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

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Climate and Riparian Areas Workshop, Casa Grande, Arizona

April 11, 2007

San Pedro River, Arizona, National Geographic Magazine

San Pedro River, Arizona, National Geographic Magazine

Southwestern Willow Flycatcher


Photo from USGS

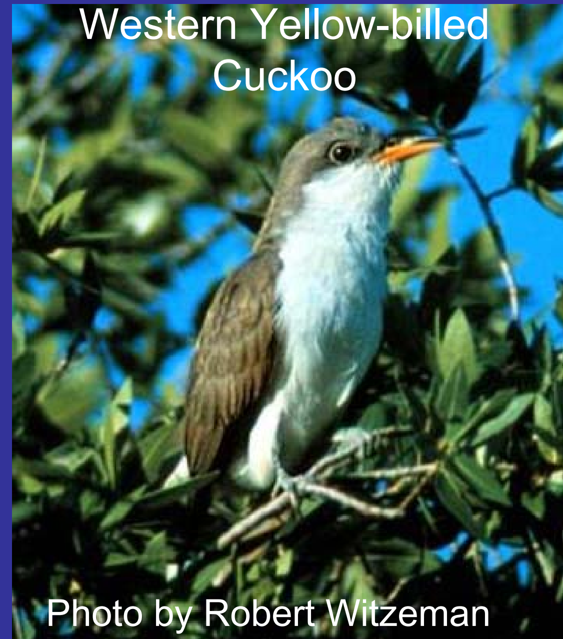


Photo by Robert Witzeman

Photo by Cam MacDonald

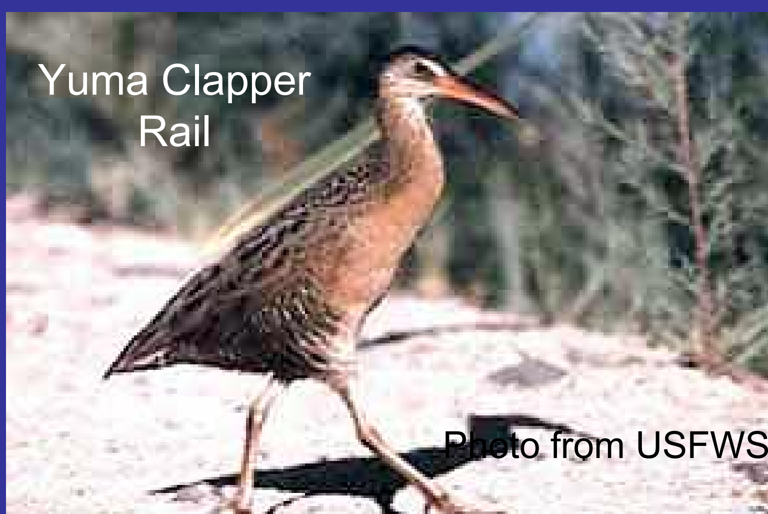


Photo from USFWS

Photo ©Peter La Tourrette

Human Impacts on SW Rivers

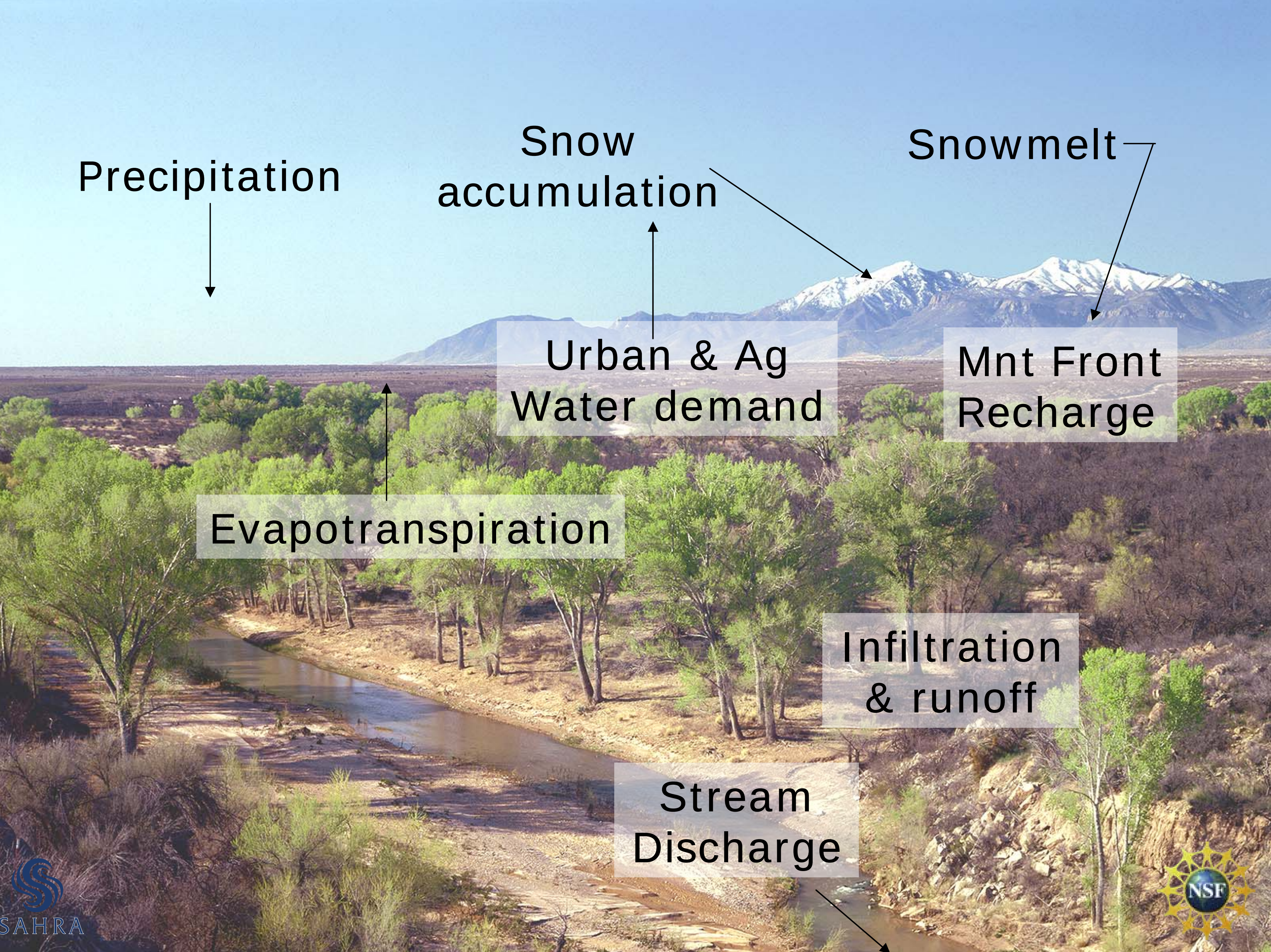
River damming for water storage, hydropower, flood control

Surface water diversion

Ground water pumping from stream and regional aquifers

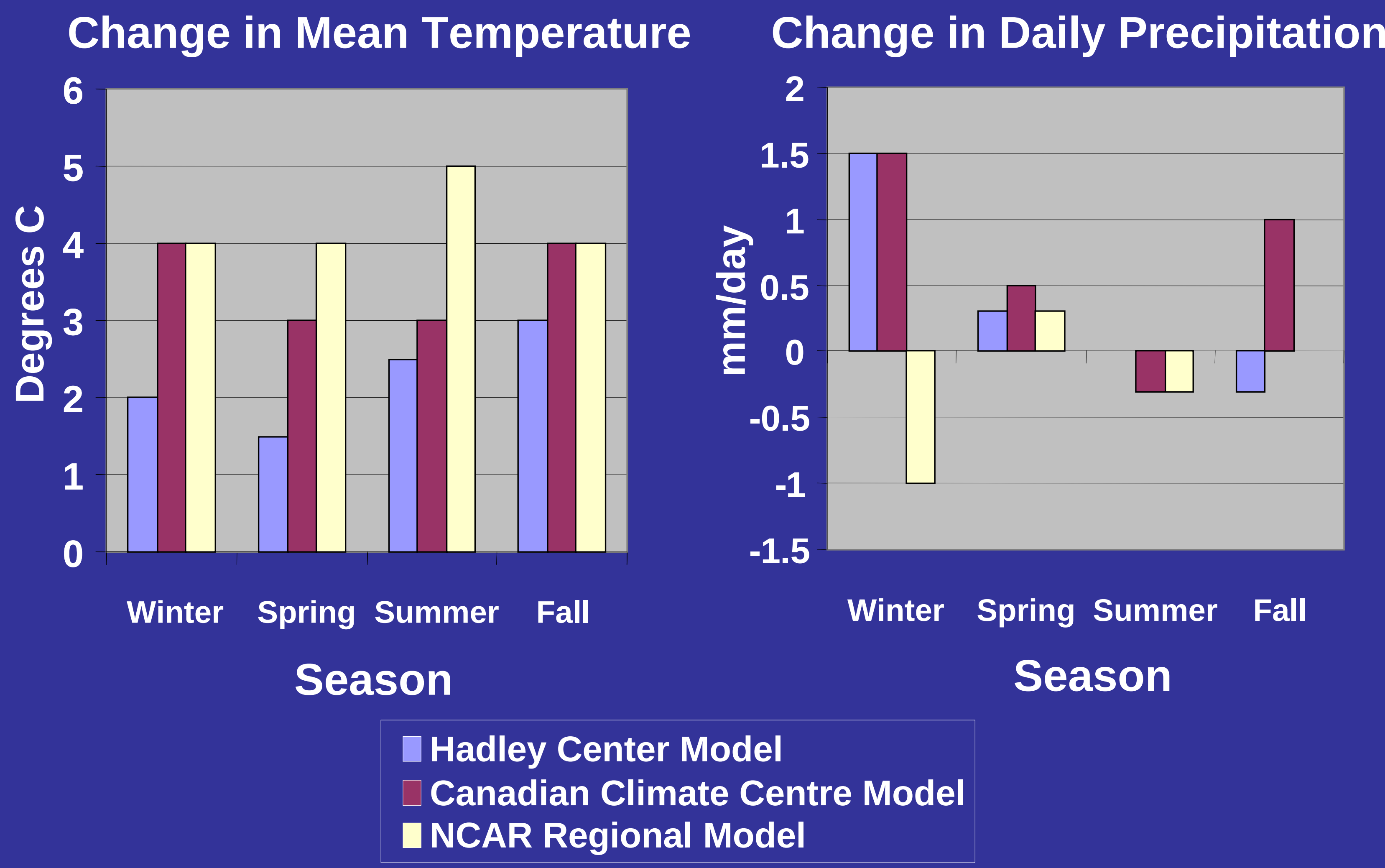
Over-use by cattle

Climate Change?


Precipitation
Snow accumulation
Snowmelt
Urban & Ag Water demand
Mnt Front Recharge
Evapotranspiration
Infiltration & runoff
Stream Discharge
SAHRA
NSF

Uncertainty in Future Climate

Projected Climate Change for SW by 2060 (SRAG 2000)



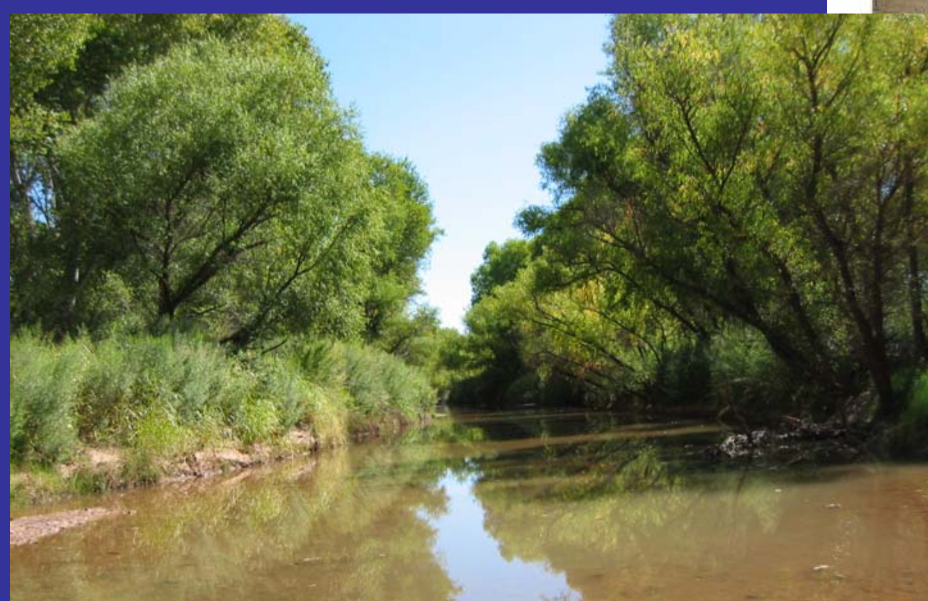
Research Question:

