Quantifying the Relationship Between Stream Flow and Groundwater Elevation

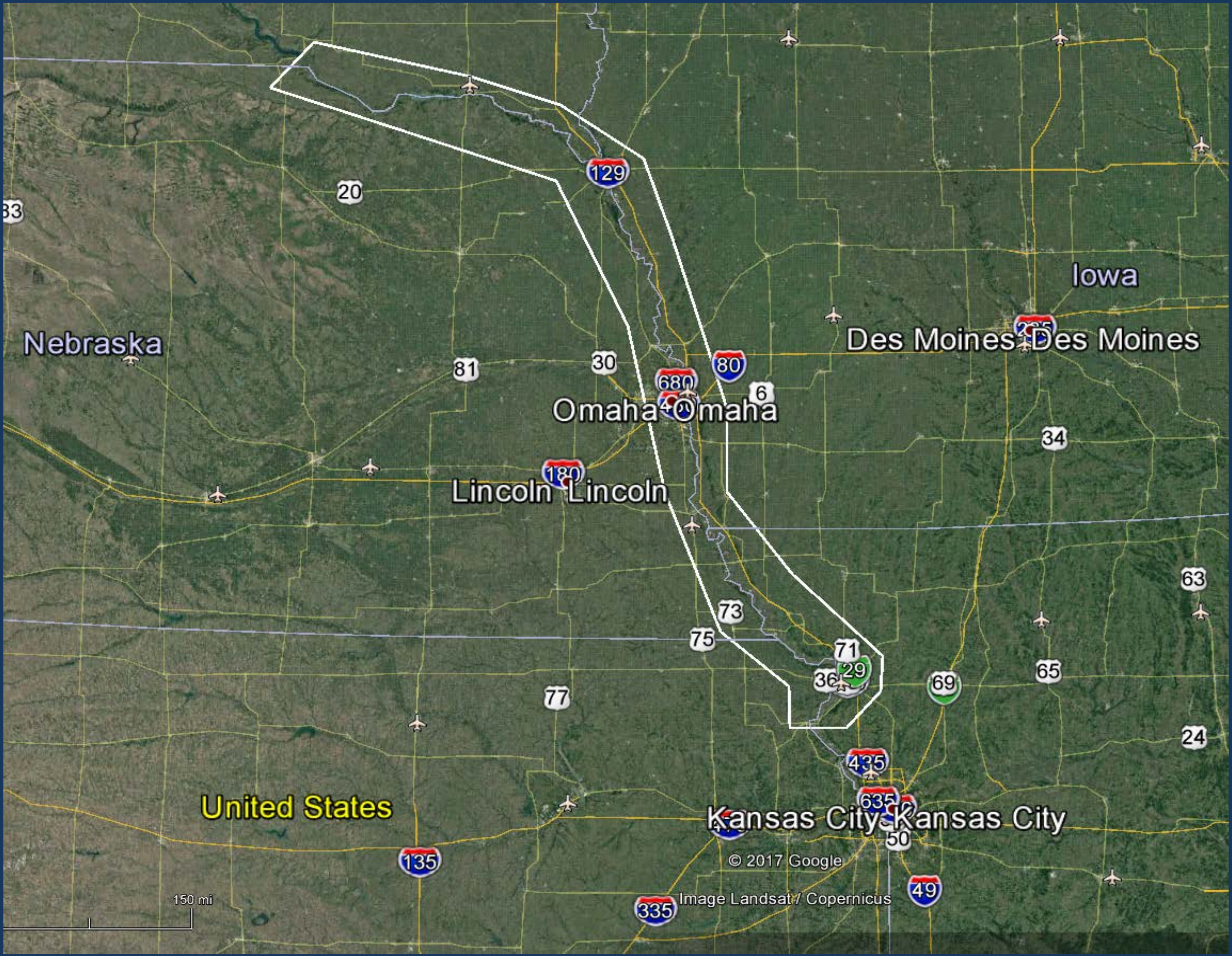
To Assess Stream Depletion and the Effects on Groundwater-Dependent Ecosystems

Dr. Andrew A. Kopania, EMKO Environmental, Inc
Joseph Turner, Kleinfelder, Inc.
Anthony Wohletz, Kleinfelder, Inc.

Outline

1) **Missouri River Case (DOJ & Army Corps)**
   - Flooding 2007 – 2014
2) **Groundwater – Surface Water Relationships**
   - Compared USGS well data with stream gage data
   - 10,000s of data points
3) **Example applications in California**

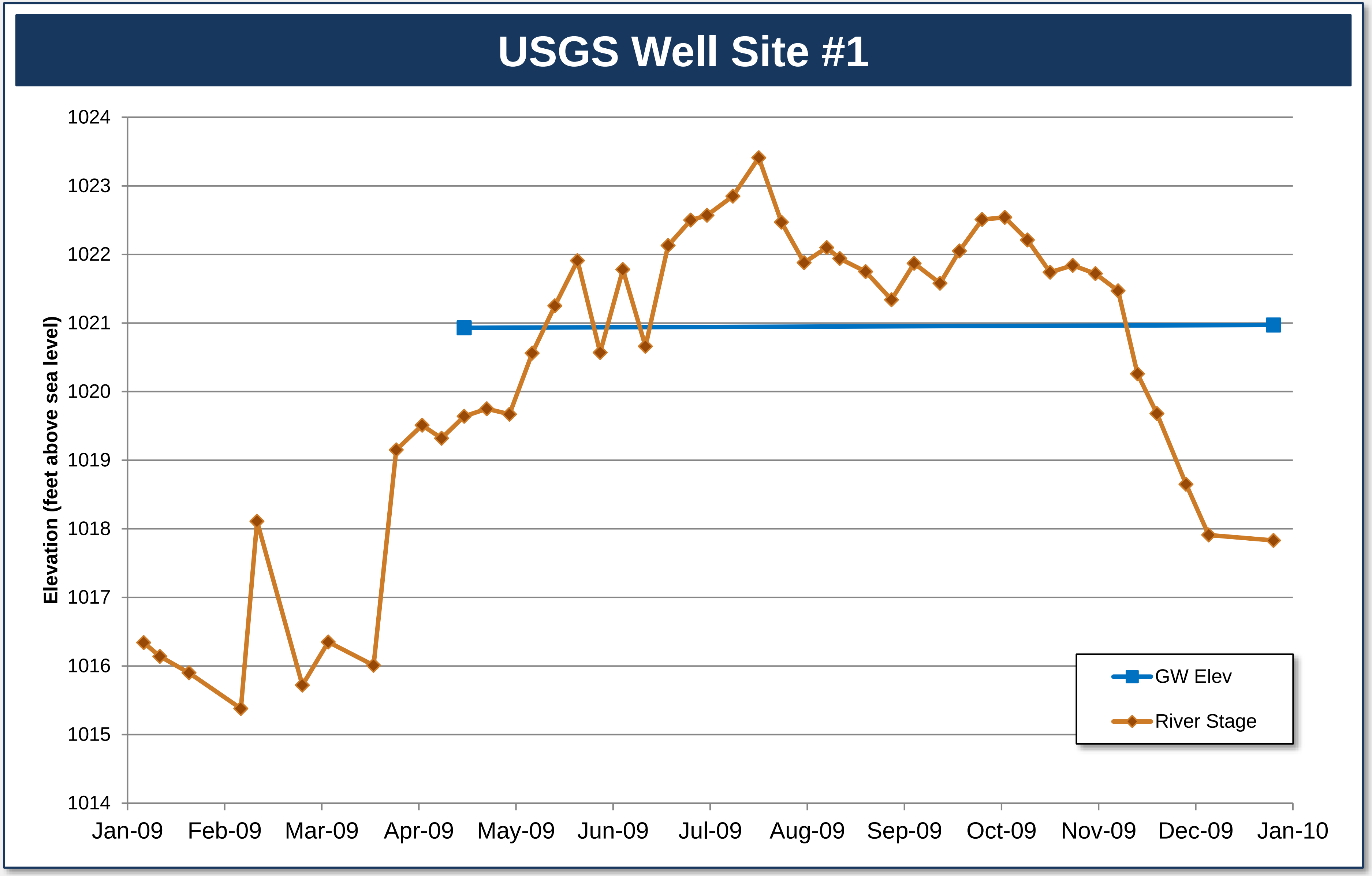
Missouri River Case: More than 400 miles, 372 plaintiffs



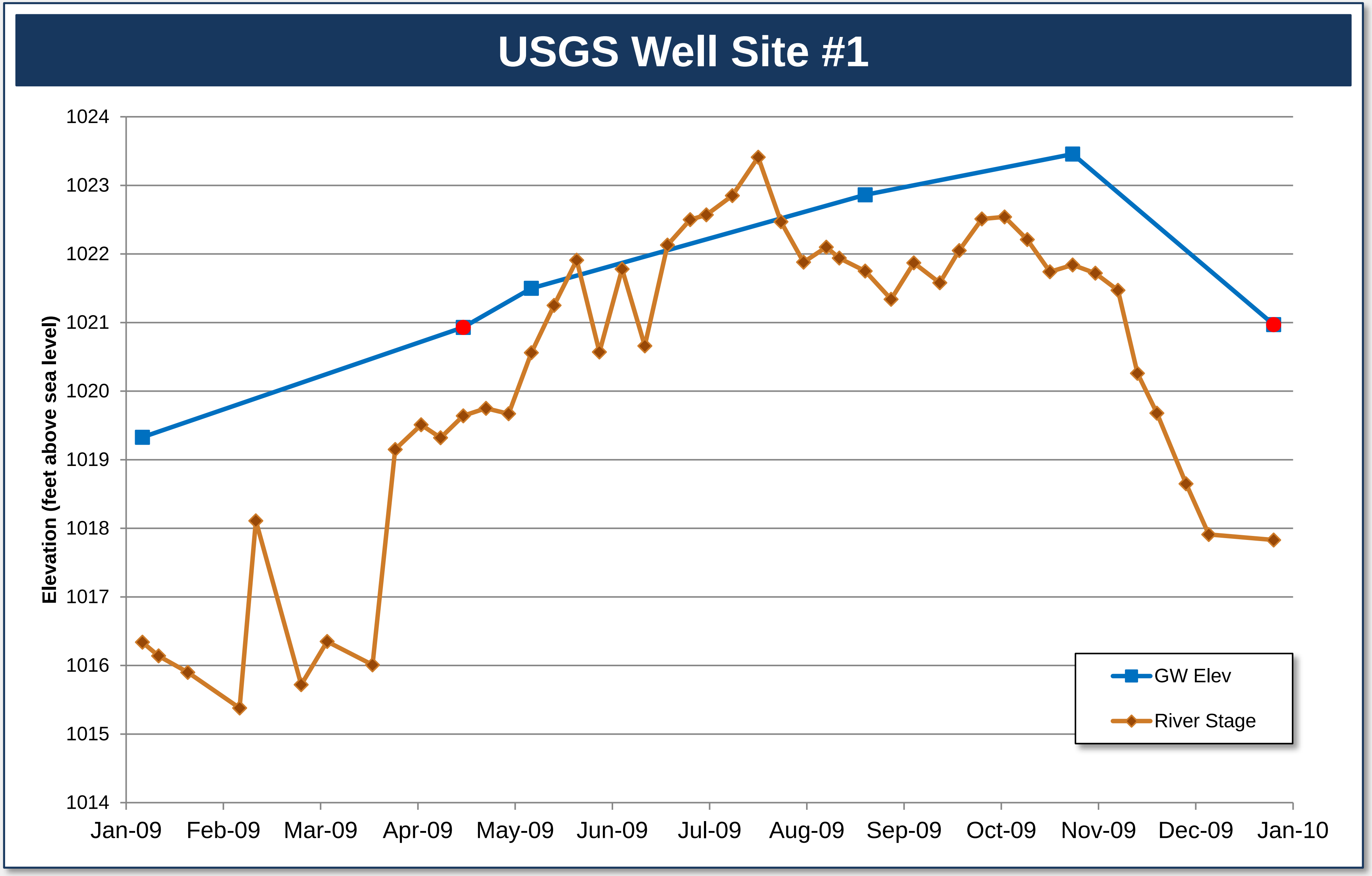
Relevant Site-Specific Data

- Numerous wells in the Study Area
- Groundwater measurements are infrequent and irregular in most wells
  - Cf. GAMA wells and water data library
- Frequent and persistent groundwater measurements are critical for comparison with river conditions
- *Example:*

