

Projecting the Effects of Climate Change on Riparian Ecosystems in the Southwest: The Upper San Pedro as a Case Study

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San Pedro River, Arizona, National Geographic Magazine

Southwestern Willow Flycatcher



Photo from USGS

Western Yellow-billed
Cuckoo

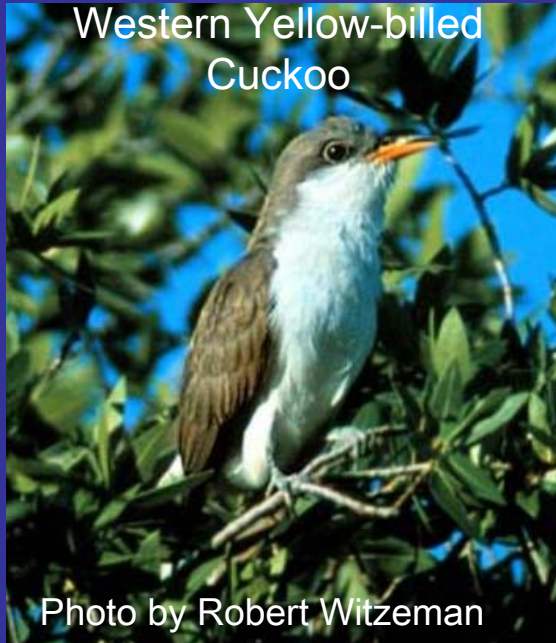


Photo by Robert Witzeman

Common
Black-hawk



Photo by Cam MacDonald

Yuma Clapper
Rail

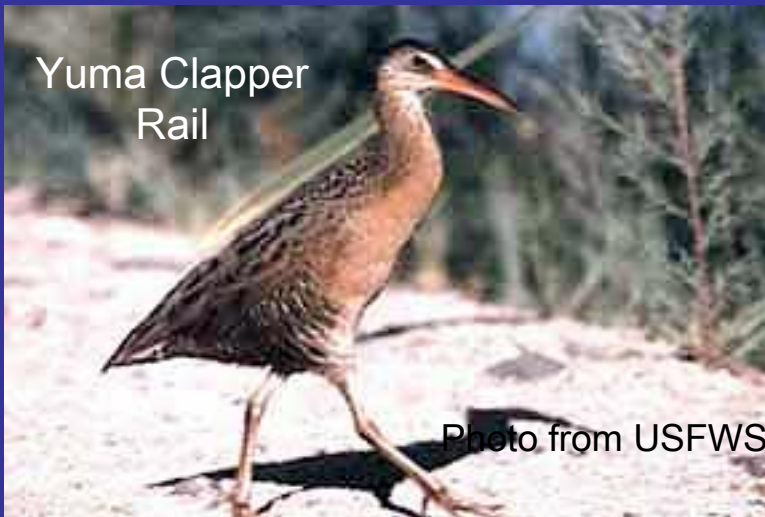


Photo from USFWS

Wilson's
Warbler



Photo ©Peter La Tourrette

Human Impacts on SW Rivers



River damming for water storage, hydropower, flood control

Surface water diversion

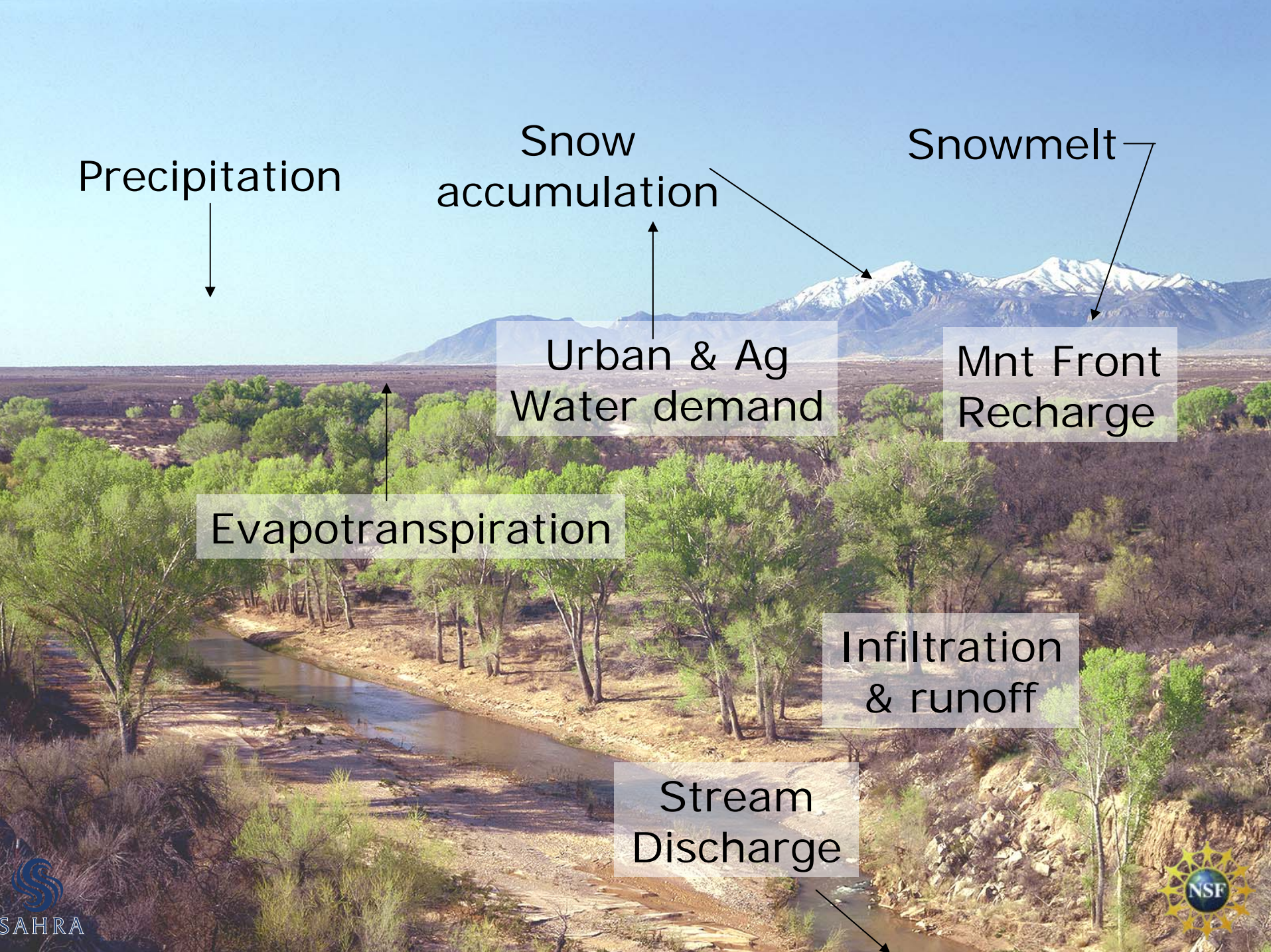


Ground water pumping from stream and regional aquifers

Over-use by cattle



Climate Change?



Precipitation



Snow
accumulation



Snowmelt



Urban & Ag
Water demand

Mnt Front
Recharge

Evapotranspiration



Infiltration
& runoff

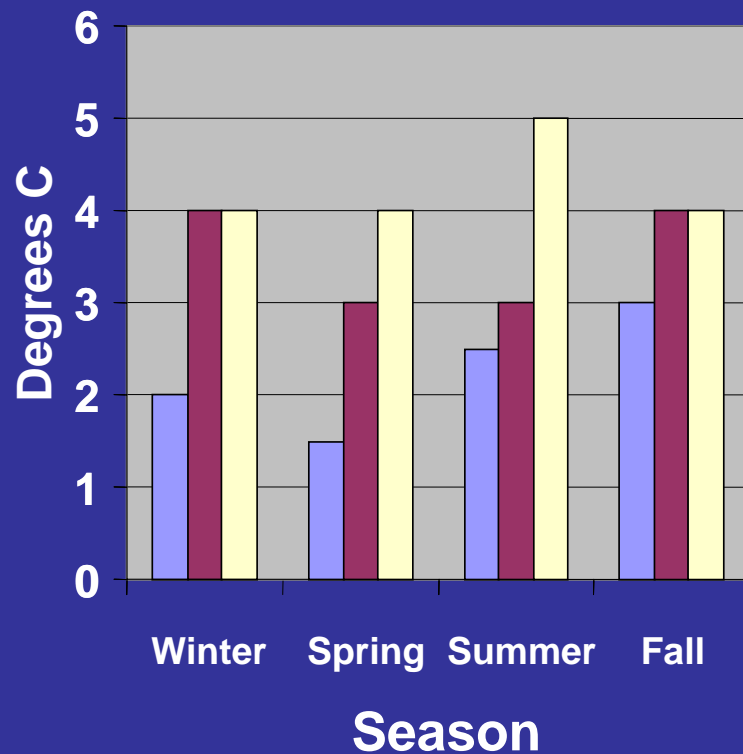
Stream
Discharge



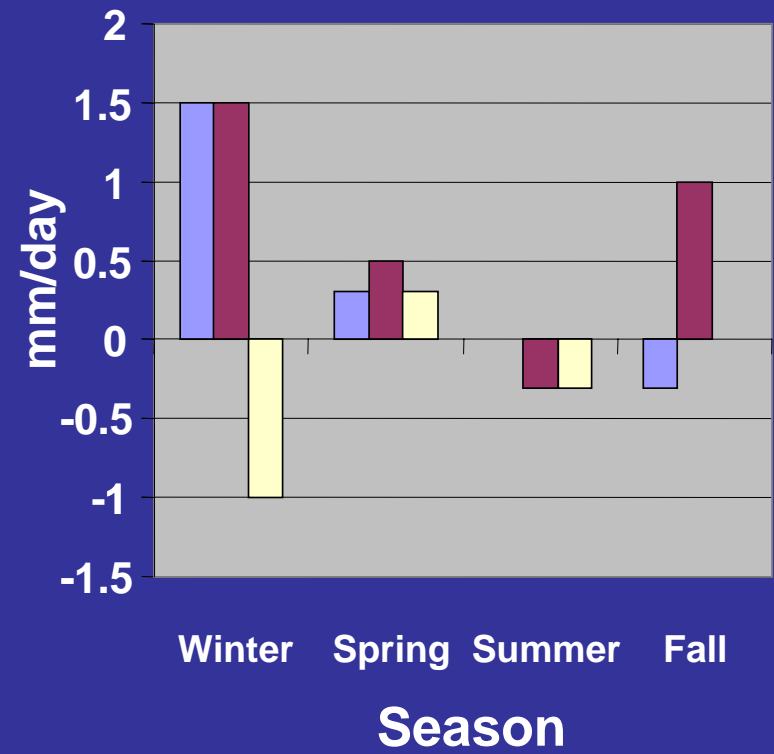
Uncertainty in Future Climate

Projected Climate Change for SW by 2060 (SRAG 2000)

