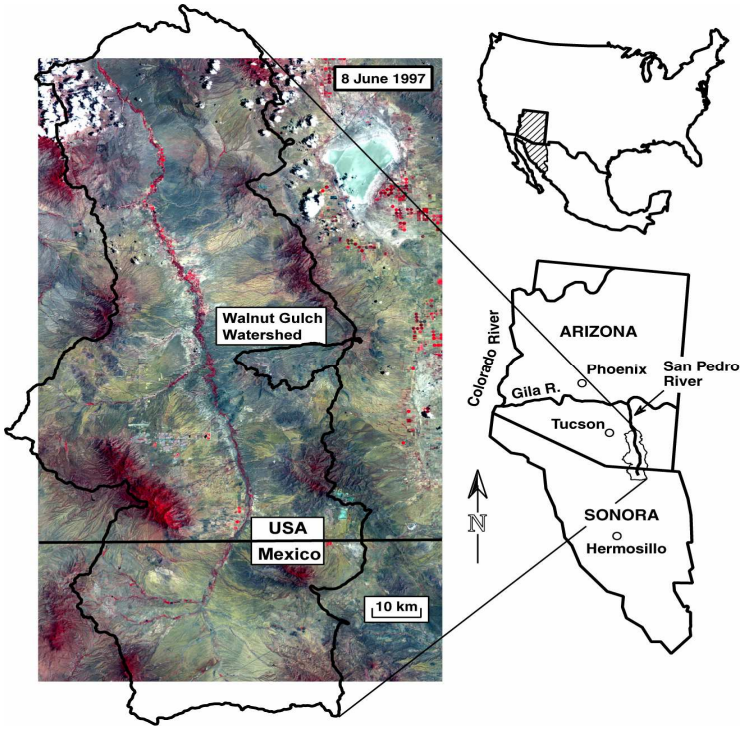
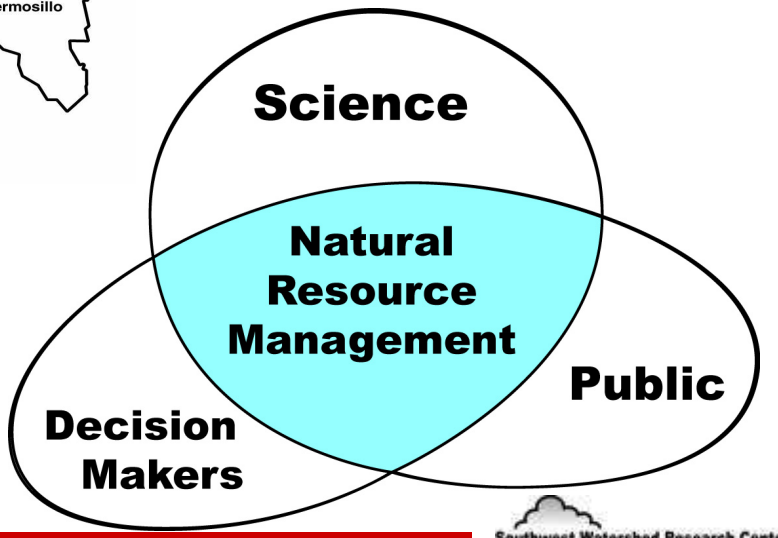
Integration of Science and Decision Making for Watershed Management in the San Pedro Basin





Results from SWRC-Walnut Gulch, SALSA, USPP, SAHRA Projects and Many Other Individuals and Organizations

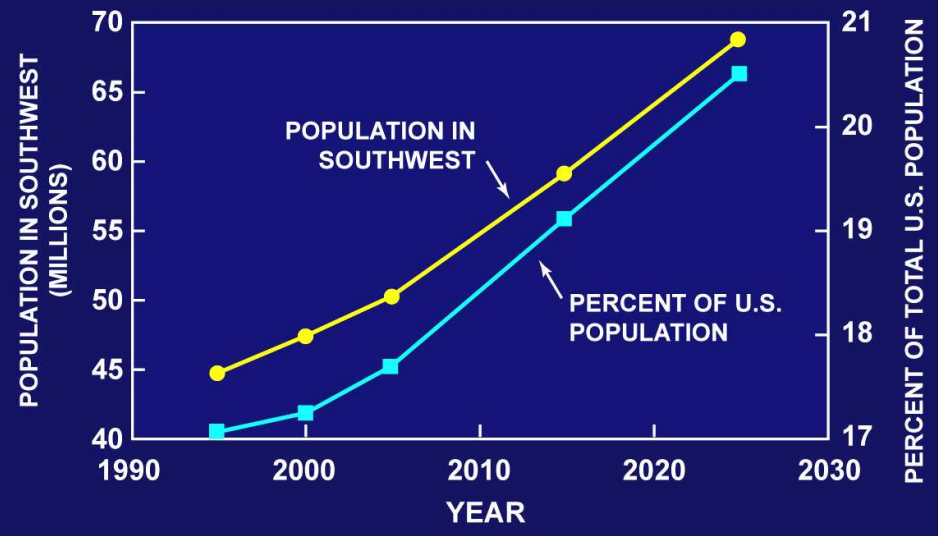
Presented by David Goodrich
USDA-ARS, Tucson, Arizona

NASA	DOE-LANL	JPL	EPA	EPRI	BLM	TNC
UCI	USU	NAU	PSU	UNM	NMT	IRD
UCM	IMADES	UCR	ADWR		PNTS	
Ft. Huachuca	Cochise Co.		WAU		CONACYT	

ASSERTION

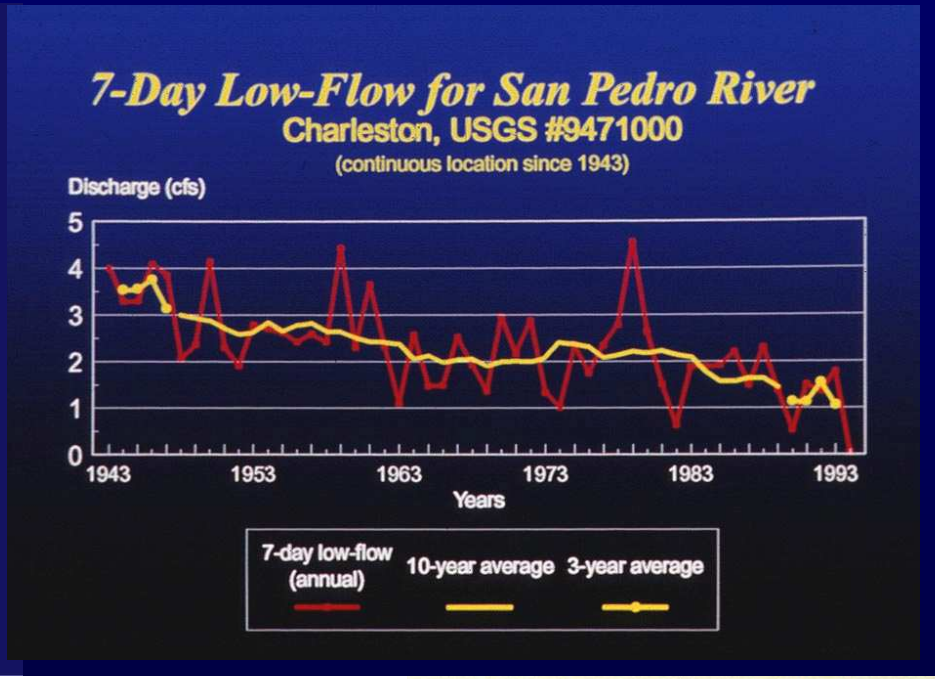
- **Good research has been, and can be done, in many watersheds but -**
- **Successes in joint policy-research efforts have often occurred due to acute needs**
  - **Recognition by policy makers that sound science is essential**
  - **Recognition by scientists that their research isn't likely to address the needs without working with policy/decision makers**
- **Trust is essential to the process (=time)**
- **Better knowledge of basin-scale water balance components is essential for sound management in water limited areas**

Trends in SW Population



Projected population growth in the Southwest, 1995-2025, including Arizona, California, Colorado, Nevada, New Mexico, and Utah

Trends in San Pedro Low Flow

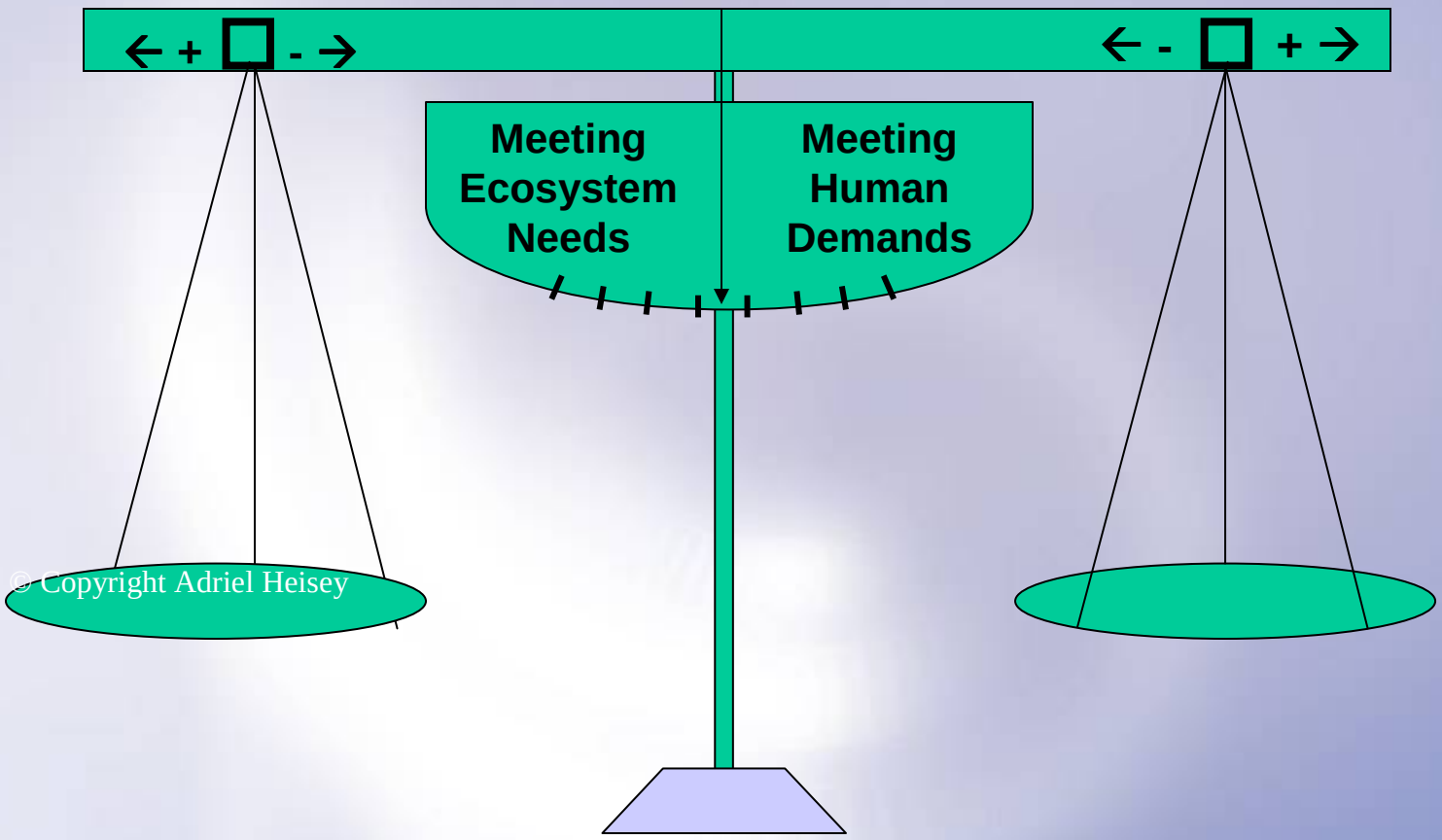


Santa Cruz R. near Tucson

1940s

1980s

Finding the Balance

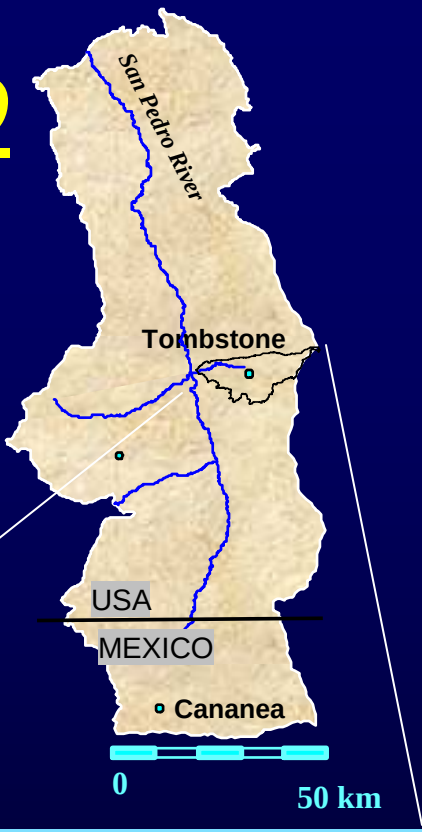


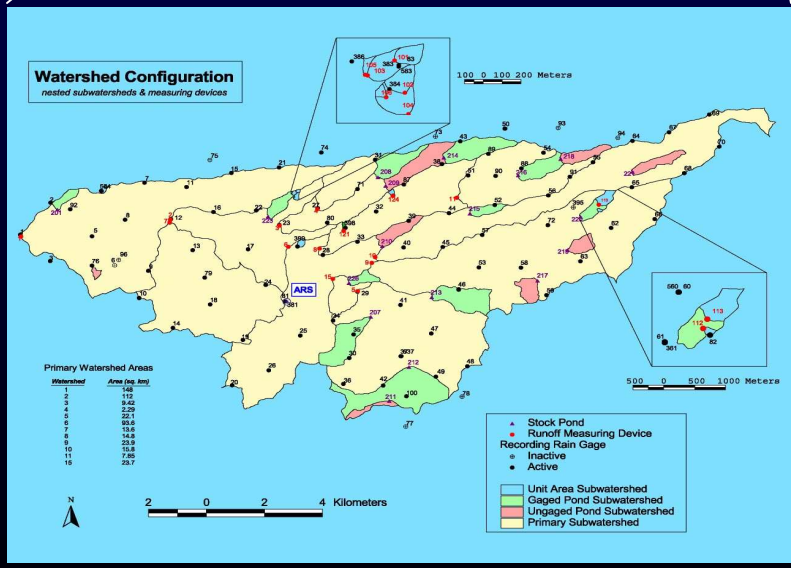
OVERVIEW

- Present an evolution of interdisciplinary, interagency research integrated with policy and decision making in the San Pedro
  - Science for understanding
  - Science for addressing a need
  - Integrated policy development and science
- Through this progression, present findings/challenges in estimating basin-scale water balance components
  - Rainfall, runoff, riparian ET, channel recharge
- Summarize lessons learned
  - Successful strategies / methods for collaboration

EVOLUTION IN WG / SAN PEDRO

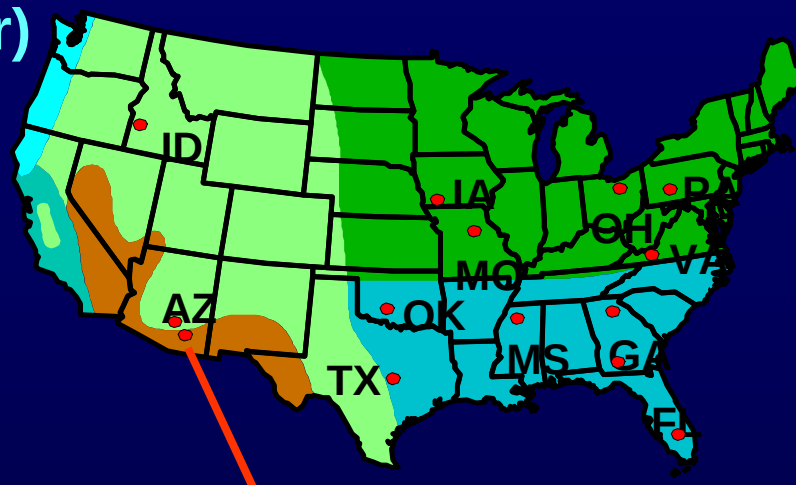
- *USDA - ARS Walnut Gulch Experimental* Watershed (since 1953 – Physical / watershed science)
- *MONSOON'90, WALNUT GULCH '92, NASA-EOS* (Interdisciplinary – physical science)
- *SALSA Program* (Interdisciplinary – physical and biological science – begin outreach & integration)
- *Upper San Pedro Partnership* (Work directly with elected officials and resource managers)
- *SAHRA NSF Science and Technology Center* (Add economics, social science, and education to all of the above)

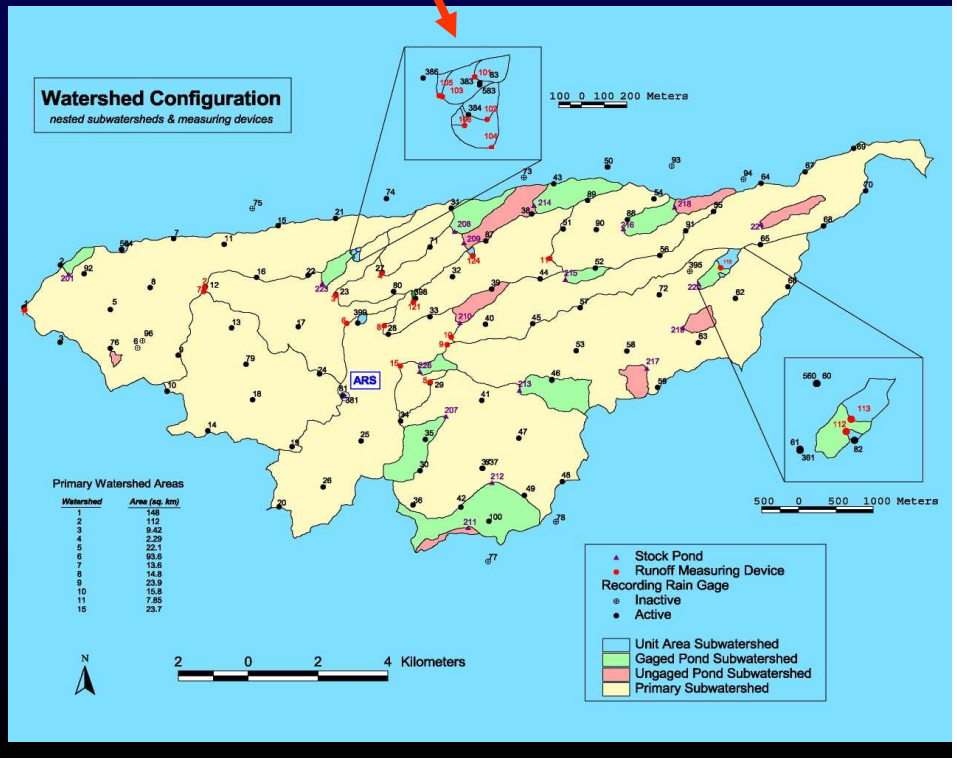




USDA-ARS Experimental Watersheds

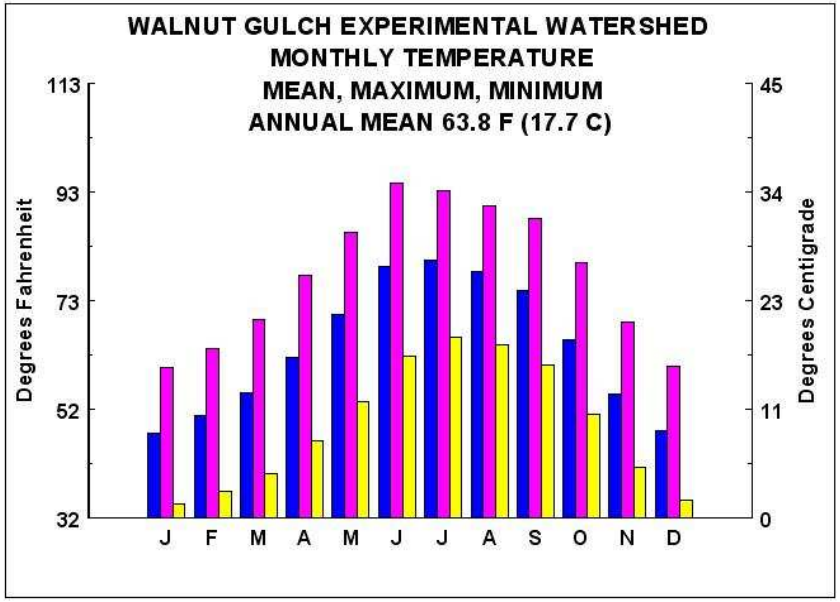
- Exceptional outdoor Labs (25 - 65 yr)
- Walnut Gulch Experimental Watershed (WGEW)
  - 148 km^2 - beginning 1953
  - ~85 recording raingages
  - 30 nested subwatersheds
  - Climate, sediment, EC, carbon, vegetation meas.
- Process-based understanding
- Stable, high-quality research platforms
- Most privately owned
- Magnets for collaboration leading to interdisciplinary experiments

