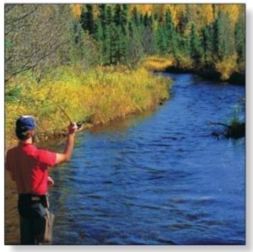
IDAHO Department of Water Resources

Groundwater Modeling

Allan Wylie, IDWR

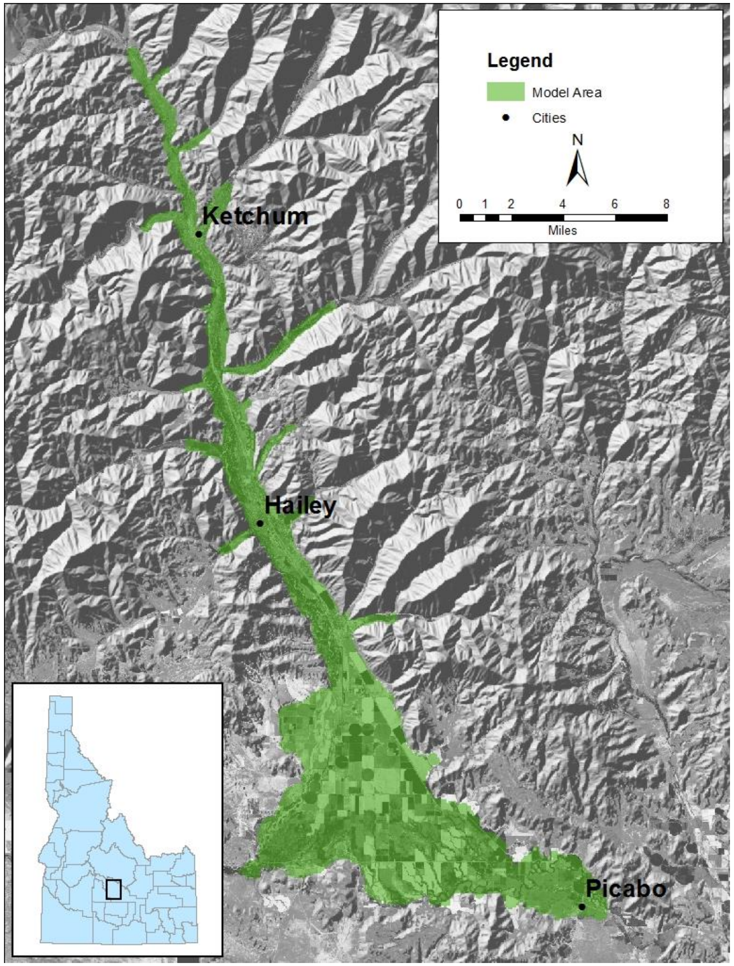
Date



Outline

- Groundwater model
  - Data
    - Geology
    - Hydrology
    - Water use
- Parameter optimization
- Collaborative Modeling

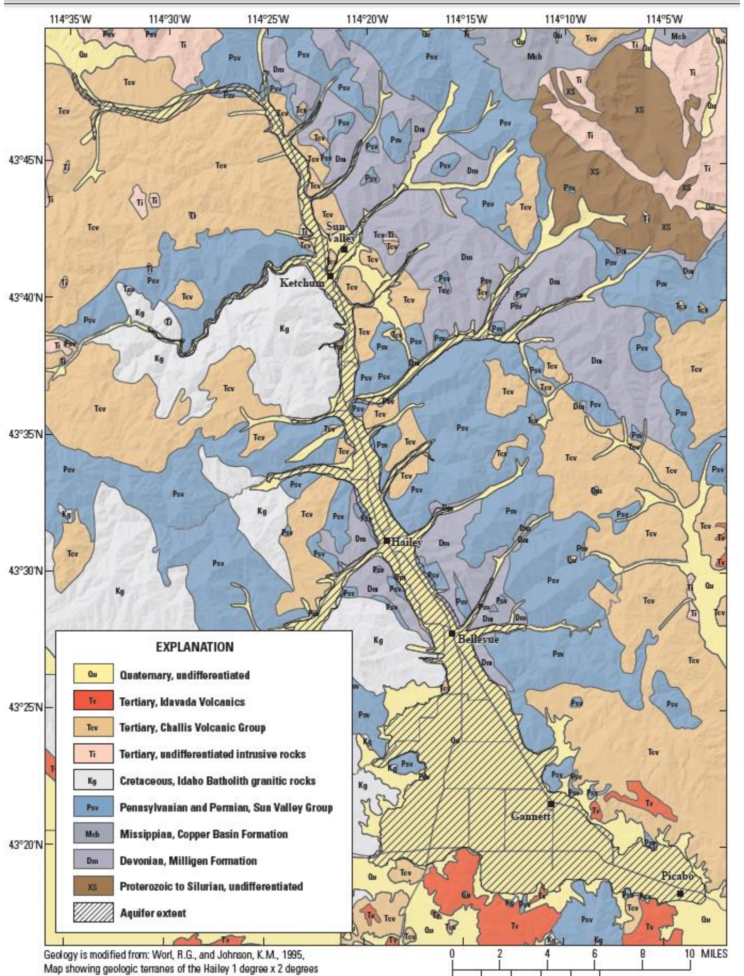
Groundwater Model



- Computer program
- Solves equation for groundwater flow
- IDWR uses MODFLOW
  - USGS
  - Transparency
  - Widely used

Geologic Data

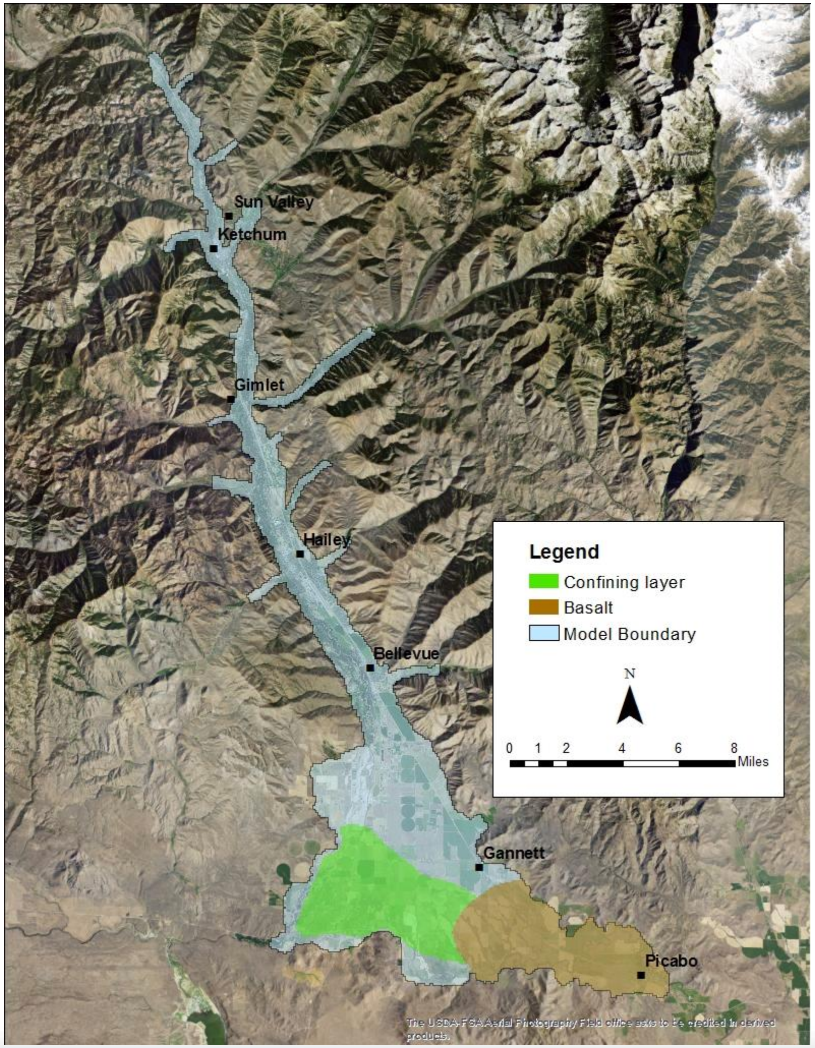
- Determine what is and is not in the model



Geology is modified from: Worl, R.G., and Johnson, K.M., 1995, Map showing geologic terranes of the Hailey 1 degree x 2 degrees quadrangle and the western part of the Idaho Falls 1 degree x 2 degrees quadrangle, south-central Idaho: U.S. Geological Survey Bulletin 2064-A, 1 Plate, scale 1:250,000. Available online at

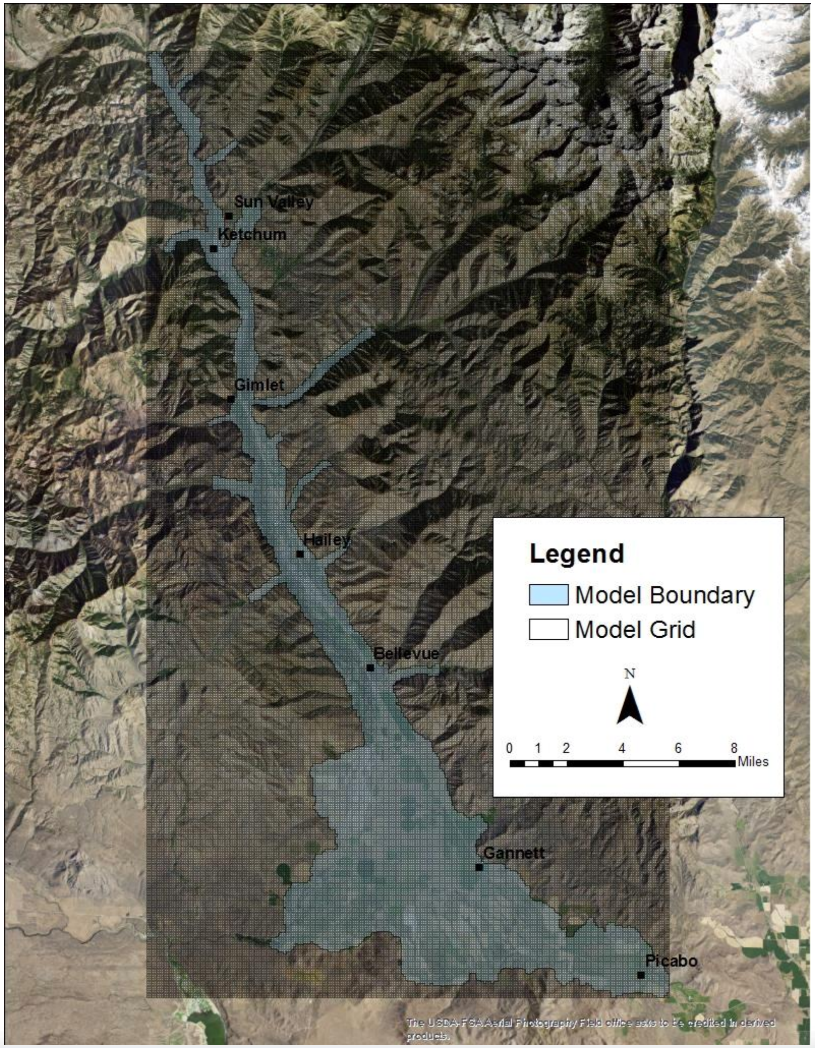
Geologic Data

- Develop model boundaries



Geologic Data

- Overlay model grid

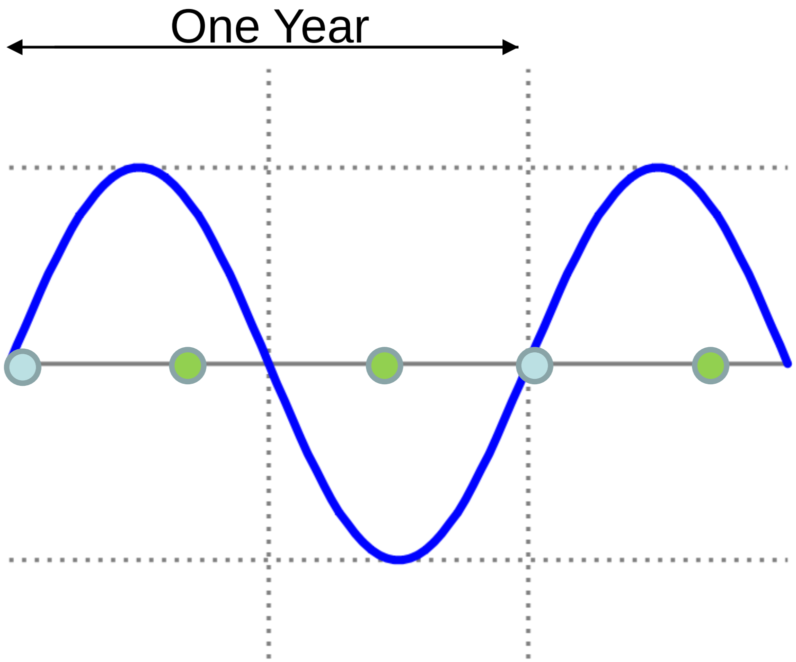


Hydrologic Data

- Historic data
  - Water level in wells
  - Stream gages
  - Water use

Time series analysis

- Collect time series data to monitor a trend
- What is the shape of the underlying trend
  - Regional trend
    - At least once a year
  - Annual cycle
    - At least 3 times a year



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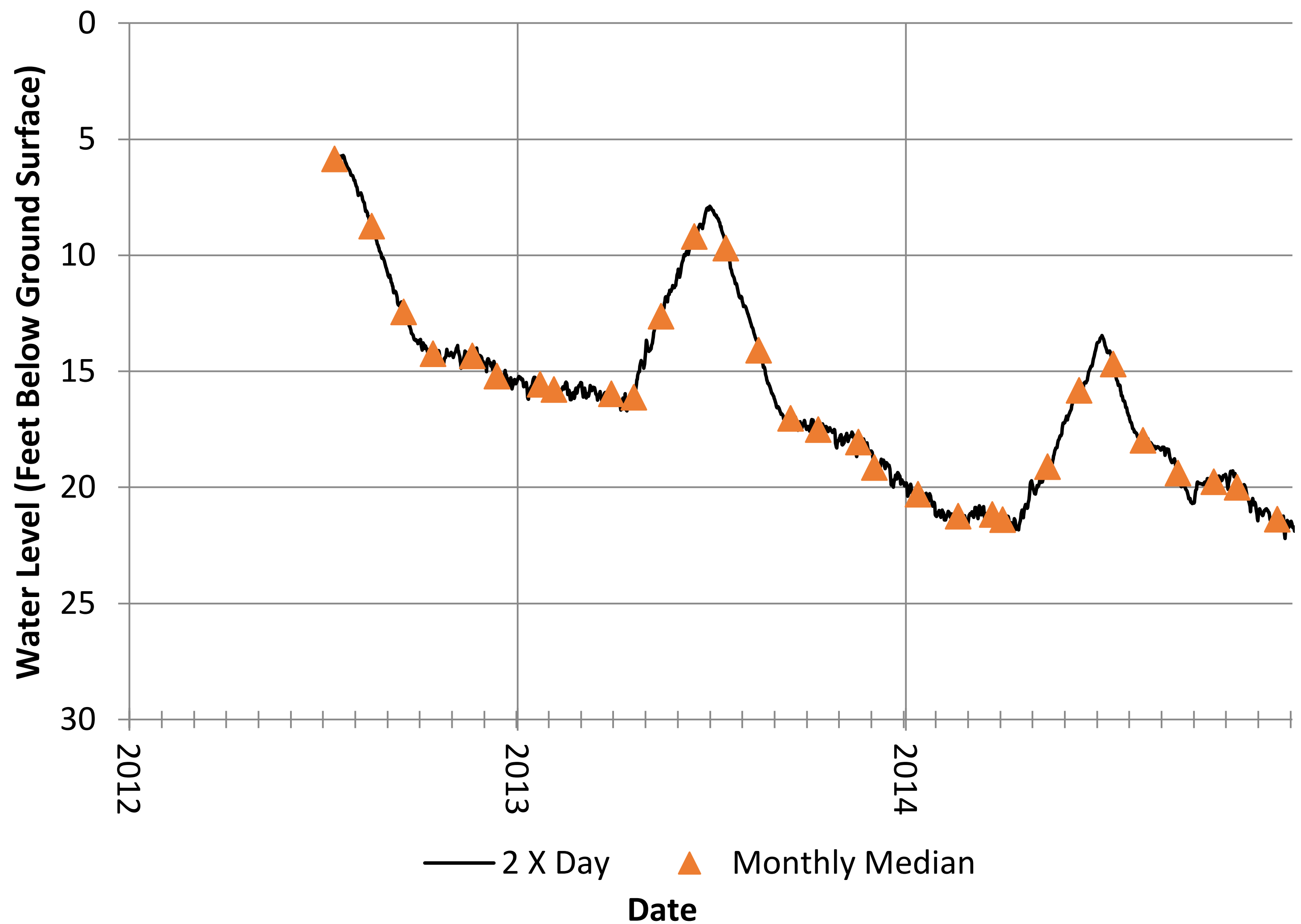

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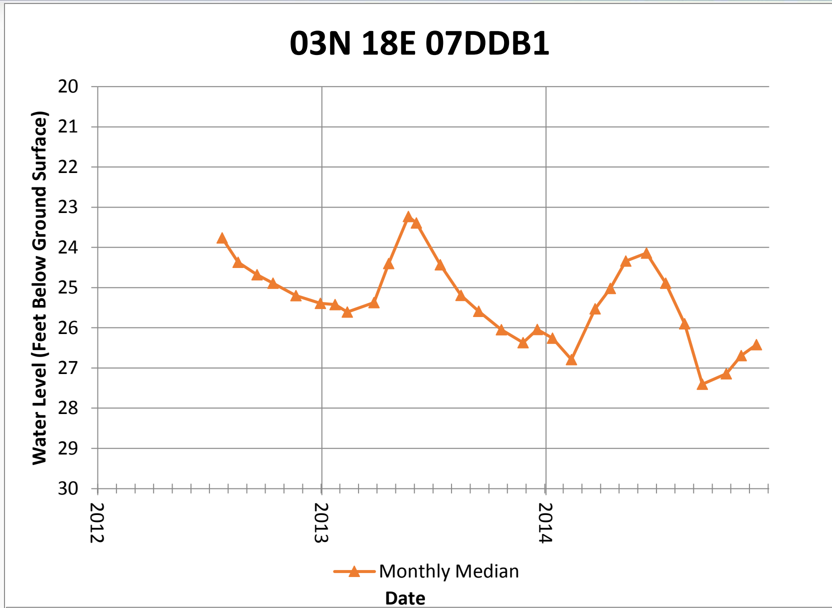