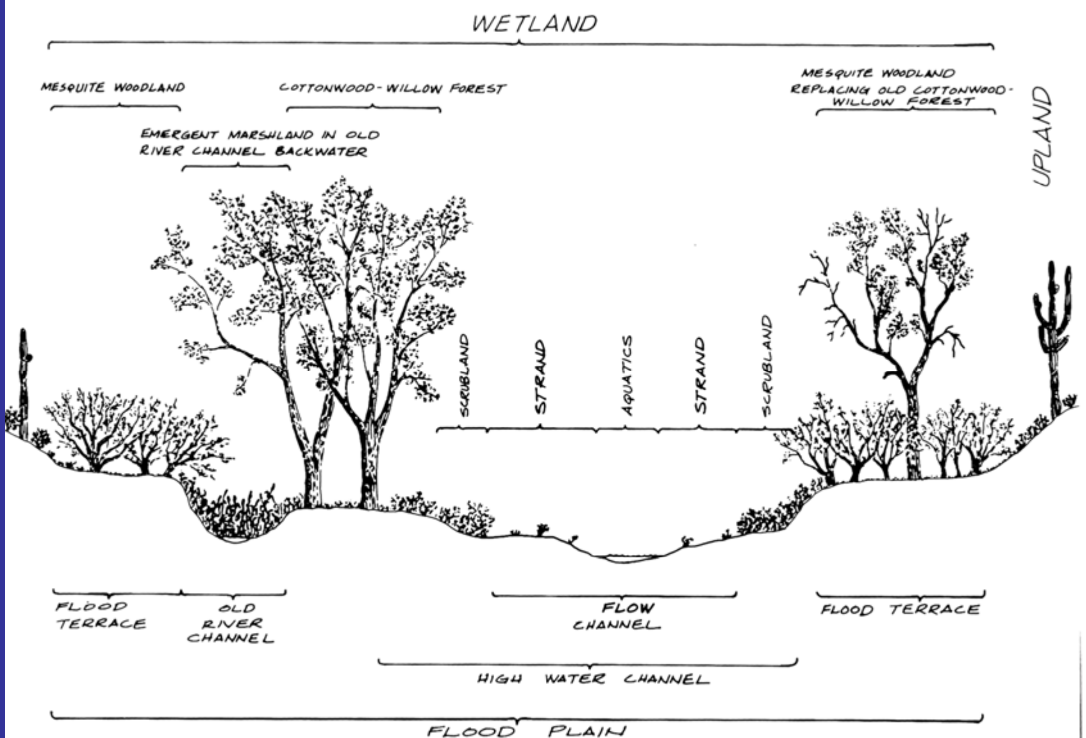
- What are the potential effects of climate change on riparian vegetation composition and dynamics in the Southwest?
    - Used the Upper San Pedro as a case study

San Pedro River, Arizona, National Geographic Magazine

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

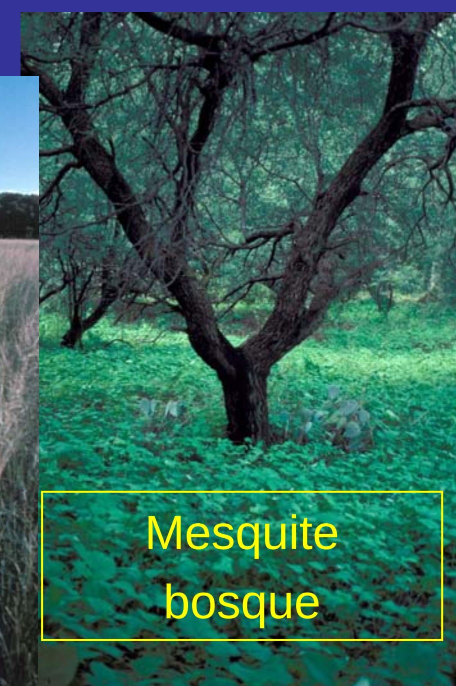



WETLAND
MESQUITE WOODLAND
COTTONWOOD-WILLOW FOREST
MESQUITE WOODLAND REPLACING OLD COTTONWOOD-WILLOW FOREST
UPLAND
EMERGENT MARSHLAND IN OLD RIVER CHANNEL BACKWATER
SCRUBLAND
STRAND
AQUATICS
STRAND
SCRUBLAND
FLOOD TERRACE
OLD RIVER CHANNEL
FLOW CHANNEL
FLOOD TERRACE
HIGH WATER CHANNEL
FLOOD PLAIN

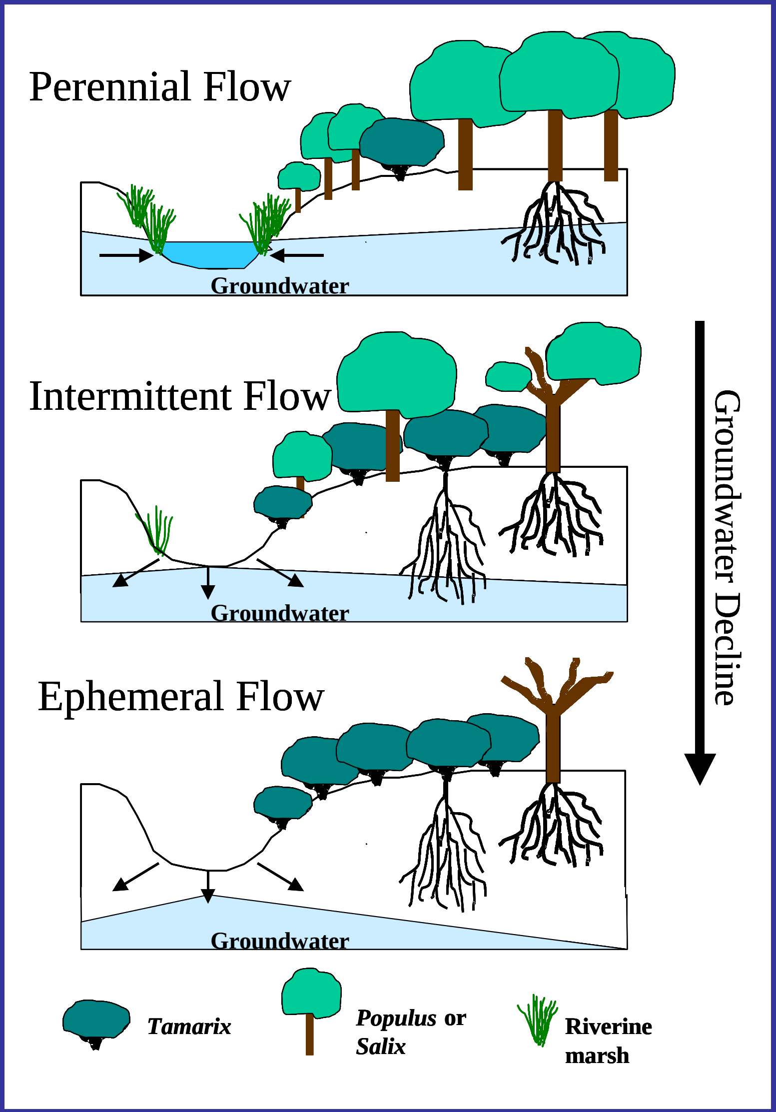

Saltcedar shrubland

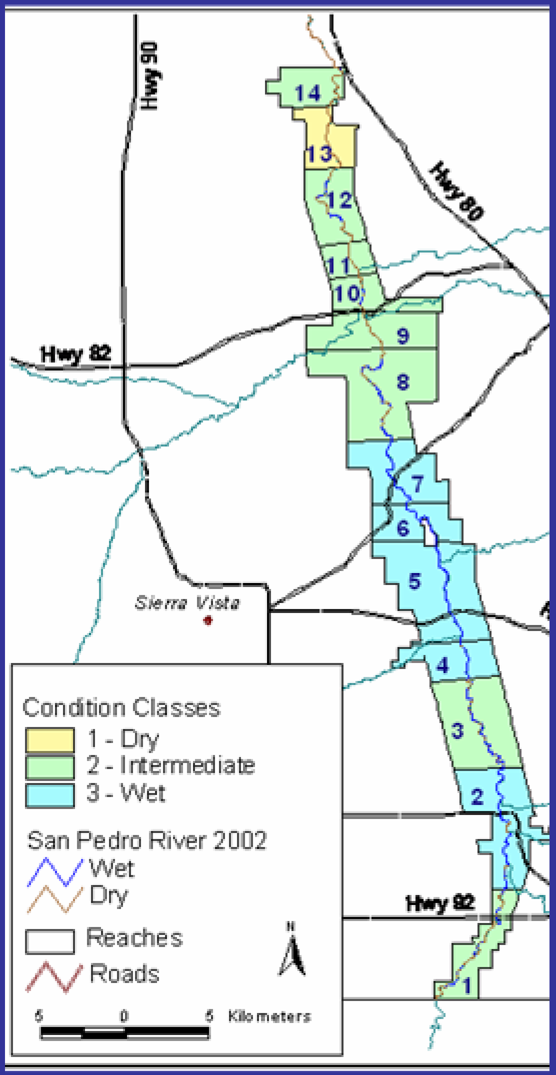

Cottonwood-Willow Forest


Mesic grassland (Sacaton)

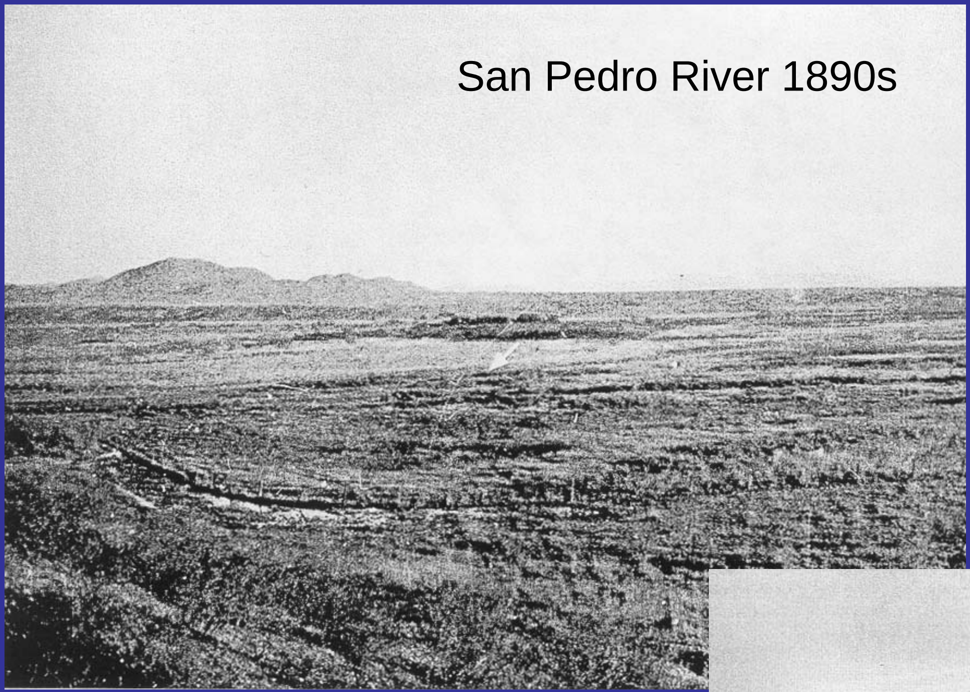

Mesquite bosque

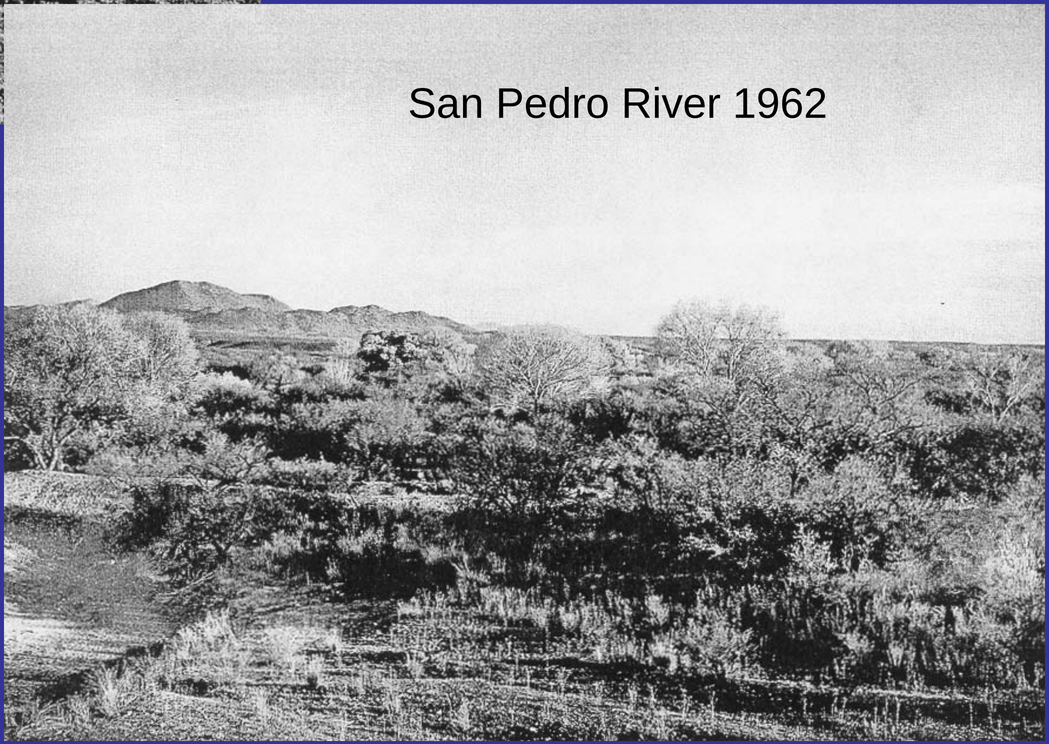
Longitudinal Variation in Riparian Vegetation