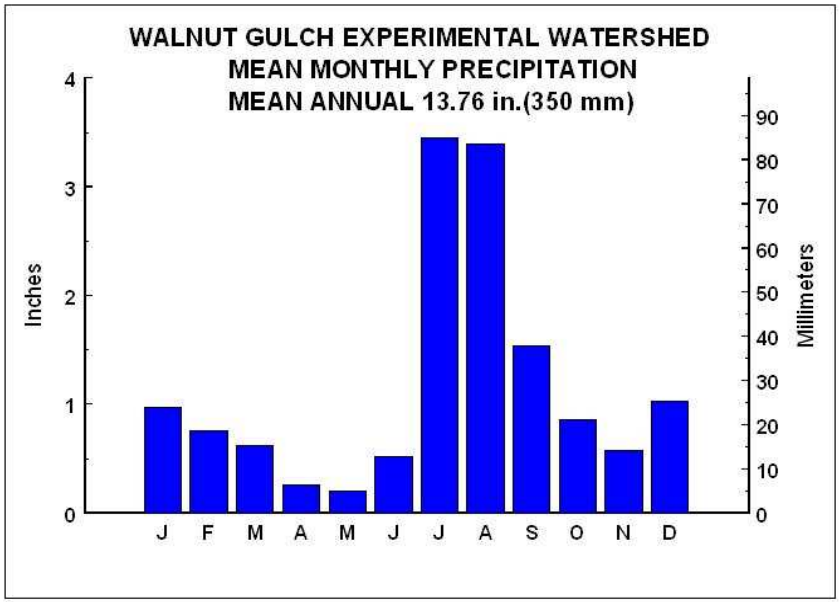


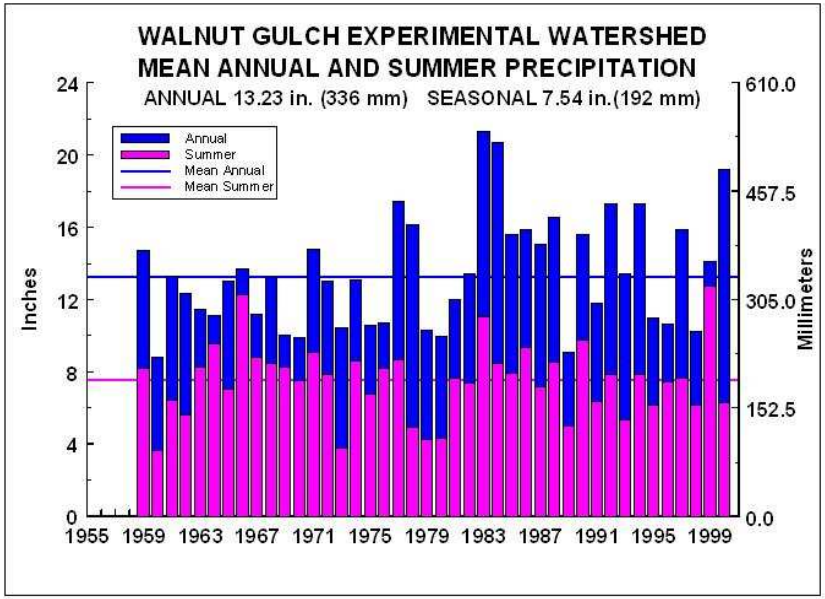


WGEW INSTRUMENTATION

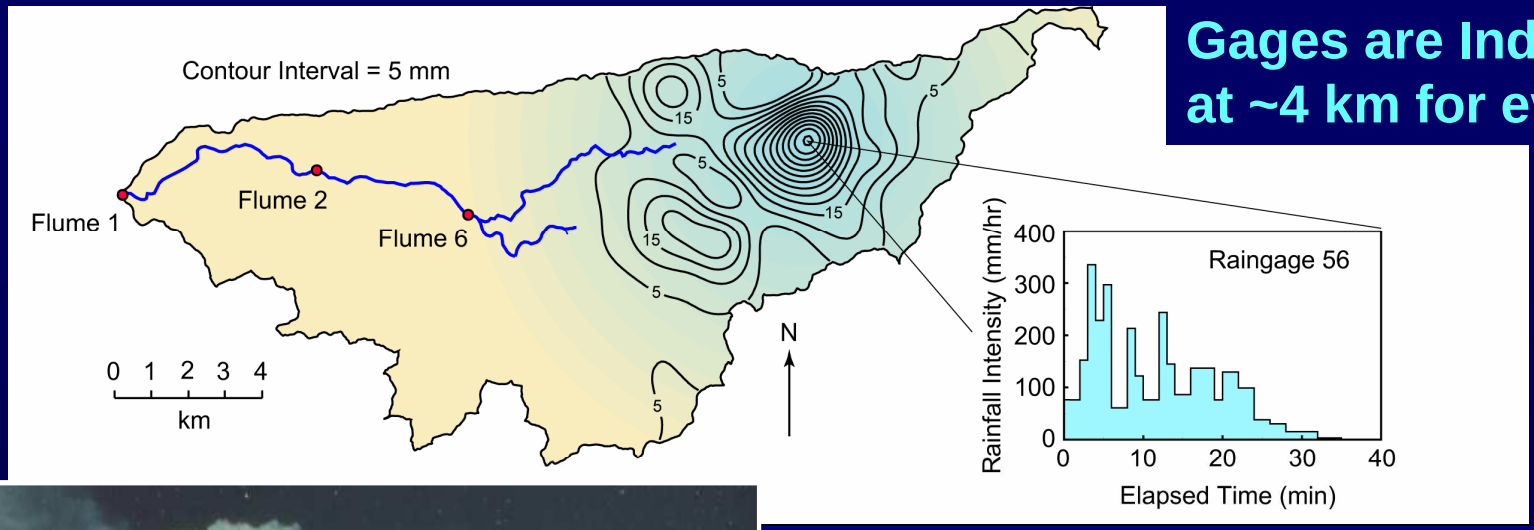
General Climatology







Persistence of Spatial Rainfall Variability

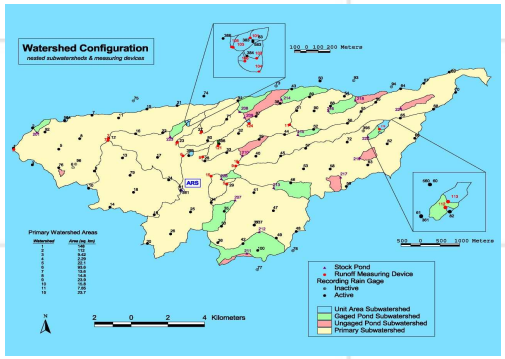


Gages are Indep. at ~4 km for events

Accumulate total precipitation Surrounding the storm above Aug. 27, 1982

Interval	Min	Max	Max/Min
Event	0	68	---
Month	35	102	2.9
Summer	165	275	1.7
Year	260	395	1.5

Mean of (total storm area (A_{st}) / catchment area) and (storm core area (A_{cor}) / catchment area) versus catchment area for $A_{st} > 0$ and $A_{cor} > 0$



Mean $\left[\frac{\text{Area}_{\text{storm}}}{\text{Area}_{\text{watershed}}}\right]$

Mean $\left[\frac{\text{Area}_{\text{storm core}}}{\text{Area}_{\text{watershed}}}\right]$

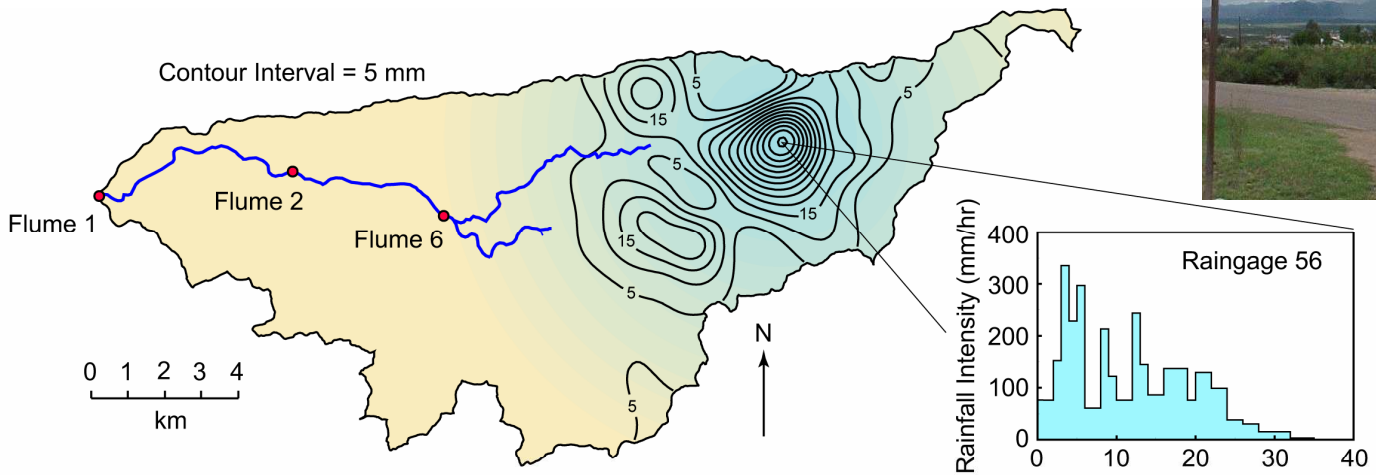
Ratio

1.0
0.8
0.6
0.4
0.2
0.0

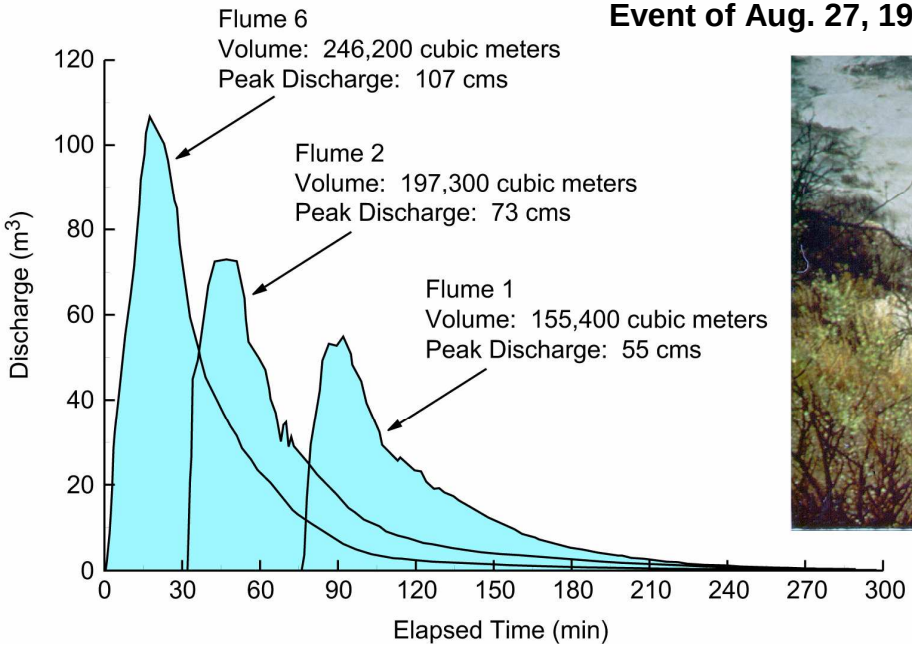
1E+4
1E+5
1E+6
1E+7
1E+8

Watershed Area (m^2)

Runoff and Channel Losses

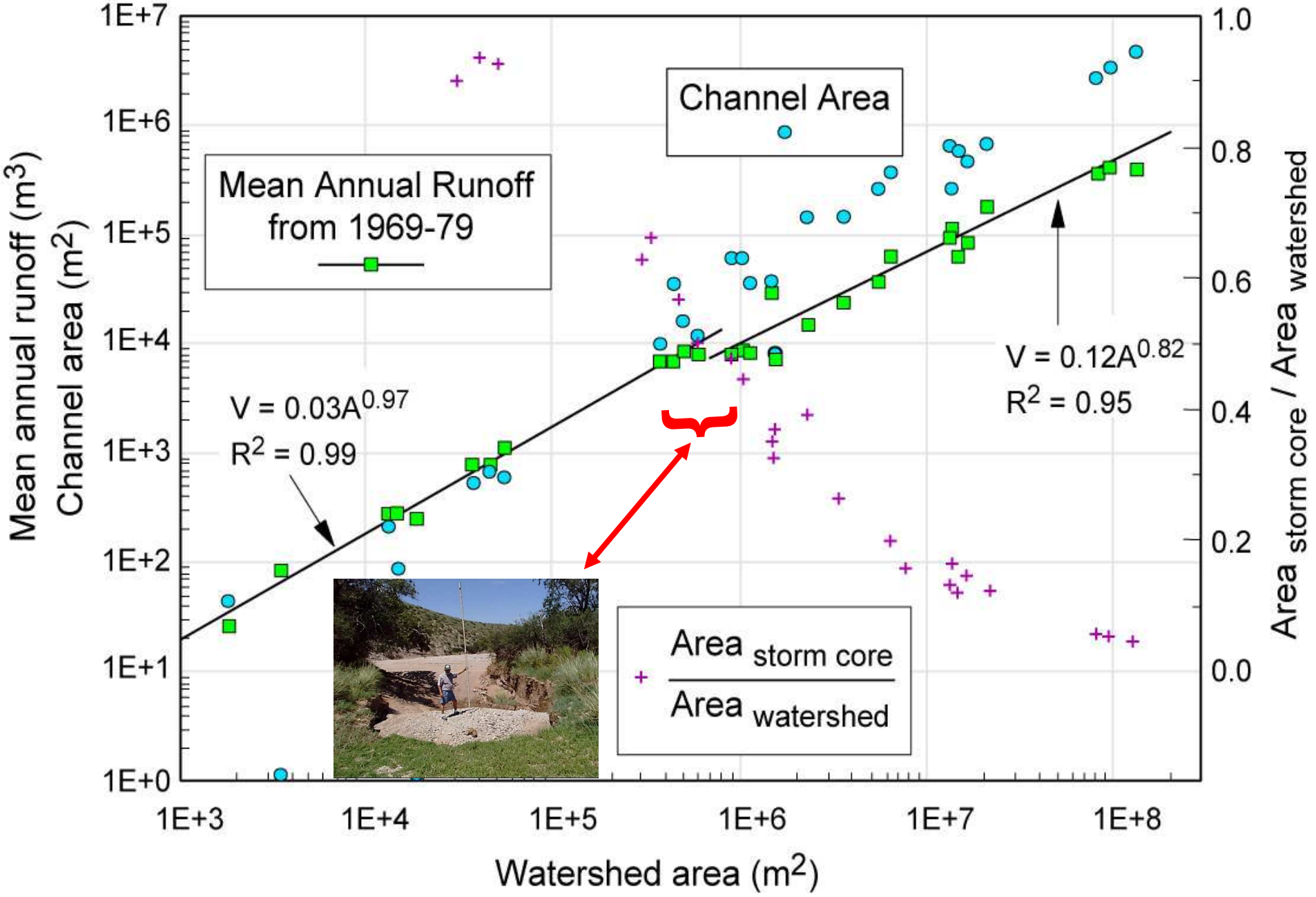


Event of Aug. 27, 1982



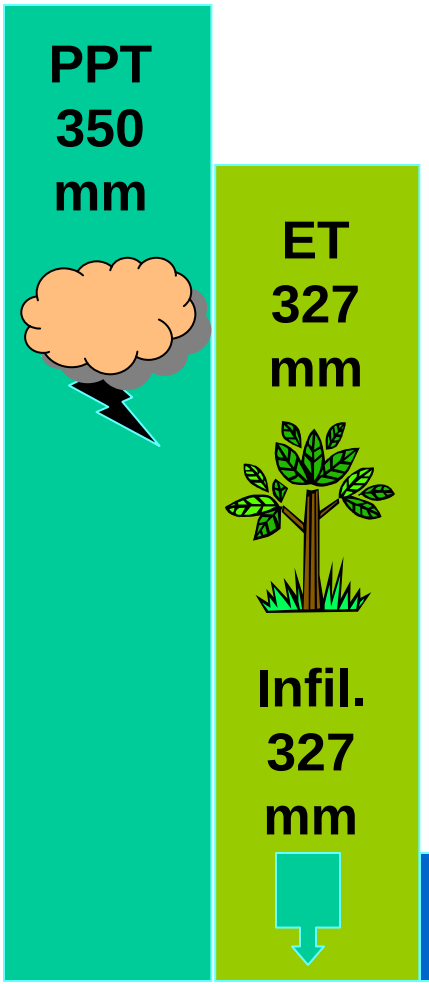
Mean annual runoff volume versus contributing catchment area

**** Basin response becomes more non-linear with increasing area ****



SEMI-ARID RAINFALL - RUNOFF ISSUES

Walnut Gulch (148 km^2)
Average Annual Water Balance



Runoff
2 mm
= ~ 0.6% of
rainfall

- Small Output/Input (O/I) ratio
- Large Noise/Output (N/O) ratio
  - Rain gauge measurement error ~ 3mm
  - Wind induced gauge
    errors ~ 5 to 15% of total
    rain depth (~15-45 mm)
  - N/O ratio increases as scale increases

