Springs and Groundwater Monitoring and Modeling of Recent and Long-Term Climate Change

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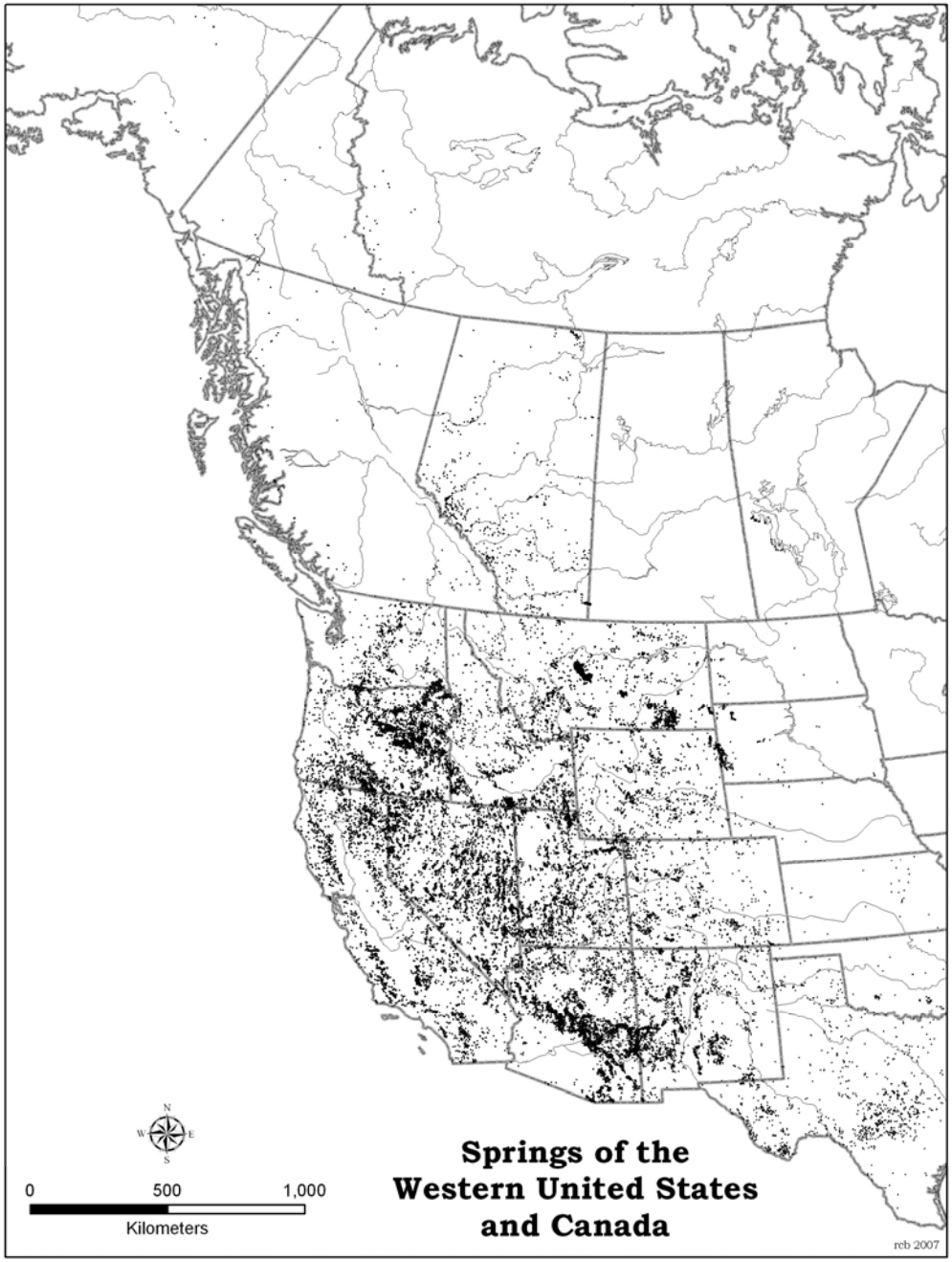
Outline

- Monitoring Desert Springs
  - Adams and others (2006)
- Springs as indicators of climate change
  - Physical, geochemical, biological analyses
  - Rice (2007)
- Reasons for decline in discharge and length of flowing channel
  - Kobor (2004)