Historic Vegetation Change



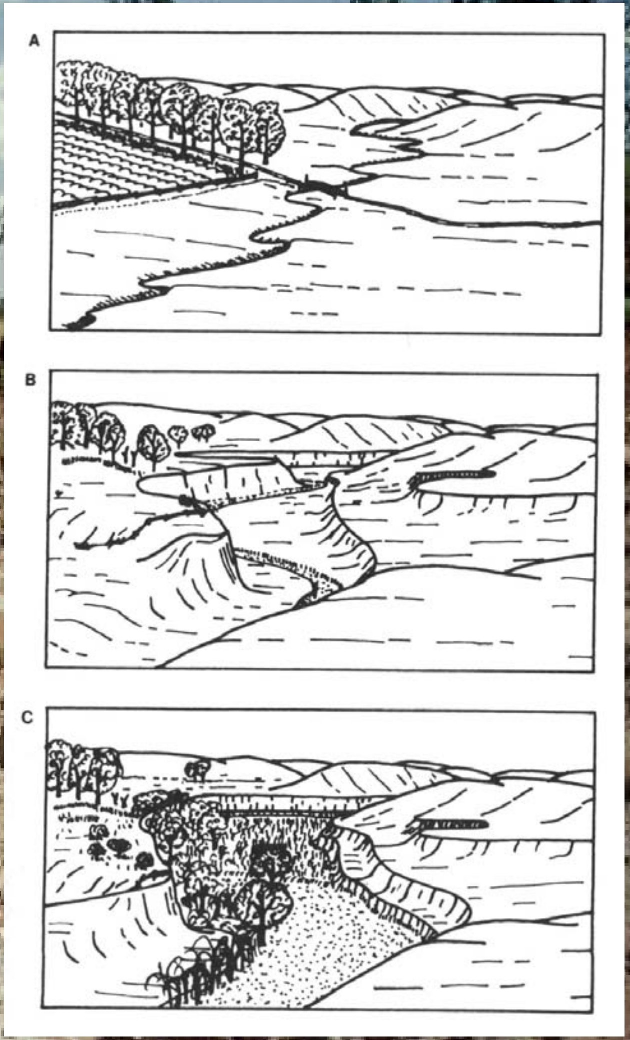


Turner at al. 2003

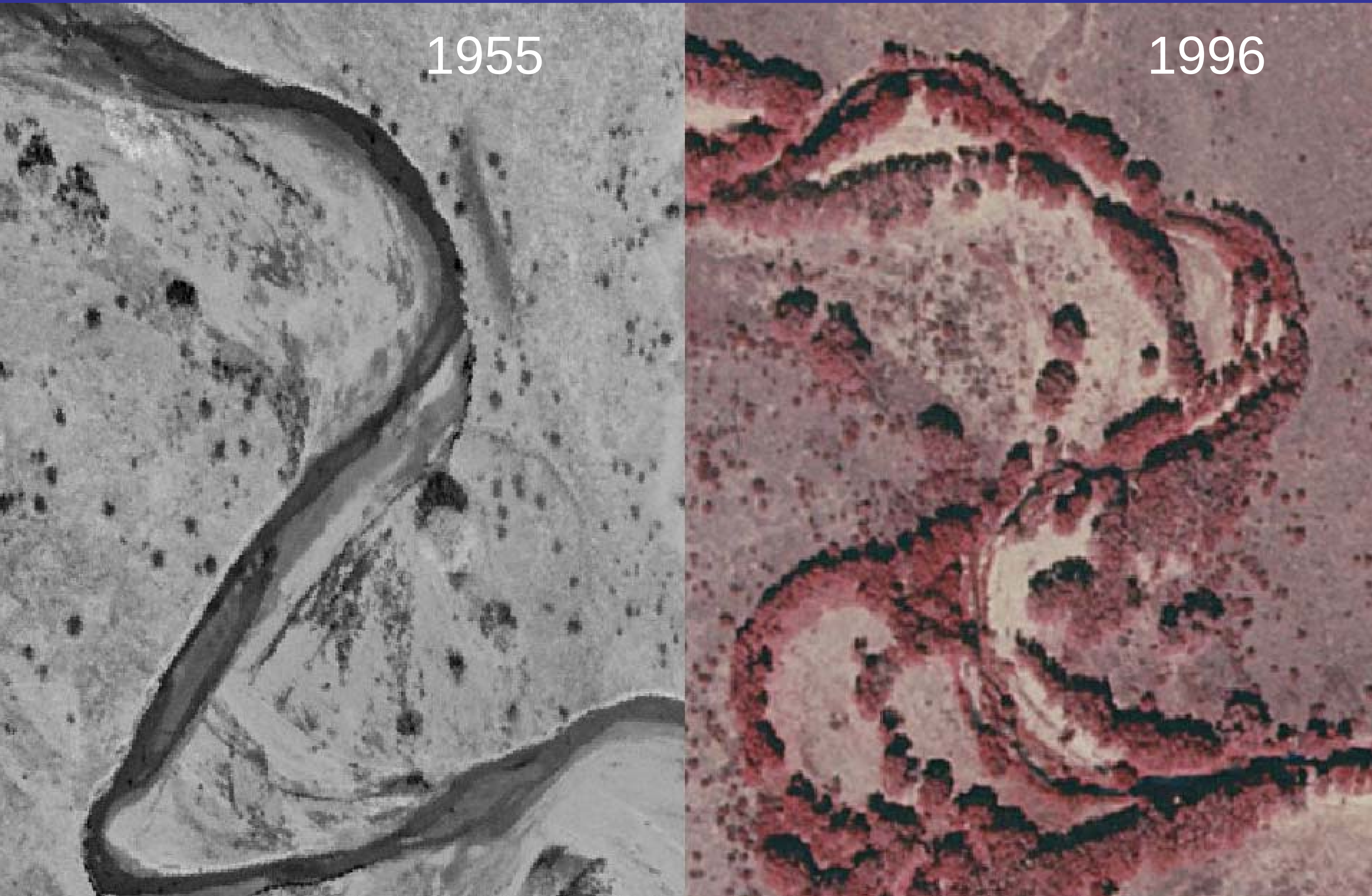
The Changing Mile Revisited

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

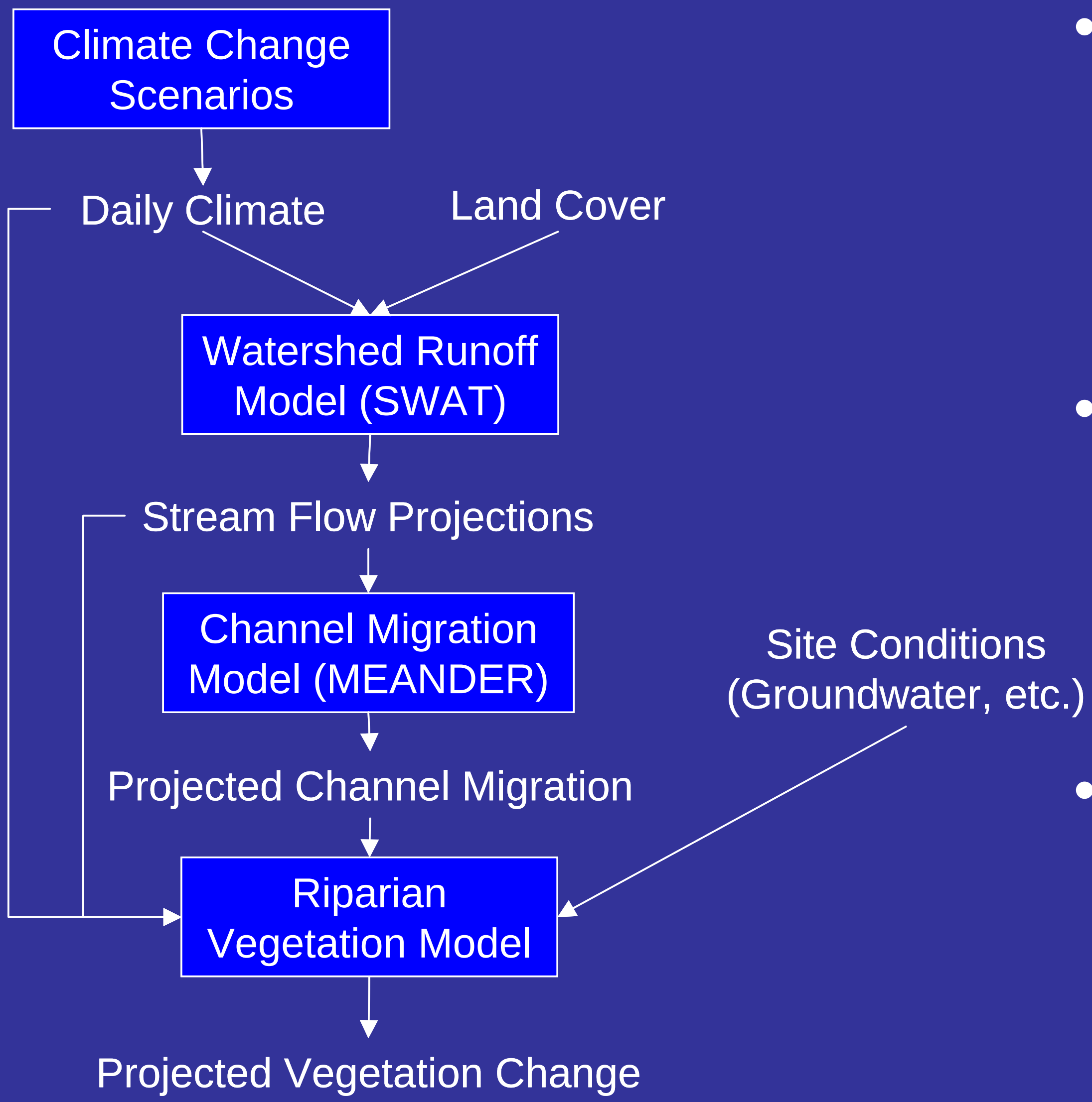


Research Question:

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

San Pedro River, Arizona, National Geographic Magazine

Modeling Climate Change Effects



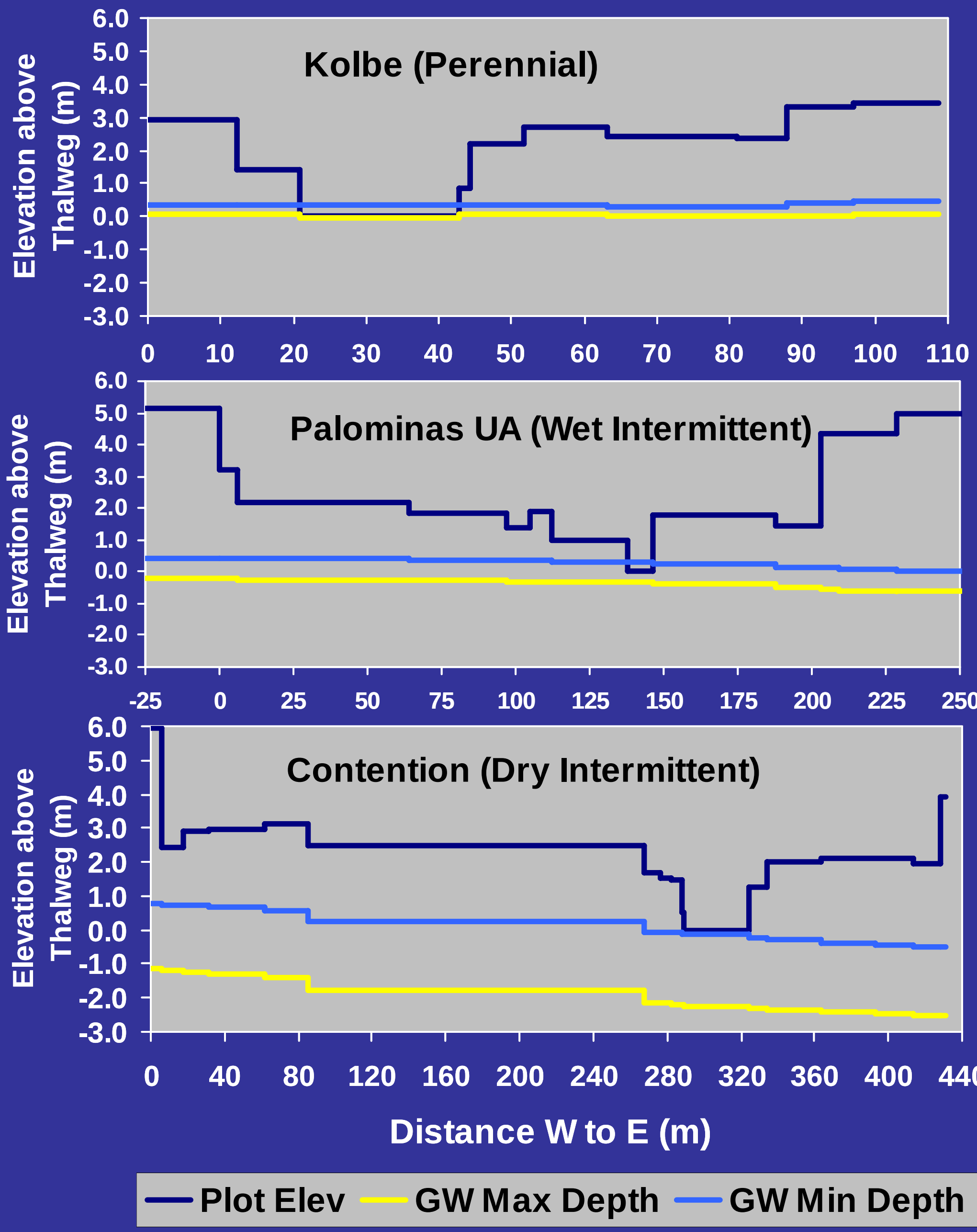
- Simulate range of transient climate change scenarios (2003-2102)
- Model effects of climate on physical processes (stream flow, channel migration)
- Model response of vegetation to changes in physical (and biotic) drivers