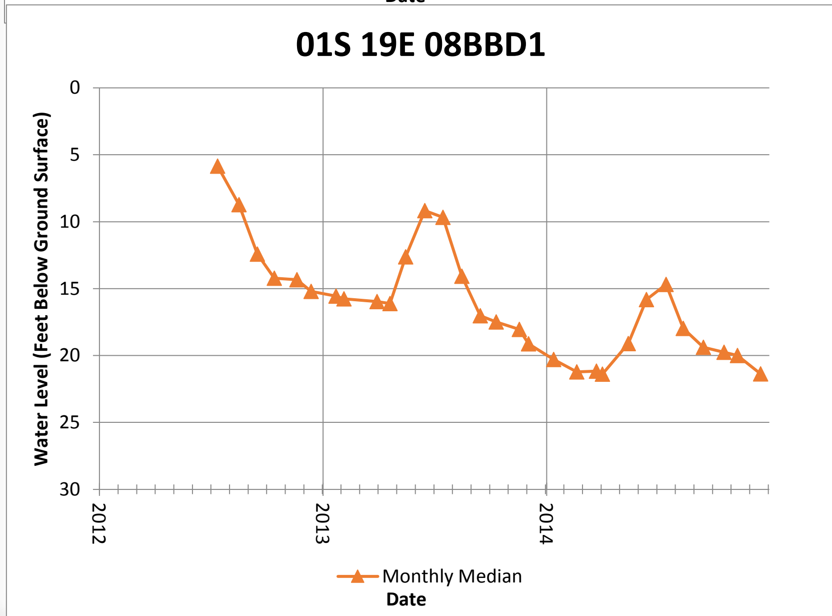

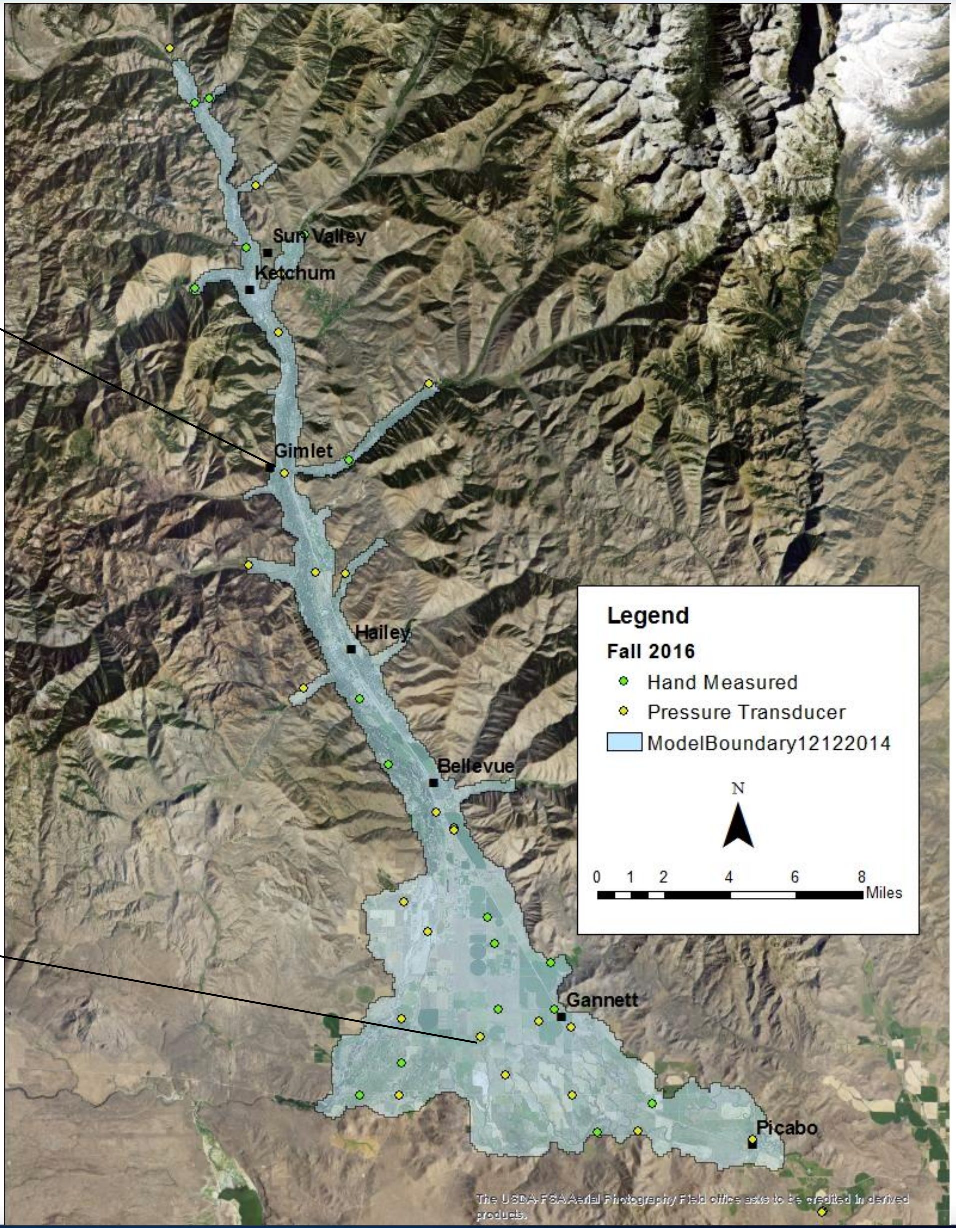

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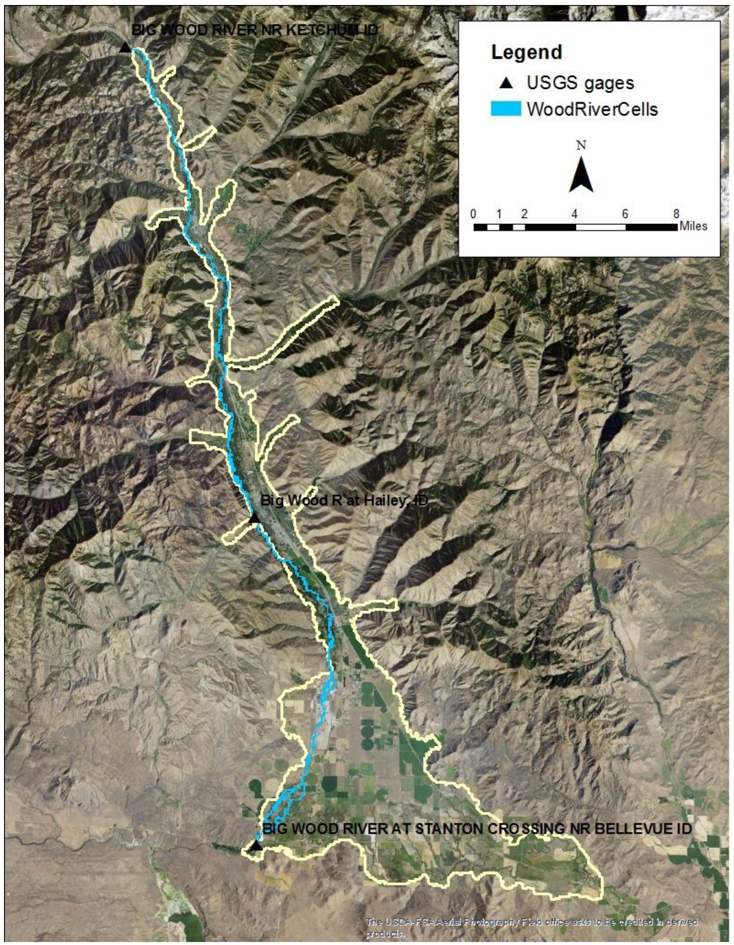
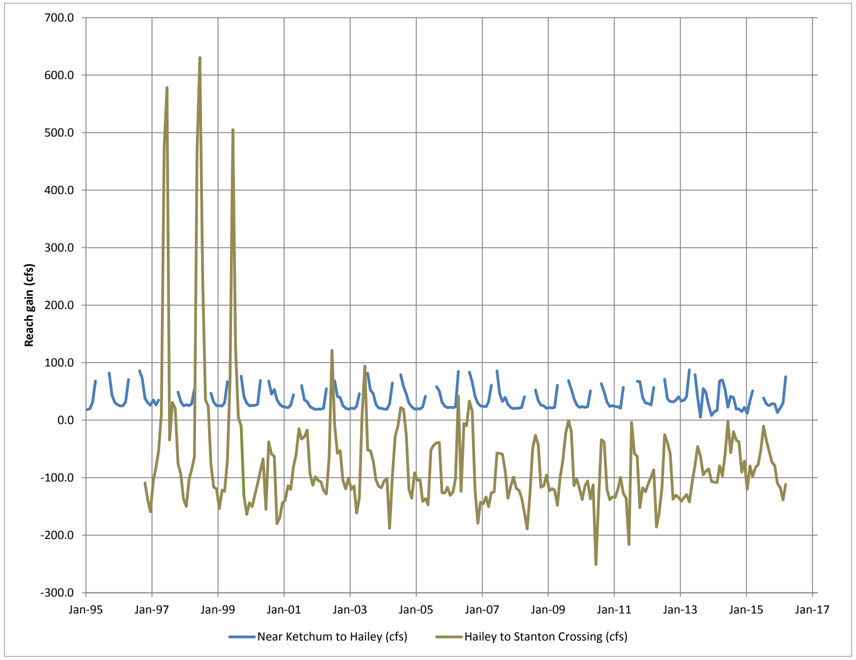
Stream Gages



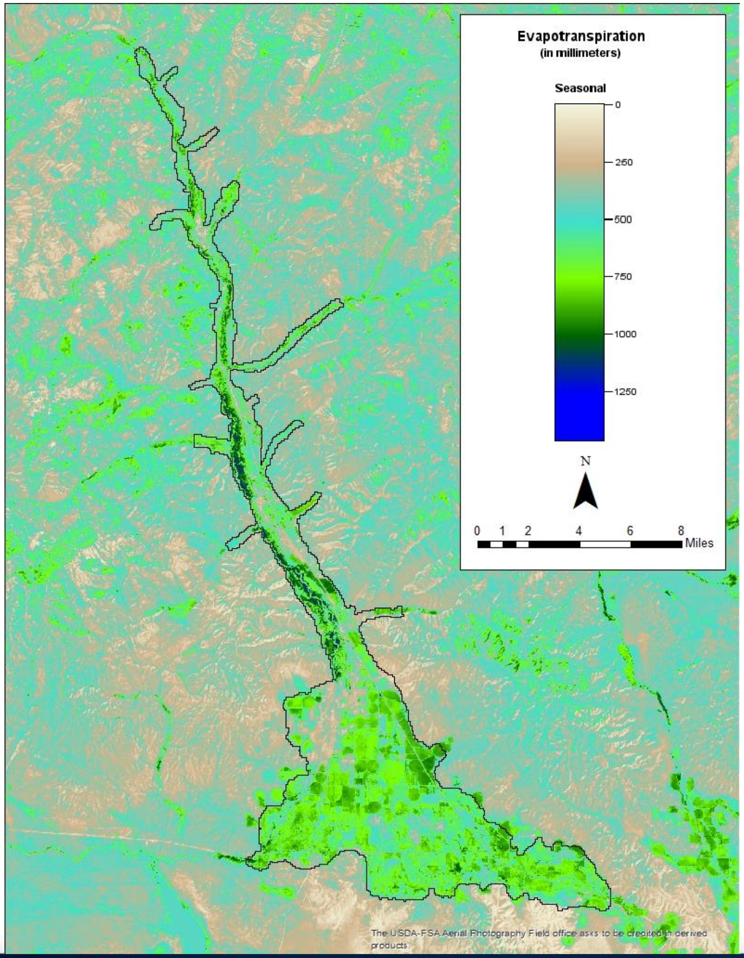
- Nr Ketchum
- At Hailey
- At Stanton Crossing

Stream Gages

- Calculate reach gain
  - Difference upstream and down stream gage
  - Account for diversions, returns, and tributaries
  - Calculate gain from or loss to the aquifer

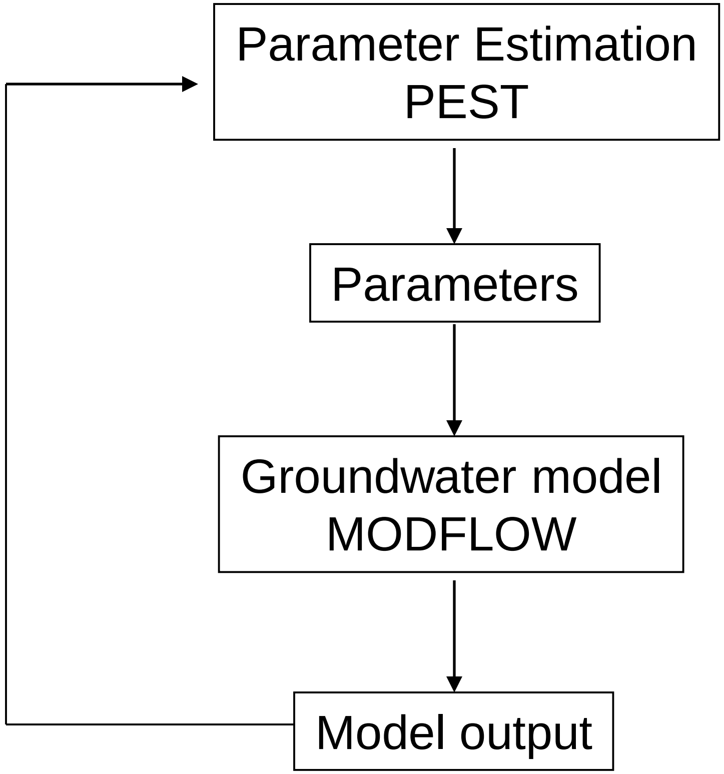


Water Use



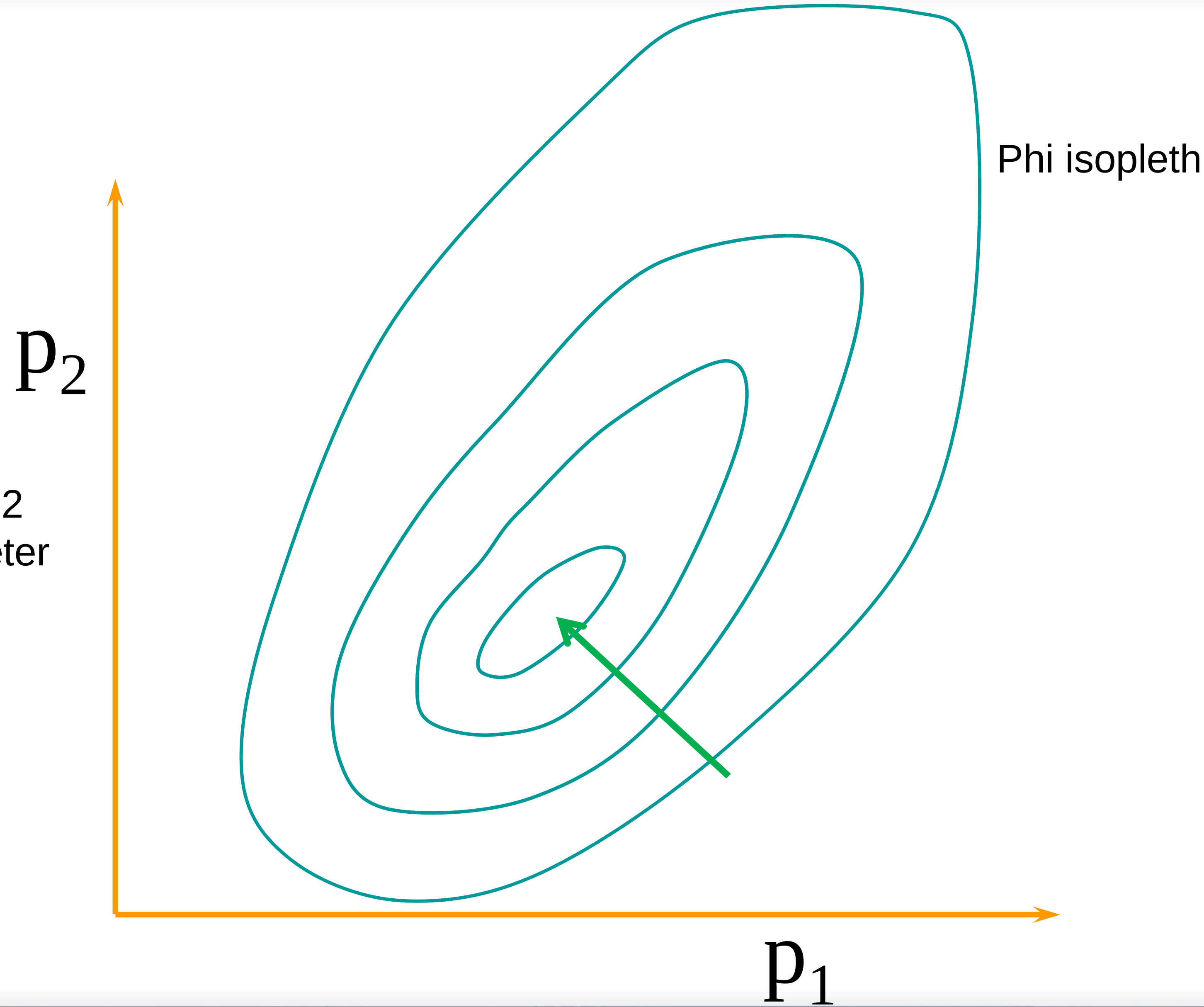
- Crop Water Use
  - Requirements by crop type are well known
- Municipal Use
  - Pumping is reported
  - Treatment plant discharge is reported