Challenge

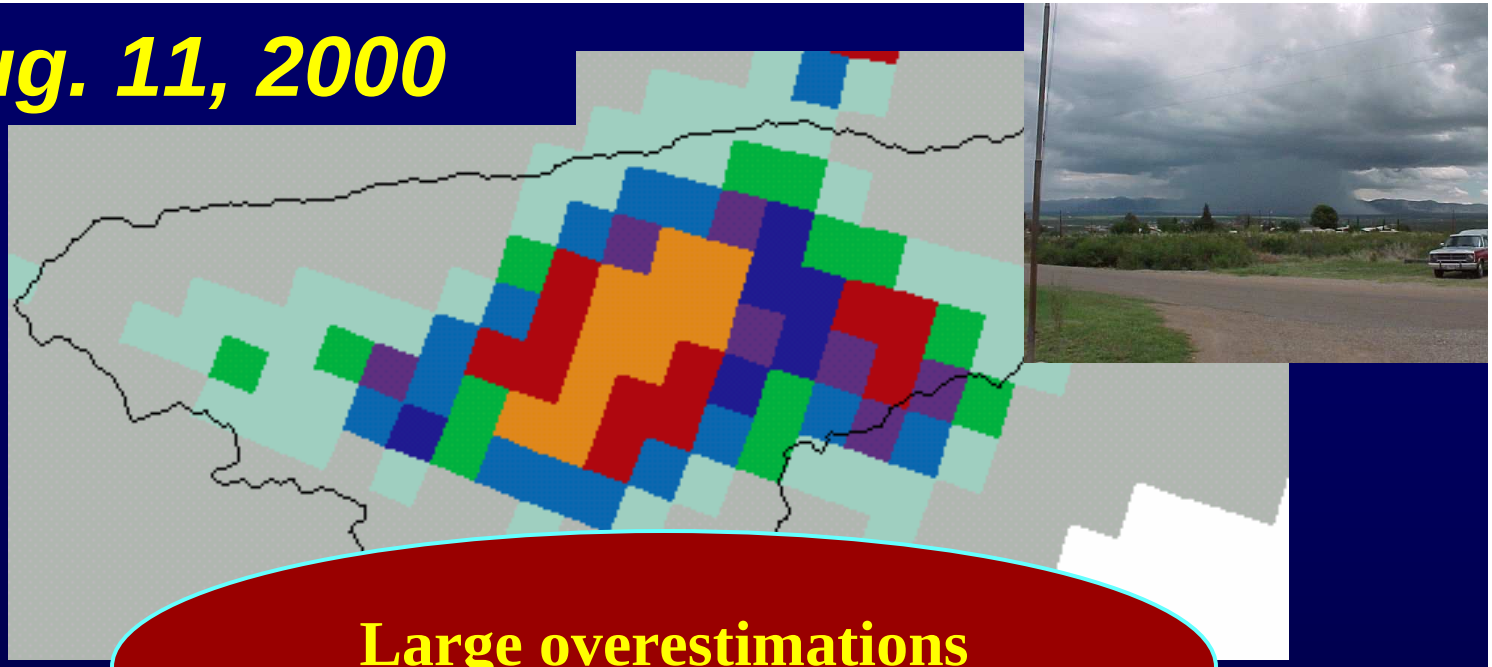
- At the large scale, in arid in semiarid regions where runoff / rainfall ratios are small, we are between a rock and hard place.
- Can we start measuring spatially distributed components of the water balance that are of much greater magnitude - e.g. ET, infiltration?
- Will radar or satellite estimates of rainfall improve our ability to estimate large-area areal rainfall outside of WG?

Storm: Aug. 11, 2000

Radar reflectivity images

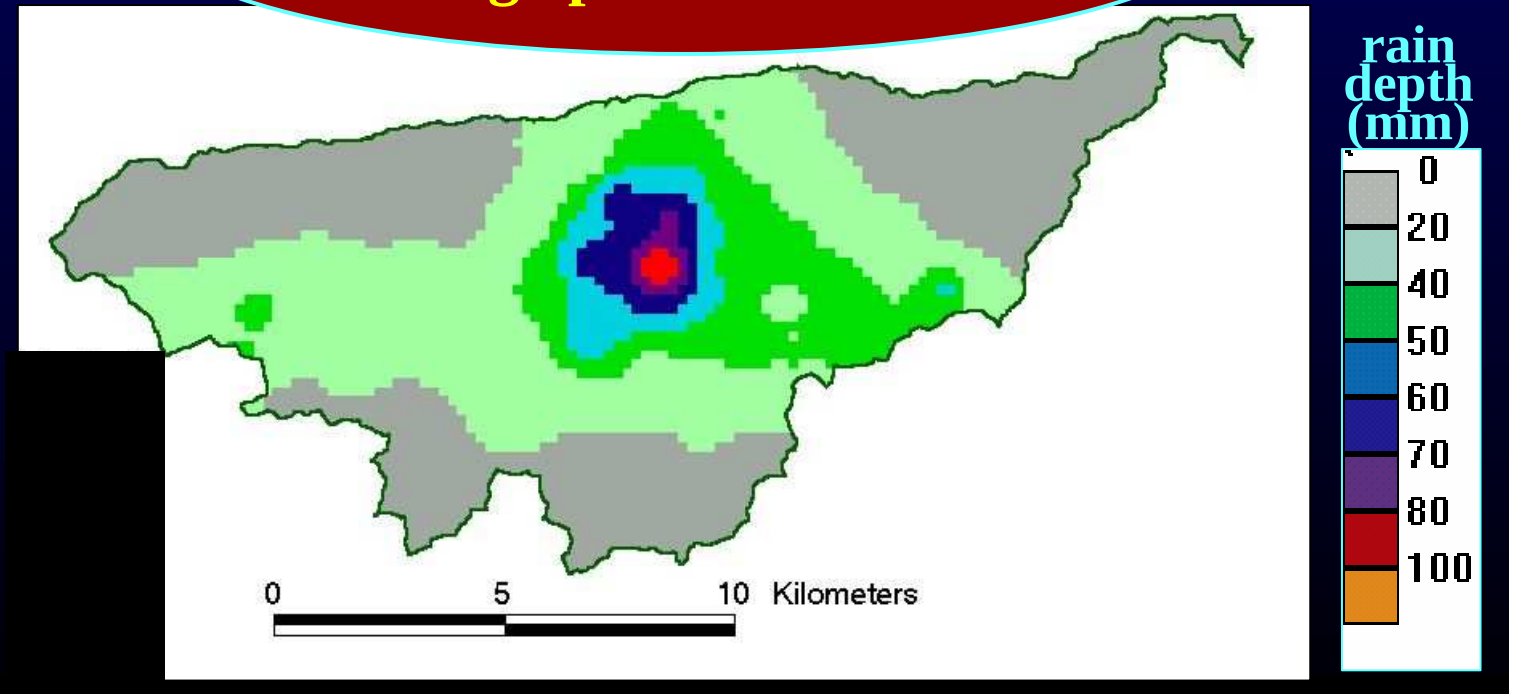
Storm: Aug. 11, 2000

Radar based rainfall using operational Z-R



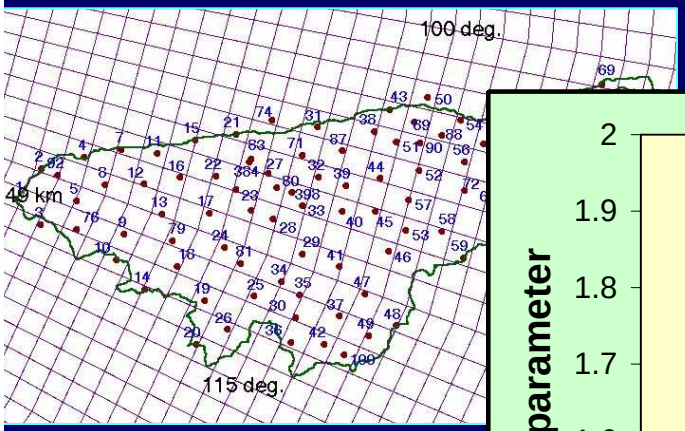
Large overestimations using operational Z-R!

Gage based rainfall

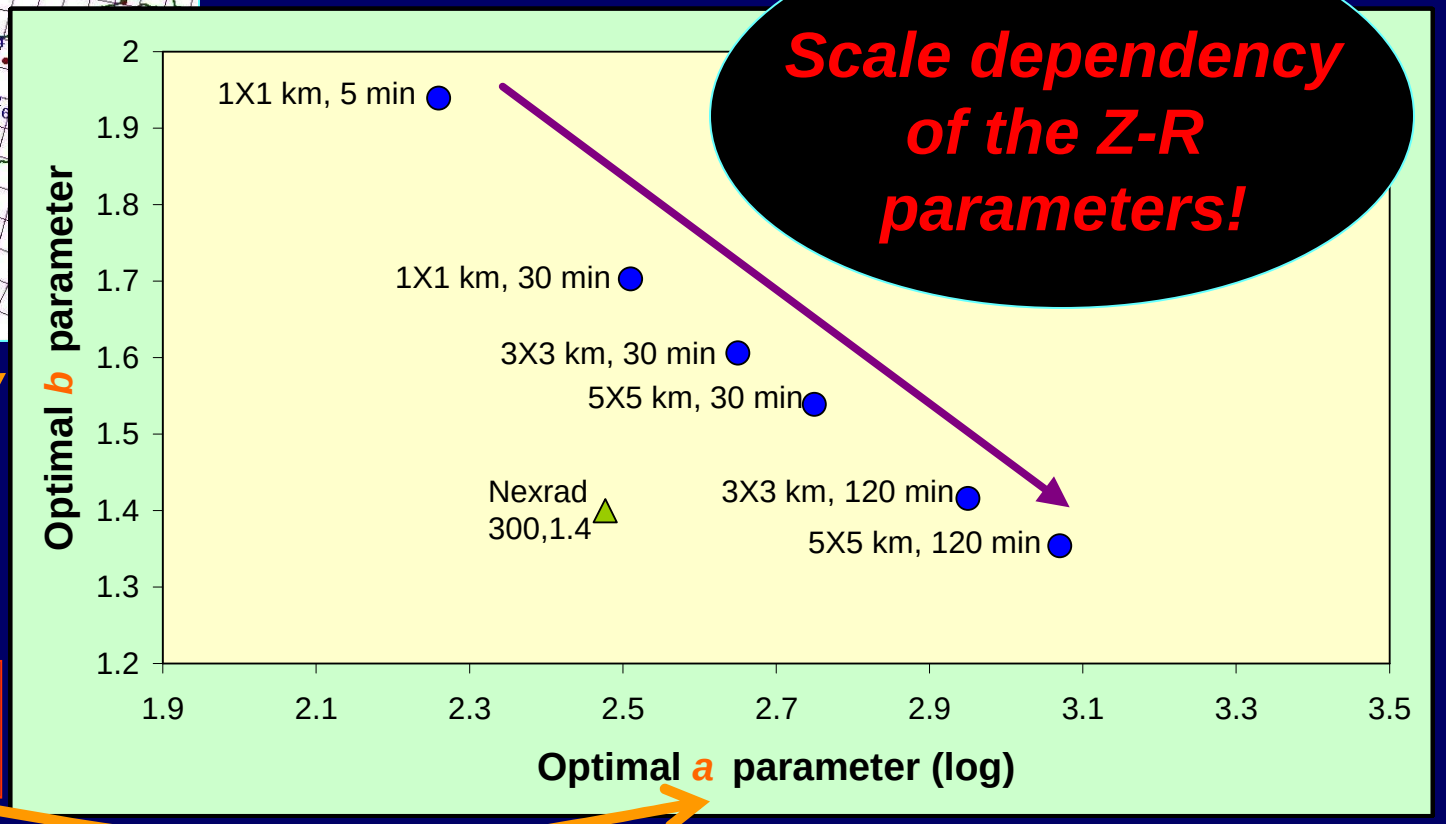


Rainfall estimation based on NEXRAD data over WG

Assuming the conventional NWS power-law relationship and the RMSE objective function, estimate the optimal Z-R parameters over 11 storms

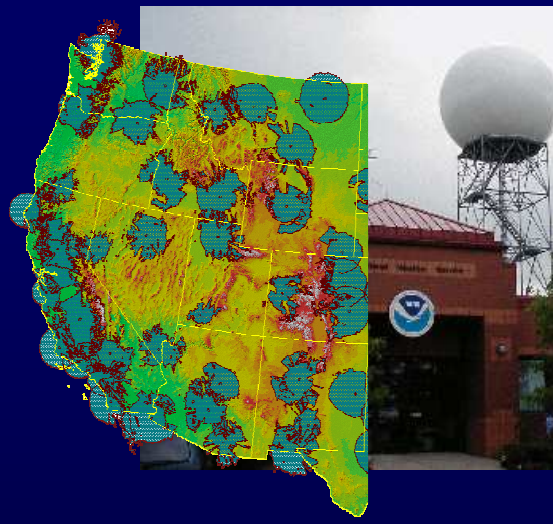


$$Z = aR^b$$



Satellite Derived Precipitation – UC-Irvine

PERSIANN_CCS (Precipitation Estimation from Remotely Sensed Information using ANN with Cloud Class. System) Precipitation product generated from processing cloud images using pattern recognition techniques to produce rainfall rates.

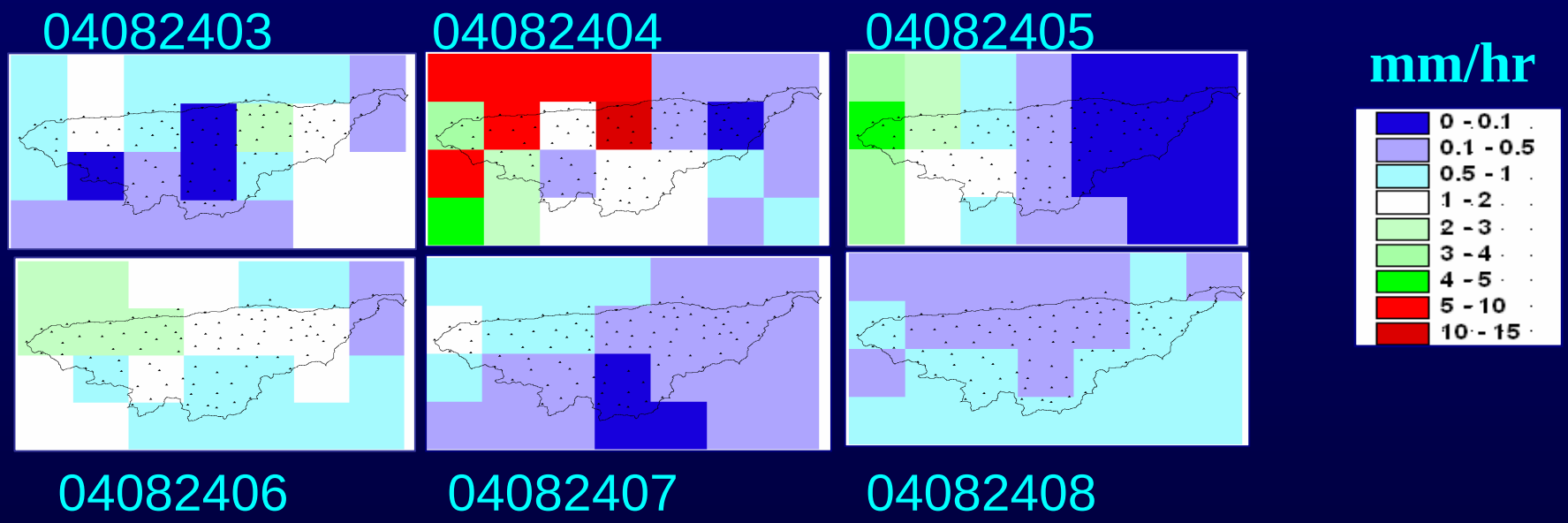


Radar Issues

- **Uncertainty in the Z-R relationship**
- **Beam overshooting and blockage**
- **Bright band, hail contamination**
- **Lack of coverage over Ocean – West. US**

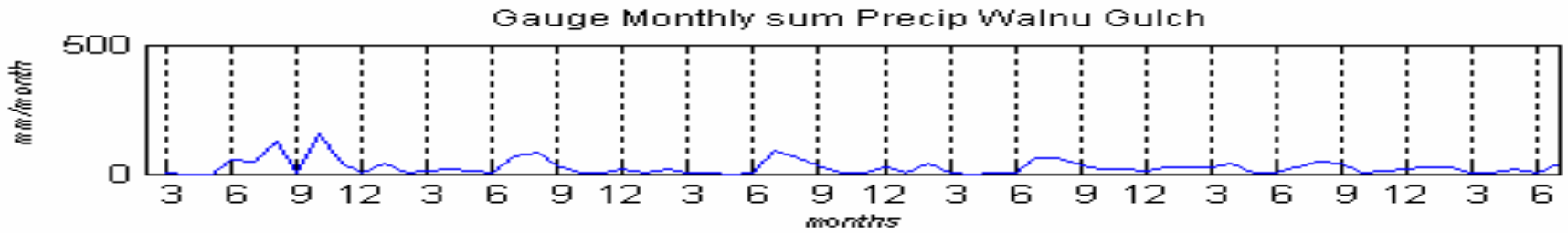
Satellite Products now being generated at hourly intervals over 4 x 4 km grids

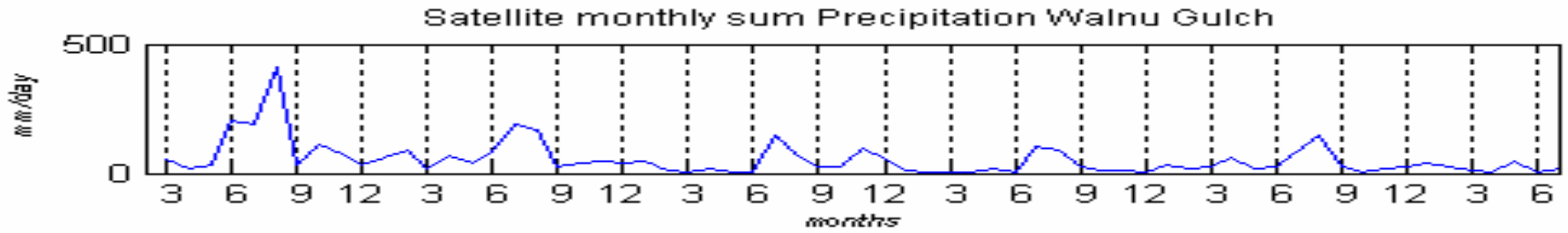
Hourly Evaluation – PERSIANN over WGEW

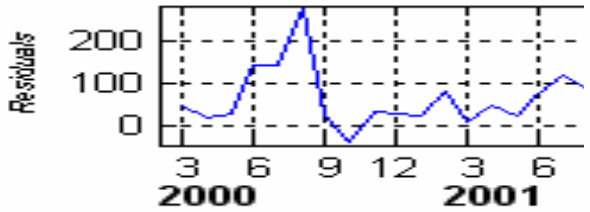


The August 24, 2004 storm was used to compare PERSIANN_CCS at the event scale.