Climate Change Scenarios (2003-2102)

- **No change** over 1951-2002 conditions
- **Warm**: Warmer (+5 º 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

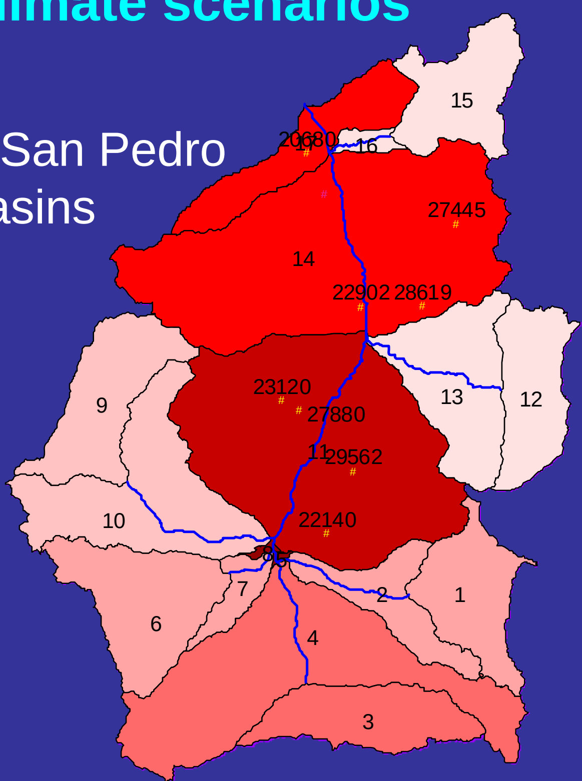
- Modeling sites that span the range of hydro conditions along Upper San Pedro

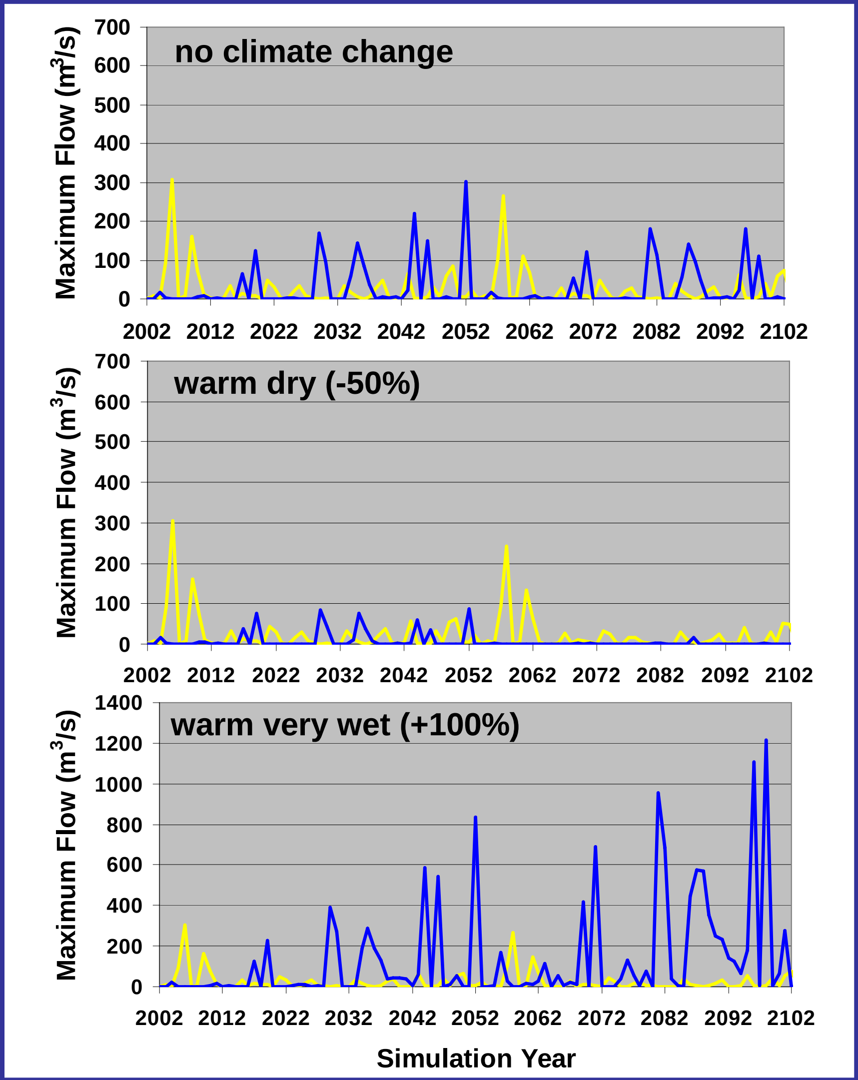


Modeling Watershed Runoff and Streamflow

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

Upper San Pedro
Sub-basins

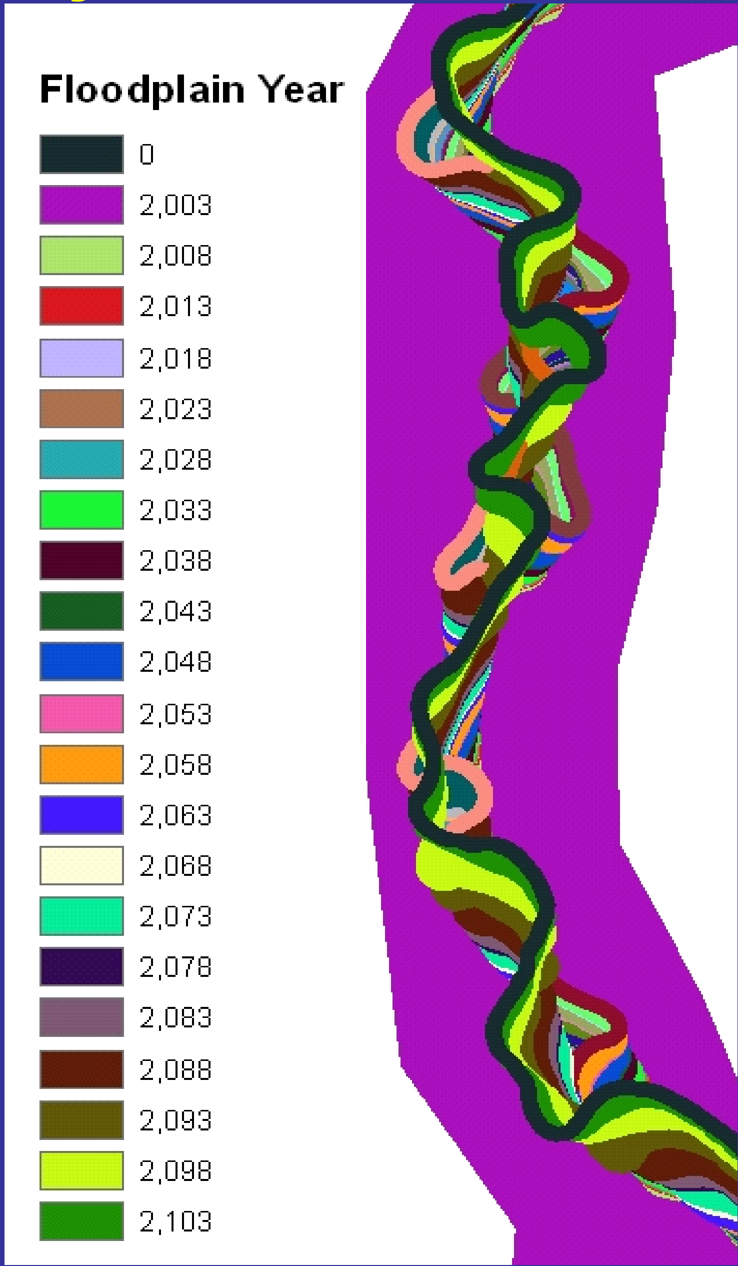




Graphic courtesy of M. Hernandez, ARS, Tucson

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)



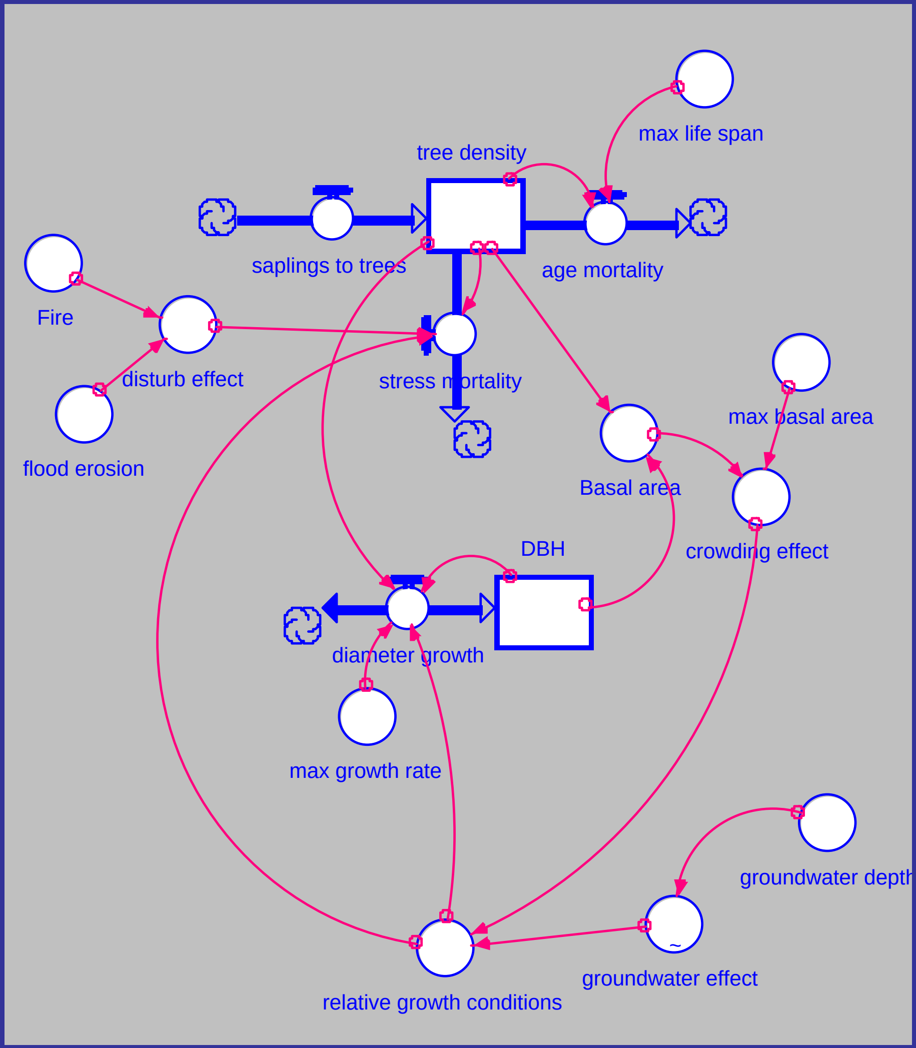
Modeling Vegetation Dynamics

- 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

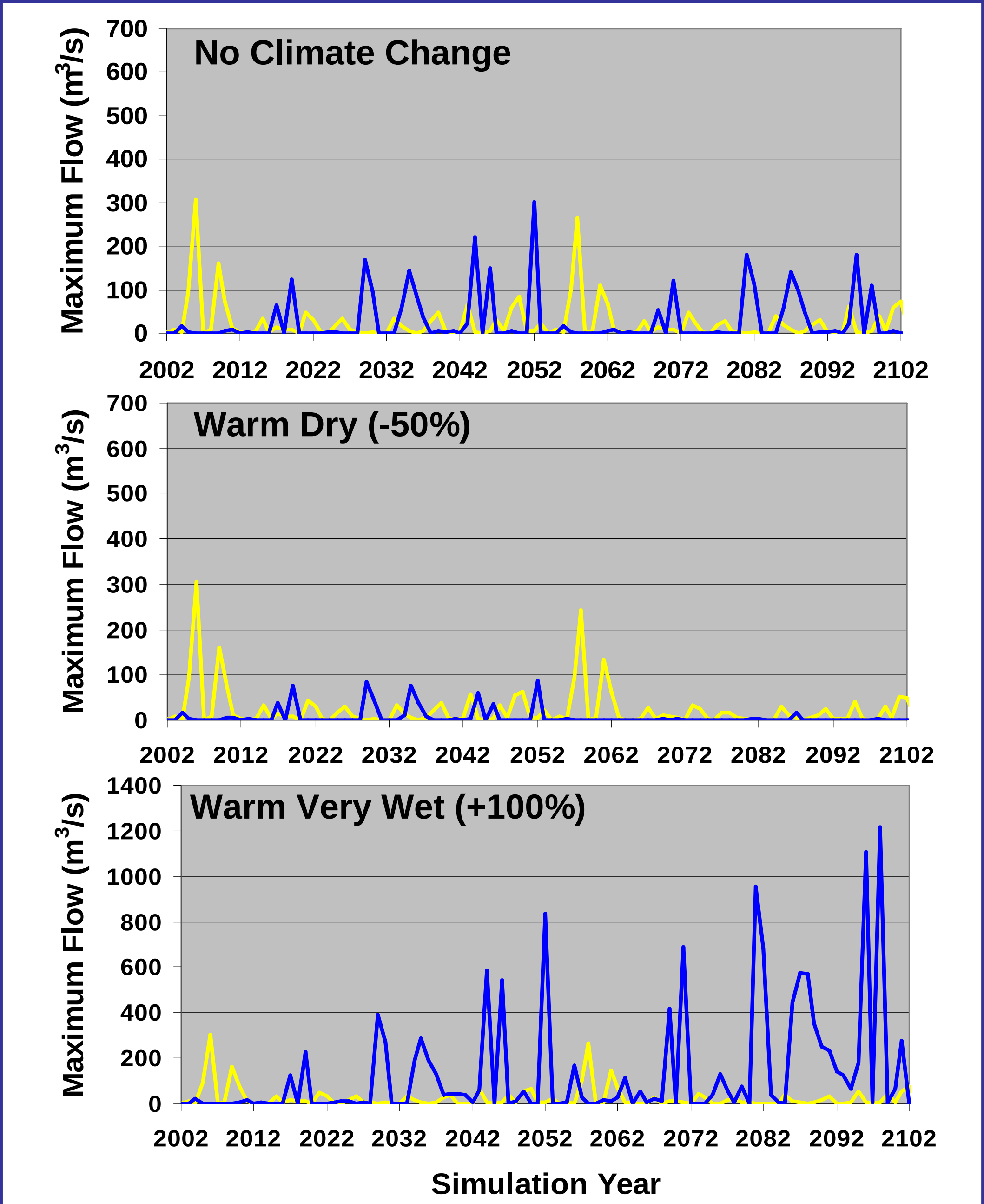
- Ran fine-scale model multiple times to scale results up to patch and site