Model Calibration

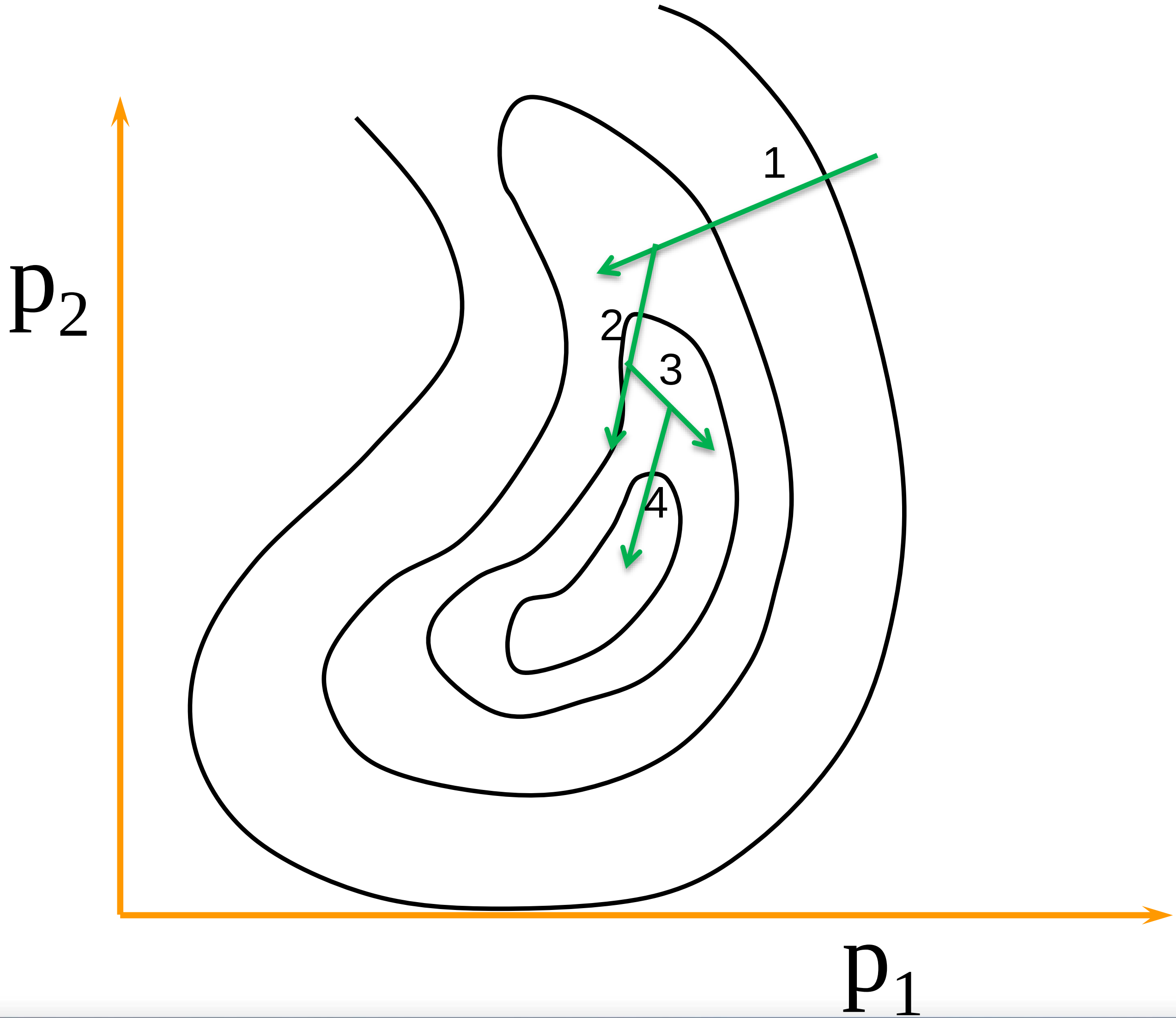


Jacobian matrix

$$
\begin{bmatrix}
\partial o_1 / \partial p_1 & \partial o_1 / \partial p_2 & \partial o_1 / \partial p_3 & \partial o_1 / \partial p_4 \\
\partial o_2 / \partial p_1 & \partial o_2 / \partial p_2 & \partial o_2 / \partial p_3 & \partial o_2 / \partial p_4 \\
\partial o_3 / \partial p_1 & \partial o_3 / \partial p_2 & \partial o_3 / \partial p_3 & \partial o_3 / \partial p_4 \\
\partial o_4 / \partial p_1 & \partial o_4 / \partial p_2 & \partial o_4 / \partial p_3 & \partial o_4 / \partial p_4 \\
\partial o_5 / \partial p_1 & \partial o_5 / \partial p_2 & \partial o_5 / \partial p_3 & \partial o_5 / \partial p_4 \\
\partial o_6 / \partial p_1 & \partial o_6 / \partial p_2 & \partial o_6 / \partial p_3 & \partial o_6 / \partial p_4 \\
\partial o_7 / \partial p_1 & \partial o_7 / \partial p_2 & \partial o_7 / \partial p_3 & \partial o_7 / \partial p_4 \\
\partial o_8 / \partial p_1 & \partial o_8 / \partial p_2 & \partial o_8 / \partial p_3 & \partial o_8 / \partial p_4 \\
etc & & &
\end{bmatrix}
$$



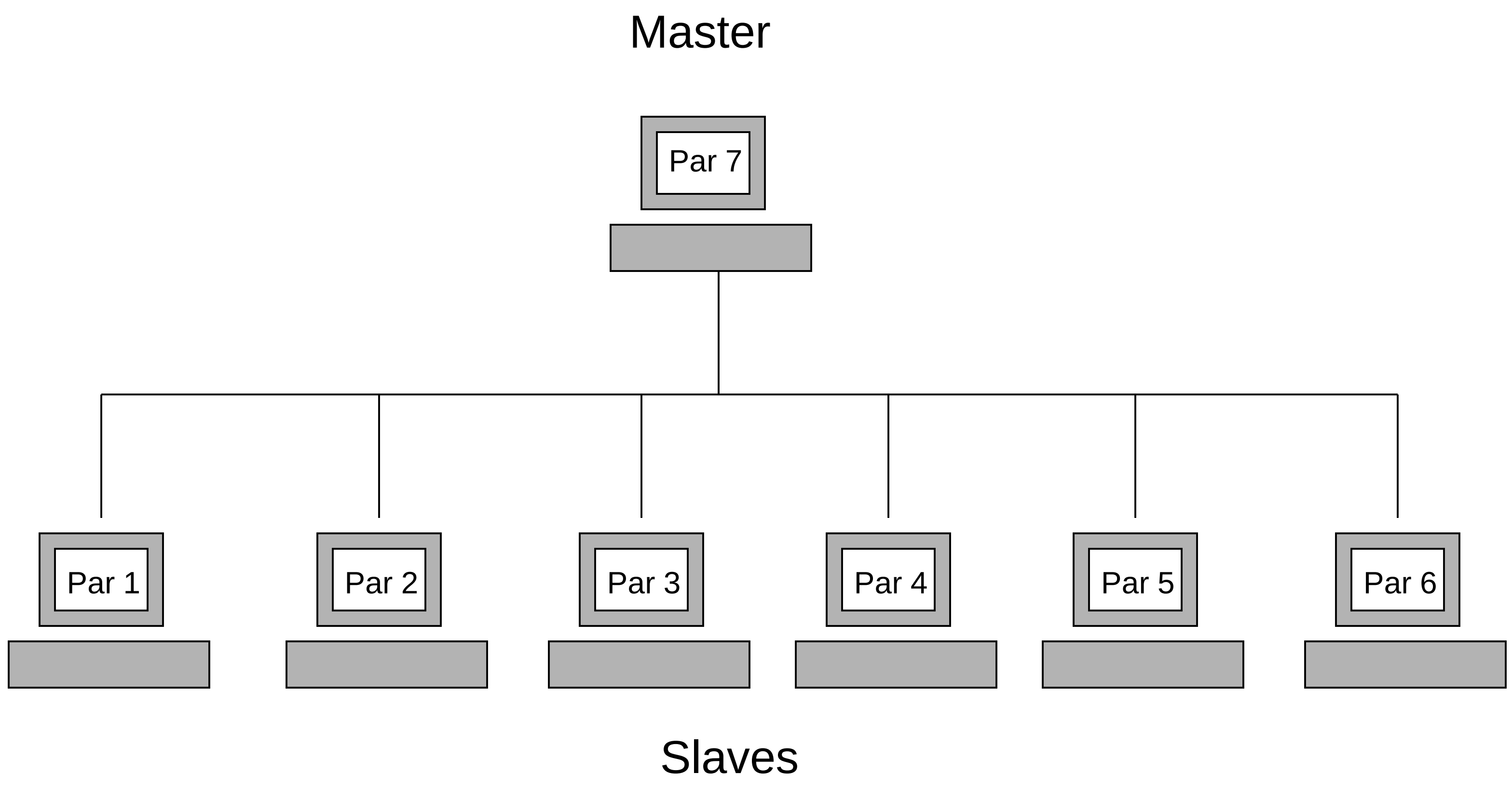
Simple 2 parameter system



p_2
p_1
1
2
3
4

Jacobian matrix
Each column is independent

$$\begin{bmatrix} \partial o_1 / \partial p_1 & \partial o_1 / \partial p_2 & \partial o_1 / \partial p_3 & \partial o_1 / \partial p_4 \\ \partial o_2 / \partial p_1 & \partial o_2 / \partial p_2 & \partial o_2 / \partial p_3 & \partial o_2 / \partial p_4 \\ \partial o_3 / \partial p_1 & \partial o_3 / \partial p_2 & \partial o_3 / \partial p_3 & \partial o_3 / \partial p_4 \\ \partial o_4 / \partial p_1 & \partial o_4 / \partial p_2 & \partial o_4 / \partial p_3 & \partial o_4 / \partial p_4 \\ \partial o_5 / \partial p_1 & \partial o_5 / \partial p_2 & \partial o_5 / \partial p_3 & \partial o_5 / \partial p_4 \\ \partial o_6 / \partial p_1 & \partial o_6 / \partial p_2 & \partial o_6 / \partial p_3 & \partial o_6 / \partial p_4 \\ \partial o_7 / \partial p_1 & \partial o_7 / \partial p_2 & \partial o_7 / \partial p_3 & \partial o_7 / \partial p_4 \\ \partial o_8 / \partial p_1 & \partial o_8 / \partial p_2 & \partial o_8 / \partial p_3 & \partial o_8 / \partial p_4 \\ etc & & & \end{bmatrix}$$


Master
Par 7
Par 1
Par 2
Par 3
Par 4
Par 5
Par 6
Slaves

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Modeling by Committee

- Modeling committee
  - Technical advisory committee
  - Open meetings
  - All are welcome
  - Modeling takes longer
  - Legal process is less painful

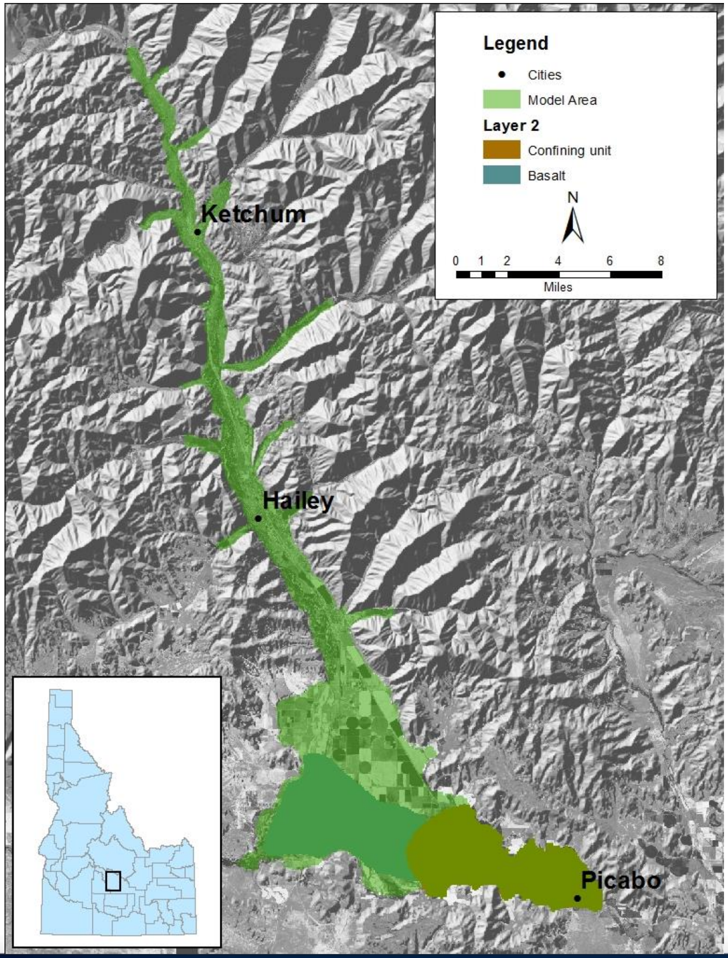
Essentially, all models are wrong, but some are useful.

(George E. P. Box)

Keys to Making a Useful Model

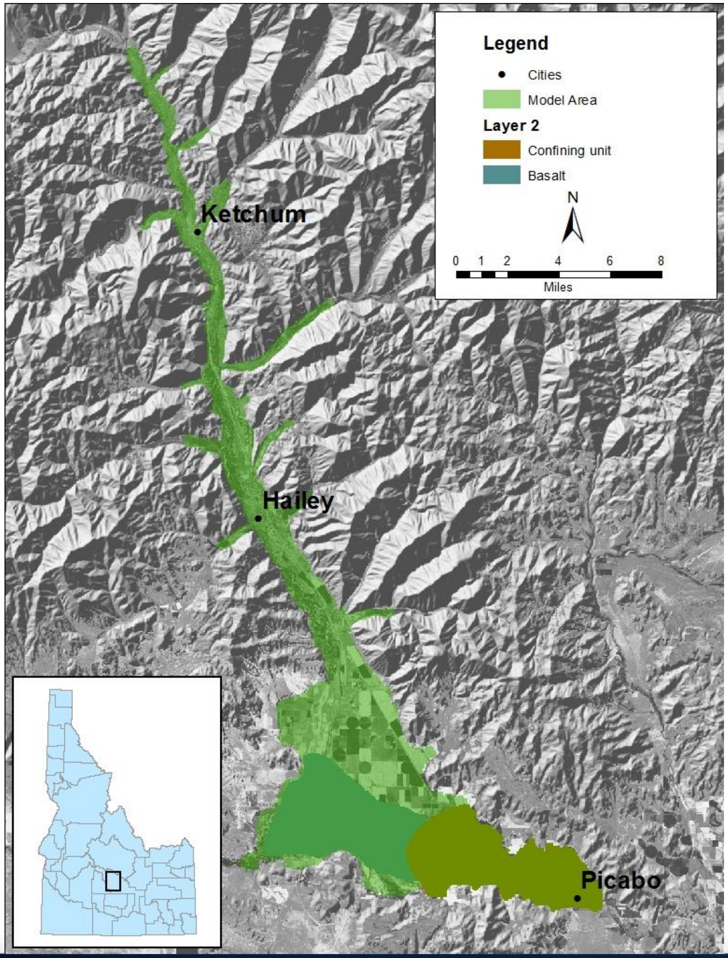
- Who is going to use your model
- What are they going to use it for
- What should they know about your model
- Model IS going to be used for some unintended purpose

Wood River Valley Aquifer Model



- Client is Idaho Water Resource Board
- Collaborator US Geological Survey
- Technical advisory committee

Objectives



- Objectives should be aligned with how the client intends to use the model
  - No one is clairvoyant
  - Model can't be good at everything
  - Model will be used for some unintended purpose

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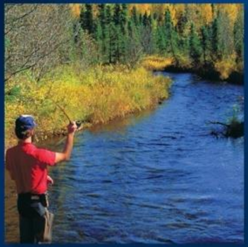
Objectives

- IDWR
  - Be transparent
- US Geological Survey
  - Collaborator
  - Improved understanding of the aquifer system and guide future investigations
- Technical Advisory Committee
  - Provide a basis for conjunctive administration
    - Ground water and surface water are one source
    - Junior users are curtailed so seniors can have full allotment of water
- Idaho Water Resource Board
  - Client
  - Transfers
    - Change point of diversion, or use, or both

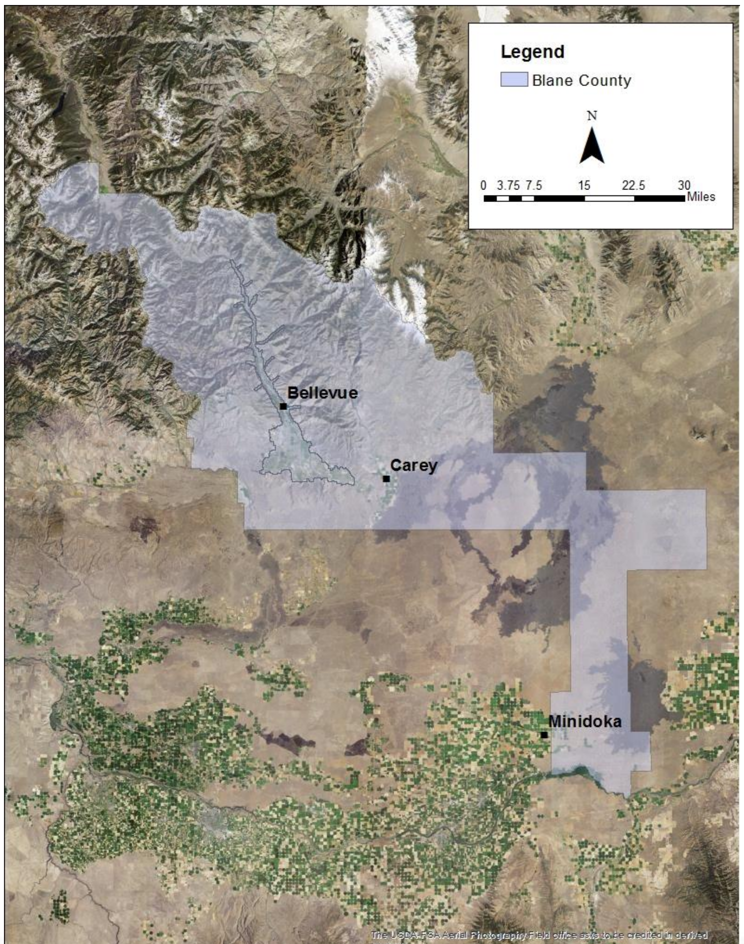
Data Necessary to Meet Objectives

- Consumptive use of water and how it has changed 1995-2015
  - NASS
  - ET Idaho
  - METRIC
- How aquifer has responded to consumptive use 1995-2015
  - Water levels in wells
- How Wood River, Willow Creek, and Silver Creek have responded to consumptive use 1995-2015
  - River gages and gaged diversions

