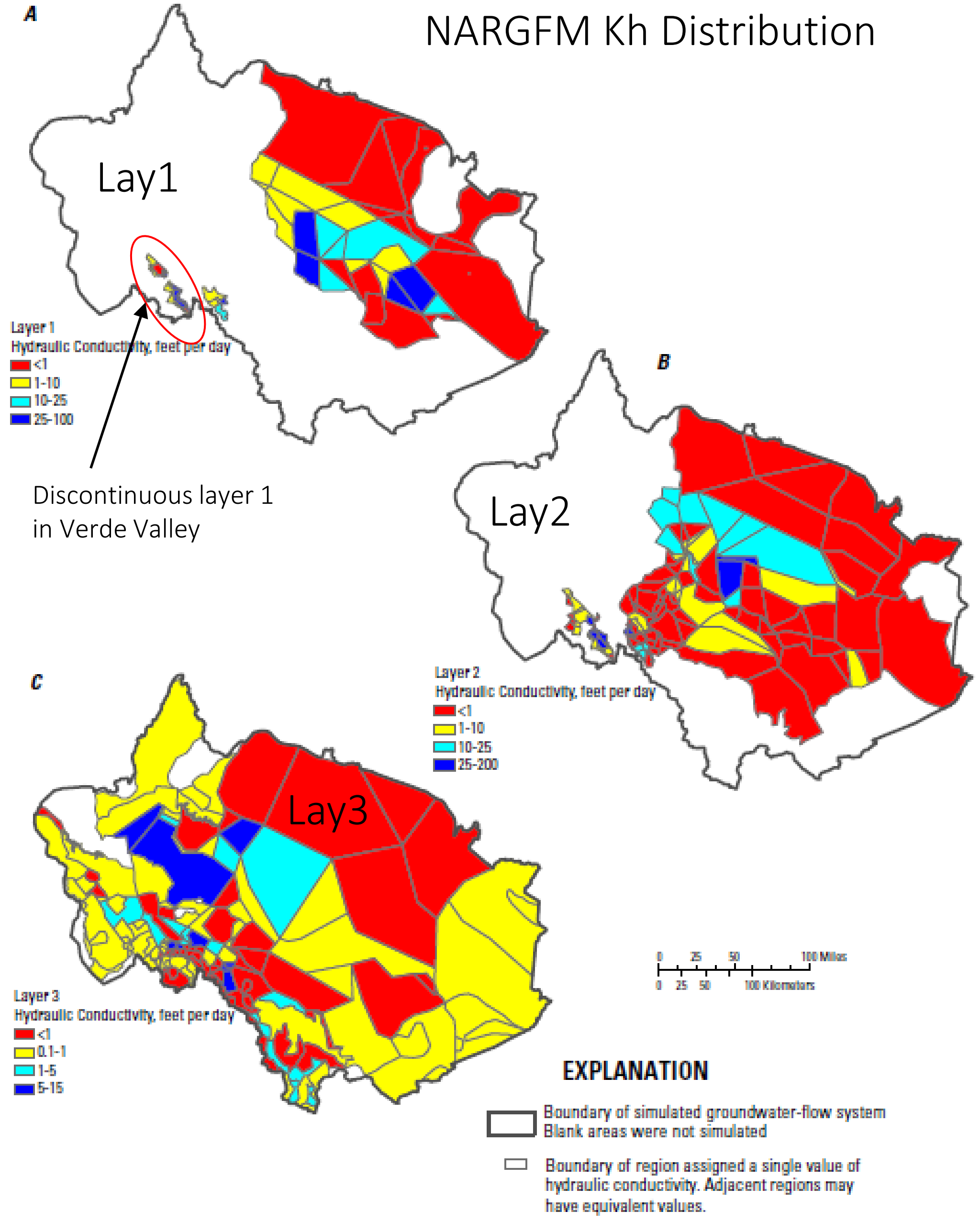


Figure 14. Distributions of hydraulic conductivity along rows for the Northern Arizona Regional Groundwater-Flow Model layers. *A*, Layer 1. *B*, Layer 2. *C*, Layer 3.

Pool, D.R., Blasch, K.W., Callegary, J.B., Leake, S.A., and Graser, L.F., 2011, Regional groundwater-flow model of the Redwall-Muav, Coconino, and alluvial basin aquifer systems of northern and central Arizona: U.S. Geological Survey Scientific Investigations Report 2010-5180, v. 1.1, 101 p.

MIKESHE Regional Model Calibration Issues Related to NARGFM Subsurface

- Springs not emerging correctly
- Some areas have strongly biased groundwater levels (too high or too low)
- Some stream baseflows hard to match

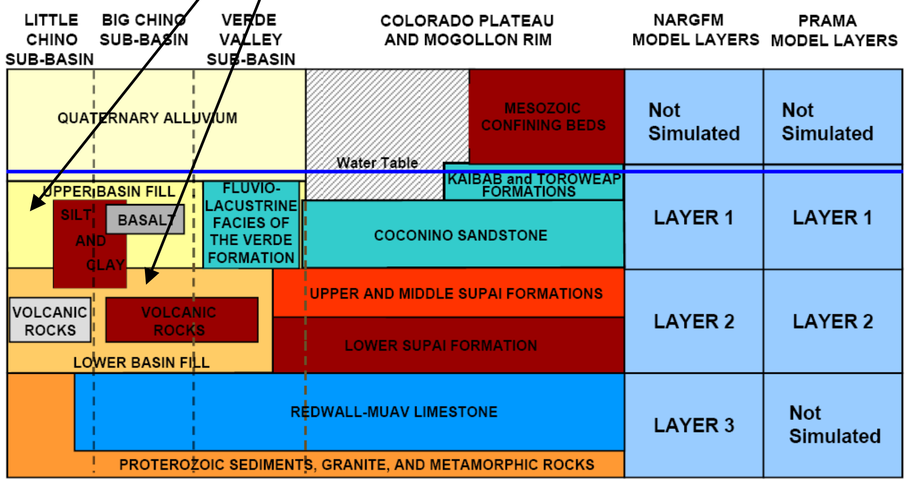
Diagnosis: MIKESHE needs a revised subsurface to improve simulation of springs and internal flows

FULL VERDE BASIN GEOLOGIC MODEL REQUIRED

Hydrogeologic Representation

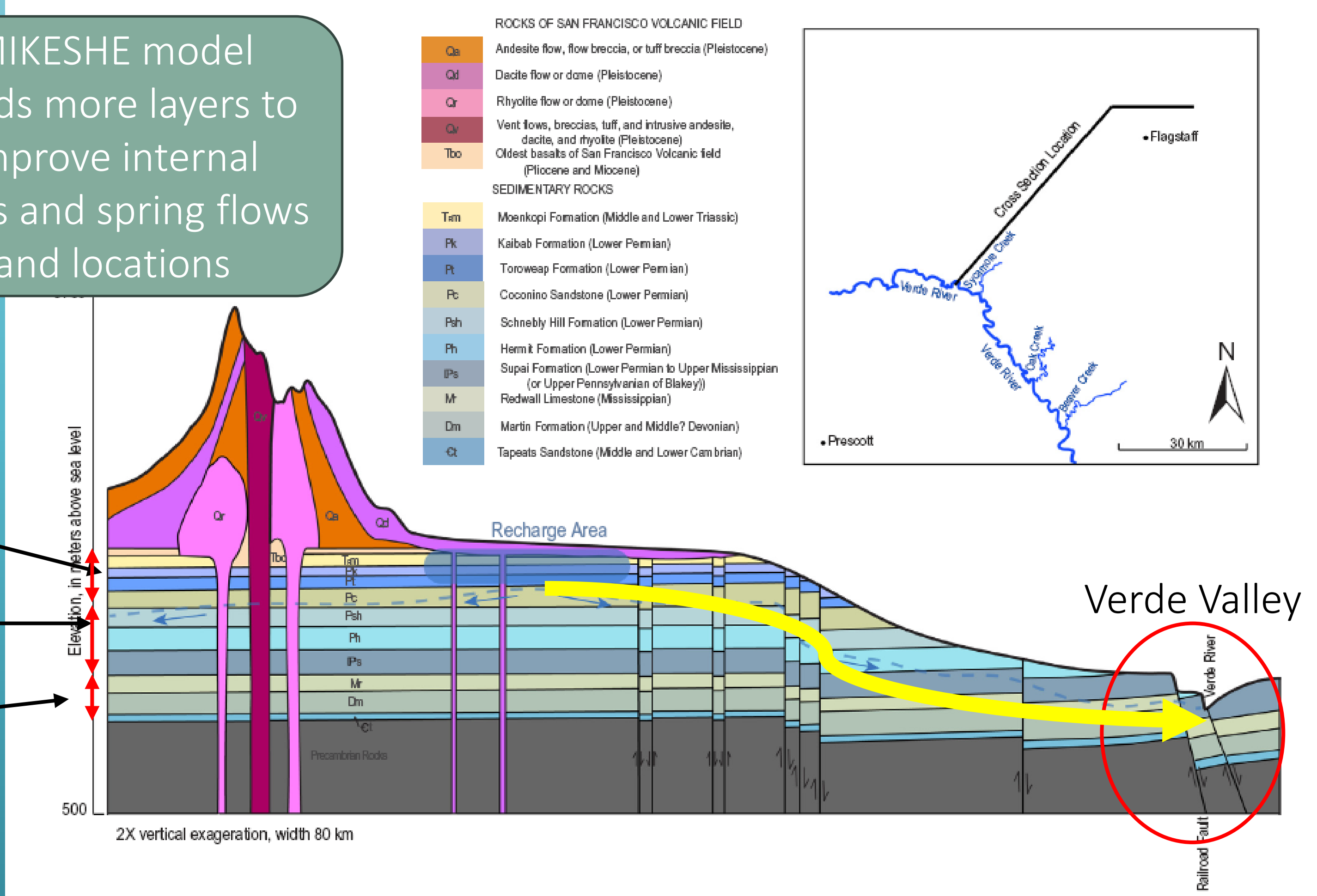
NARGFM: Top 2 layers discontinuous across model

MIKESHE model needs more layers to improve internal flows and spring flows and locations



Confining beds indicated by red-brown shading

Figure 12. Conceptualized relations among major hydrogeologic units and Northern Arizona Regional Groundwater-Flow Model layers.



NARGFM 3-Layer Description

Published section with more detail in hydrostratigraphic layers

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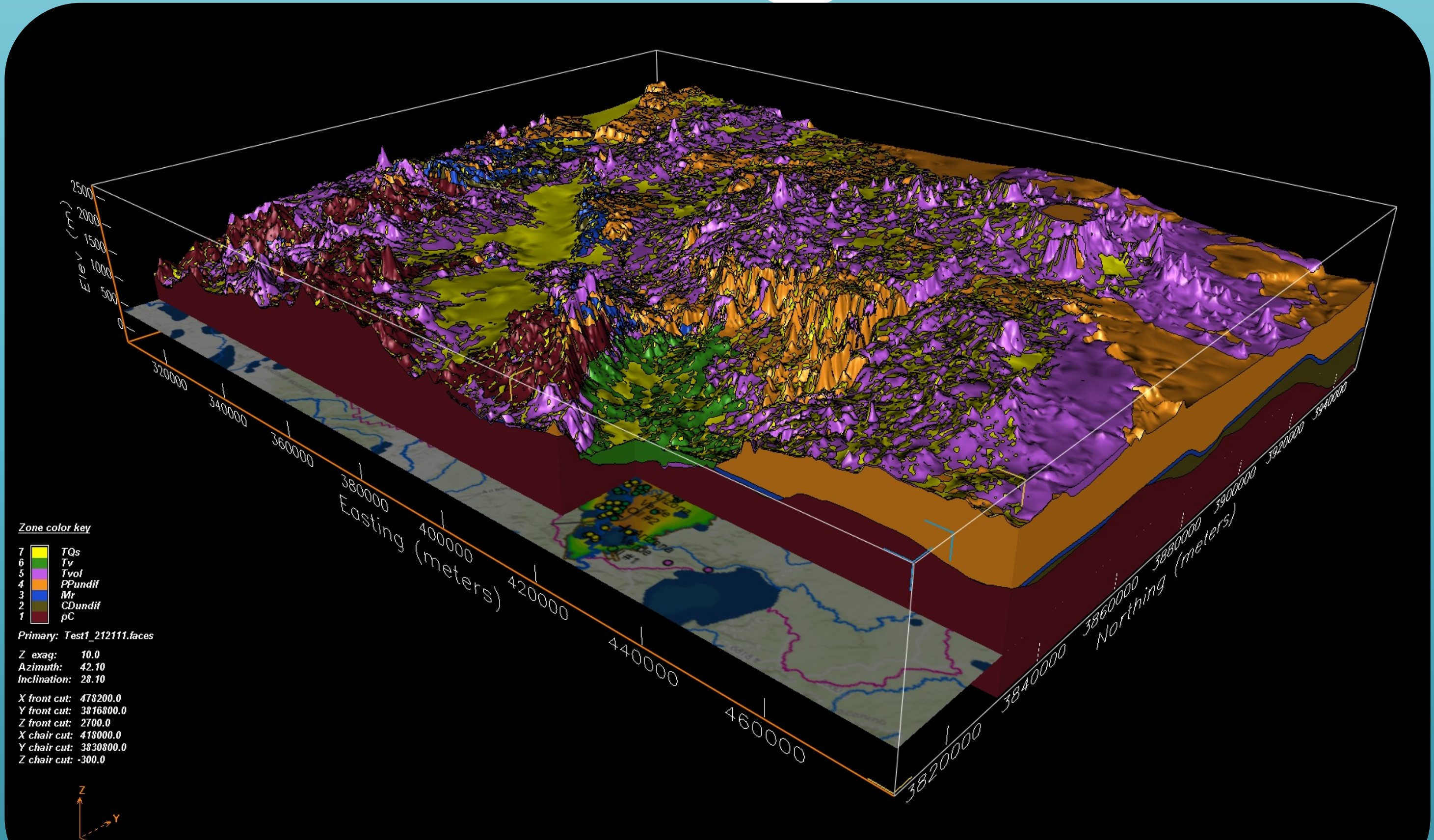
EarthVision® Geologic Model

Provided stratigraphic framework for new MIKE SHE subsurface configuration



Graphic courtesy of Todd Kincaid

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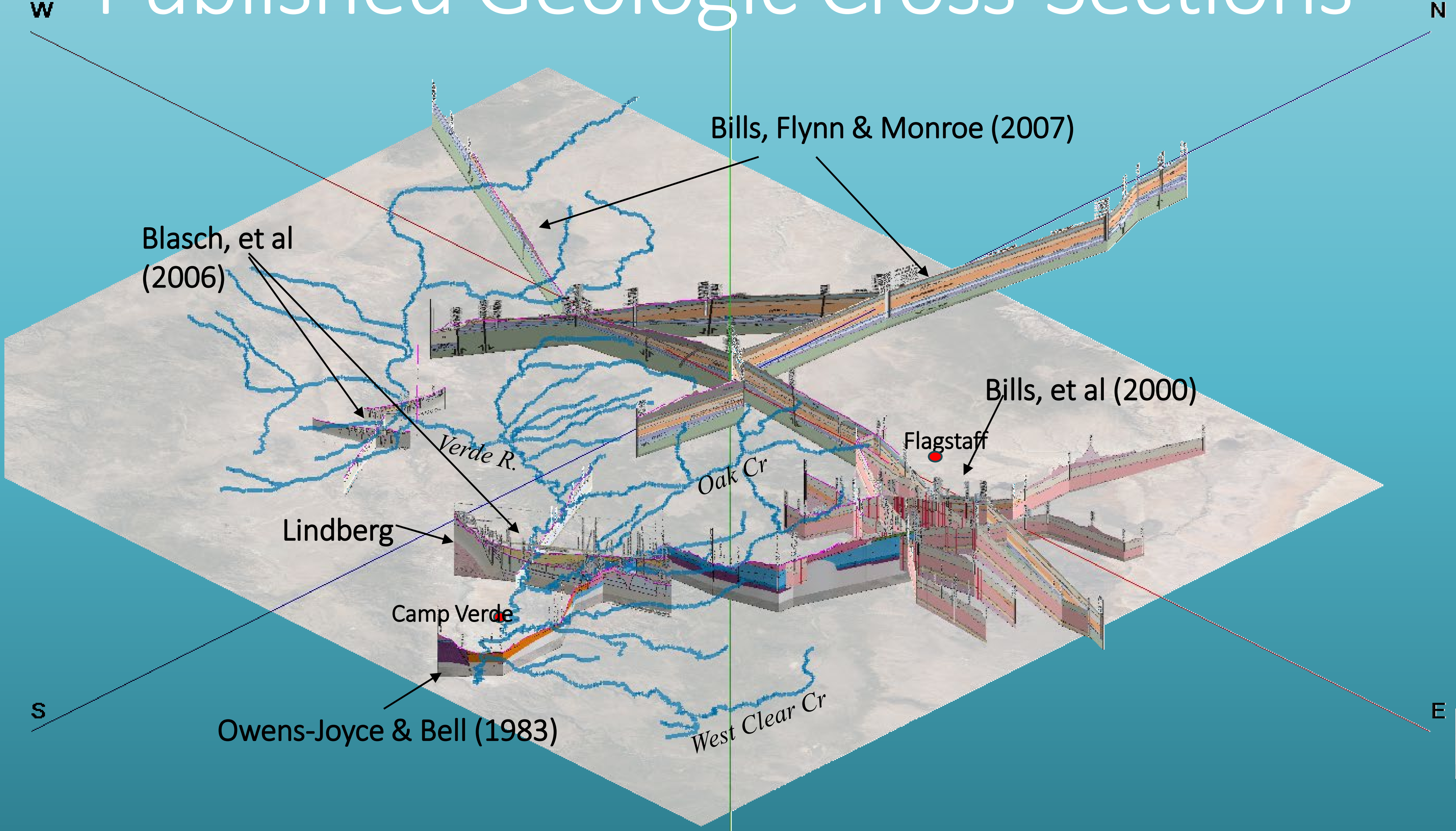
Published Geologic Cross-Sections



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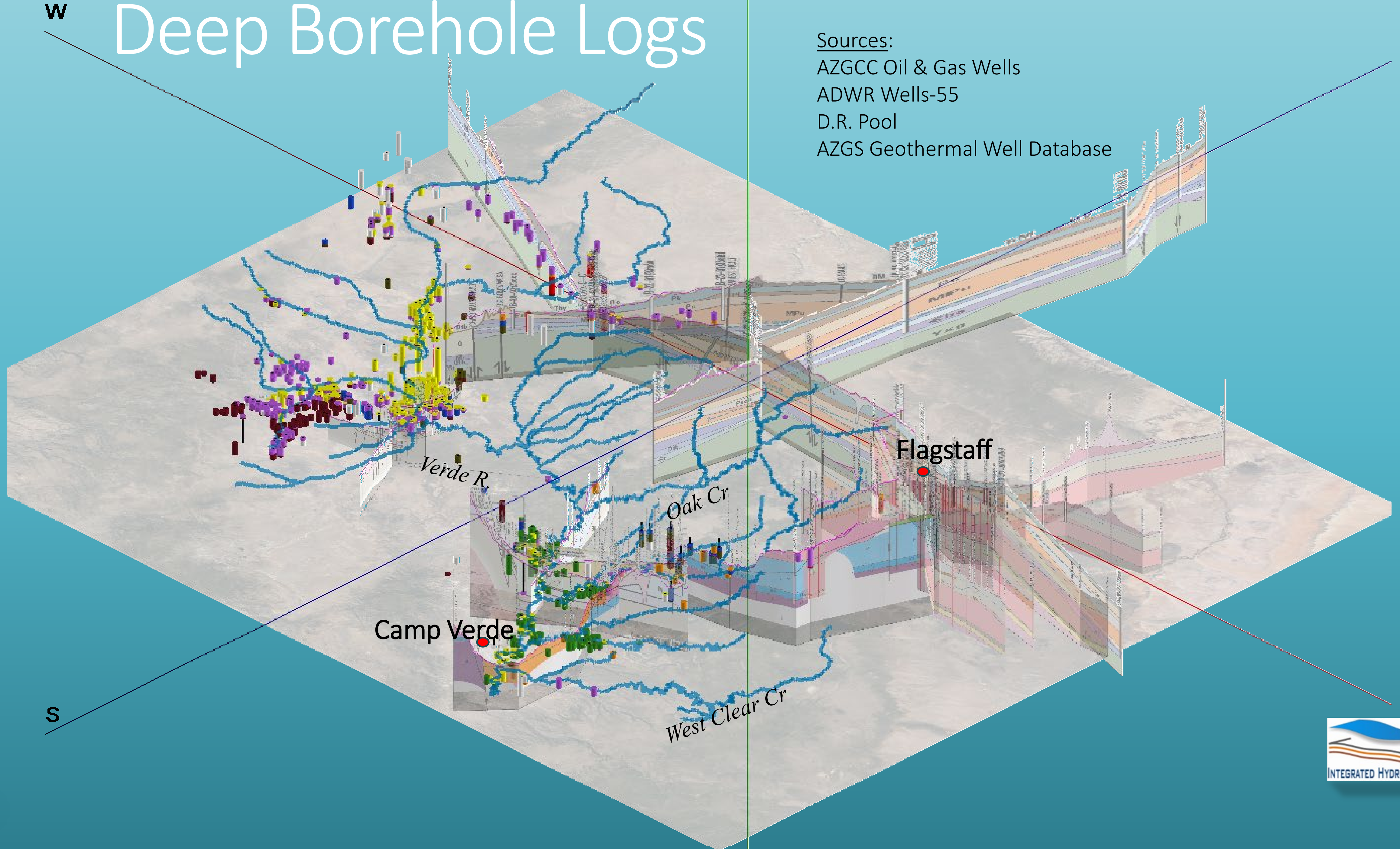
Deep Borehole Logs

Sources:
AZGCC Oil & Gas Wells
ADWR Wells-55
D.R. Pool
AZGS Geothermal Well Database



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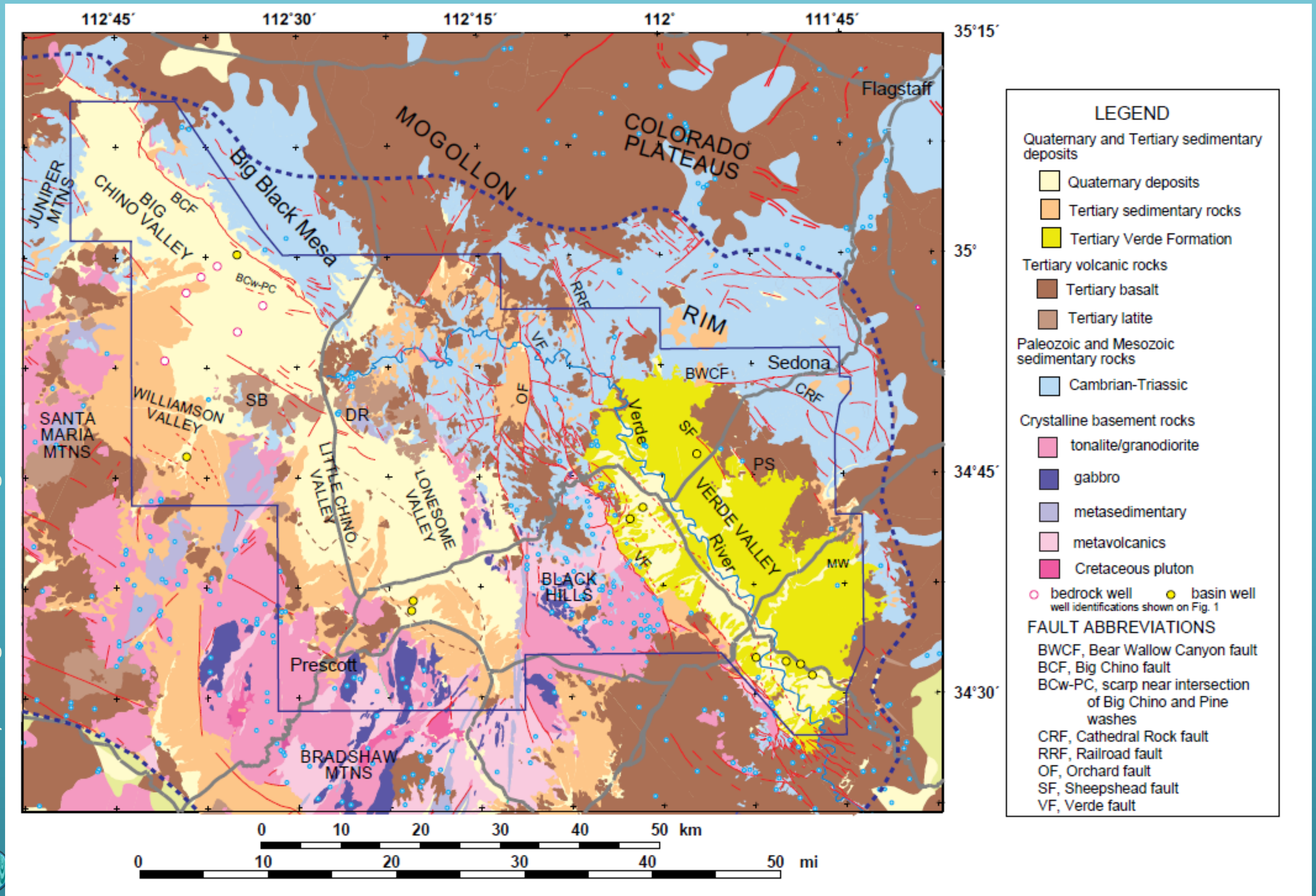
Geologic Maps



2. Simplified geologic map of the Yavapai County study area (from DeWitt and others, in press). Geology outside of thick dotted

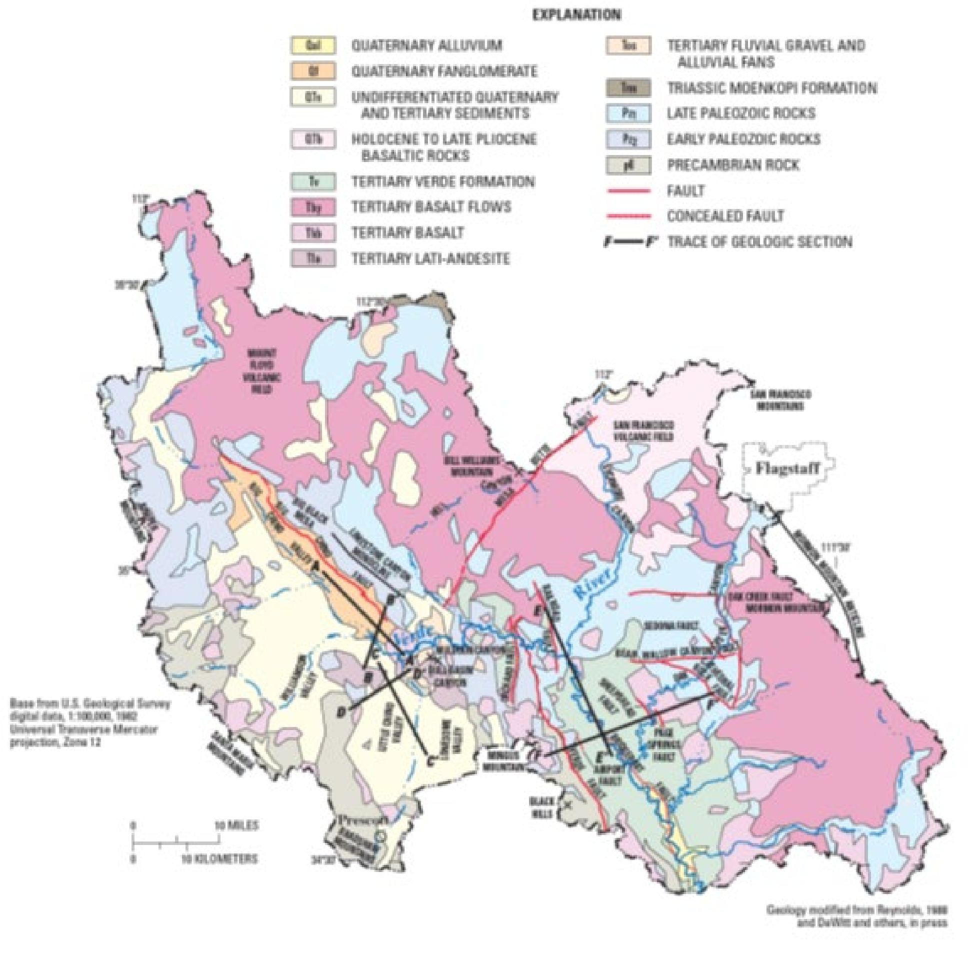


Figure 2. Generalized geology, geologic structures, and location of geologic sections, upper and middle Verde River watersheds, central Arizona.