Results

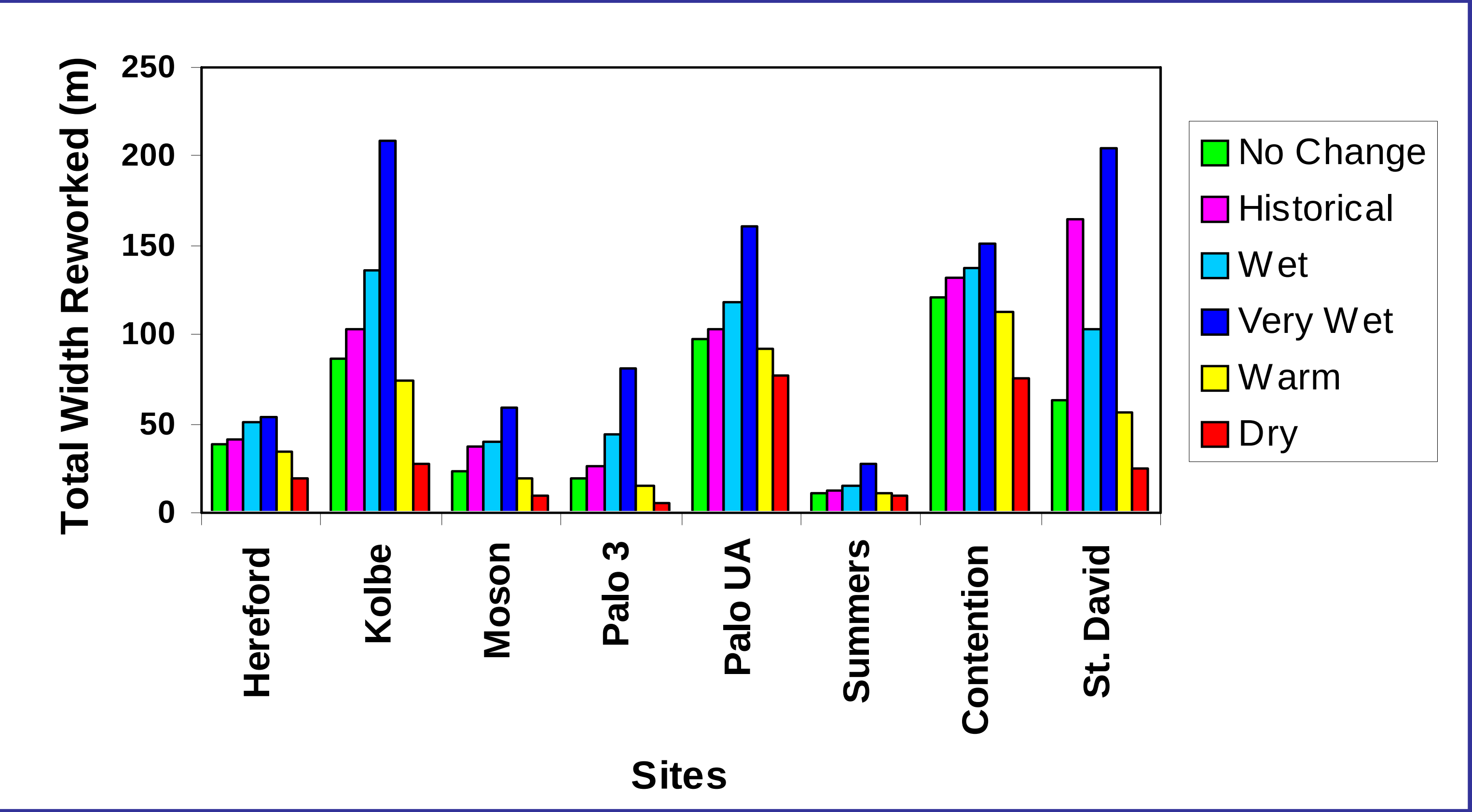
Results: Hydrologic Change

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



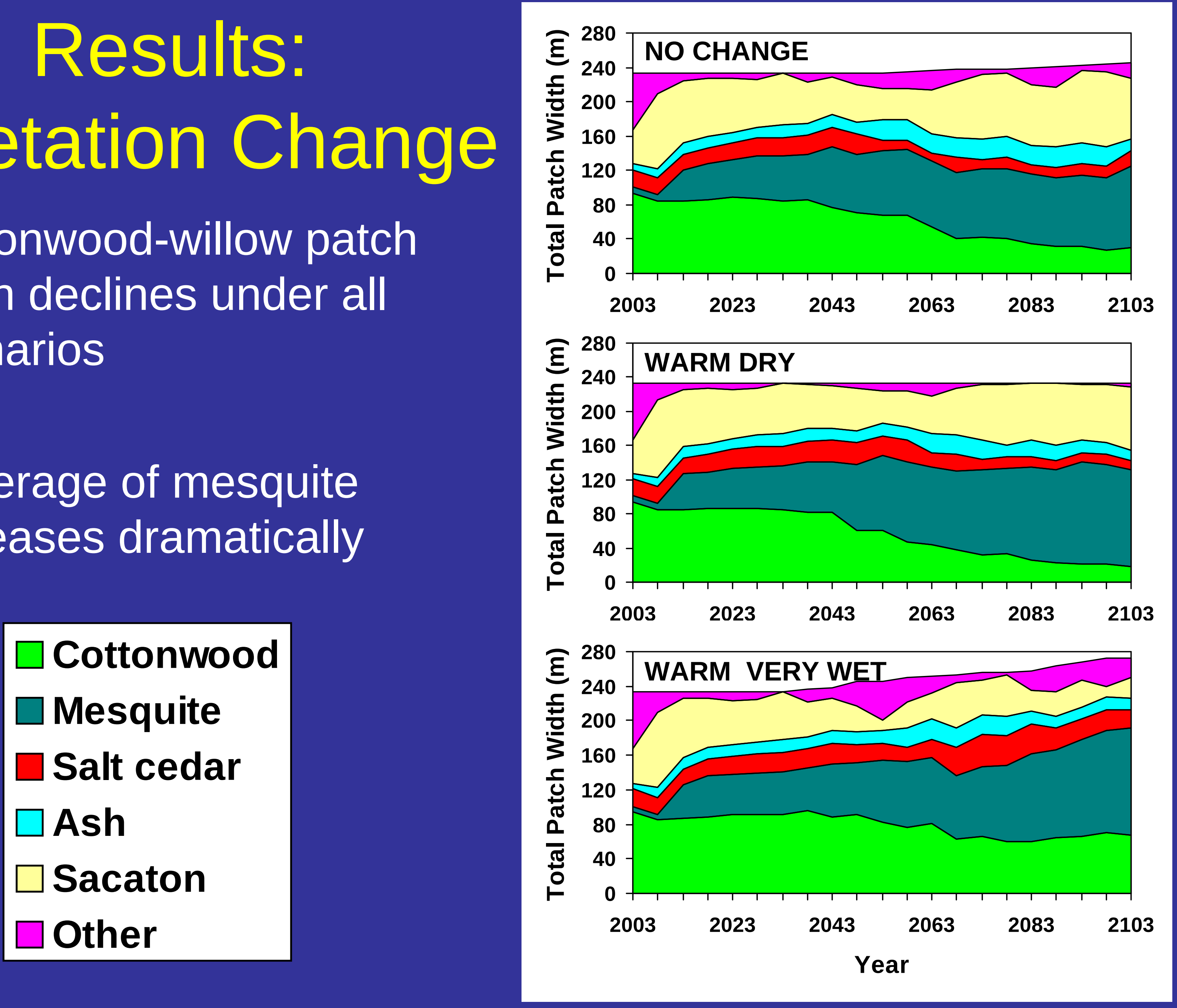
Results: Channel Migration

- Strong differences in simulated channel migration among scenarios & sites



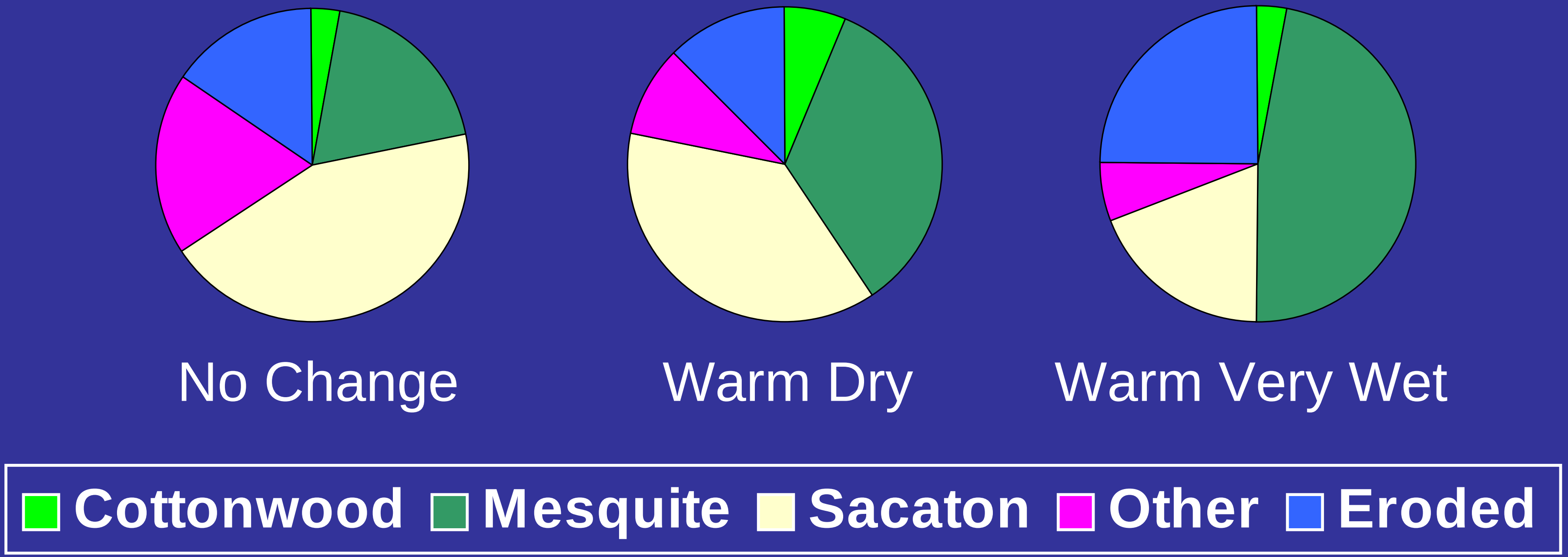
Results: Vegetation Change

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



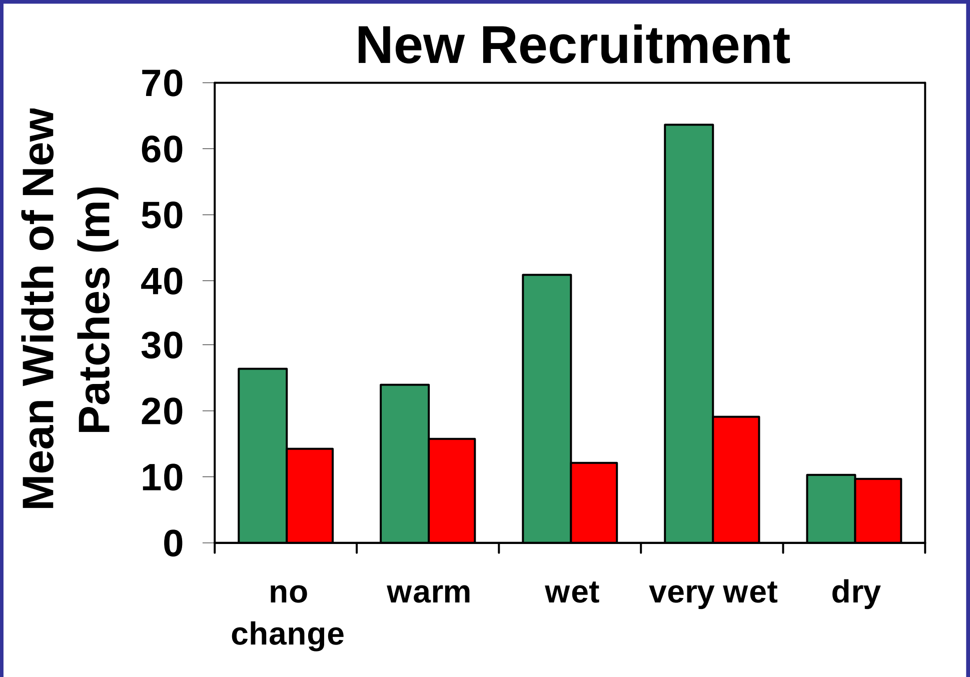
Loss of Original Cottonwood Patches

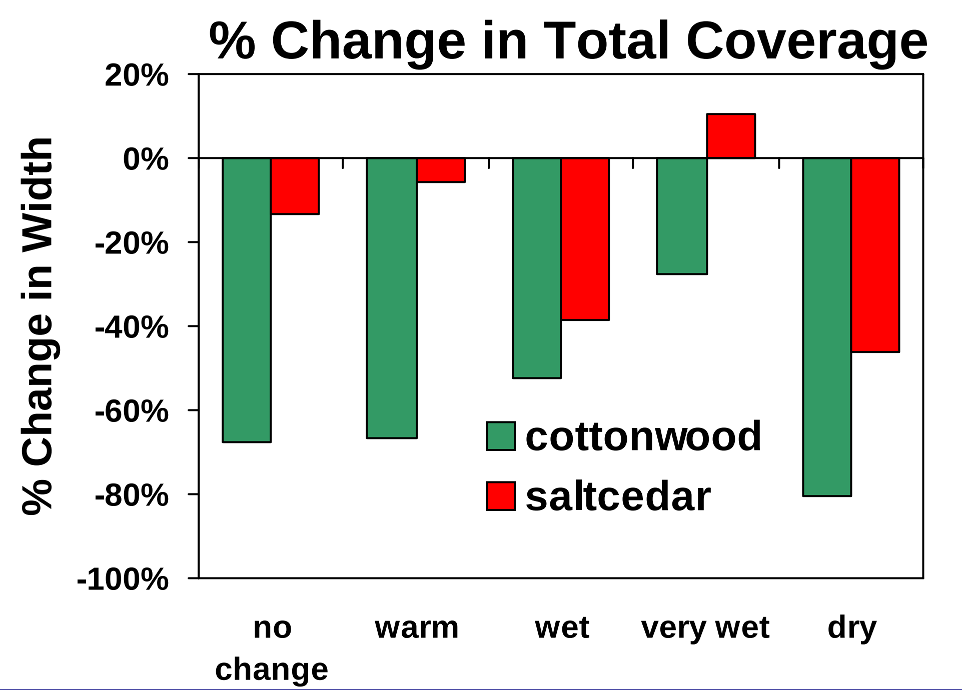
- >90% of original cottonwood patches gone by 2102