End

Available Data



- Crop water use
  - ET Idaho
    - ET = Evapotranspiration
    - Crop water use
  - NASS USDA
    - Crops by county
      - County has large footprint
    - Department of Agriculture will change crop mix if one grower dominates a crop type

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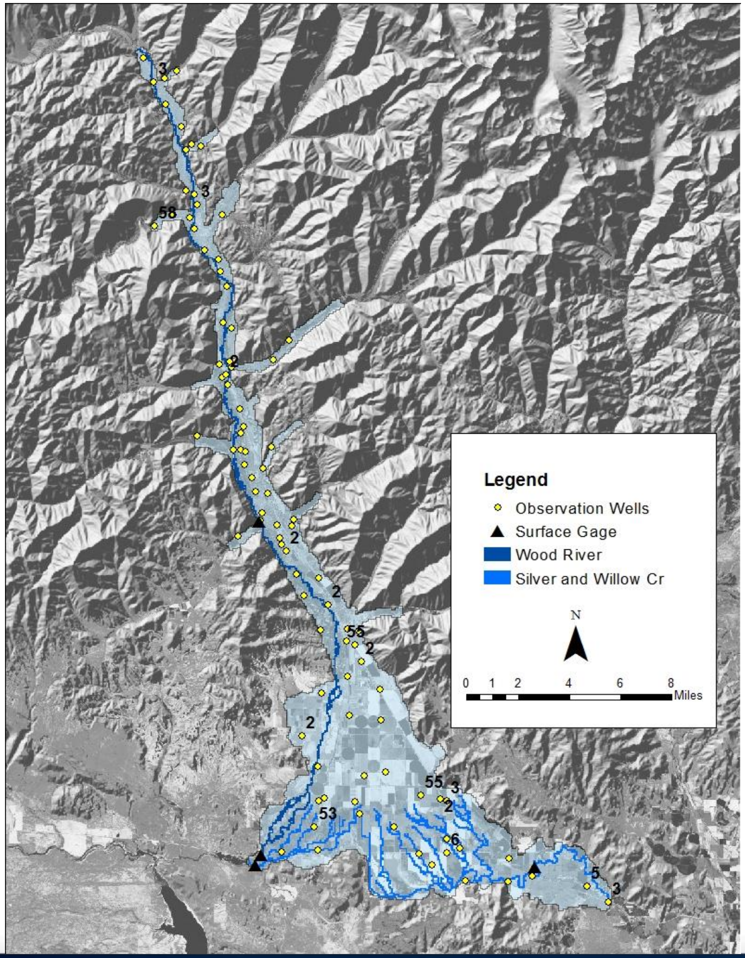
Available Data

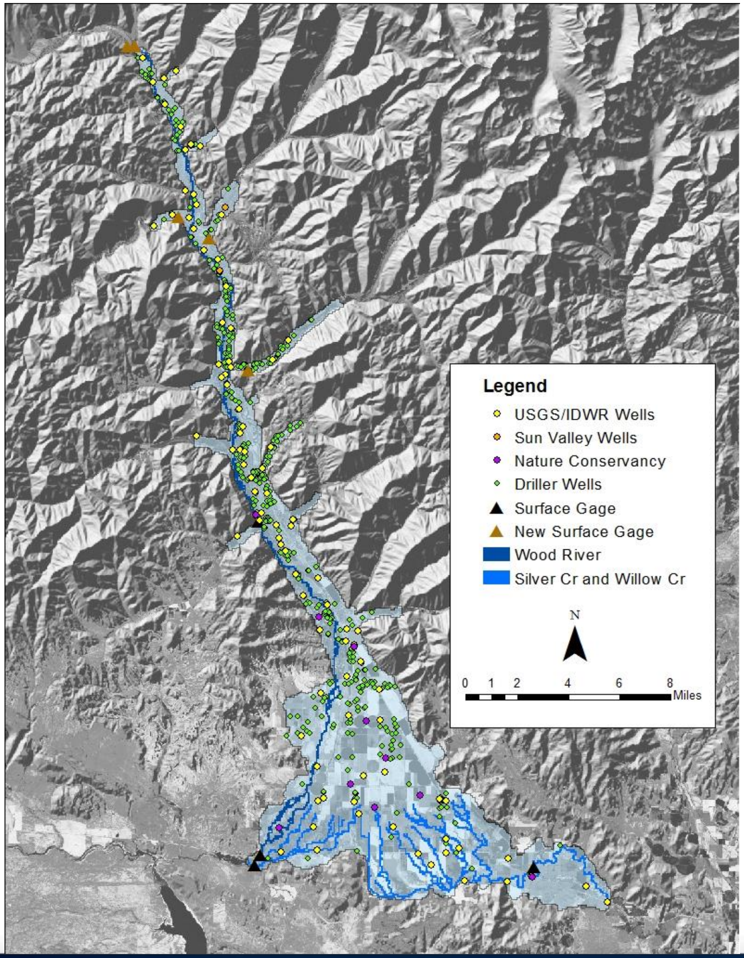


- Water levels in wells
  - 94 wells
  - 4 with 16 or more water levels between 1995-2010
- 4 surface water gaging stations
  - 2 on Wood River
  - 1 Willow Creek
  - 1 Silver Creek

Matching Objectives with Available Data

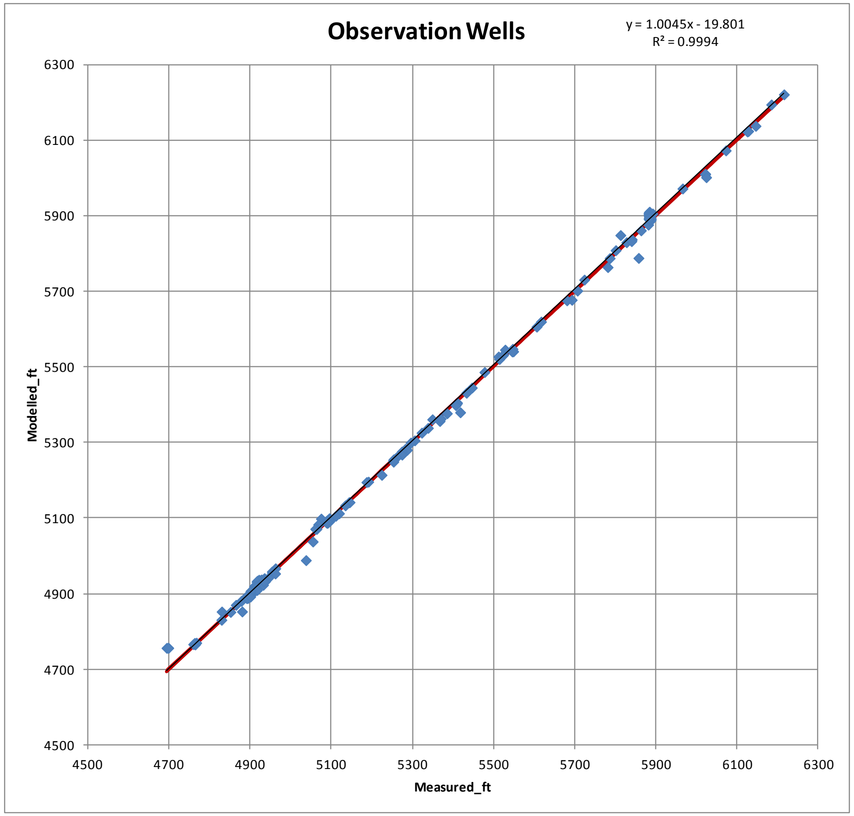
- IDWR
  - Transparent
  - Achievable
- US Geological Survey
  - Collaborator
  - Improved understanding of the aquifer system and guide future investigations
  - Achievable
- Technical Advisory Committee
  - Provide a basis for conjunctive administration
  - Not achievable
- Idaho Water Resource Board
  - Client
  - Transfers
  - Not achievable

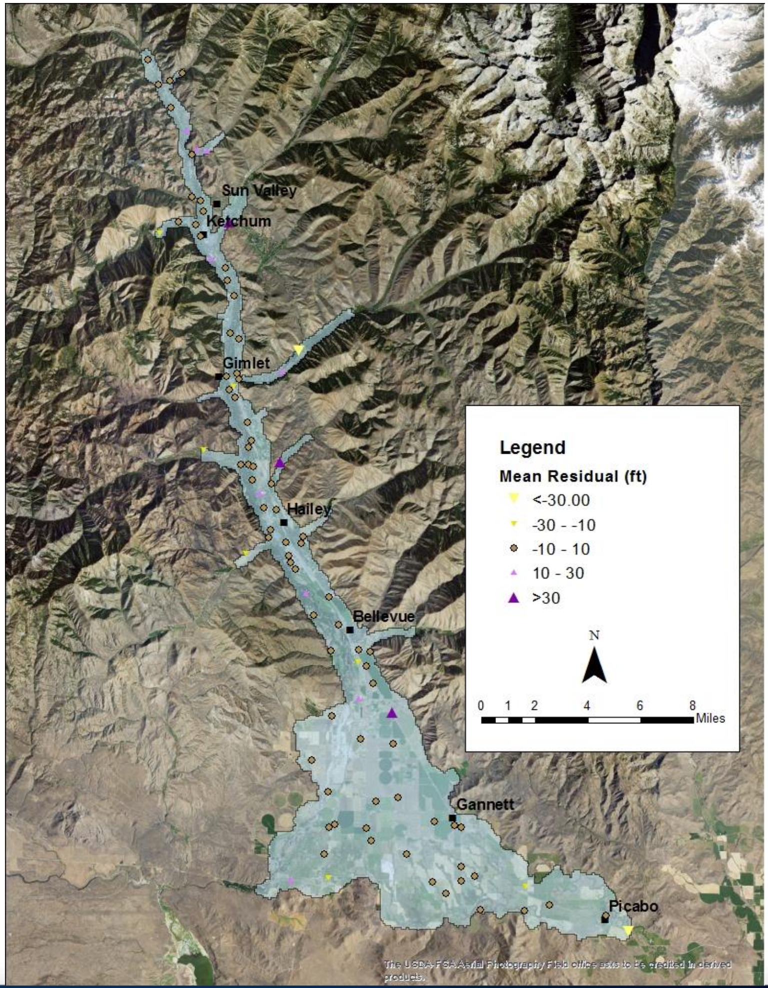
More Data Necessary to Meet Objectives



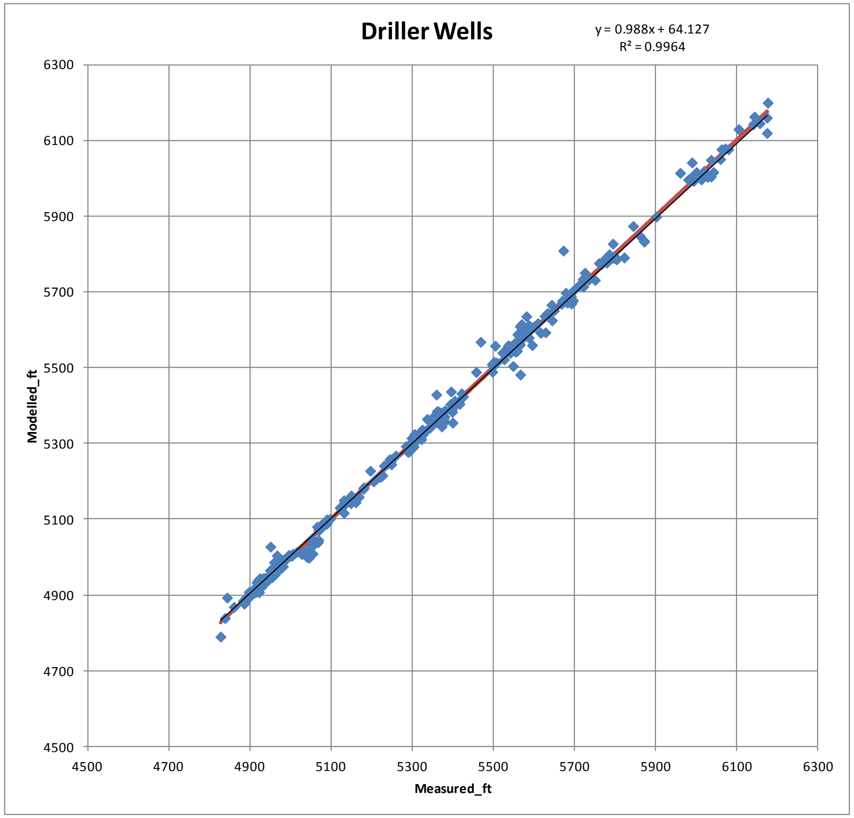
- Water level data
  - Drillers must record water level in wells
  - Sun Valley production wells
  - The Nature Conservancy transducer data for 2010
- Surface water gages
  - Established correlations between the gage at Hailey and gages established since 2010

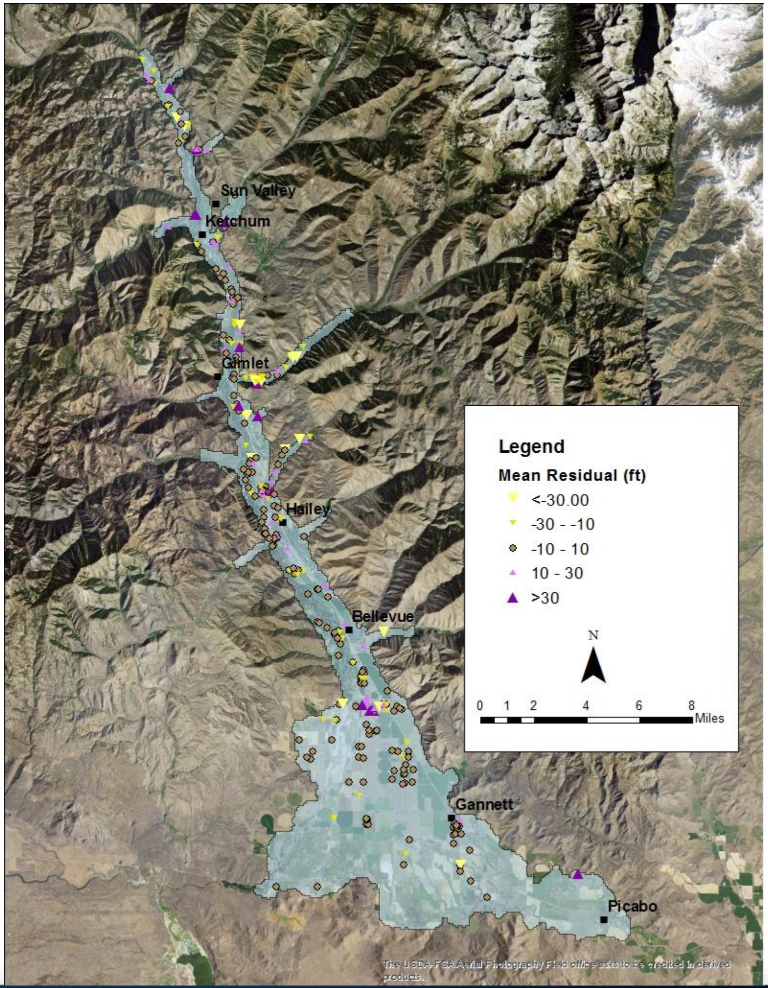
Wood River Valley Aquifer Model Calibration



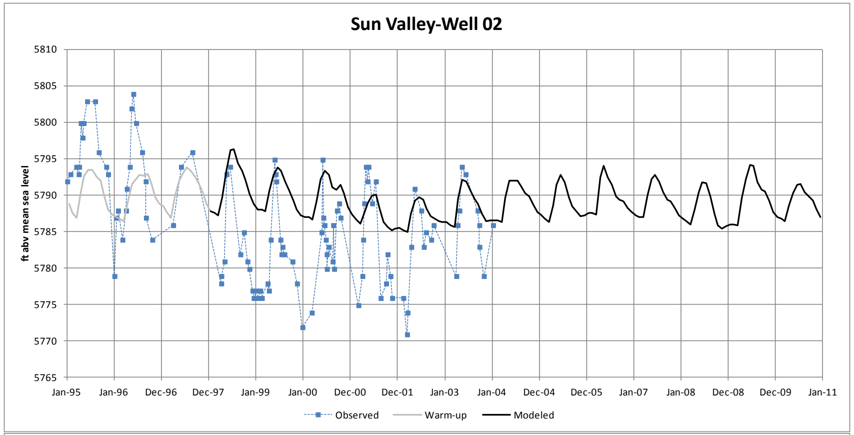


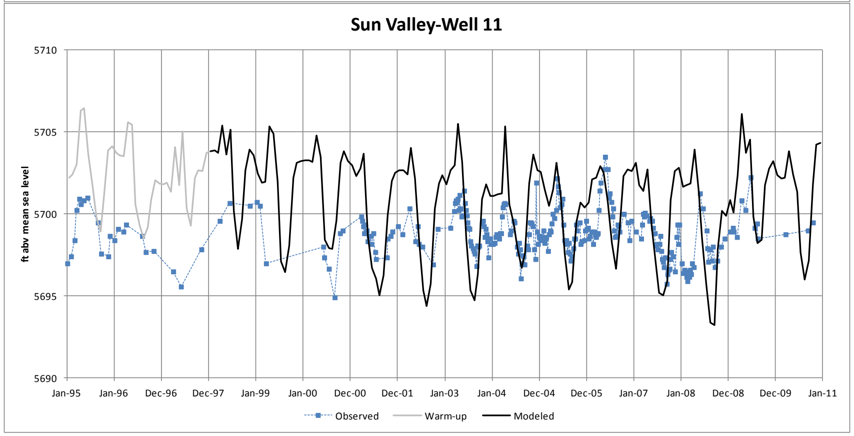
Wood River Valley Aquifer Model Calibration