Change in Mean Temperature



Change in Daily Precipitation



- Hadley Center Model
- Canadian Climate Centre Model
- NCAR Regional Model



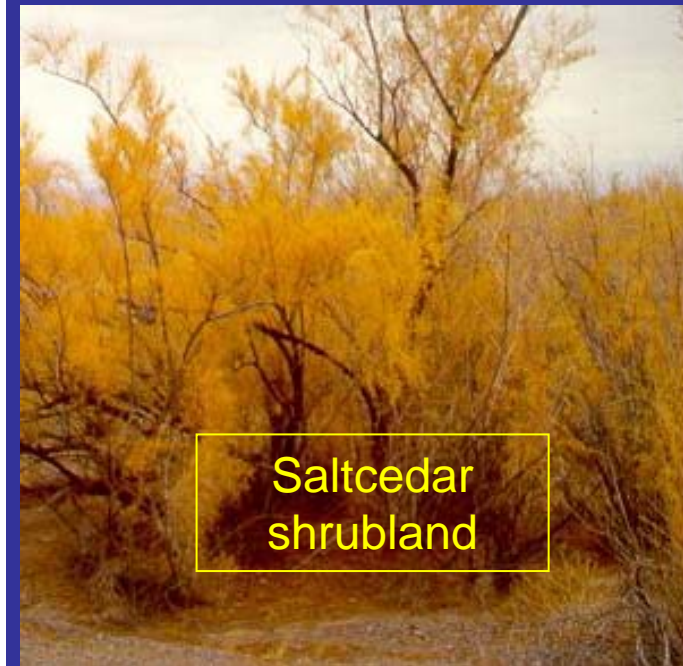
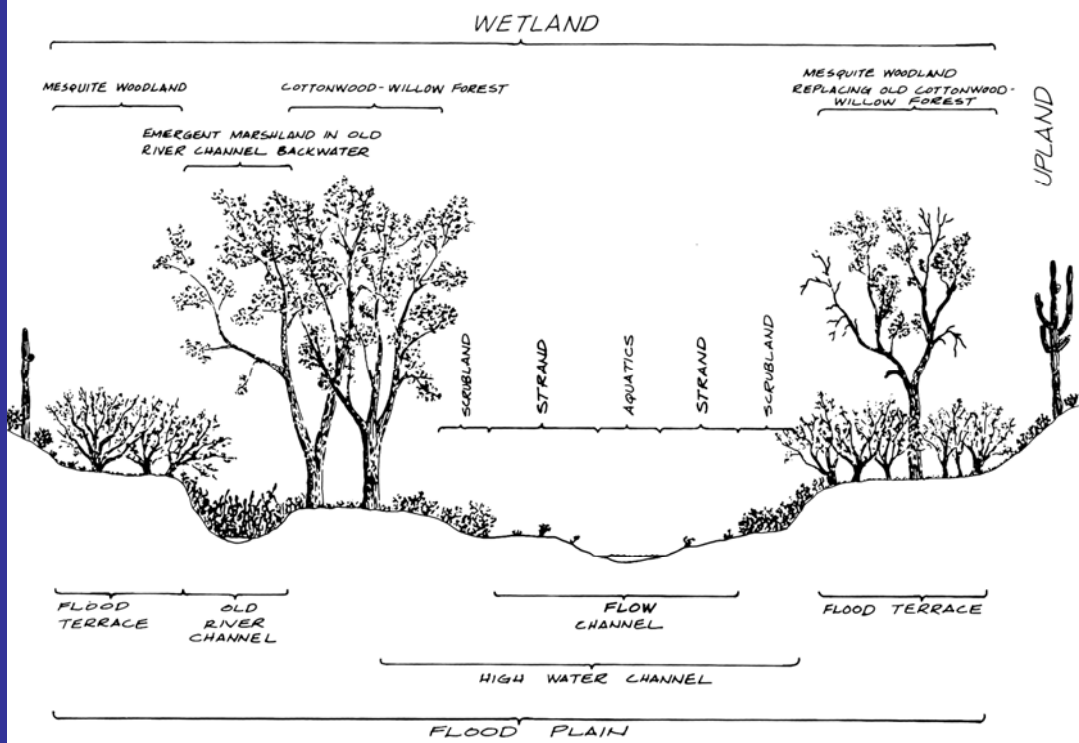
Research Question:

- What are the potential effects of climate change on riparian vegetation composition and dynamics in the Southwest?
 - Used the Upper San Pedro as a case study

THE UPPER SAN PEDRO (SE Arizona)

- One of few undammed, low elevation rivers in the SW US with perennial flow
- Biodiversity hotspot (“Last Great Places”)
- Valuable migratory bird habitat
- Growing human population & riparian ecosystem both depend on groundwater
- Threats from groundwater overdrafts





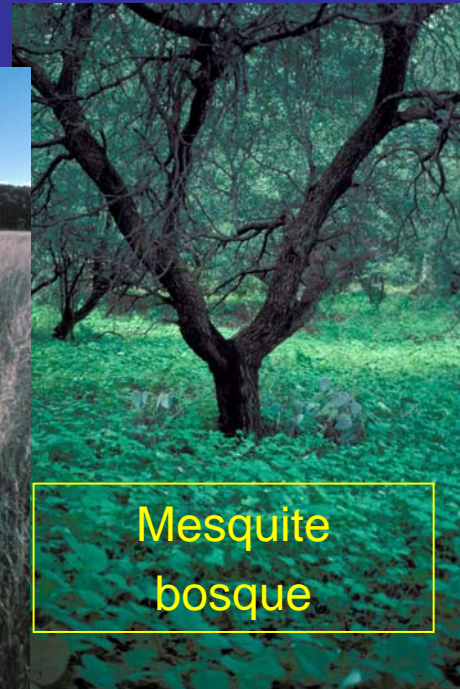
Saltcedar shrubland



Cottonwood-Willow Forest

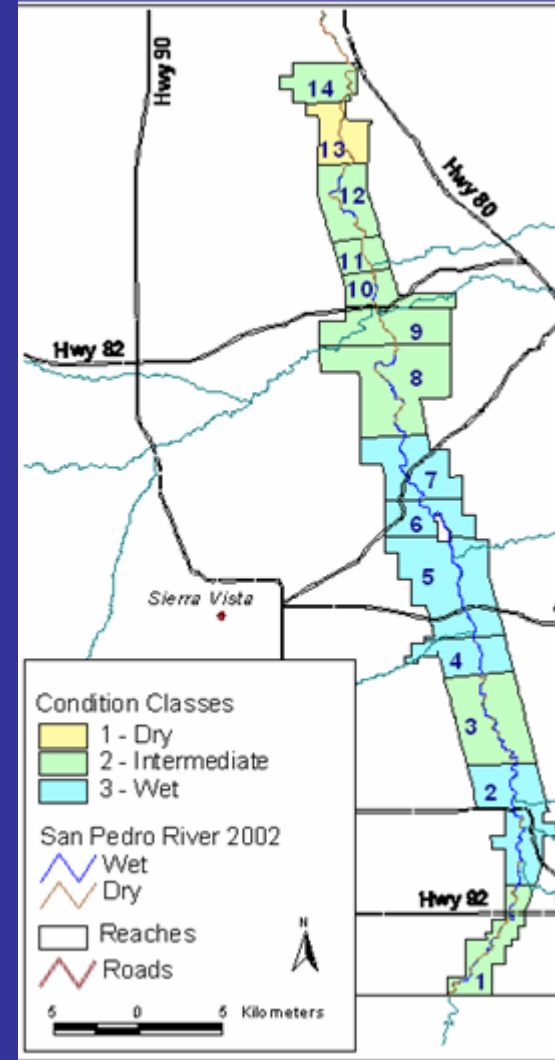
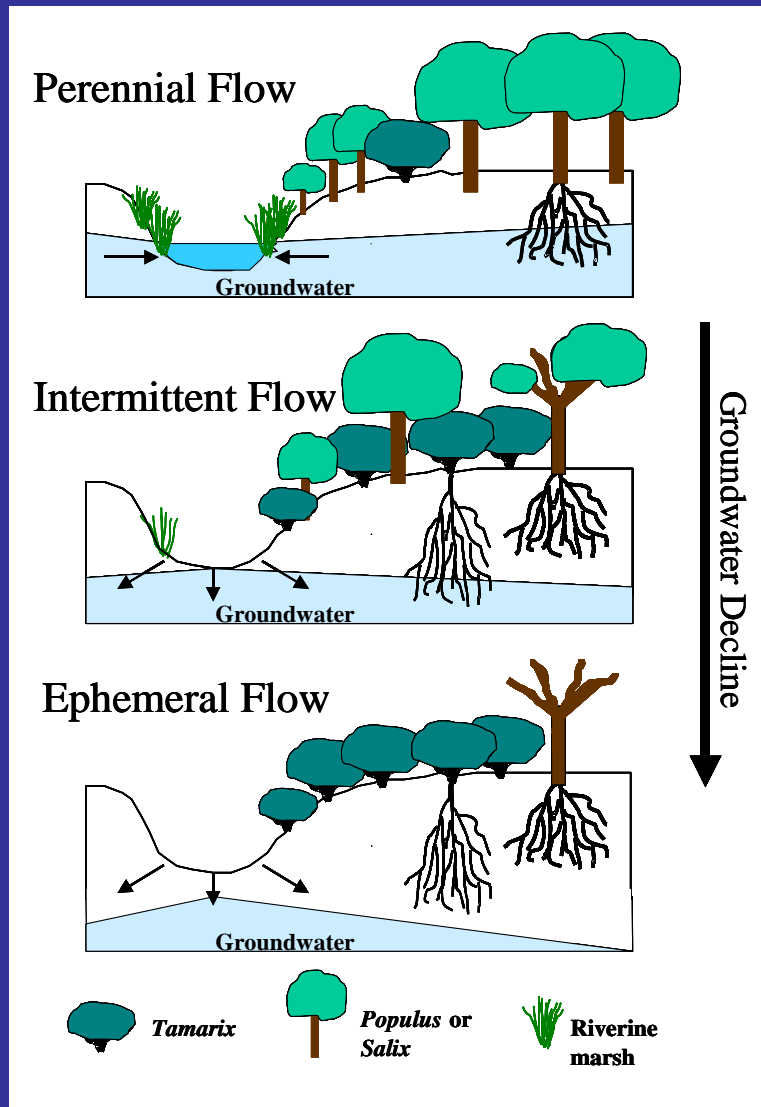


Mesic grassland (Sacaton)