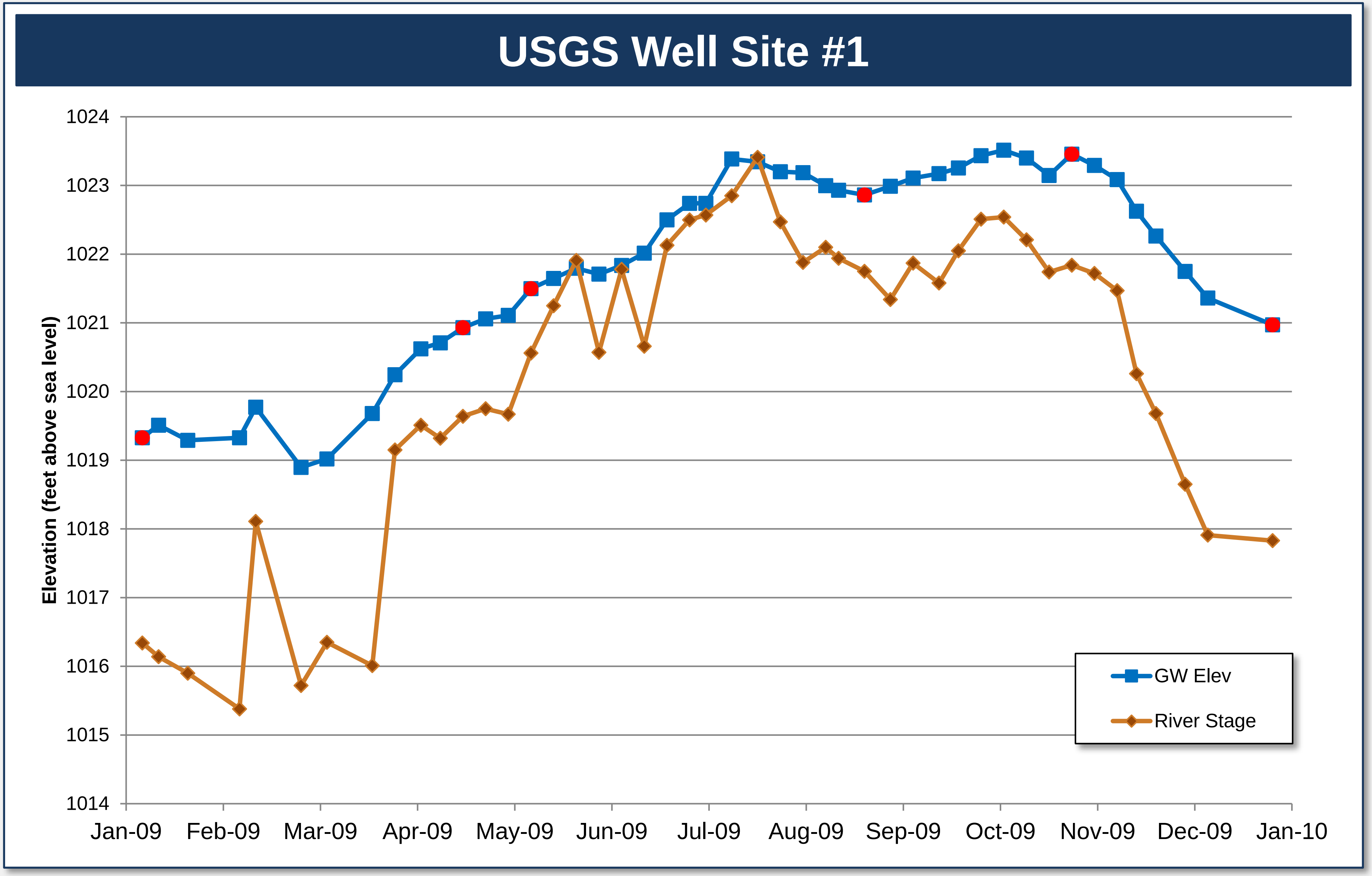
Decatur Gauge Data and Semiannual Groundwater Measurements



More Frequent Groundwater Measurements



Very Frequent Groundwater Measurements



Relevant Site-Specific Data

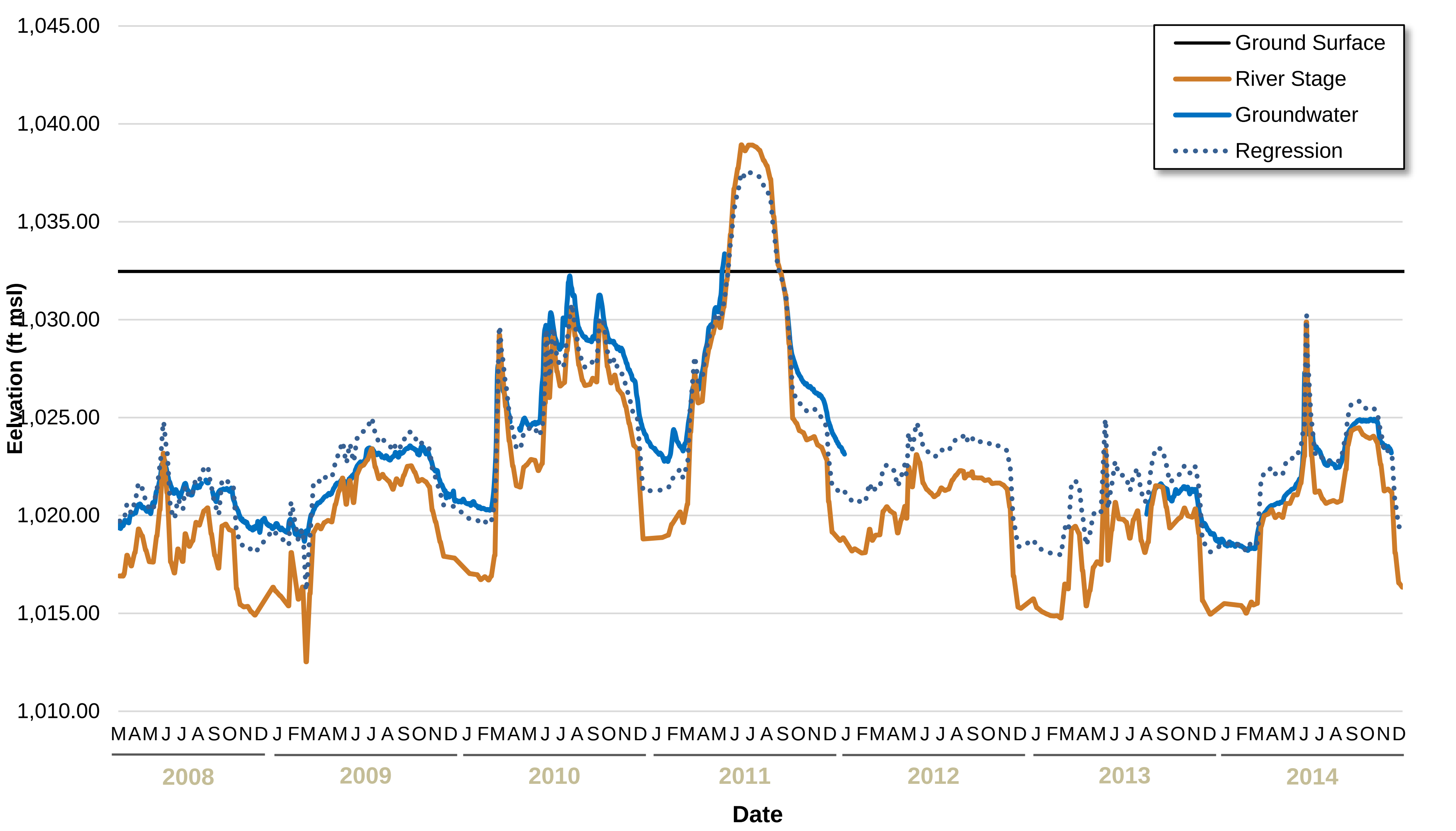
- **Identified four locations where very frequent groundwater measurements were made over several alleged seepage-flooding years**
- **Based on U.S. Army Corps and U.S. Geological Survey monitoring studies of river levels and groundwater elevations**

Relevant Site-Specific Data: USGS Well Site 1

- Well located **185 ft** from left (east) bank
- Data from 2008-2014, except 2011 flood and 2012
- River levels from Decatur, Nebraska gage
  - 11 miles upstream
  - Gage levels adjusted per USGS (1998) – 1 ft/mile

Relevant Site-Specific Data: USGS Well Site 1

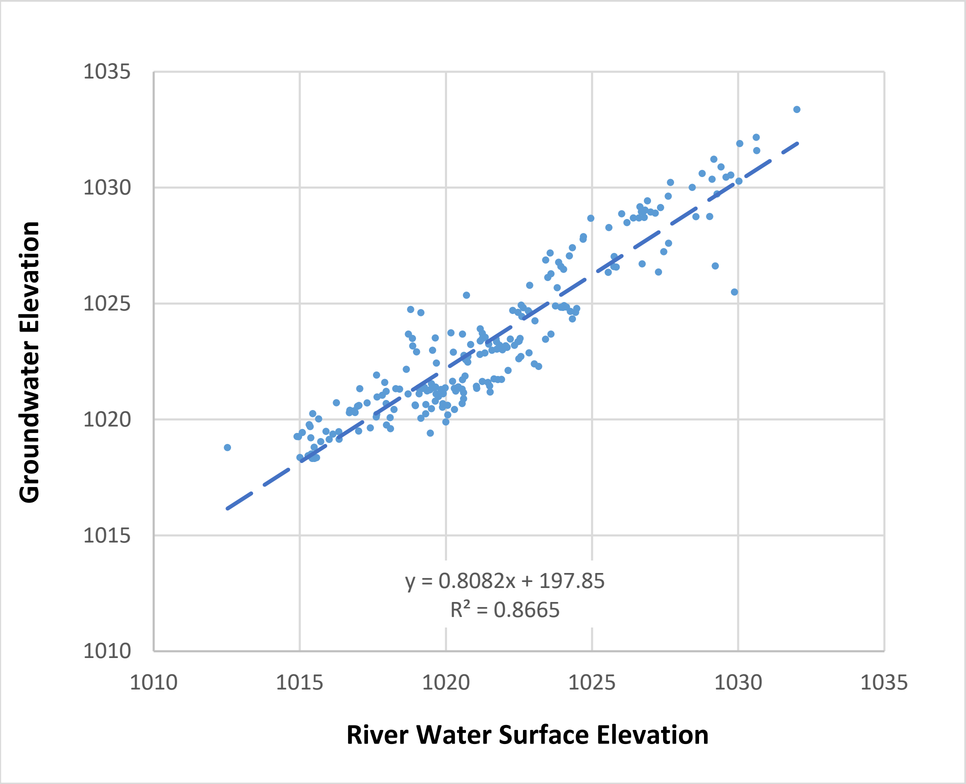
Timeseries Data



Relevant Site-Specific Data: USGS Well Site 1

- Regression model
- Slope = 0.81
  - Implies GW change is 81% of river level change
- No lag in response
- Groundwater higher than river except when river above its banks
  - Flow is toward river (gaining stream)