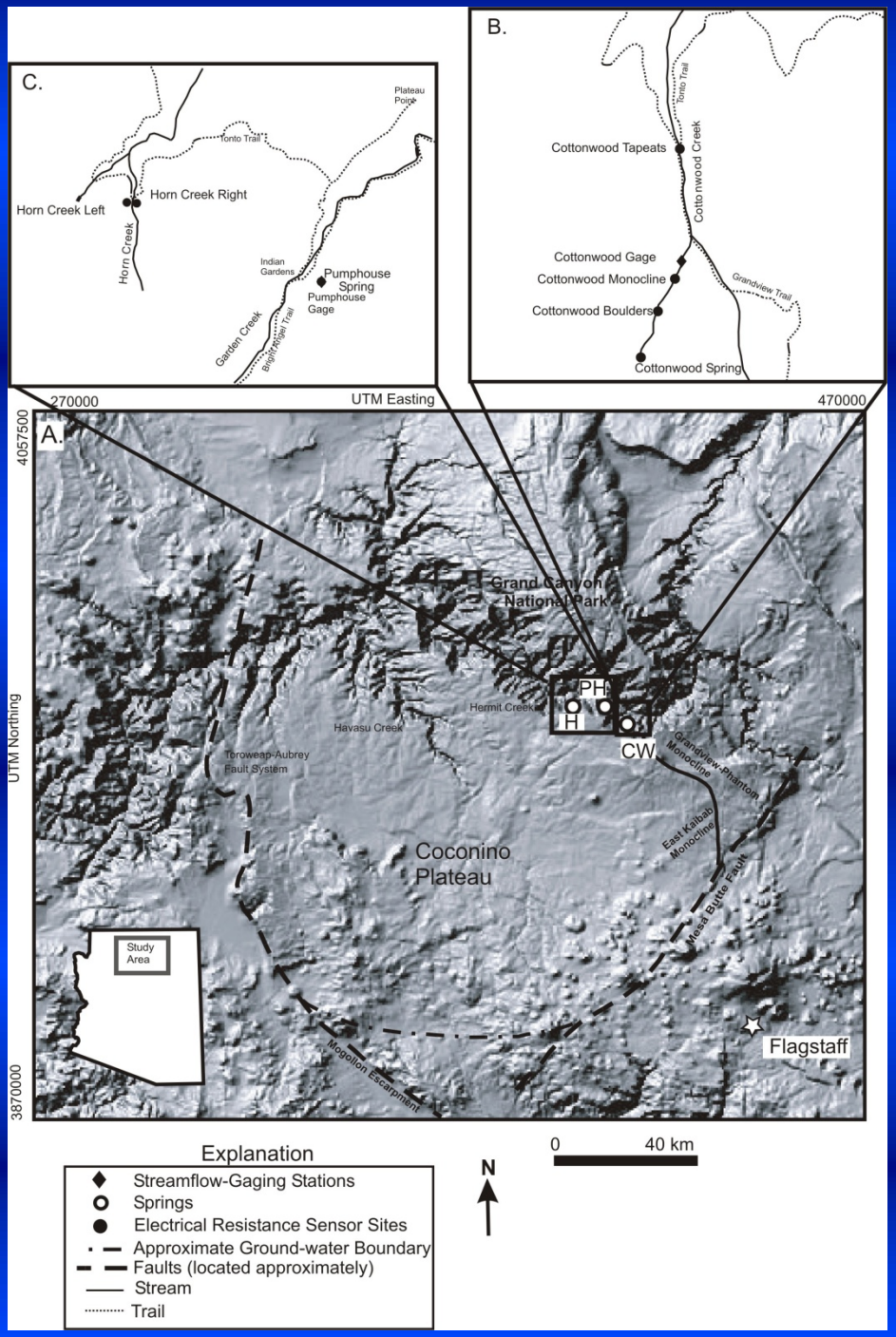


Springs of the Western U.S. and Canada

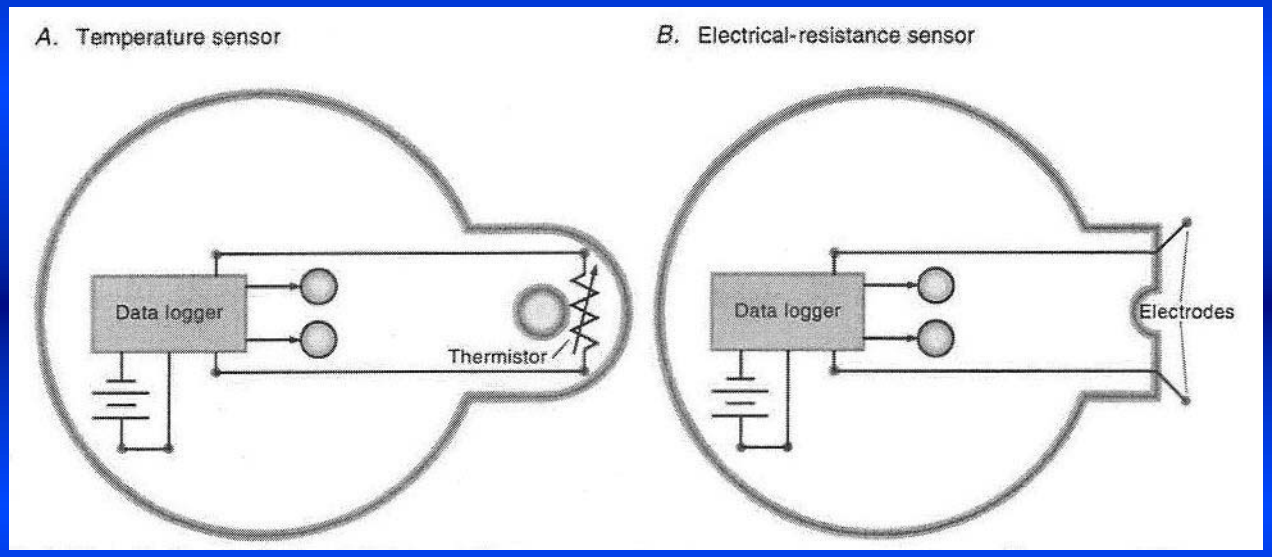
Springs Monitoring

Horn Creek
Pumphouse Spring
Cottonwood Spring

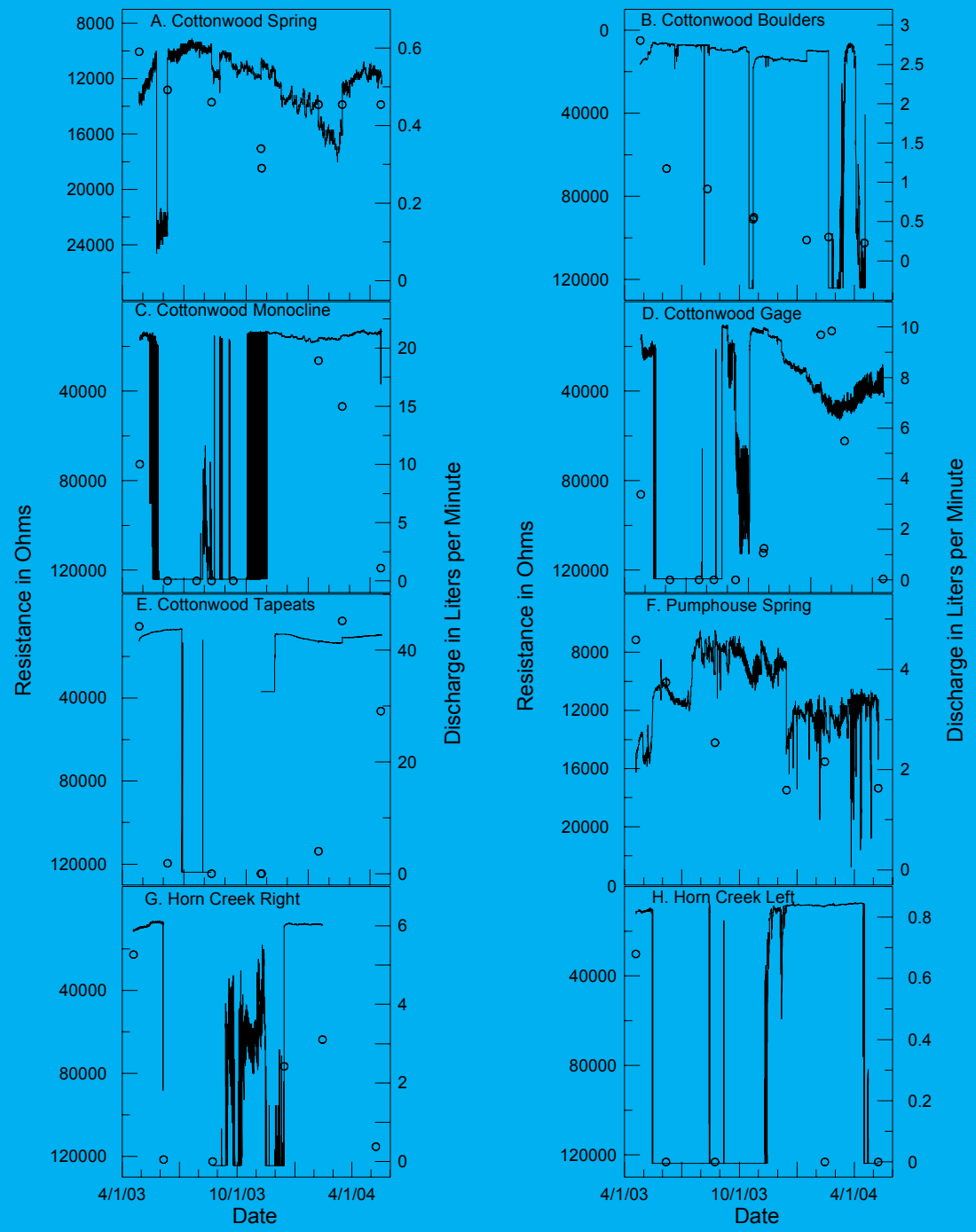
Modified temperature sensors
Monitor electrical resistance



Electrical resistance sensor



Sensors in the field



Field Sensor Results

Immediately detect wetting.

Dampened, delayed response to drying.

Climate Monitoring with Springs

- Correlate climate data to responses of springs throughout the Middle Verde River watershed.

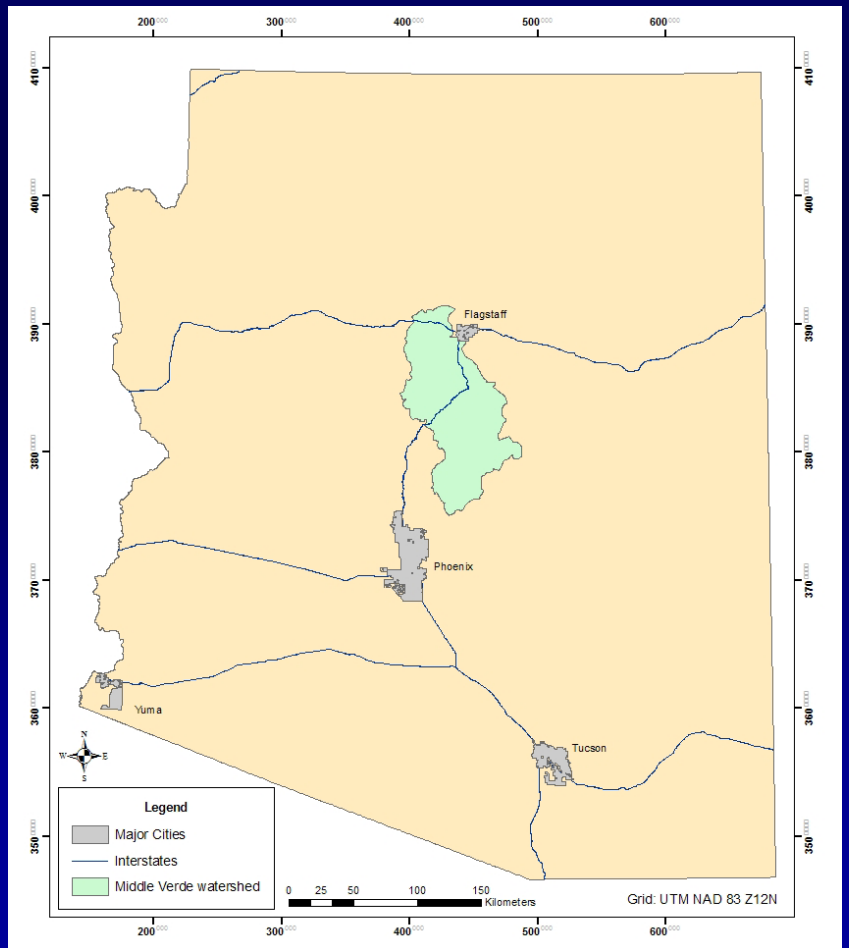
  -Springs are a window into the aquifers supplying them.
  -Insight into aquifer size, recharge area, residence time, drought sensitivity.

- Use relationships to develop a new set of drought indicators and triggers.

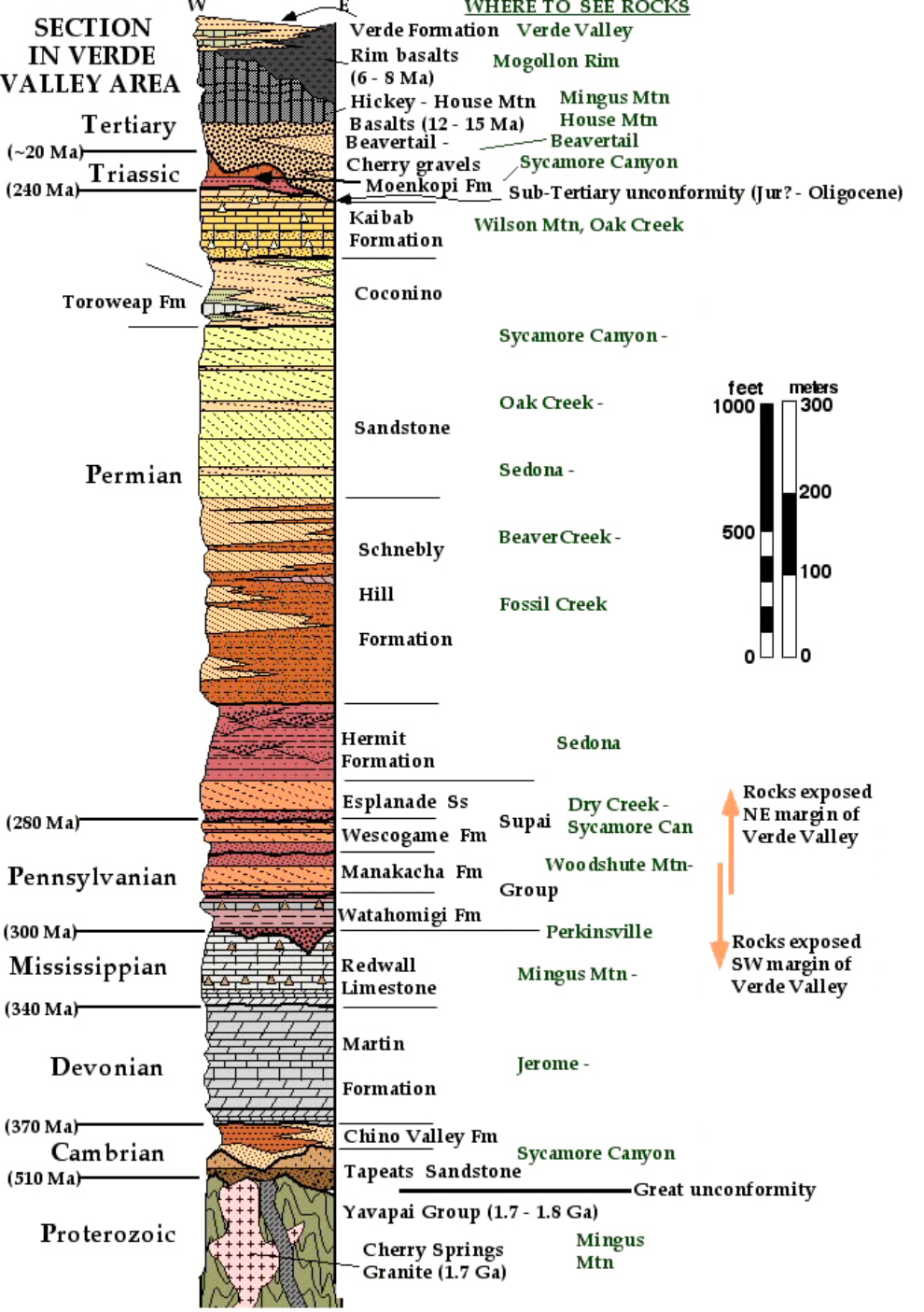
- Help mitigate impacts of drought-affected areas and help reduce drought vulnerability.