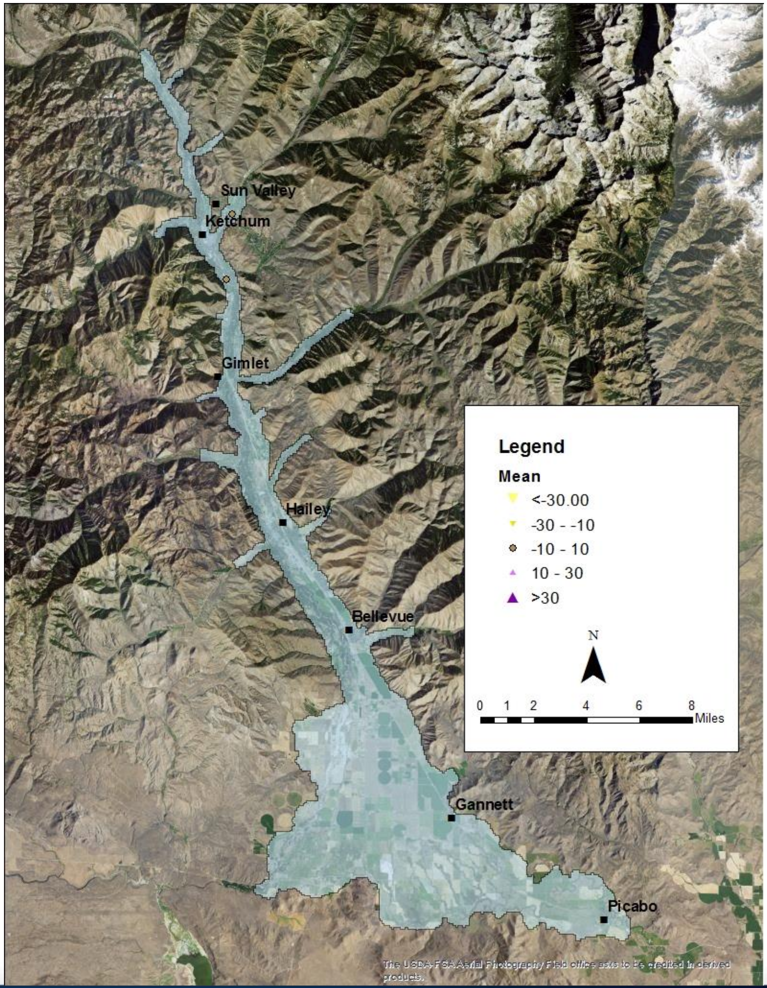




Wood River Valley Aquifer Model Calibration







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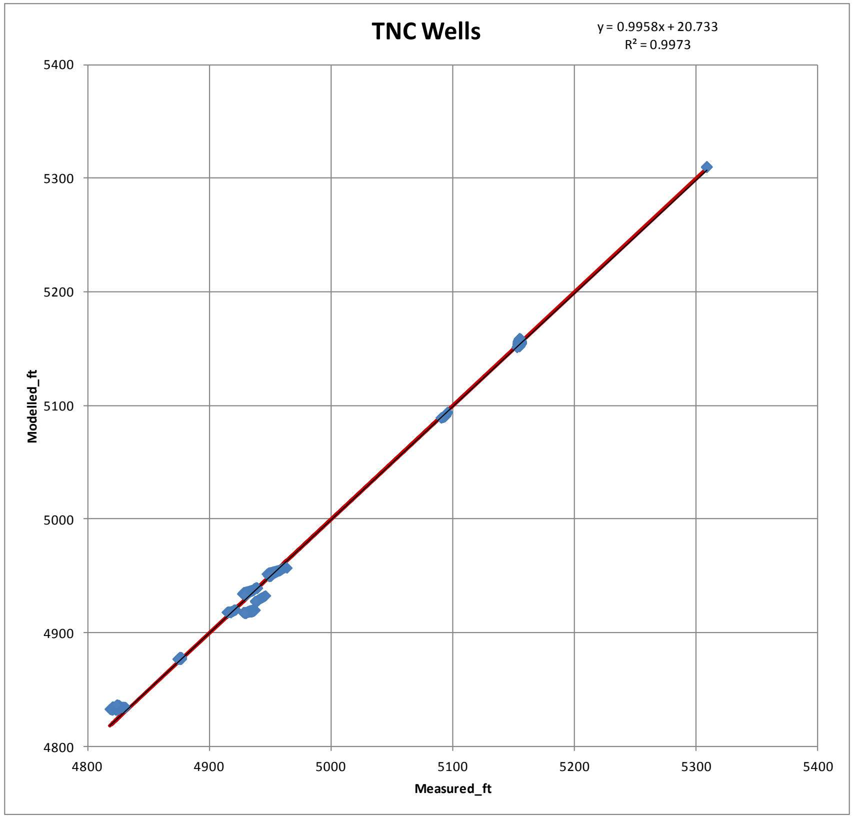
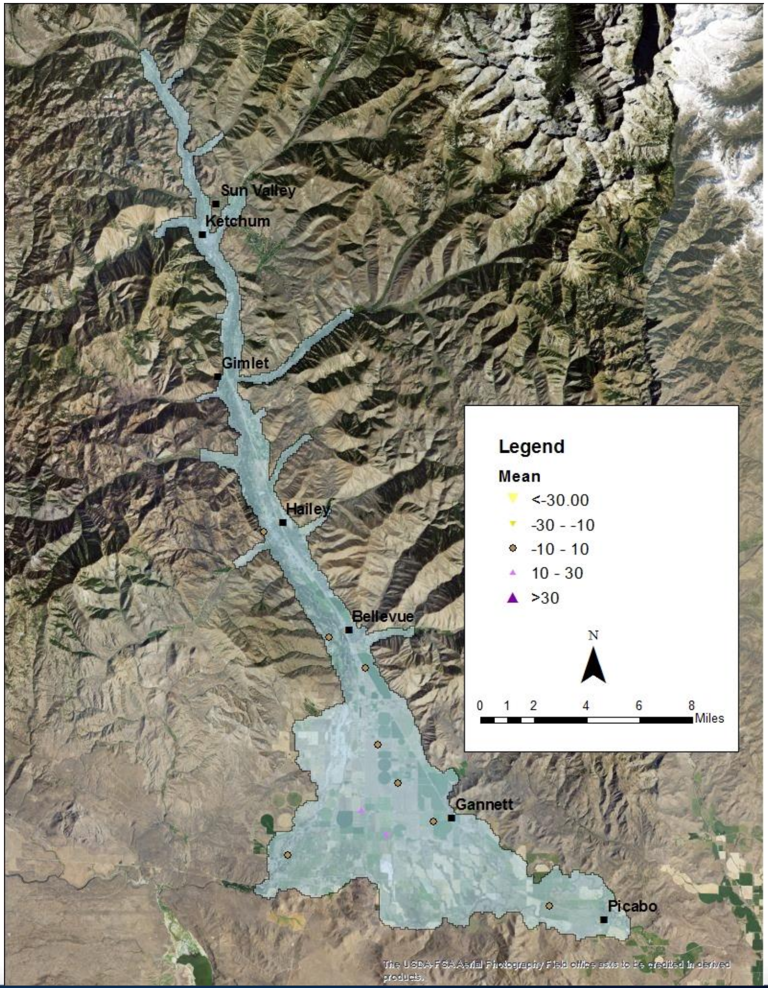
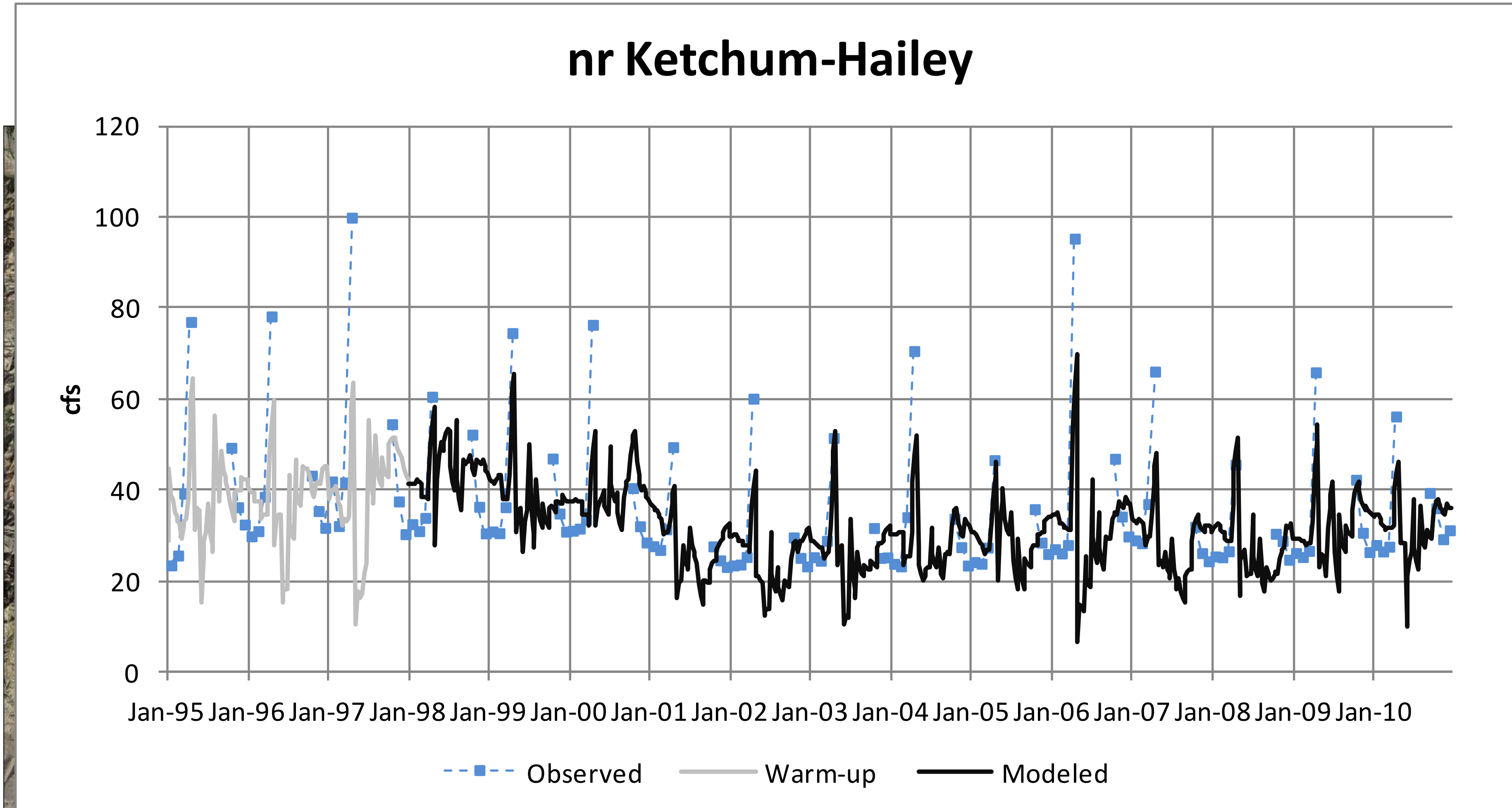
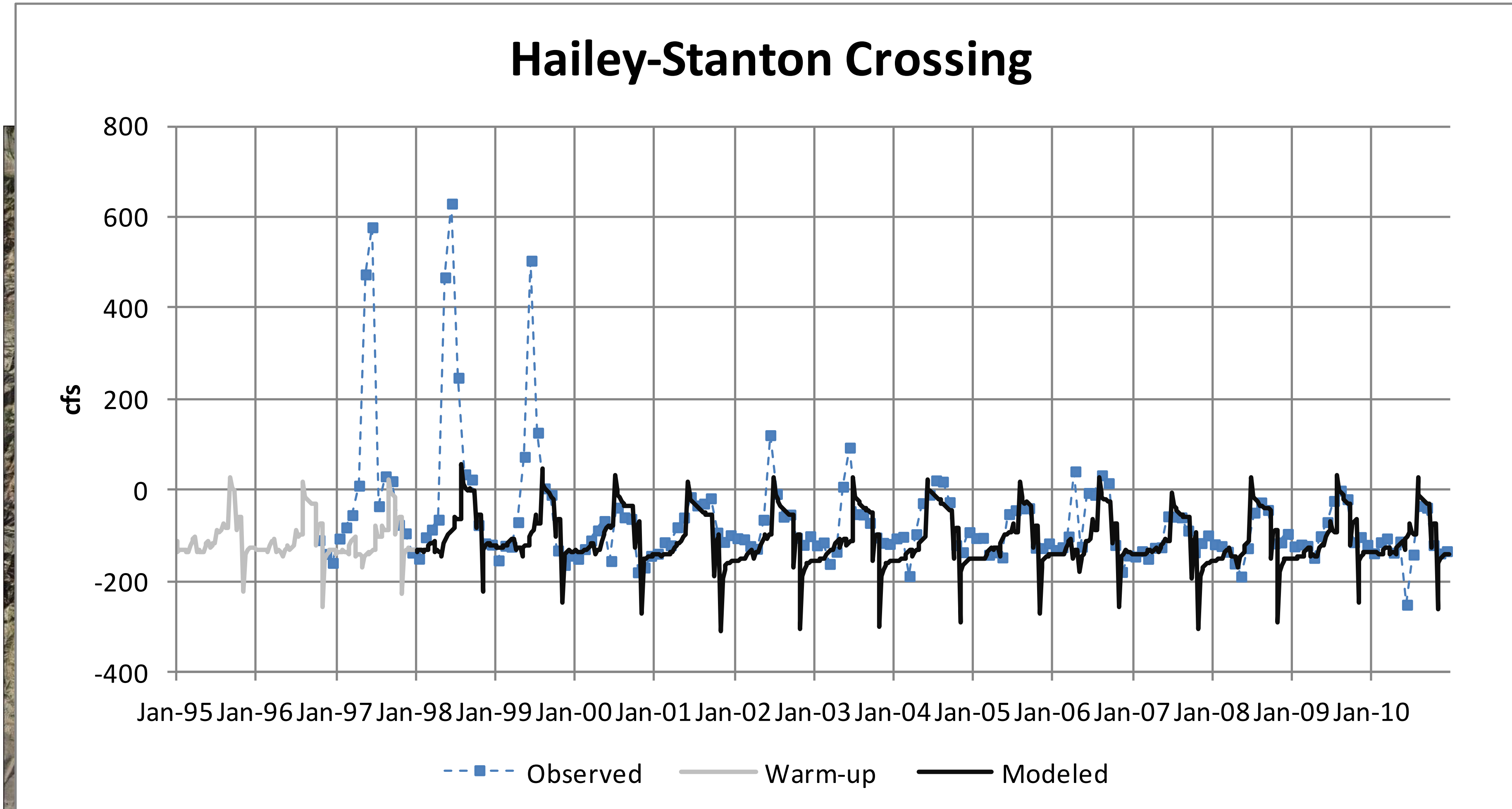
Wood River Valley Aquifer Model Calibration






BIG WOOD RIVER AT STANTON CROSSING NR BELLEVUE ID
The USDA-FSA Aerial Photography Field office asks to be credited in derived products.


nr Ketchum-Hailey
cfs
120
100
80
60
40
20
0
Jan-95 Jan-96 Jan-97 Jan-98 Jan-99 Jan-00 Jan-01 Jan-02 Jan-03 Jan-04 Jan-05 Jan-06 Jan-07 Jan-08 Jan-09 Jan-10
Observed
Warm-up
Modeled


Hailey-Stanton Crossing
800
600
400
200
0
-200
-400
cfs
Jan-95 Jan-96 Jan-97 Jan-98 Jan-99 Jan-00 Jan-01 Jan-02 Jan-03 Jan-04 Jan-05 Jan-06 Jan-07 Jan-08 Jan-09 Jan-10
Observed
Warm-up
Modeled