Figure 8: USGS Well Site 1 Regression Model

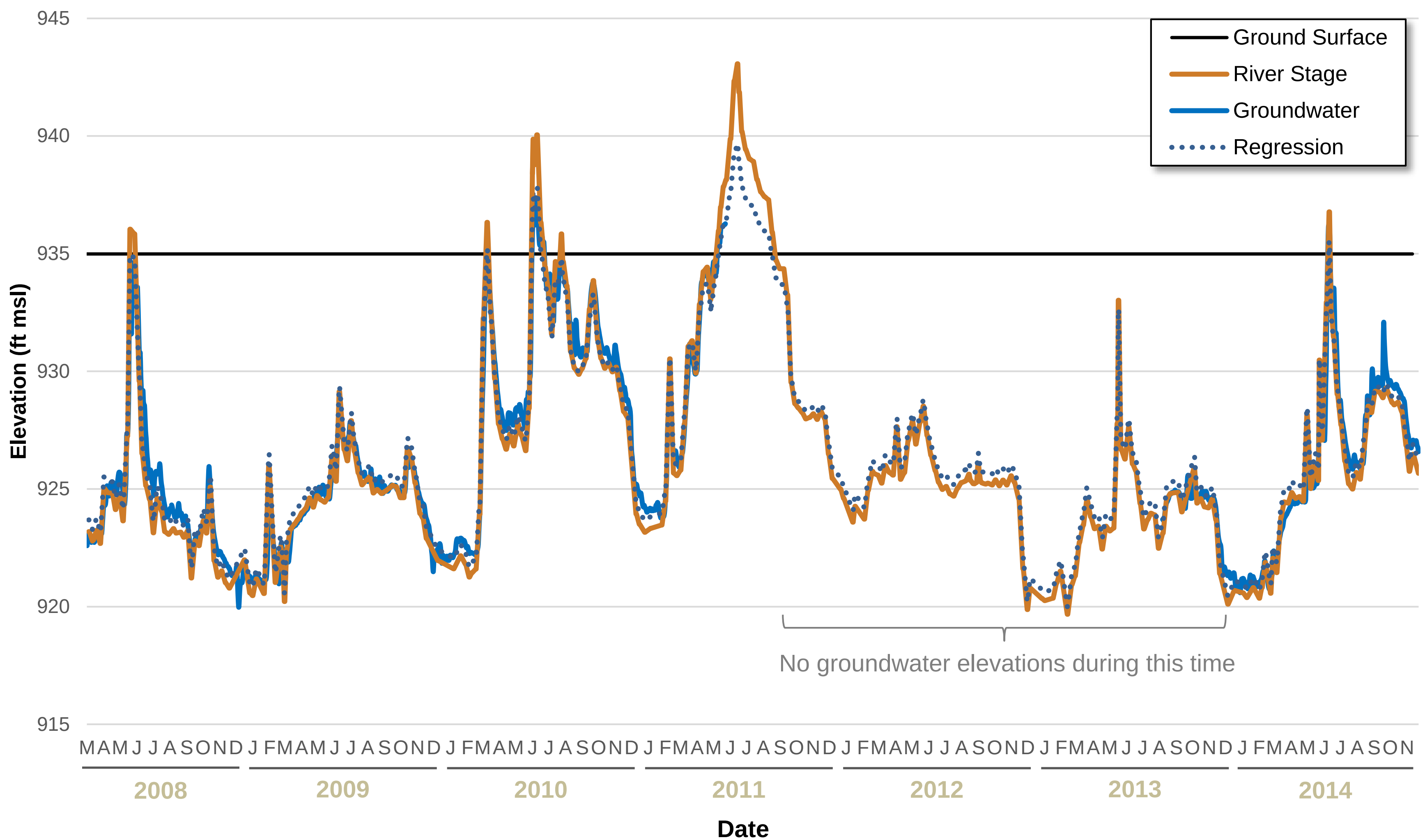


Relevant Site-Specific Data: USGS Well Site 2

- Well located **375 ft** from left (east) bank
- Data from 2008-2014, except 2011 flood and 2012
- River levels from Nebraska City, Nebraska gage
  - 9 miles downstream
  - Gage levels adjusted per USGS (1998) – 1 ft/mile

Relevant Site-Specific Data: USGS Well Site 2

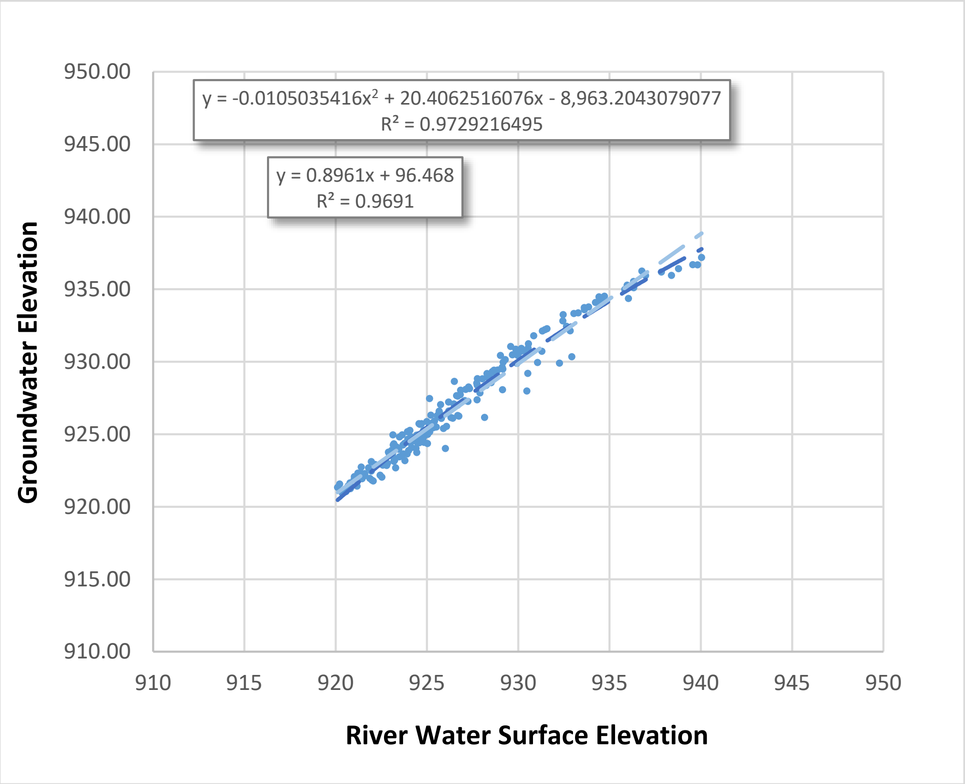
Timeseries Data



Relevant Site-Specific Data: USGS Well Site 2

- Regression model
- Slope = 0.9
  - Implies GW change is 90% of river level change
- No lag in response
- Groundwater higher than river except when river above its banks
  - Flow is toward river (gaining stream)

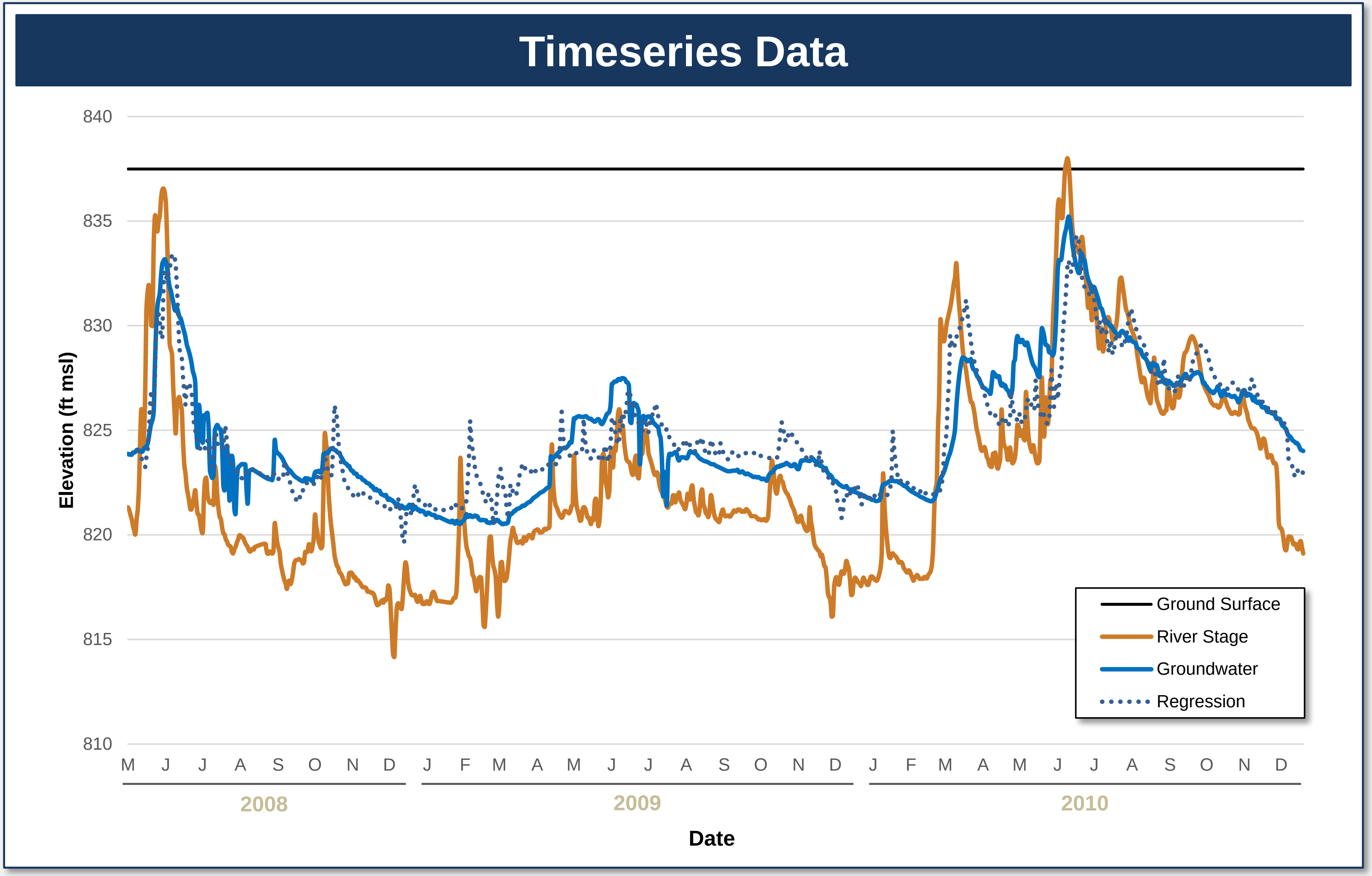
Figure 10. USGS Well Site 2 Regression Model



Relevant Site-Specific Data: USGS Well Site 3-9

- Well located **2,500 ft** from left (east) bank
- Data from 2008-2010 and limited periods from 1995-1998
- River levels from Rulo, Nebraska gage
  - 26 miles upstream
  - Gage levels adjusted per USGS (1998) – 1 ft/mile

Relevant Site-Specific Data: USGS Well Site 3-9



Relevant Site-Specific Data: USGS Well Site 3-9

- Regression model with 7-day lag in response
- Slope = 0.62
  - Implies GW change is 62% of river level change
- Groundwater higher than river except during peak flood pulses
  - Flow is toward river (gaining stream)