  - Most established in 1960s and 1970s
  - Senesce as approach 100 years old
  - Patches convert to mesquite under wetter conditions, sacaton grasslands under drier



Recruitment of New Patches

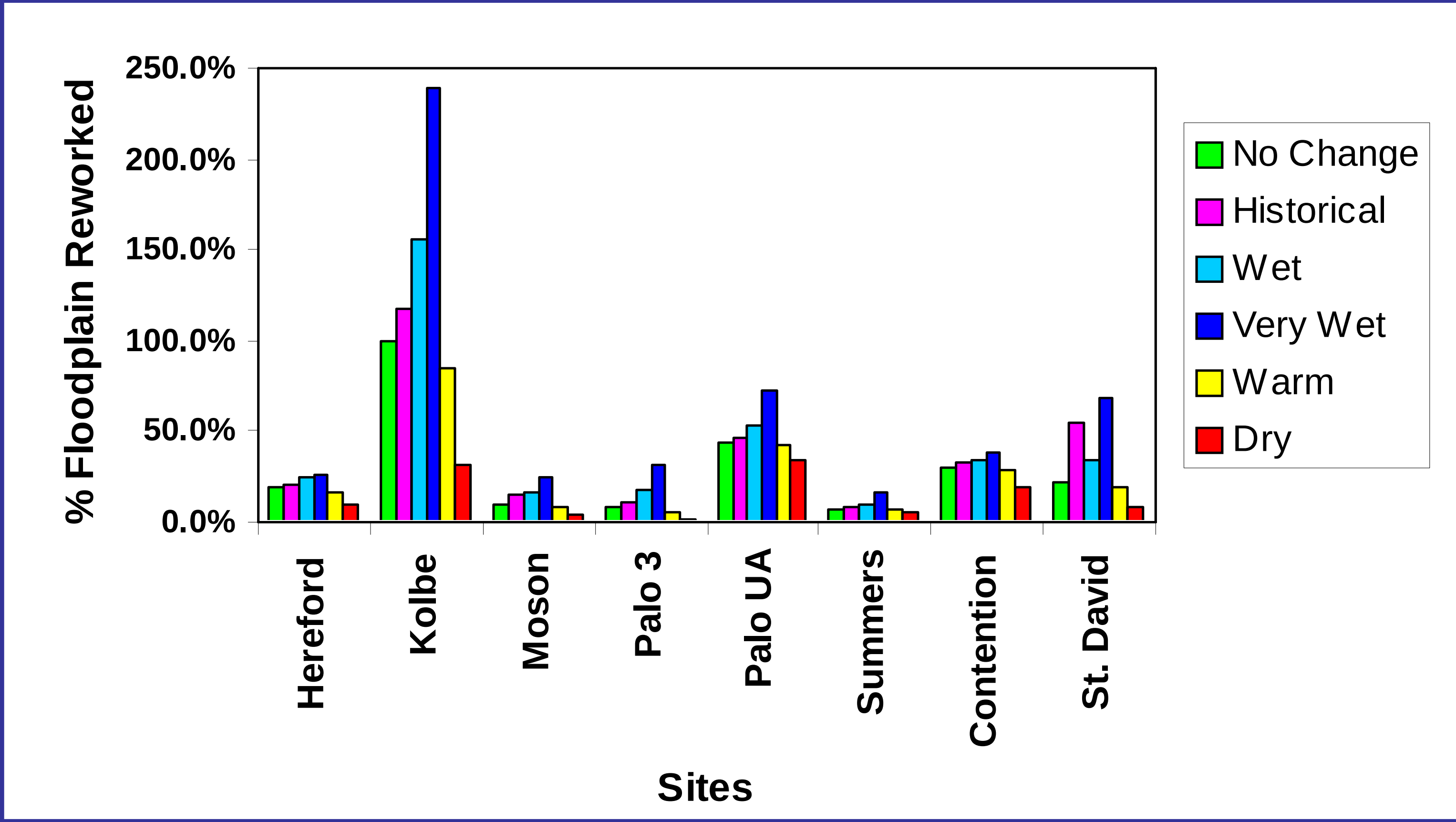
- New cottonwood & saltcedar patches form by channel migration
- But, recruitment is insufficient to balance senescence of old stands
- Greatest cottonwood decline under driest scenario, least under wettest





Results: Vegetation Change

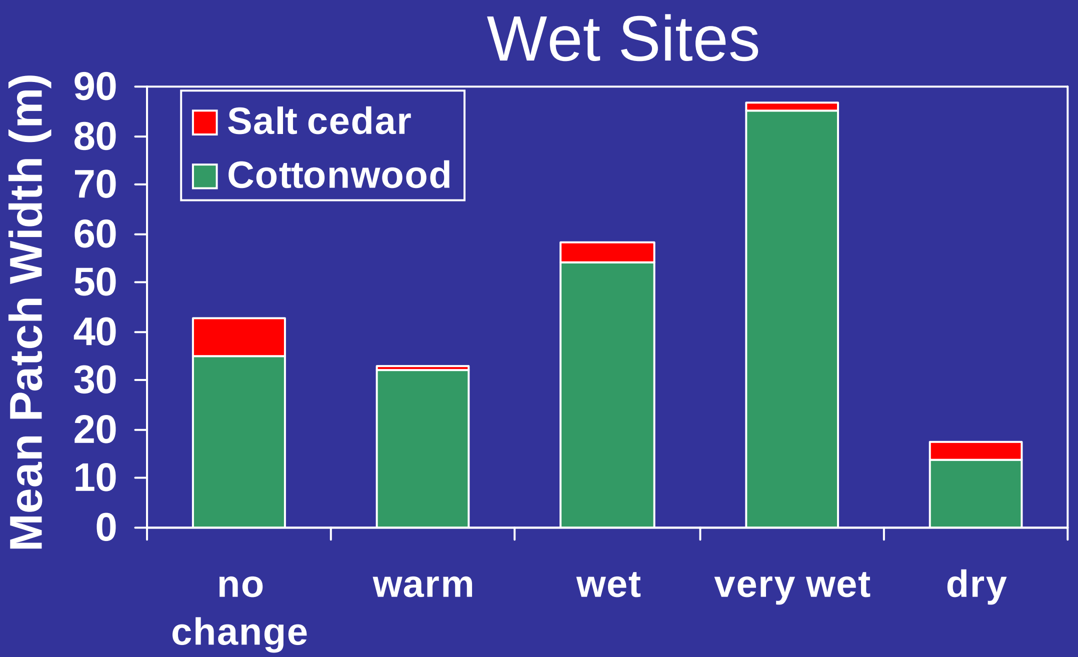
- Least reduction of pioneer species (cottonwood, saltcedar) at most geomorphically dynamic sites