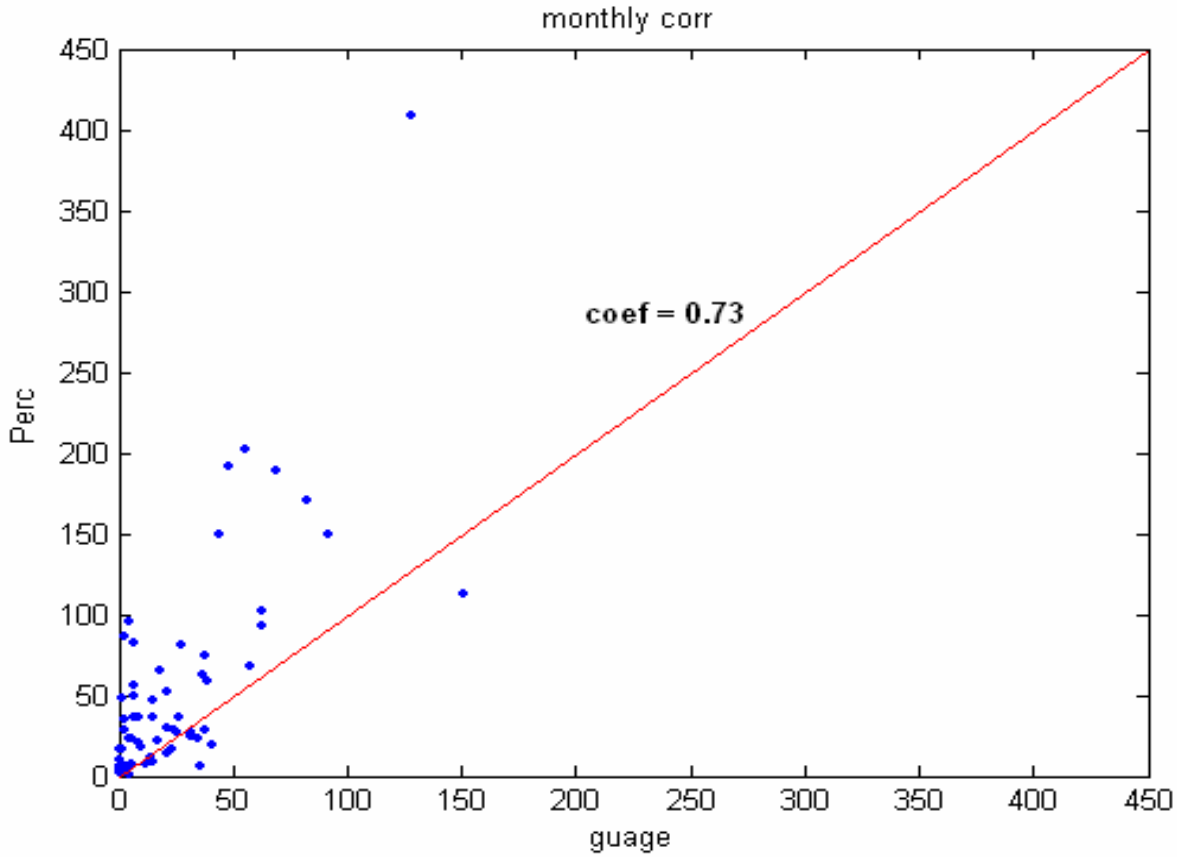
It captures the storm over the WGEW with relatively agreeable intensity but the peak intensity of the storm is recorded one hour after it was picked up by the gauge network.







Monthly Evaluation

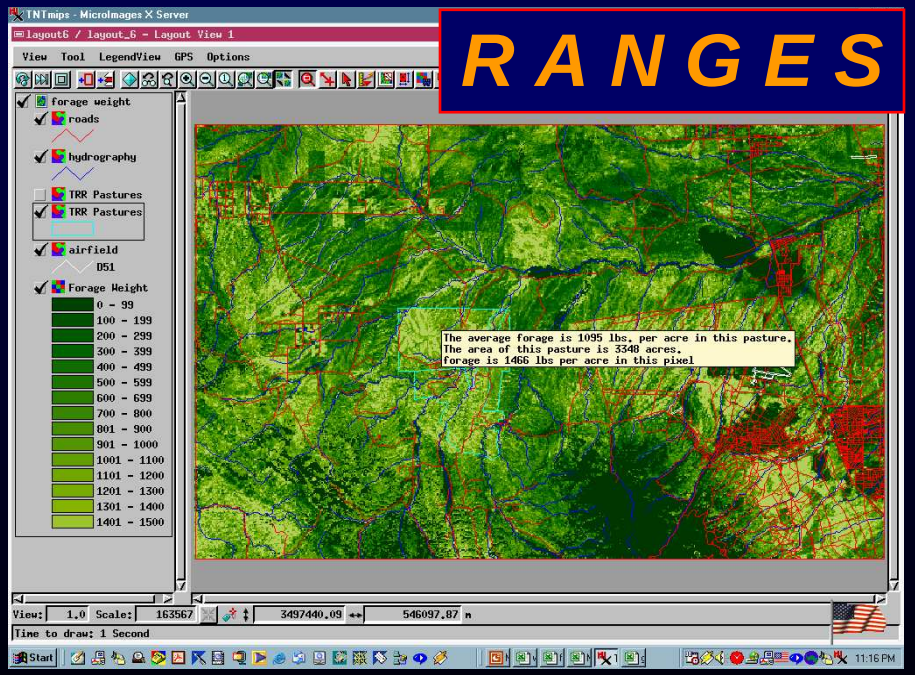


Challenge

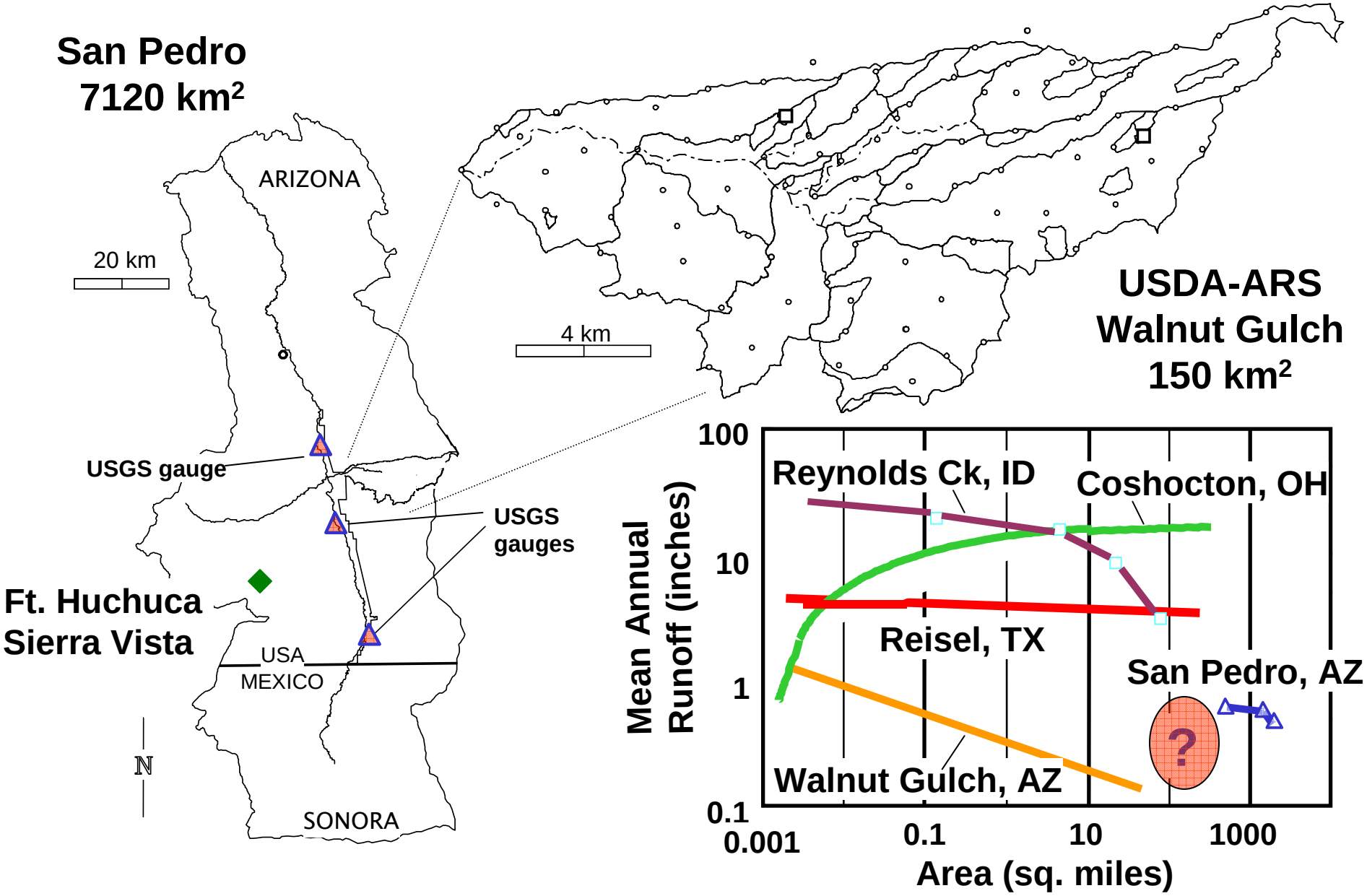
Can “fast” responding vegetation or remotely sensed changes in soil moisture be used as a distributed infiltration gauge in water-limited environments?

Point Measure Rain

Distributed Forage Weight Image (green or senescent)



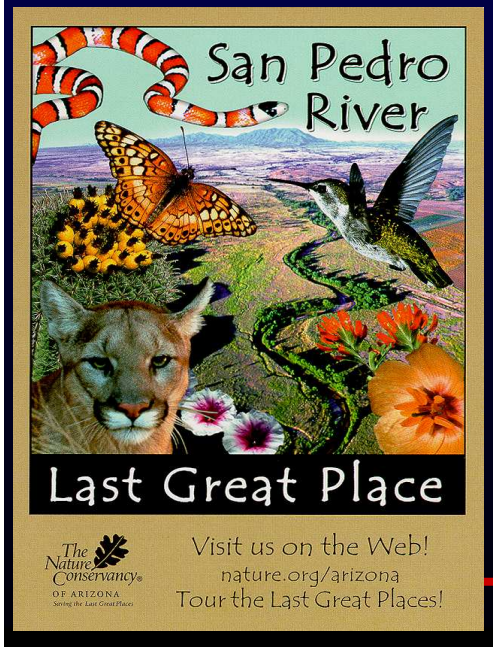
Scaling Behavior Beyond Walnut Gulch



ATTRIBUTES OF THE SAN PEDRO BASIN

Microcosm of local, state, and international water & ecology issues

- **Ft. Huachuca – largest employer (>10,000) in S. Arizona (Payroll > $800,000,000 M/yr)**
- **Cananea Mine: 2-3% world's copper**



- **One of world's most ecologically diverse areas – 1st Congressionally designated Nat. Riparian Cons. Area**
- **First application of International Environ. Law (NAFTA Accords) in the US**
- **Groundwater is sole source of water for human use and sustaining flow**

EVOLUTION IN WG / SAN PEDRO

- *USDA - ARS Walnut Gulch Experimental* Watershed (since 1953 – Physical / watershed science)
- *MONSOON'90, WALNUT GULCH '92, NASA-EOS* (Interdisciplinary – physical science)
- *SALSA Program* (Interdisciplinary – physical and biological science – begin outreach & integration) ('95-'00)
- *Upper San Pedro Partnership* (Work directly with elected officials and resource managers)
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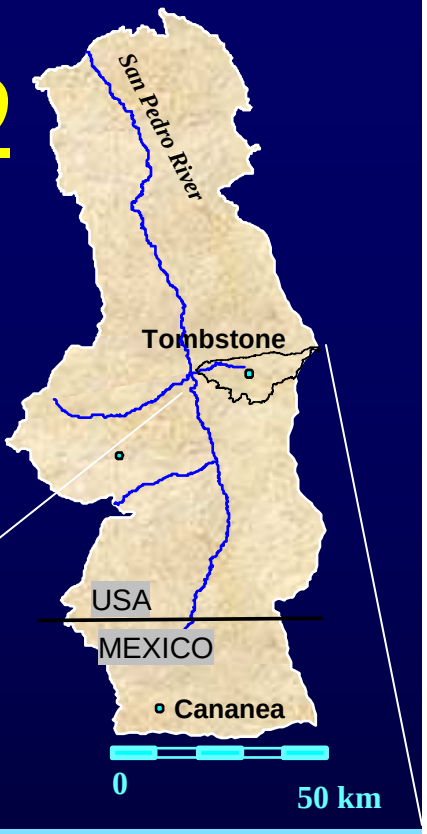
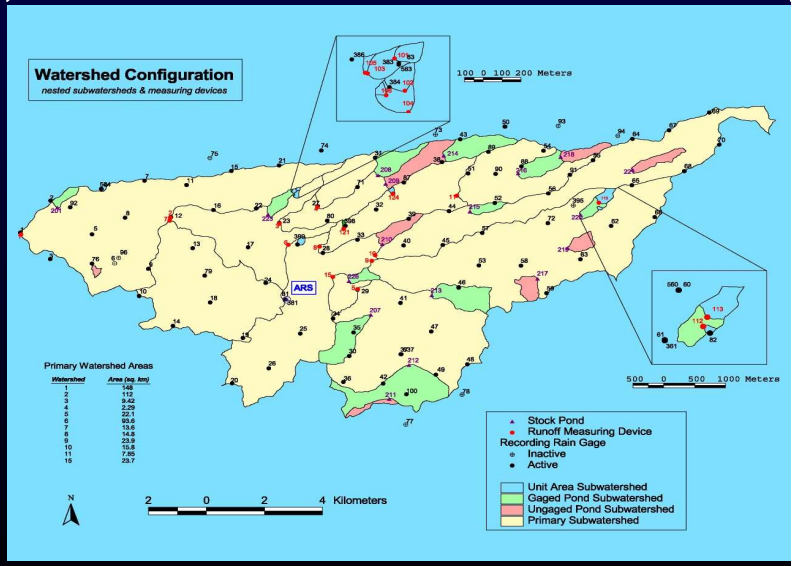


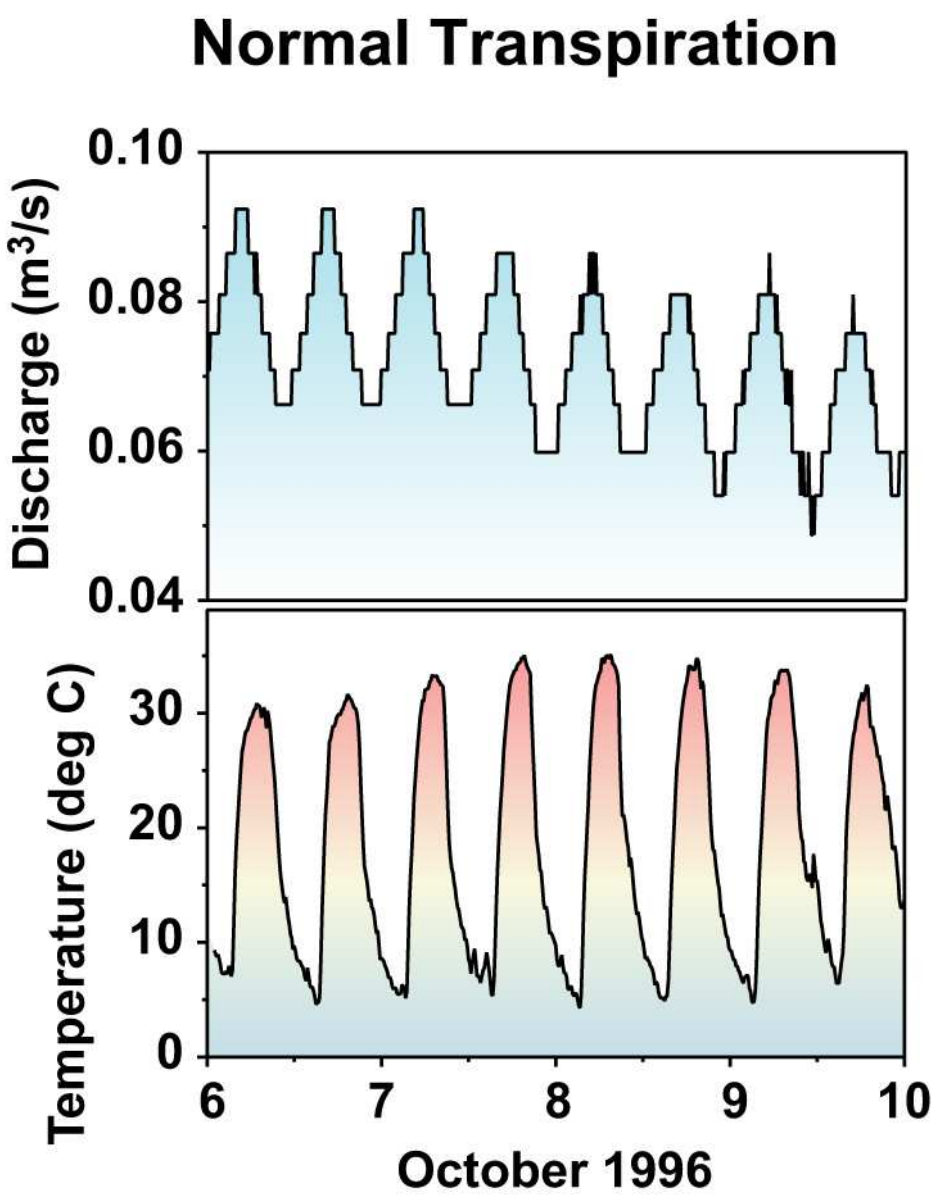


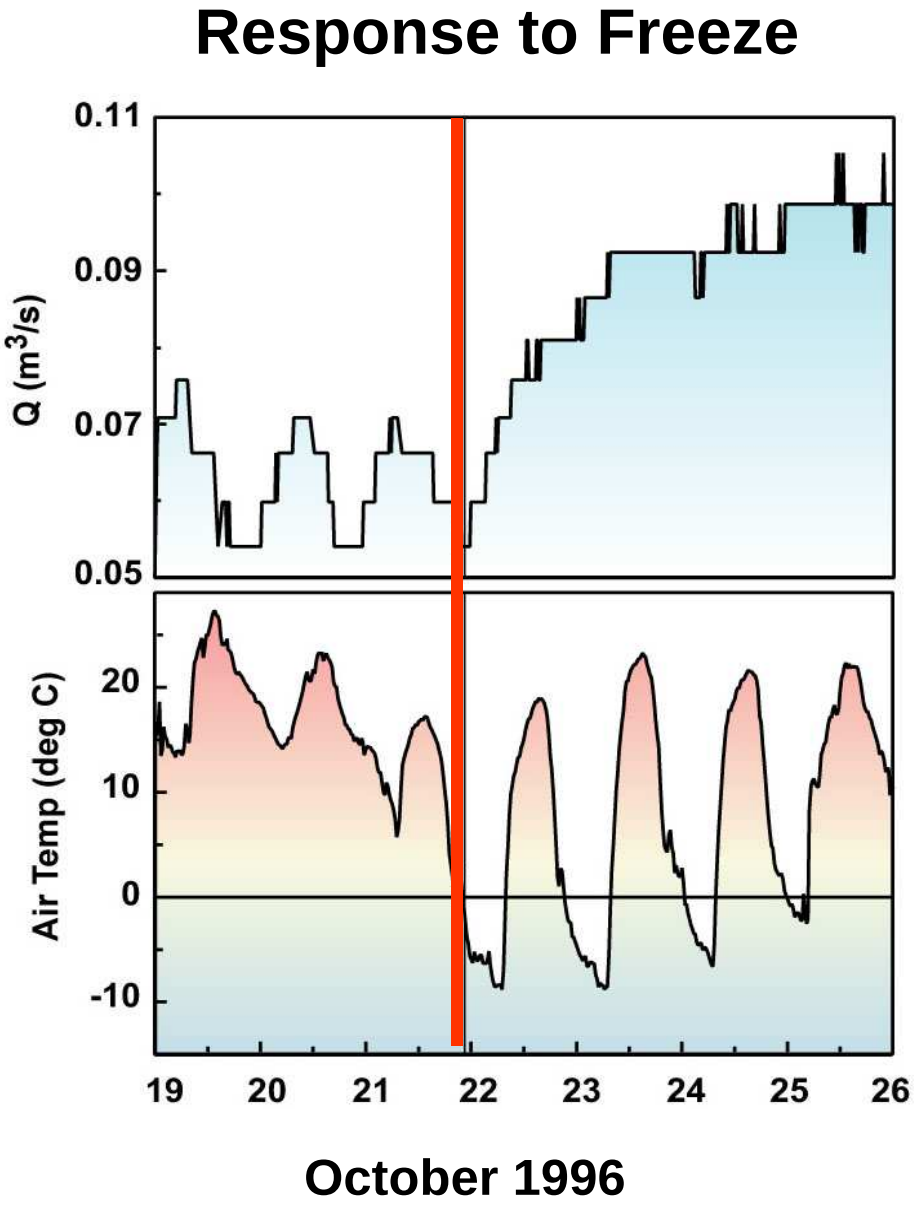
RIPARIAN WATER USE

Simple Question:

How much water does the riparian vegetation use and where does it come from ?