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Next Generation Verde MIKE SHE Model

New Features of Regional MIKE SHE

- 9 model layers corresponding to **8 hydrologic units** plus Precambrian basement
  - > Redwall Limestone and Coconino/Kaibab specified
- Extensive faulting
- Grid refinement (1000 m --> 400 m)
- Dynamic snowpack/snow melt calibration improvements
- Updated pumping and incidental/artificial recharge through 2024
- Prescott Reservoir structures and operations
- Big Chino groundwater irrigation

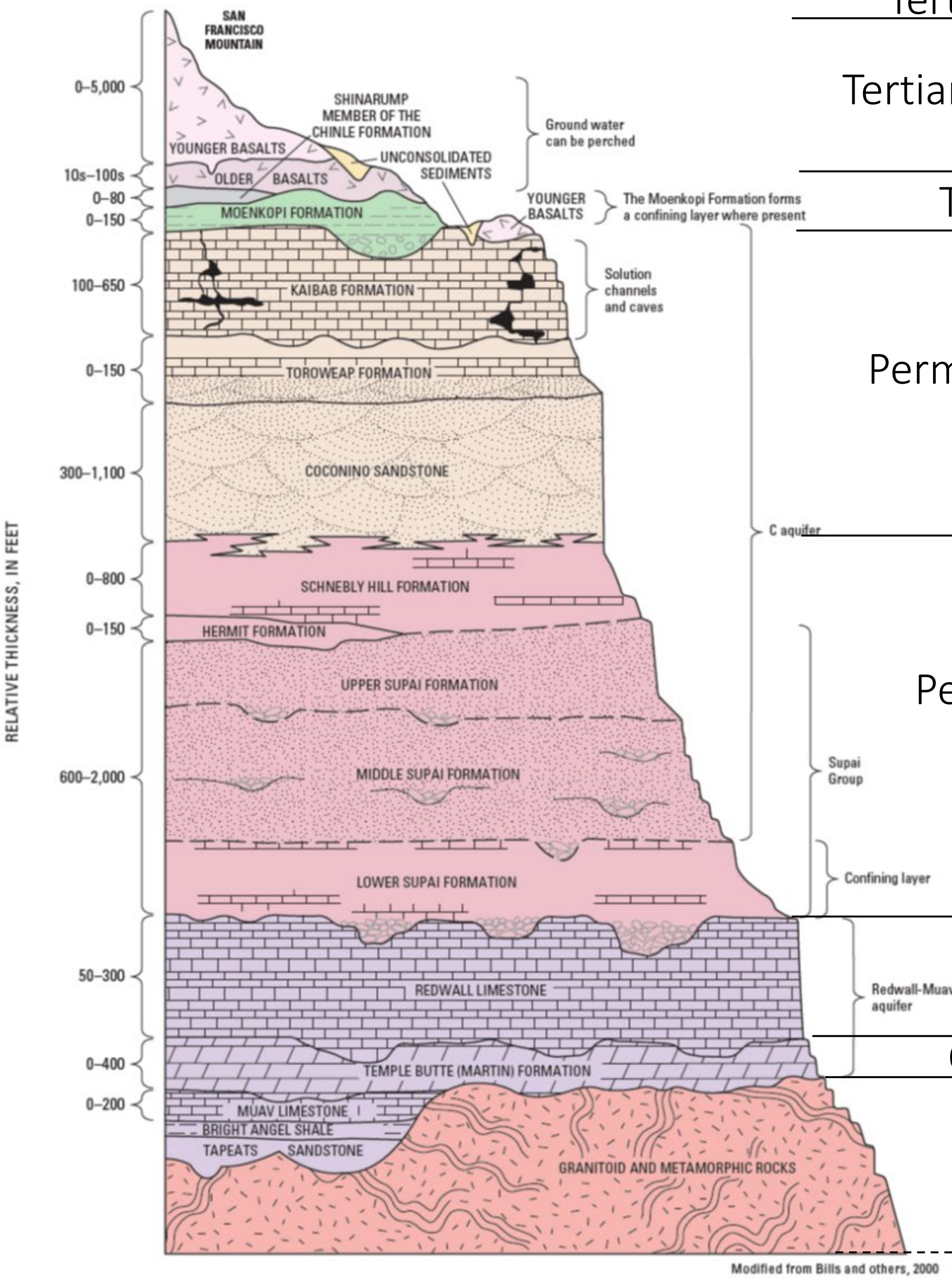

Figure 8. Generalized stratigraphic section of rock units in the Coconino Plateau study area, Coconino and Yavapai Counties, Arizona.

Tertiary/Quaternary Seds L1

Tertiary Verde Fm. (only in VV) L2

Tertiary Volcanics L3

Permian Coconino-Kaibab L4

Pennsylvanian Undiff. L5

Mississipian Redwall L6

Cambrian-Devonian L7

Pre-Cambrian L8

Model Base L9

MIKE SHE Model Layers

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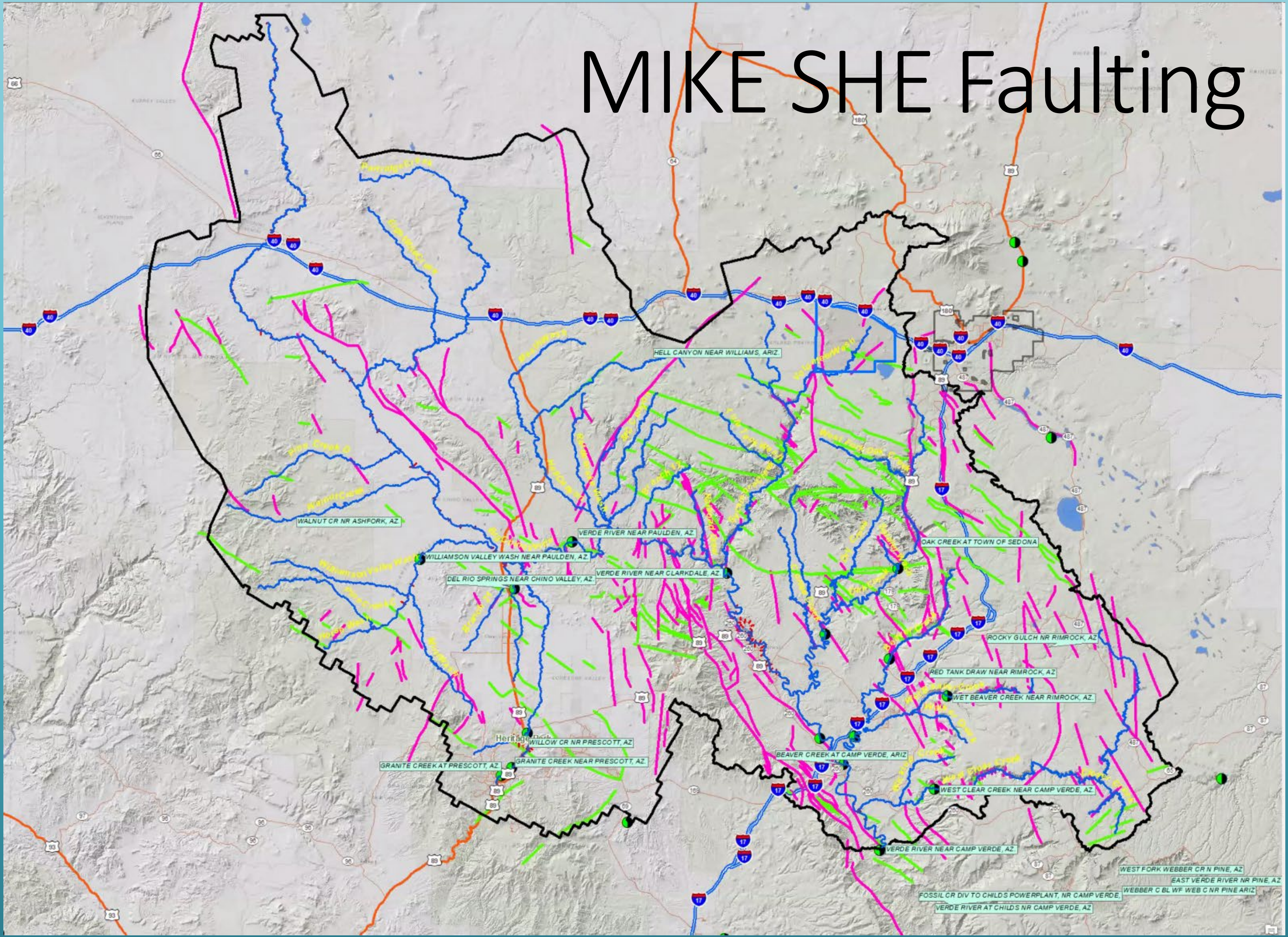
MIKE SHE Faulting



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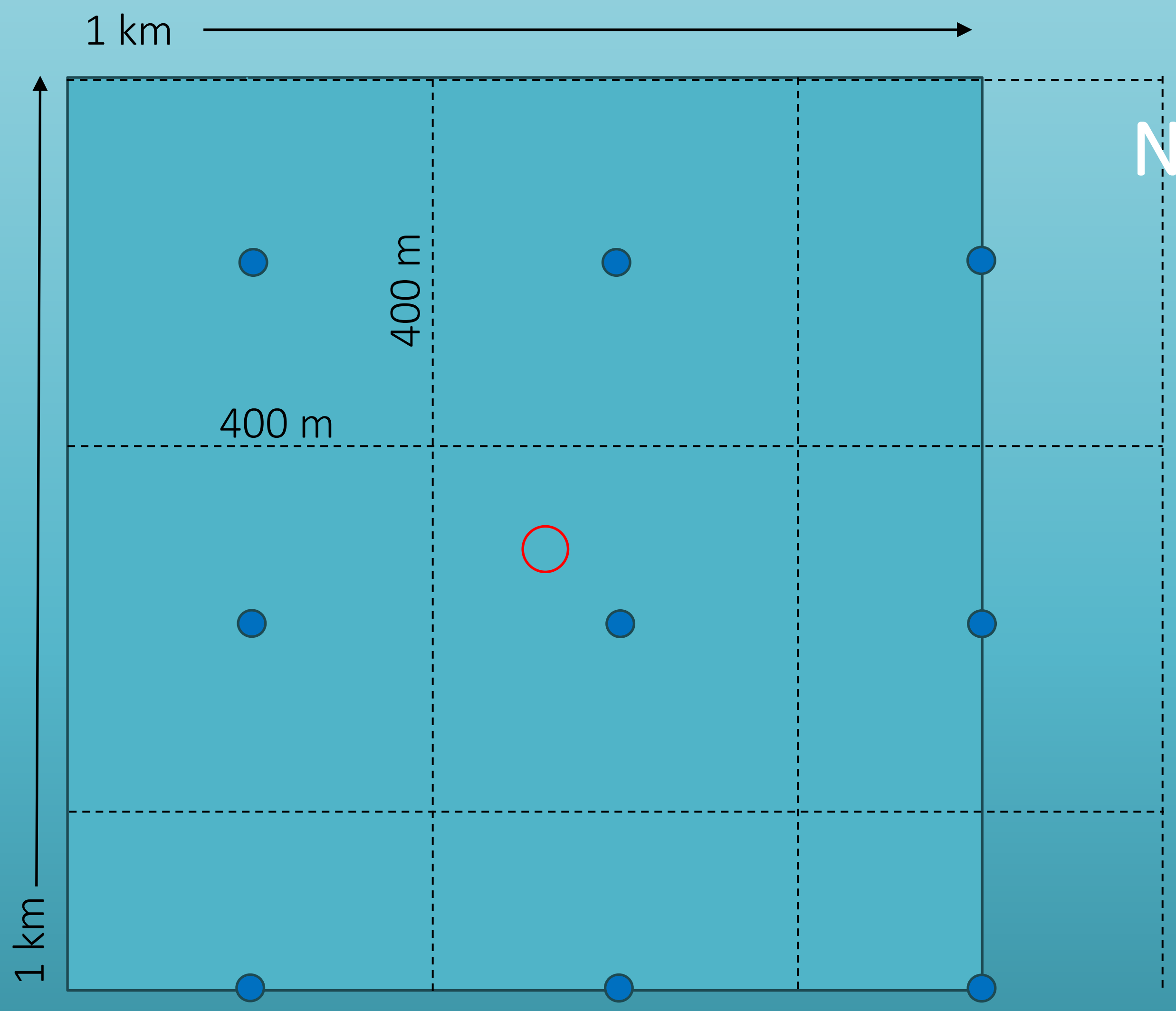
New MIKE SHE Grid Refinement

400 x 400 m cells



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Initial Test of New Model Layering

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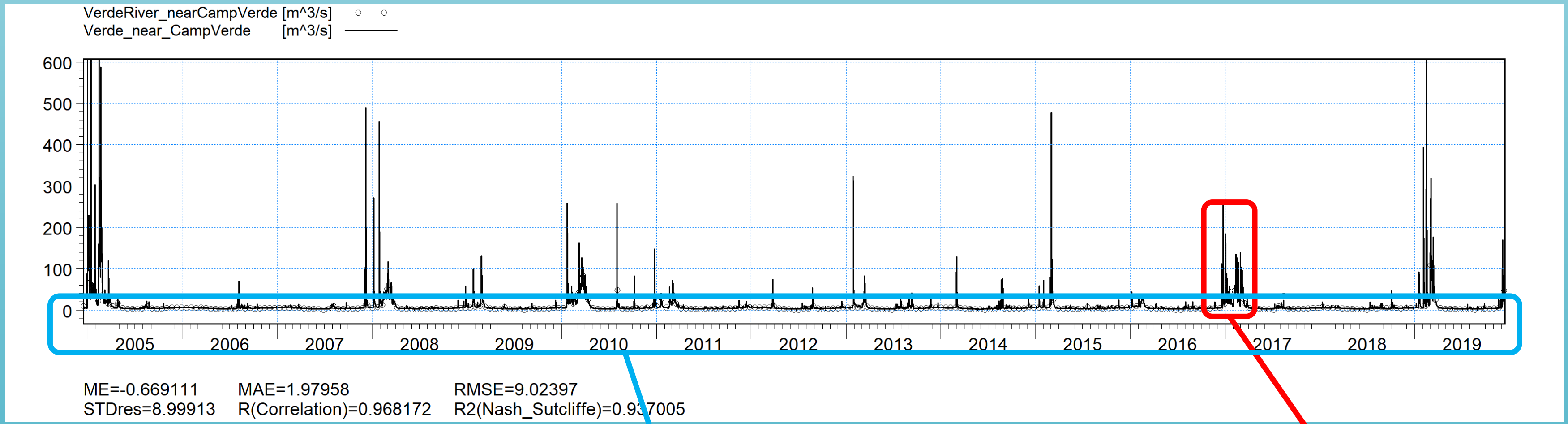
Initial Simulations with Verde Valley Model Showed Good Calibration to Major Streams

- Some tributaries difficult to match baseflows

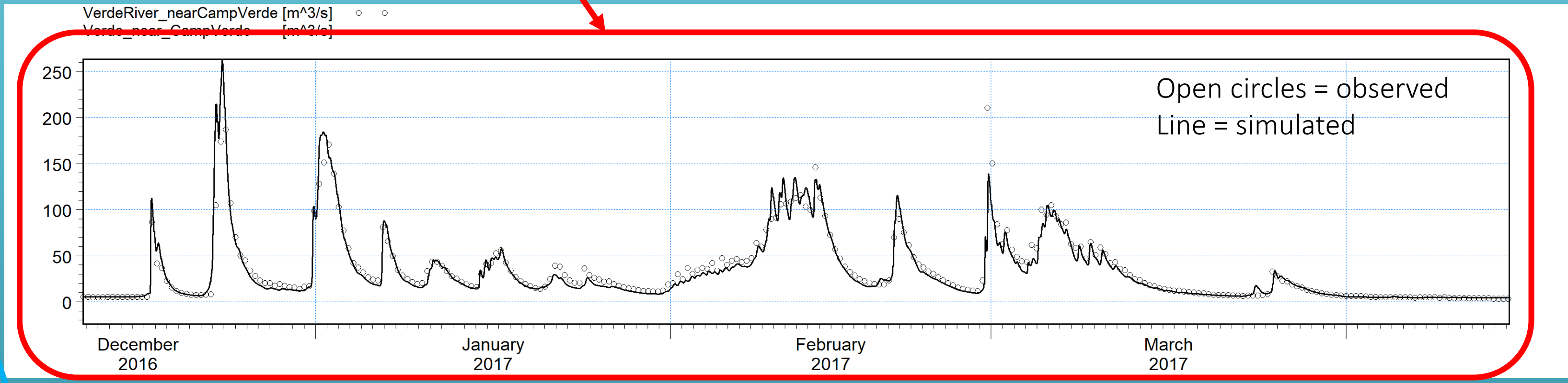
Stream Discharge – Verde River near Camp Verde (09506000)

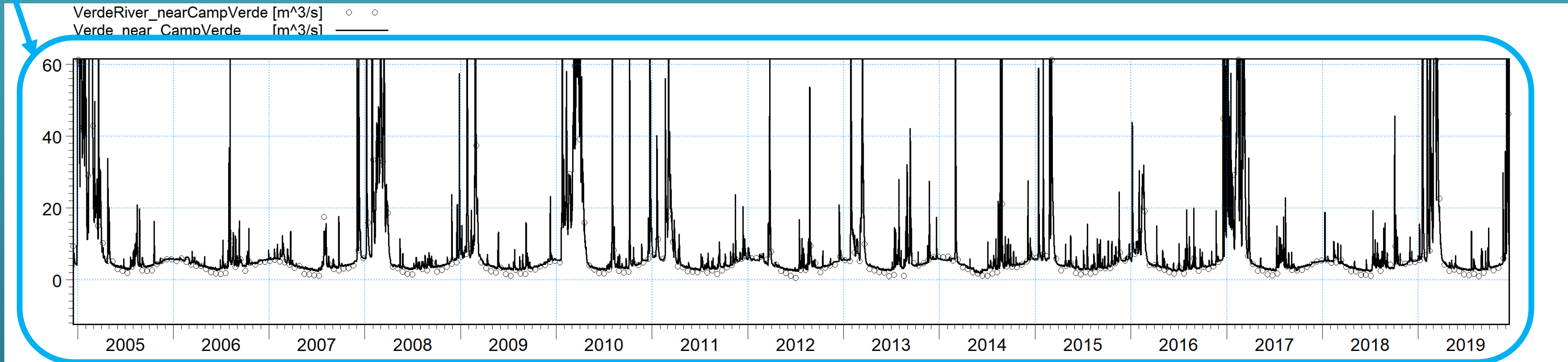


Calibration very good.
Correlation R → ~97%

Peak flows, ascension & recession response reproduced well.