BIG WOOD RIVER AT STANTON CROSSING NR BELLEVUE ID

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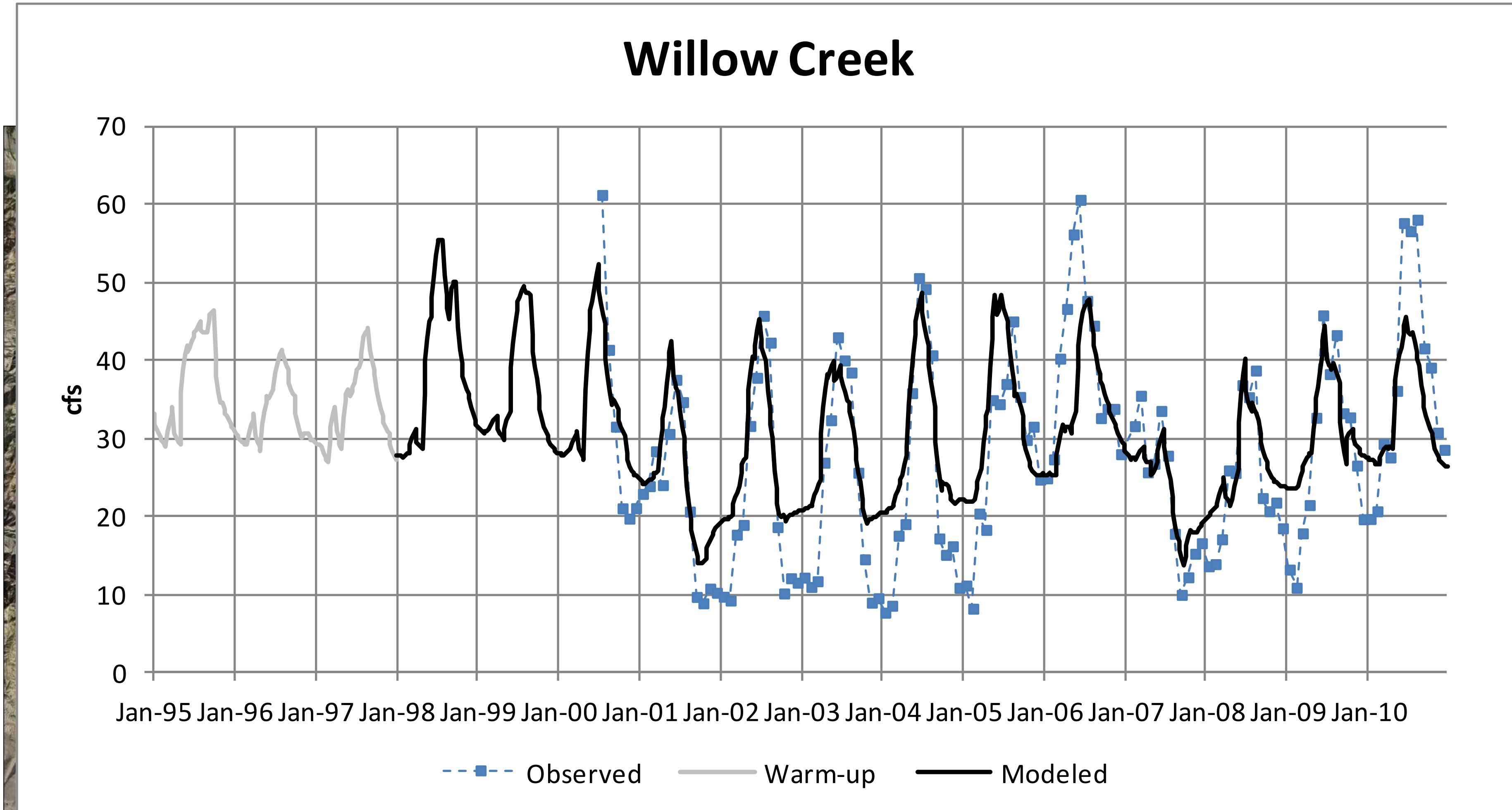
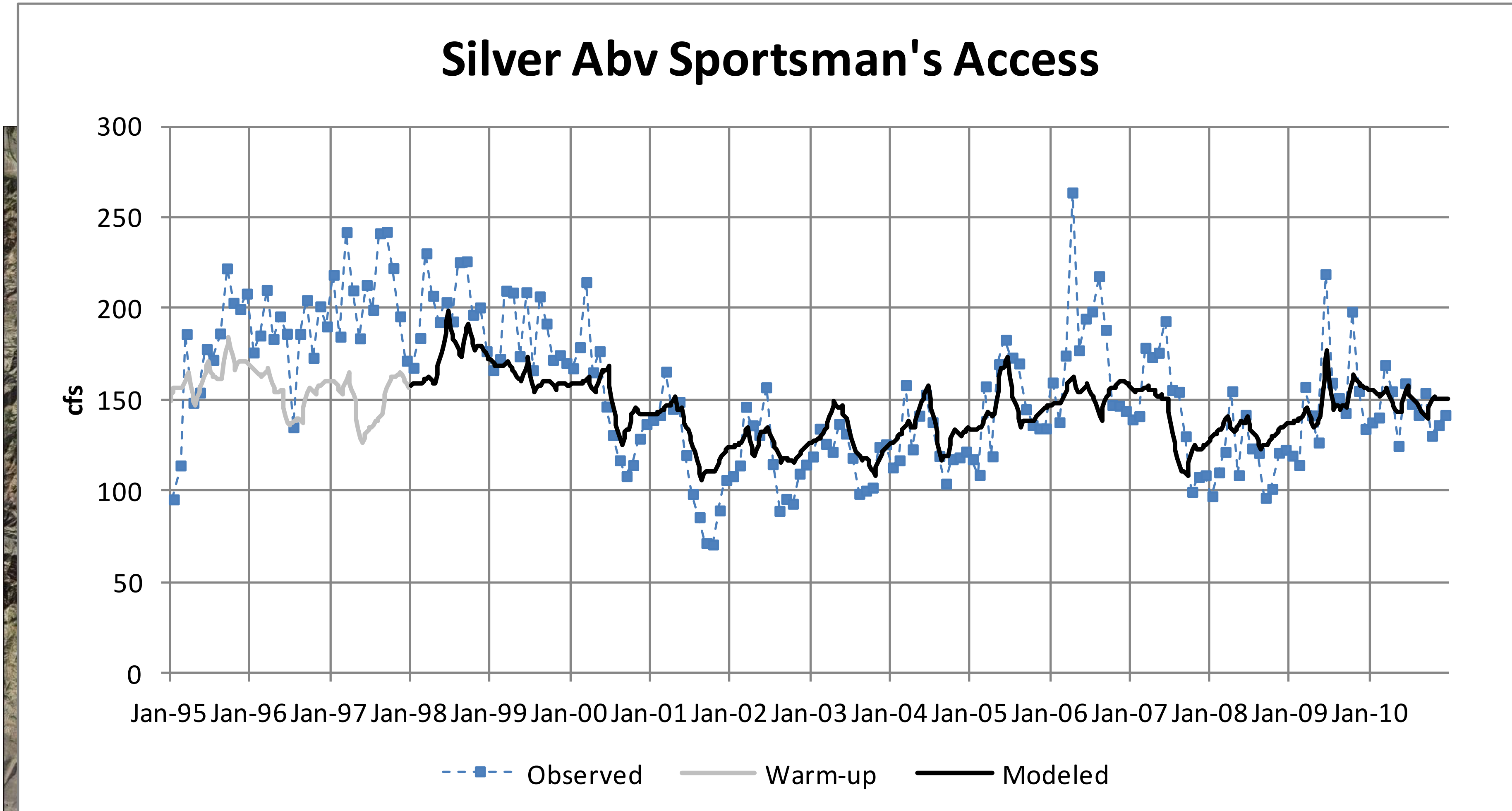
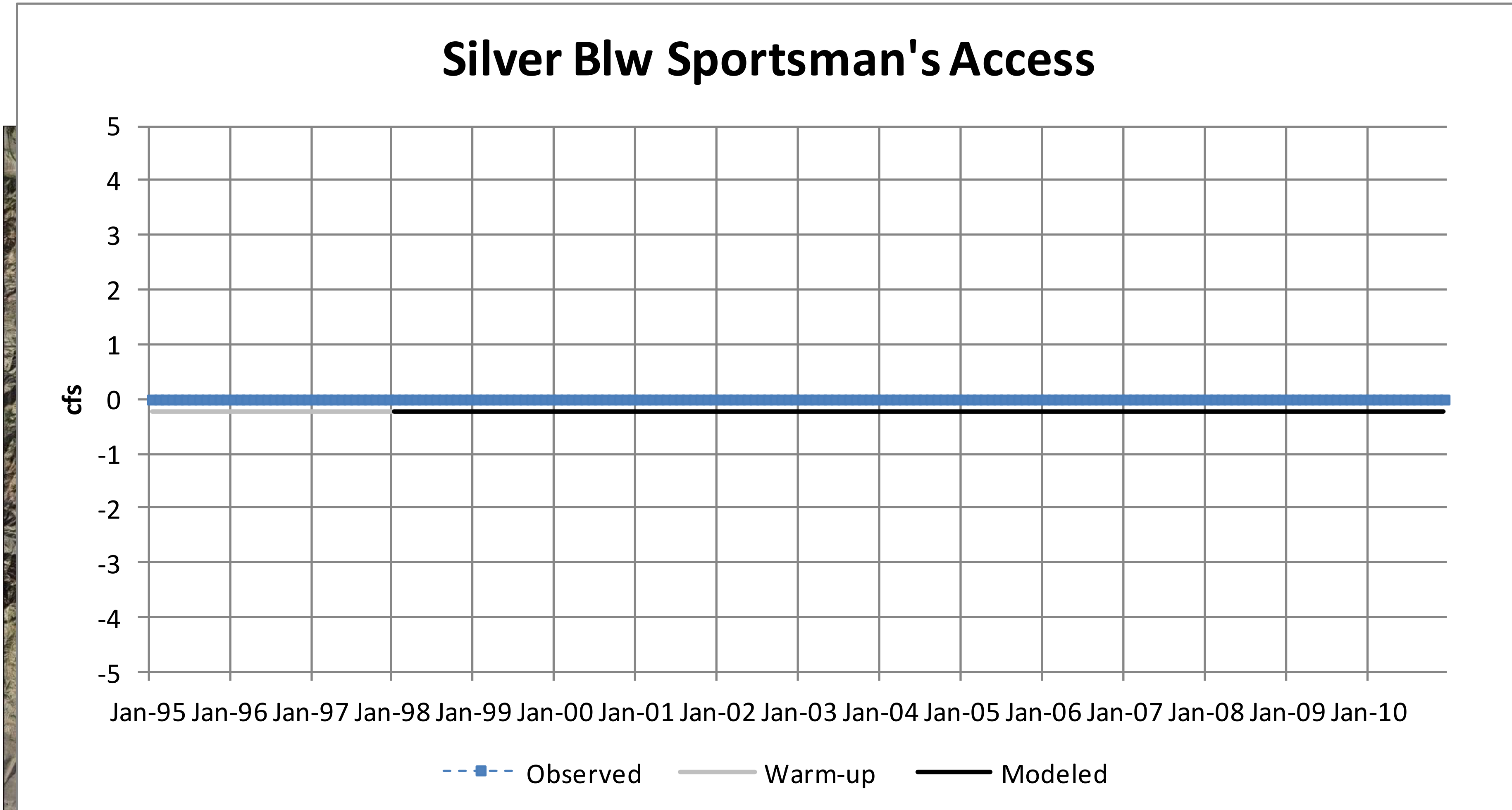


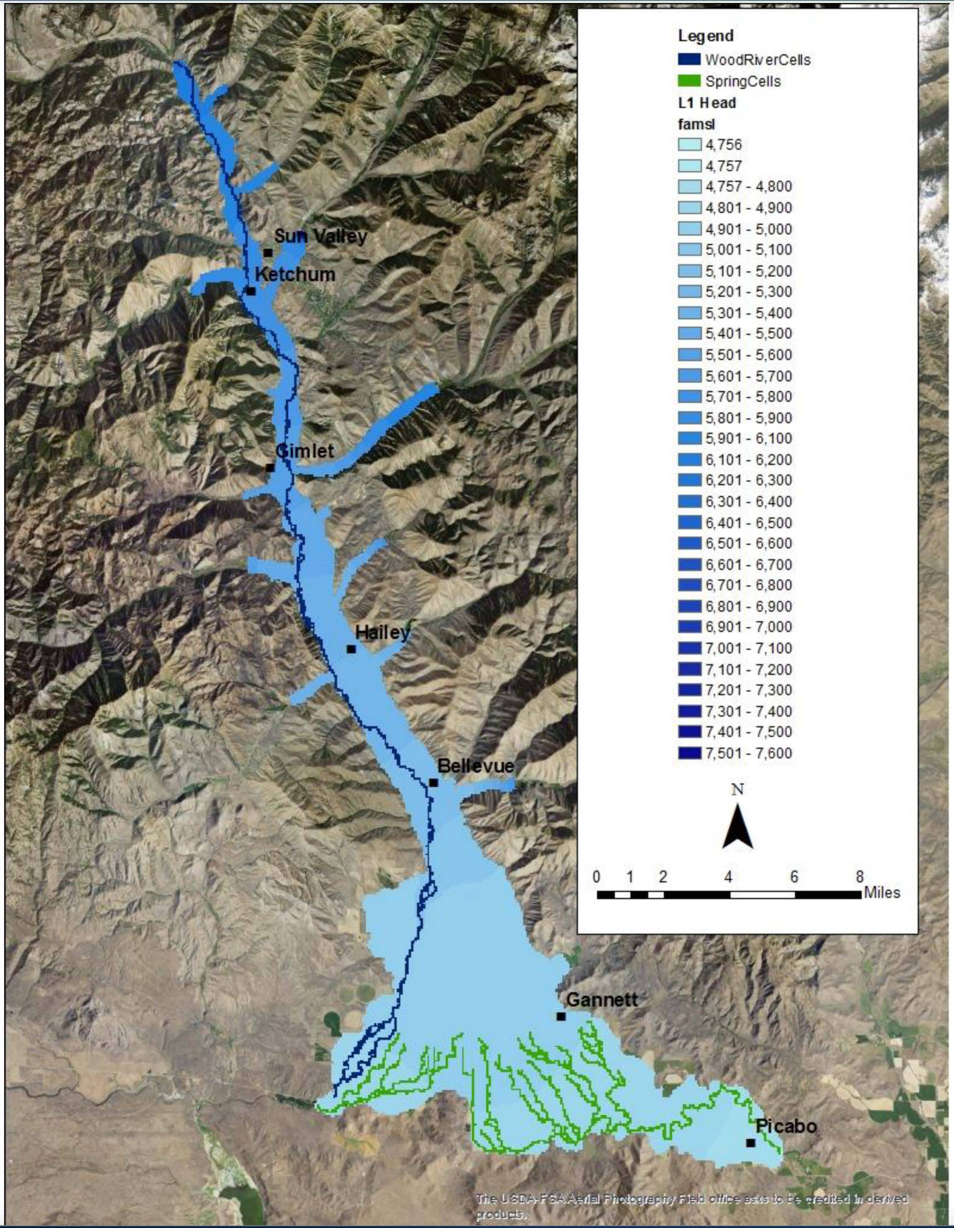


Silver Abv Sportsman's Access
cfs
300
250
200
150
100
50
0
Jan-95 Jan-96 Jan-97 Jan-98 Jan-99 Jan-00 Jan-01 Jan-02 Jan-03 Jan-04 Jan-05 Jan-06 Jan-07 Jan-08 Jan-09 Jan-10
Observed
Warm-up
Modeled

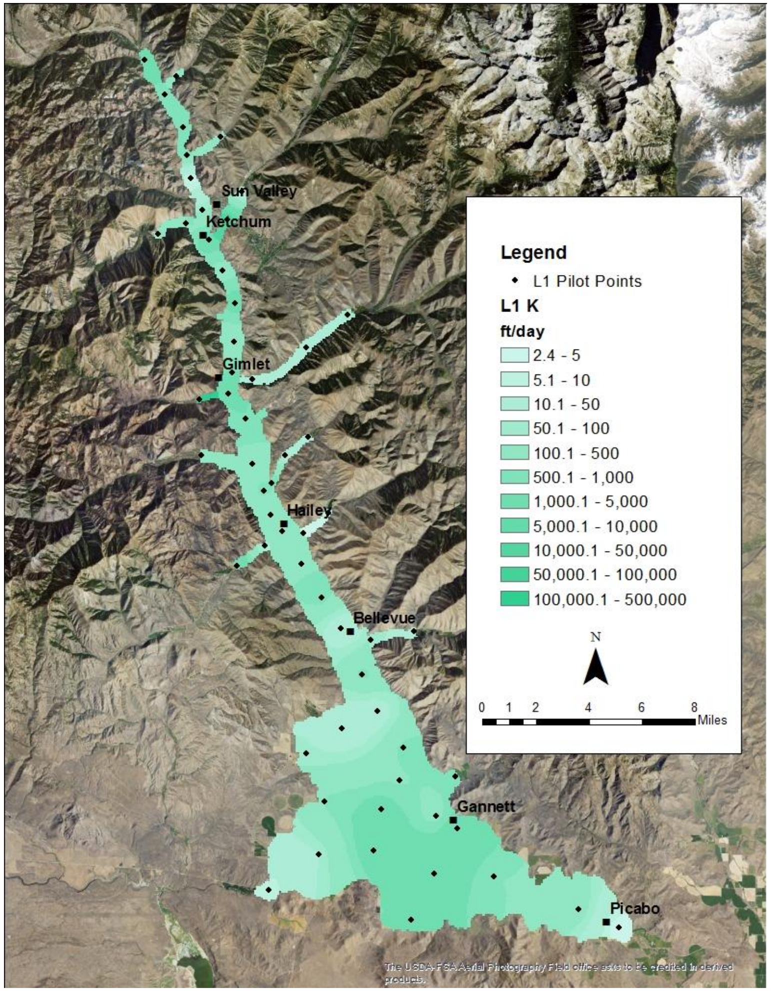
BIG WOOD RIVER AT STANTON CROSSING NR BELLEVUE ID


Silver Blw Sportsman's Access
cfs
5
4
3
2
1
0
-1
-2
-3
-4
-5
Jan-95 Jan-96 Jan-97 Jan-98 Jan-99 Jan-00 Jan-01 Jan-02 Jan-03 Jan-04 Jan-05 Jan-06 Jan-07 Jan-08 Jan-09 Jan-10
Observed
Warm-up
Modeled


BIG WOOD RIVER AT STANTON CROSSING NR BELLEVUE ID


Sun Valley
Ketchum
Gimlet
Hailey
Bellevue
Gannett
Picabo
Legend
WoodRiverCells
SpringCells
L1 Head
famsl
4,756
4,757
4,757 - 4,800
4,801 - 4,900
4,901 - 5,000
5,001 - 5,100
5,101 - 5,200
5,201 - 5,300
5,301 - 5,400
5,401 - 5,500
5,501 - 5,600
5,601 - 5,700
5,701 - 5,800
5,801 - 5,900
5,901 - 6,100
6,101 - 6,200
6,201 - 6,300
6,301 - 6,400
6,401 - 6,500
6,501 - 6,600
6,601 - 6,700
6,701 - 6,800
6,801 - 6,900
6,901 - 7,000
7,001 - 7,100
7,101 - 7,200
7,201 - 7,300
7,301 - 7,400
7,401 - 7,500
7,501 - 7,600
N
0 1 2 4 6 8
Miles

Layer 1 Hydraulic Conductivity



- Layer 1
- Tributary valleys are in their own zones
- In valley and triangle
  - Min = 2.4 ft/day
  - Max = 122,344 ft/day
  - Mean = 831 ft/day