Figure 12. USGS Well Site 3-9 Lag Analysis

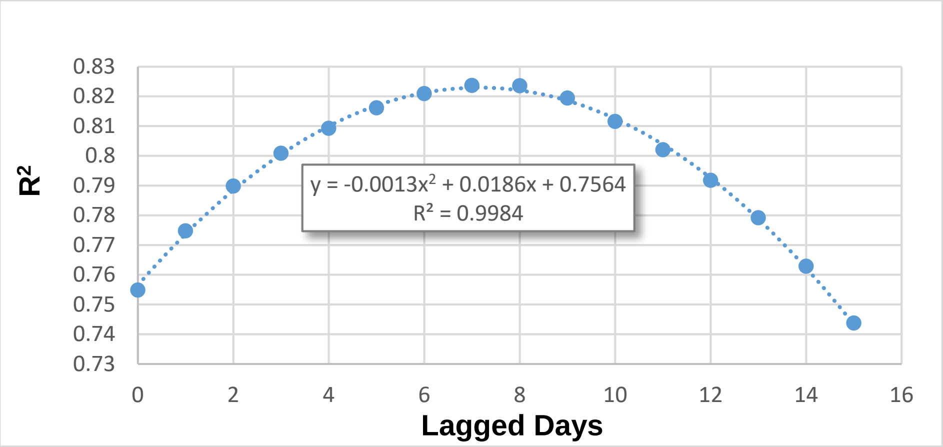
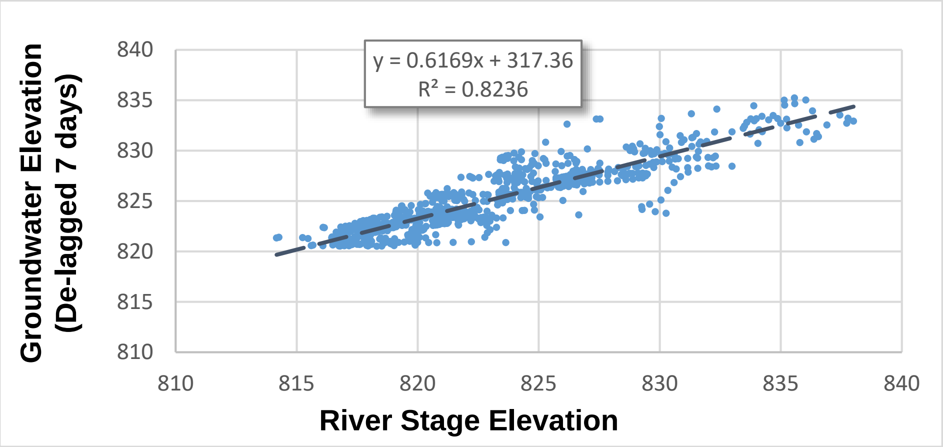
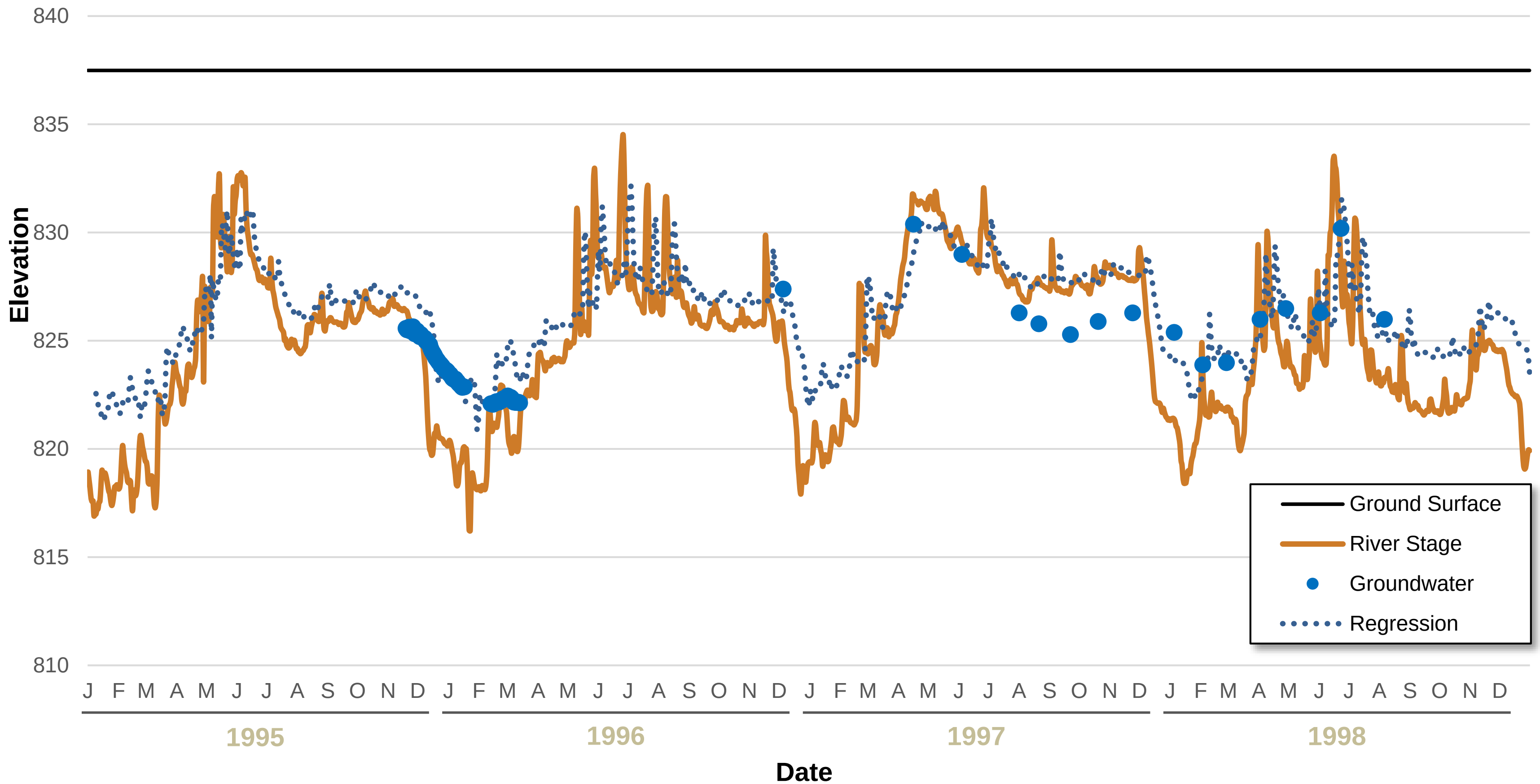


Figure 13. USGS Site 3-9 Regression Model



Relevant Site-Specific Data: USGS Well Site 3-9

1995-1998 Timeseries Data



Groundwater data also available from 1995 to 1998

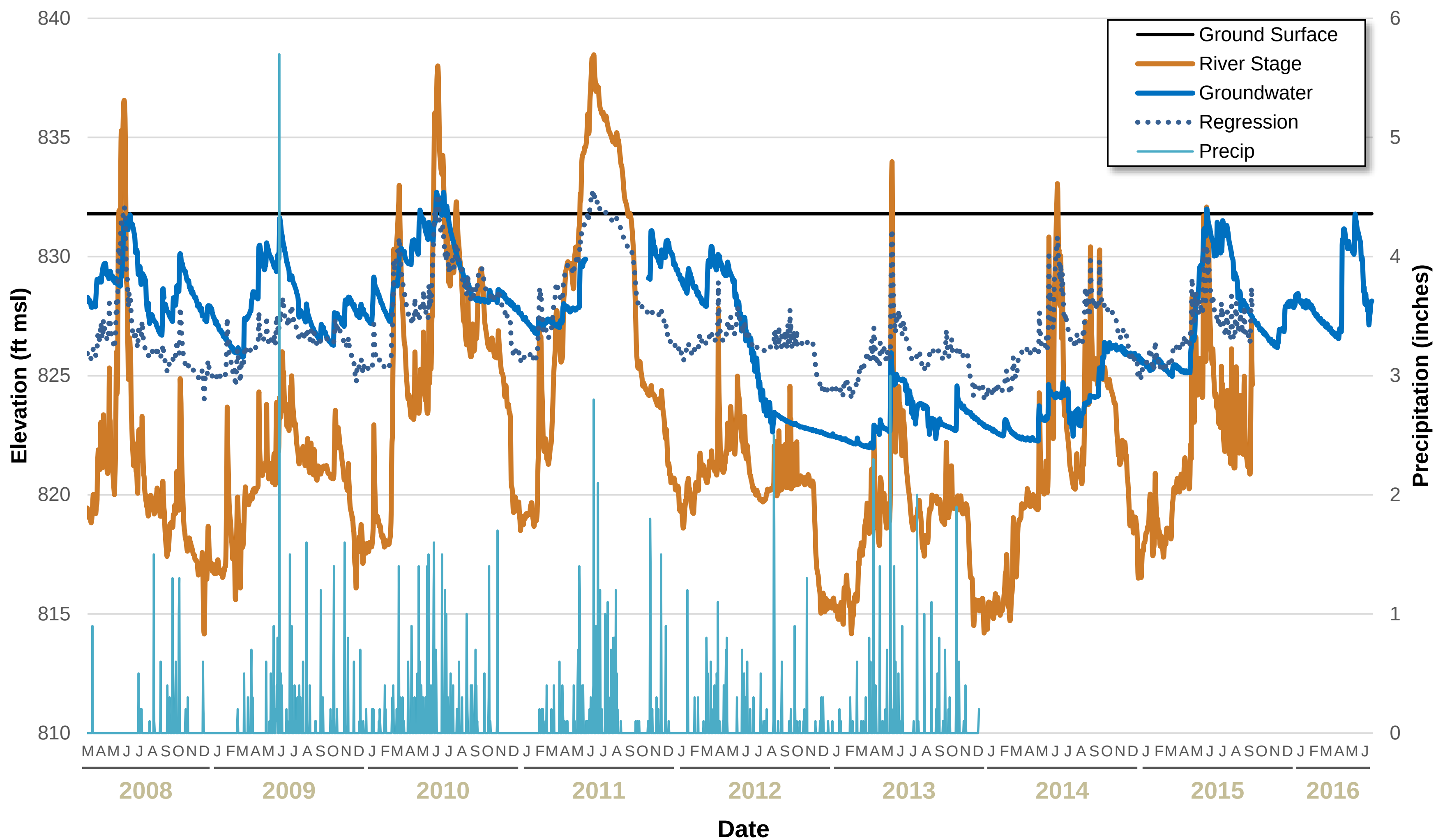
Generally show the same correlation to river level

Relevant Site-Specific Data: USGS Well Site 3-7

- Well located **12,000 ft** from left (east) bank
- Data from 2008-2016
- River levels from Rulo, Nebraska gage
  - 26 miles upstream
  - Gage levels adjusted per USGS (1998) – 1 ft/mile