Tight Coupling between GW-SW-ET

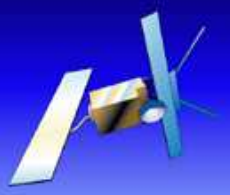




Riparian Ecosystems Processes

Coordinated Measurements for Water Source and Exchange conducted during the SALSA Program

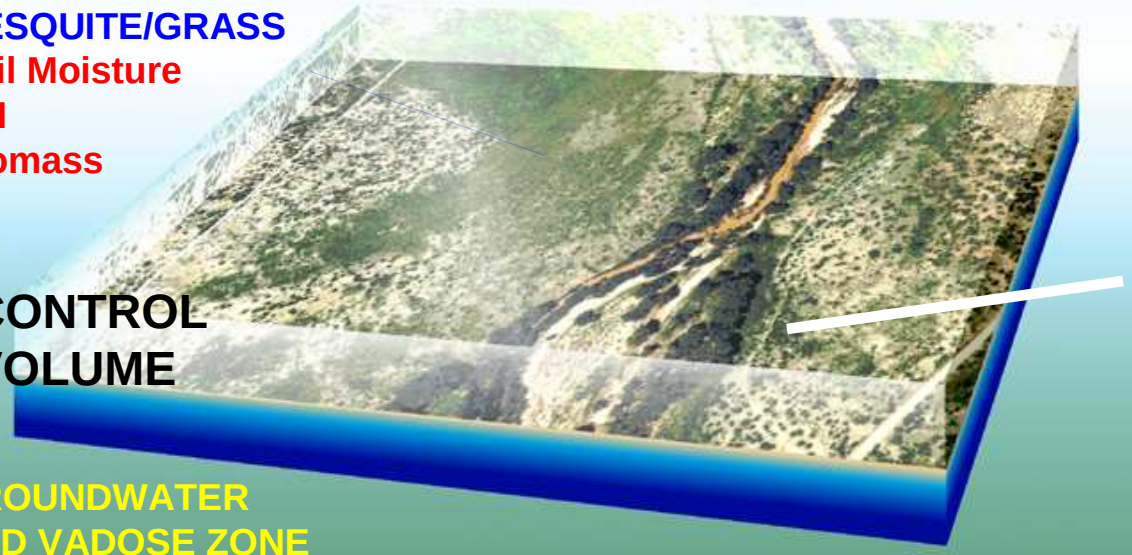
REMOTE SENSING



NEAR-SURFACE ATMOSPHERIC LAYER
Surface Met/Flux Stations
Scintillometer, LIDAR, SODAR

SAN PEDRO RIVER
Stage/Discharge
Dye Tracer Dilution
Bank Conductance

MESQUITE/GRASS
Soil Moisture
LAI
Biomass



CONTROL VOLUME

GROUNDWATER AND VADOSE ZONE
Deep Wells
Piezometers
Isotopes

RIPARIAN FOREST GALLERY
Sapflow, LAI, Stomatal Conductance
Leaf Carbon Isotope, Plant Water Isotope
Photosynthetic Rate

Interdisciplinary and Public Integration

ATMOSPHERIC SCIENCES

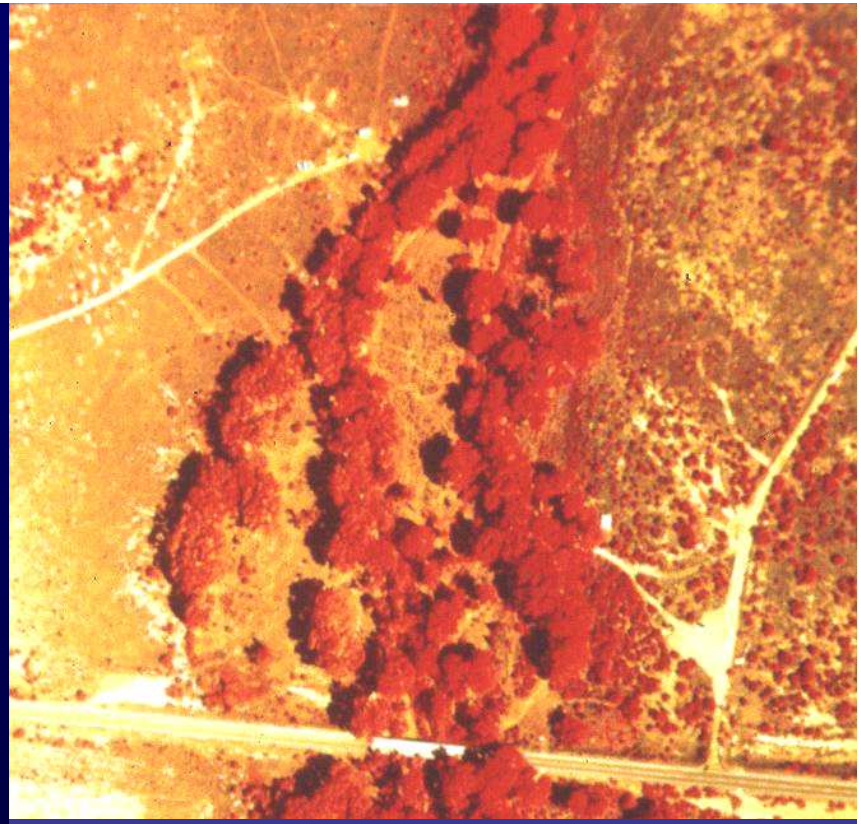
SURFACE WATER & UNSATURATED ZONE HYDROLOGY

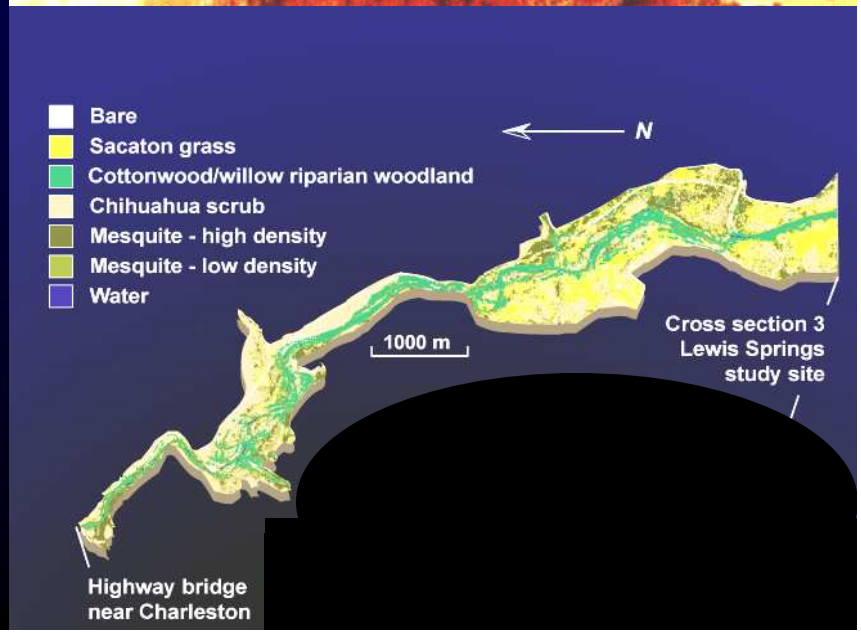
ECOLOGY/BIOLOGY

GROUNDWATER HYDROLOGY, GEOPHYSICS

APPROACH

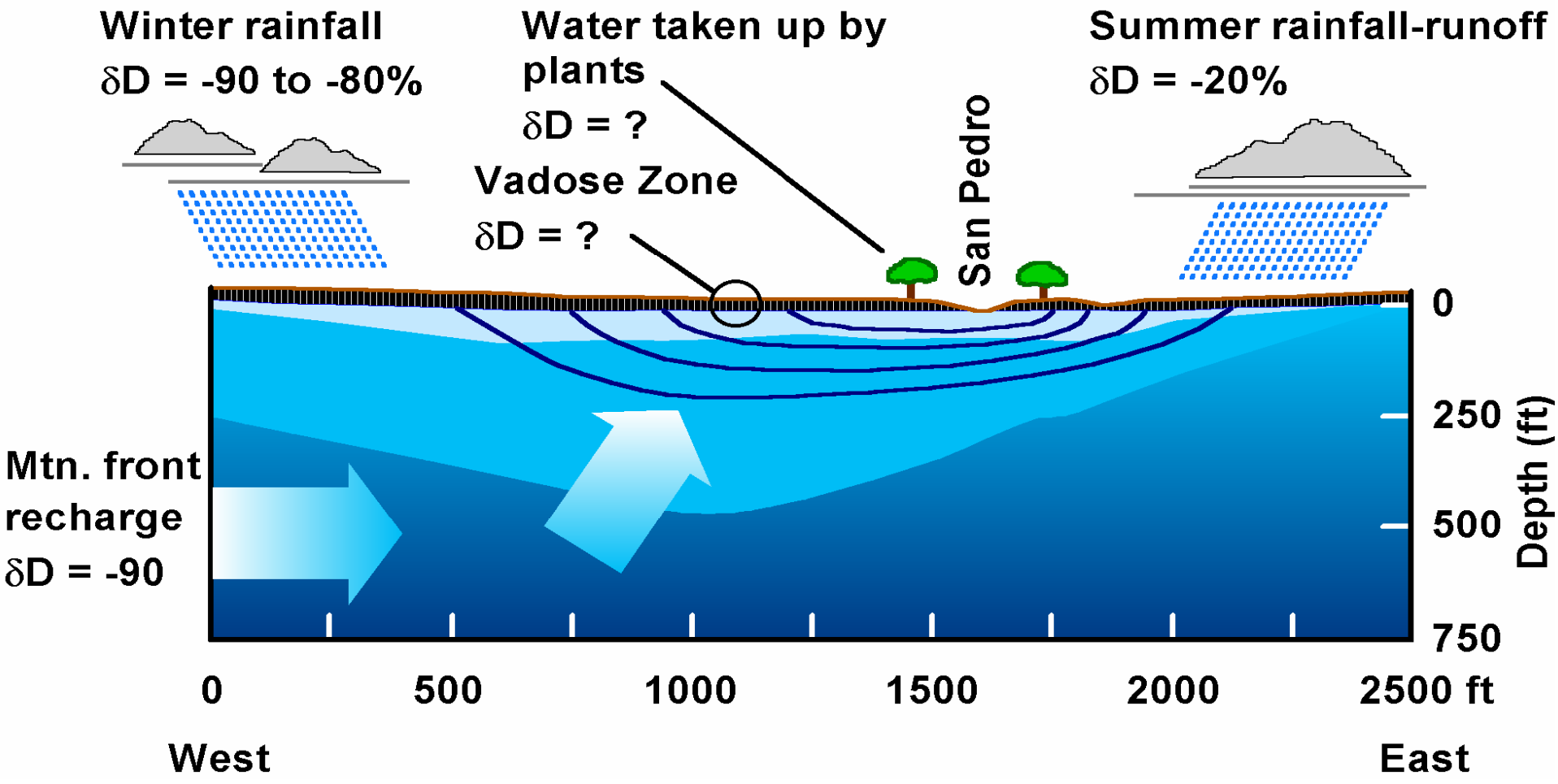
- Water source ID via isotopes
- Stepwise scaling of ET (space-time)
  - Plant to tree cluster to 300 meter reach to 10 km reach (corridor scale)
  - Day to season
- Water balance at reach & multi-day scale and corridor and 90 day pre-monsoon scales (with uncertainty)
- Independent measure of water balance components





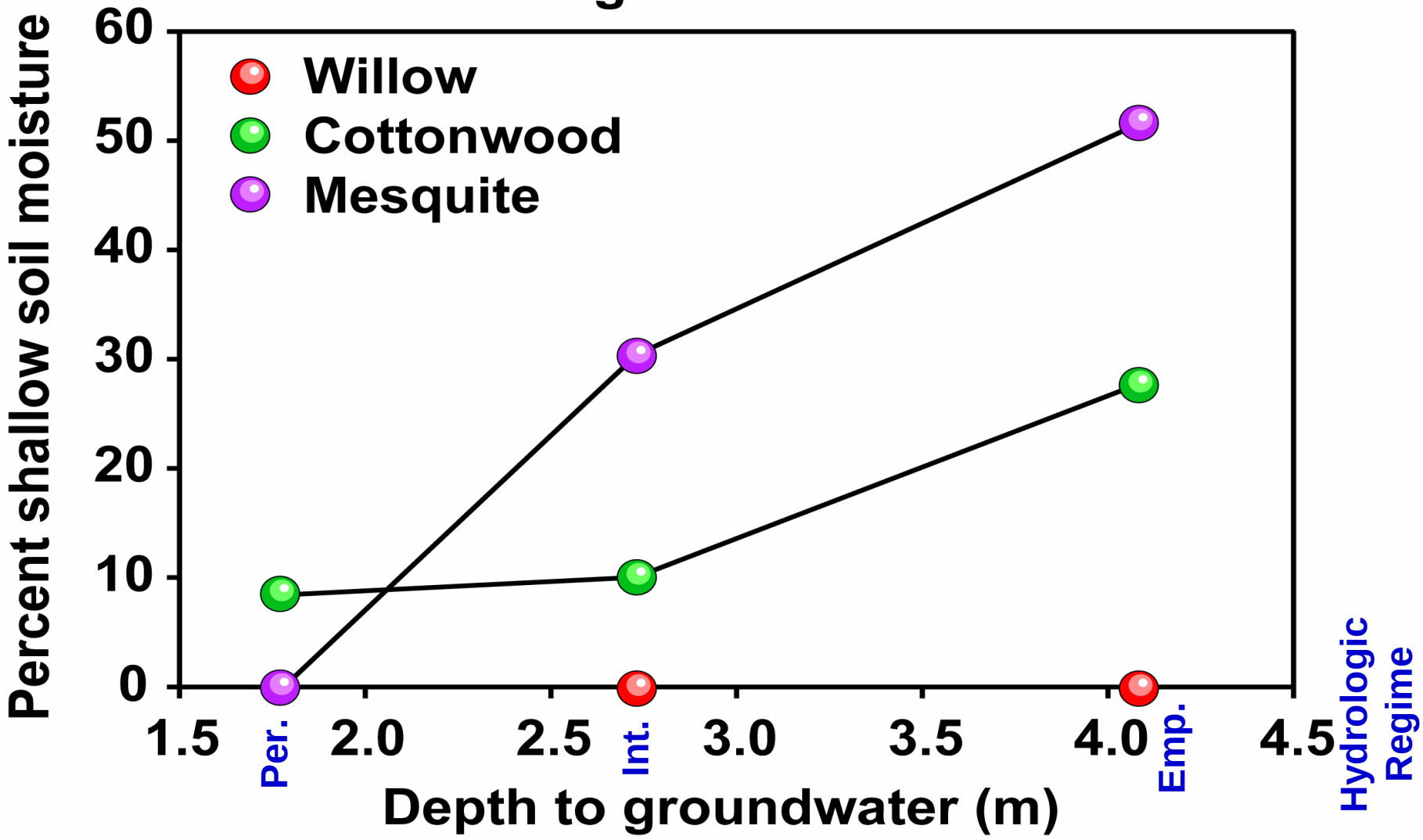
Water Source / Isotope Measurments

- Basin Scale – Recharge Sources (H / Deuterium)
- Riparian Plant Water Sources (Gaining/Ephem. Reaches)
  - (Hydrogen / Deuterium and O^{16} / O^{18}



Plant Water Sources

Relationship Between Percent Shallow Soil Moisture Use and Depth to Groundwater After a Monsoon Rain Event August 1997

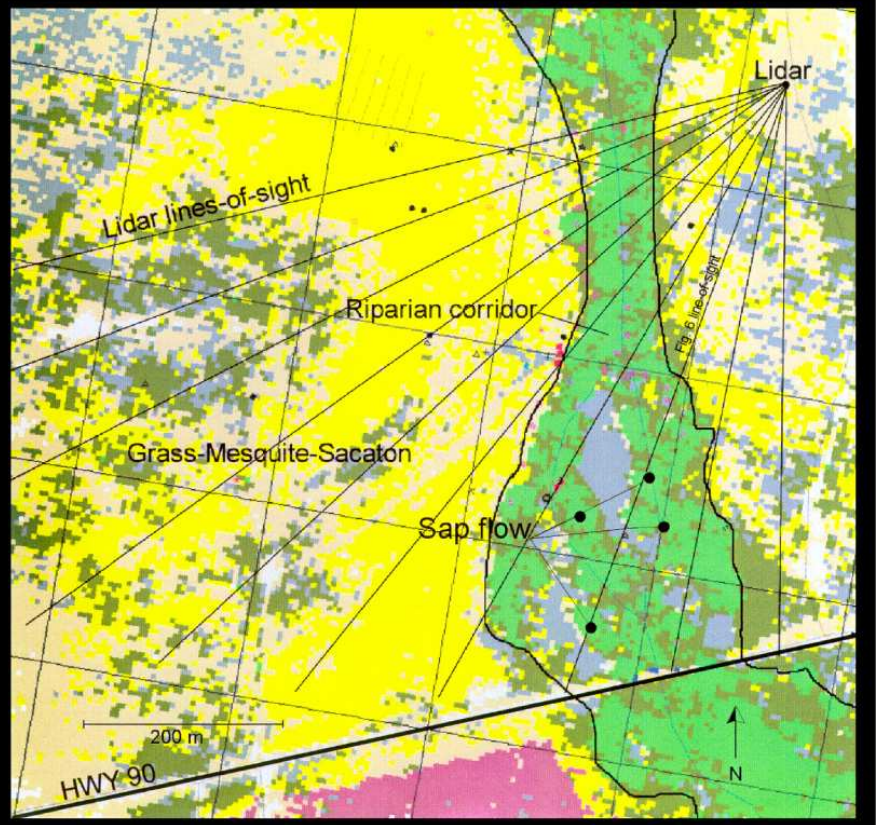


ET - MEASUREMENTS

- Cottonwood / Willow
  - Sapflux scaled by breast height diameter and stand surveys
  - Scale sapflux to Dev. daily P-M model
  - LANL LIDAR (Aug.)
- Mesquite / sacaton
  - Bowen ratio (continuous) / EC
  - Scintillometer (H_{sens} – Aug.)
- Spatially scale with remote sensing