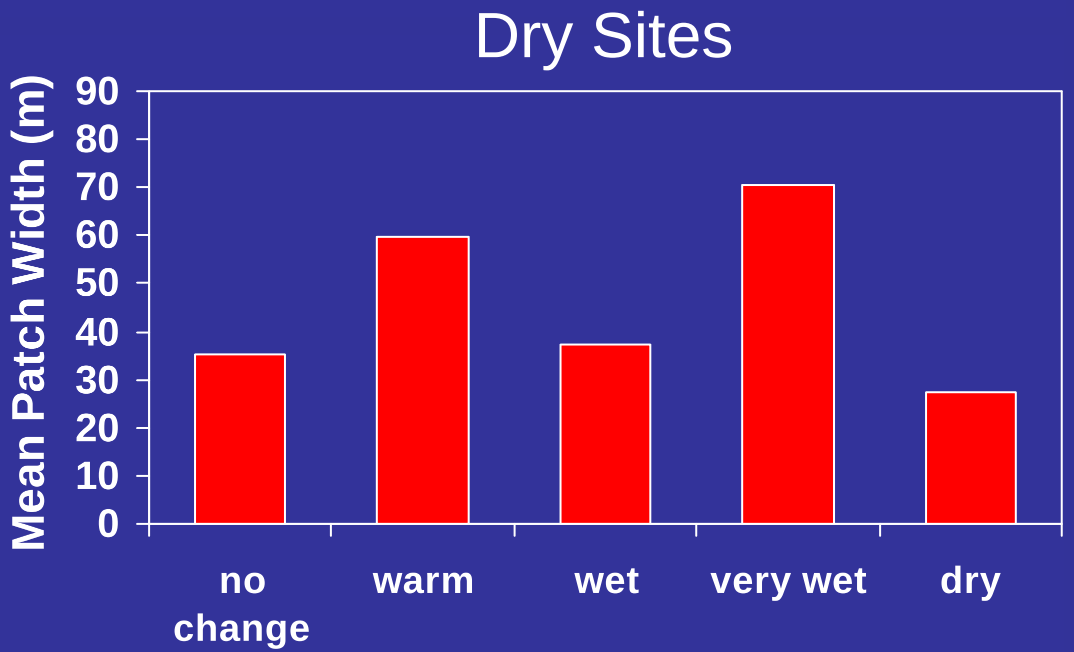


Results: Vegetation Change

- 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

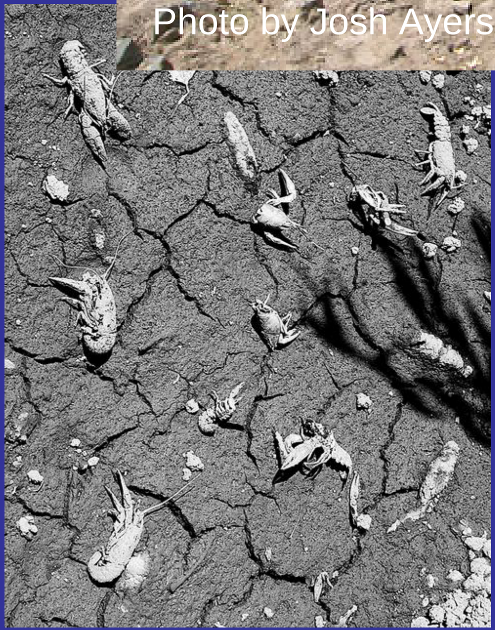
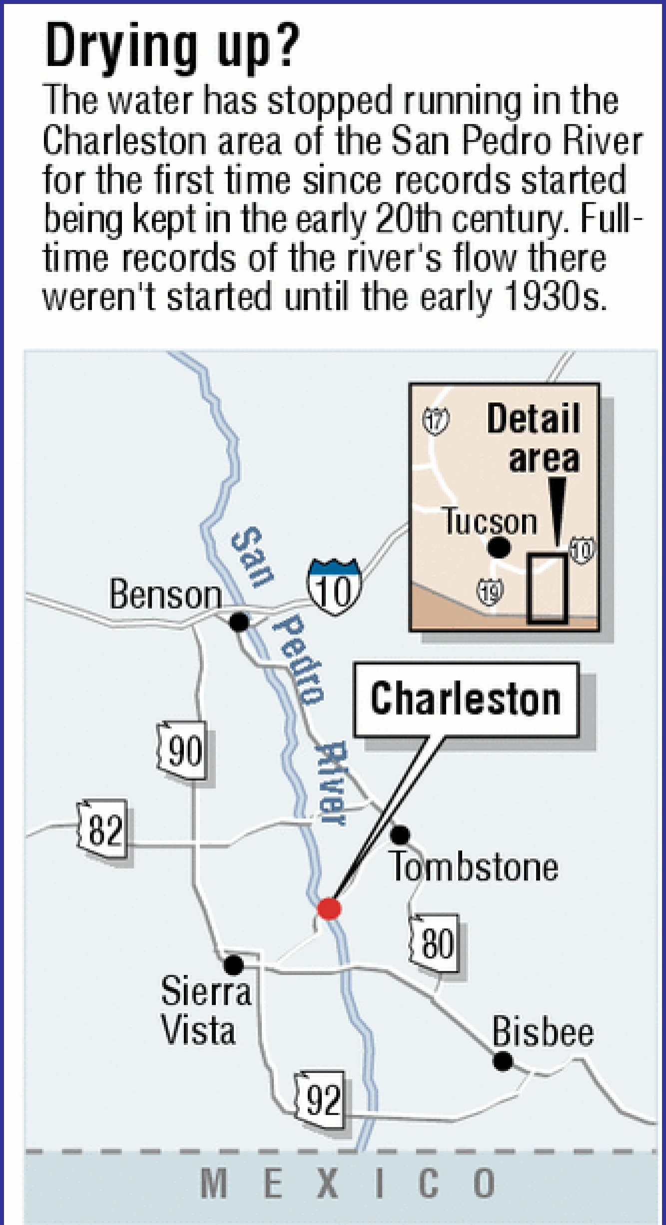


Photo from AZ Daily Star

Photo by Mark Anderson, USGS



Graphic from AZ Daily Star

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

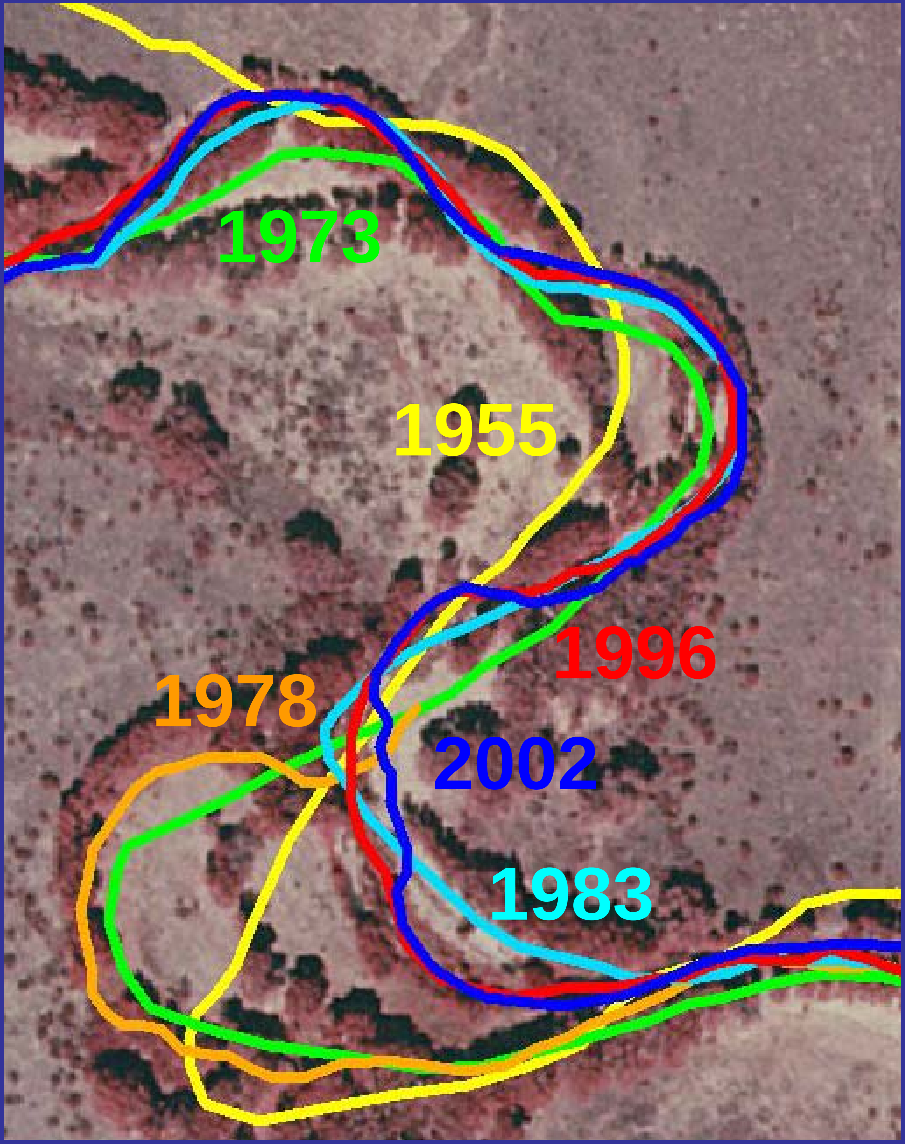
- Uncertainty about how climate will change
- Effects of climate change on riparian vegetation may depend on:
  - Population age structure, successional trajectories of vegetation
  - Effects on disturbance – floods, fire
  - Geomorphic context, history, and trajectory
  - Human uses of water resources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

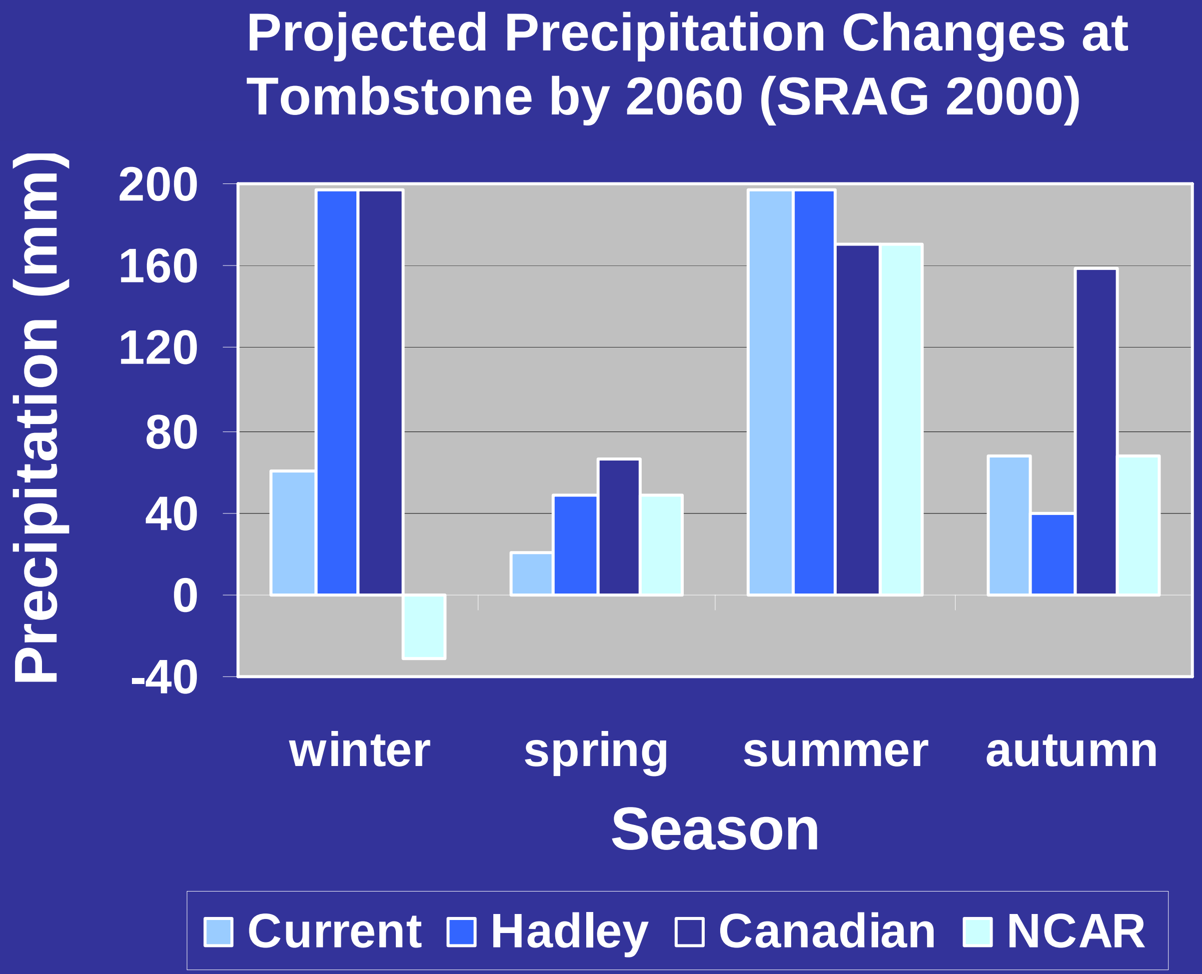
- Increased establishment of pioneer trees (cottonwood, willow, salt cedar)
- Increased rates of river channel migration
- Increased re-soaking of floodplain soils and floodplain aquifers
- Greater recharge of regional aquifer
- Greater plant growth during the dry season