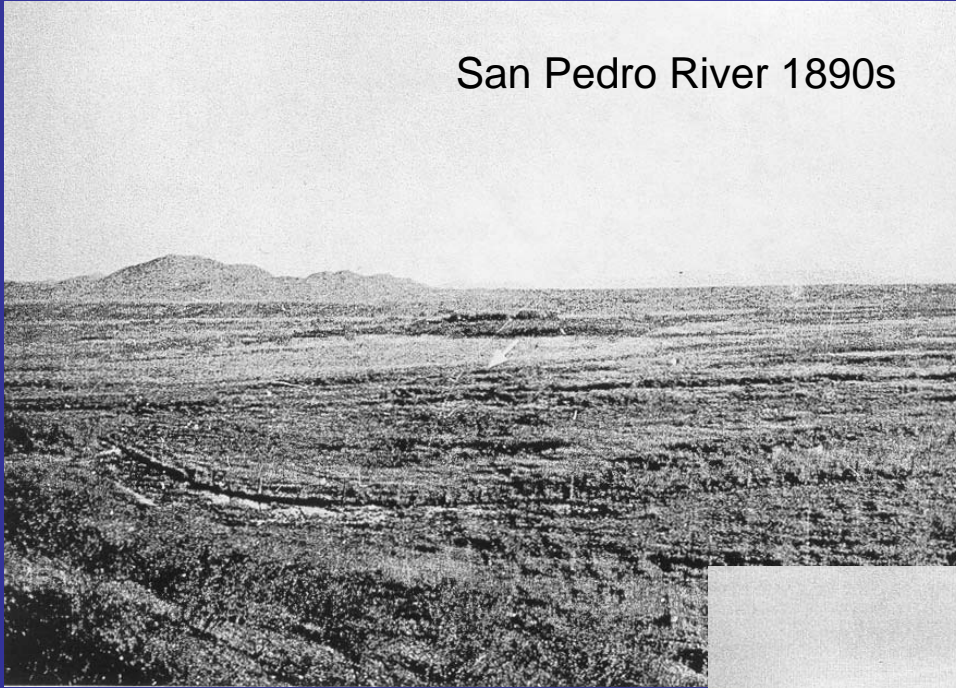
Mesquite bosque

Longitudinal Variation in Riparian Vegetation

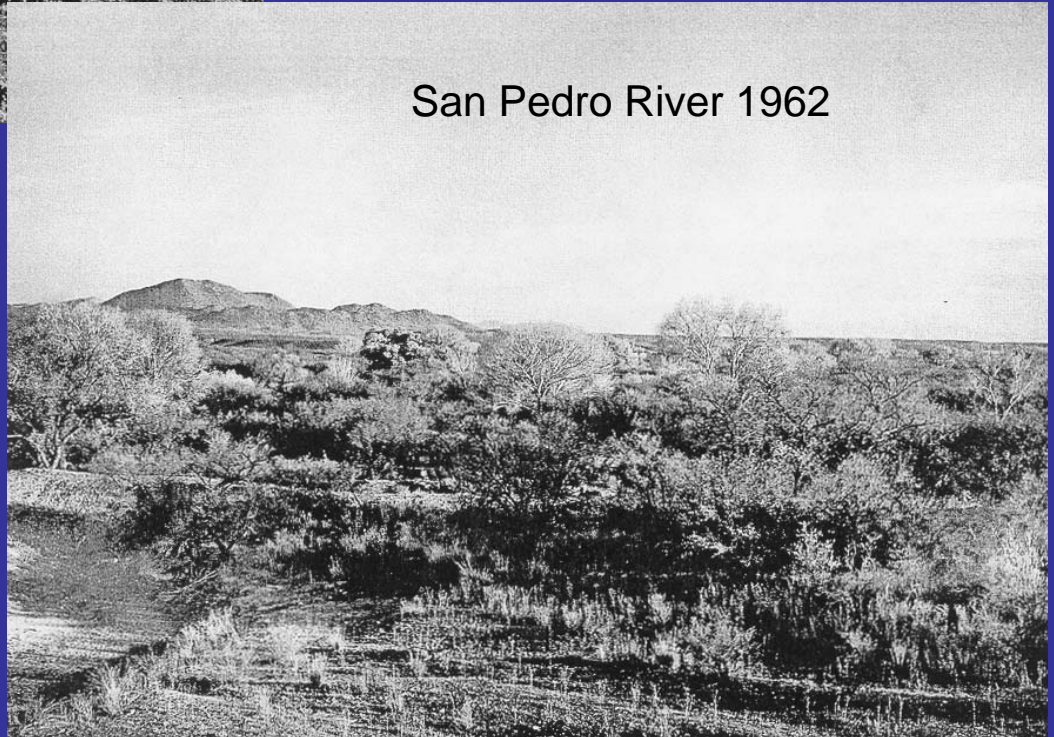


Historic Vegetation Change

San Pedro River 1890s



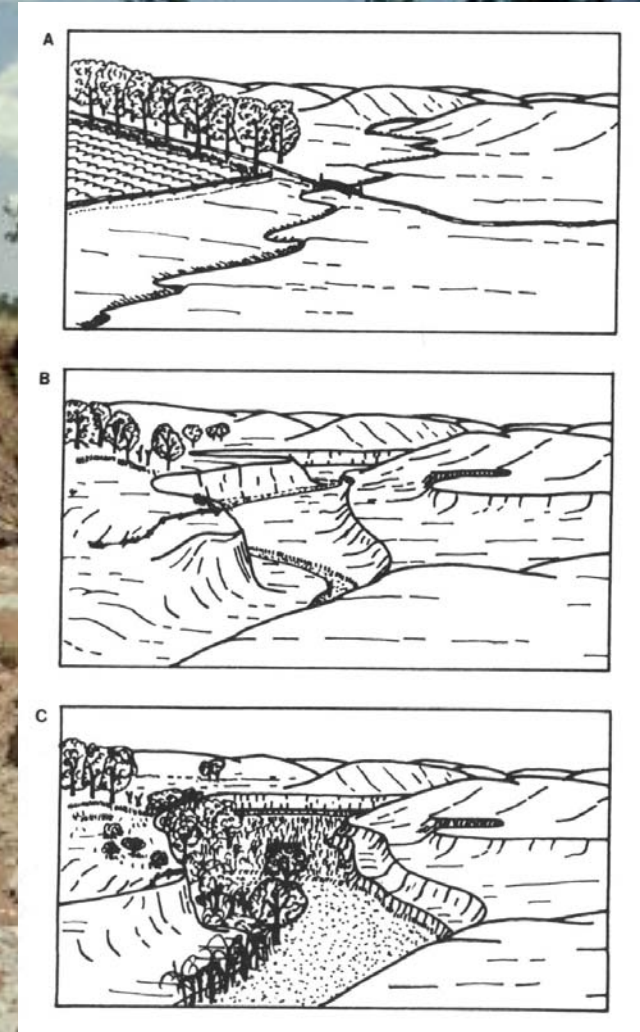
San Pedro River 1962



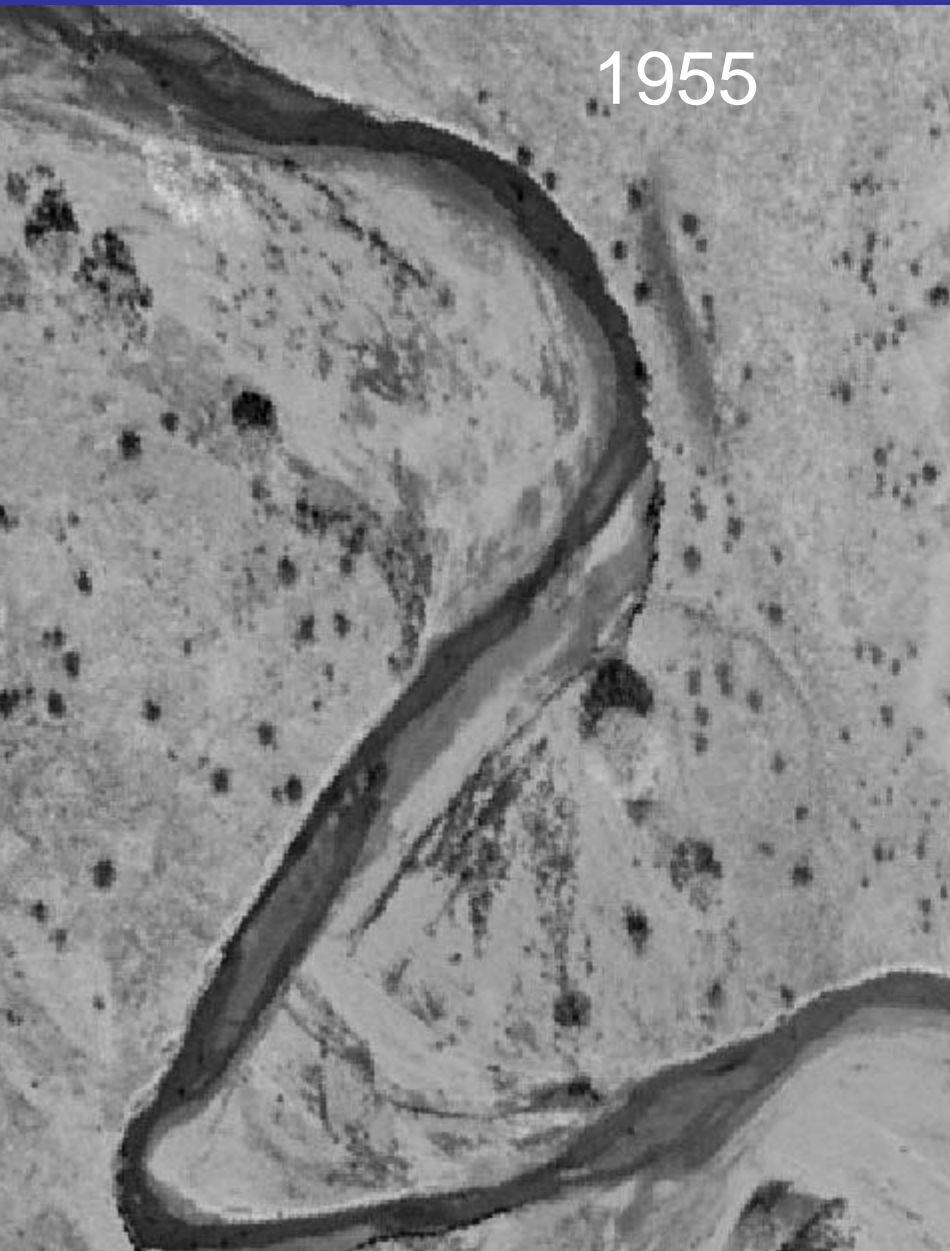
Turner et al. 2003
The Changing Mile Revisited

Historic Geomorphic Change

- Regionally synchronous channel entrenchment (arroyo cutting) in 1890s – early 1900s
- Incision of 1-10 m on San Pedro
- Channel widening until ~1950s
- Channel narrowing & floodplain formation after 1950s
- Reduced rates of channel migration since 1980s



Riparian Forest Expansion since 1950s

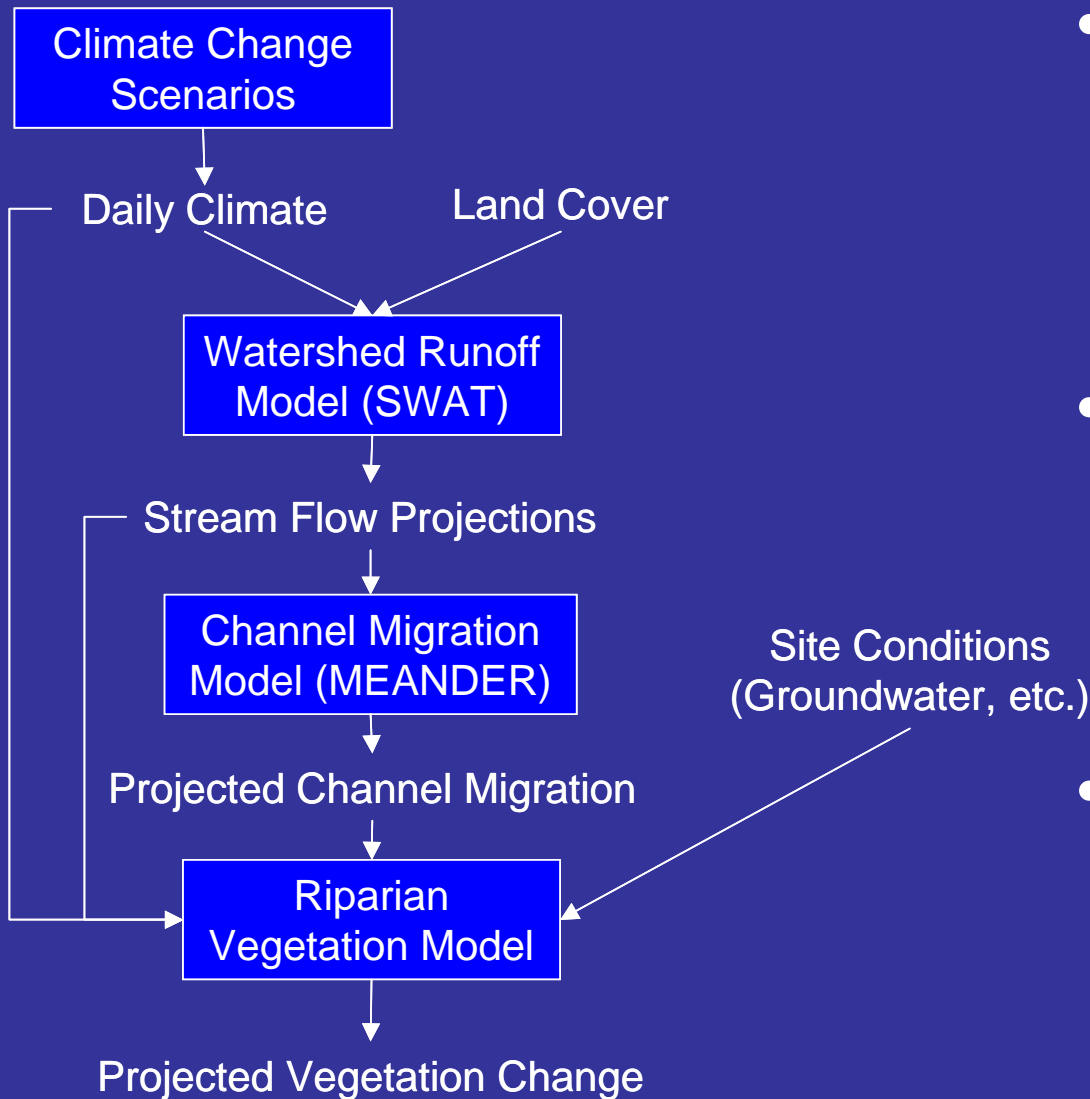


An aerial photograph of a wide river valley. The river is visible in the lower right corner, winding through a dense forest of green and brown trees. The valley floor is covered in thick vegetation, and the surrounding landscape is a mix of green and brown. In the distance, a range of mountains is visible under a clear sky.

Research Question:

What are the potential effects of climate change on riparian vegetation composition and dynamics on the Upper San Pedro?