Layer 1 Hydraulic Conductivity

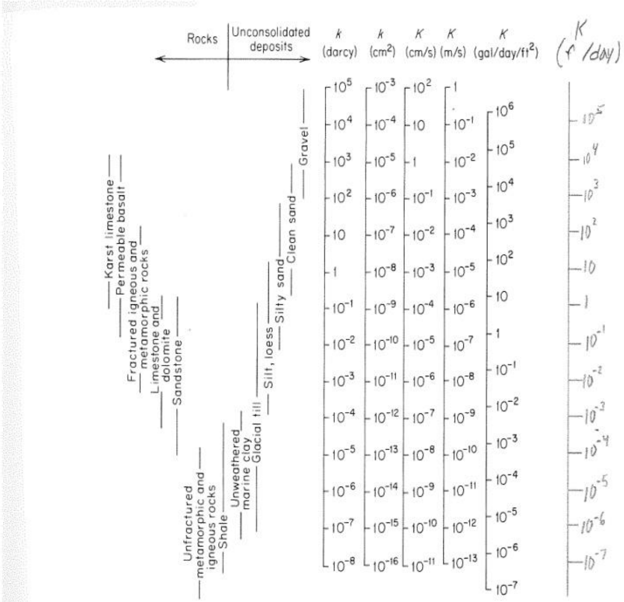


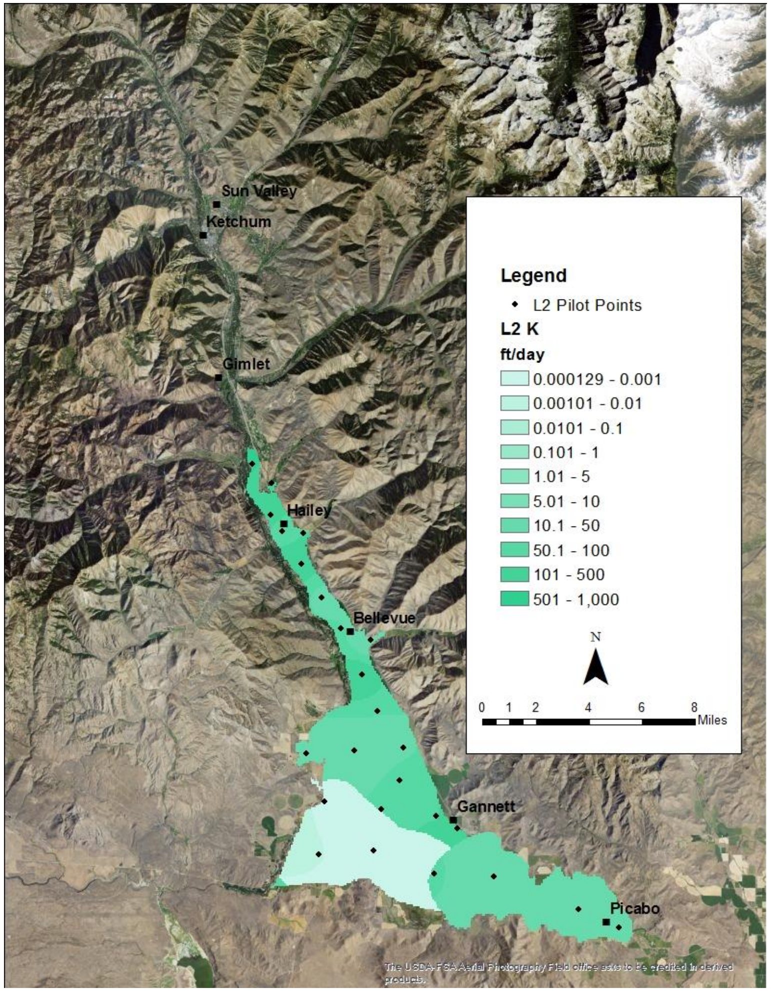
Table 2.3 Conversion Factors for Permeability and Hydraulic Conductivity Units

	Permeability, k*			Hydraulic conductivity, K		
	cm^2	ft^2	darcy	m/s	ft/s	U.S. gal/day/ft^2
cm^2	1	1.08×10^{-3}	1.01×10^{8}	9.80×10^{2}	3.22×10^{3}	1.85×10^{9}
ft^2	9.29×10^{2}	1	9.42×10^{10}	9.11×10^{5}	2.99×10^{6}	1.71×10^{12}
darcy	9.87×10^{-9}	1.06×10^{-11}	1	9.66×10^{-6}	3.17×10^{-5}	1.82×10^{1}
m/s	1.02×10^{-3}	1.10×10^{-6}	1.04×10^{5}	1	3.28	2.12×10^{6}
ft/s	3.11×10^{-4}	3.35×10^{-7}	3.15×10^{4}	3.05×10^{-1}	1	6.46×10^{5}
U.S. gal/day/ft^2	5.42×10^{-10}	5.83×10^{-13}	5.49×10^{-2}	4.72×10^{-7}	1.55×10^{-6}	1

Groundwater, Freeze & Cherry, 1979

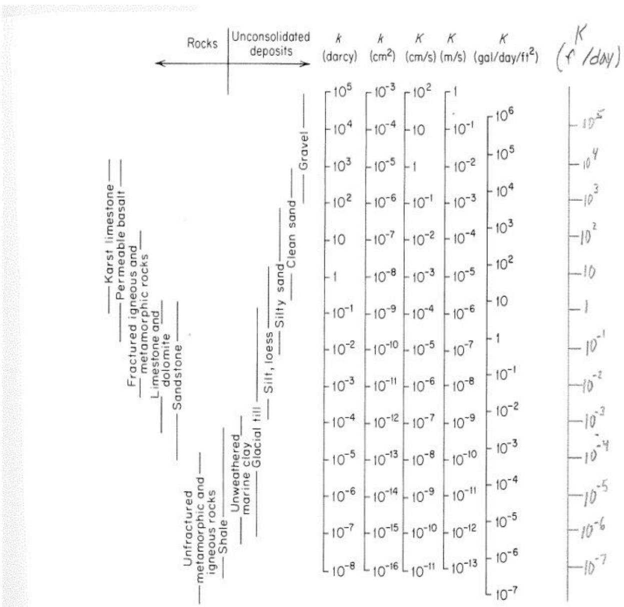
- Tributary valleys are in their own zones
  - Contain maximum and minimum values
- In valley and triangle
  - Min = 2.4 ft/day
  - Max = 122,344 ft/day
  - Mean = 831 ft/day
- 437 wells in Wood River alluvial sediments.

Layer 2 Hydraulic Conductivity



- Layer 2 modeled as confined
- Includes basalt in east
- Includes confining layer
- Sand and gravel aquifer in valley and triangle
  - Min = 2 ft/day
  - Max = 237 ft/day
  - Mean = 42 ft/day

Layer 2 Hydraulic Conductivity



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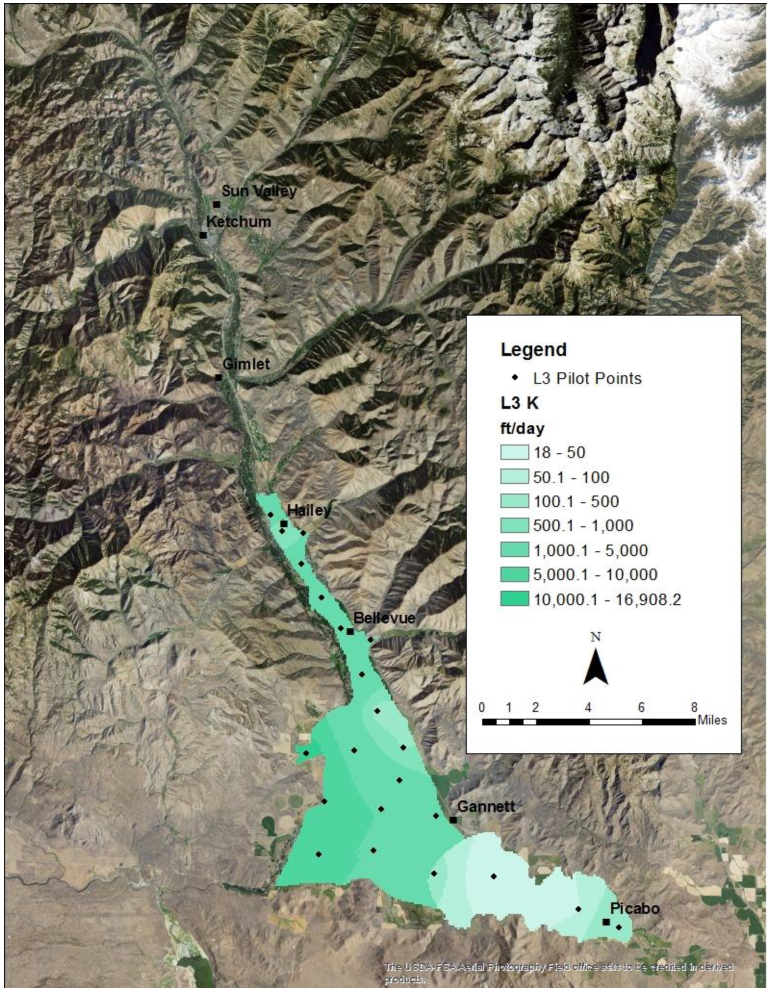
	Permeability, k*			Hydraulic conductivity, K		
	cm²	ft²	darcy	m/s	ft/s	U.S. gal/day/ft²
cm²	1	1.08×10^{-3}	1.01×10^{8}	9.80×10^{2}	3.22×10^{3}	1.85×10^{9}
ft²	9.29×10^{2}	1	9.42×10^{10}	9.11×10^{5}	2.99×10^{6}	1.71×10^{12}
darcy	9.87×10^{-9}	1.06×10^{-11}	1	9.66×10^{-6}	3.17×10^{-5}	1.82×10^{1}
m/s	1.02×10^{-3}	1.10×10^{-6}	1.04×10^{5}	1	3.28	2.12×10^{6}
ft/s	3.11×10^{-4}	3.35×10^{-7}	3.15×10^{4}	3.05×10^{-1}	1	6.46×10^{5}
U.S. gal/day/ft²	5.42×10^{-10}	5.83×10^{-13}	5.49×10^{-2}	4.72×10^{-7}	1.55×10^{-6}	1

Groundwater, Freeze & Cherry, 1979

- Low hydraulic conductivity in confining layer
  - Min = 0.00004 ft/day
  - Max = 0.0002 ft/day
- Basalt
  - Min = 5 ft/day
  - Max = 20 ft/day
- Sand and gravel In valley and triangle
  - Min = 2 ft/day
  - Max = 237 ft/day
  - Mean = 42 ft/day
- 14 wells in Wood River alluvial sediments.

Layer 3 Hydraulic Conductivity



- Layer 3 modeled as confined
- Basalt
  - Min = 5 ft/day
  - Max = 96 ft/day
- Sand and gravel aquifer in valley and triangle
  - Min = 106 ft/day
  - Max = 6684 ft/day
  - Mean = 1138 ft/day

Layer 3 Hydraulic Conductivity

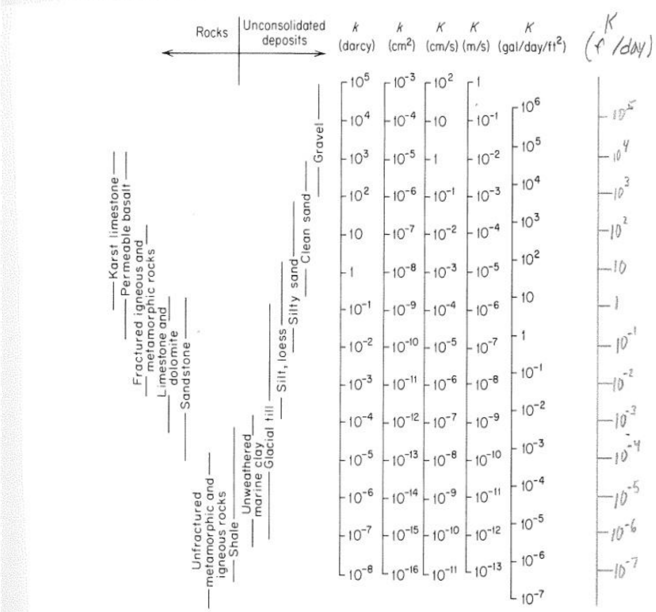


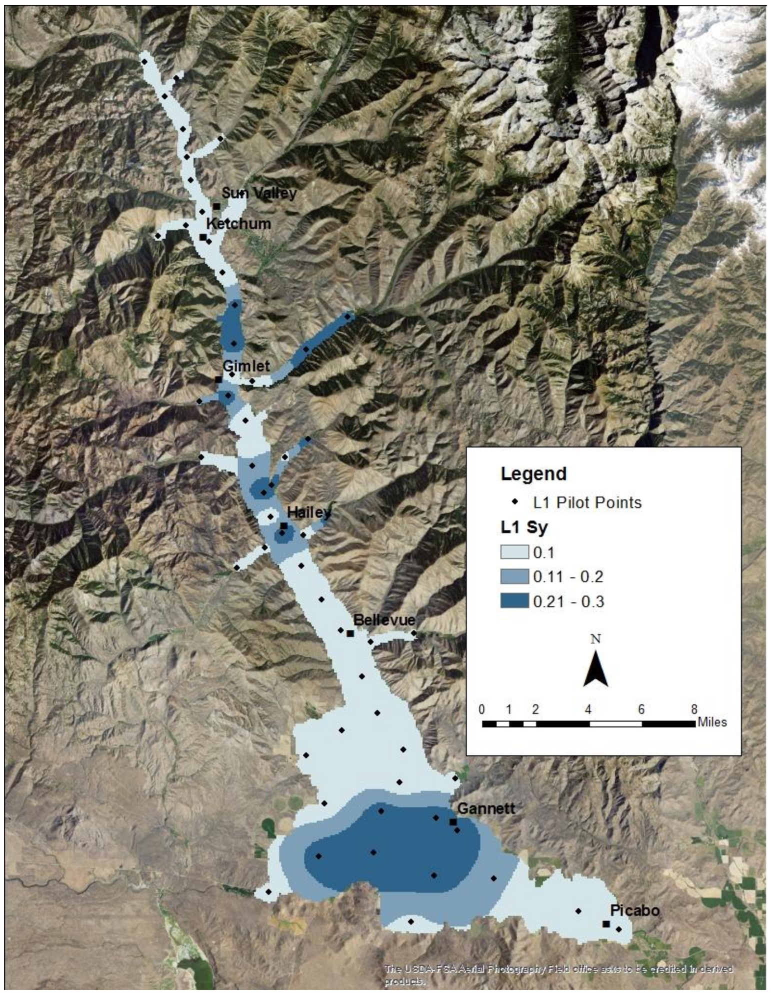
Table 2.3 Conversion Factors for Permeability and Hydraulic Conductivity Units

	Permeability, k*			Hydraulic conductivity, K		
	cm^2	ft^2	darcy	m/s	ft/s	U.S. gal/day/ft^2
cm^2	1	1.08×10^{-3}	1.01×10^{8}	9.80×10^{2}	3.22×10^{3}	1.85×10^{9}
ft^2	9.29×10^{2}	1	9.42×10^{10}	9.11×10^{5}	2.99×10^{6}	1.71×10^{12}
darcy	9.87×10^{-9}	1.06×10^{-11}	1	9.66×10^{-6}	3.17×10^{-5}	1.82×10^{1}
m/s	1.02×10^{-3}	1.10×10^{-6}	1.04×10^{5}	1	3.28	2.12×10^{6}
ft/s	3.11×10^{-4}	3.35×10^{-7}	3.15×10^{4}	3.05×10^{-1}	1	6.46×10^{5}
U.S. gal/day/ft^2	5.42×10^{-10}	5.83×10^{-13}	5.49×10^{-2}	4.72×10^{-7}	1.55×10^{-6}	1

Groundwater, Freeze & Cherry, 1979

- Basalt
  - Min = 5 ft/day
  - Max = 96 ft/day
- Sand and gravel aquifer in valley and triangle
  - Min = 106 ft/day
  - Max = 6684 ft/day
  - Mean = 1138 ft/day

Layer 1 Storage



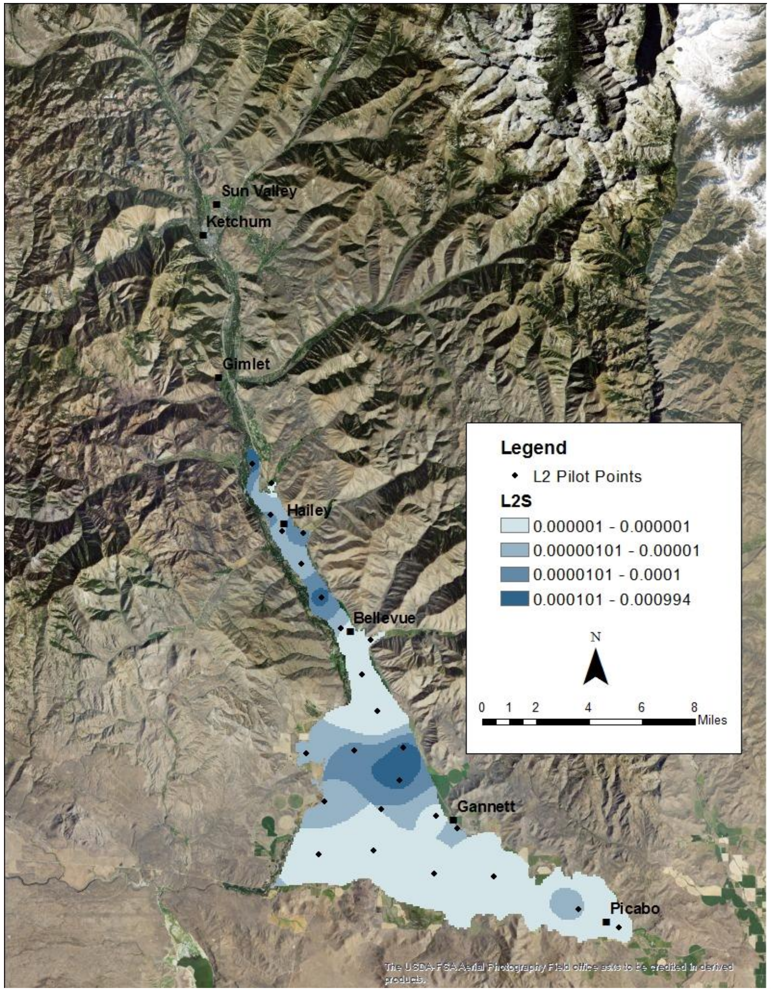
- Layer 1
  - Min = 0.1 ft/day
  - Max = 0.3 ft/day
  - Mean = 0.15 ft/day

Material	Specific Yield (%)		
	min	avg	max
Unconsolidated deposits			
Clay	0	2	5
Sandy clay (mud)	3	7	12
Silt	3	18	19
Fine sand	10	21	28
Medium sand	15	26	32
Coarse sand	20	27	35
Gravelly sand	20	25	35
Fine gravel	21	25	35
Medium gravel	13	23	26
Coarse gravel	12	22	26

Johnson (1967)