Middle Verde River Watershed

- Watershed encompasses ~ 7,900 km^2 of central Arizona
- Located in the Transition Zone between Colorado Plateau and Basin and Range
- Elevation range from 2,812 m to 610 m
- Two distinct precipitation periods:
  - -winter rain / snow
  - -summer monsoon
  - -75% of annual total
  - -(Bills et al., 2007)
- Land ownership: USFS-64%
  Private-23%
  State Land-10%
  Other-3%

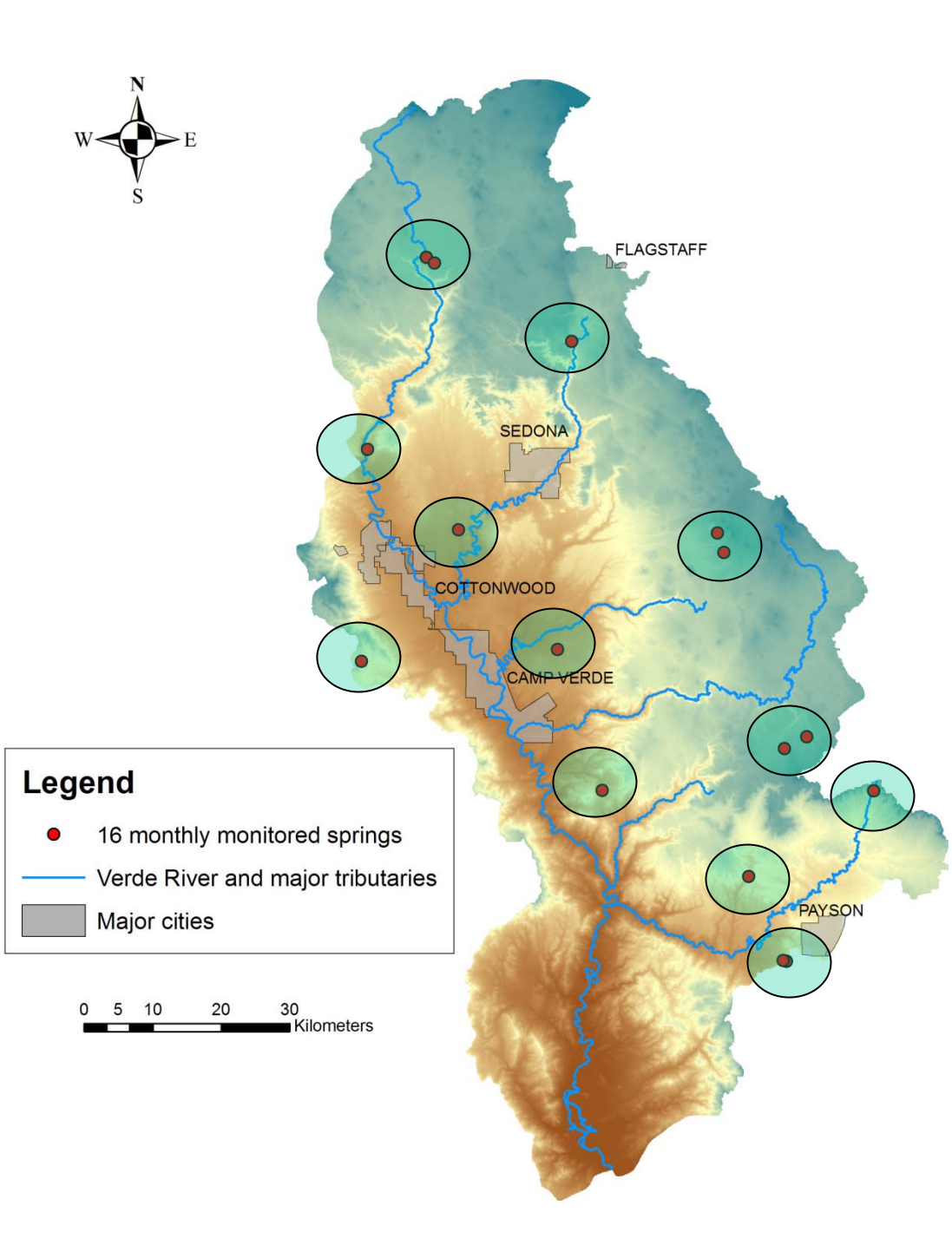


Geologic Setting



Geologic Cross Section for the Verde Valley area Modified from Ron Blakey (http://jan.ucc.nau.edu/~rcb7/verde.html)

Photo by S. Flora



Source Geology

"Suite 16"

- 3 springs in Precambrian Granitic rocks
- 2 in regional Mississippian/Devonian Limestone aquifers
- 2 in regional Permian Sandstone aquifers
- 2 in a shallow Permian Limestone aquifer
- 4 in Tertiary Basalt flows
- 2 in Tertiary sedimentary
- 1 in Quaternary alluvium

Hydrogeologic Characteristics

•Watershed rec winter.

•2 regional aqui

-Commun re faulting.

and fractu

-Multiple s

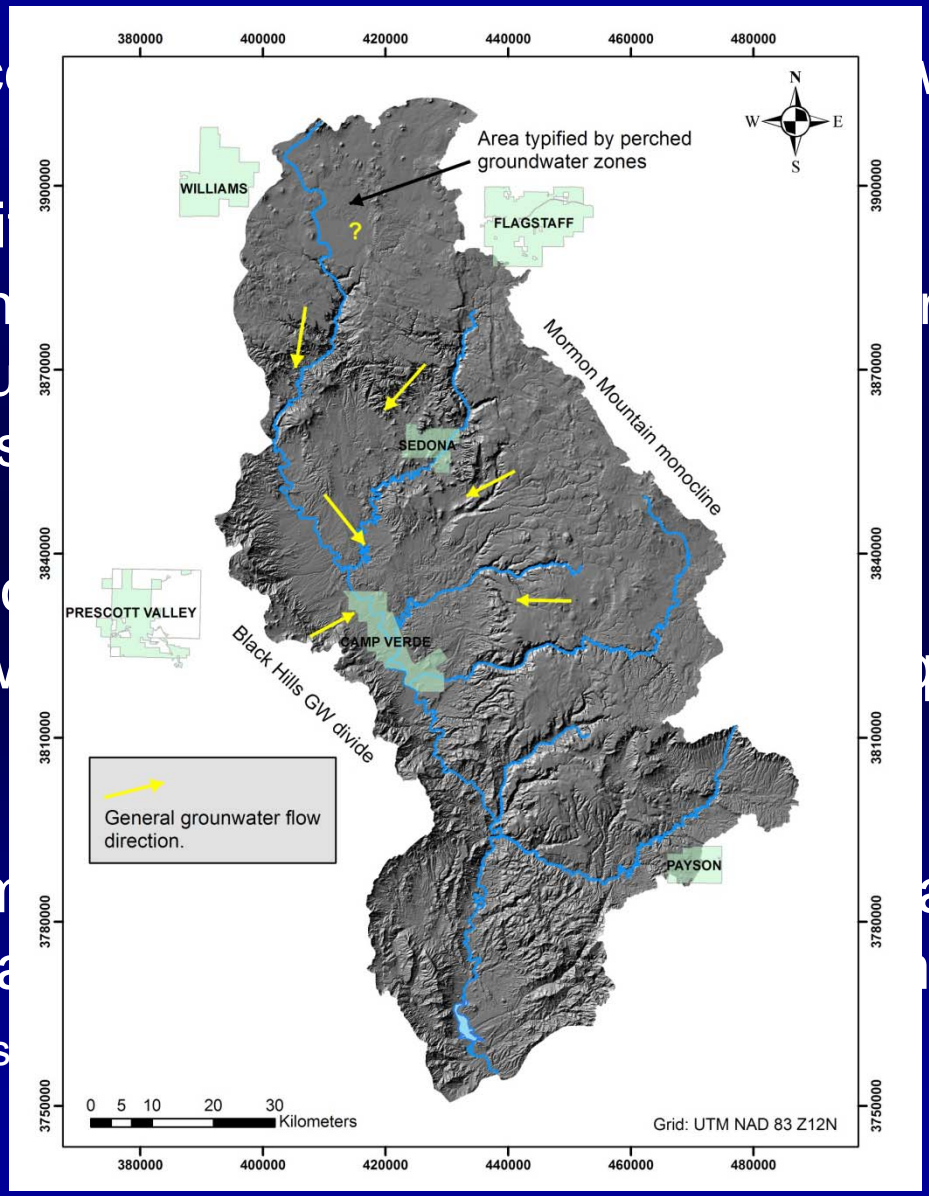
•Source water t Big Chino

alluvial aquifer v quifer. (Wirt and DeWitt, 2005).

•Groundwater m a, SW from

Mormon Mounta Verde

headwaters (Blas



Physical Analyses

- Suite of 16 springs selected for year-long monitoring.

- Monthly field visits include measurements of spring discharge and water-quality parameters:

  -pH, temperature, conductivity, DO.

- Conducted seasonal wet/dry springs inventory.
- Continuous monitoring of 4 sites in 2007-2008.

Geochemical Analyses

- Samples collected seasonally (Oct ’05, Feb ’06, May ’06)