Modeling Climate Change Effects



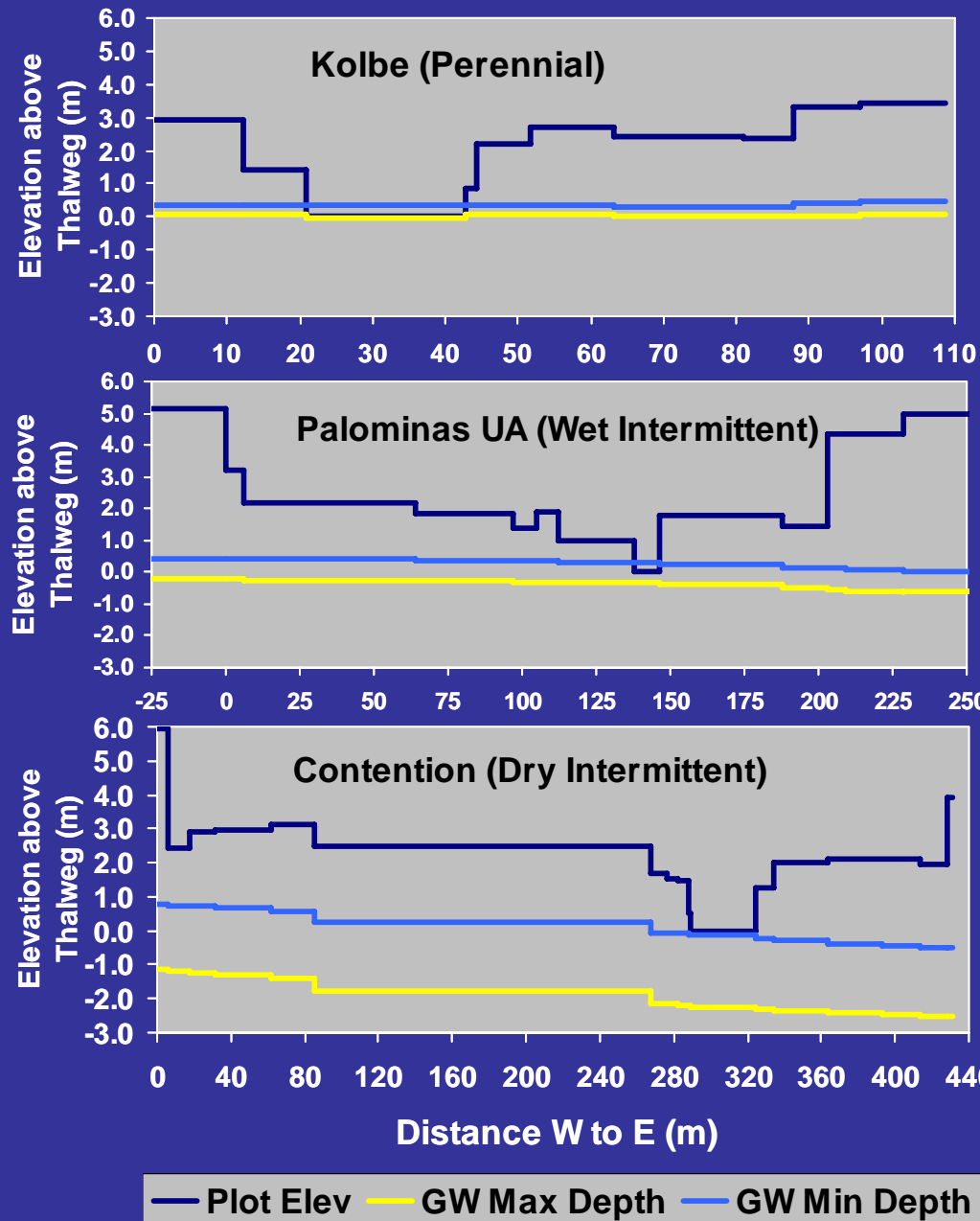
- Simulate range of transient climate change scenarios (2003-2102)
- Model effects of climate on physical processes (stream flow, channel migration)
- Model response of vegetation to changes in physical (and biotic) drivers

Climate Change Scenarios (2003-2102)

- No change over 1951-2002 conditions
- Warm: Warmer (+5 ° C), but no change in precipitation
- Warm Wet: Warmer, 50% increase in winter precipitation
- Warm Very Wet: Warmer, 100% increase in winter precip
- Warm Dry: Warmer, 50% decrease in winter precipitation

- Transient scenarios, developed by modifying 1951-2002 daily weather time series

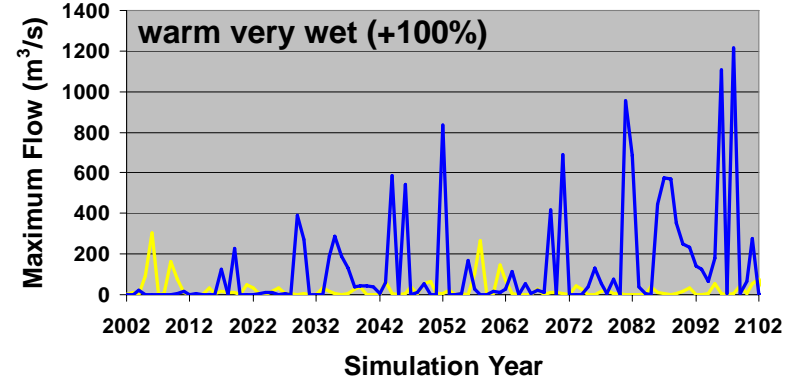
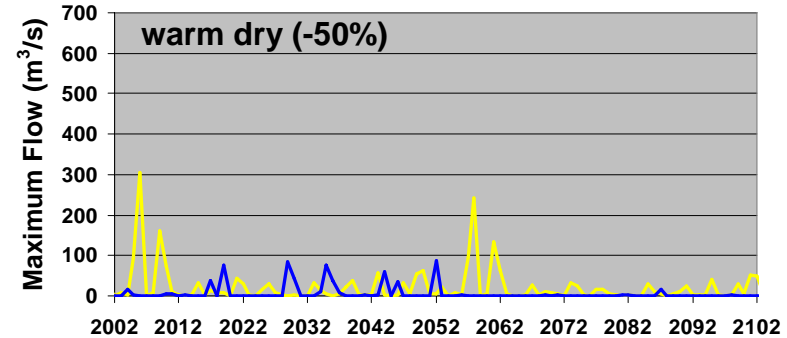
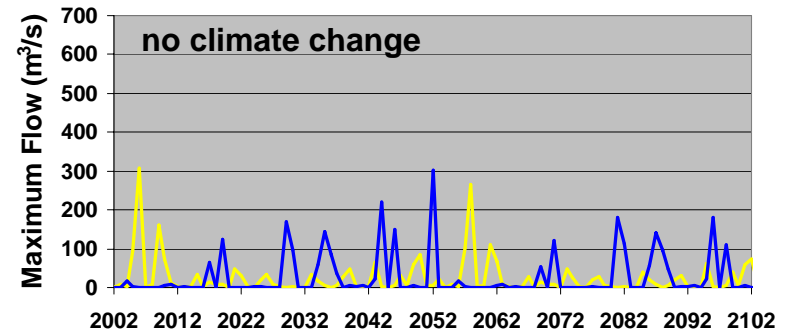
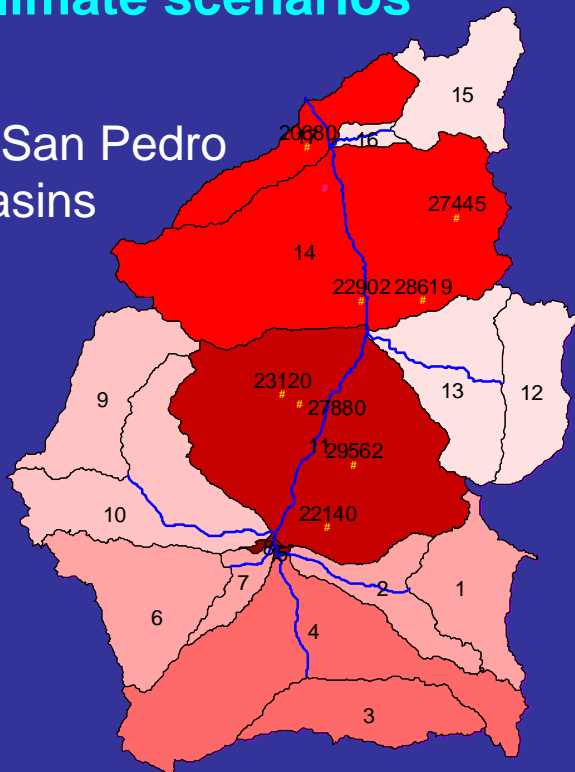
- Modeling sites that span the range of hydro conditions along Upper San Pedro



Modeling Watershed Runoff and Streamflow

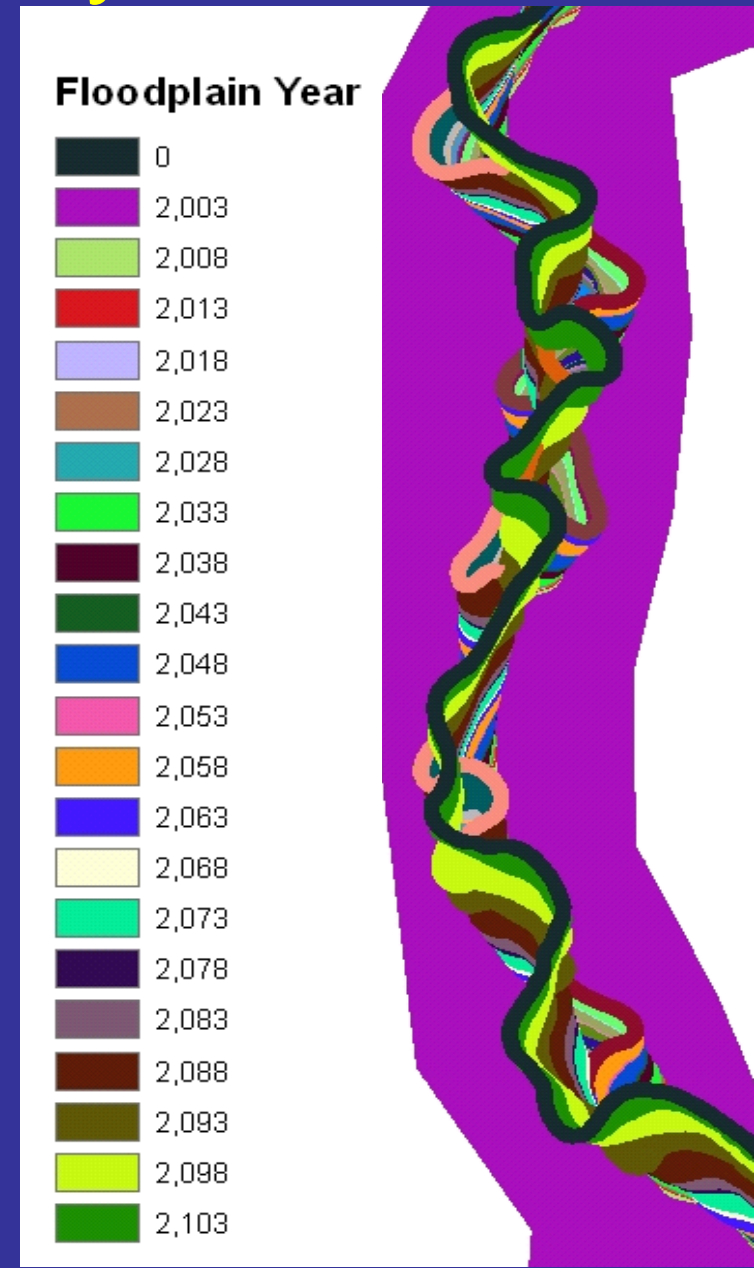
- Flow scenarios
 - Ran calibrated basin runoff model (SWAT) for the upper San Pedro basin for the five climate scenarios

Upper San Pedro
Sub-basins



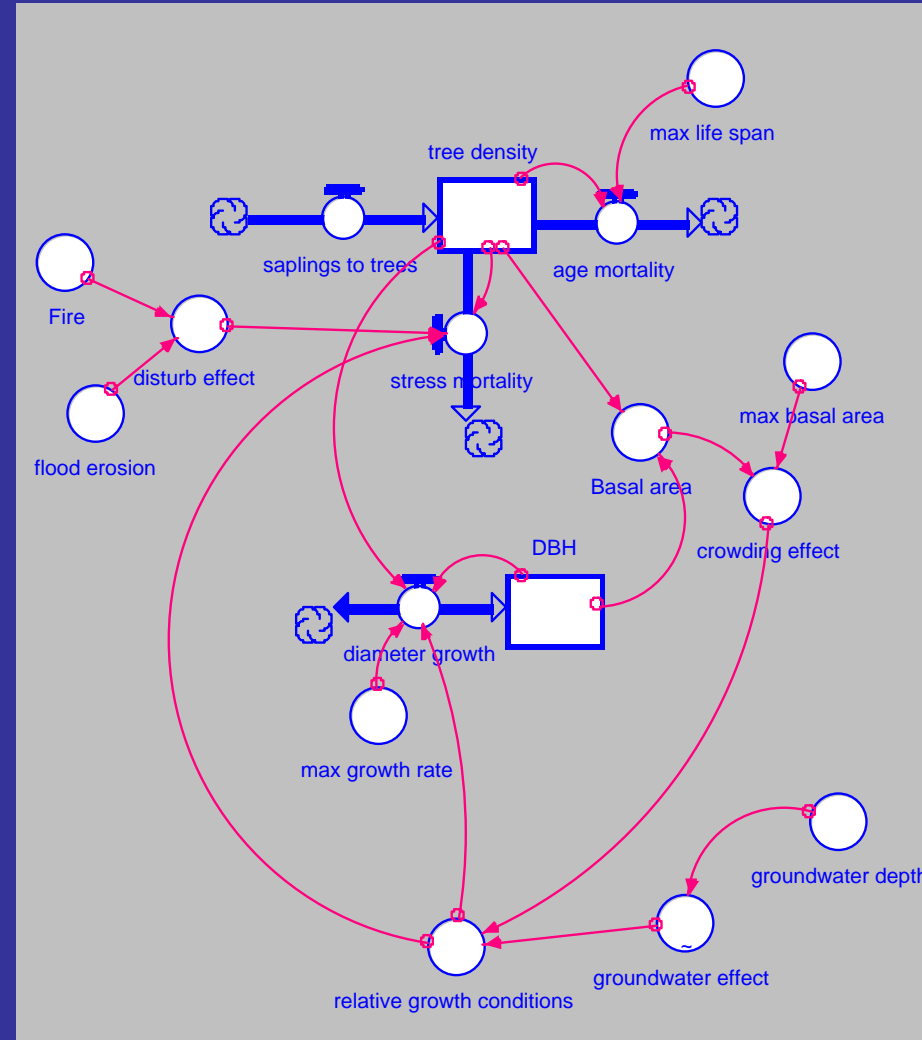
Modeling Channel Dynamics

- Simulated channel migration (2003-2102) using MEANDER (Eric Larsen, UC-Davis)
 - Calibrated against historic conditions
- Ran with simulated flows from the 5 climate scenarios
- Assumed channel movement creates recruitment sites for pioneer species (cottonwood, willow, tamarisk)