Baseflows → function of cumulative irrigation, consumptive AG loss, Kh





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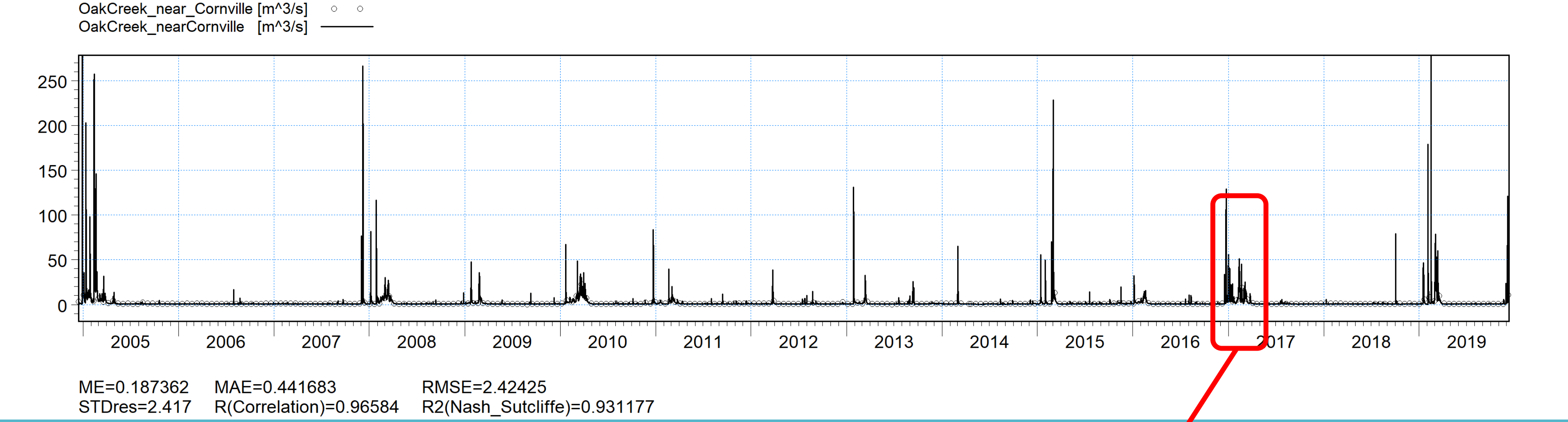
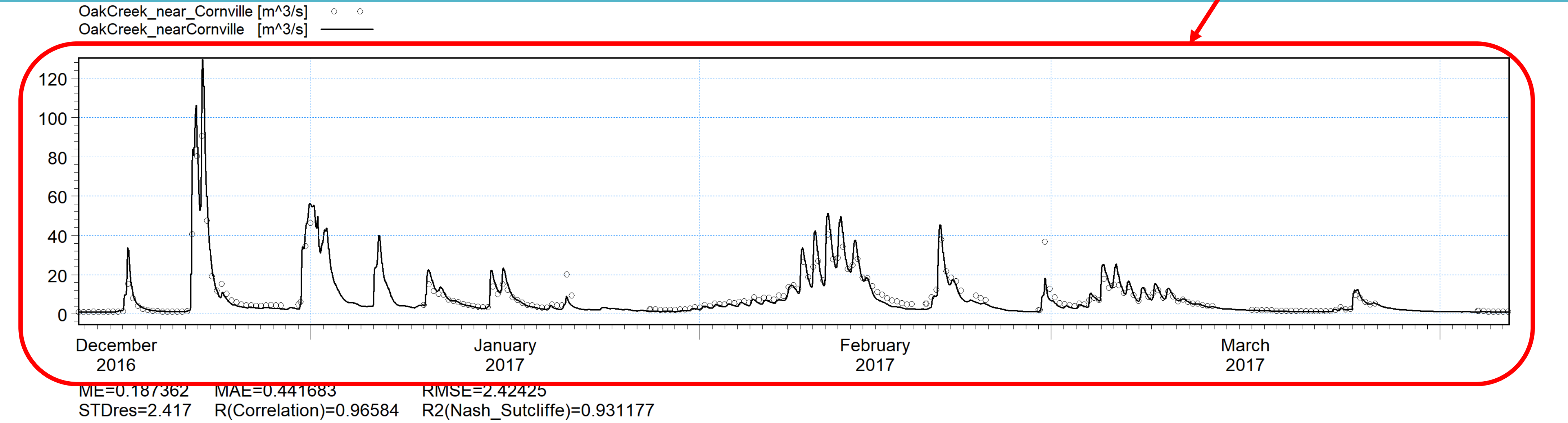
Stream Discharge – Oak Creek near Cornville (09504500)

- Flows reproduced well
- Correlation R ~97%





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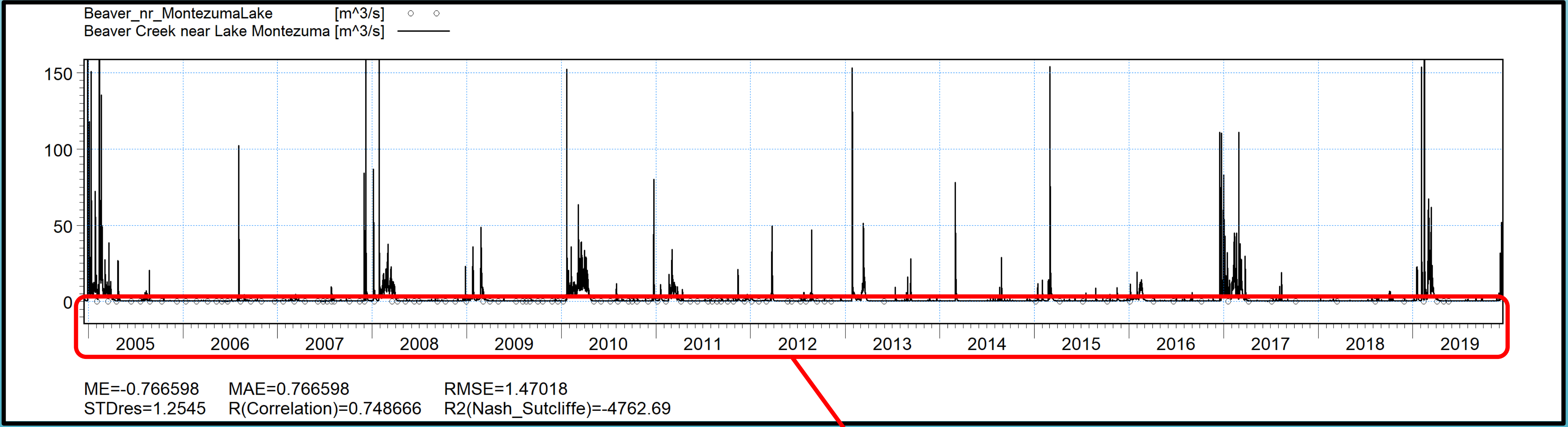
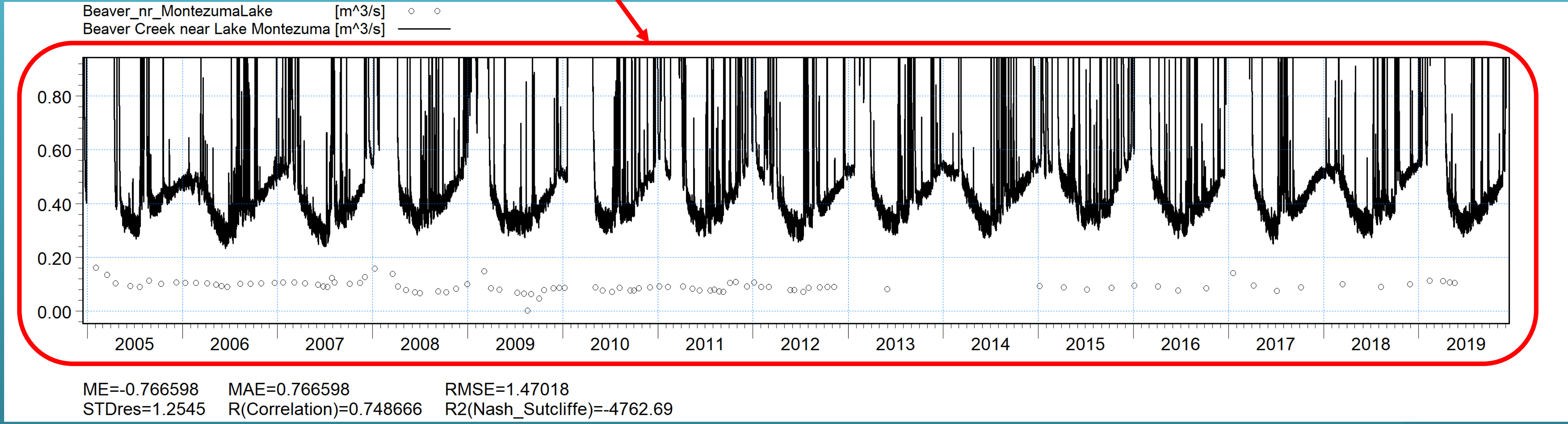
Stream Discharge – Beaver Creek near Montezuma Lake





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New Geologic Layering Shows Immediate Improvement in Baseflows

-- even in tributaries

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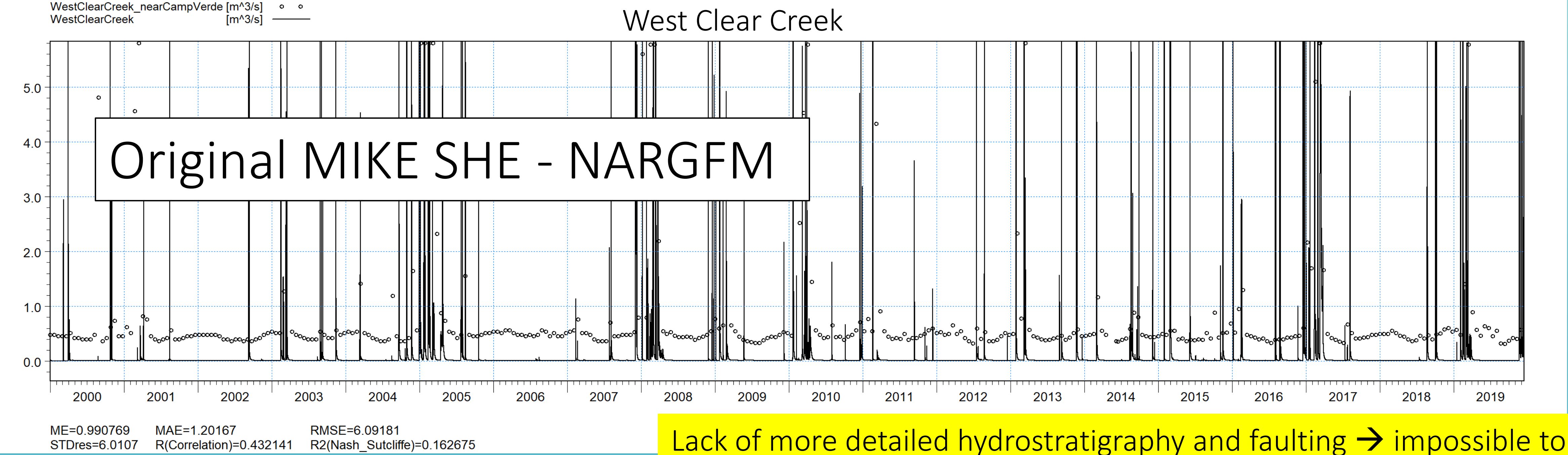
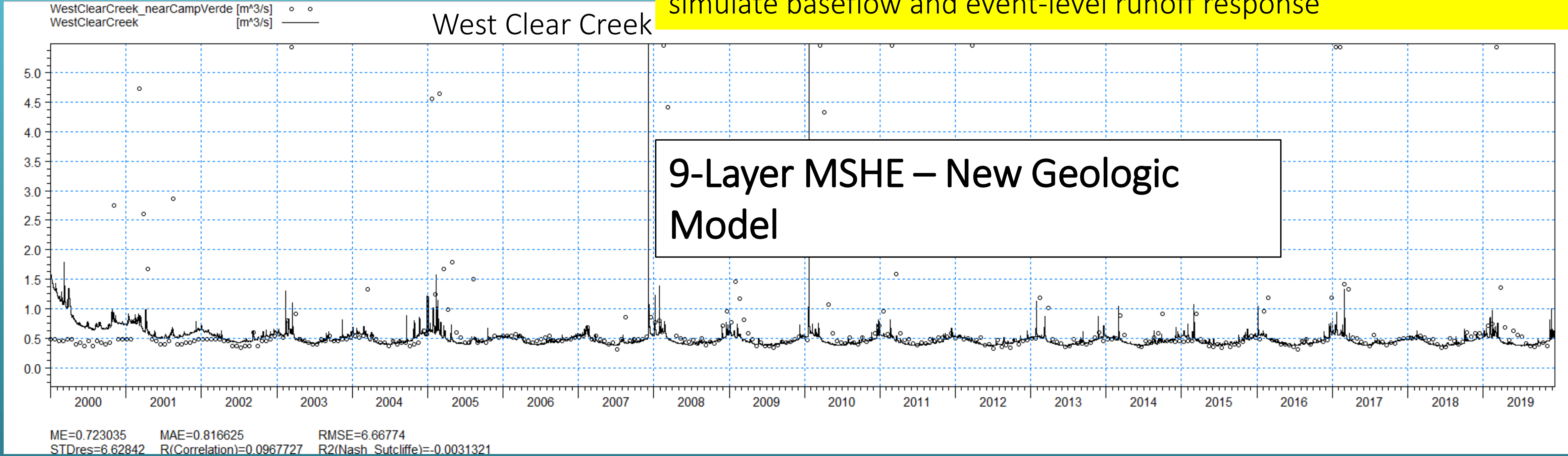


Lack of more detailed hydrostratigraphy and faulting → impossible to simulate baseflow and event-level runoff response



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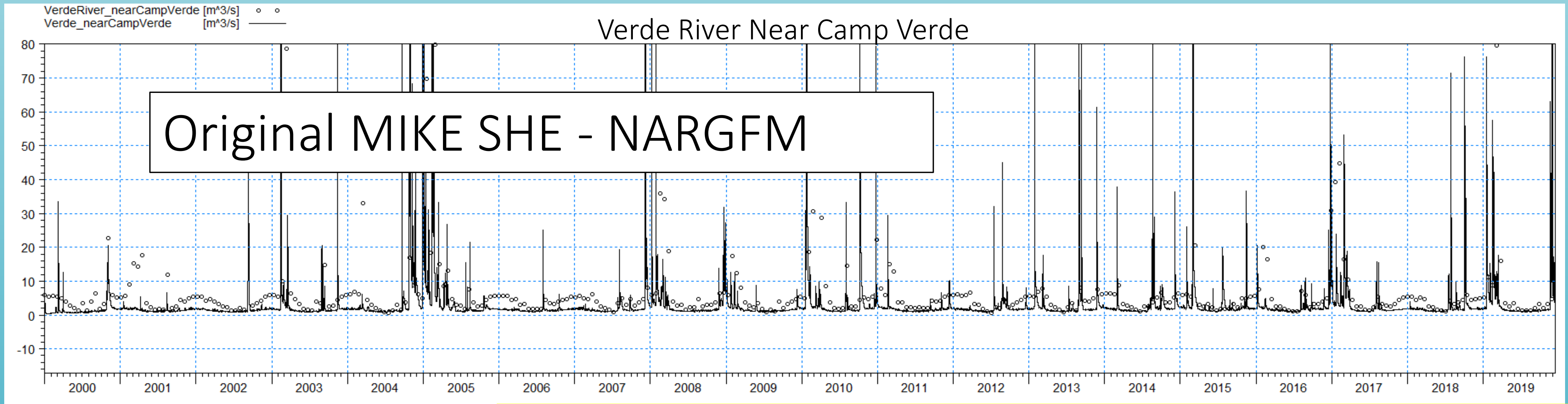
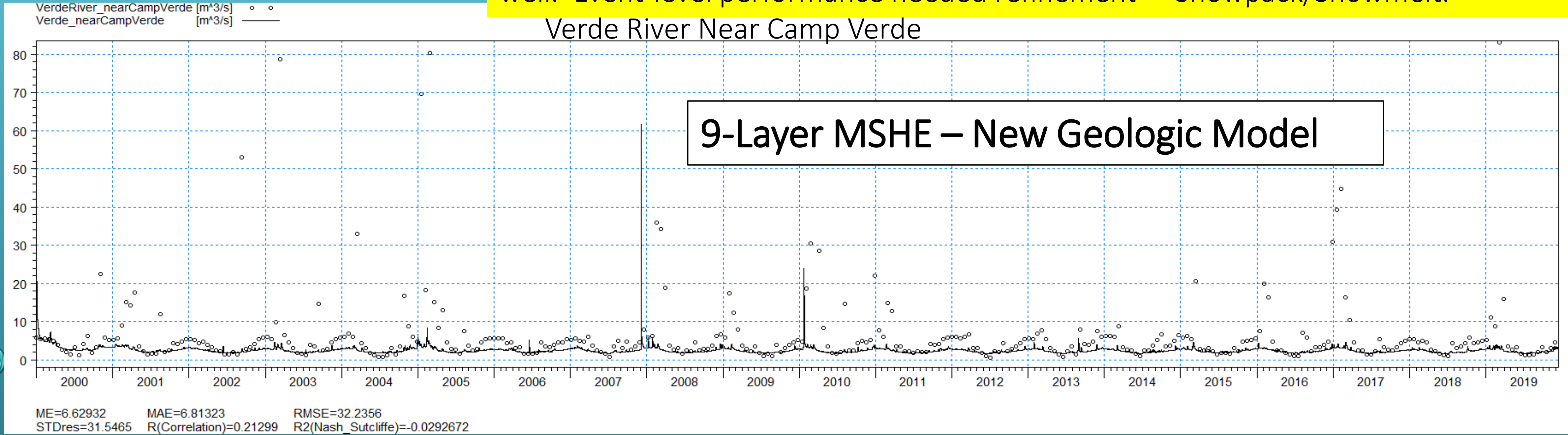


ME=5.91549 MAE=6.84284 RMSE=28.7652
STDres=28.1504 R(Correlation)=0.482006 R2(Nash_Sutcliffe)=0.180419

Initial runs with new Geologic Model → baseflows at key gages reproduced very well. Event-level performance needed refinement>> Snowpack/Snowmelt.



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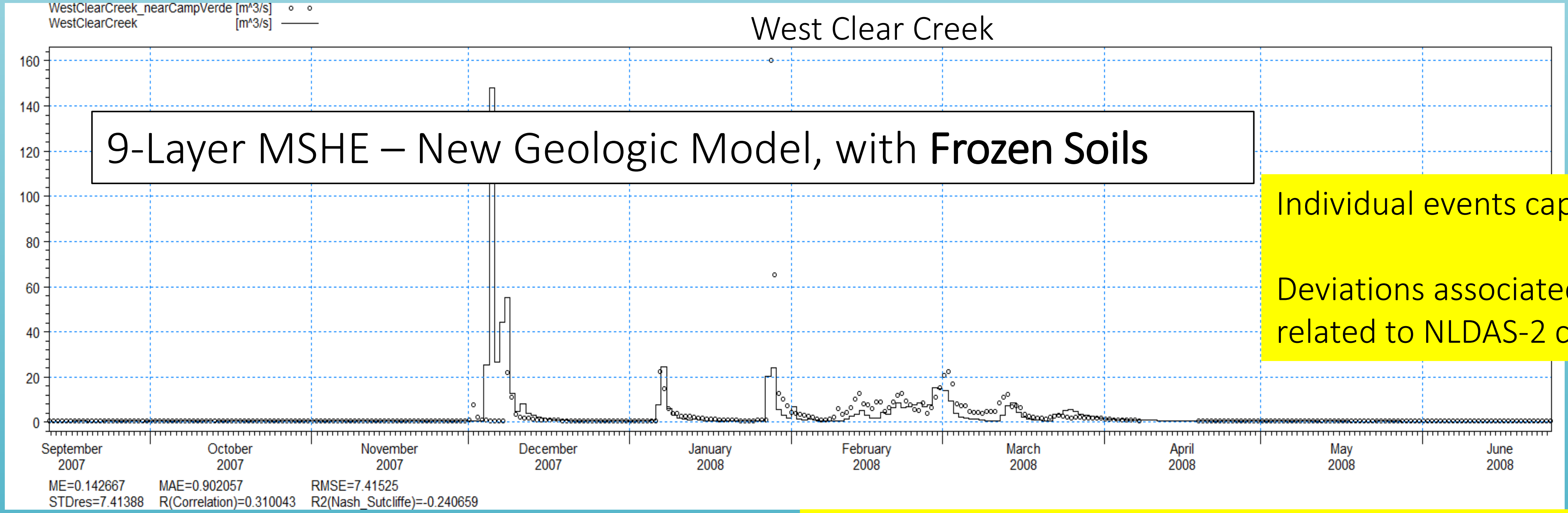
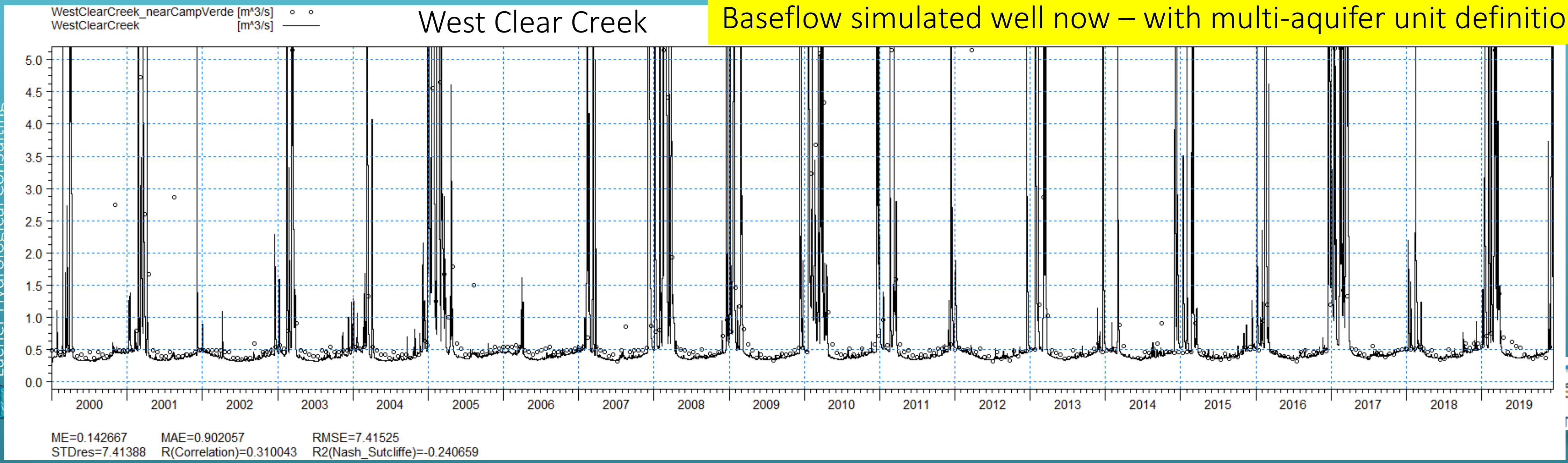
9-Layer MSHE – New Geologic Model, with **Frozen Soils**



Individual events captured well.

Deviations associated with errors related to NLDAS-2 climate inputs

Baseflow simulated well now – with multi-aquifer unit definition



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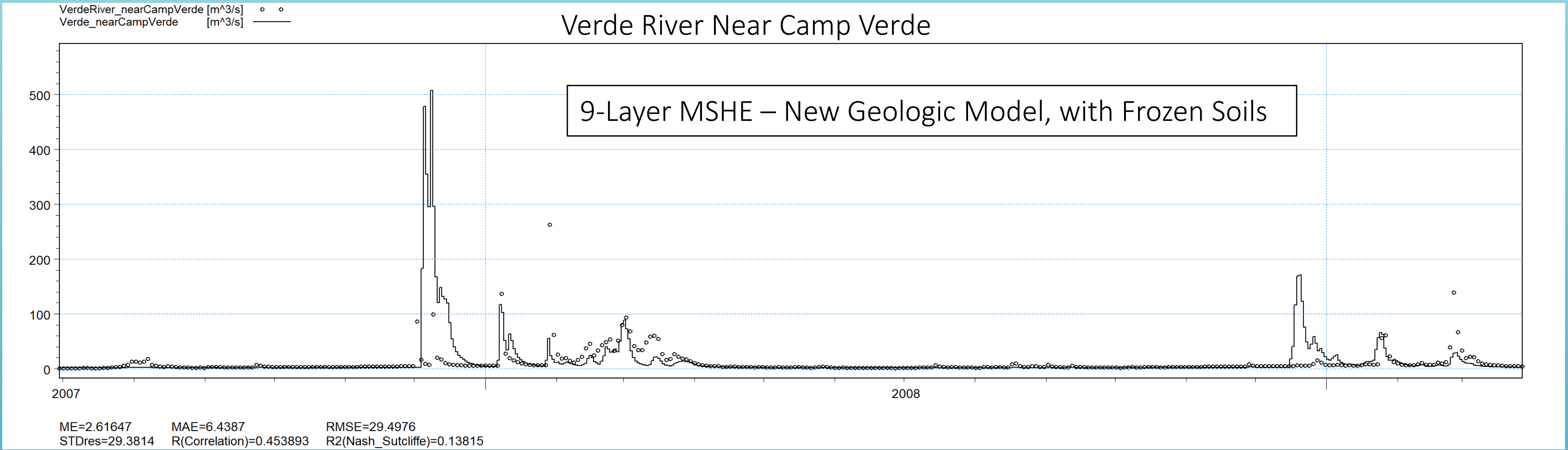

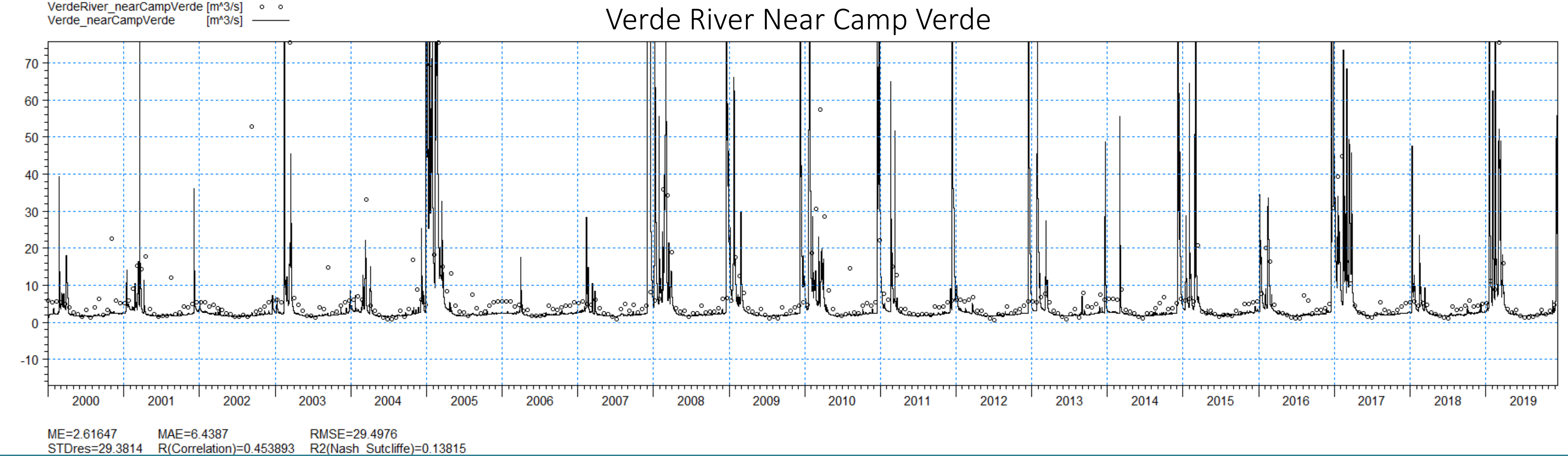

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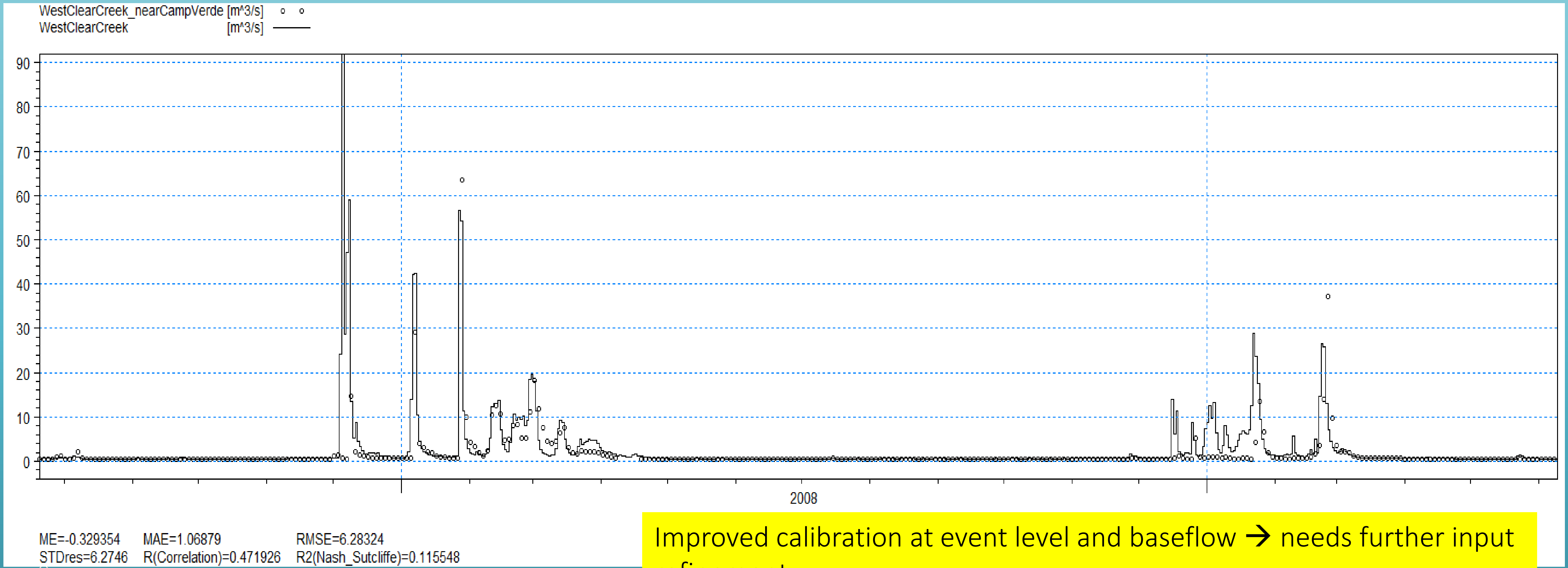
Latest Simulations 9-Layer MSHE – New Geologic Model, with Frozen Soils and Revised Snowpack/melt (slope, aspect) and time-varying Native Vegetation Crop Coefficients



Improved calibration at event level and baseflow → needs further input refinement.