Relevant Site-Specific Data: USGS Well Site 3-7

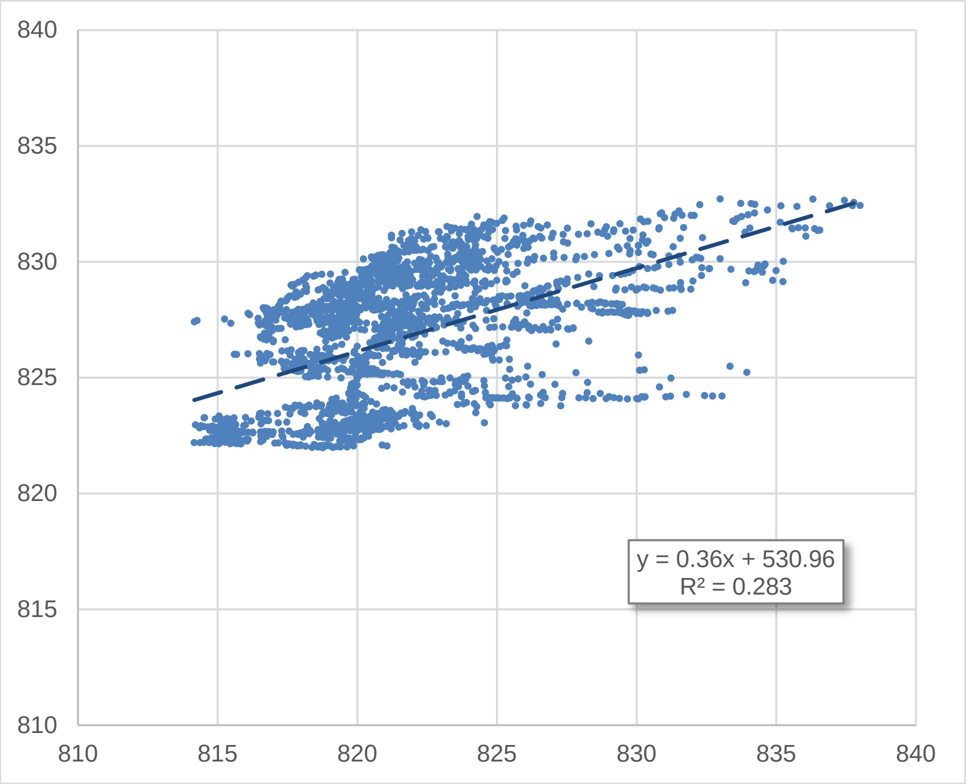
Timeseries Data



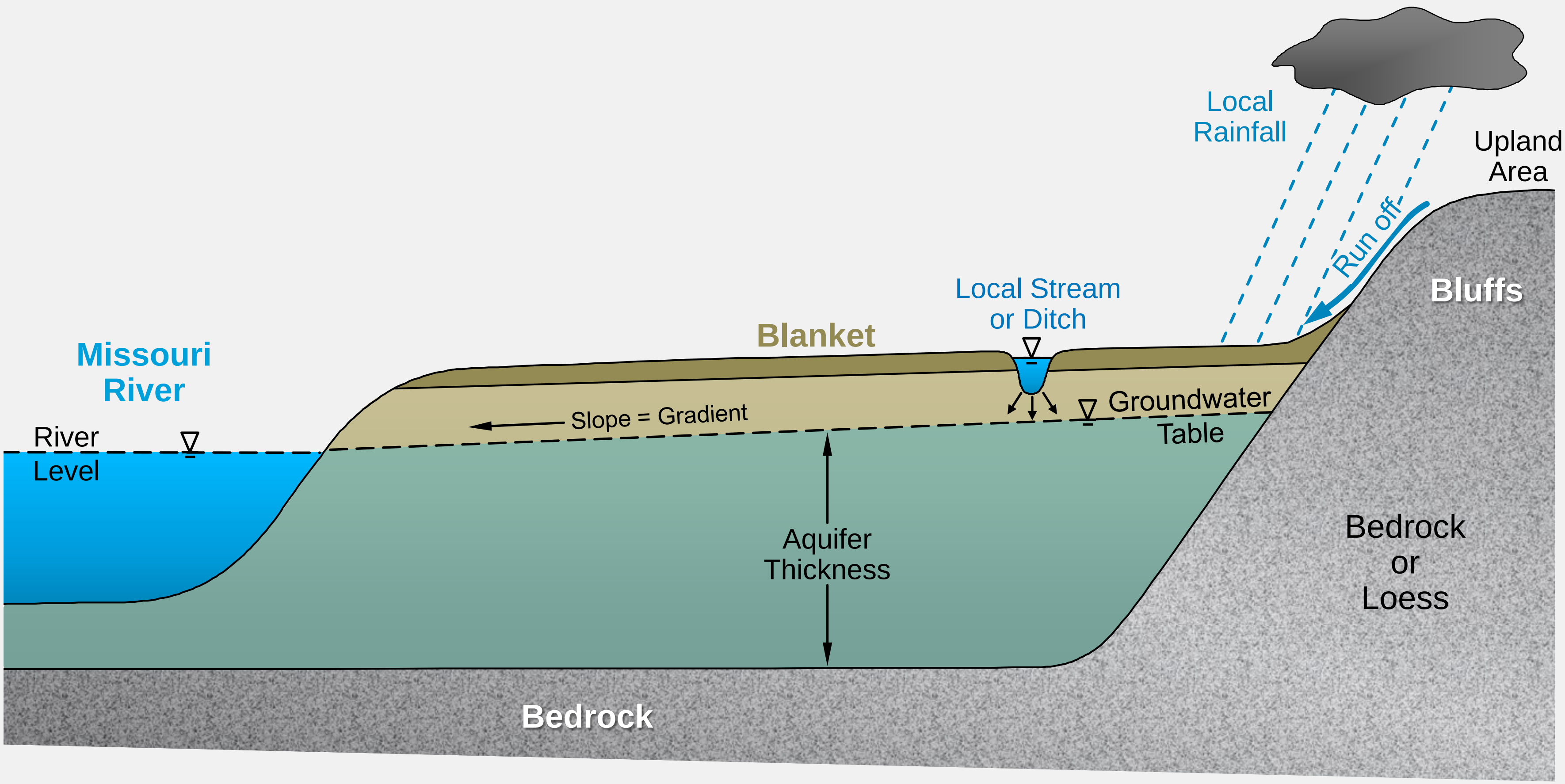
Relevant Site-Specific Data: USGS Well Site 3-7

- Regression model
- Poor correlation
  - Under predicts 2008 to mid-2012
  - Over predicts mid-2012 to mid-2014
- No lag despite distance
- Implies local recharge is dominant
- Groundwater generally higher than river except during major flood events
  - Flow is toward river (gaining stream)

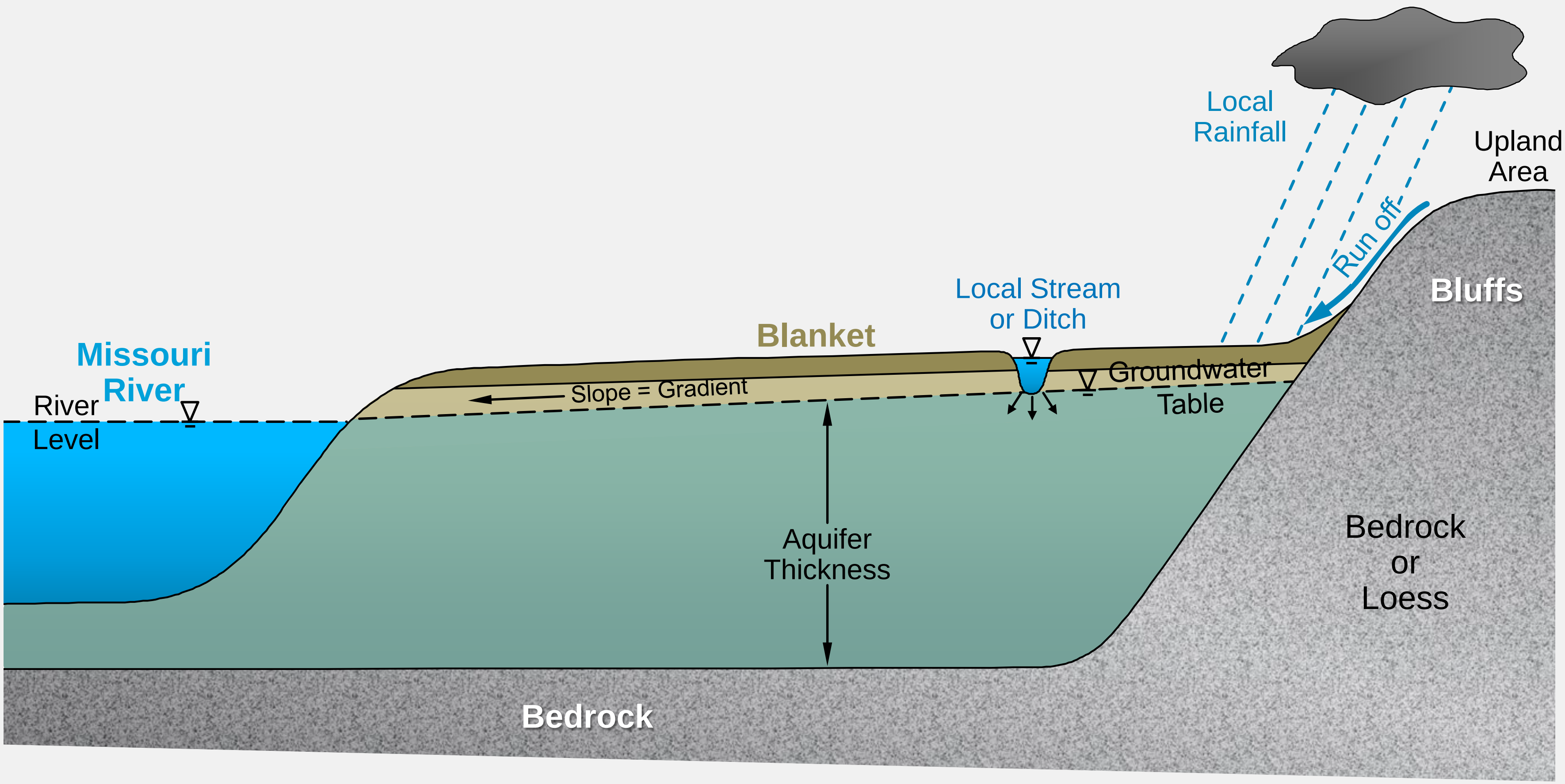
Figure 16. USGS Site 3-7 Regression Model