IDAHO Department of Water Resources

Layer 2 Storage

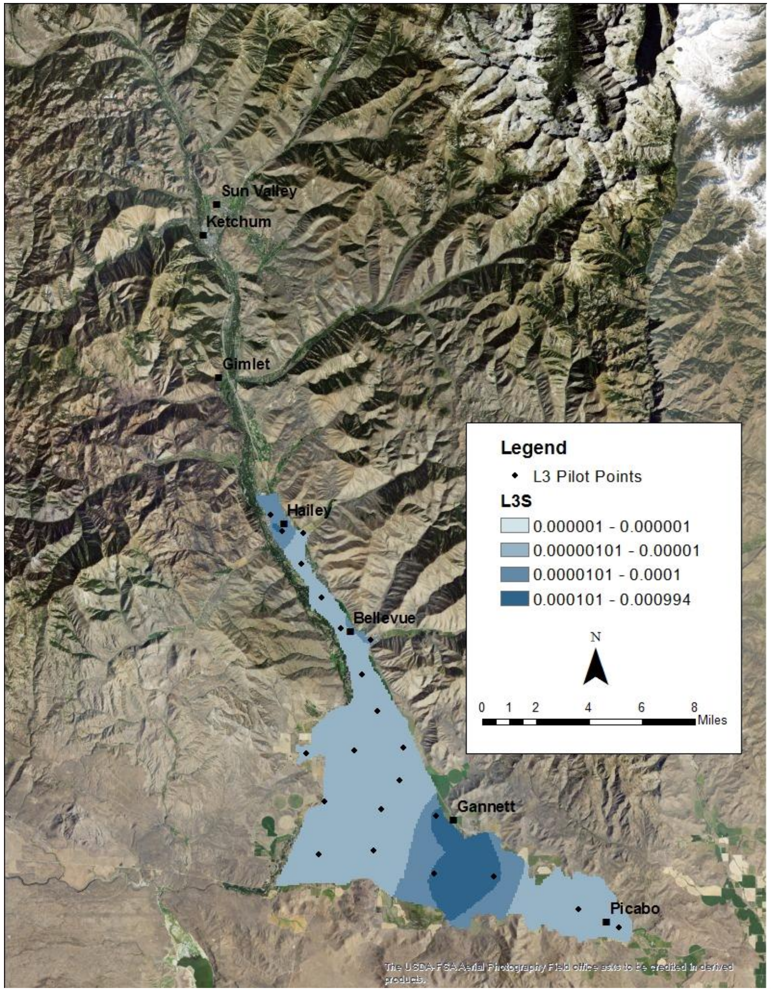


- Layer 2 storage
- Includes basalt in east
- Includes confining layer
  - Min = $1E^{-6}$
  - Max = $1E^{-3}$
  - Mean = $2E^{-5}$

Material	Bulk Modulus of Compression			Specific Storage with β=0		
	E(lb/ft2)			Ss (1/ft) [Ss=γα]		
Plastic Clay	1.00E+004	to	8.00E+004	6.2E-03	to	7.8E-04
Stiff Clay	8.00E+004	to	1.60E+005	7.8E-04	to	3.9E-04
Medium hard clay	1.60E+005	to	3.00E+05	3.9E-04	to	2.1E-04
Loose sand	2.00E+005	to	4.00E+05	3.1E-04	to	1.6E-04
Dense sand	1.00E+006	to	1.60E+06	6.2E-05	to	3.9E-05
Dense sandy gravel	2.00E+006	to	4.00E+06	3.1E-05	to	1.6E-05
Rock, fissured, jointed	3.00E+006	to	6.25E+07	2.1E-05	to	1.0E-06
Rock, sound	6.25E+007			1.0E-06		

Domenico and Mifflin (1965)

Layer 3 Storage

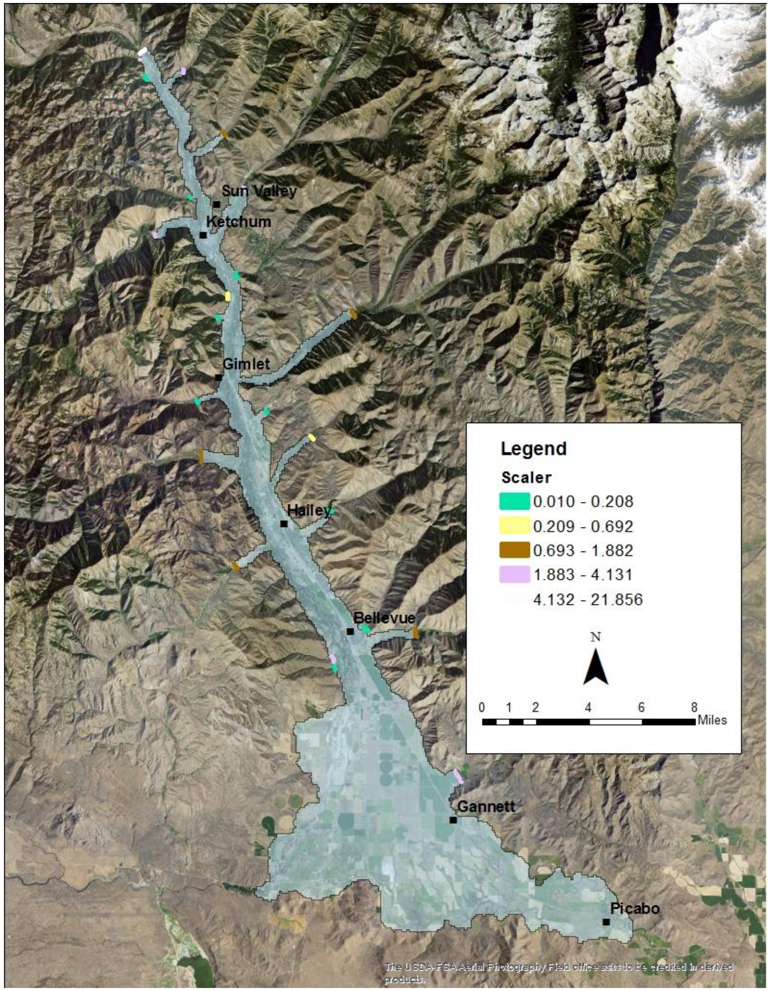


- Layer 3 storage
- Includes basalt in east
  - Min = $5E^{-5}$
  - Max = $6E^{-4}$
  - Mean = $4E^{-4}$

Material	Bulk Modulus of Compression			Specific Storage with β=0		
	E(lb/ft2)			Ss (1/ft) [Ss=γα]		
Plastic Clay	1.00E+004	to	8.00E+004	6.2E-03	to	7.8E-04
Stiff Clay	8.00E+004	to	1.60E+005	7.8E-04	to	3.9E-04
Medium hard clay	1.60E+005	to	3.00E+05	3.9E-04	to	2.1E-04
Loose sand	2.00E+005	to	4.00E+05	3.1E-04	to	1.6E-04
Dense sand	1.00E+006	to	1.60E+06	6.2E-05	to	3.9E-05
Dense sandy gravel	2.00E+006	to	4.00E+06	3.1E-05	to	1.6E-05
Rock, fissured, jointed	3.00E+006	to	6.25E+07	2.1E-05	to	1.0E-06
Rock, sound	6.25E+007			1.0E-06		

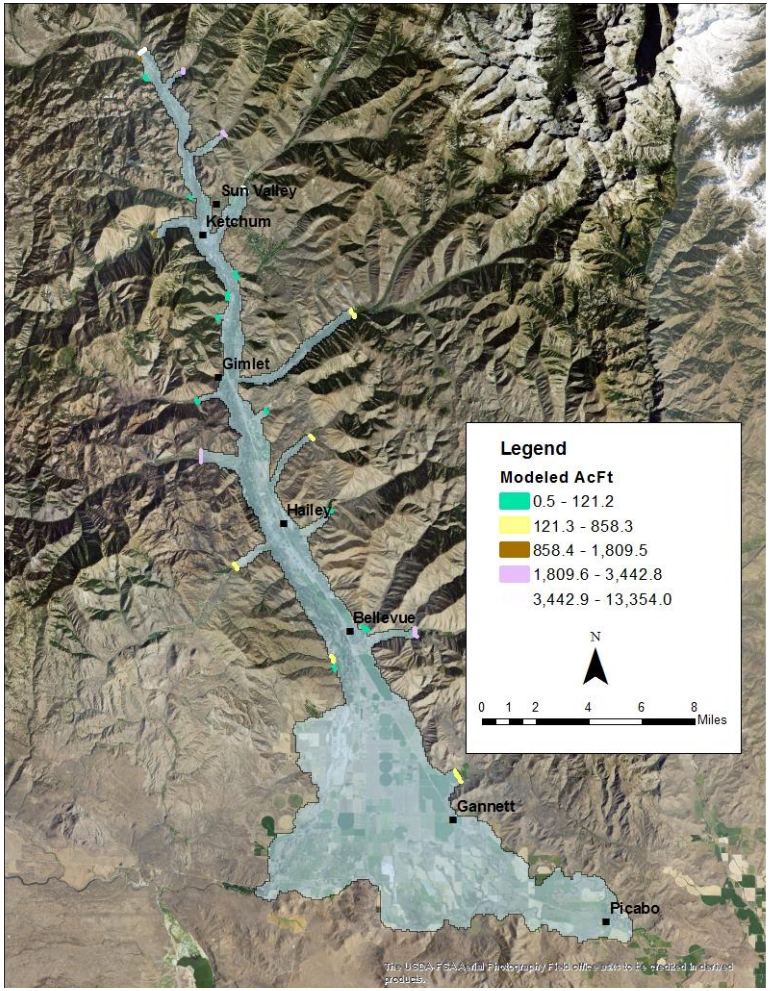
Domenico and Mifflin (1965)

Tributary Underflow



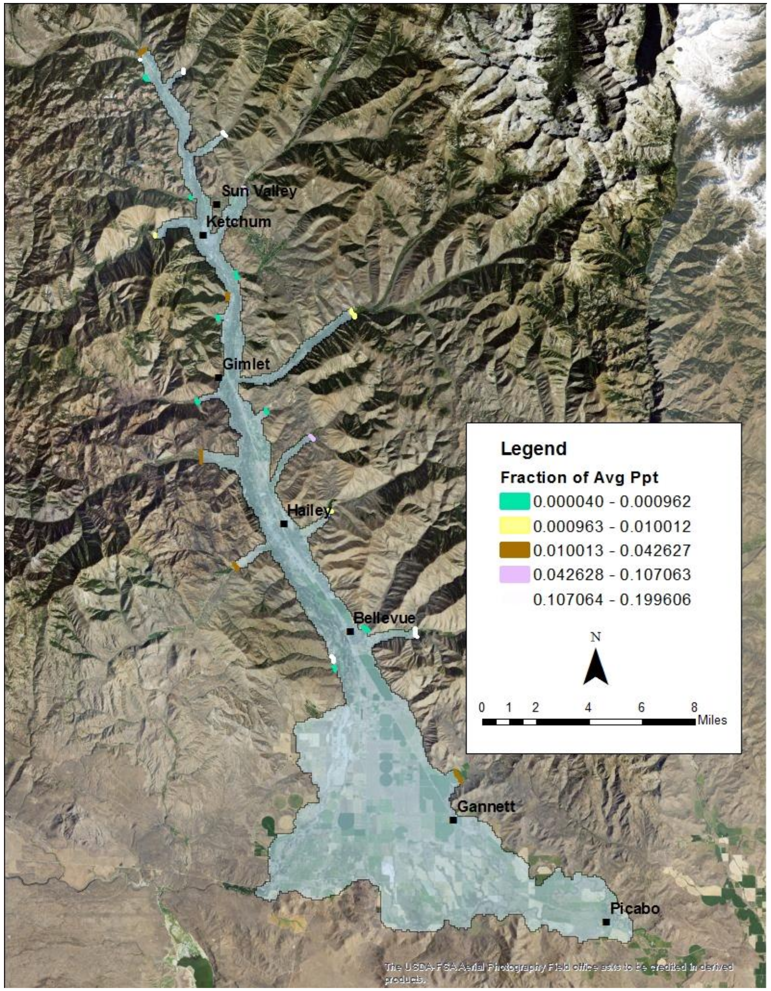
- Trib underflow adjusted using
  - Adjustment factors
    - Adjust average flux

Tributary Underflow



Tributary	Scalar	Av Basin Precip AcFt	Modeled AcFt	% Basin Av
Adams Gulch	0.01	17600	8.51	0.05%
Chocolate Gulch	0.01	864	0.58	0.07%
Cold Springs Gulch	0.69	3,341	121.17	3.63%
Clear Creek	0.01	2,288	1.17	0.05%
Cove Canyon	2.52	11,200	360.66	3.22%
Croy Creek	1.22	23,595	858.26	3.64%
Deer Creek	1.88	74,213	2744.17	3.70%
Eagle Creek	3.40	17,248	3442.80	19.96%
Elkhorn Gulch	0.01	12,757	0.51	0.00%
East Fork	1.30	120,629	610.00	0.51%
Greenhorn Gulch	0.01	30,464	6.81	0.02%
Indian Creek	0.33	10,149	786.58	7.75%
Lake Creek	1.44	17,280	3440.42	19.91%
Lees Gulch	2.99	2,240	355.80	15.88%
Ohio Gulch	0.01	4,270	2.14	0.05%
Oregon Gulch	3.72	6,919	1278.07	18.47%
Quigley Creek	0.21	15,504	116.89	0.75%
Seamans Creek	1.46	18,768	2828.20	15.07%
Slaughterhouse Gulch	0.01	11,509	5.04	0.04%
Trail Creek	4.13	111,274	11913.32	10.71%
Townsend Gulch	0.02	960	0.92	0.10%
Upper Big Wood River	21.86	313,278	13354.02	4.26%
Warm Springs Creek	3.75	180,735	1809.46	1.00%

Tributary Underflow



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Cold Springs Gulch	0.69	3,341	121.17	3.63%
Clear Creek	0.01	2,288	1.17	0.05%
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East Fork	1.30	120,629	610.00	0.51%
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Indian Creek	0.33	10,149	786.58	7.75%
Lake Creek	1.44	17,280	3440.42	19.91%
Lees Gulch	2.99	2,240	355.80	15.88%
Ohio Gulch	0.01	4,270	2.14	0.05%
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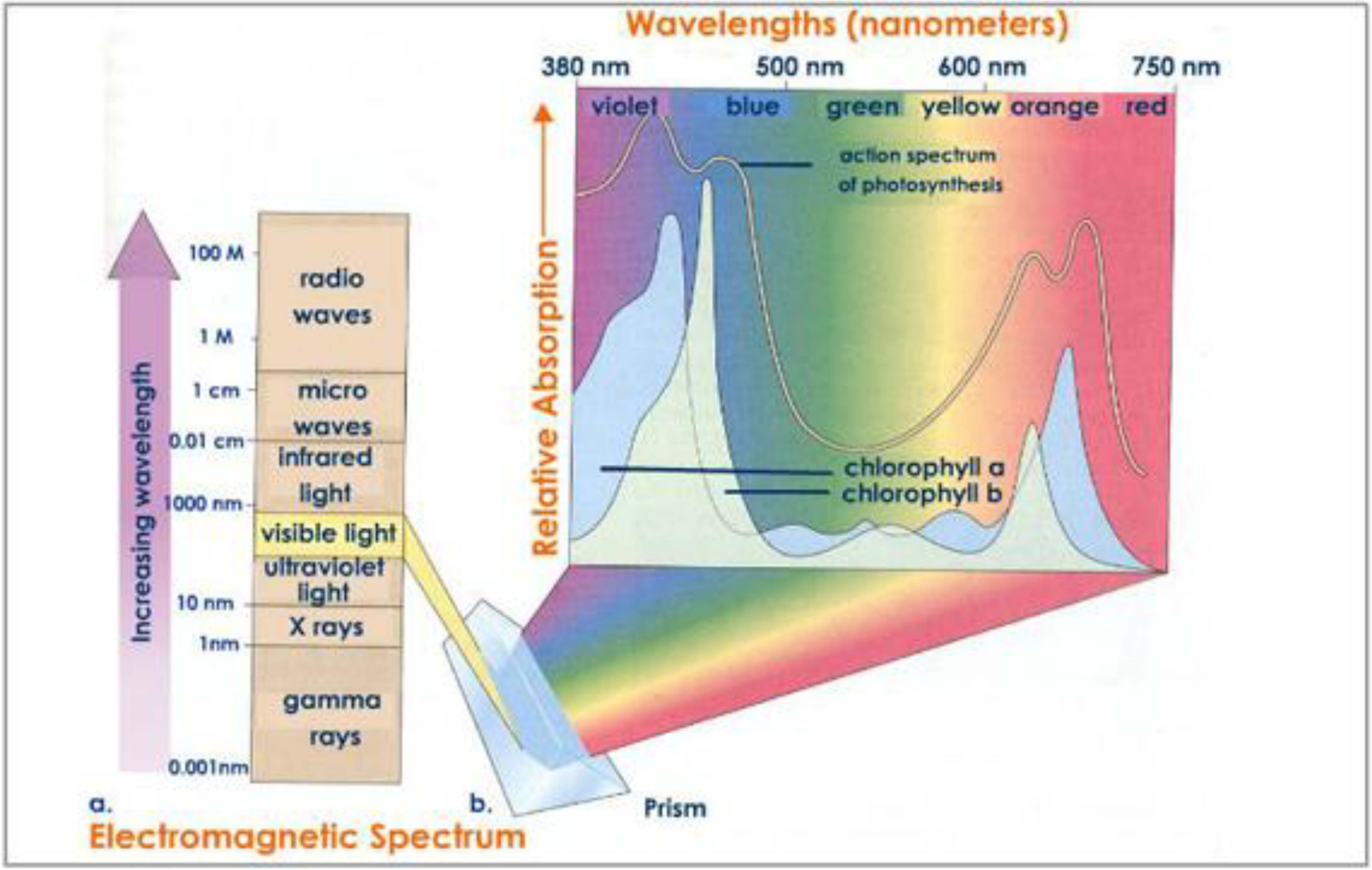
Townsend Gulch	0.02	960	0.92	0.10%
Upper Big Wood River	21.86	313,278	13354.02	4.26%
Warm Springs Creek	3.75	180,735	1809.46	1.00%


Wavelengths (nanometers)
380 nm
500 nm
600 nm
750 nm
violet
blue
green
yellow
orange
red
action spectrum of photosynthesis
Relative Absorption
chlorophyll a
chlorophyll b
Increasing wavelength
100 M
radio waves
1 M
1 cm
micro waves
0.01 cm
infrared light
1000 nm
visible light
ultraviolet light
10 nm
X rays
1nm
gamma rays
0.001nm
a.
b.
Prism
Electromagnetic Spectrum

Normalized Difference Vegetative Index (NDVI)

$$NDVI = \frac{\mathrm{NIR} - \mathrm{VIS}}{\mathrm{NIR} + \mathrm{VIS}}$$

- Near-infrared (NIR) and photosynthetic spectrum (VIS) are about equal i.e. both reflected snow
  - NDVI ~ 0
- Mixed sage and grass – NIR and some of VIS reflected
  - NDVI small (0.2-0.4)
- Well watered crops – NIR reflected and VIS adsorbed
  - NDVI ~ 1.0