-$\delta^{18}O$ and $\delta^{2}H$

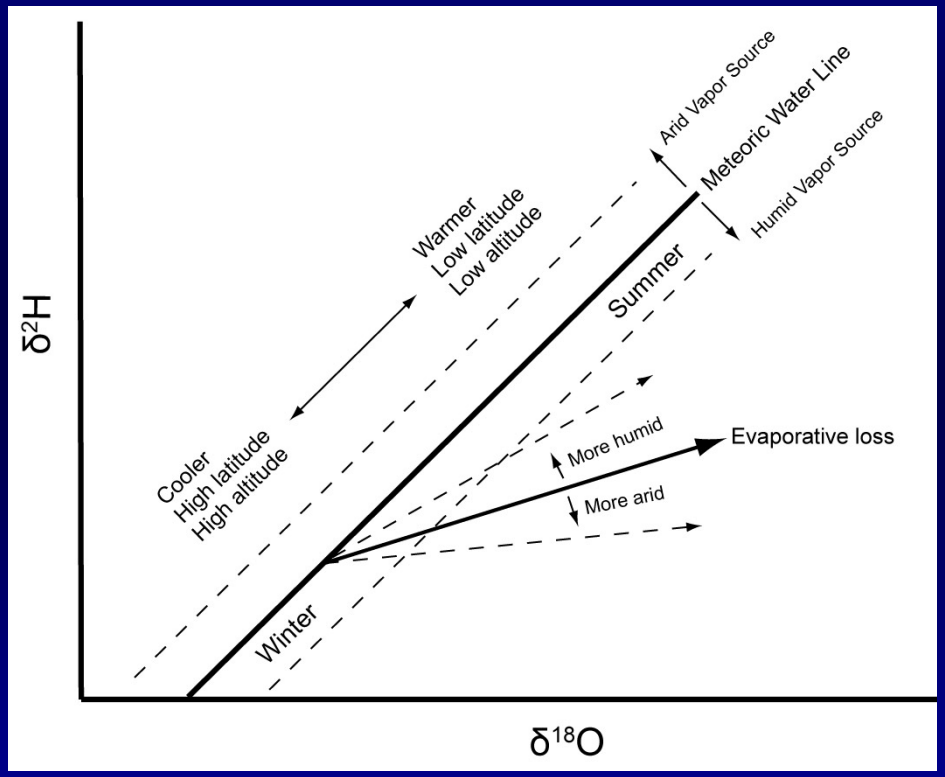
-Tritium (^{3}H), ^{14}C-$\delta^{13}C$

-Cl/Br and Cl/SO_4 ratios

-Defining recharge areas

-Estimating residence times

-Quantifying aquifer mixing and contact with certain geologic materials



Statistical Analyses

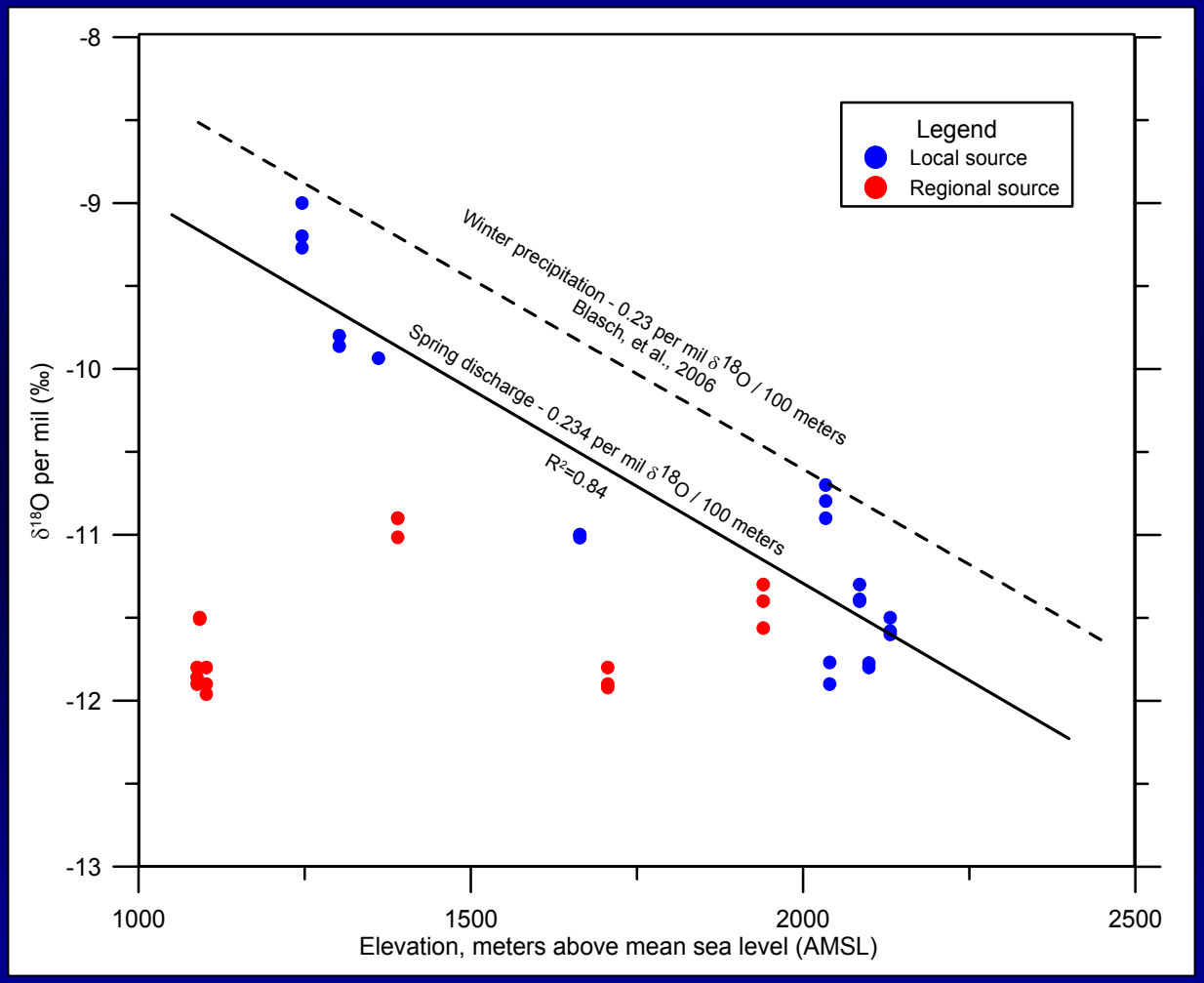
- Descriptive statistics
- Discharge variability
- Coefficient of variation
- Correlations and covariances

- Correlation coefficients between:
  - -Discharge
  - -Temperature
  - -Streamflow
  - -Water Quality Parameters
  - -Precipitation
  - -Palmer Drought Index (PDSI)

- Discharge trend analyses.

- Development of drought-levels based on discharge.

•Stable isotope data show that winter precipitation is the dominant source of recharge for all study area springs.



•Drought conditions during summer may affect State levels but do not have large effect on springs, especially regional.

Biological Indicators

- Indicators of springs flow perenniality
  - Hydrobiid snails
  - Amphipods
  - Stoneflies
  - Elmid and dryopid beetles
  - Northern leopard frogs
- Vegetation poor indicators of flow perenniality and interannual flow variation

Biological Indicators

- Highest diversity at sites with disturbance
  - Rheocrene (flowing) springs

Regional vs. Local Aquifer Designations

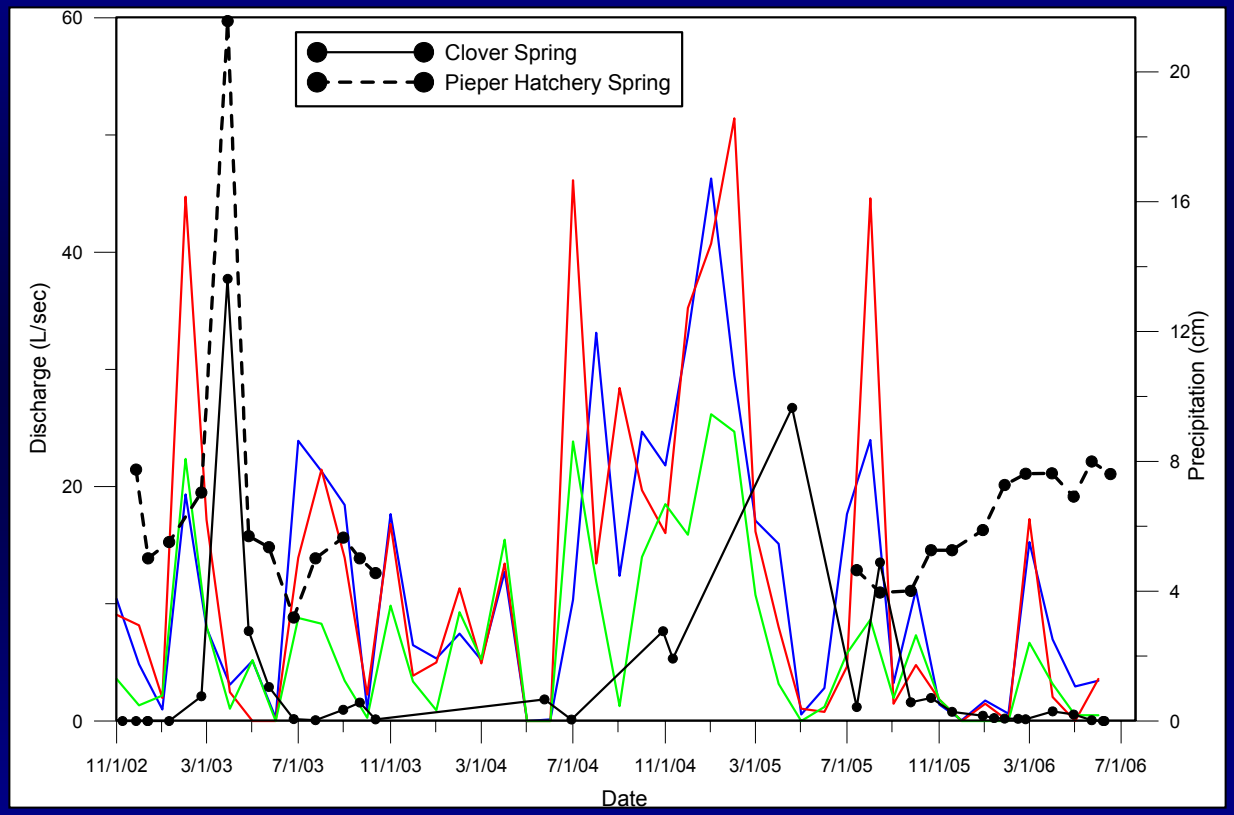
- Most springs were identifiable as regional or local based on geology and/or discharge rate.

- Geochemistry helped distinguish two previously local springs as regional.
  - -Important in the later statistical analyses
  - -Helped develop concept of a continuum between regional and local.

- Stable and radioactive isotopes indicate that two springs discharging from the Verde Fm. were sourced from the C-aquifer.
  - -Some mixing places these along the continuum line.

Precipitation Sensitivity

- Shallow karst aquifer shows rapid and strong response to both snowmelt and monsoon precipitation (R^2=0.66).