Modeling Vegetation Dynamics

- Designed fine-scale riparian vegetation model in STELLA
- Simulated reproduction, growth, survival of 11 dominant plant species
 - Competition for light and water
 - Ecological differences among species
 - Initial veg., site hydrology & channel migration
- Projected veg changes under the 5 climate scenarios
- Ran fine-scale model multiple times to scale results up to patch and site

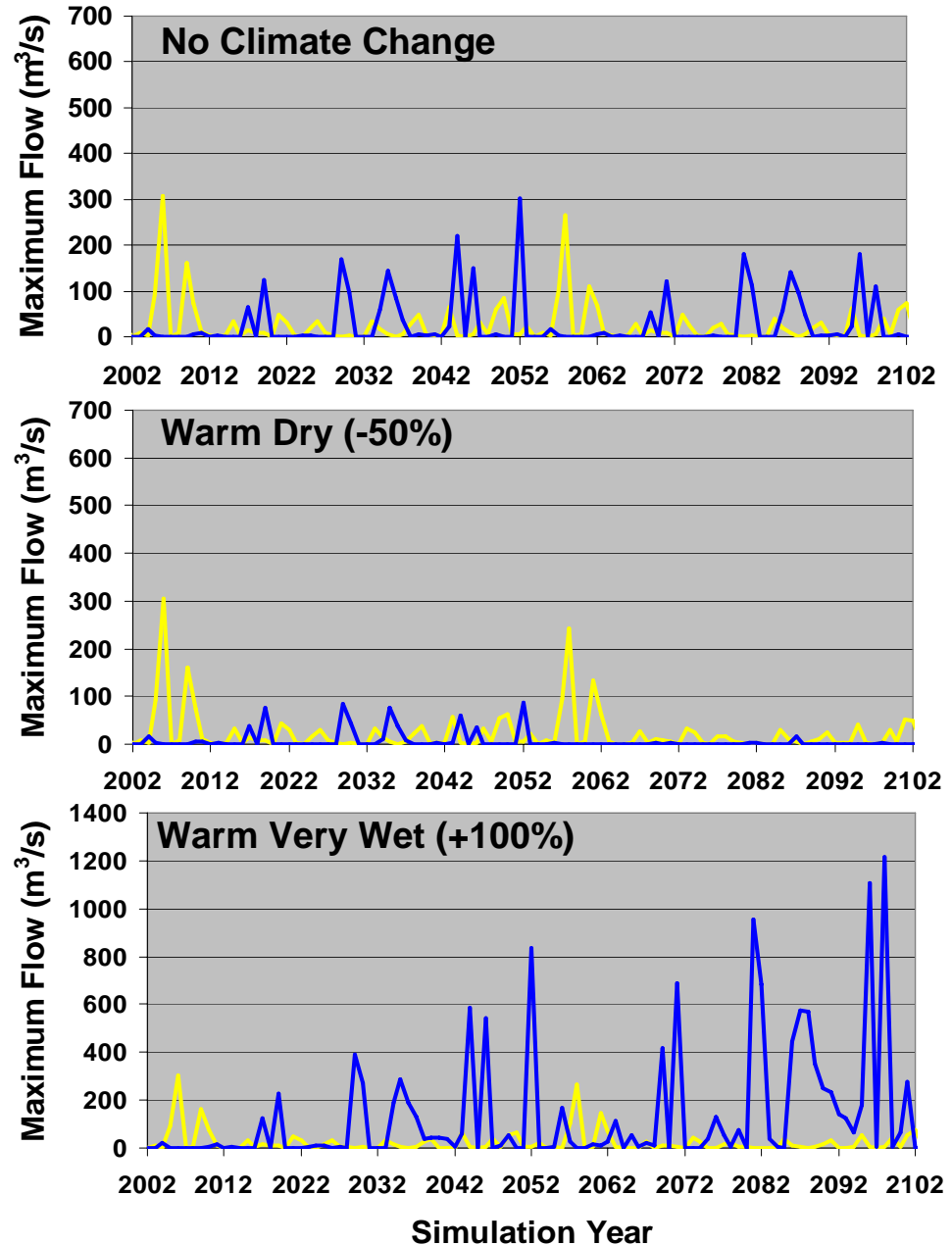


Results



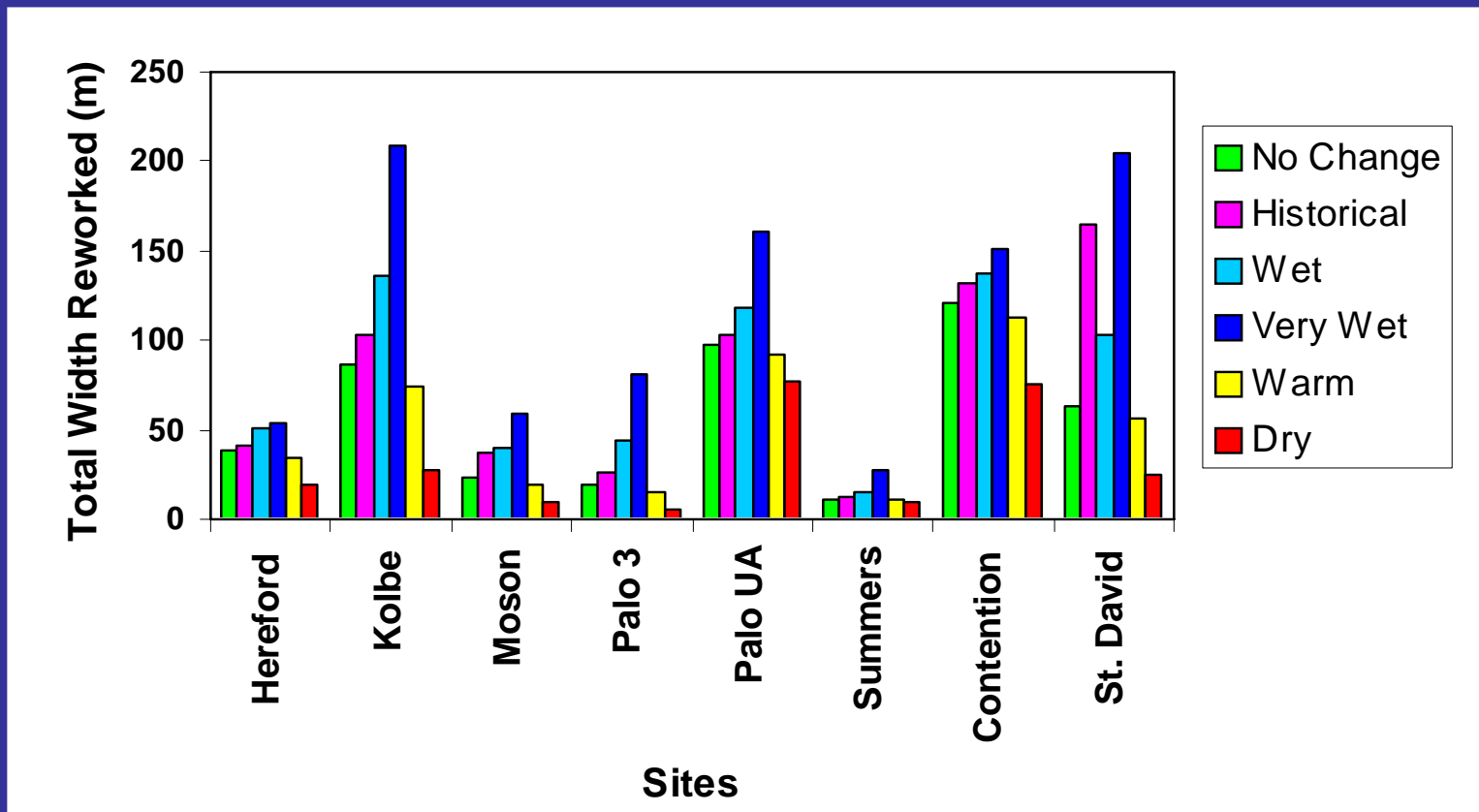
Results: Hydrologic Change

- Major increase in flood magnitude & frequency under wetter scenarios
- Near cessation of winter floods under warm dry scenario



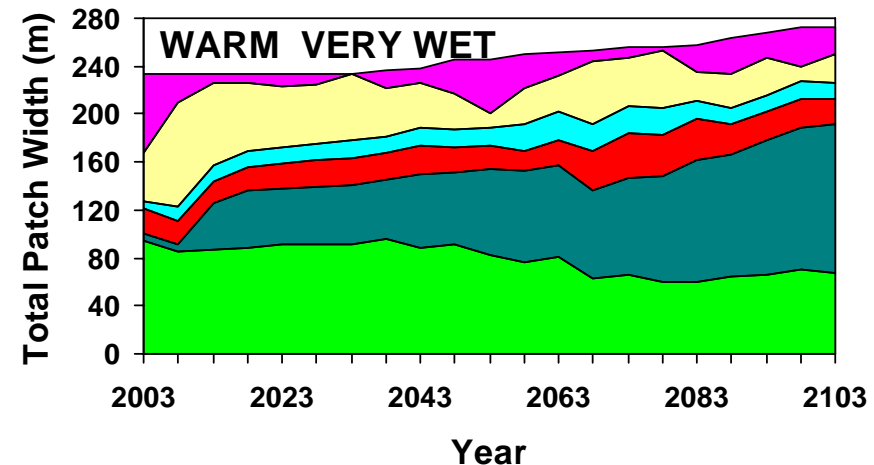
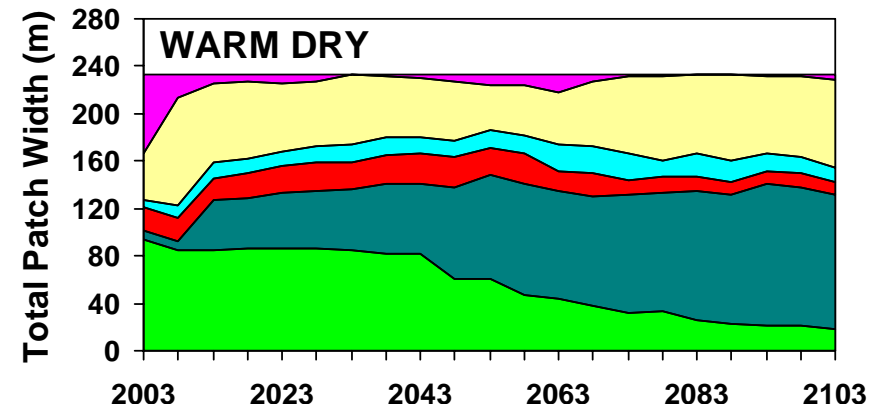
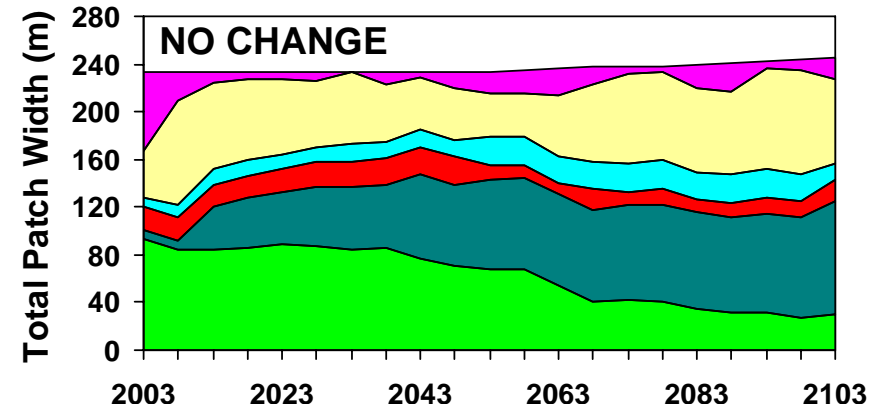
Results: Channel Migration