LIDAR

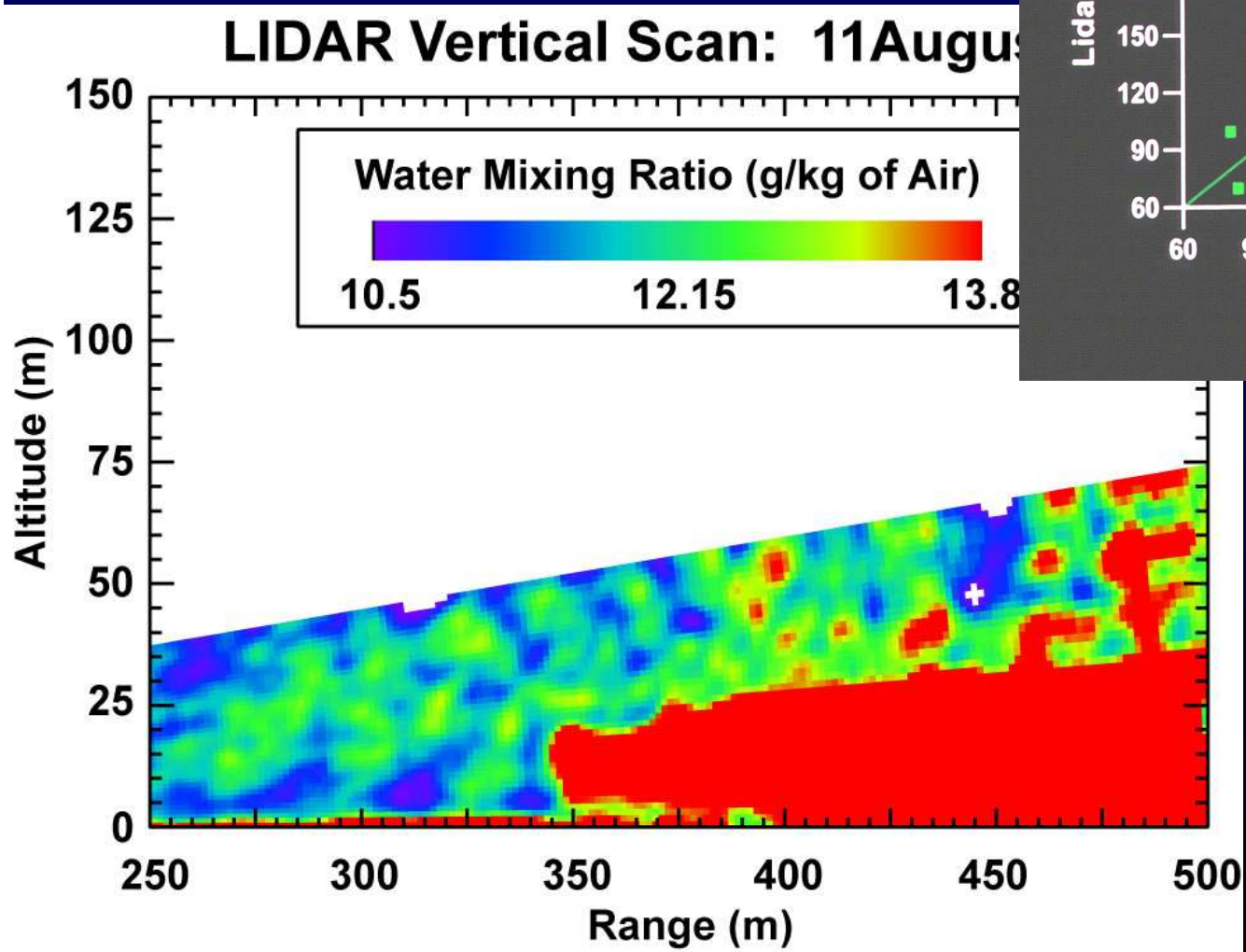
- **Spatially distributed water vapor**

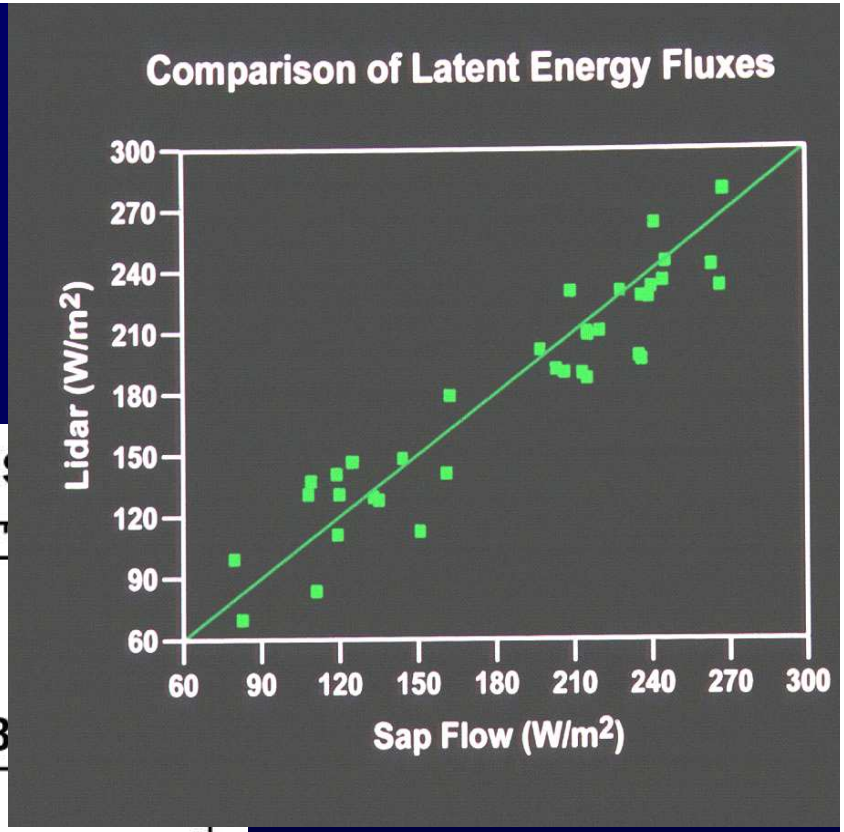


Site Map of the Lewis Springs Study Area

LIDAR

- Data and results



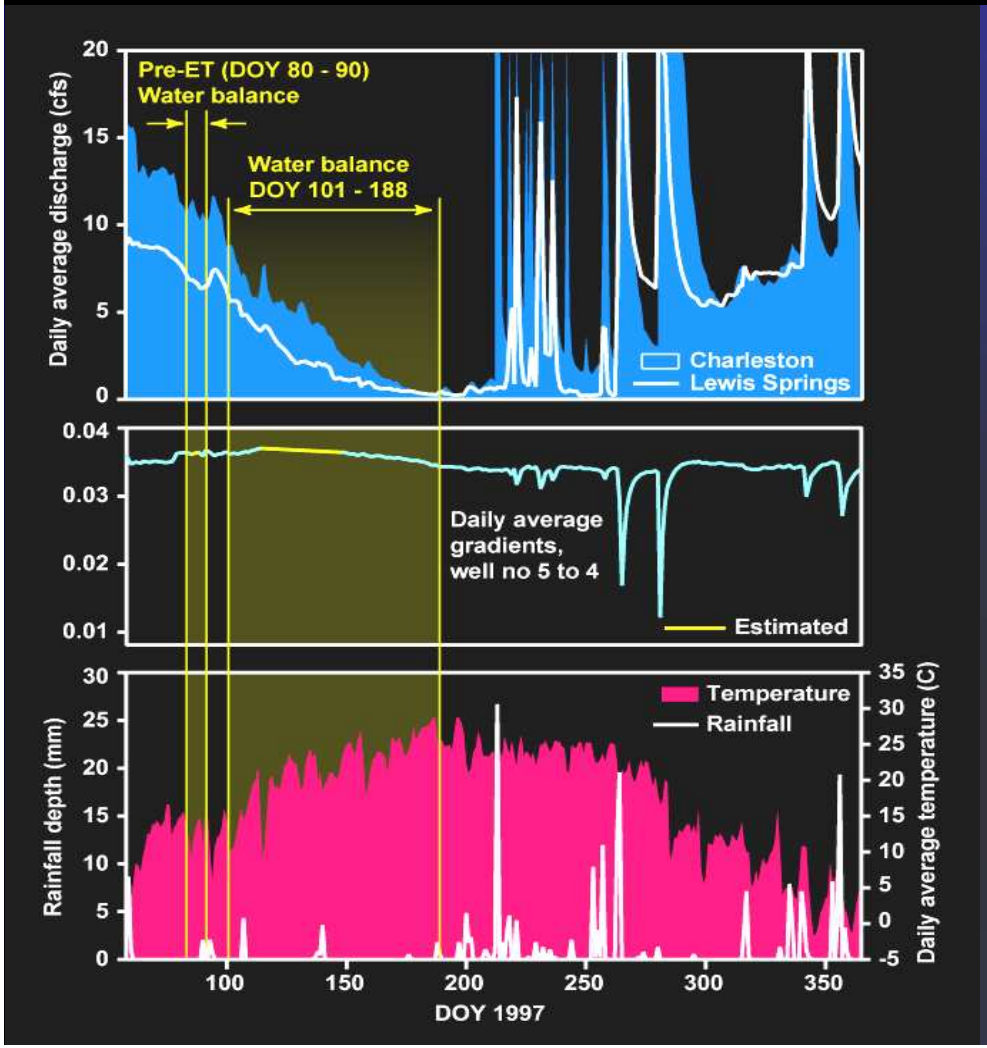


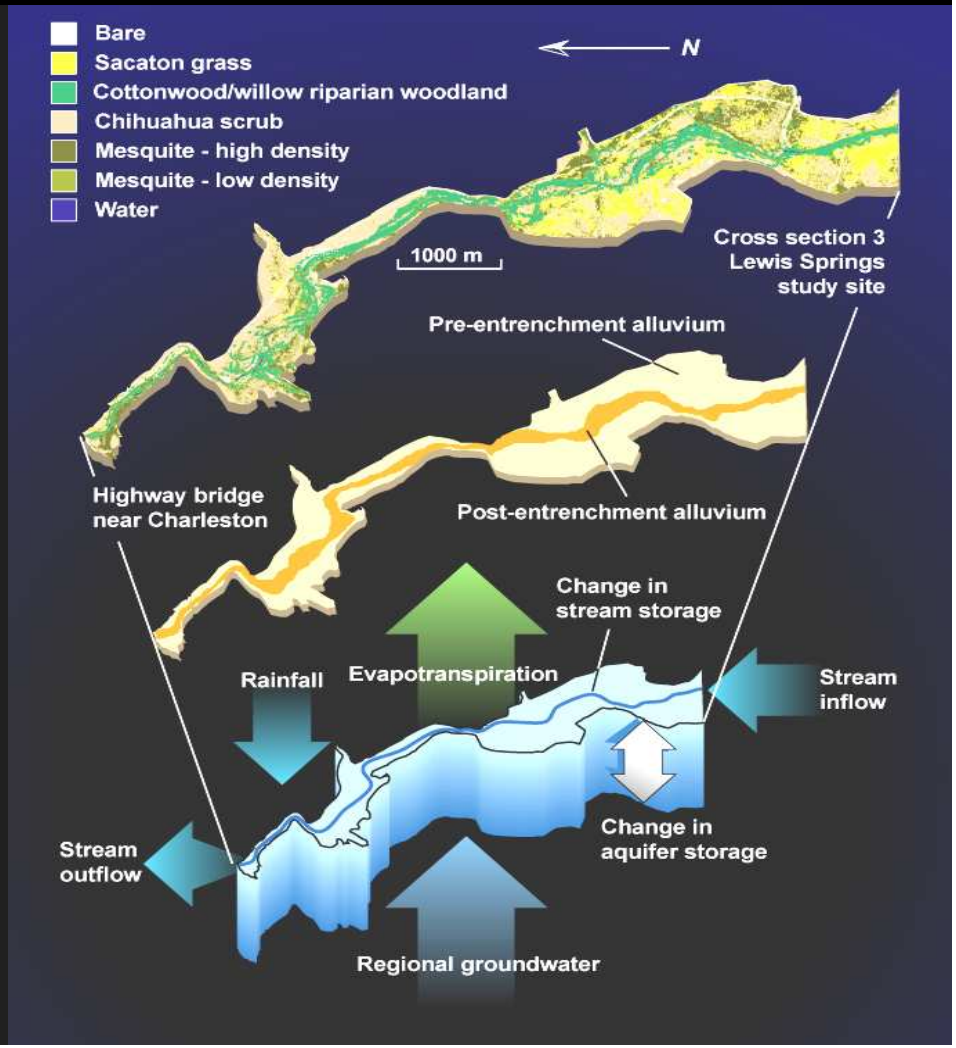
WATER BALANCE

- **Inputs - Outputs = Delta Storage**

  Qin + Gwnet + Ppt – Qout – ET = △S

  Results: **DOY 101–191, 10 km reach, closure Error = 5.2 %**





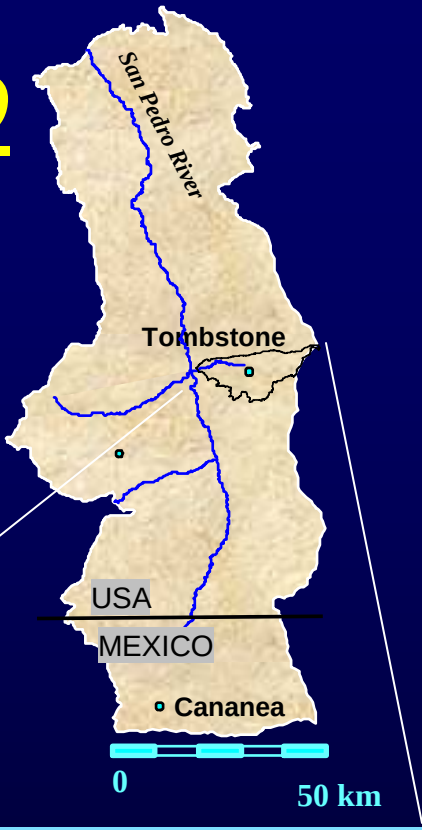
SALSA Products

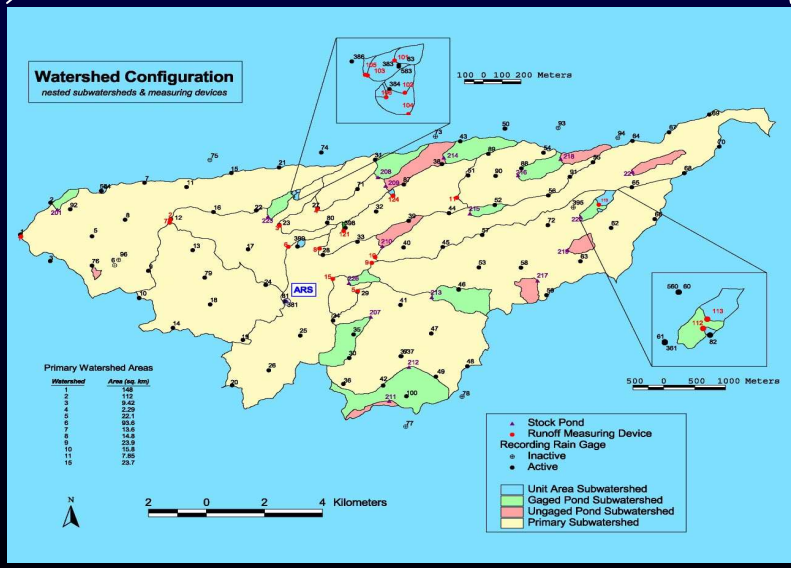
- Special SALSA journal issue (Nov. 2000 – Ag & Forest Met.)
- Special sessions at professional society meetings

- Spatial data (GIS) archive CD
- Public meetings, e-mail news, science/popular press
- “Miracle of the Desert River” multi-media bilingual CD
- Bi-national conference <u>with</u> basin residents

EVOLUTION IN WG / SAN PEDRO

- *USDA - ARS Walnut Gulch Experimental* Watershed (since 1953 – Physical / watershed science)
- *MONSOON'90, WALNUT GULCH '92, NASA-EOS* (Interdisciplinary – physical science)
- *SALSA Program* (Interdisciplinary – physical and biological science – begin outreach & integration) ('95-'00)
- *Upper San Pedro Partnership* (Work directly with elected officials and resource managers) ('99 – Pres.)
- *SAHRA NSF Science and Technology Center* (Add economics, social science, and education to all of the above) ('00 – present)





Upper San Pedro Partnership

A consortium of 21 agencies, NGOs and private firms that cooperate in the implementation of policies & projects to assist in meeting the water needs of the Upper San Pedro. Recently designated by Congress as the entity to bring the basin into balance by 2011. Sec. 321 of PL 108-36 requires annual reports to Congress on progress towards balancing the water budget.