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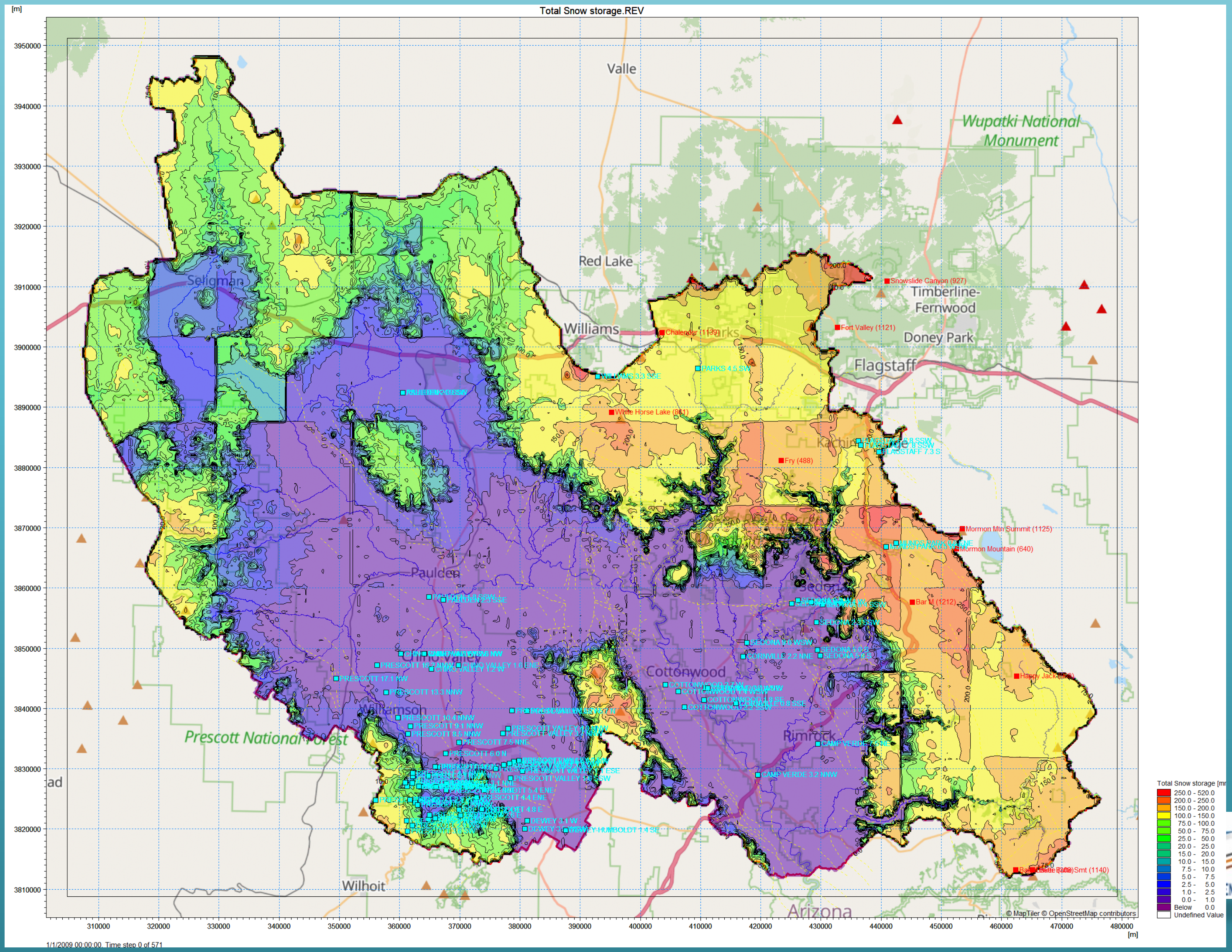
Importance of Snowpack/Melt

Verde surface-subsurface (integrated) hydrology → dominated by snowmelt

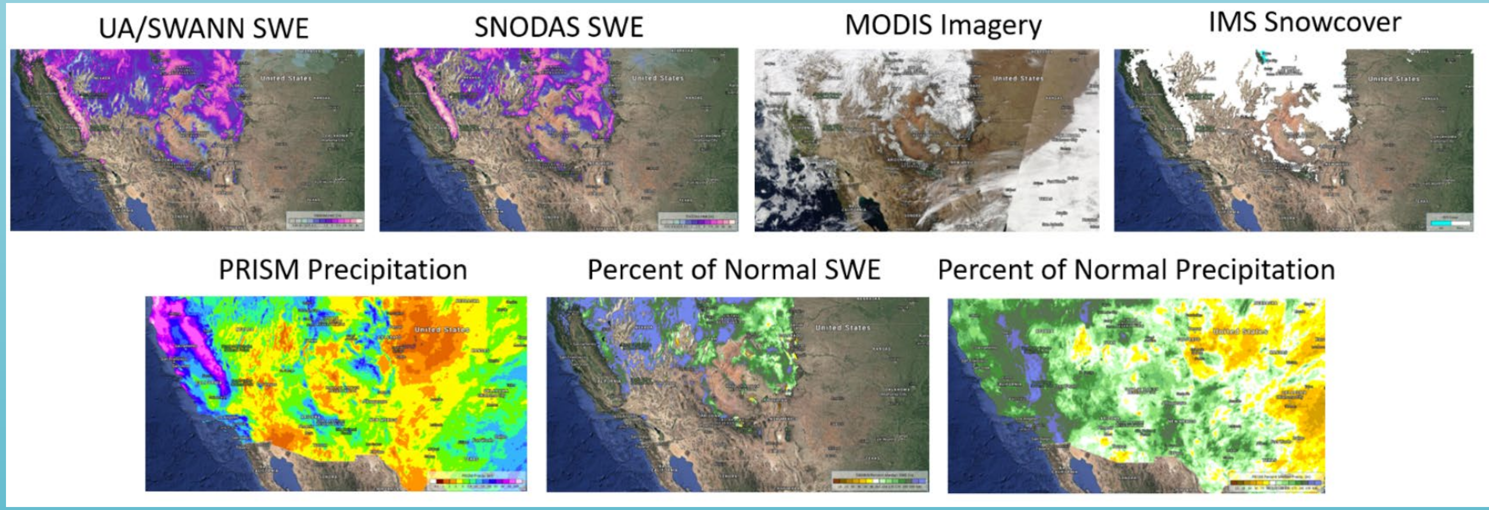
Snowpack and melt dynamics → complex and depend on many factors.

Calibration of snowpack/melt → essential and must be done prior to calibrating all other parameters

Permits simulation of shifts in future snowpack and melt due to climate change



Snow Datasets



Many snow products – we chose 3:

SWE (snow water equivalent) observation station data (mm)

- SNOTEL and CoCoRahs stations

MODIS estimated Snow Cover (% of cell area covered by snow)

- NASA product; 500-m, daily

SWANN estimated SWE (mm)

- UA “Snowview” simulated product; 800m, daily, based on PRISM climate data, observ. Data, terrain, forest cover

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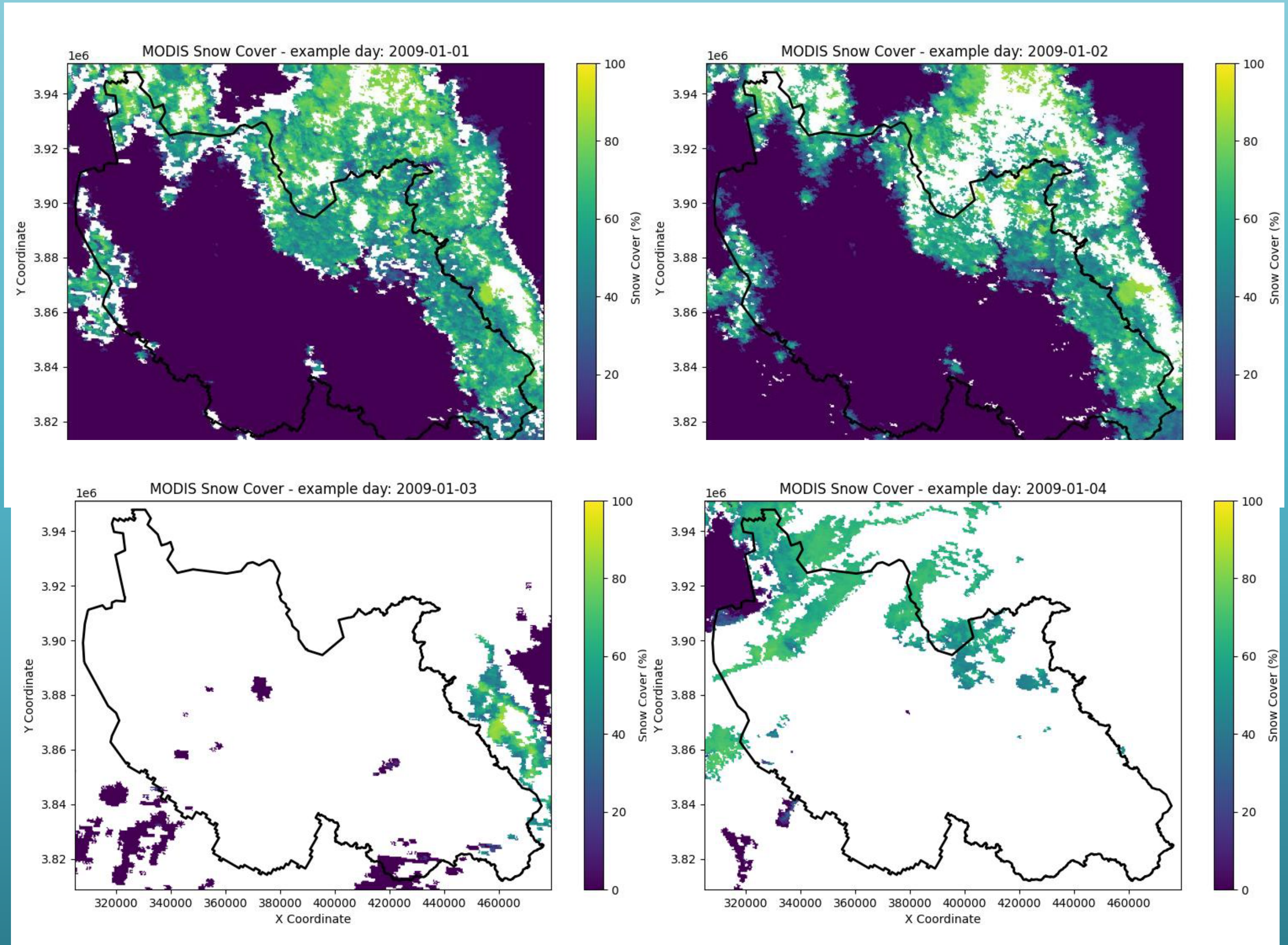
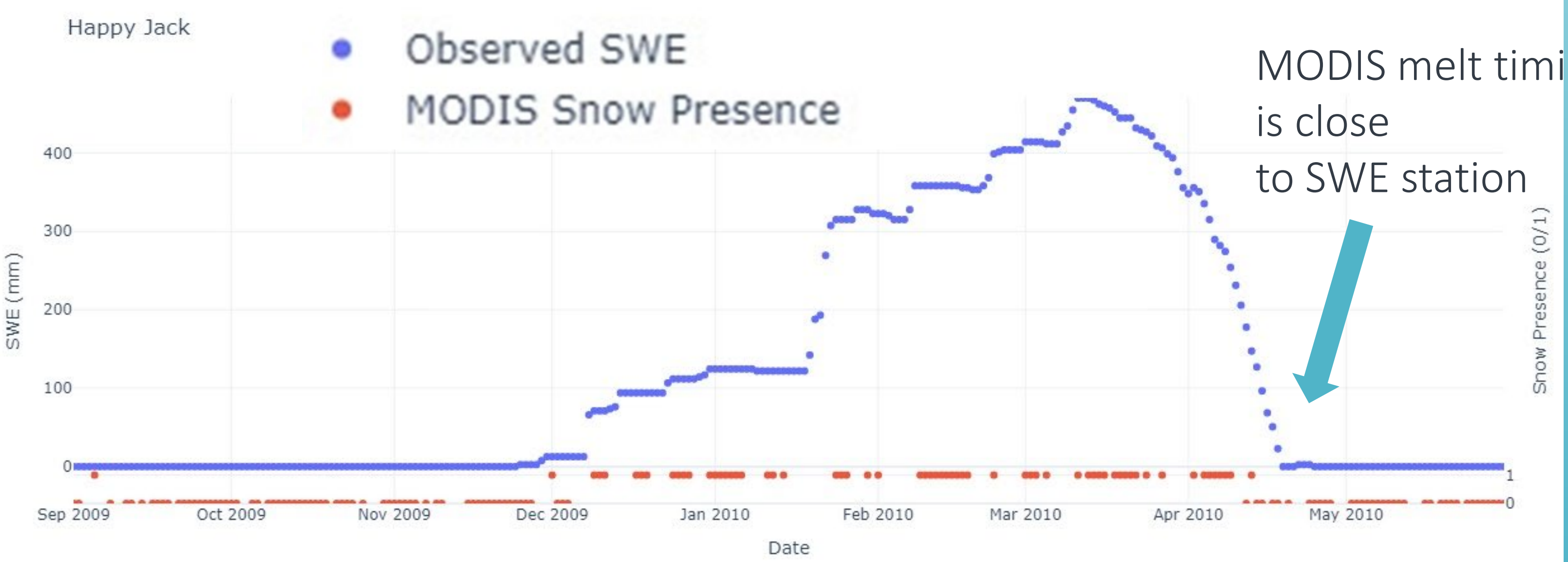
MODIS: cloud cover = data gaps



Example 4 days in Jan 2009

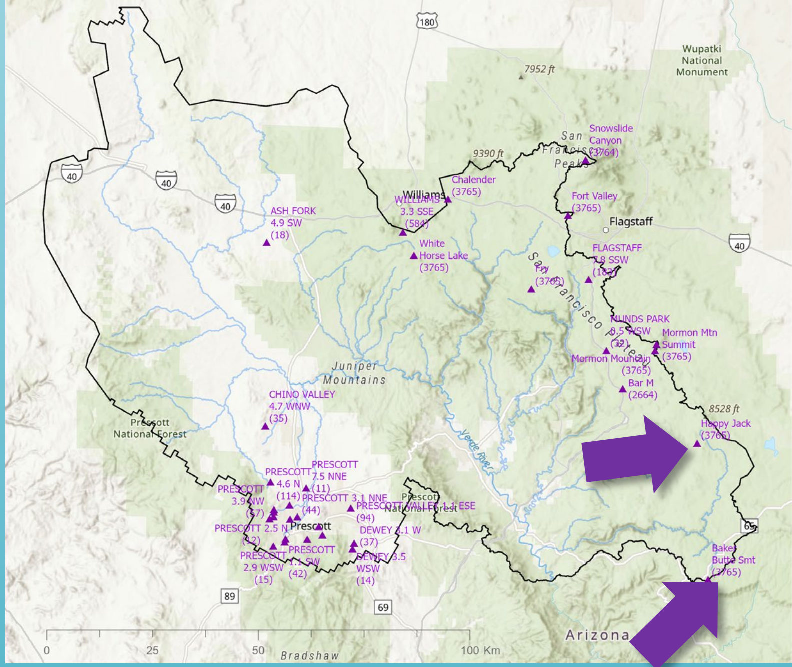
- White = missing data for the day
- Color = % snow cover data

MODIS vs observed SWE



MODIS melt timing is close to SWE station

MODIS melt timing is a month earlier than SWE station



Mixed results in terms of capturing the melt timing vs SWE observations across different sites and years… use with caution

(note: point data vs 500m cell)

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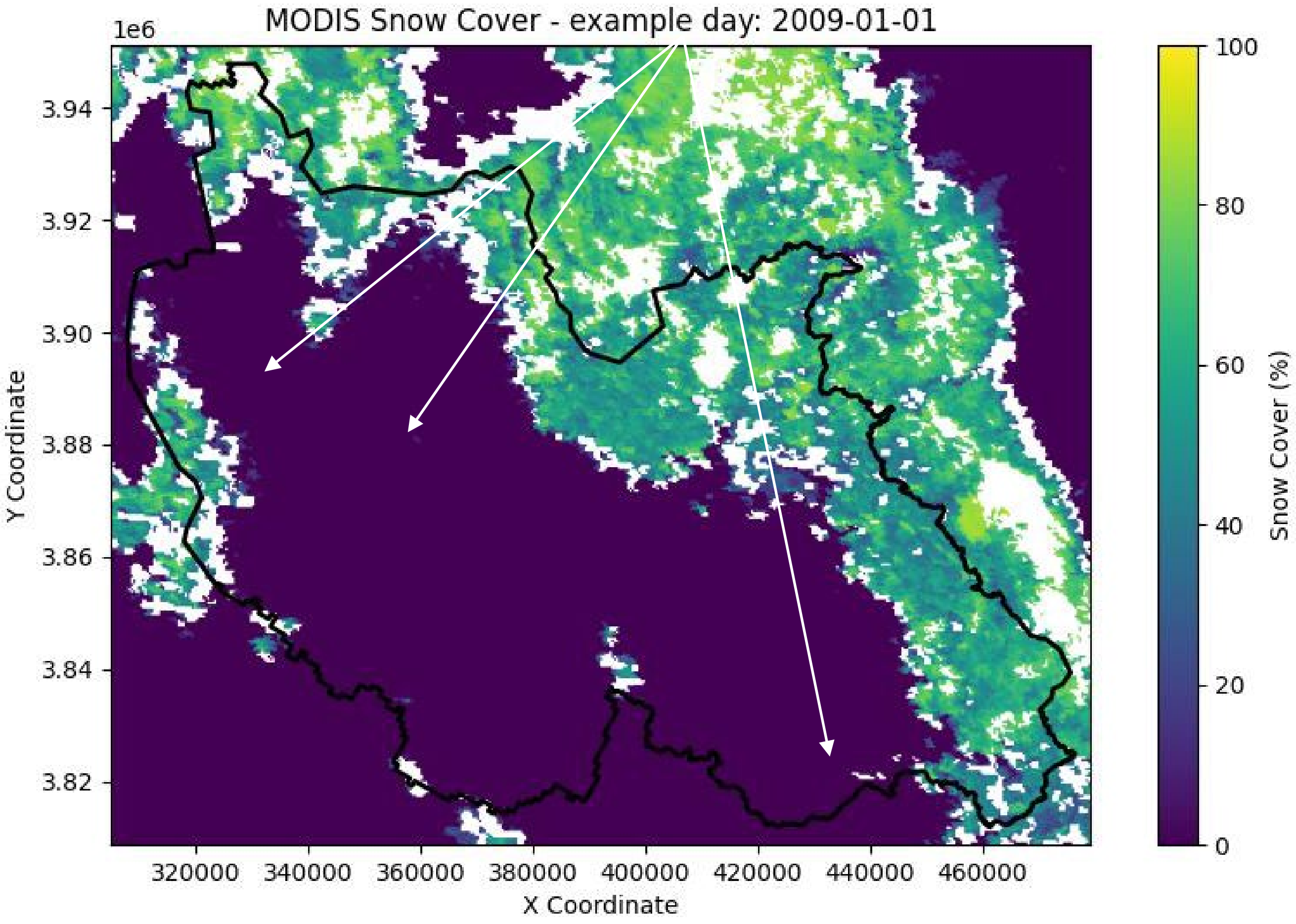
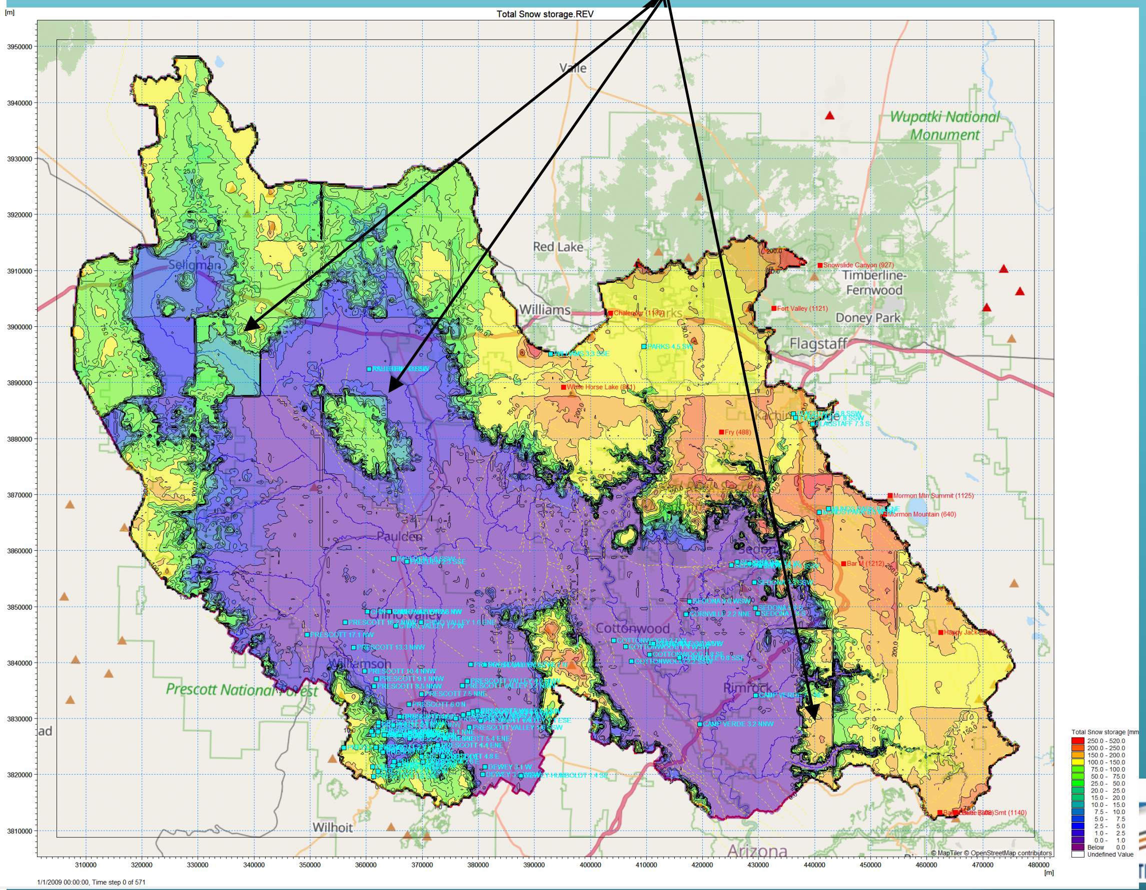
Comparison of MODIS snow cover and MIKESHE Output – January 1, 2009