- Strong differences in simulated channel migration among scenarios & sites



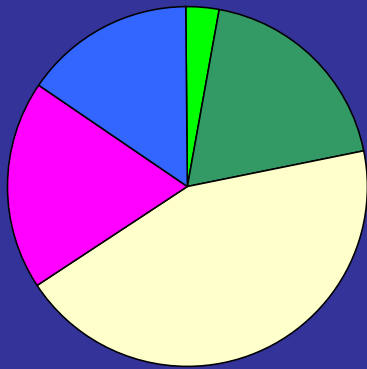
Results: Vegetation Change

- Cottonwood-willow patch width declines under all scenarios
- Coverage of mesquite increases dramatically

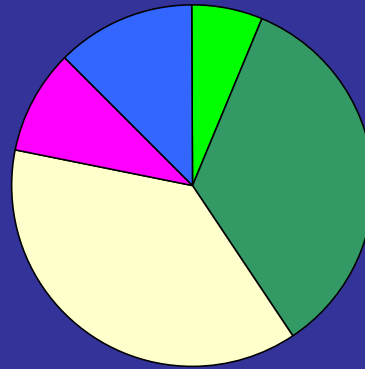


Loss of Original Cottonwood Patches

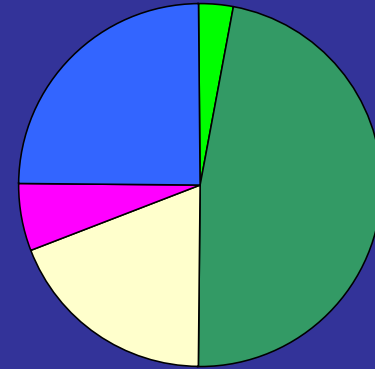
- >90% of original cottonwood patches gone by 2102
 - Most established in 1960s and 1970s
 - Senesce as approach 100 years old
 - Patches convert to mesquite under wetter conditions, sacaton grasslands under drier



No Change



Warm Dry

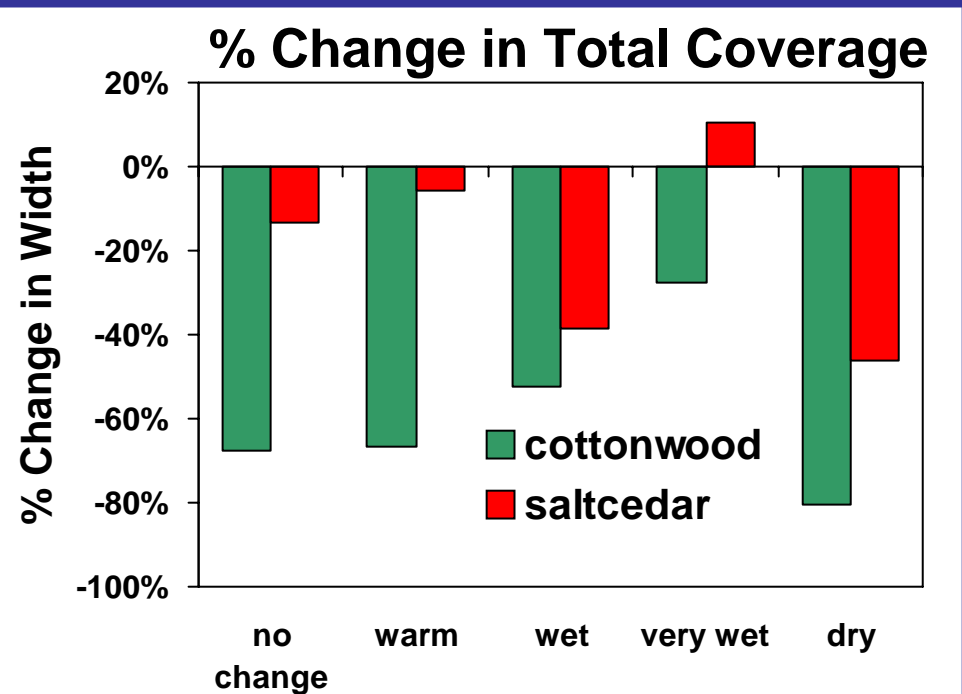
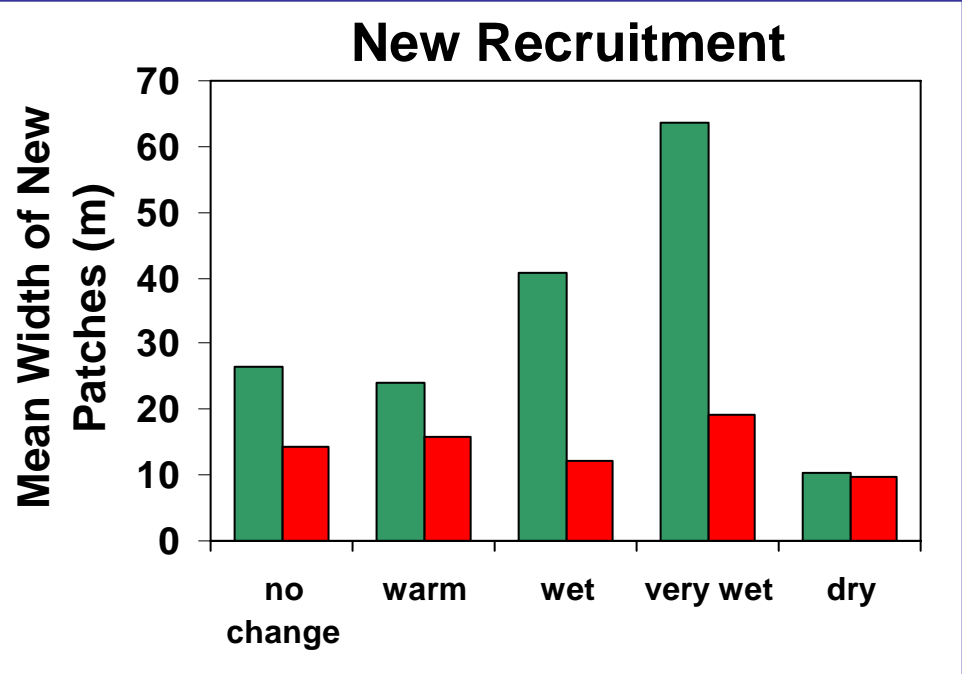


Warm Very Wet

■ Cottonwood ■ Mesquite ■ Sacaton ■ Other ■ Eroded

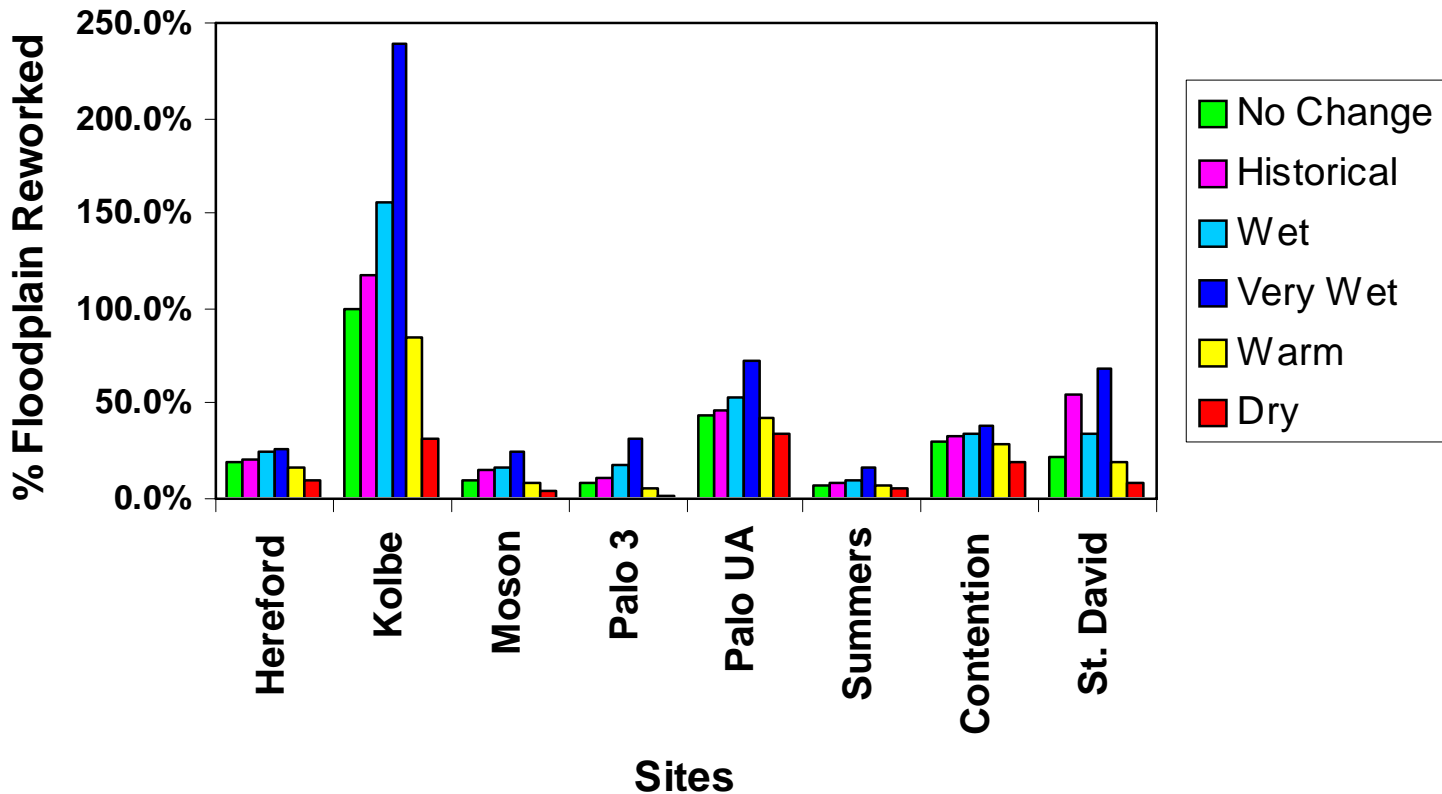
Recruitment of New Patches

- New cottonwood & saltcedar patches form by channel migration
- But, recruitment is insufficient to balance senescence of old stands
- Greatest cottonwood decline under driest scenario, least under wettest