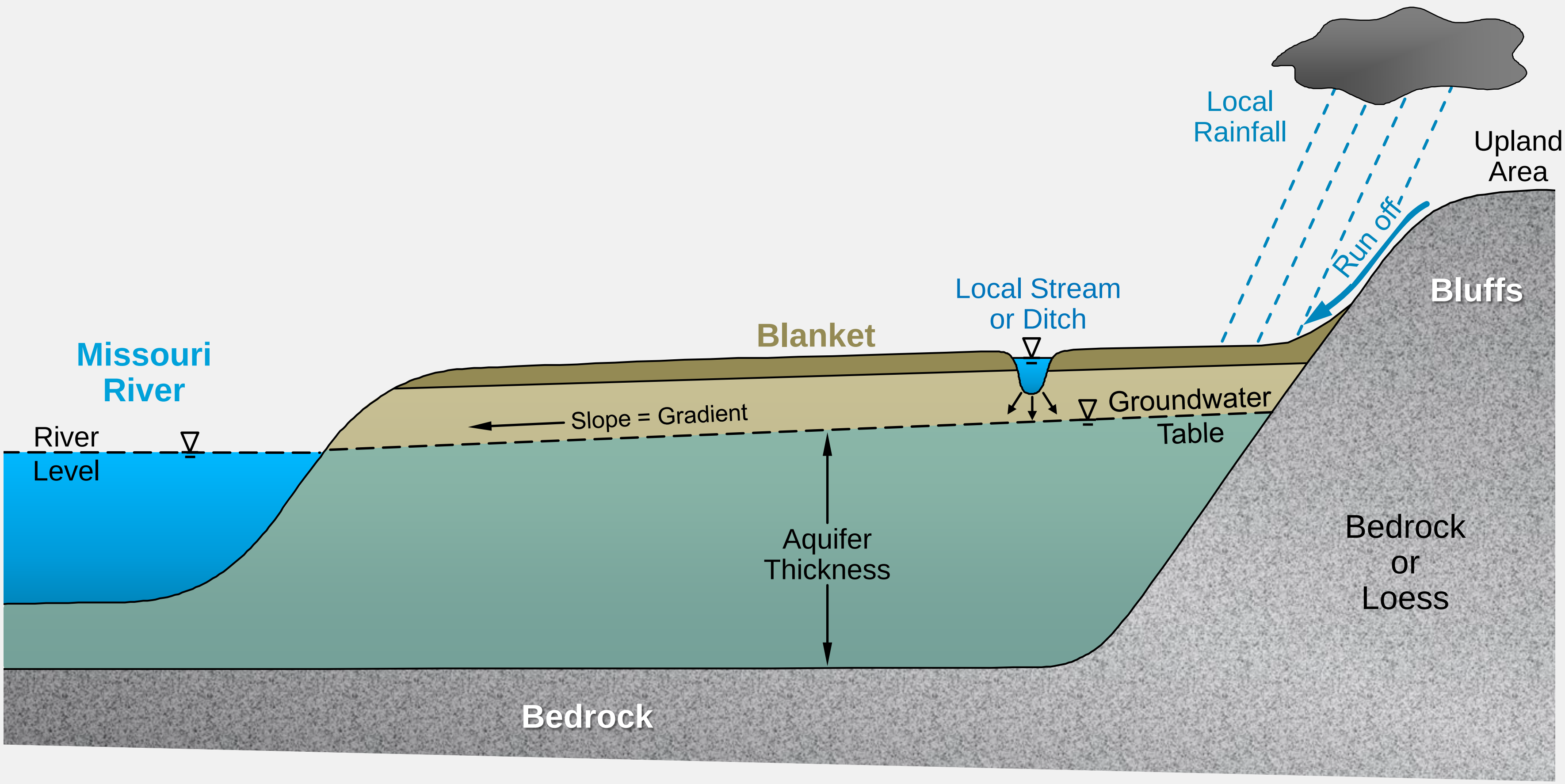
River Stage: Normal River Level



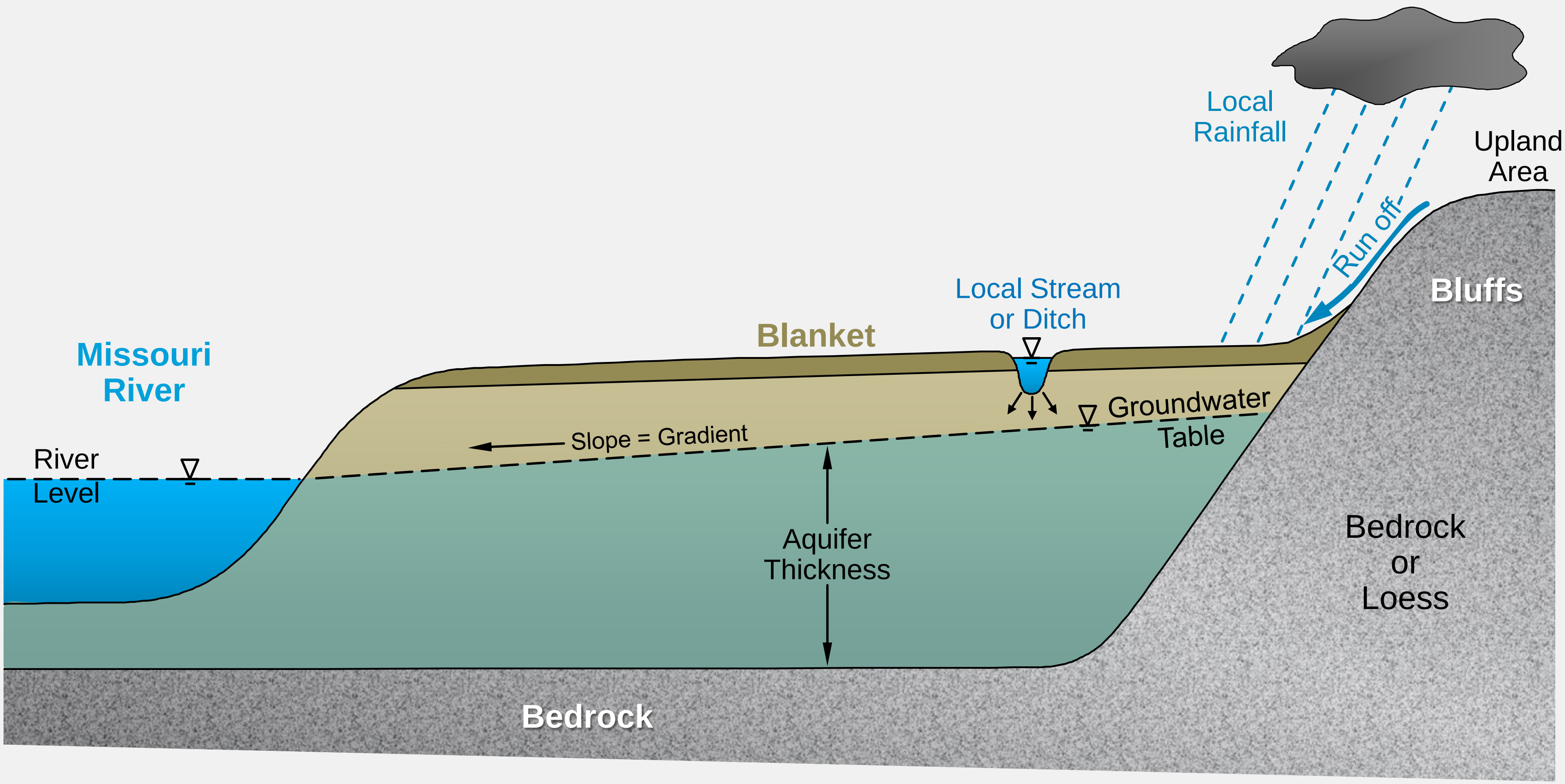
River Stage: High River Level



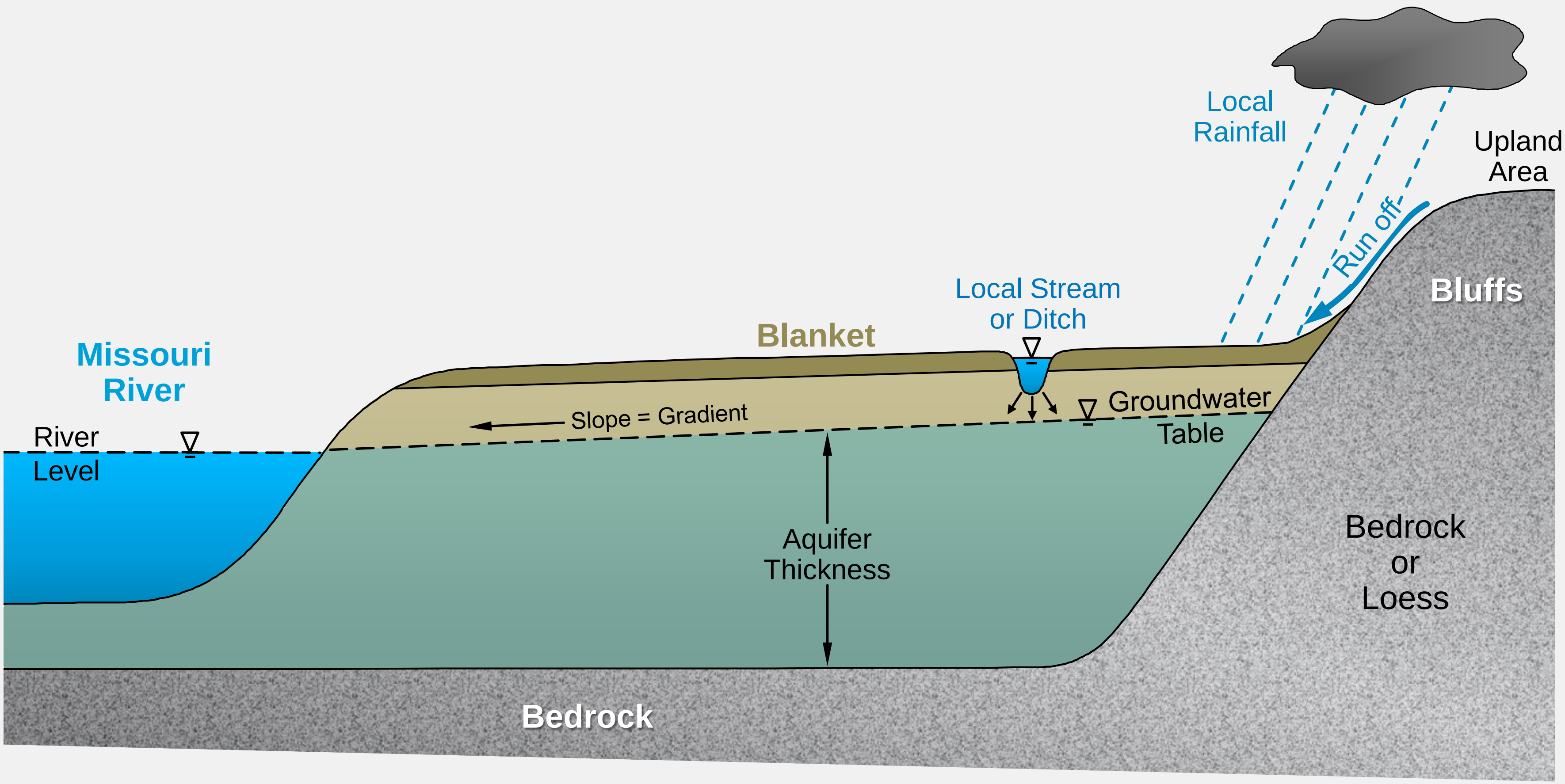
River Stage: Normal River Level



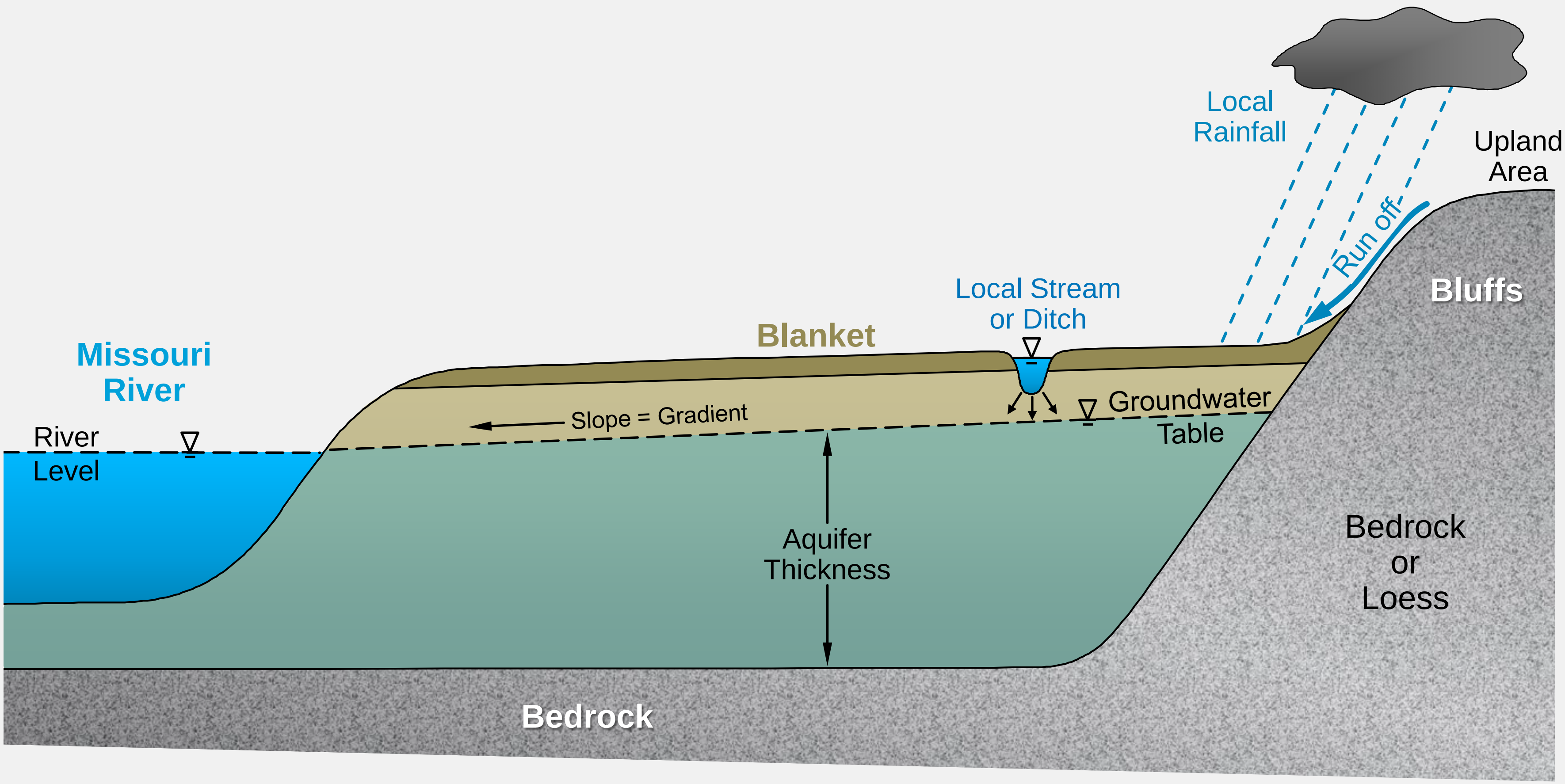
River Stage: Low River Level



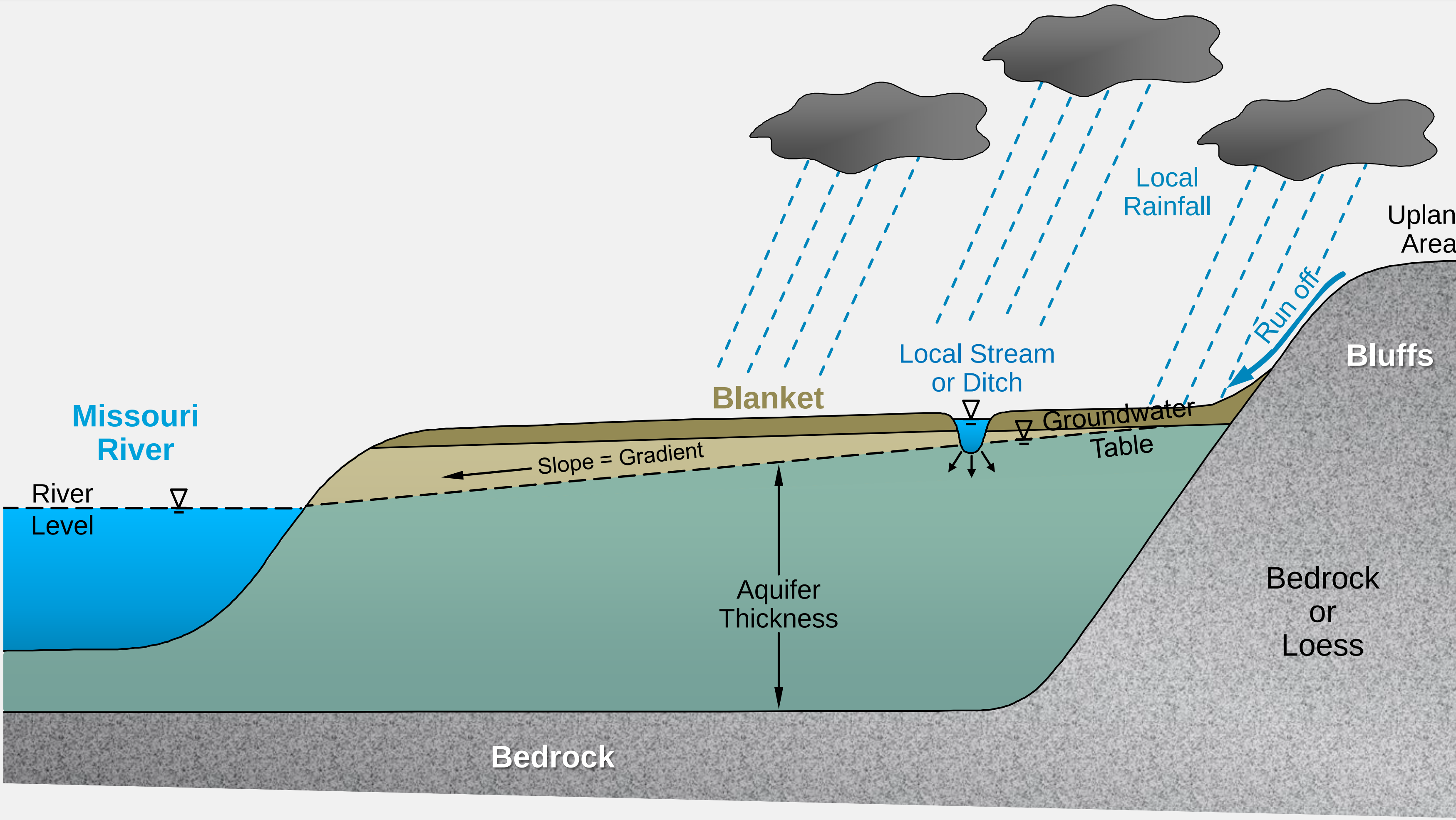
River Stage: Normal River Level



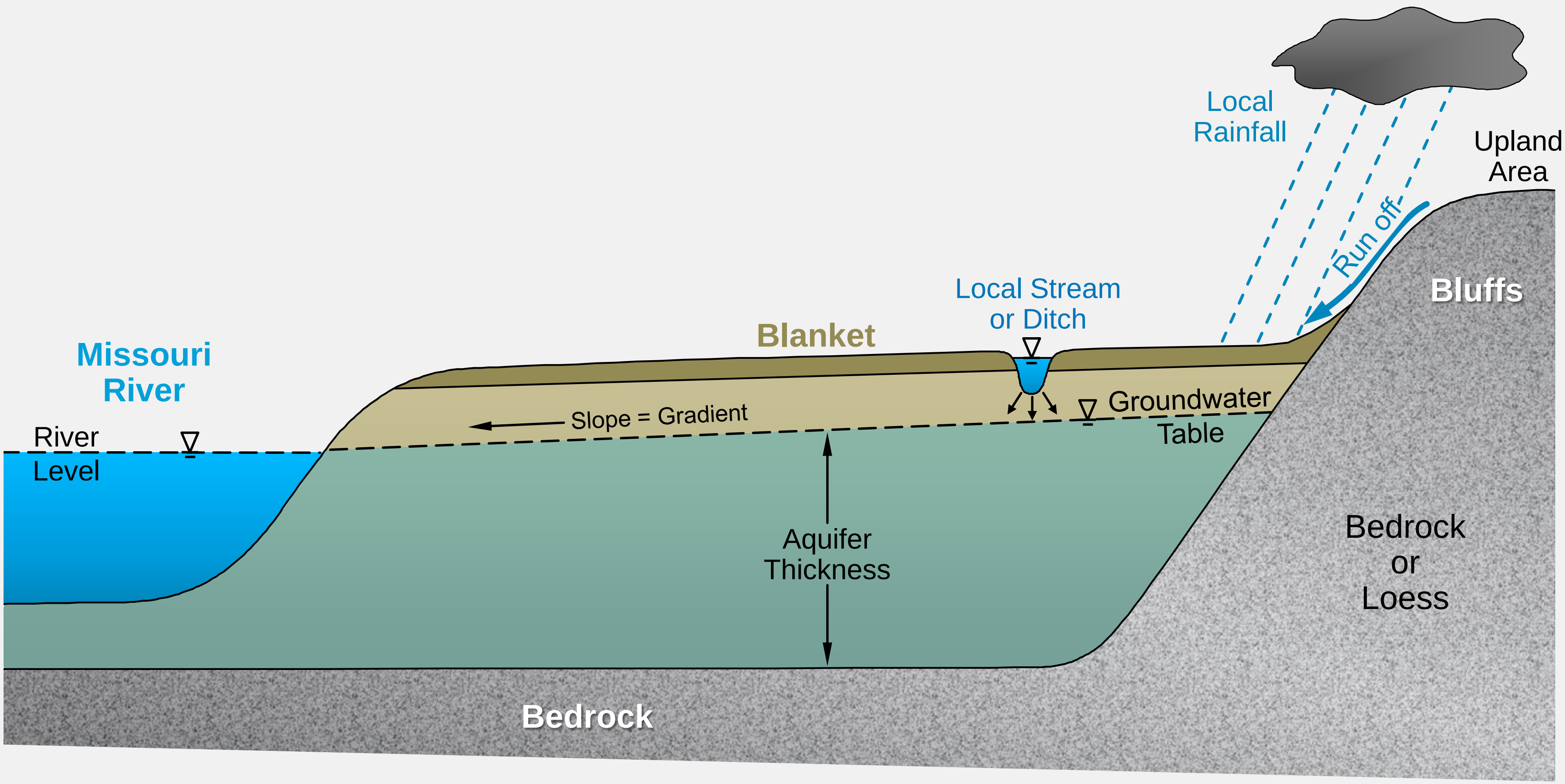
Rainfall: Normal



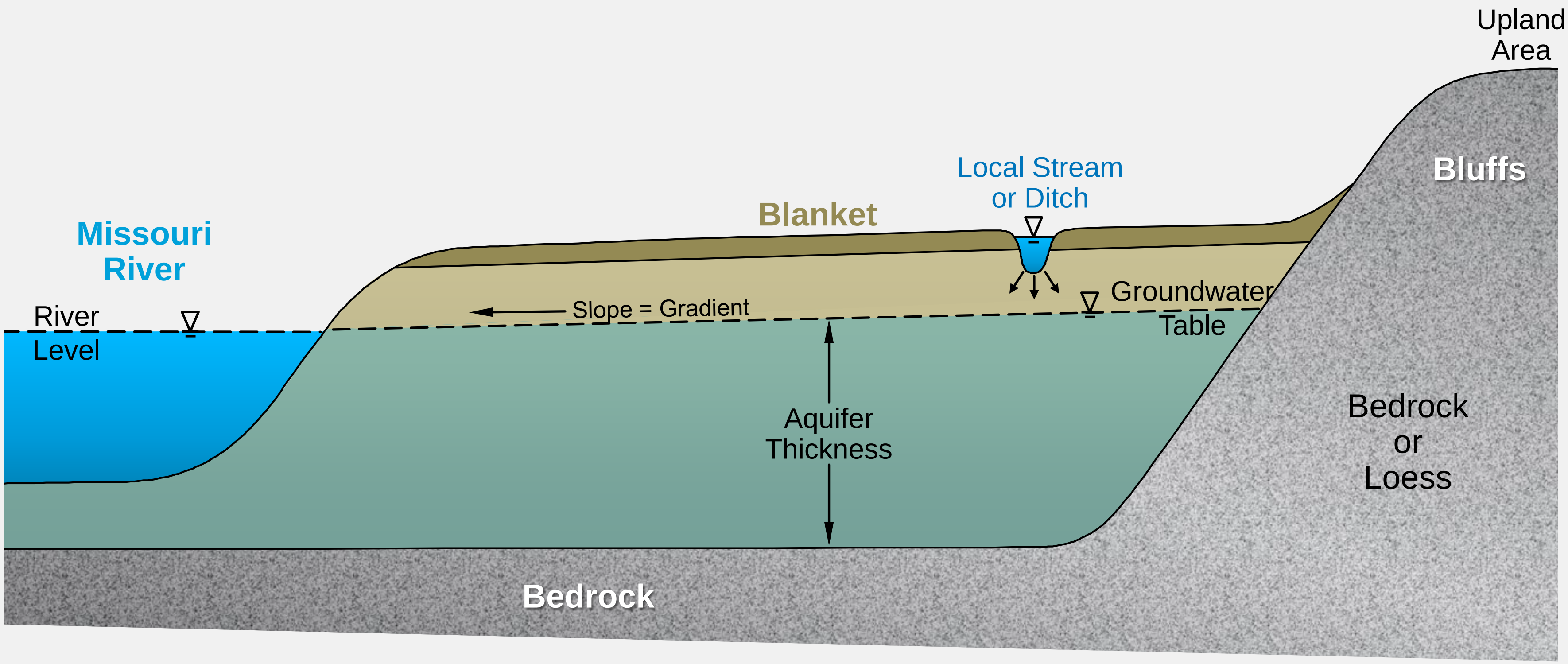
Rainfall: Heavy



Rainfall: Normal



Rainfall: Low