MSHE model predicts snow where the MODIS data says it is not present → adjust snowmelt parameters & lapse rates in MIKE SHE



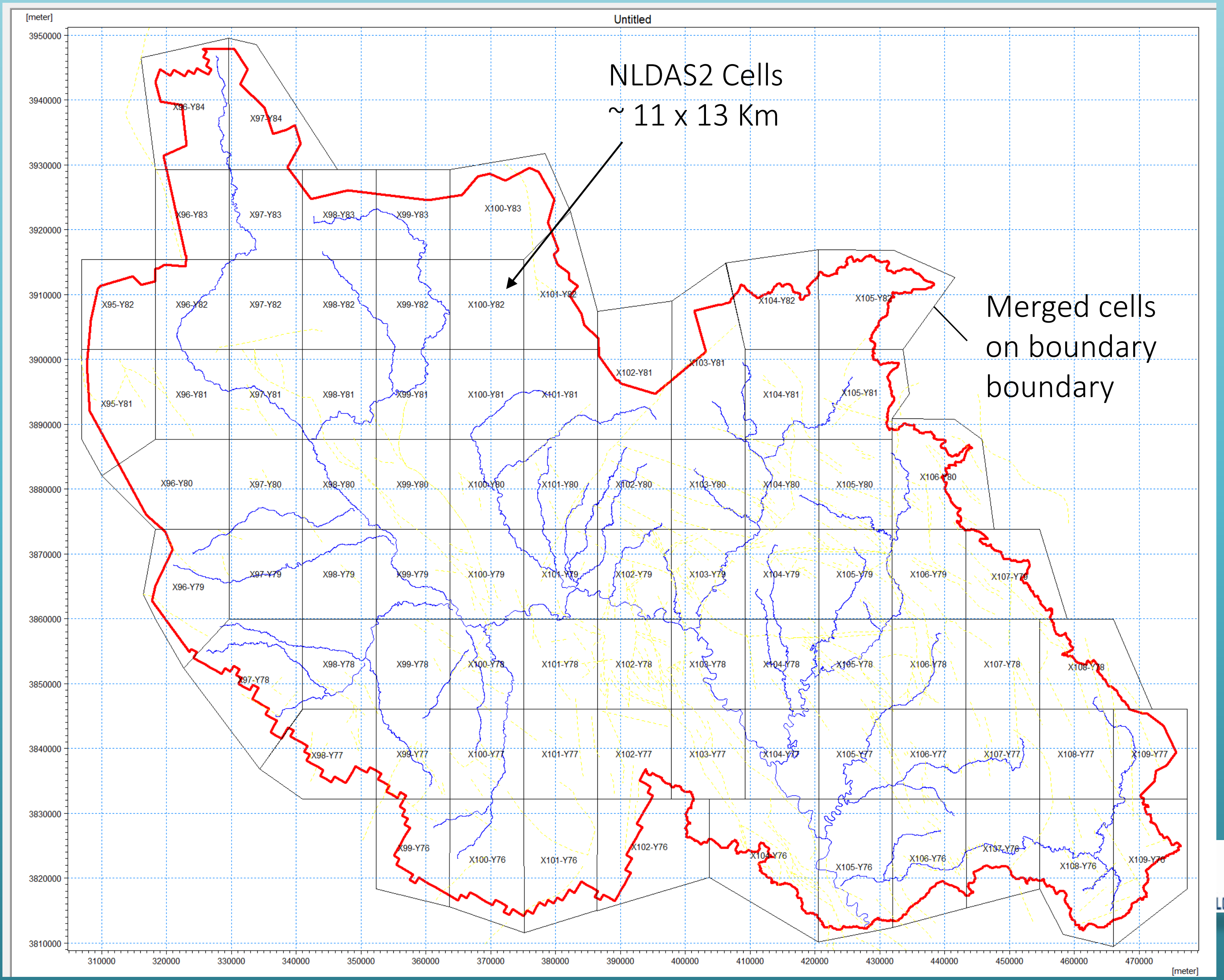


NLDAS-2 Weather Data:

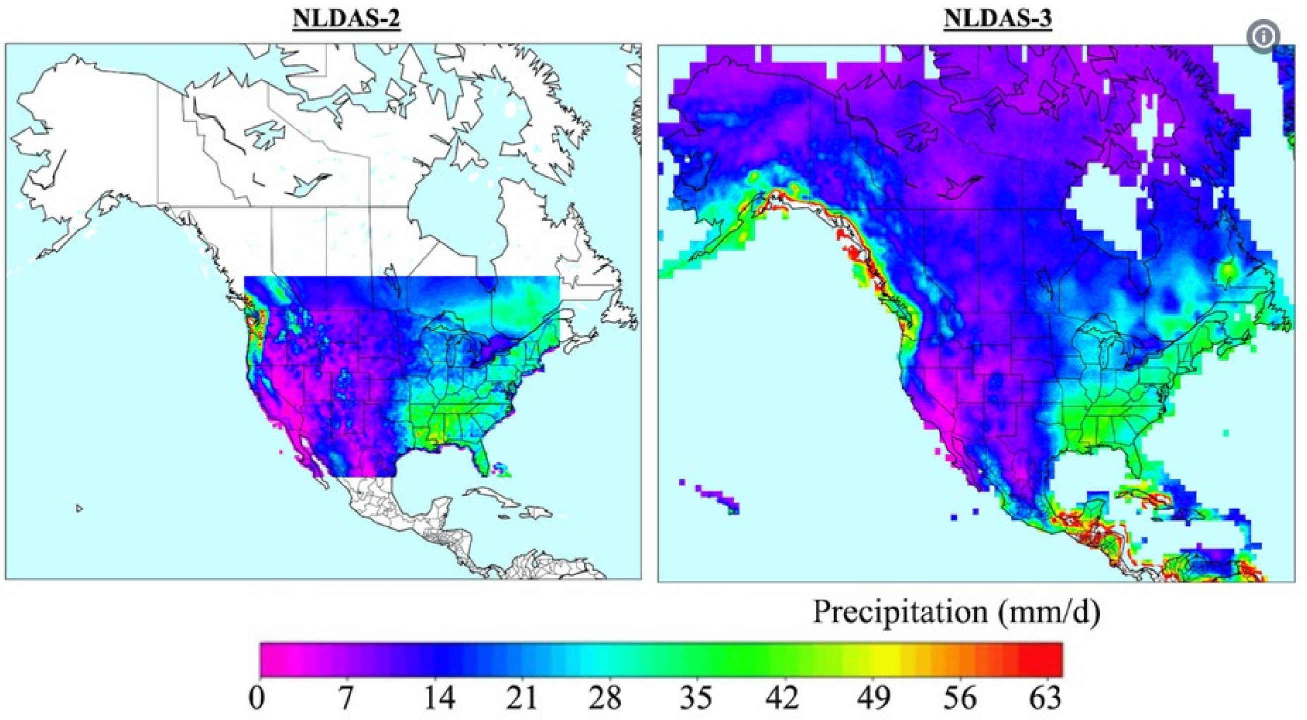
- Hourly T_{air}, P, RefET
- Full CONUS

Spatial Scale of NLDAS2 Weather Data Inputs Affects Snowpack Calibration

- ❑ One NLDAS cell may span several thousand feet in elevation
- ❑ Requires correction for temperature and precip lapse rates



Verde MIKE SHE will be among first BETA Testers for **NLDAS -3**!



Spatial domain of NLDAS-2 (CONUS) vs. NLDAS-3 (North and Central America).

Summary of NLDAS-3 improvements

Attribute	NLDAS-2	NLDAS-3
Spatial Coverage	CONUS (25-53 North / 125-67 West)	North America including Alaska, Hawaii, Puerto Rico and Central America (7-72 North / 169-52 West)
Spatial resolution	12.5-km	1.0-km
Latency	~4 days	~7 hours
Precipitation	CDC daily 12.5-km analysis over CONUS	Assimilation using gauges, CaPA, IMERG, with MERRA-2/ GEOS-IT as background
Surface meteorology	NARR with constant lapse rate adjustments	MERRA-2/GEOS-IT with advanced downscaling
Land Surface Modeling	4 (Noah, VIC, Mosaic, SAC)	1 (Noah-MP)
Surface Water Modeling	None	1 (HyMAP)
Data assimilation	None	Assimilation of remotely sensed datasets of soil moisture (e.g., SMAP), leaf area index (e.g., MODIS), snow (e.g., AMSR), terrestrial water storage (GRACE-FO)

https://www.earthdata.nasa.gov/dashboard/stories/nldas

- Significant corrections for spurious precipitation values
- Corrections along borders of coverage area

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Pumping Update

Through 2024

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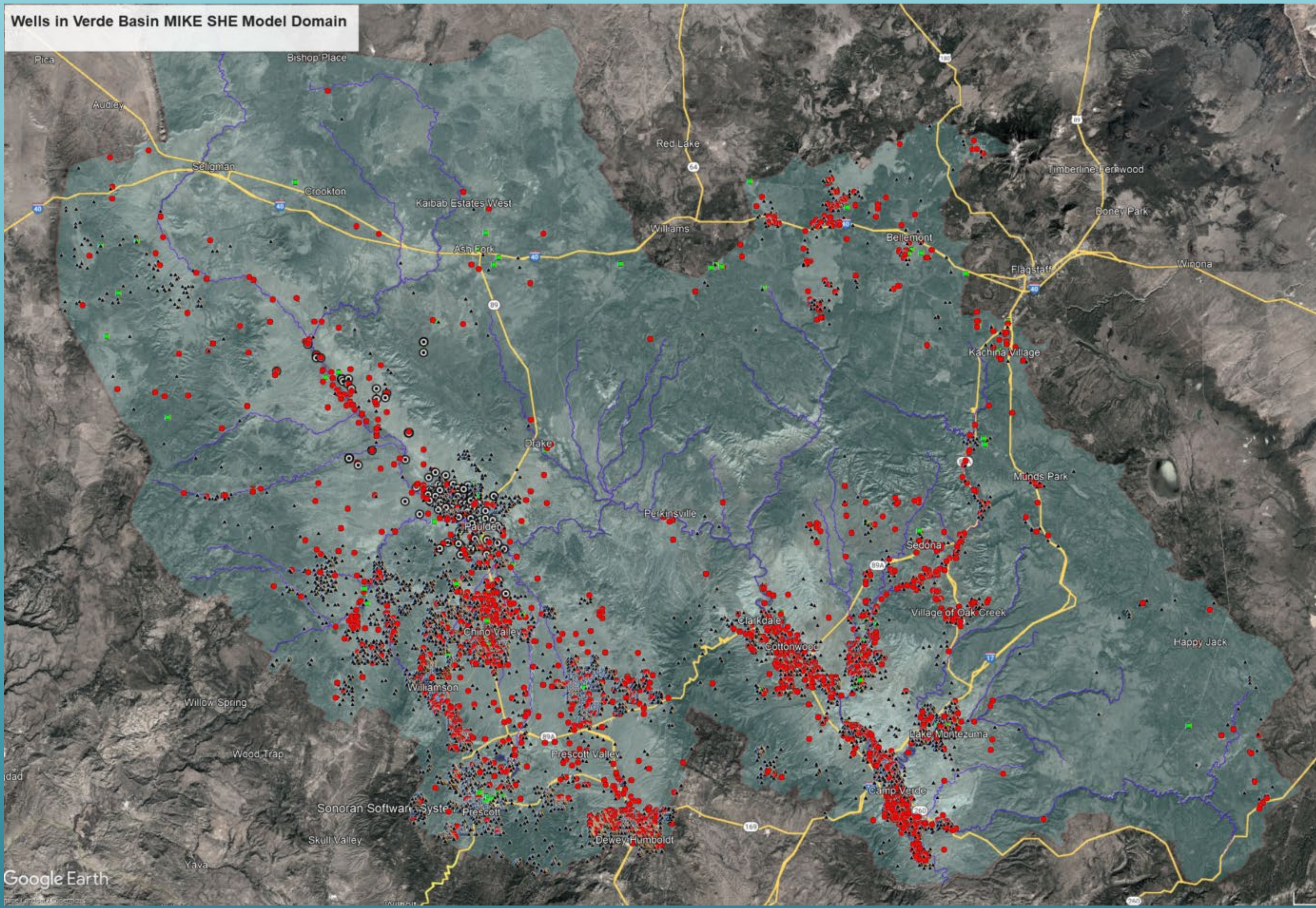
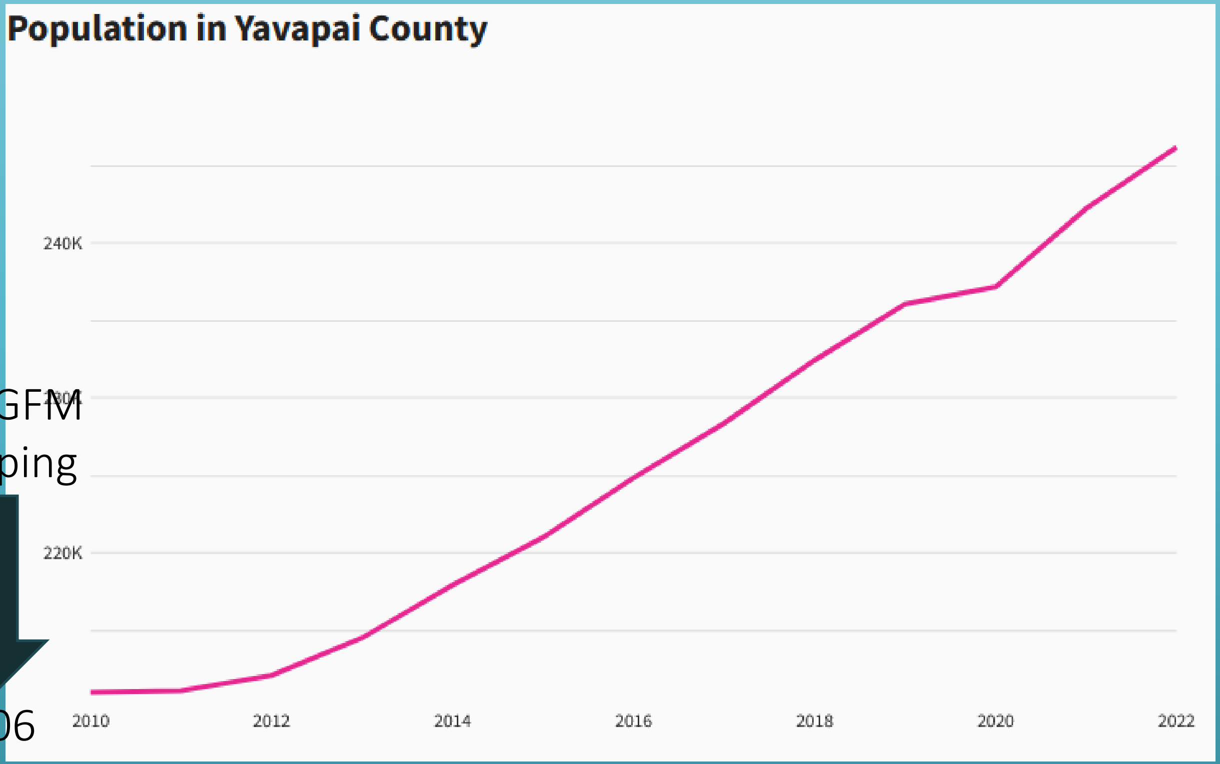
Verde Basin Wells 2006-2024

- > 30,000 active pumping wells
- Other wells – gw monitoring, geothermal investigation, etc.
- Data sources:
  - ADWR
    - Wells-35
    - Wells-55
    - Comm. Water Syst.
    - Prescott AMA
  - NWIS
  - GWSI
  - Individual communities
  - CA1 Group
  - Reports & Studies

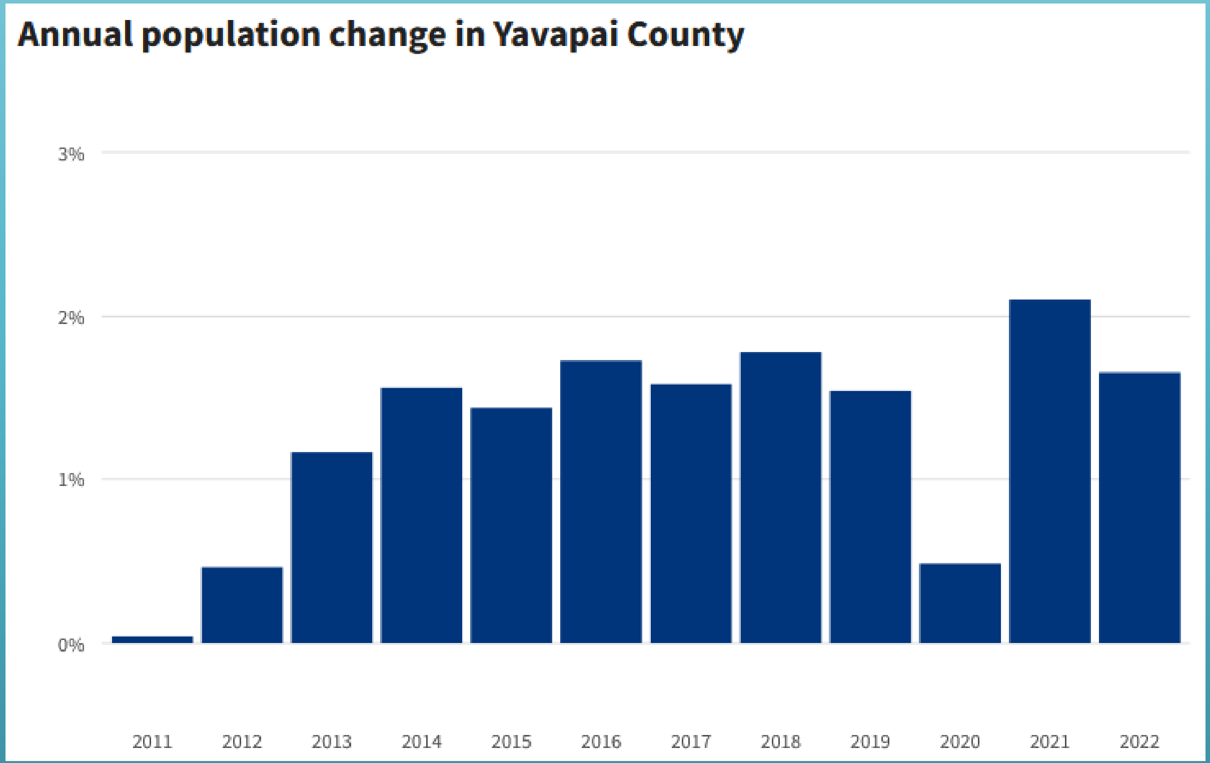


Yavapai County is nearly 100% GW Dependent for Drinking Water



NARGFM Pumping

2006



https://usafacts.org/data/topics/people-society/population-and-demographics/our-changing-population/state/arizona/county/yavapai-county/?endDate=2022-01-01&startDate=2010-01-01#population-change-by-year

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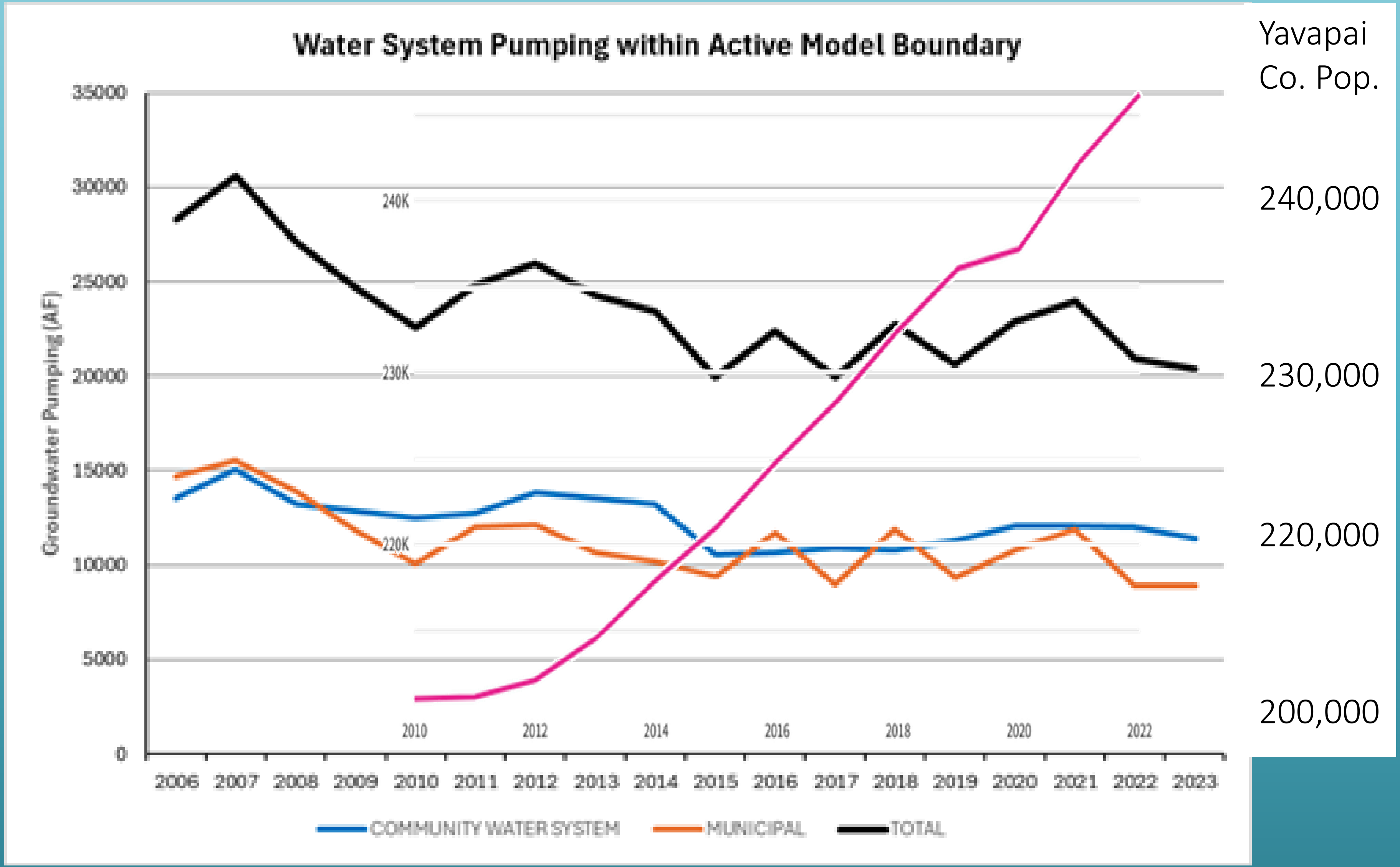
Pumping and Population Growth Have Decoupled