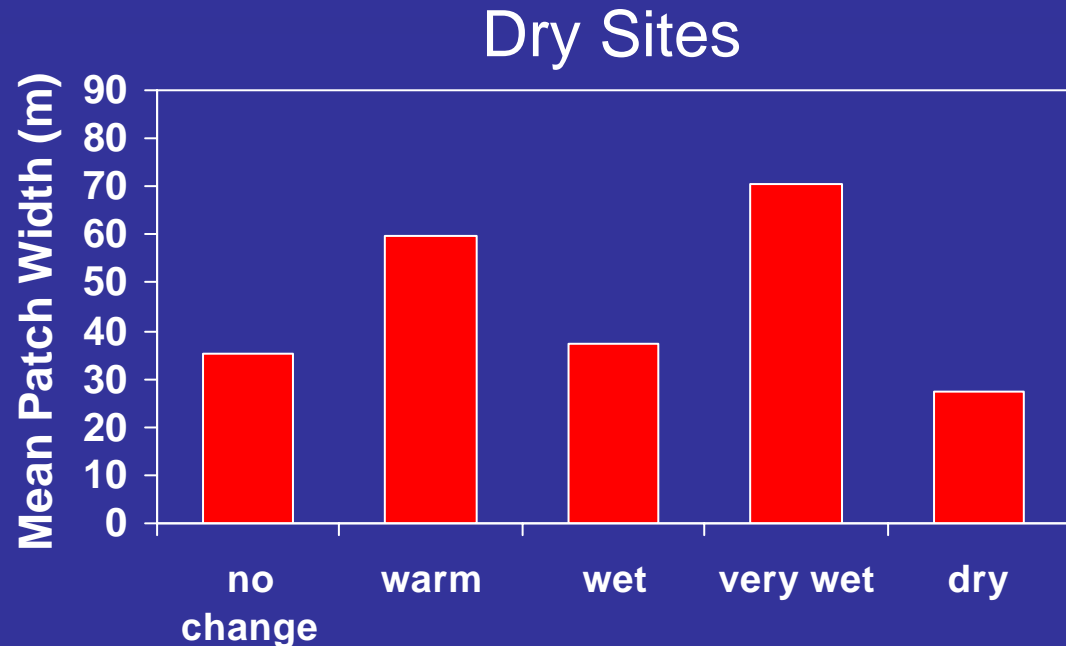
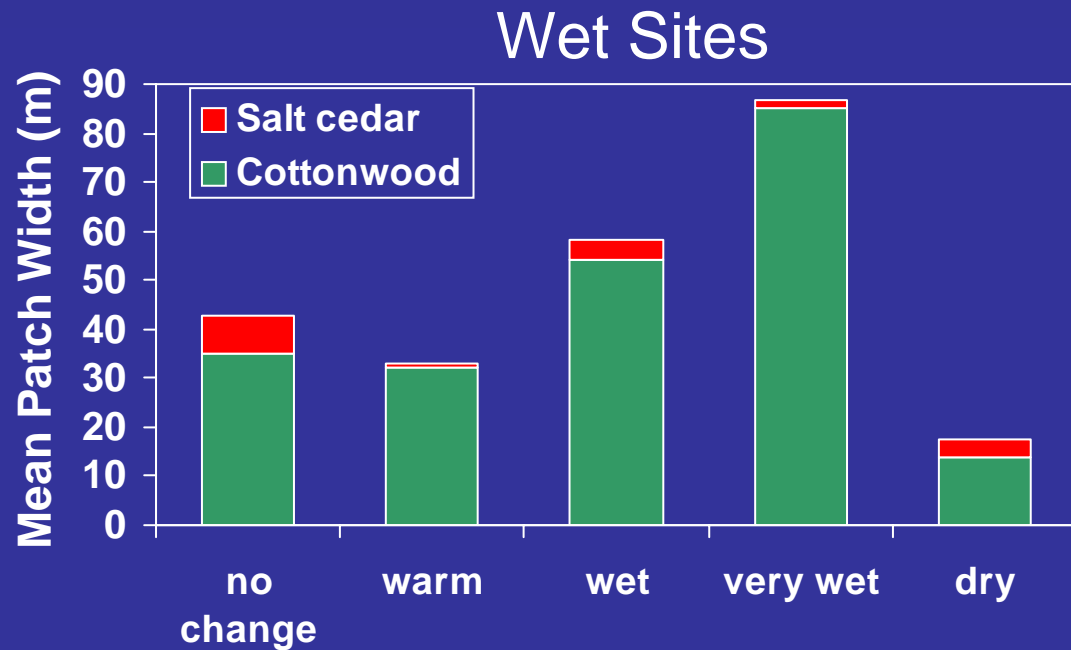
Results: Vegetation Change

- Least reduction of pioneer species (cottonwood, saltcedar) at most geomorphically dynamic sites



Results: Vegetation Change

- Site hydrology influences recruitment of cottonwood vs. saltcedar
- Suggests that future groundwater conditions will have strong effect on composition



Drought Effects on San Pedro River (2005)



Photo by Josh Ayers, USGS

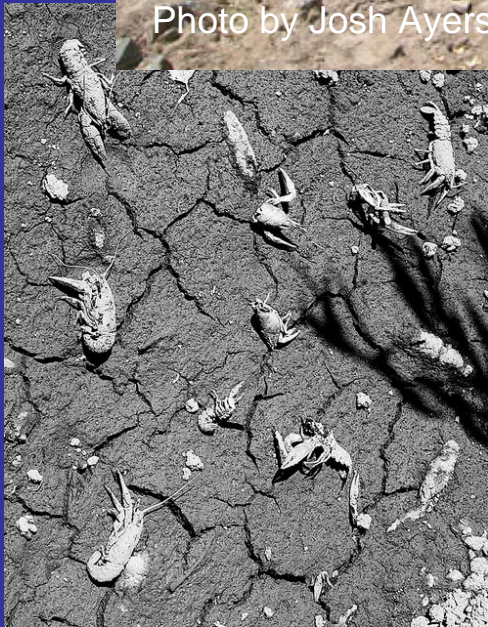


Photo from AZ Daily Star

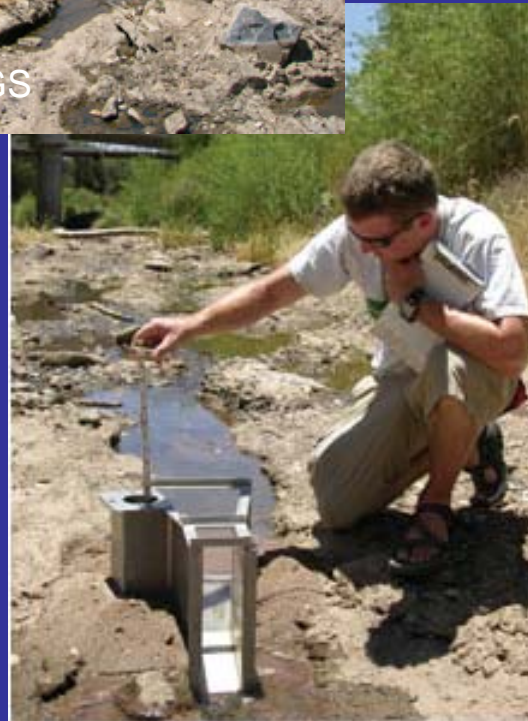
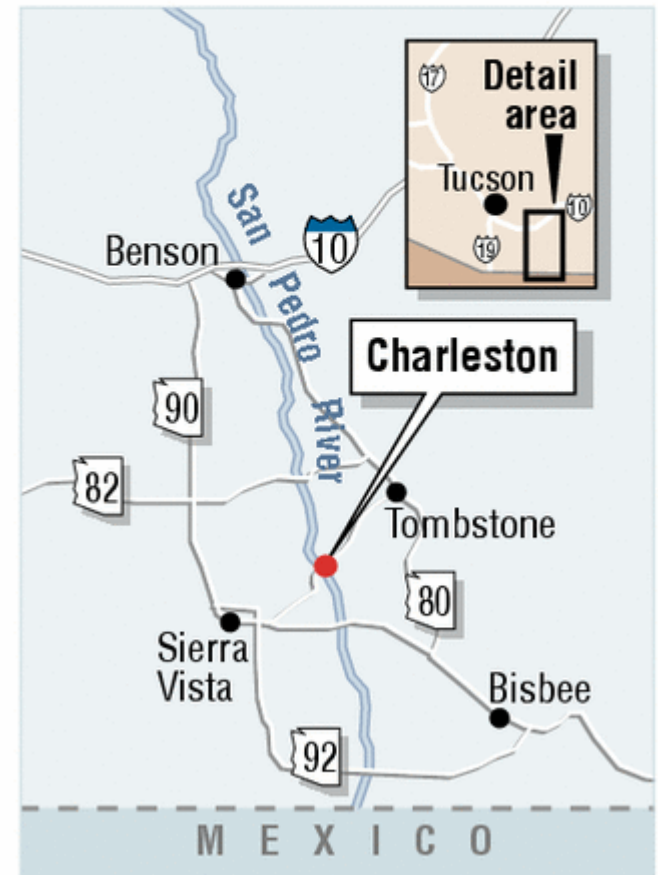


Photo by Mark Anderson, USGS

Drying up?

The water has stopped running in the Charleston area of the San Pedro River for the first time since records started being kept in the early 20th century. Full-time records of the river's flow there weren't started until the early 1930s.



Graphic from AZ Daily Star

Staff

Keys to Future Change on the Upper San Pedro

- Successional processes
 - Cottonwoods and willows are short-lived pioneer species that require fluvial disturbance to persist
- Geomorphic legacies
 - Riparian forest distribution is a legacy of the San Pedro's geomorphic history, not in equilibrium with present processes
- Future geomorphic constraints
 - Riparian forest coverage will depend, in part, on future flood disturbance and geomorphic processes
- Human exploitation of groundwater
 - Human water use will strongly influence future species composition (saltcedar vs. cottonwood)

Conclusions

- Uncertainty about how climate will change
- Effects of climate change on riparian vegetation may depend on:
 - Population age structure, successional trajectories of vegetation
 - Effects on disturbance – floods, fire
 - Geomorphic context, history, and trajectory
 - Human uses of water resources
- Present riparian zones are a product of past events

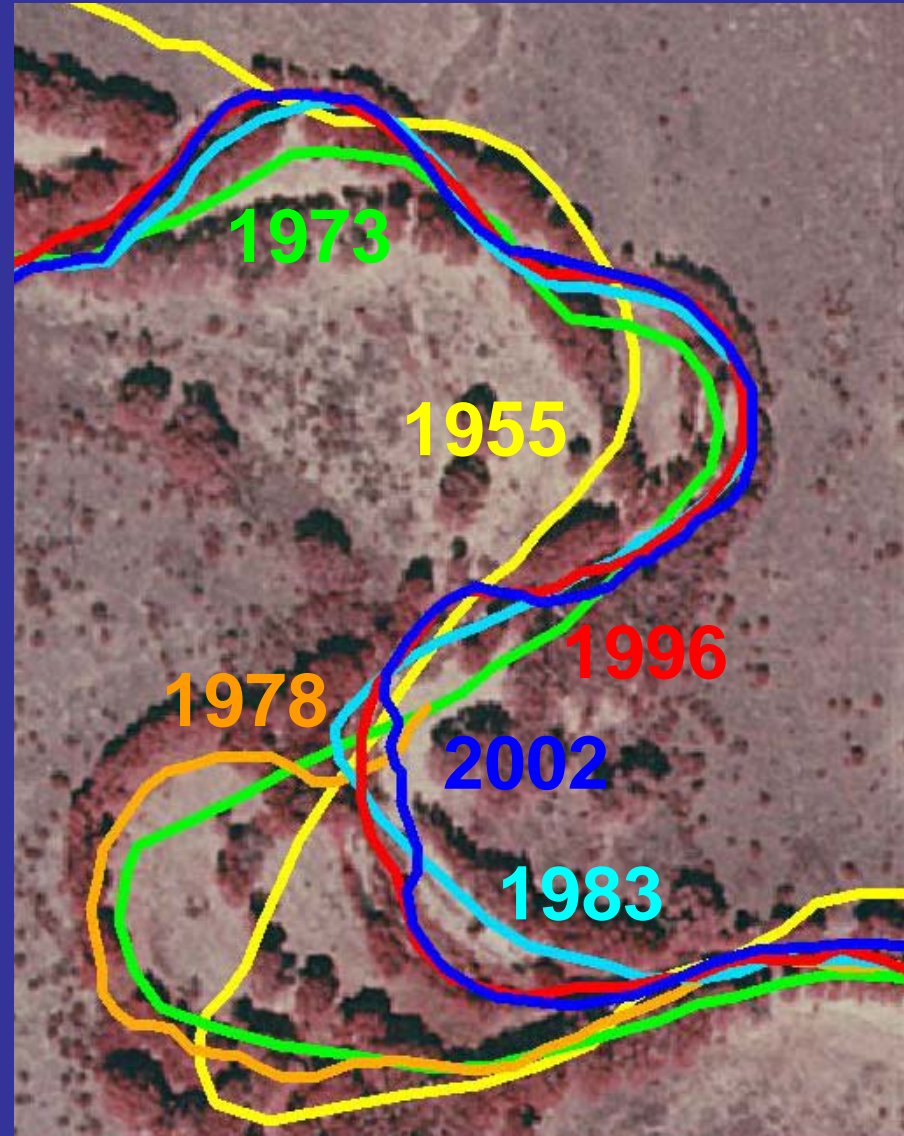
Acknowledgments

- Sharon Lite, Tyler Rychener (Stromberg lab, ASU)
- Jingle Wu and Alex Buyantuyev (Landscape ecology lab, ASU)
- Eric Larsen and Alex Fremier (UC-Davis) – Channel migration modeling
- Mariano Hernandez & Dave Goodrich (ARS) – help with SWAT model
- Jeff Price (CSU-Chico) and Hector Galbraith – Climate change project
- Funding by SAHRA, Department of Defense Legacy Program, Upper San Pedro Partnership, US EPA & American Bird Conservancy



Quantifying Historic Channel Migration

- Traced channel centerline on historic aerial photos
- Calculated area “reworked” by the river between dates
- Related to historic flows (cumulative stream power) between photo dates



Functions of Floods

Winter floods (longer duration)

- Move channels
- Stimulate cottonwood-willow and sycamore recruitment
- Re-soak floodplains and help sustain baseflows

Summer floods (short duration)

- Stimulate growth of annual and perennial plants and recruitment of mesquite
- Re-soak floodplain and sustain baseflows
- Move leaf litter and stimulate decomposition

Possible Effects of Climate Change on Riparian Ecosystems

Increased temperatures

- Longer growing seasons
- Expansion of mesquite and saltcedar to higher elevations?
- Higher evaporative demand and groundwater uptake by phreatophytes
- Higher water use by human ecosystems?
- Greater risk of groundwater decline, channel drying, and degradation of riparian zones?