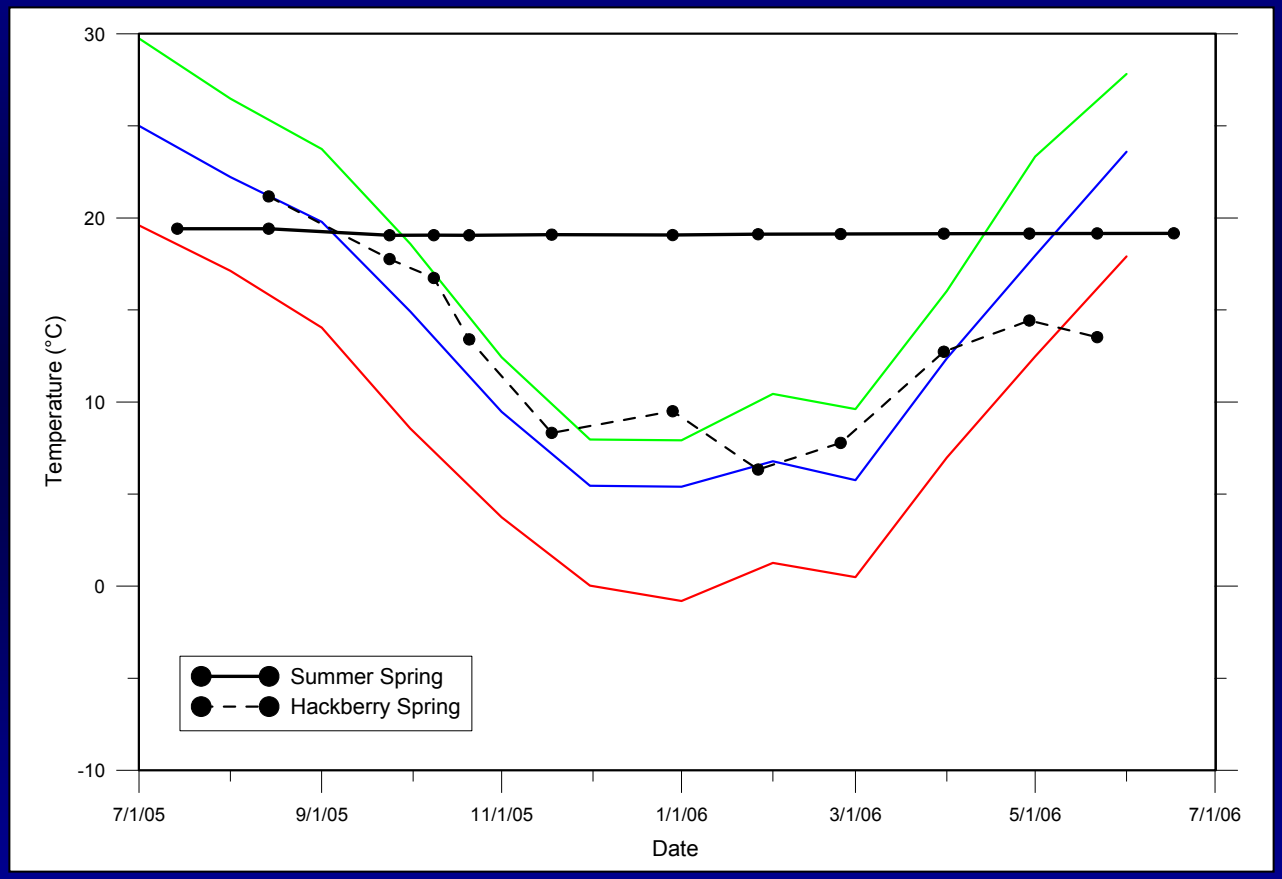


- Regional aquifers show greater response to snowmelt than to rainfall events.

  -delayed response (R^2=0.28).

Temperature Sensitivity

- Regional aquifers not sensitive to seasonal temperature fluctuations (R^2=0.37).



- Local and shallow aquifer systems mimic seasonal temperature changes (R^2=0.77).

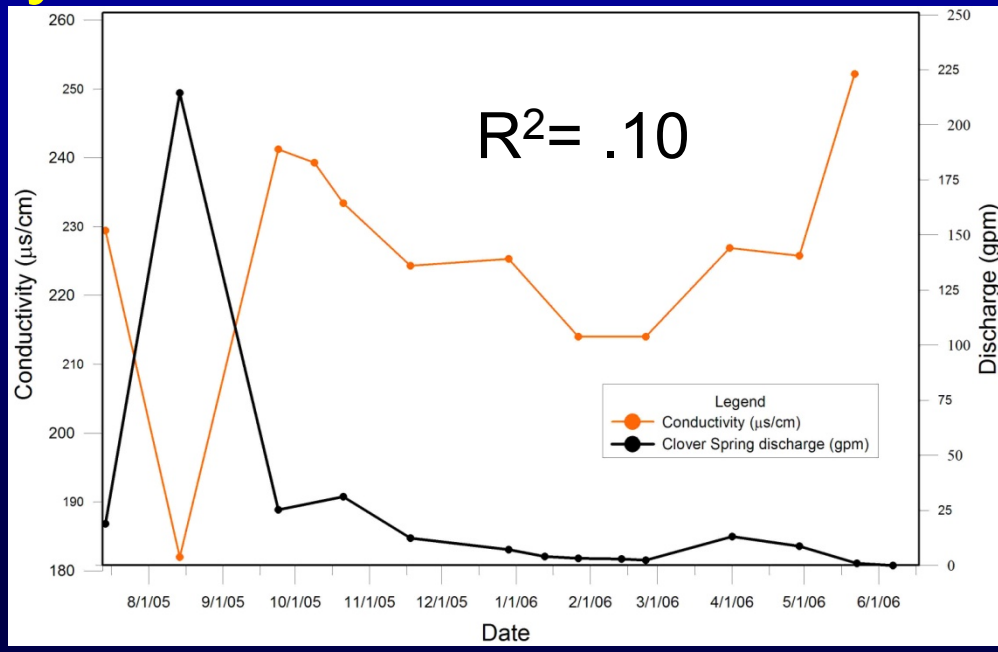
Water Quality Parameters

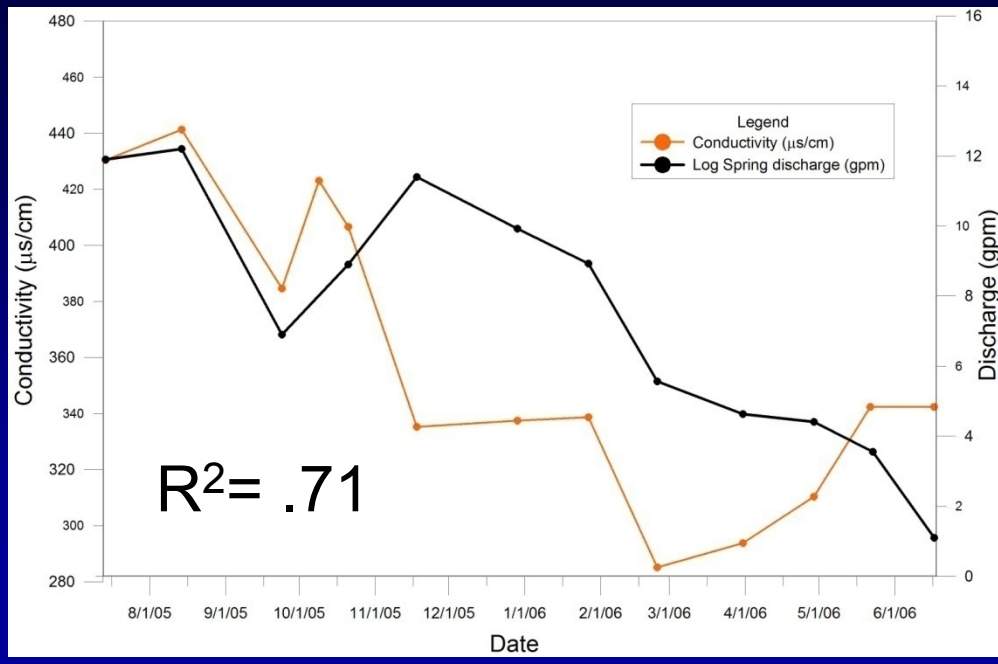
- Aquifers with low residence times and/or high *K* "flush out"

- EC drops with spike in discharge.

- Low conductivity recharge water enters the system.

- Aquifers with longer residence times or low *K* do not have this response.





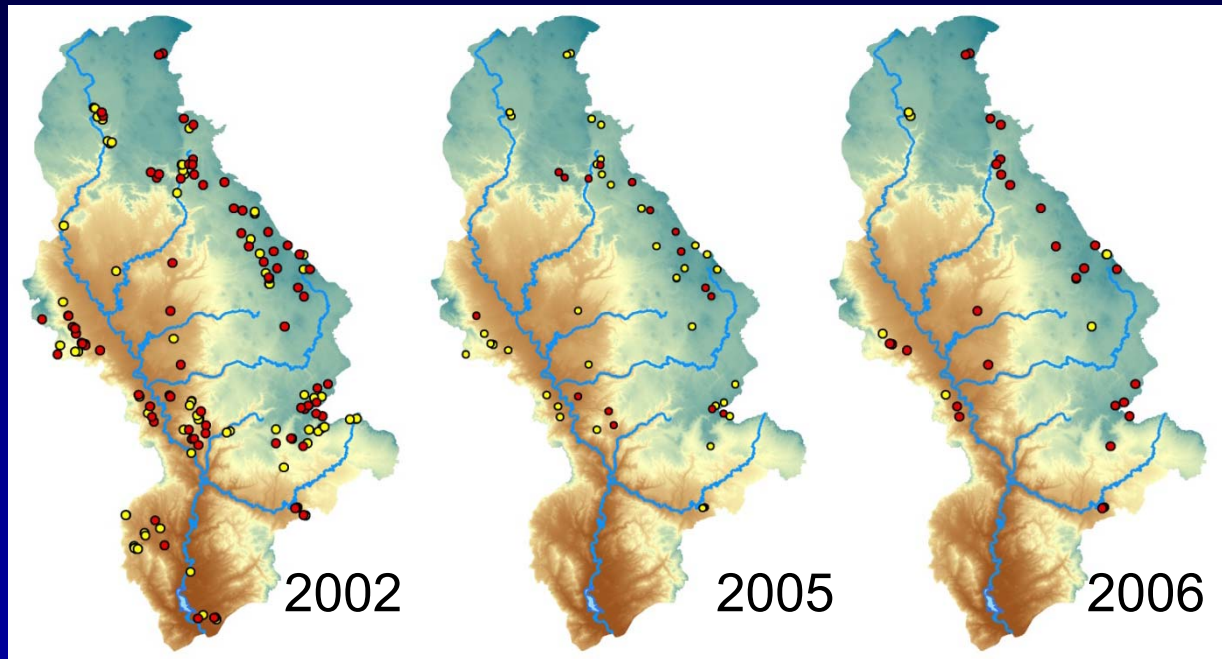
Reactivation / Deactivation of Springs

- In a 2002-2003 survey, 50% (80 of 160) were found to be dry.

- Most of the dry springs revisited after wet winter of 2004-05; 72% had reactivated.

- After a historically dry first half of 2006, the flowing springs from 2005 were revisited; 78% had gone dry.

- Remaining flowing springs decreased in discharge by 82%.



Reactivation / Deactivation Findings

• 2005 : 95% of reactivated springs discharged from local or shallow aquifer systems.