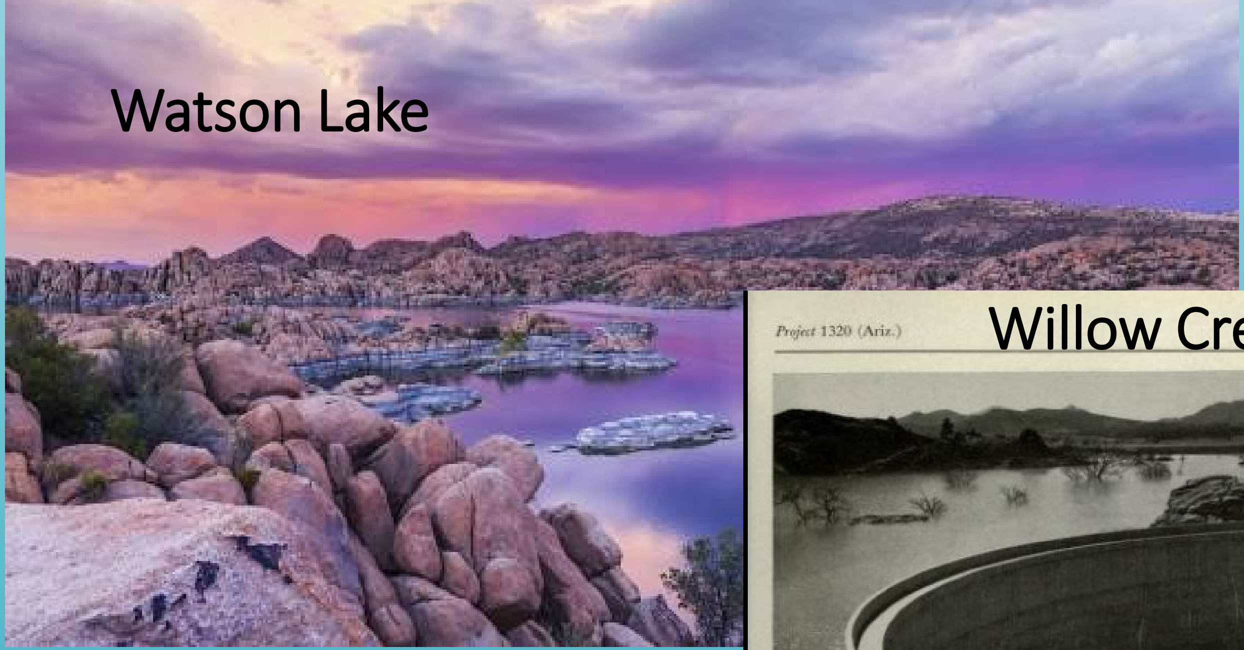


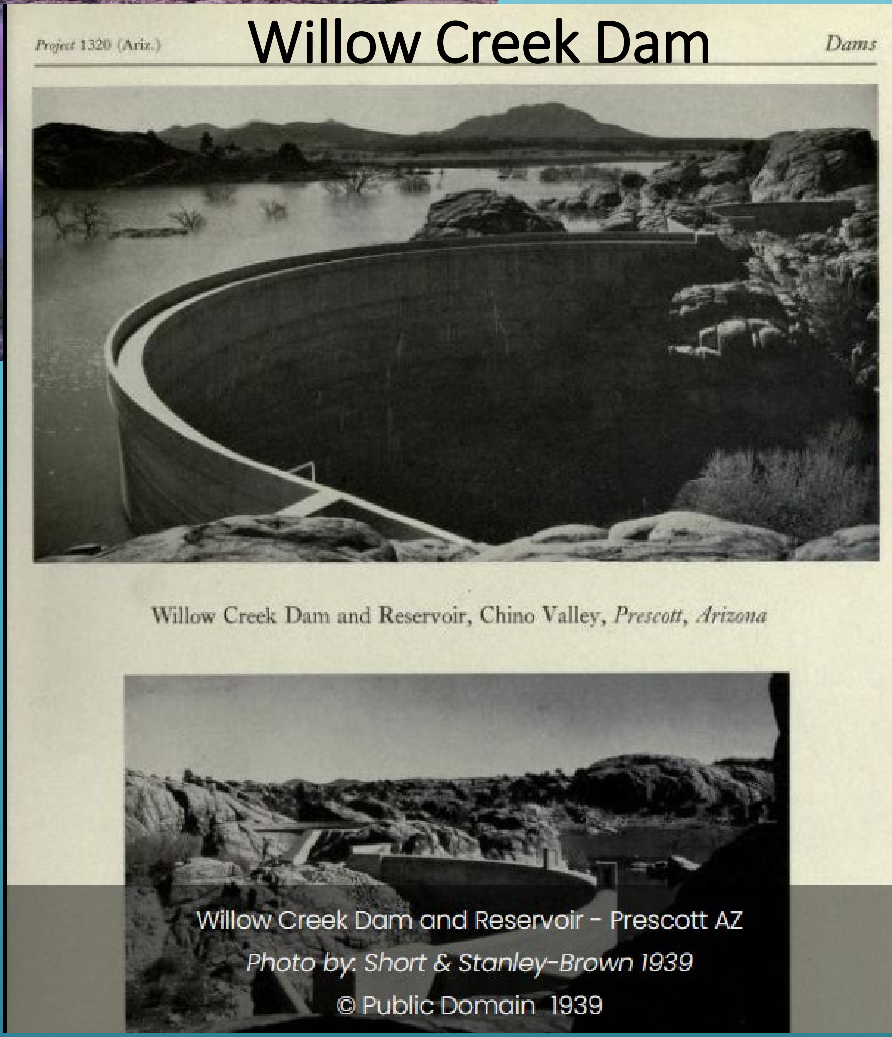
Prescott Reservoirs

- Affect downstream flows
- Influence groundwater recharge
  - Seepage below reservoir
  - Managed recharge near airport
- Likely influence Del Rio Springs

Simulated OUTFLOWS, SEEPAGE, and ET depend on accurate reservoir construction and operations

https://www.google.com/search?client=firefox-b-1-d&q=watson+lake+prescott



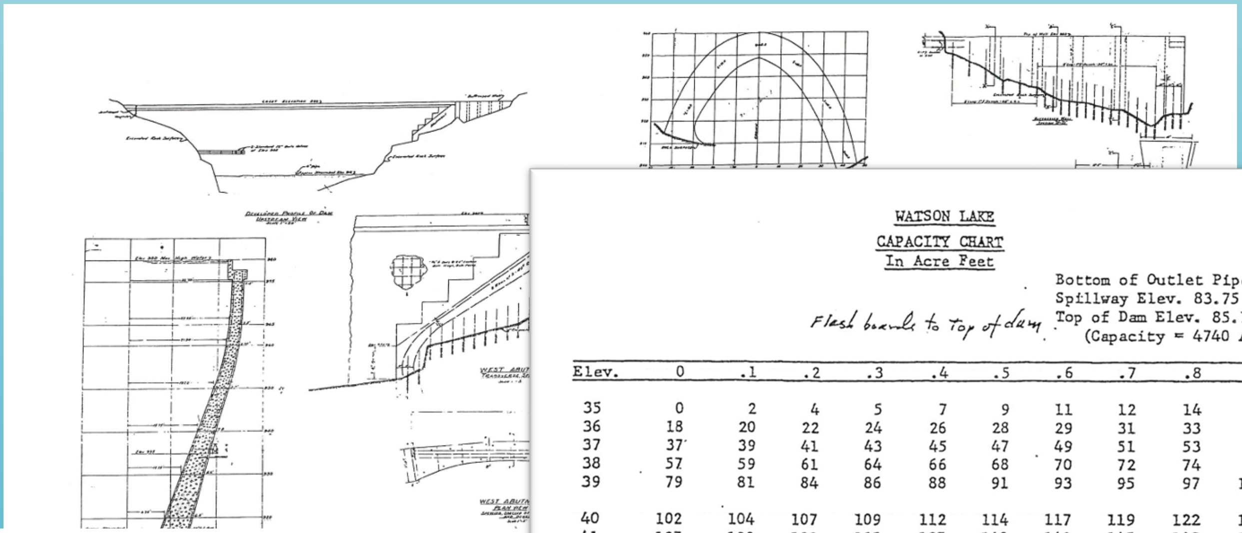


https://livingnewdeal.org/sites/willow-lake-prescott-az/#lg=1&slide=0

MIKE SHE incorporates:
- Measured inflows
- Dam details
- Operations
- Stage-storage-surface area curve

Calibration to:
- Measured stage
- Measured outflows

ological Consulting

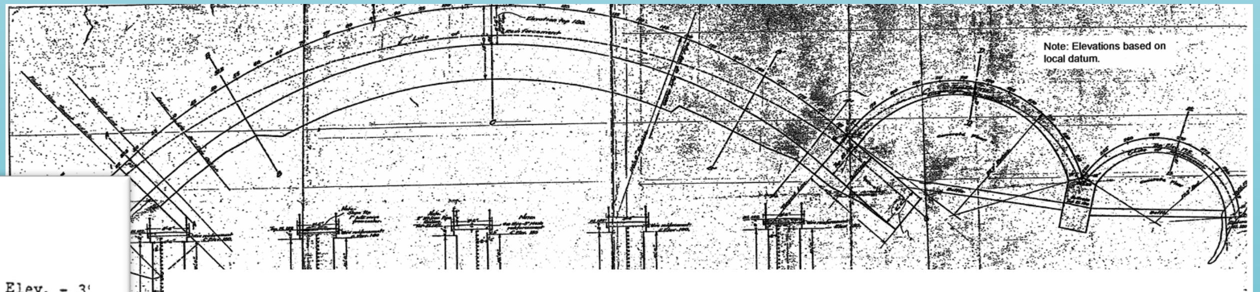


WATSON LAKE
CAPACITY CHART
In Acre Feet

Flash boards to Top of dam

Bottom of Outlet Pipe Elev. - 3
Spillway Elev. 83.75 - - 4324
Top of Dam Elev. 85.75 - 4740
(Capacity = 4740 Acre Feet)

Elev.	0	.1	.2	.3	.4	.5	.6	.7	.8	.9
35	0	2	4	5	7	9	11	12	14	16
36	18	20	22	24	26	28	29	31	33	35
37	37	39	41	43	45	47	49	51	53	55
38	57	59	61	64	66	68	70	72	74	77
39	79	81	84	86	88	91	93	95	97	100
40	102	104	107	109	112	114	117	119	122	124



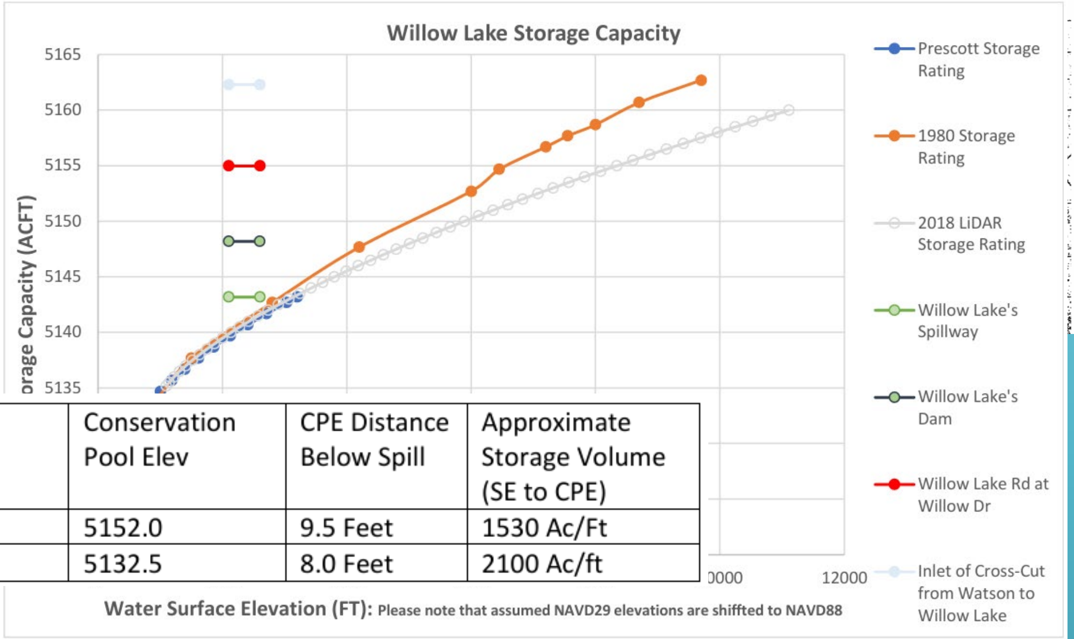


Figure 4 – Willow Lake storage capacity in relation to elevation

Lake	Spillway Elevations	Conservation Pool Elev	CPE Distance Below Spill	Approximate Storage Volume (SE to CPE)
Watson	5161.5	5152.0	9.5 Feet	1530 Ac/Ft
Willow	5140.5	5132.5	8.0 Feet	2100 Ac/ft

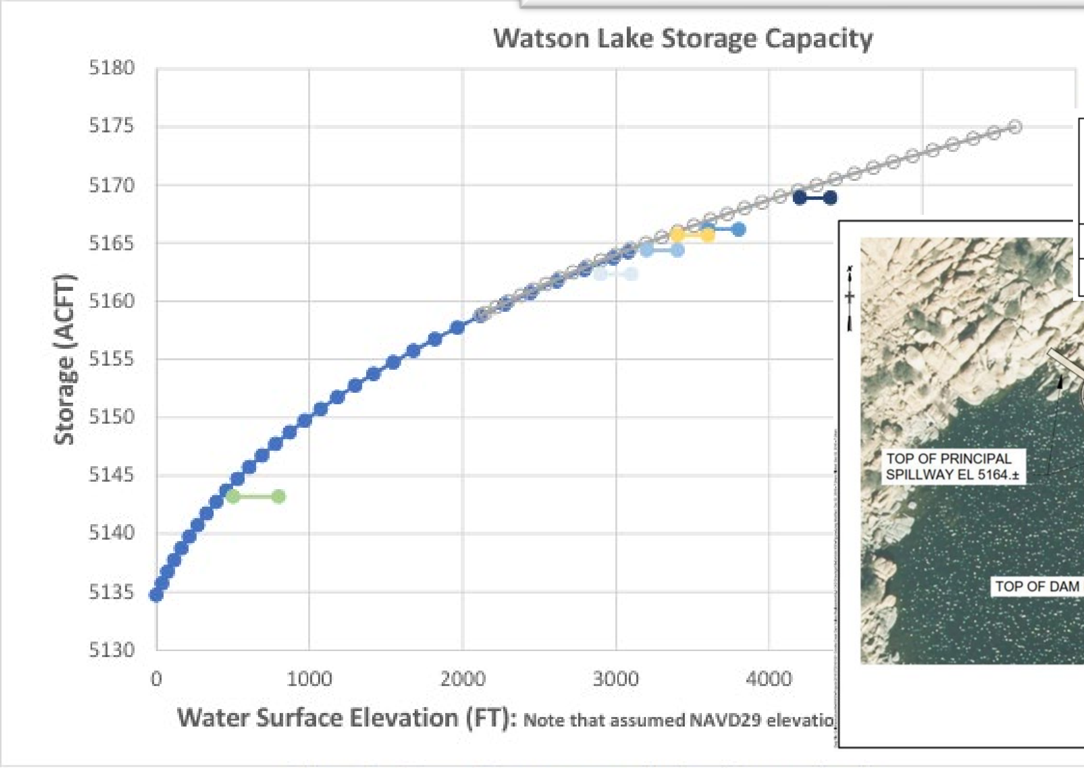
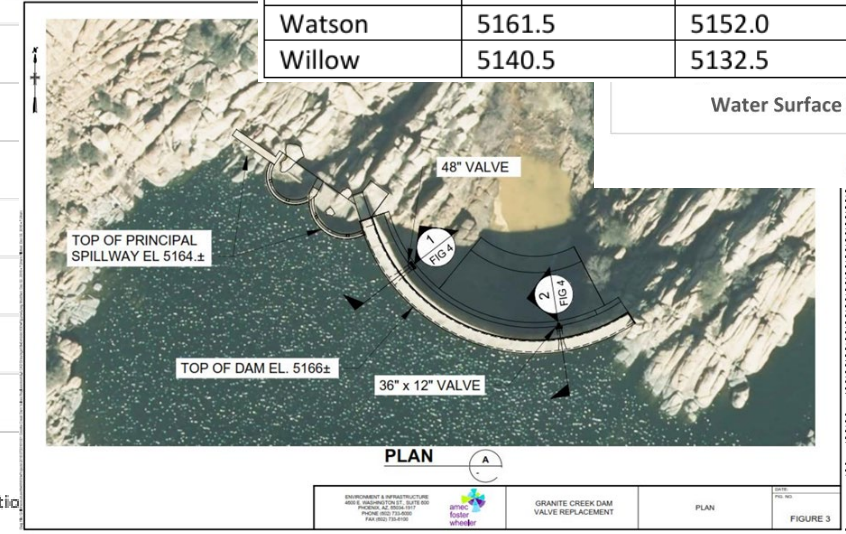


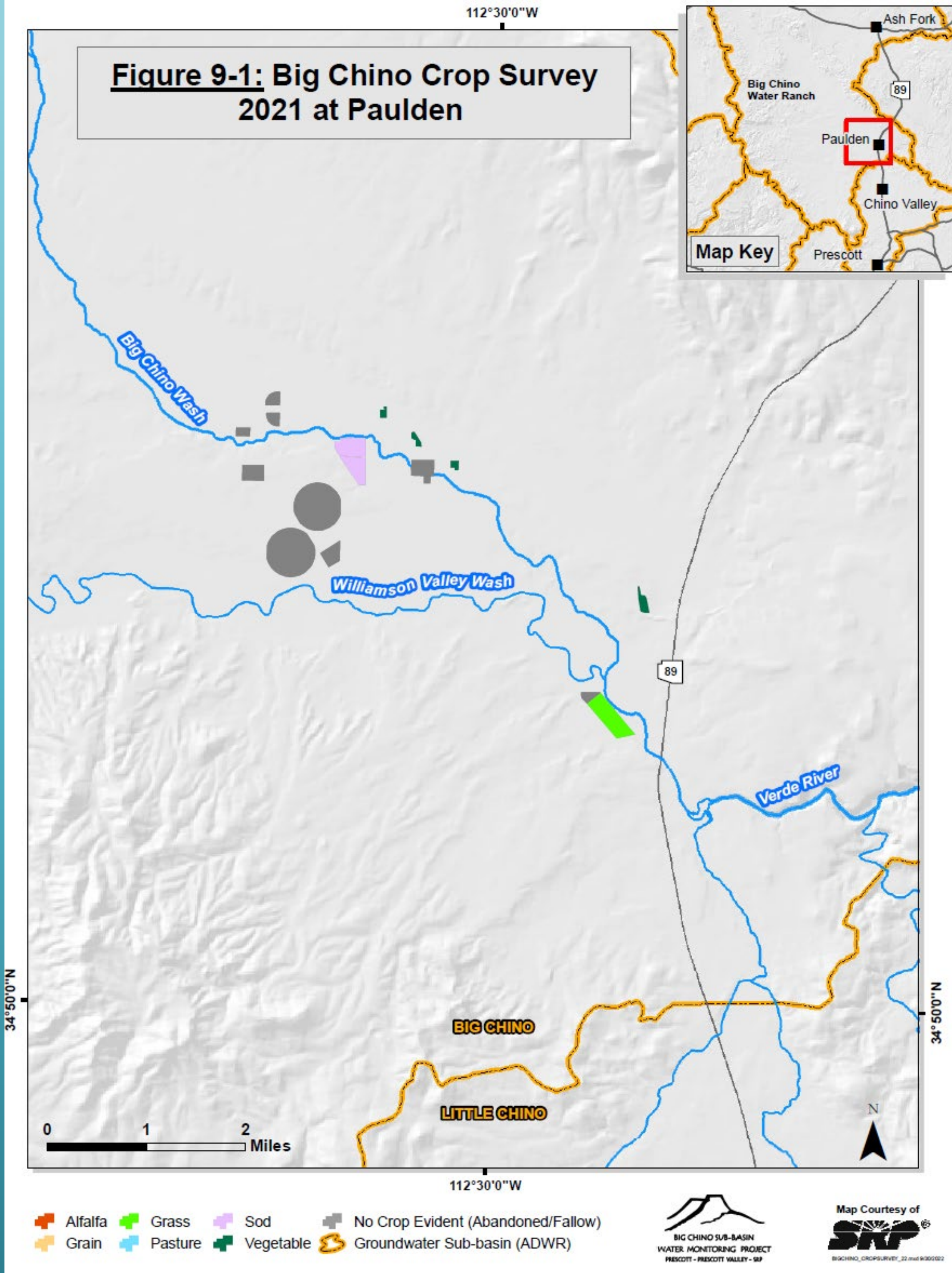
Figure 2 – Watson Lake storage capacity in relation to elevation



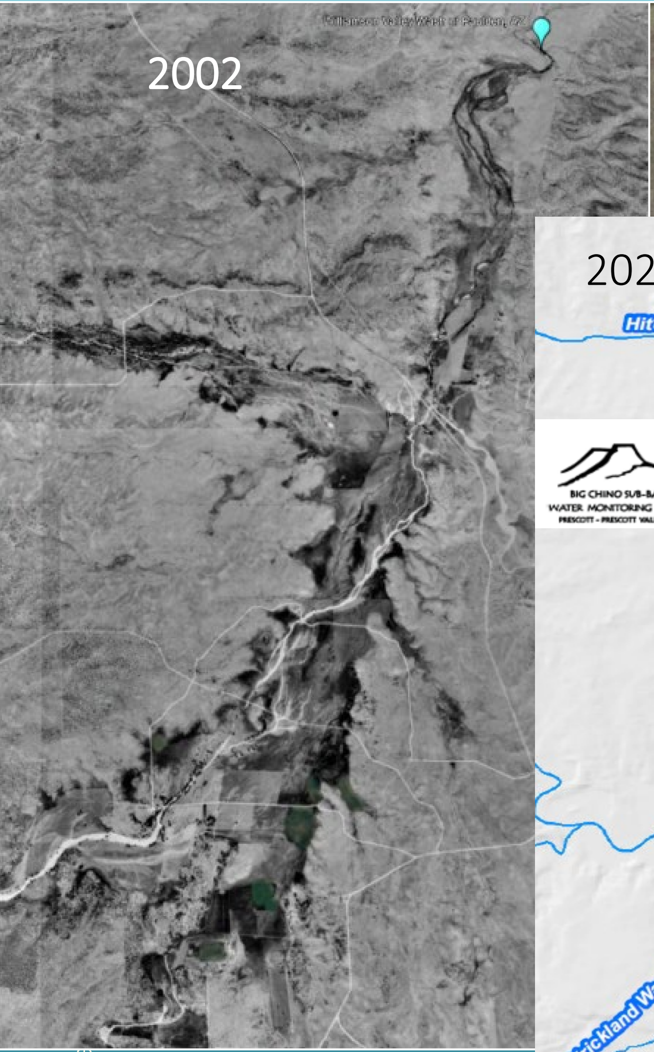
2002	0	0		In AR I have not found SW deliveries to USF
2003	362,346,312	1,112		
2004	294,243,453	903		
2005	526,901,067	1,617		
2006	77,878,389	239		
2007	0	0		Dry conditions -No SW was diverted of the lakes for recharge
2008	793,773,036	2,436		
2009	526,249,365	1,615		
2010	923,548,947	2,834		
2011	179,863,235	552		Surface water recharge pipeline replacement project.
2012	146,636,209	450		
2013	437,373,505	1,342		
2014	764,120,595	2,345	41.5	After Recreation Services Outdoor Festival, Ops moved large quantites (Oct - 579 AF, Nov 845 AF)
2015	974,884,280	2,992	55.3	Largest quantities moved April -July, backed off thereafter
2016	128,150,000	1,085	12.15	Recharge slowed in the summer due to reservoirs at or nearing their conservation pool. Late Oct/early Nov recharge resumed.
2017	1,351,629,948	4,148	77.8	SRP contacted the City on 2/16/17 to commence recharge in accordance with Stipulated Judgement, and again on 3/20/17 to continue to recharge to March 31, 2017. In early April the City had recharged approx. 1,150 AF.
2000-2015 avg		1,251		
2000-2016 avg		1,241		
2000-2017 avg		1,403		

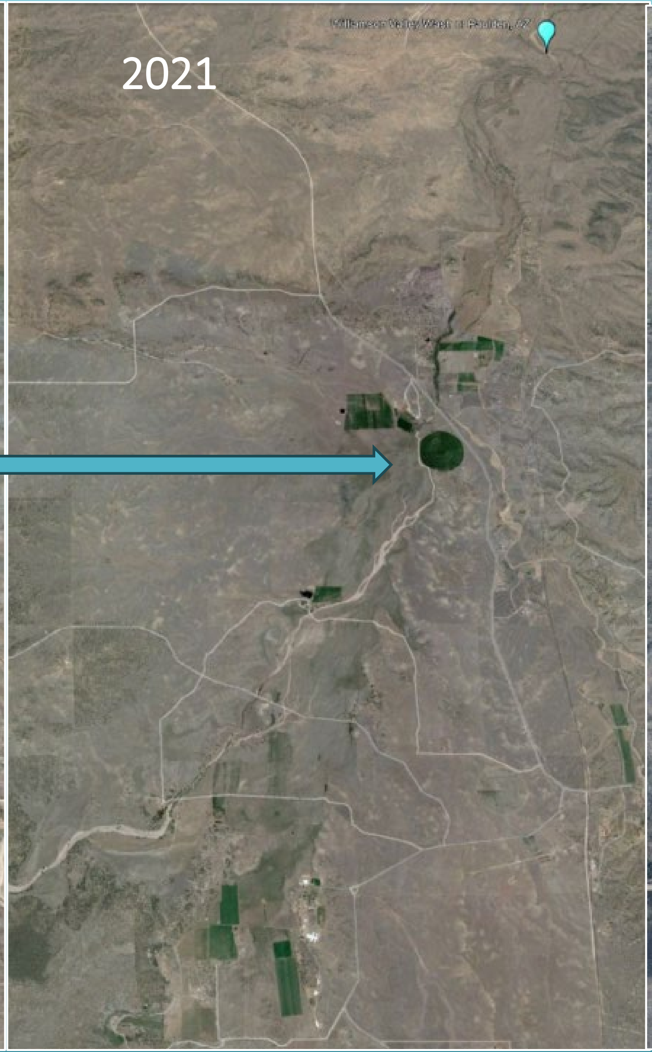
Big Chino Irrigation

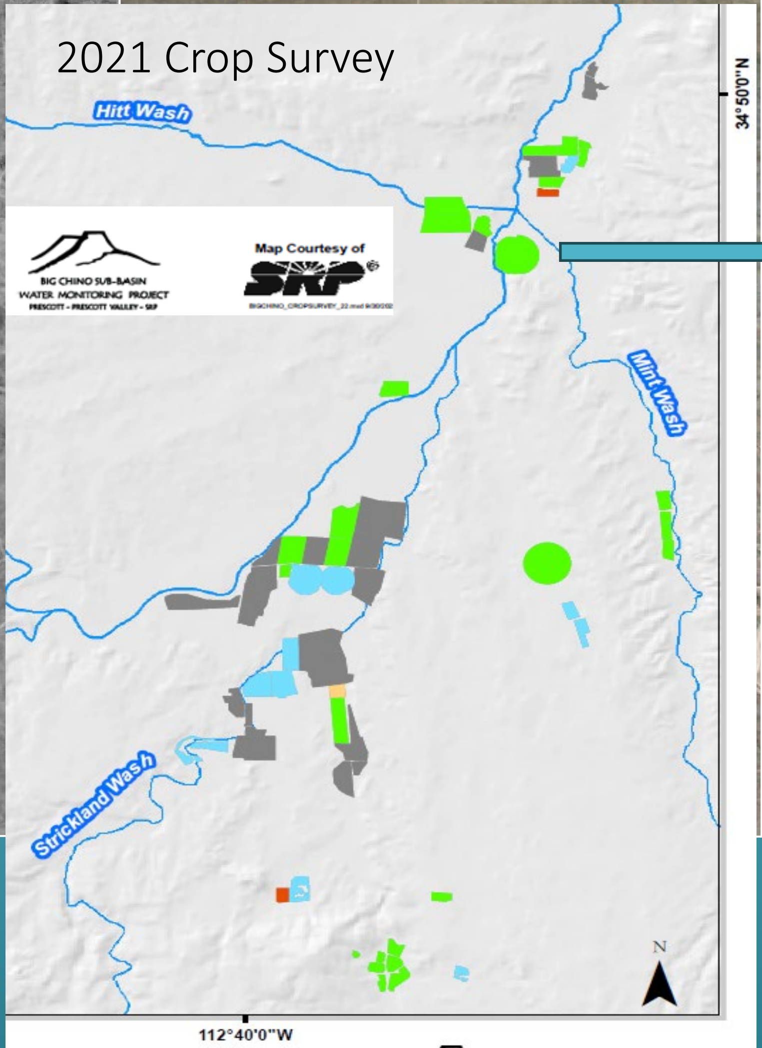
- ➢2021 Crop Surveys by SRP's Big Chino Sub-basin Water Monitoring Project
- ➢Groundwater-based
- ➢Time-varying imagery
- ➢Hourly weather data
- ➢Simulated soil moisture
- ➢Simulated crop water demand