Summary & Conclusions

To establish meaningful statistical relationships between groundwater and surface water measurements:

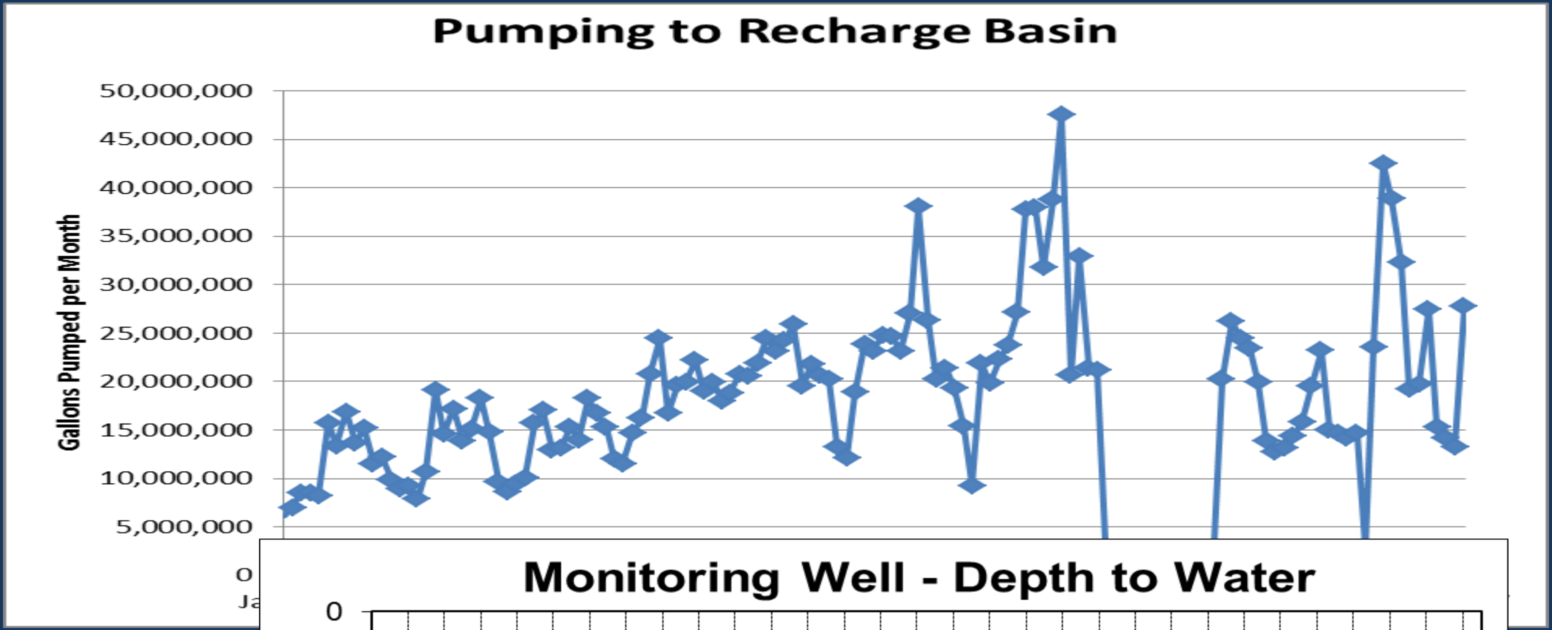
- **Need sufficient data at multiple locations**
  - **100s to 1,000s of data points per location**
- **Measurements must be made at comparable frequencies at all monitoring points**
  - **Wells, rivers and streams, ponds, wetlands, etc.**
- **Measurements must be more frequent than known local variables**
  - **E.g. daily changes in dam releases to rivers**