Members

Local: Bisbee, Huachuca City, Sierra Vista, Tombstone, Cochise County, Hereford NRCD

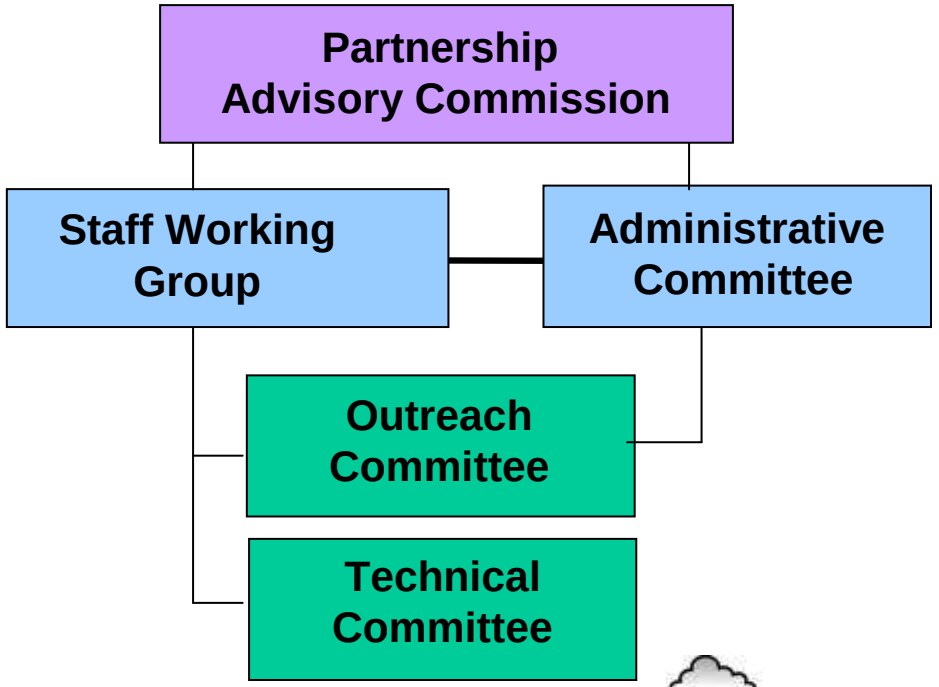
State: AZ Dept. of Water Res., State Land Department, ADEQ, AZ Assoc. Conservation Districts

Federal: *USDA-ARS-SWRC, USGS*, USFS, BLM, Ft. Huachuca, NP, US Fish & Wildlife Service, BOR

NGOs: TNC, Audubon

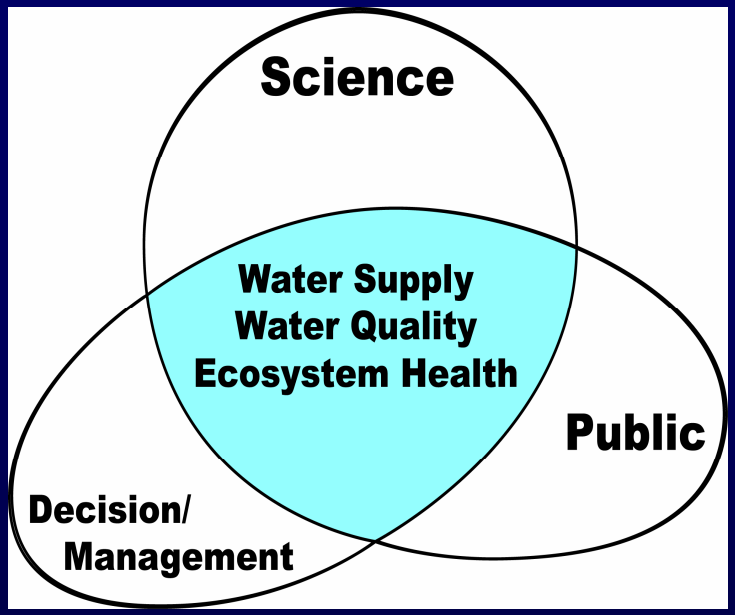
Private: Bella Vista Water Company

Organizational Structure



What does "Partnership" mean?

- Working together to gather and share data, information, and ideas
- Lending political and/or institutional support for each other's projects
- Identifying and leveraging funding resources



"This effort is a step beyond the traditional science-stakeholder technology transfer to that of a true partnership where research is planned and conducted specifically to meet the needs of decision makers and resource managers"

Find and Maintain a Balance

Ecosystem *Human Needs*

Integration of ARS/SAHRA Research into USPP

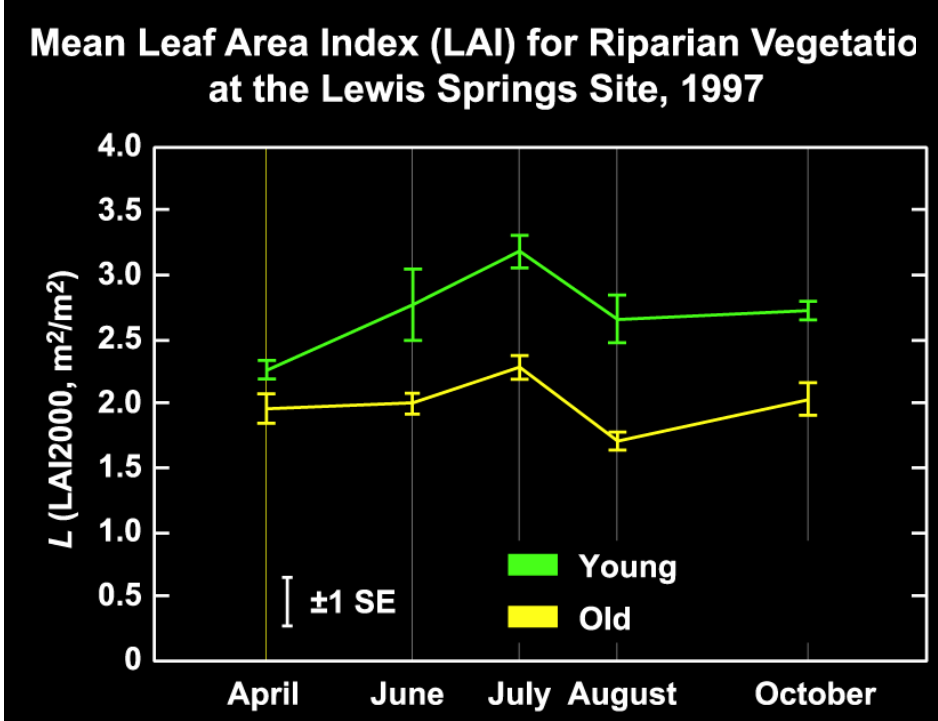
- **Research is *designed and planned* with the USPP to provide observations, information, and models for complex decision making**
- **How:**
  - **Regular (~2 days/month) USPP committee meetings of decision makers and scientists**
  - **Research Scope of Work reviewed and approved by multiple USPP committees**
  - **Frequent oral and written research updates presented to multiple USPP committees**

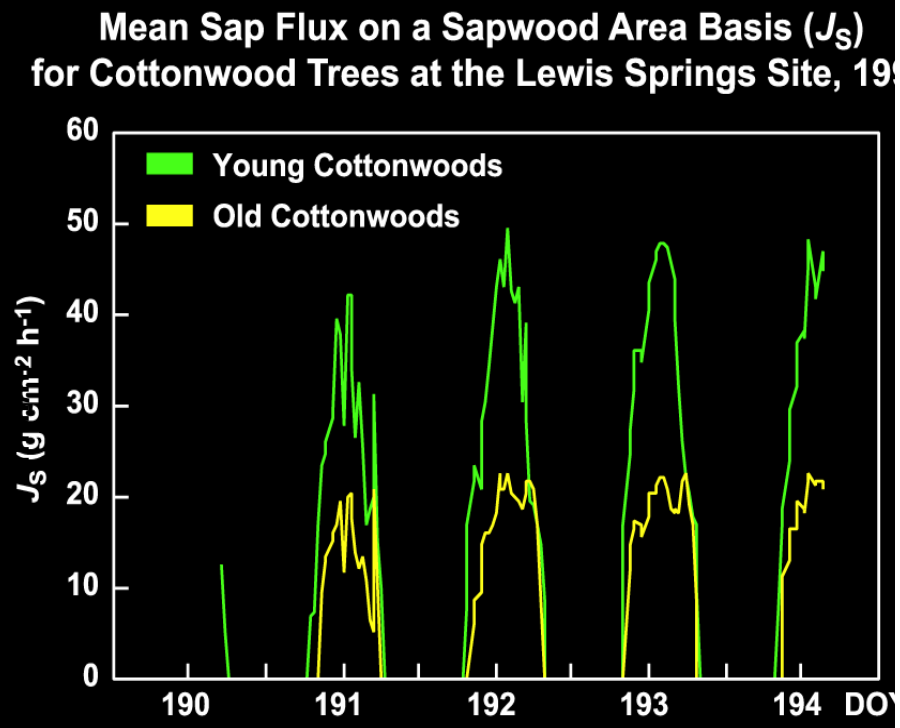
Partnership Studies

(Jointly Designed by Scientists & Decision Makers)

- **Quantify riparian water needs**
- **Basin characterization**
- **Quantify basin recharge**
- **State of the Art Groundwater Model**
- **Decision Support Tools (SAHRA)**

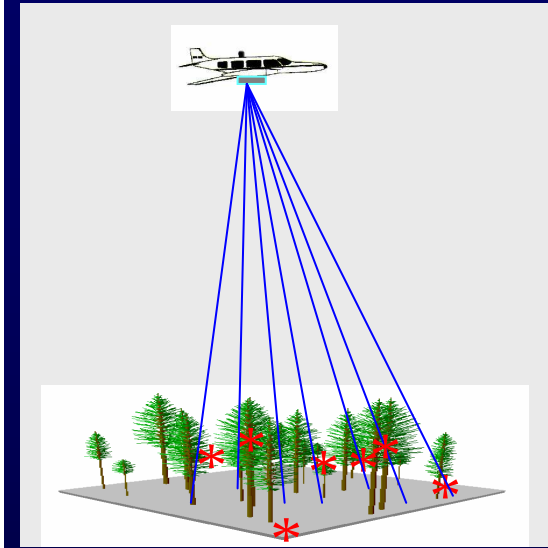
Cottonwood Water Use Varies by Age Class

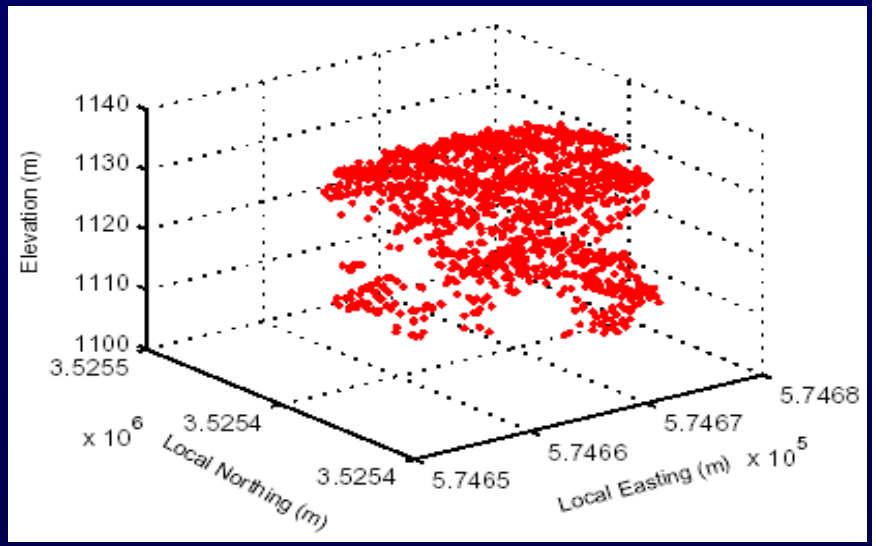




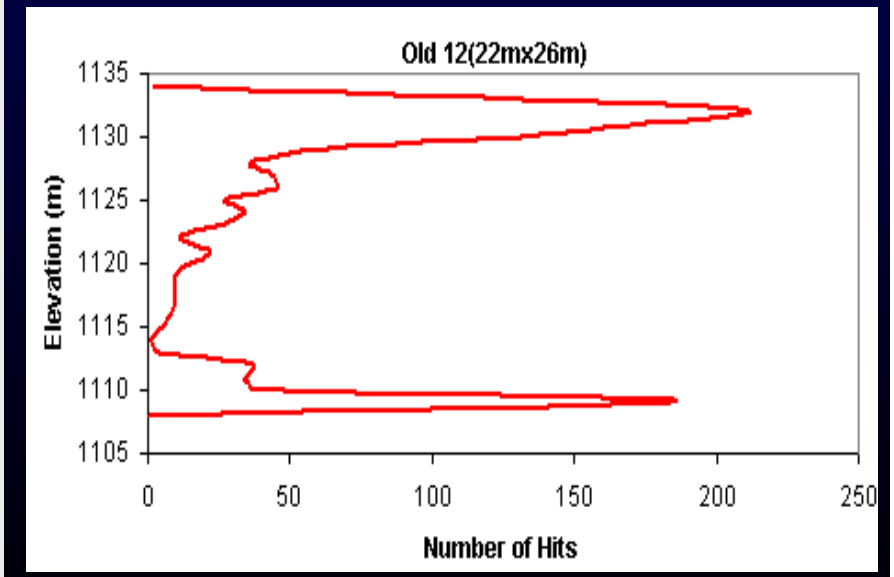
Young — *Cottonwood Age* → Old — Aerial View

Estimation of Leaf Area Index from LIDAR data





- **Sum LIDAR returns in elevation bands to create a synthetic LIDAR waveform**
- **Compute canopy metrics from waveform and regress them against observed LAI from the ground**
- **Good agreement (R^2 >0.76)**
- **With remotely derived LAI can improve corridor level Cottonwood water use estimates**



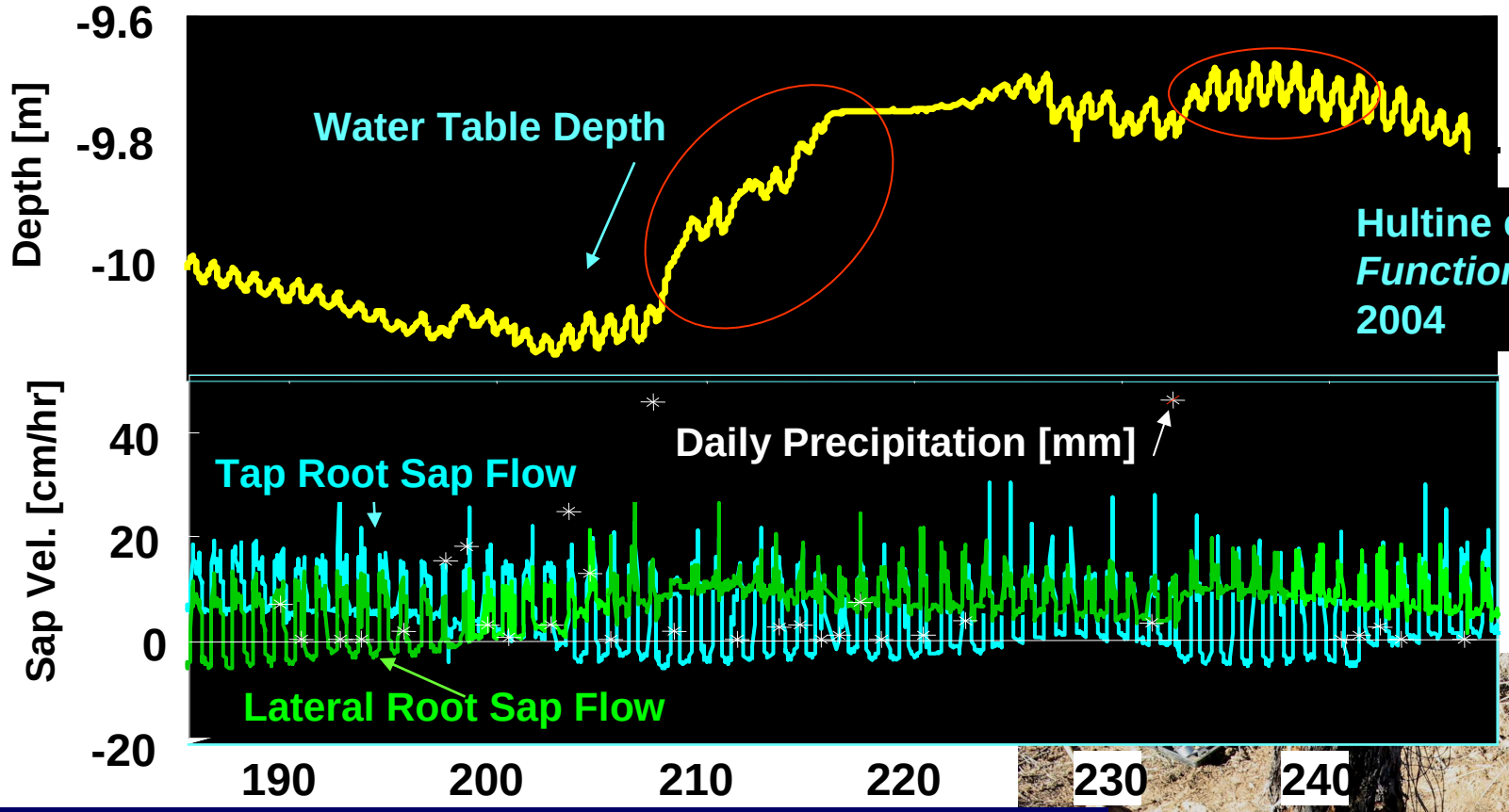
Mesquite uses water from several sources