Regional springs better at gauging longer-term climate changes; local springs are better at quantifying short-term climate changes.

• No trend in reactivation / deactivation rate based on source geology, elevation was seen.

Statistical Analyses

- Variability analyses: local springs best suited for short-term drought analysis.

- Kurtosis and skewness indicate more regional springs have normal discharge distribution.
  - -Local springs often violate this assumption.

- Correlations show local springs well correlated with primary State drought indices.
  - -Especially those with short residence times.

- Regional springs correlate best with these indices on a lag basis.
  - -Number of lagged months varied by spring.
  - -Lags on precipitation between 1-2 years for Upper Verde River (Bills, et al., 2007).

Development of Drought Trigger Levels

- Discharge percentiles calculated on a scale similar to State:

No drought:	40.1th percentile or higher
Level 1:	25.1 to 40th percentile
Level 2:	15.1 to 25th percentile
Level 3:	5.1 to 15th percentile
Level 4:	0 to 5th percentile

- Springs did not register at the same scale as the State's.
  - -Springs levels fluctuated less than state-generated.
  - -Less sensitive to climate perturbations that drive current designations.

- Relatively short period of record for the springs.
- Takes more significant climate perturbations to influence them.

Recommendations for Climate Monitoring of Springs

- Springs should be selected for instrumentation/monitoring along the regional/local continuum line.

- Local springs would benefit most from continuous monitoring.
  - -Regional springs: longer period of record.

- More robust statistical analyses could be performed.

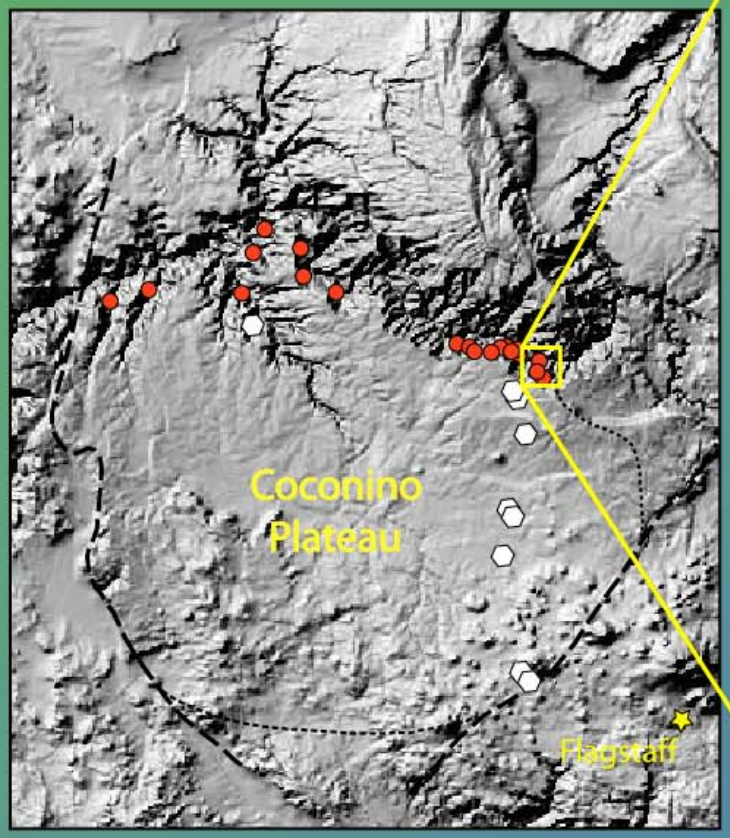
- Instrumentation needs range from simple pressure transducers to installing flumes.
  - -Several locations could be monitored and maintained at a cost much less than one stream gage.

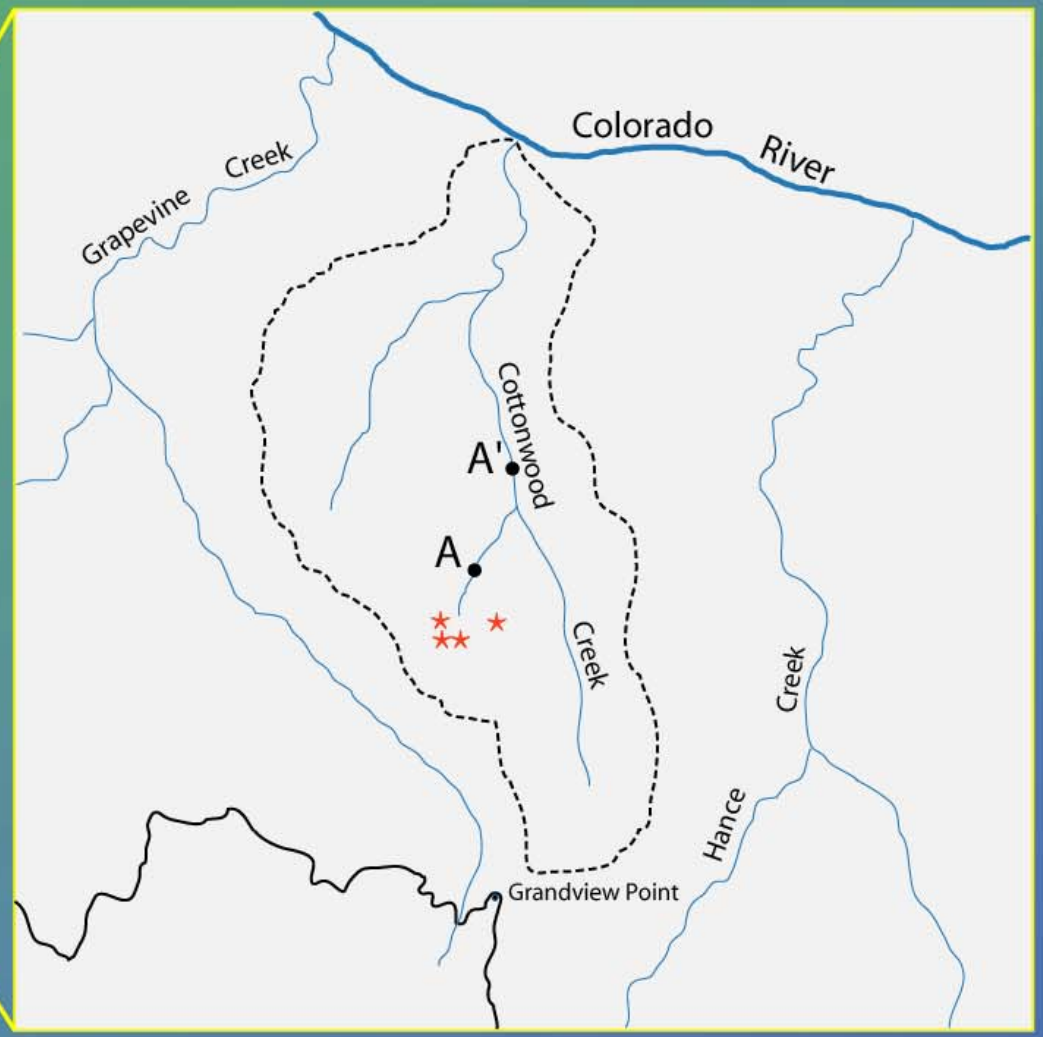
- Monitoring of stable isotopes and anions is relatively inexpensive and provides a wealth of information.

Grand Canyon: Site specific model

- Created groundwater model for one specific small discharge spring, Cottonwood Spring.
- Determined changes is water availability along the short, spring-discharge supported channel.

Study Site:





Explanation

- Springs
- Wells
- Approx. GW Boundary
- Faults (approx.)

0 40 km

N

Explanation

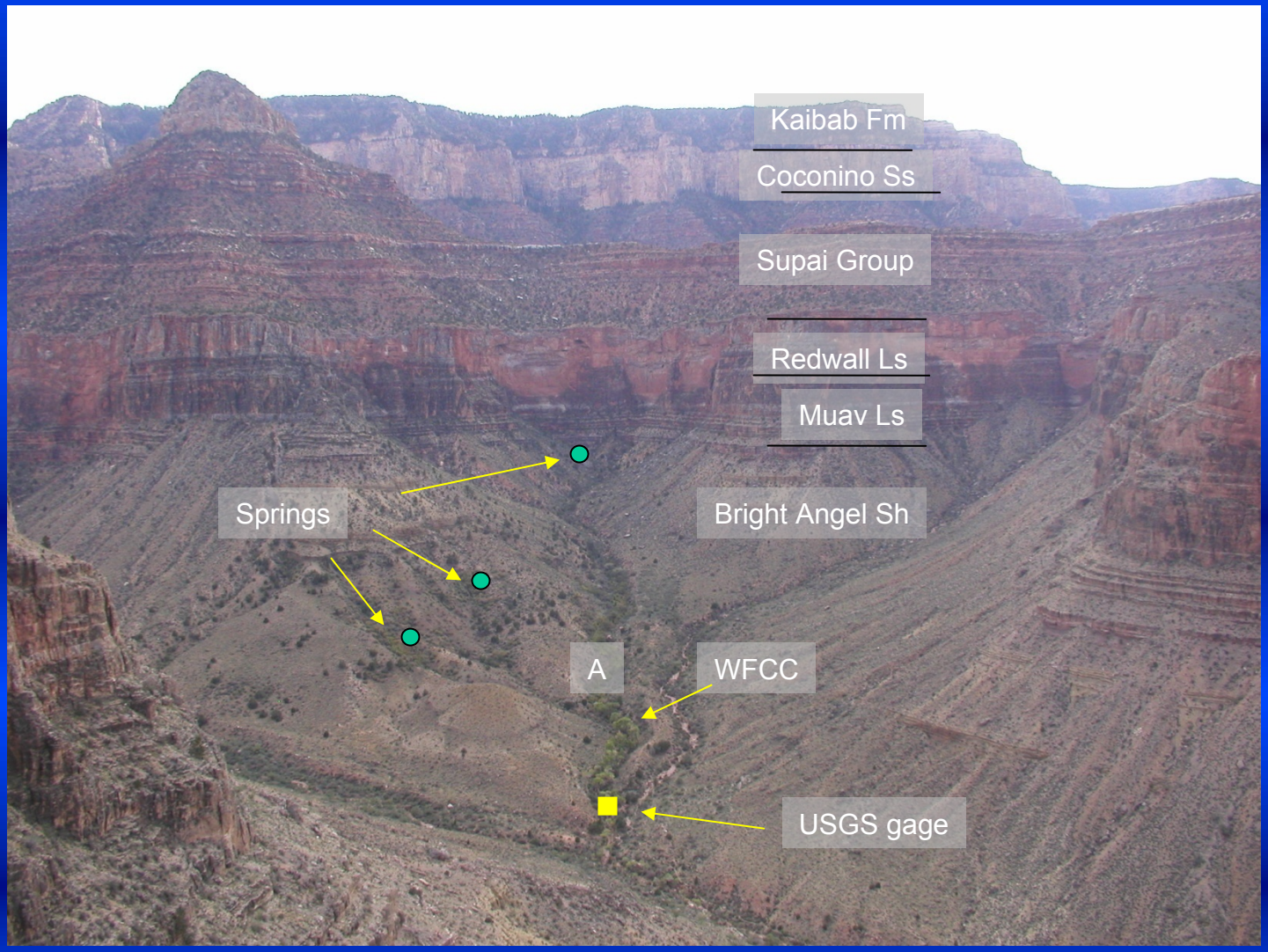
- Drainage Divide
- Cottonwood Springs
- South Rim
- Study Reach