Williamson Valley Irrigation







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MIKE SHE CROP IRRIGATION

1. Crop command area defined for unique crop type and irrigation water source

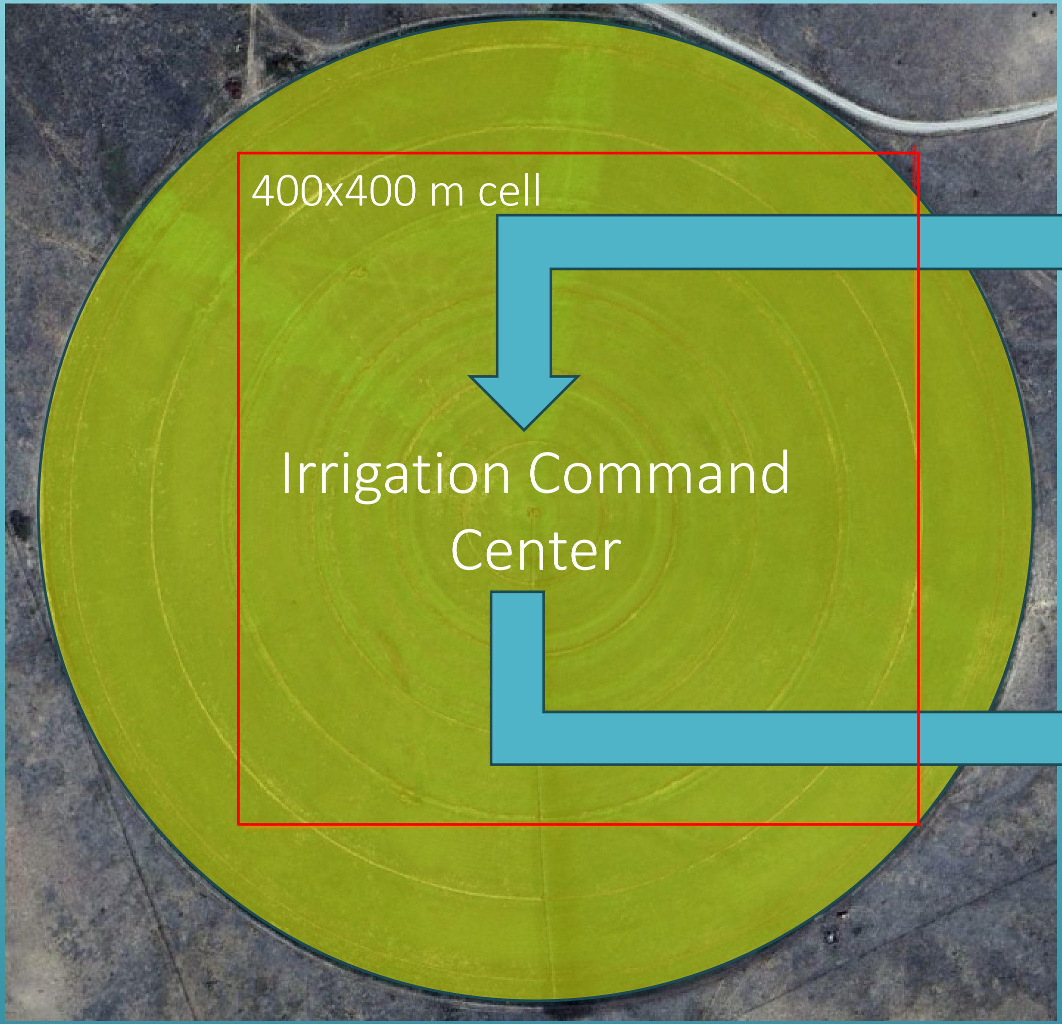
2. Crop parameters (eg, crop type, rooting depth, crop coefficient, crop stress factor)

3. Water source (eg, stream, ditch, groundwater)

4. Hourly weather ($T_{air,}$ Precip, ReferenceET) from NLDAS combined with crop parameters and simulated soil moisture determines **crop stress**

CROP STRESS (%RefET) –> Triggers WATER APPLIED TO SATISFY CROP DEMAND (Q_{irrig})

MIKE SHE Groundwater Irrigation Example



Site-specific pumping despite lack of reported pumping data

Q_{irrig}

Crop Water Demand

Irrigation well specs from ADWR Database

Aquifer assigned based on well depth and model layers

Lacher Hydrological Consulting

Integrated Hydro Systems, LLC

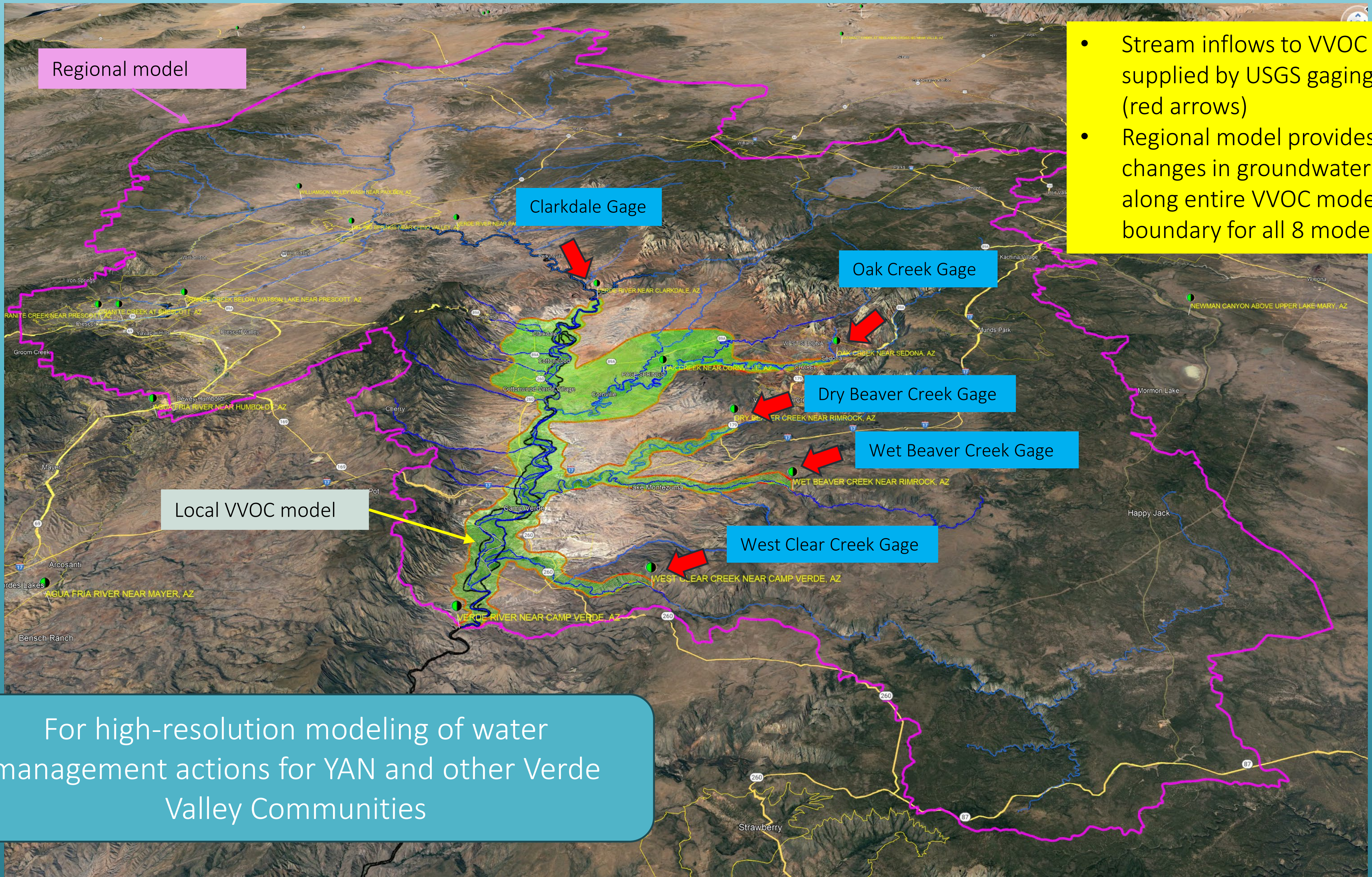
Verde Valley MIKE SHE

High-resolution (100-m grid) and directly compatible with new Regional MIKE SHE

Lacher Hydrological Consulting

Integrated Hydro Systems, LLC

Verde Regional and Verde Valley-Oak Creek MIKE SHE models



- Stream inflows to VVOC model supplied by USGS gaging stations (red arrows)
- Regional model provides daily changes in groundwater level along entire VVOC model boundary for all 8 model layers.

For high-resolution modeling of water management actions for YAN and other Verde Valley Communities

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Integrated Hydro Systems, LLC

Local 3D Lithologic Model

(Verde Valley Area)

8 Layers:

Quaternary/Tertiary:

1. *Alluvium plus Upper Verde*
2. *Middle Verde*
3. *Lower Verde*

4. Tertiary Volcanics/Basalt

5. Permian Coconino Sandstone

6. Pennsylvanian-Permian (Supai/Hermit)

7. Mississippian Redwall Formation

8. Devonian Martin-Cambrian.

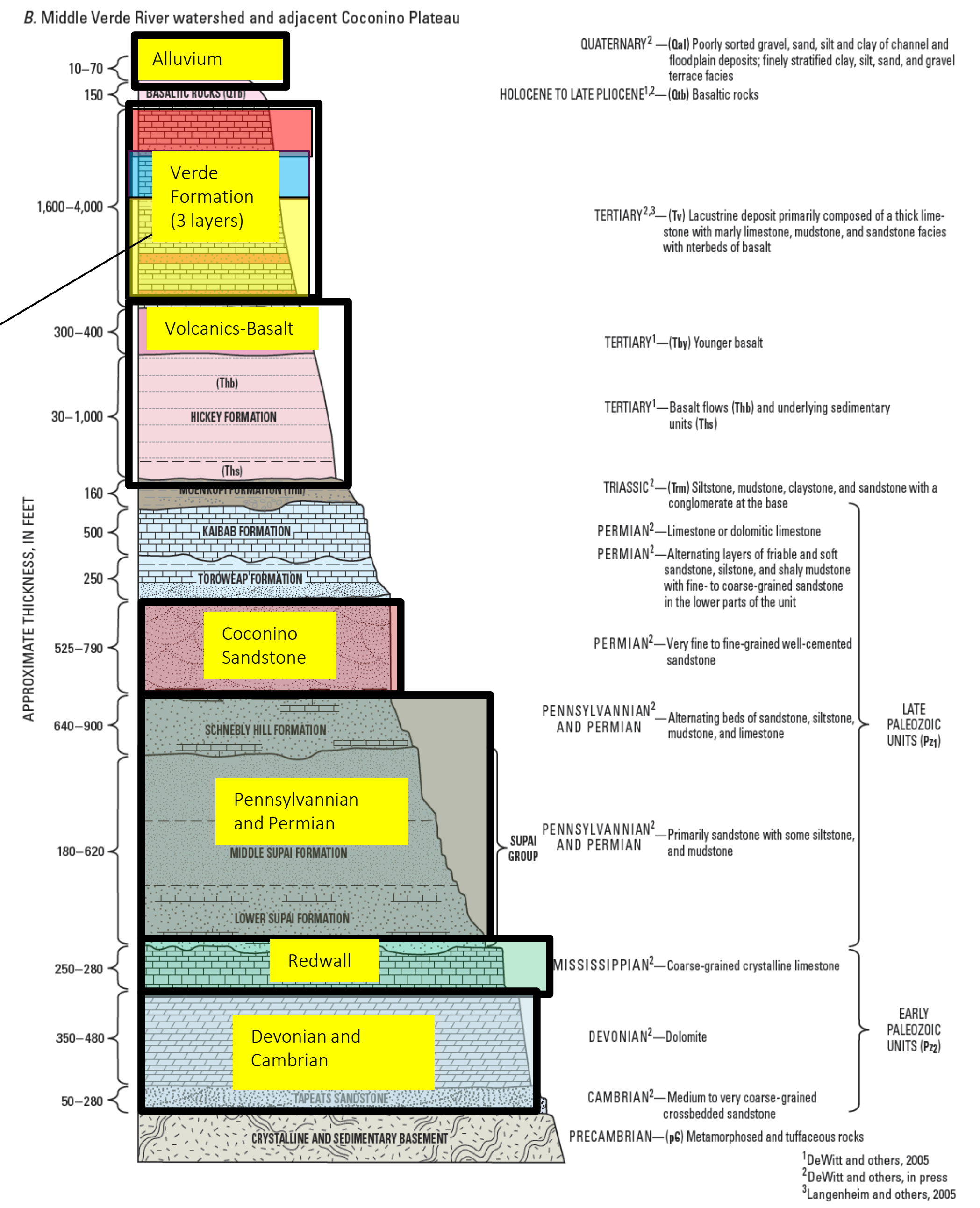

Figure 17. Continued.

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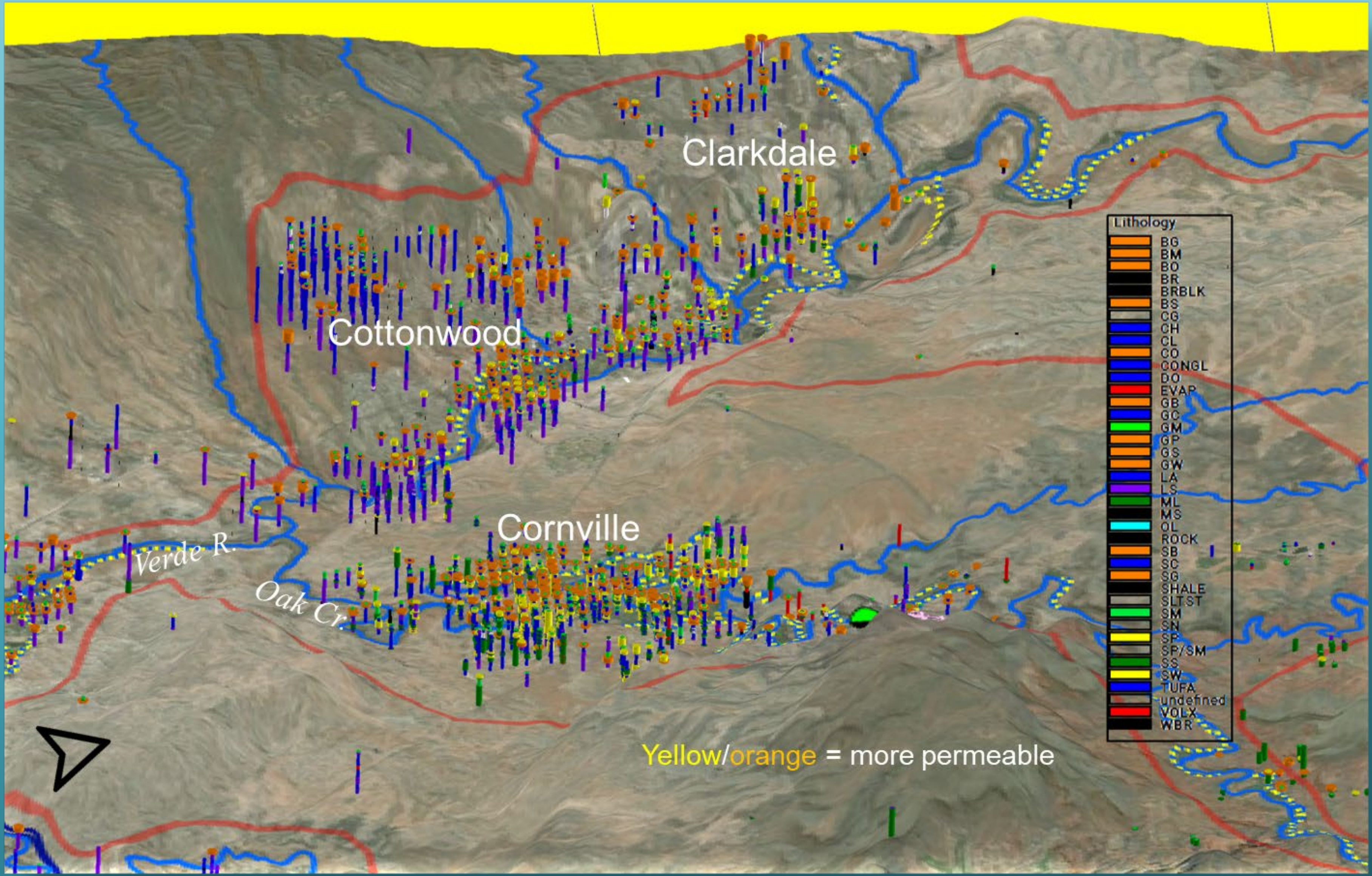
Thousands of Wells Studied in Verde Valley



Most pump From **Verde Formation**

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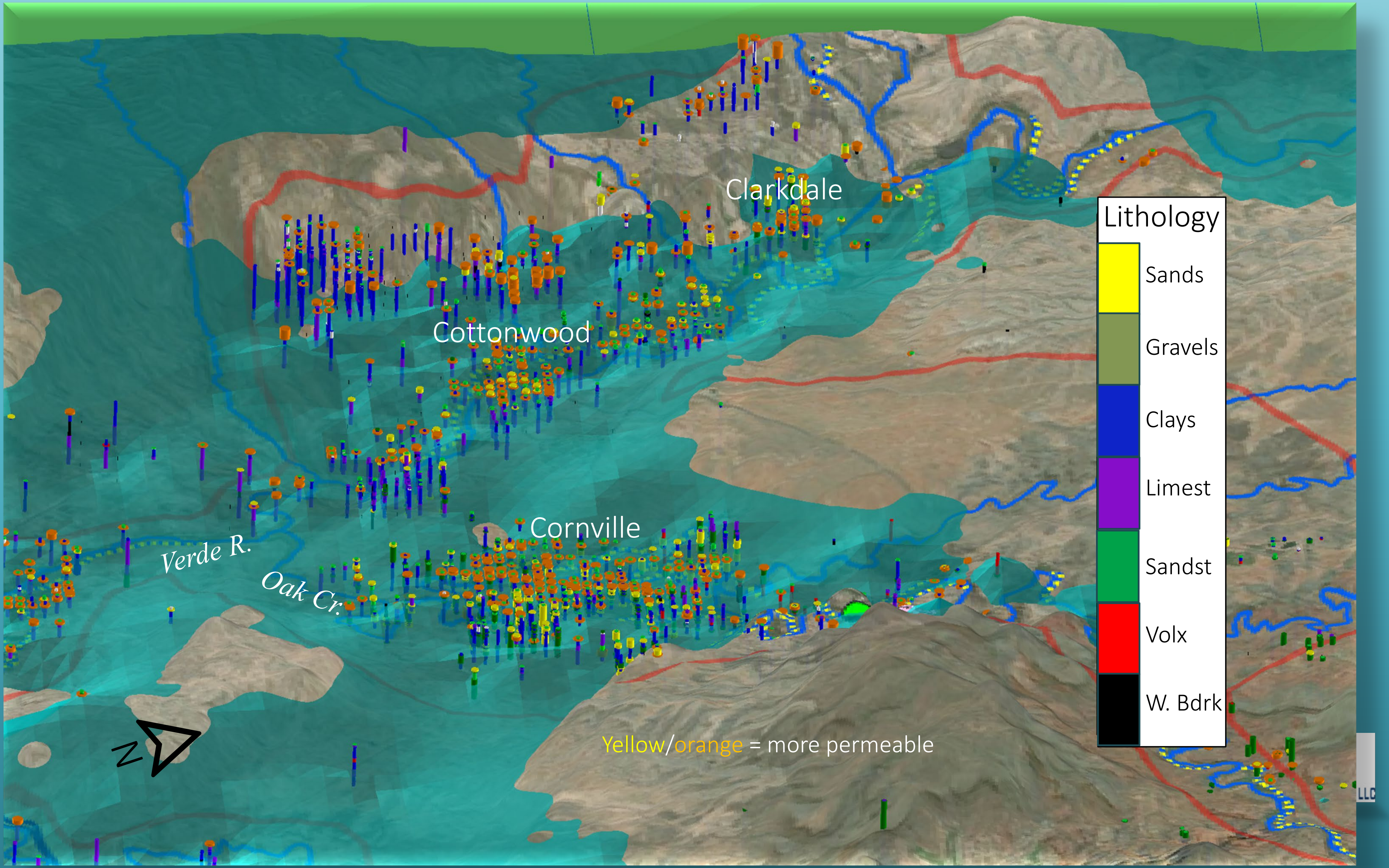
Borehole Lithology and Groundwater Table – Upper Model Area

Mostly unsaturated below uppermost thin permeable units



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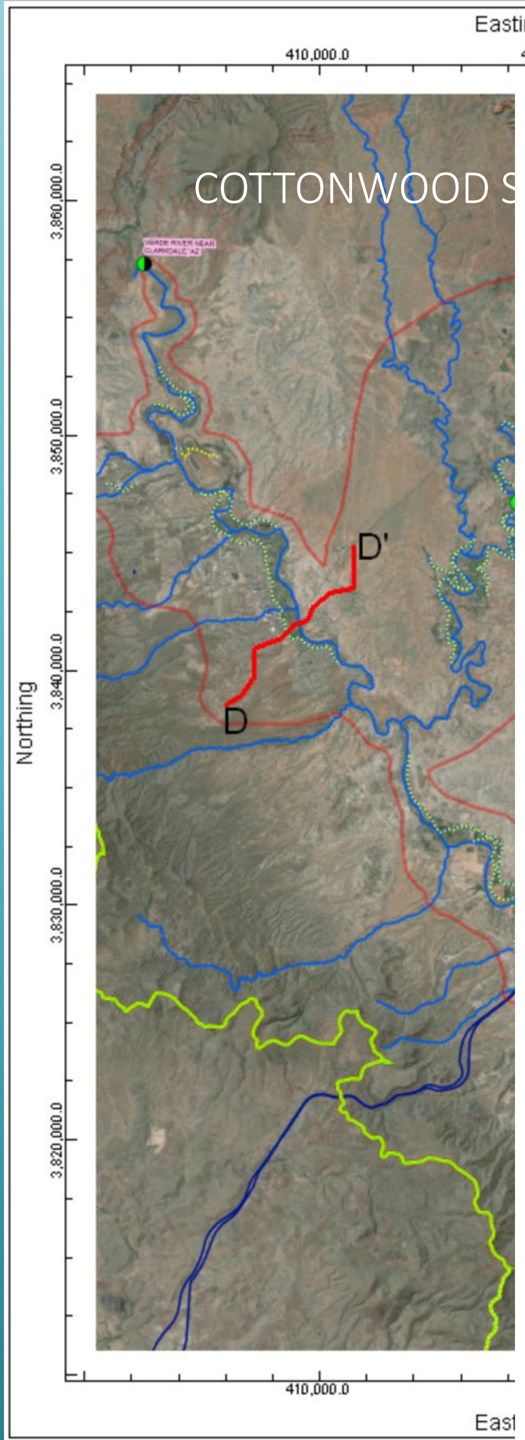