Shallow soil water from recent precipitation

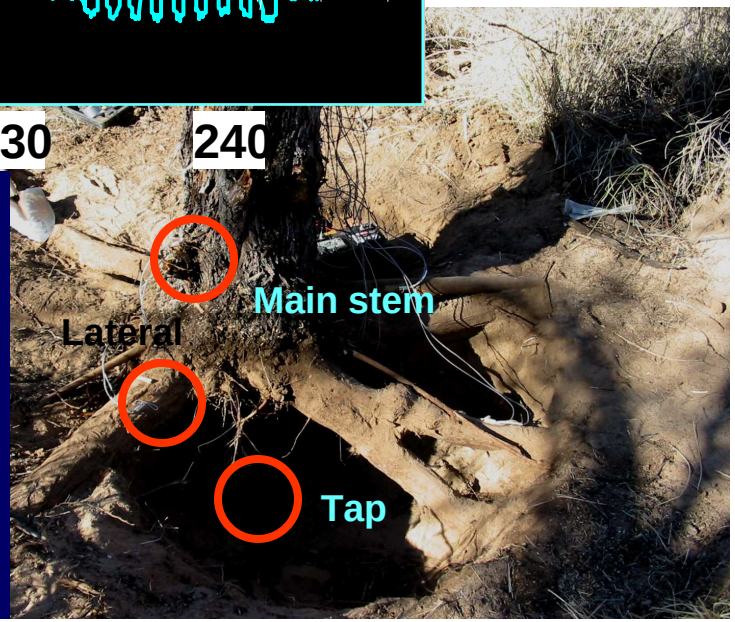
Deep vadose zone soil water

Groundwater

The Amazing Mesquite

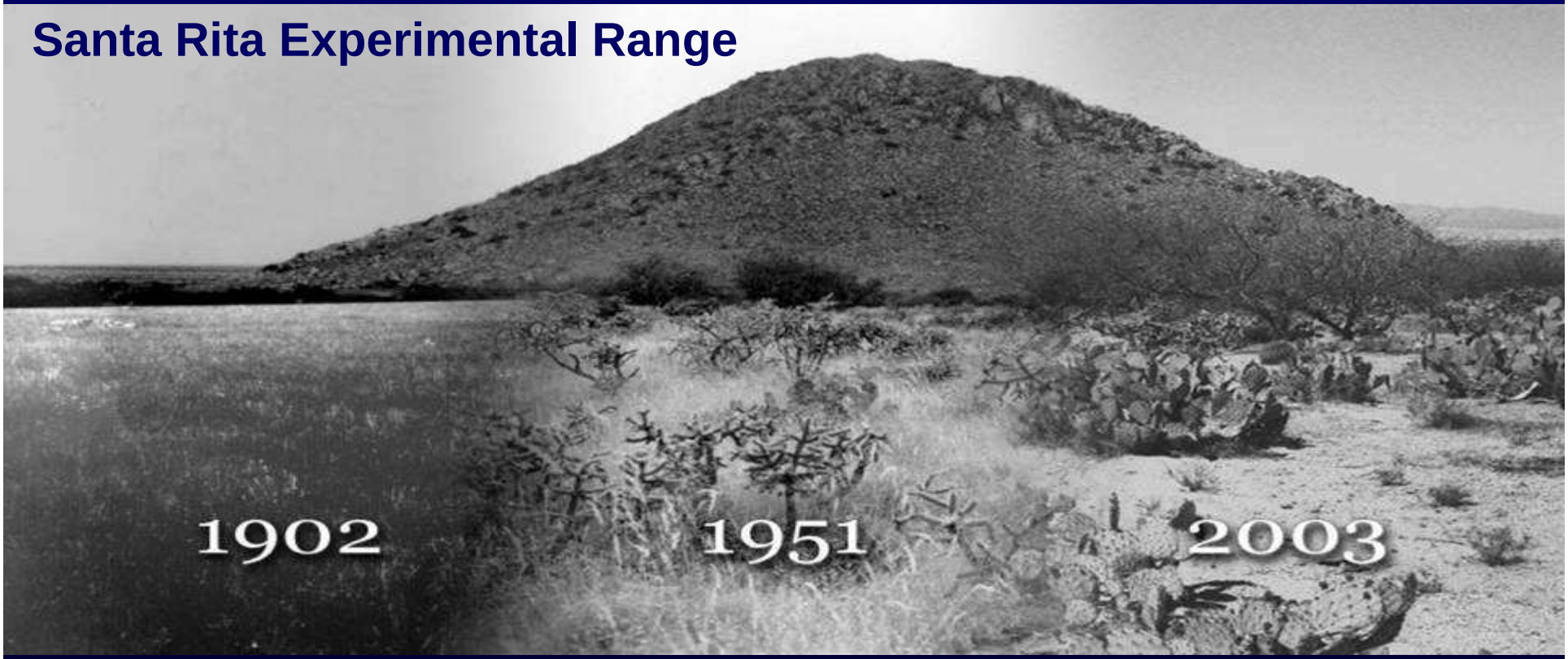


- Sap flow bi-directional
- Redistribute upward when dry
- Downward with abundant rainfall
- GW fluctuations increase with downward tap root flow
- Stable isotopes indicate 25-50% is from precipitation
- Downward flow in winter - and in upland areas with no access to GW - *Water Banking !!*



CHANLLENGE

Santa Rita Experimental Range



- **How many more xeric species can redistribute water to their advantage?**

- **Is this attribute an important factor in woody species encroachment going on worldwide ?**

Ephemeral Channel Recharge

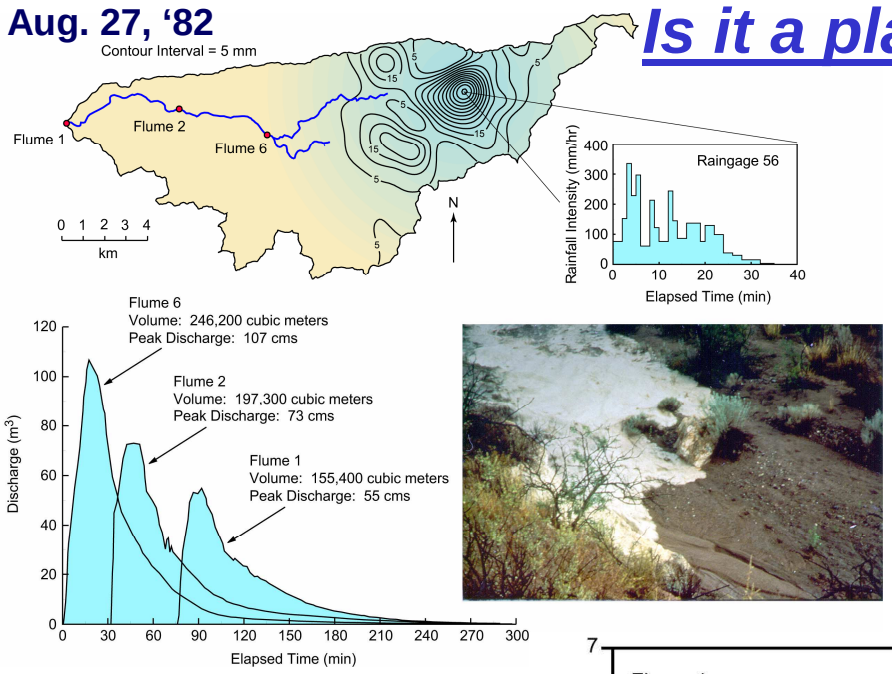
Why is this Important?

- **Common assumption is that most recharge occurs along the mountain front in Basin and Range province.**

- **Is ephemeral channel recharge a player in the overall basin water balance?**

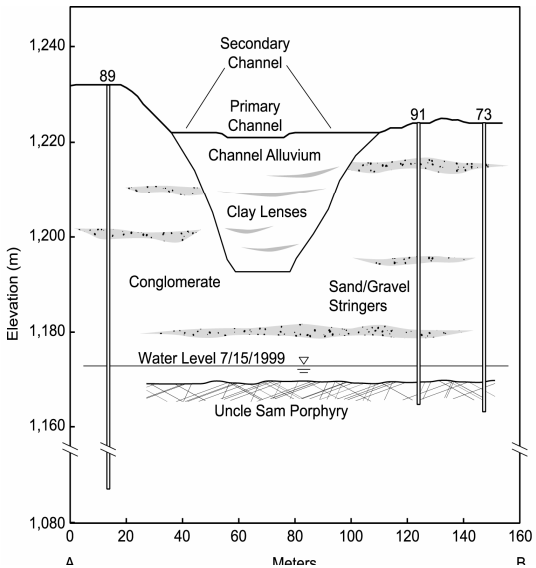
- **Compare and contrast a variety of independent methods to estimate ephemeral channel recharge**

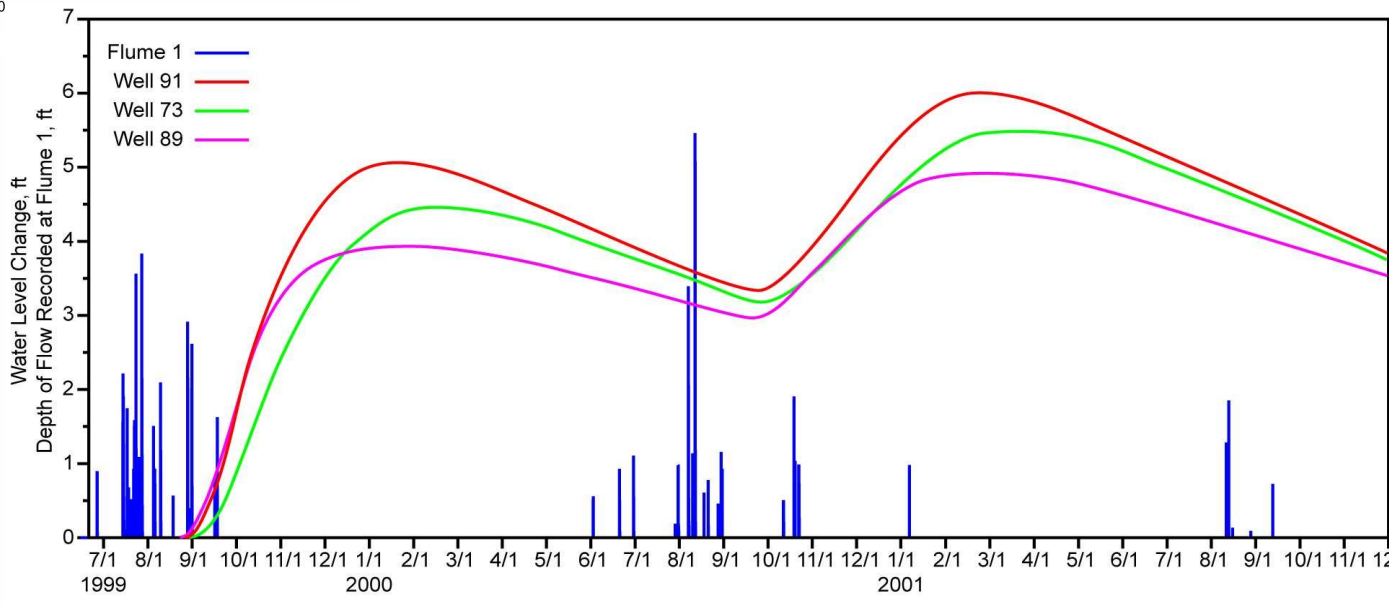
Ephemeral Channel Recharge



Is it a player in the Basin Water Balance ?

- Reach Water Balance
- Groundwater mound model
- Cl Conc. change
- Isotopic tracers (Ppt, SW, GW)
- Microgravity changes
- Vadose zone water and temperature transport model





Est. Ephemeral Channel Recharge

Comparison of Recharge Est. Across Methods (m^3)

Year	Trans. Loss less Abstract.	Chloride Well (89)	GW Model Aver.	Micrograv Change Prior to 2-23-01	Vadose Zone Temp. Mod.
1999	472000	269000	188000		438000
2000	370000	211000	127000		163000
Total	842000	480000	315000	455000	601000

- *NOTE: Simplified Cl method: 315,000 m^3* (Cl of rainfall, well, local runoff ratios, and watershed runoff)
- When scale to entire San Pedro find, in wet years, ephemeral channel recharge between 15 and 40% of total basin recharge as estimated from GW model

CHANLLENGE

- **How can micro-, macro-gravity, geochemistry, runoff, and precipitation measurements be combined to estimate recharge and introduce it in a spatially explicit, inter-annual fashion into regional groundwater models ?**

- **What relatively easily derived indices can tell us the dominant mechanisms controlling watershed response and at what scales?**

Riparian Functional Condition Model

- The model places reaches into one of three condition classes, based on 9 bioindicators which are sensitive to changes in hydrology.

- Each condition class is reflective of different levels of ecosystem functional capacity.

- Use it track changes in the abundance of each class over time.

Class 1: **Tamarisk dominant**

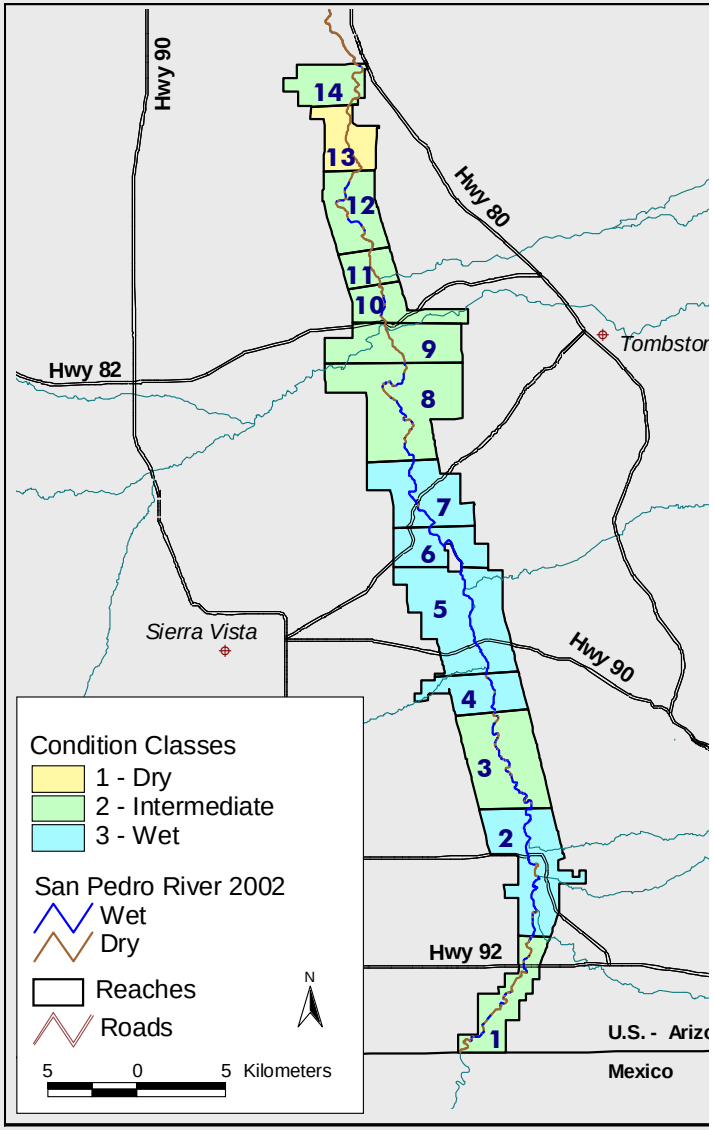
Class 2: **Tamarisk increased, cottonwood-willow still abundant, marshlands reduced**

Class 3: **Tall, dense, multi-aged cottonwood-willow forests**

SAHRA

Upper SanPedro Partnership

"State of the San Pedro"



Hydrologic Characteristics of each Condition Class

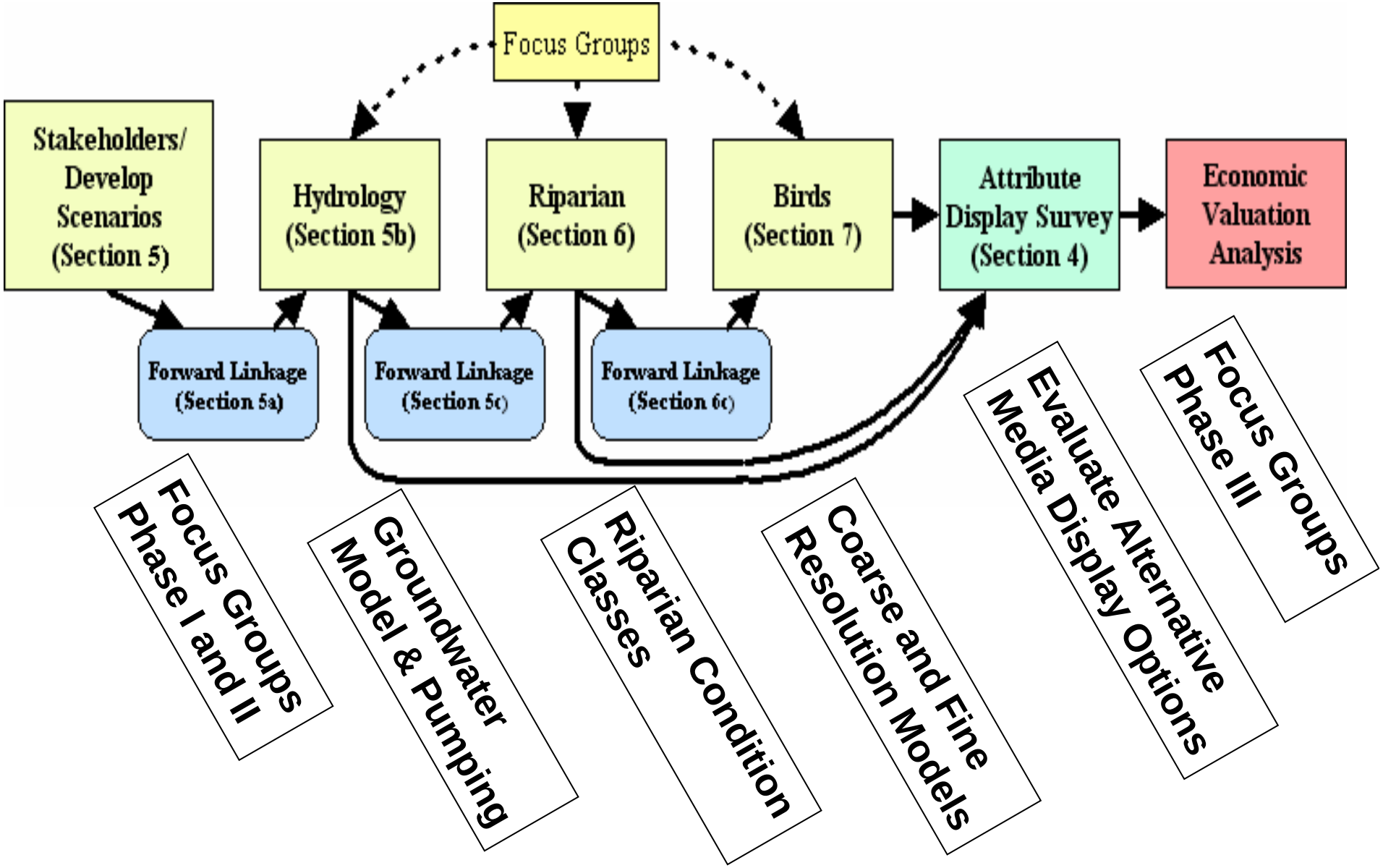
Cond. Class	Flow Permanence *	Dry Seasonal Maximum Depth to GW (m) **	GW Fluctuation (m)***
1	< 60% (intermittent-dry)	> 3.5 m (deep)	large (> 1 m difference between monthly max and min)
2	60% to 95% (intermittent-wet)	2.5 - 3.5 m (moderately shallow)	moderate (0.5 to 1 m)
3	> 95% (perennial or nearly perennial)	< 2.5 m (shallow)	small - stable (< 0.5 m difference)

* 0% = no flow the entire year, 100% = SW the entire year

** dry-season mean across the floodplain *** averaged across the floodplain

CRITICAL IMPLICATIONS FOR RESTORATION !!

Valuation of Riparian Systems



STRATEGIES & LESSONS LEARNED

- **Picking a place (e.g. watershed) is the most effective way to foster interdisciplinary science**
- **The needs/problems of the "place" are drivers for integrating science & policy**
  - **However, collaboration cannot be dictated**
- **Build it (as least the foundation) and they will come if there are compelling science/social issues**
- **Optimal size for the "place"**
  - **Large enough for a sufficient number issues**
  - **If too big may have too many issues and perhaps too many political/managerial entities**

STRATEGIES & LESSONS LEARNED

- **Motivation for Policy Makers for joint work**
  - **Community based decision making (not imposed from outside)**
  - **Avoid law suits: but even if legal action, agree on data**
  - **More complex nature of management decisions often requires thorough interdisciplinary science not typically available in the consulting community**

- **Important Point: Scientists don't have to give up publishable research to work with decision makers**

Science – Policy Integration

LESSONS LEARNED:

- Long-term presence-commitment counts
  - Building relationships and trust
  - Lots of communication and meetings !!
  - Significant commitment by senior scientists
  - Typical 3-year grant cycle for a project may be insufficient
- Policy and decision makers must define quantifiable measures of success

CONCLUSIONS

- **We can and must work together to address "major" challenges – think big science**
- **We can do interdisciplinary research – but its hard work**
- **My opinion – greater scientific gain per unit effort will be made at the interface between disciplines then focused efforts within a discipline**
- **We must engage and work in partnership with policy and decision makers**