0 1.5 km

N

(modified from Kessler, 2002)

Cottonwood Spring



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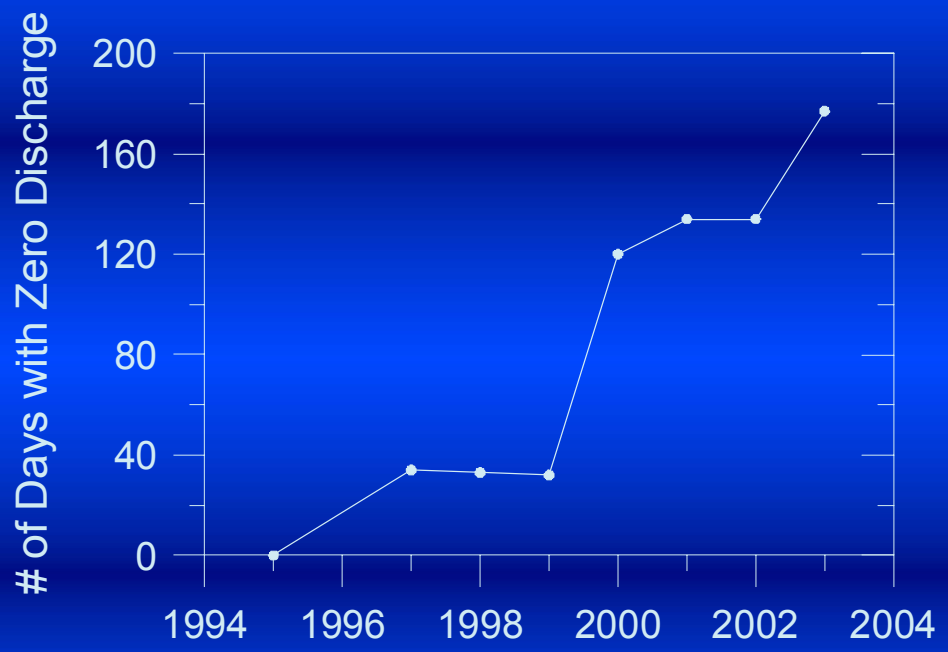
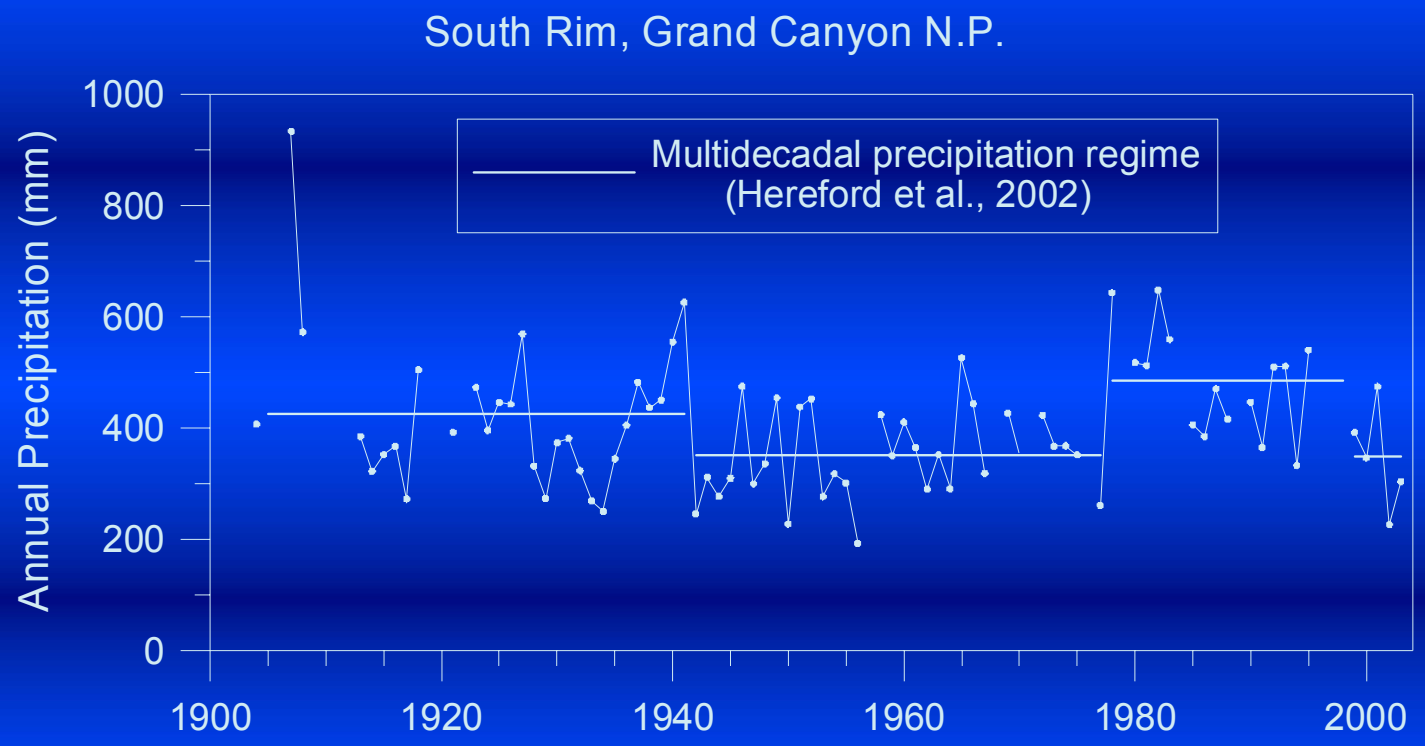
Discharge Trends: USGS stream gauge



- 0 dry days in 1995
- 177 dry days in 2003
- Mann-Kendall p = 0.0025

photo by Abe Springer

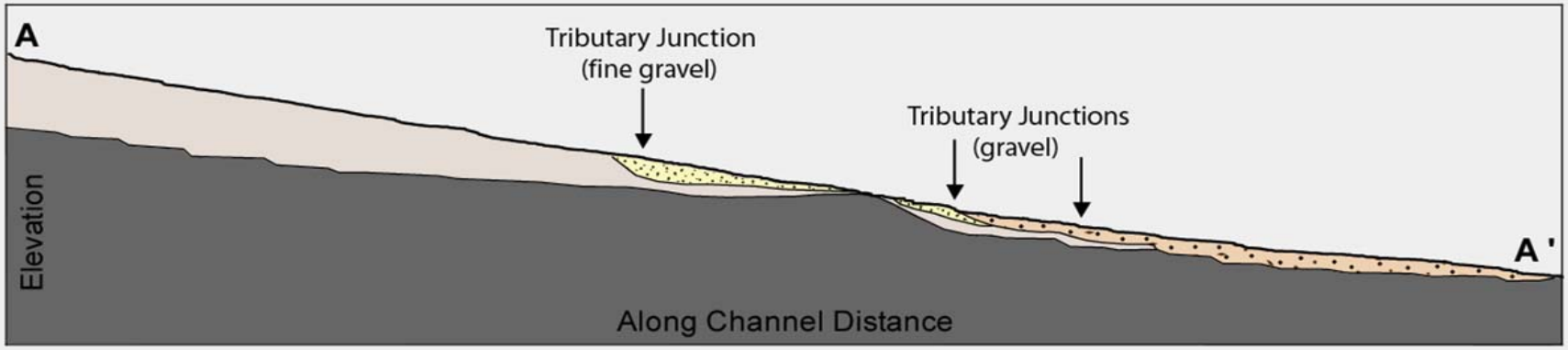
Discharge Trends: Climate and Groundwater Pumping



(1905 - 1941), (1942 - 1977), (1978 - 1998), (1999 - ?)

- Trends of decreasing discharge may be the result of climate change, timescales of response may be long or short
- Not enough data to distinguish climate from pumping