Possible Effects of Climate Change on Riparian Ecosystems

Increased winter precipitation

- Increased establishment of pioneer trees (cottonwood, willow, salt cedar)
- Increased rates of river channel migration
- Increased re-soaking of floodplain soils and floodplain aquifers
- Greater recharge of regional aquifer
- Greater plant growth during the dry season

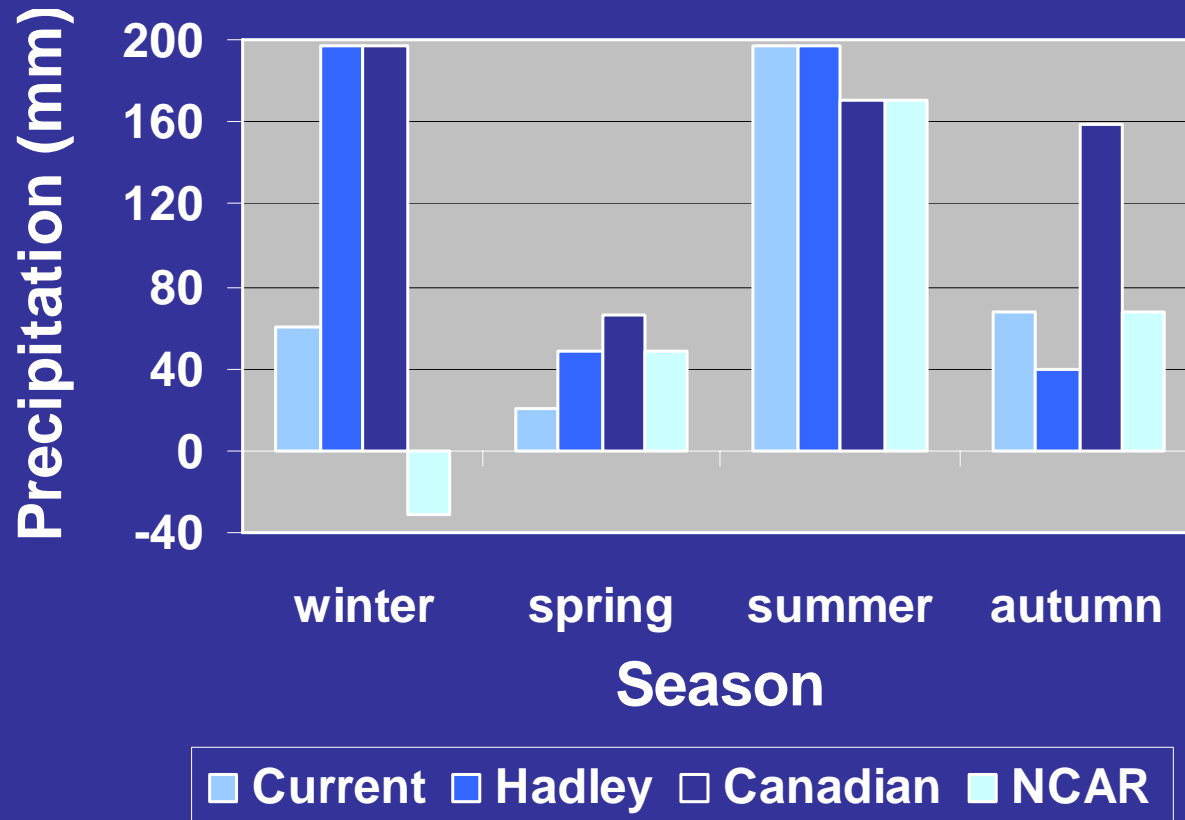
Possible Effects of Climate Change on Riparian Ecosystems

Decreased precipitation

- Decreased flooding and establishment of riparian trees (but greater vulnerability to erosive floods)
- Decreased re-soaking of floodplain soils and aquifer
- Decreased recharge of regional aquifer
- Lower plant growth during the dry season
- With higher temp, greater stress on riparian ecosystems
- Channel drying and shifts to drought tolerant species (e.g., mesquite, saltcedar)

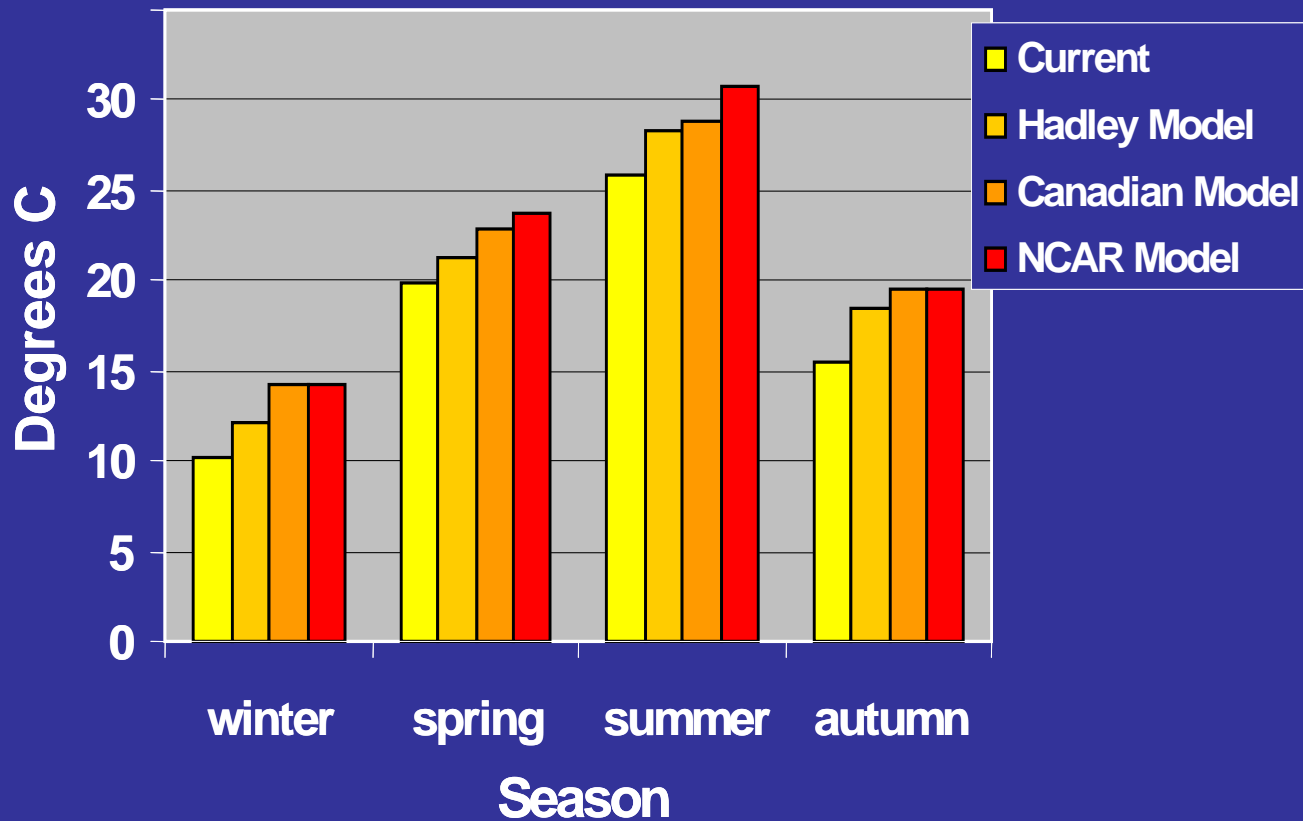
Changes in Rainfall are Uncertain

Projected Precipitation Changes at Tombstone by 2060 (SRAG 2000)



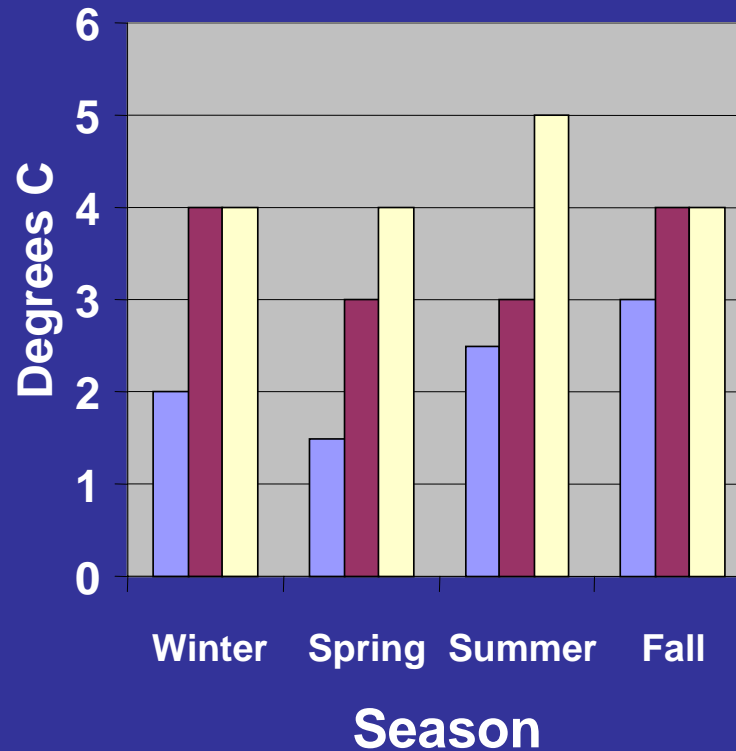
Warmer Temperatures are Likely

Projected Temperature Changes at Tombstone by 2060 (SRAG 2000)



Warmer Temperatures are Likely

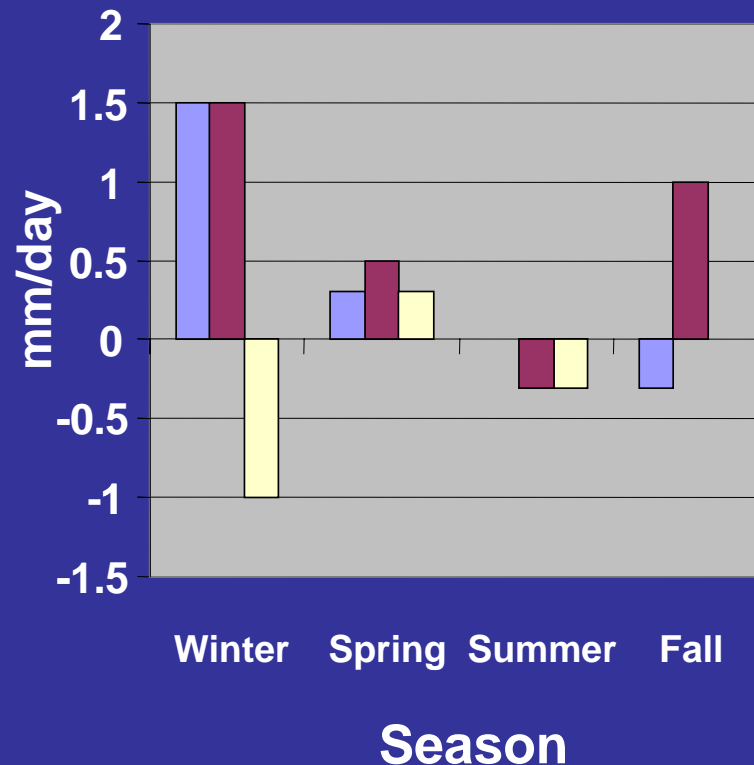
Projected Changes in Mean Temperature by 2060 (SRAG 2000)



- Hadley Center Model
- Canadian Climate Centre Model
- NCAR Regional Model

Changes in Rainfall are Uncertain

Projected Changes in Daily Rainfall
by 2060 (SRAG 2000)



- Hadley Center Model
- Canadian Climate Centre Model
- NCAR Regional Model

Riparian pioneer plants (e.g., cottonwood, willow) depend on flows to disperse seeds and establish on open, moist sediment bars.



Effects of Cattle Removal

View from Hereford Bridge



Following cattle removal in 1988...

- Expansion of riparian vegetation
- Channel narrowing & stabilization

Photos by BLM

Ecological Importance of Riparian Zones

- **Filter, buffer**
 - **Protect aquatic resources from pollution**
- **Corridor**
 - **organism movements, population viability**
- **Biodiversity**
 - **high diversity of species and habitats**
 - **“green ribbon” across arid landscapes**