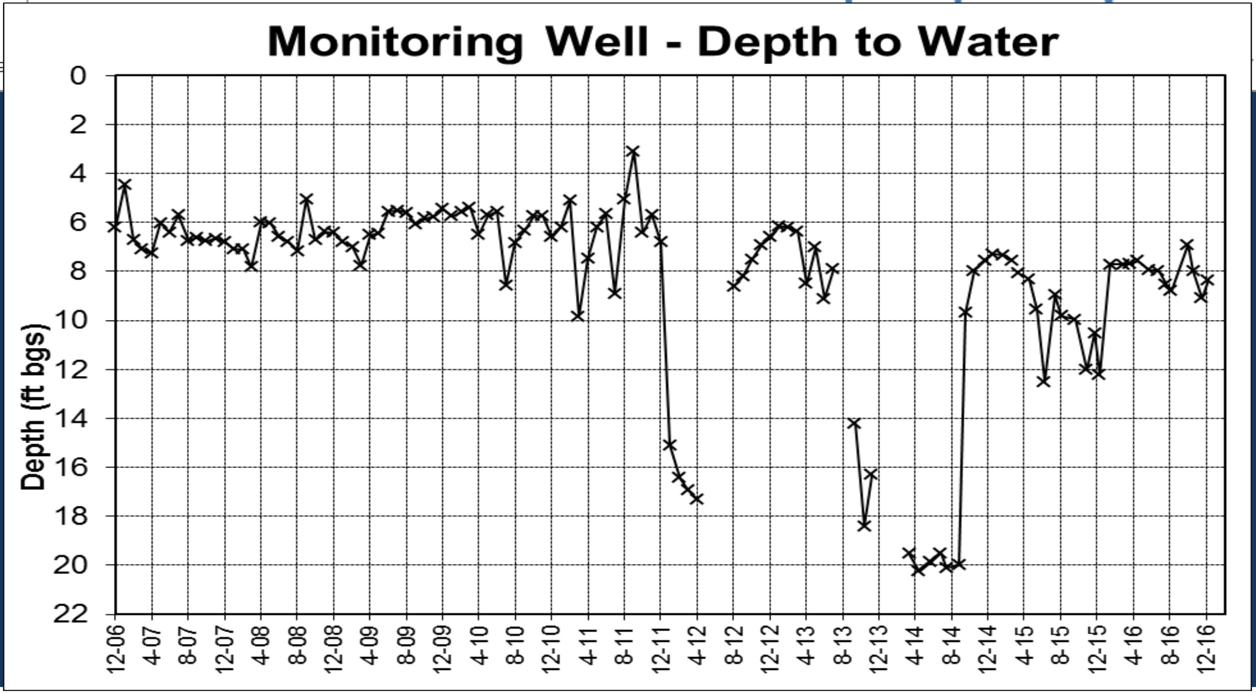
Summary & Conclusions

Once a representative statistical relationship is established, it can provide:

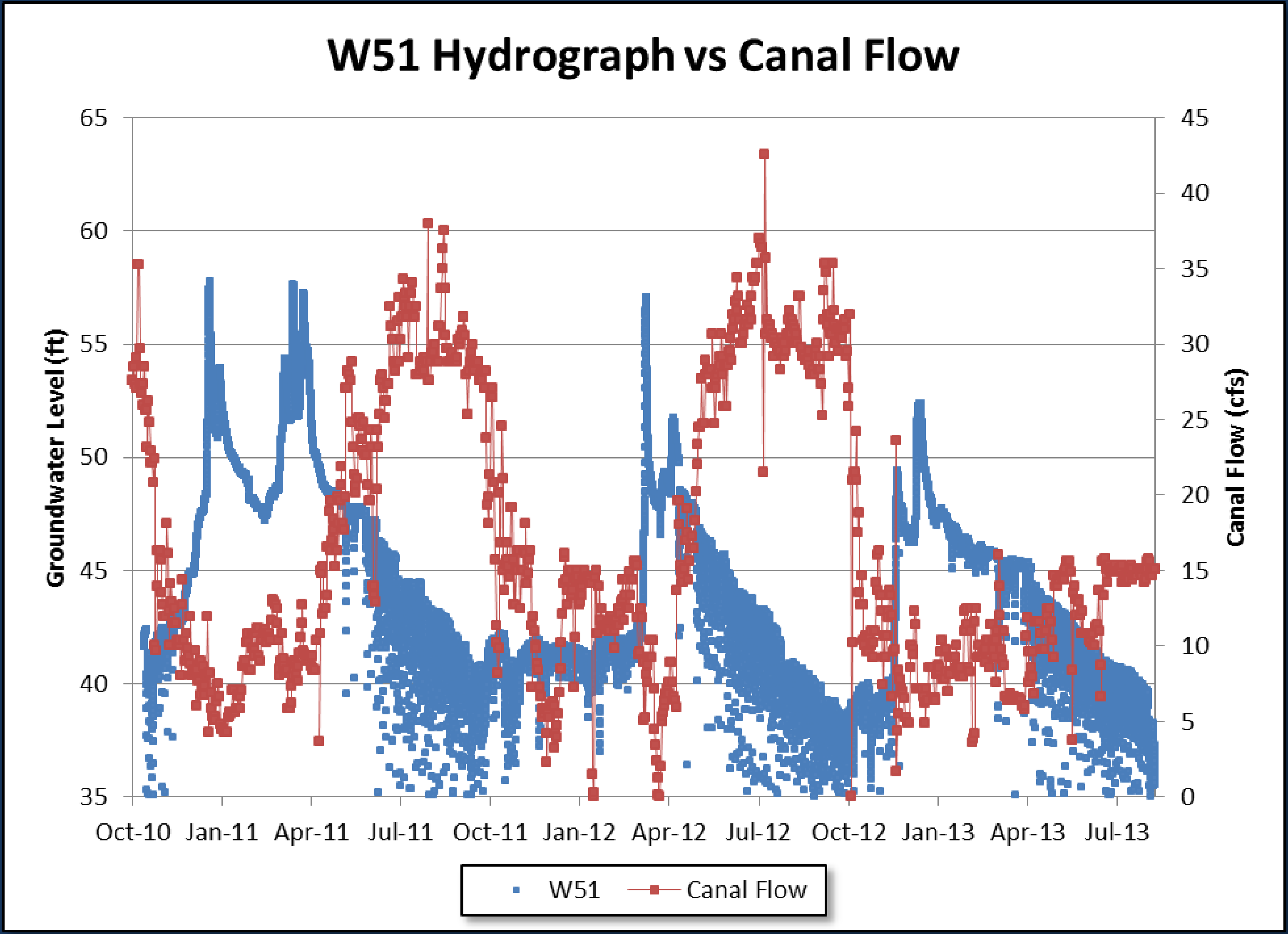
- **Predictive capabilities**
- **Changes in flux**
  - **E.g. gaining to losing conditions**
- **Boundary conditions and validation targets**
  - **E.g at what distances do correlations fall apart?**
- **Quantification of the effects of decreased surface water flows and/or increased groundwater demand**
  - **E.g water transfers that rely on groundwater substitution**

California Example: Recharge Project – San Joaquin Valley

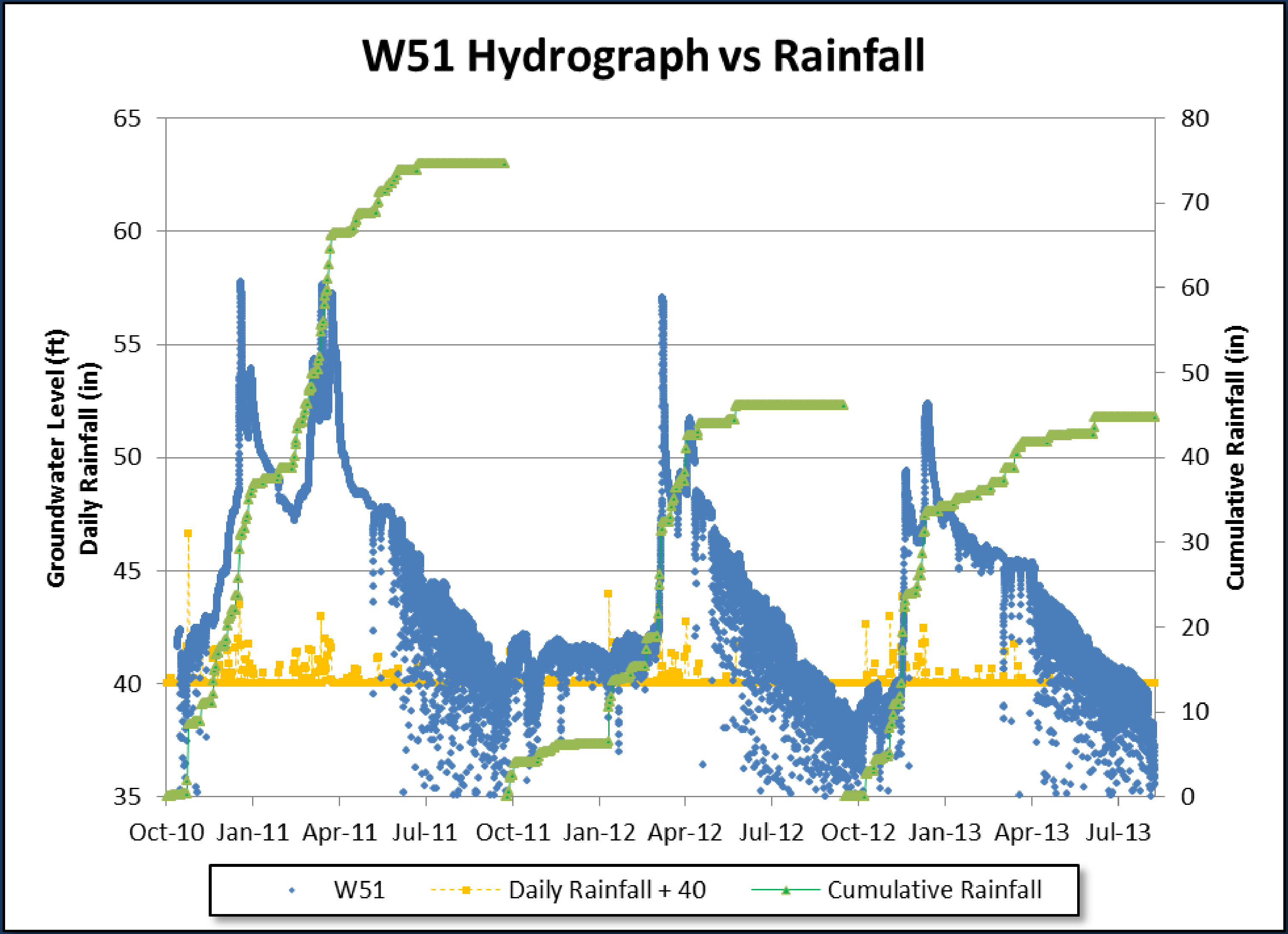




California Example: Percolation from a Canal – Sierra Foothills



California Example: Percolation from a Canal – Sierra Foothills



California Example: Eastern Sacramento-San Joaquin Valley