Site Characterization: Distribution of Alluvial Units



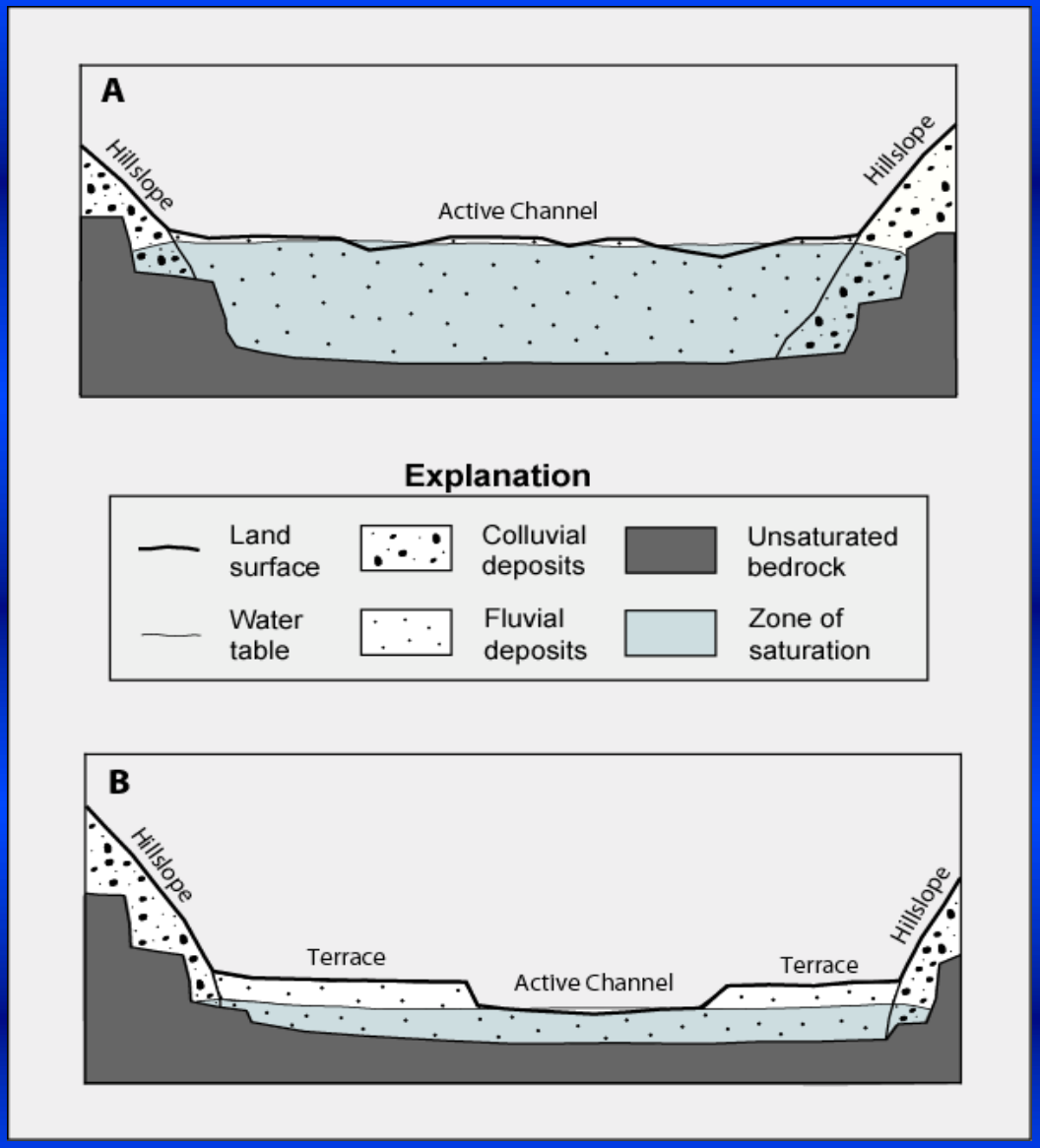
Explanation

Geologic Units

Qs1	Sandy stream-channel alluvium and floodplain deposits (Holocene).	Qs3	Gravely stream-channel alluvium and floodplain deposits (Holocene).
Qs2	Fine gravely stream-channel alluvium and floodplain deposits (Holocene).	Cba	Bright Angel Shale (Cambrian).

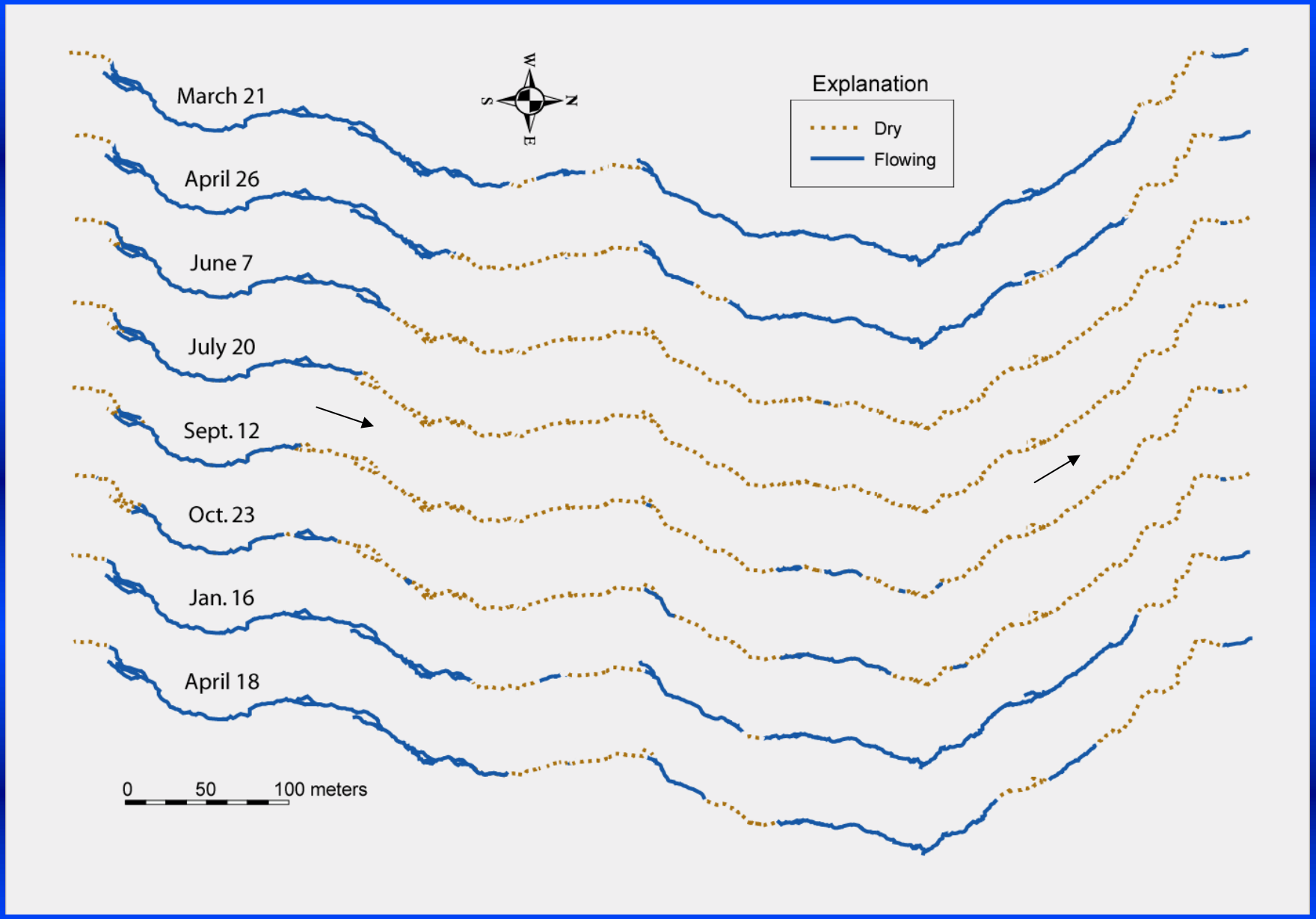
- Shallow alluvium (~0-4 m) underlain by relatively impermeable bedrock
- Along-channel variations in grain-size due to joining tributaries

Site Characterization: Zone of Saturation

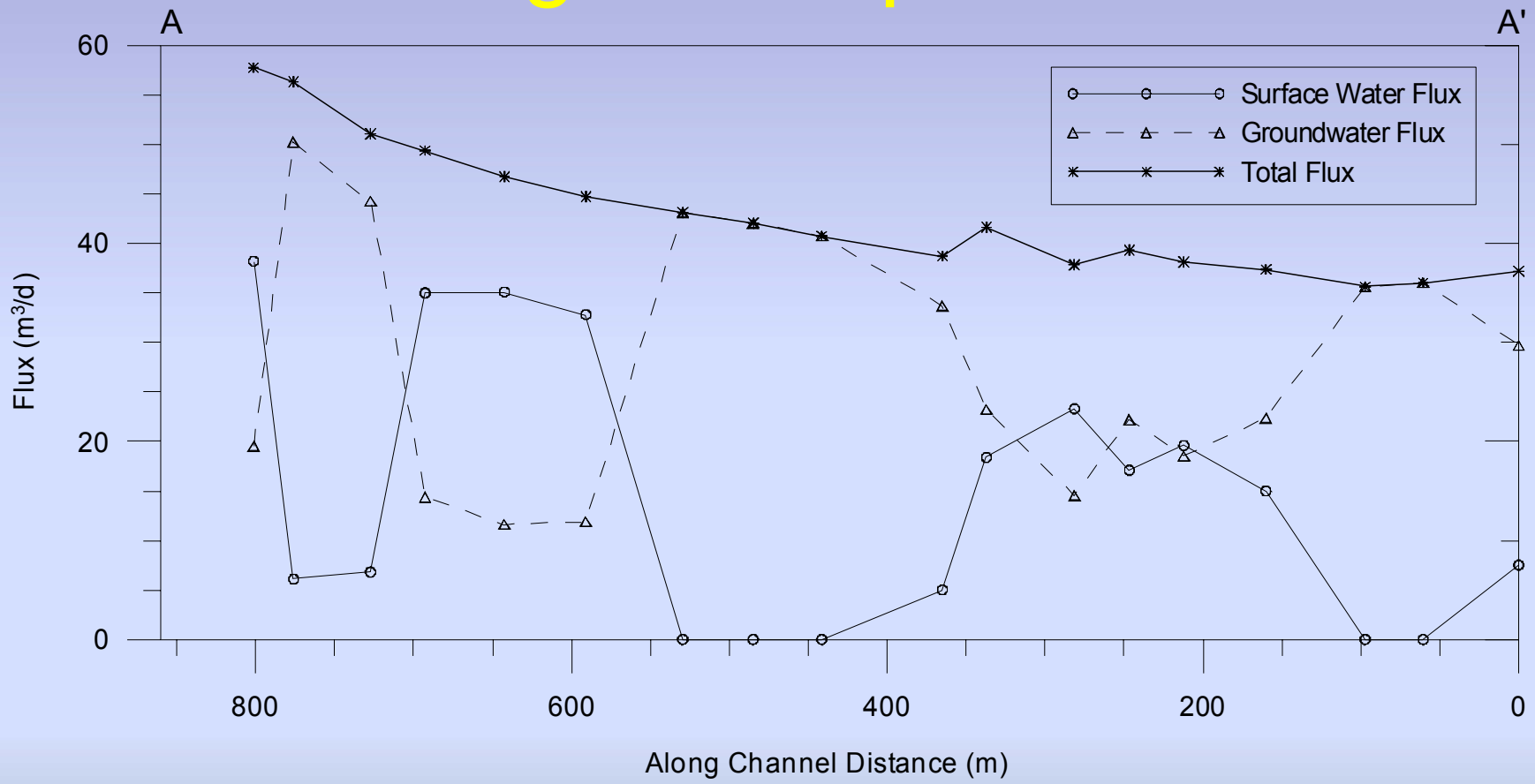


- Minimal lateral variation in grain-size
- Saturated zone confined to fluvial deposits by topography and underlying bedrock

Calibration Data: Flow Observations (2003 - 2004)



Flow variation downstream during stress period 3



Grand Canyon Summary

- Decreasing water availability downstream due to plant water used.
- Still doesn’t predict impacts to spring ecosystem.

Conclusions

- Springs useful indicators of climate change.
- Local or regional springs can monitor short- or long-term fluctuations.
- New technologies useful for remote sites.
- When coupled with groundwater flow models, monitoring can be more useful.

Questions?