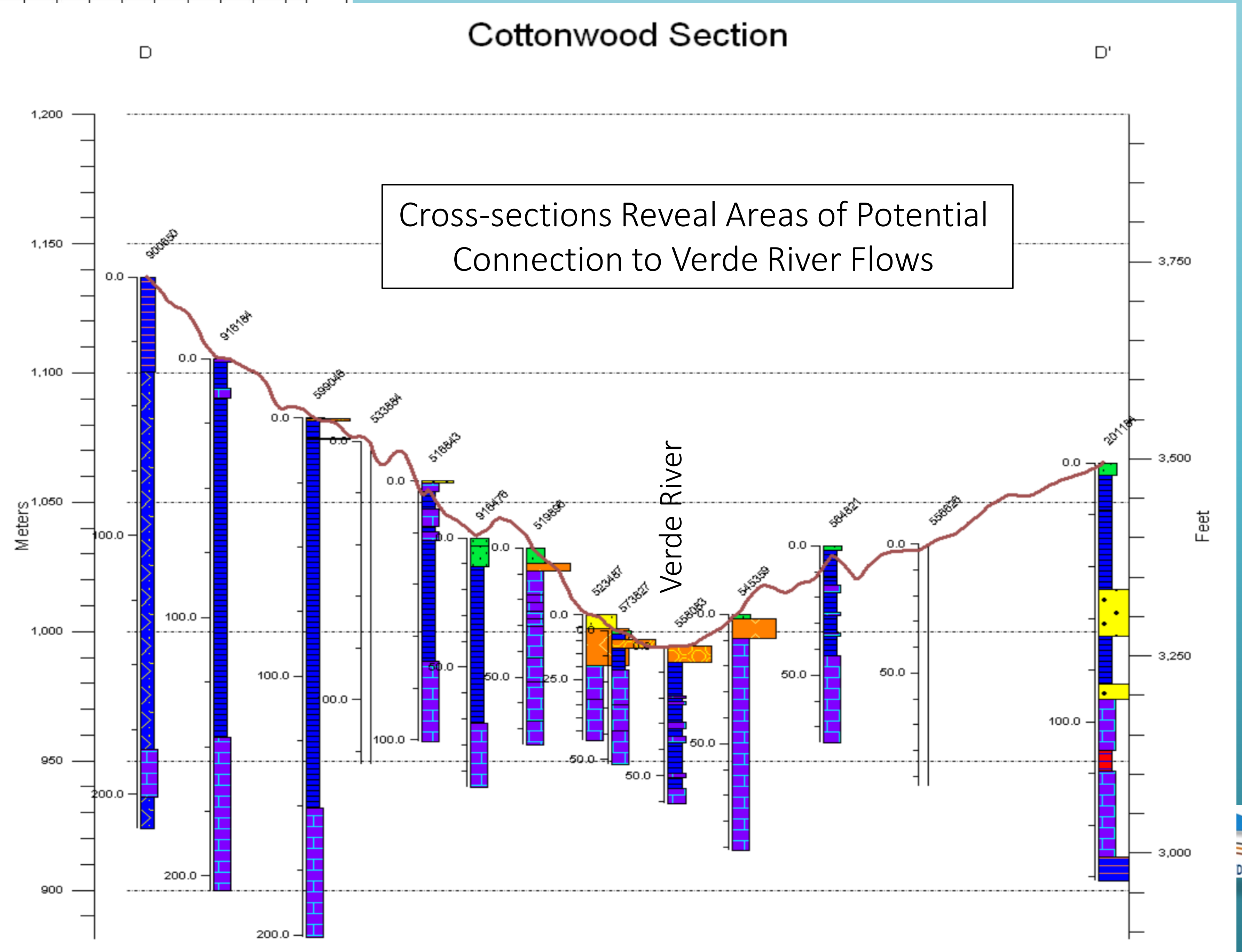

Cross-sections Reveal Areas of Potential Connection to Verde River Flows

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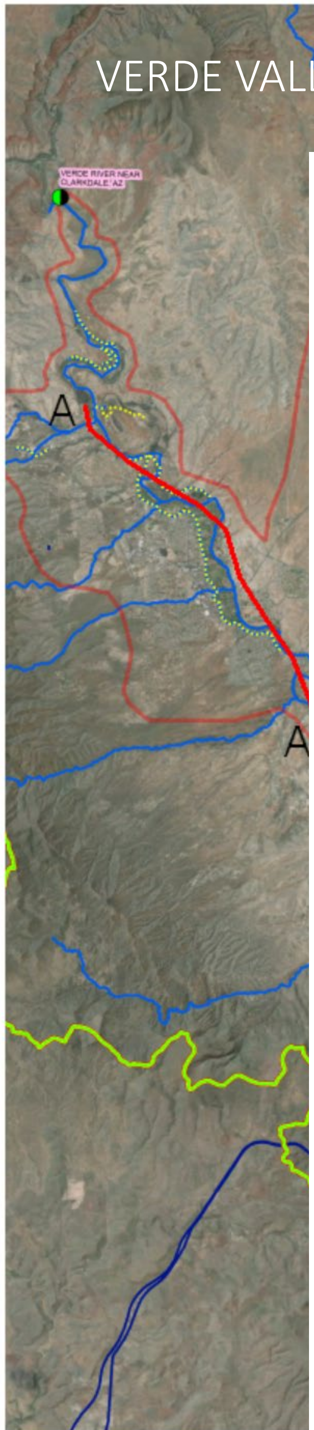
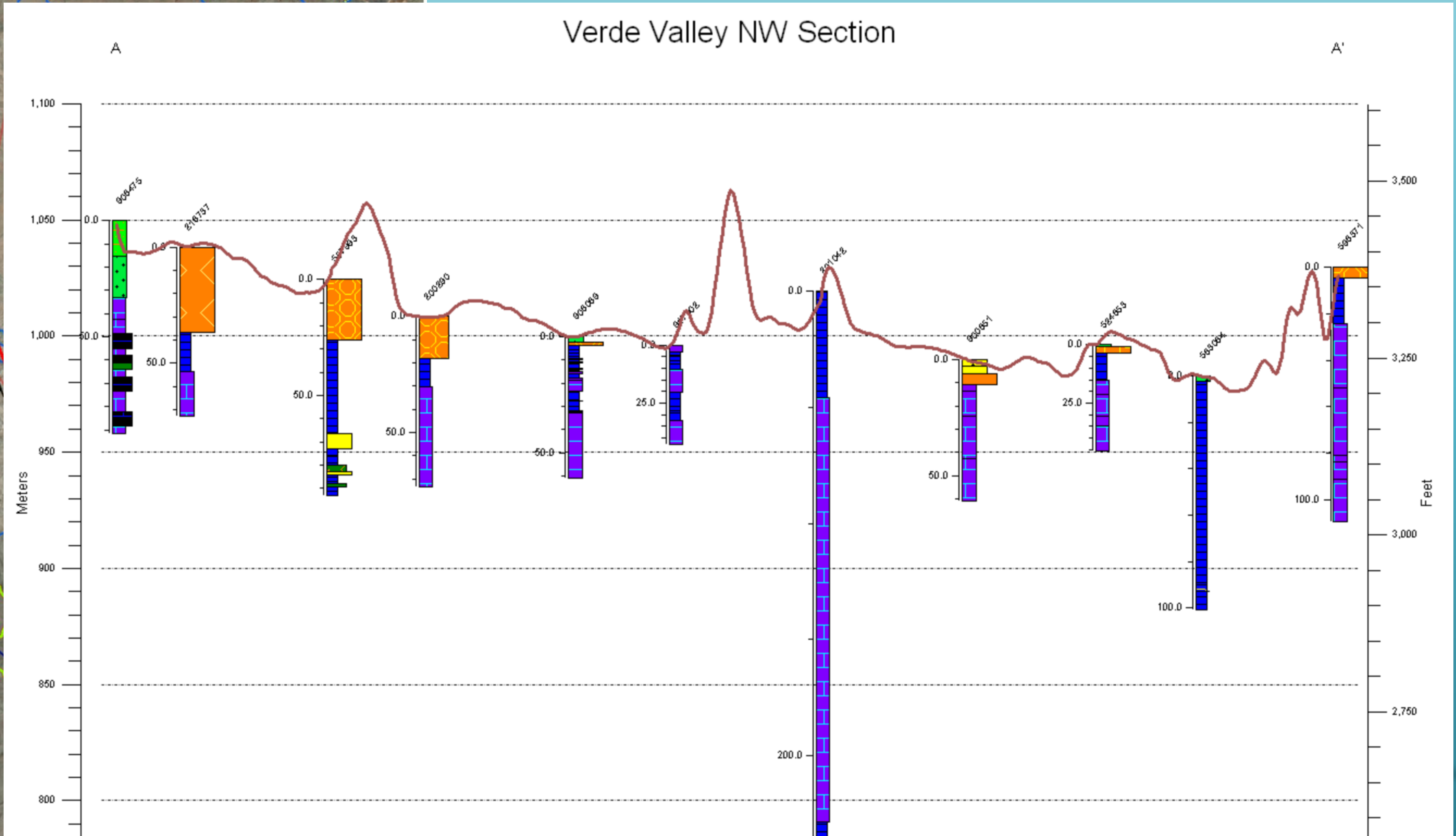
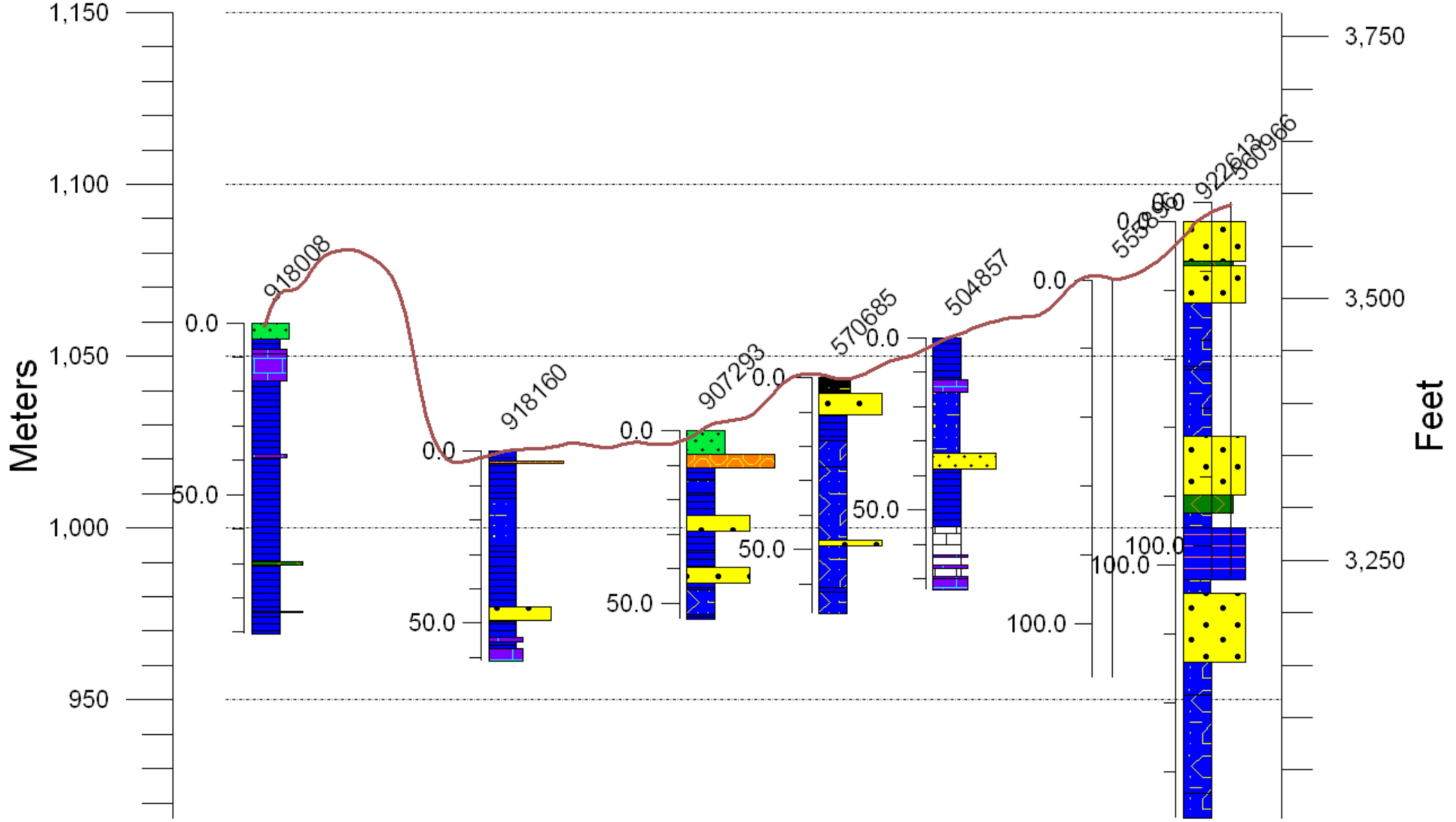
VERDE VALLEY NW SECTION

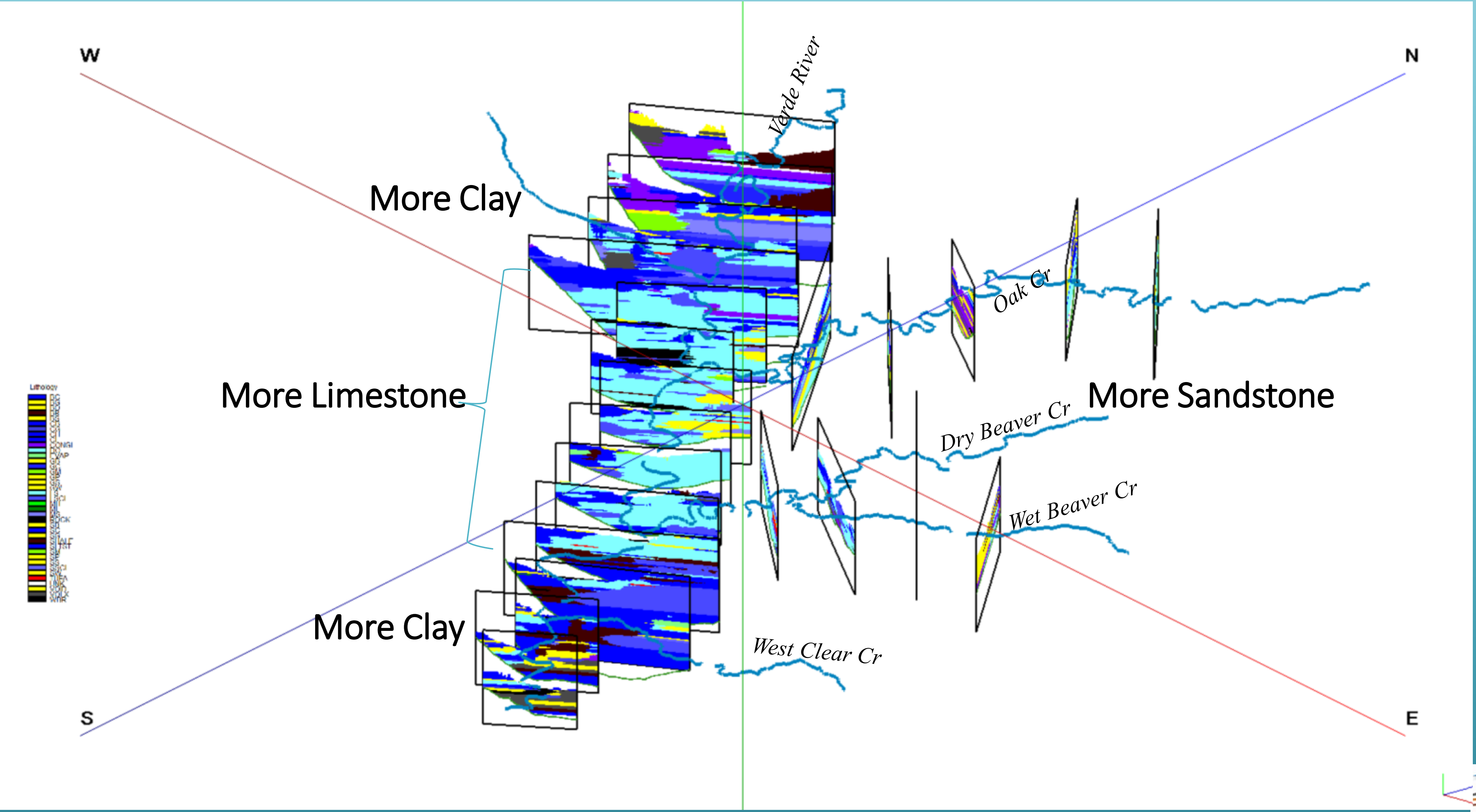




Oak Creek Section



Lithologic Trends Across Verde Valley



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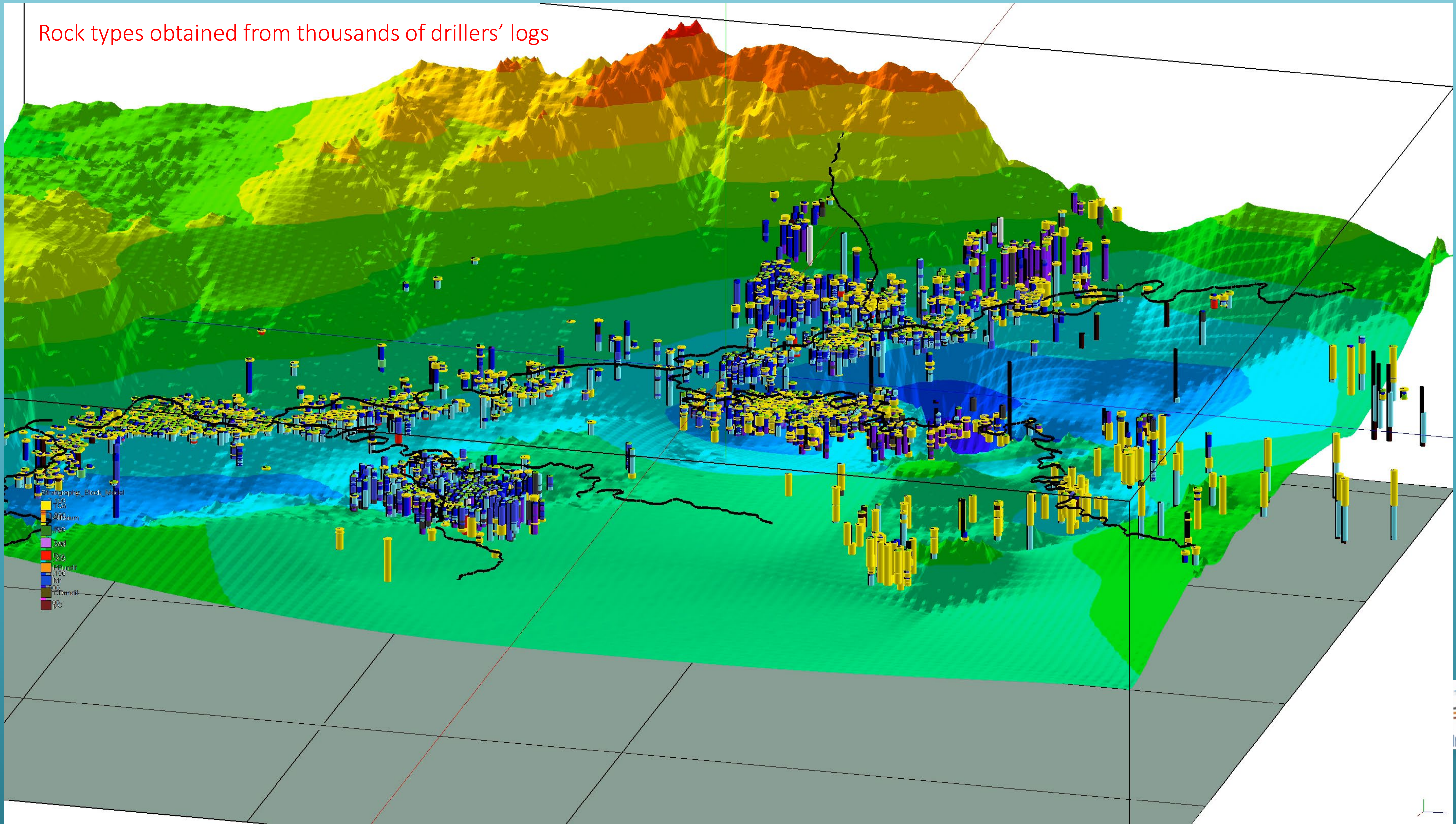
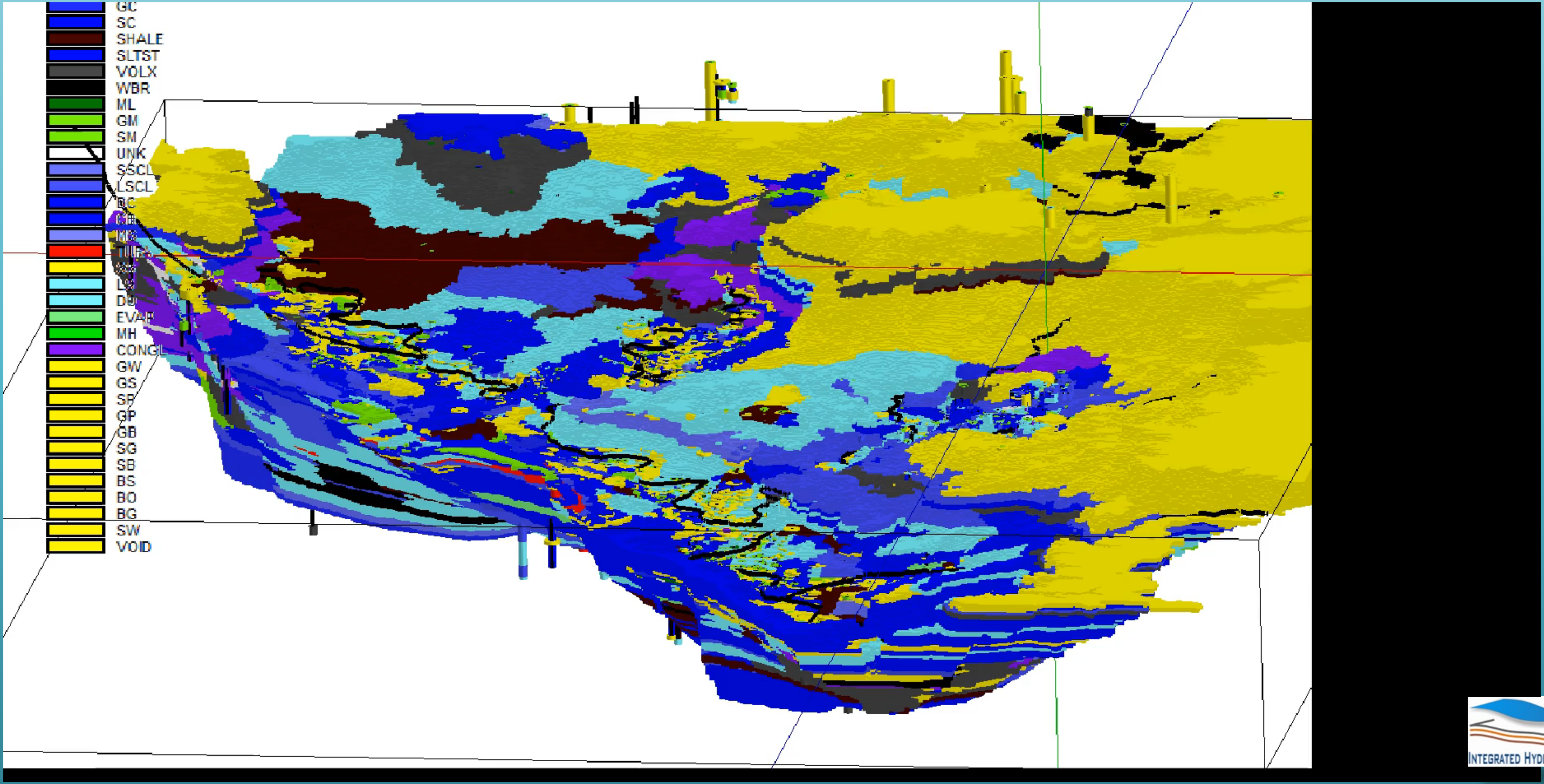
3D Lithologic Model with Bedrock Surface and Logs



BOREHOLE LOGS INTERPOLATED TO 3D SURFACES



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MIKE SHE Model Applications

- Water Management Alternatives Analysis
  - Irrigation improvements
  - Flood-control projects
  - Recharge projects
- Water Supply Studies
  - Water budgets
  - Future demand analysis
  - Groundwater sustainability (AWS)
- Water Resources Development Planning
  - Avoiding well interference
  - Mitigating impacts to streams, springs, and rivers
  - Impacts of increased impervious area with development
- Future Climate Effects
  - Soil-moisture deficits/increase crop demand
  - Effects of changing snow pack (amount, timing, duration)
  - Changing flood regime

In closing….
The Verde Basin and Verde Valley-Oak Creek MIKE SHE Models:

- Permit analysis of human-caused and natural changes to Verde Basin hydrologic system
- Shared and open development process invites parties to contribute and share in use
- Underlying geologic models may be useful for other models.

Thank you!

LLacher1@msn.com