Possible Effects of Climate Change on Riparian Ecosystems

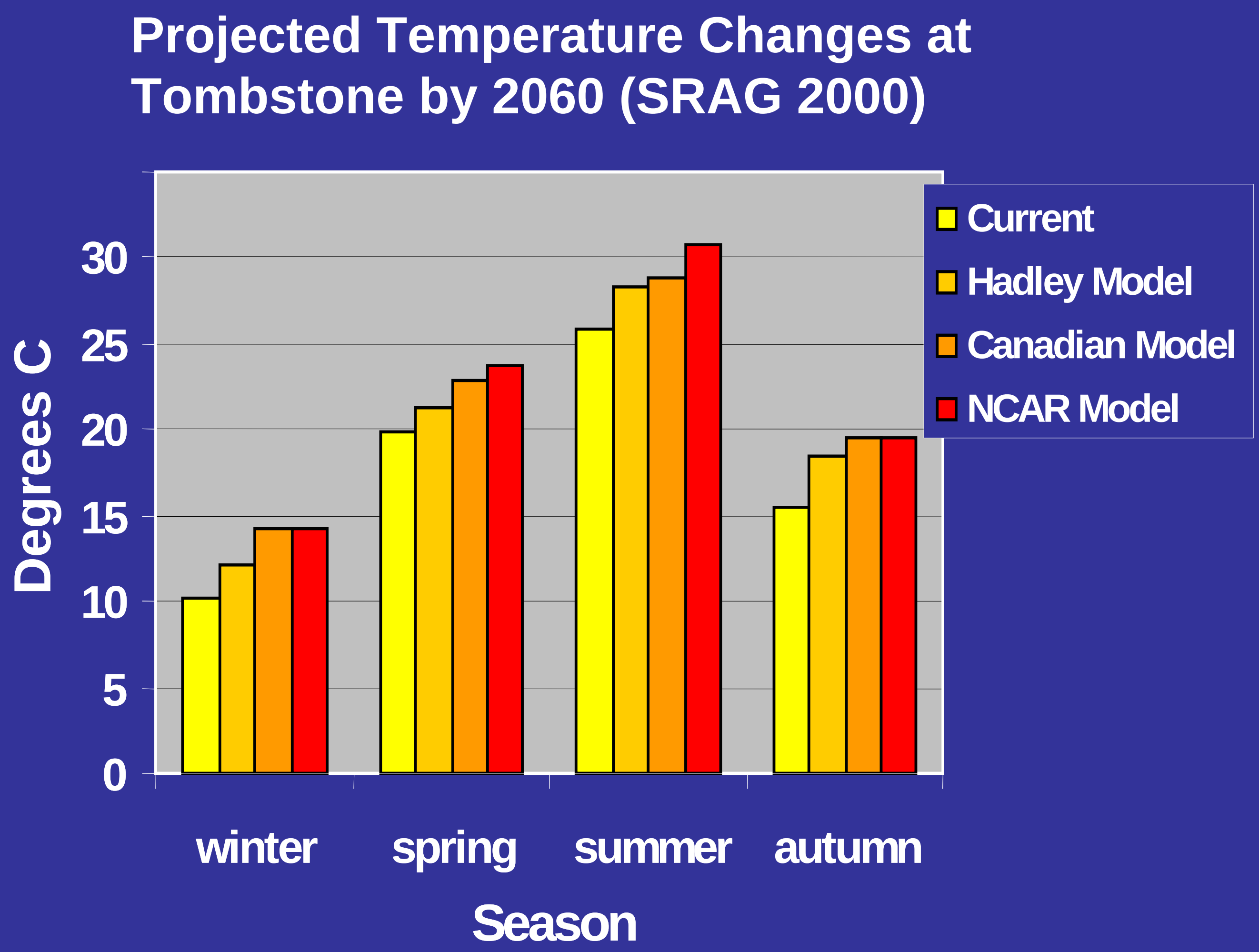
Decreased precipitation

- 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



Warmer Temperatures are Likely



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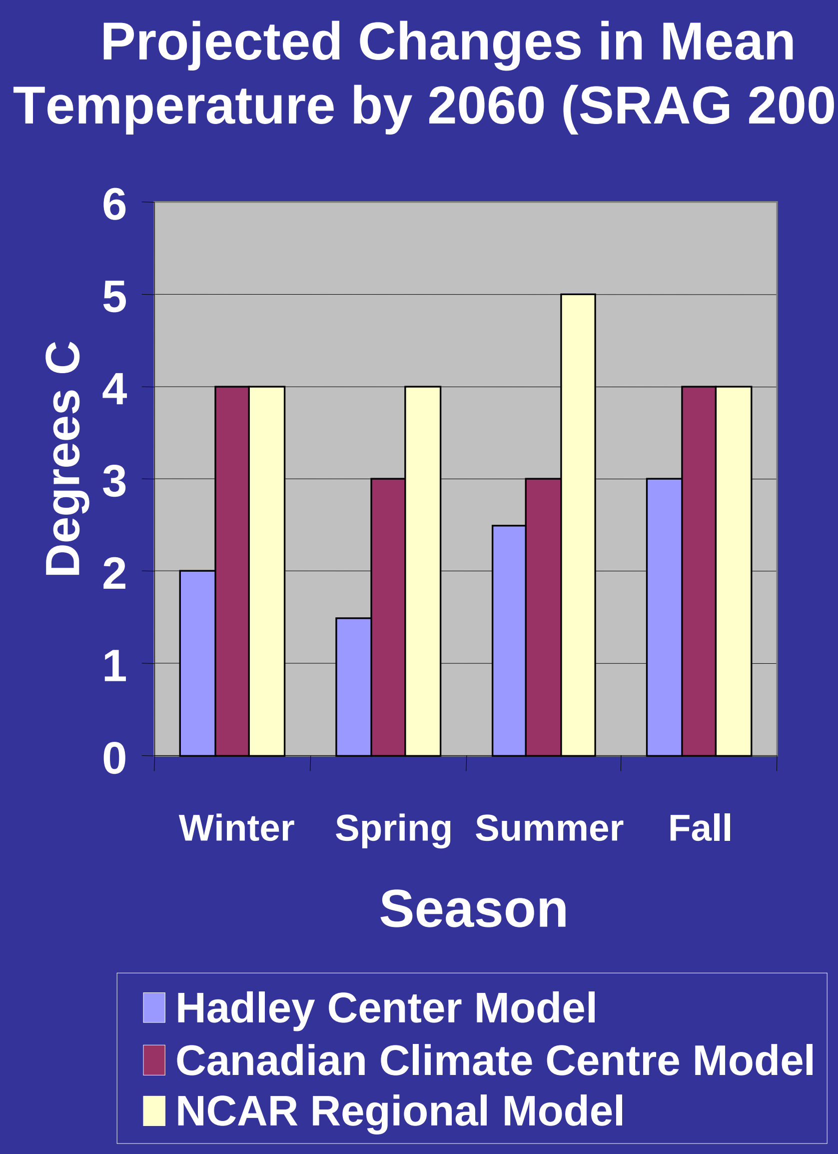

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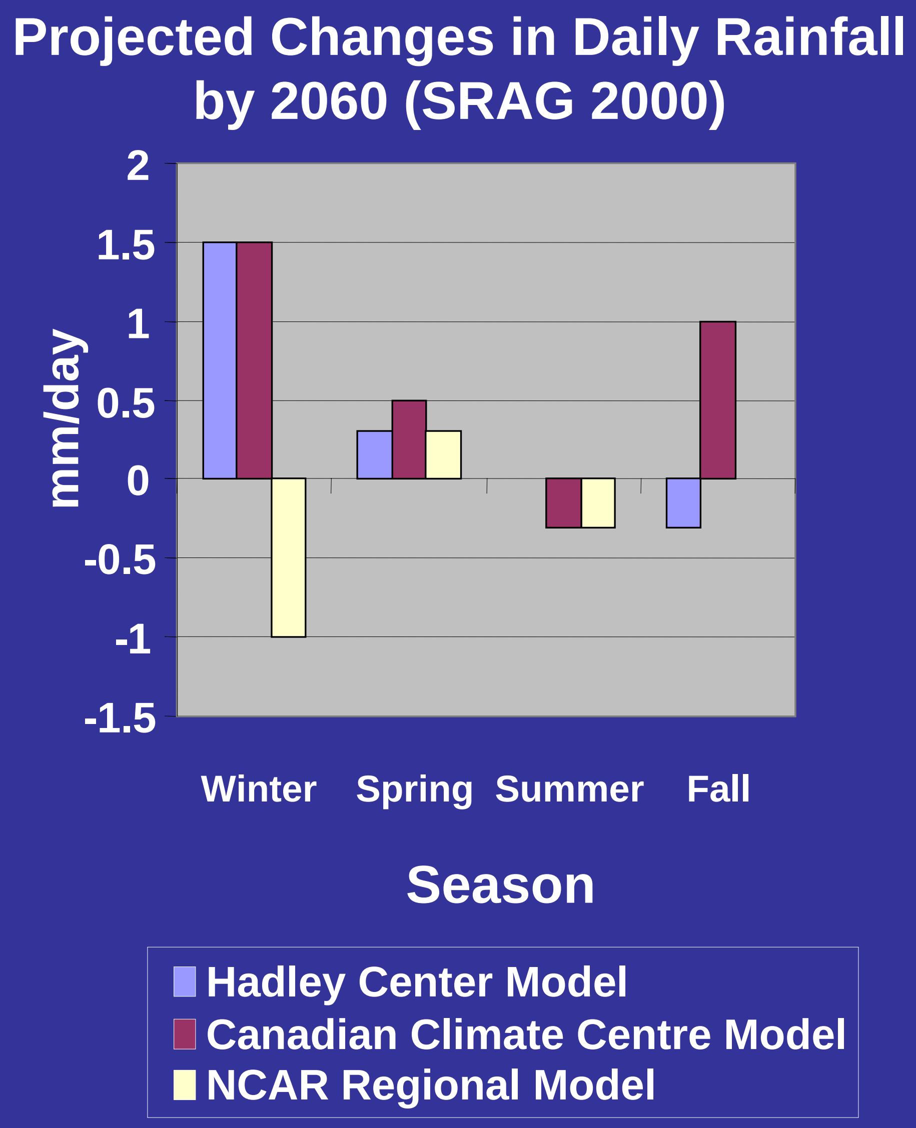
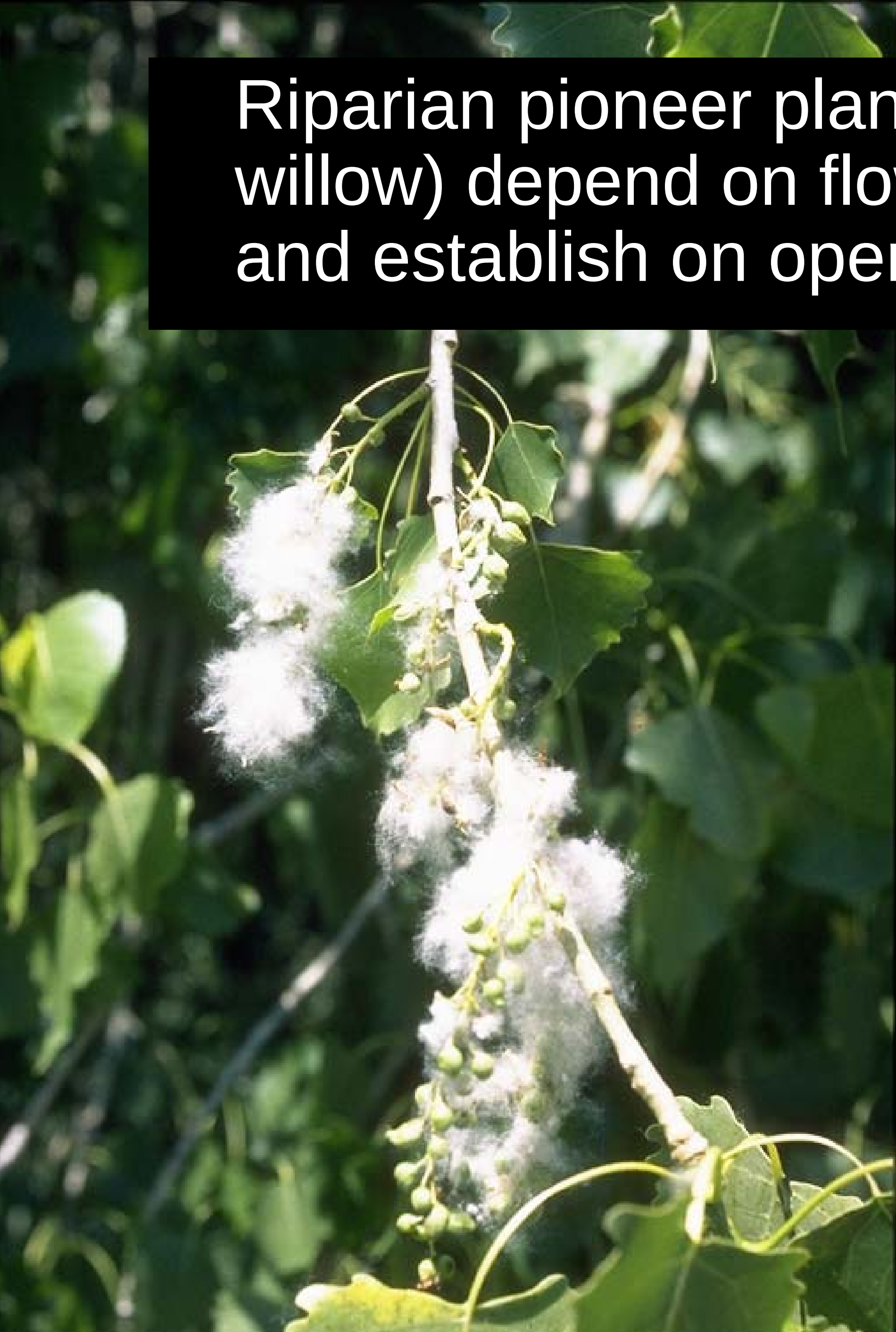
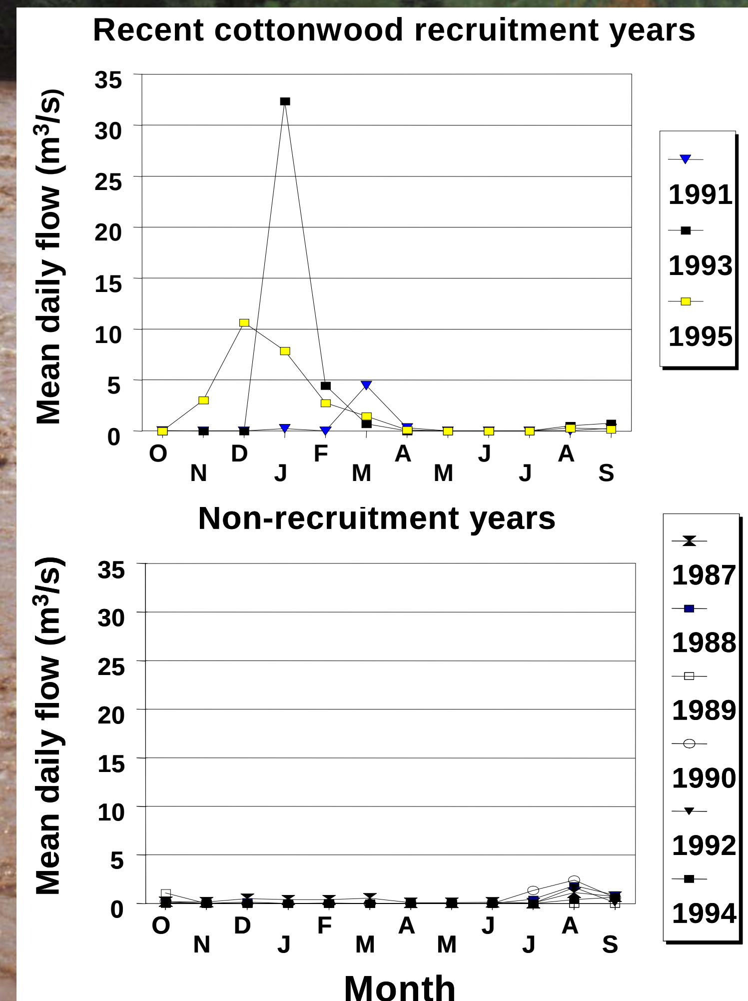


Riparian pioneer plants (e.g., cottonwood, willow) depend on flows to disperse seeds and establish on open, moist sediment bars.



Cottonwood and willow establish after winter/spring floods of appropriate size and timing

- Large, long duration winter/spring floods move and deposit sediment, preparing bare surfaces suitable for seedling growth
- Slowly receding spring floods deposit seeds and provide moisture for growth



Effects of Cattle Removal

View from Hereford Bridge

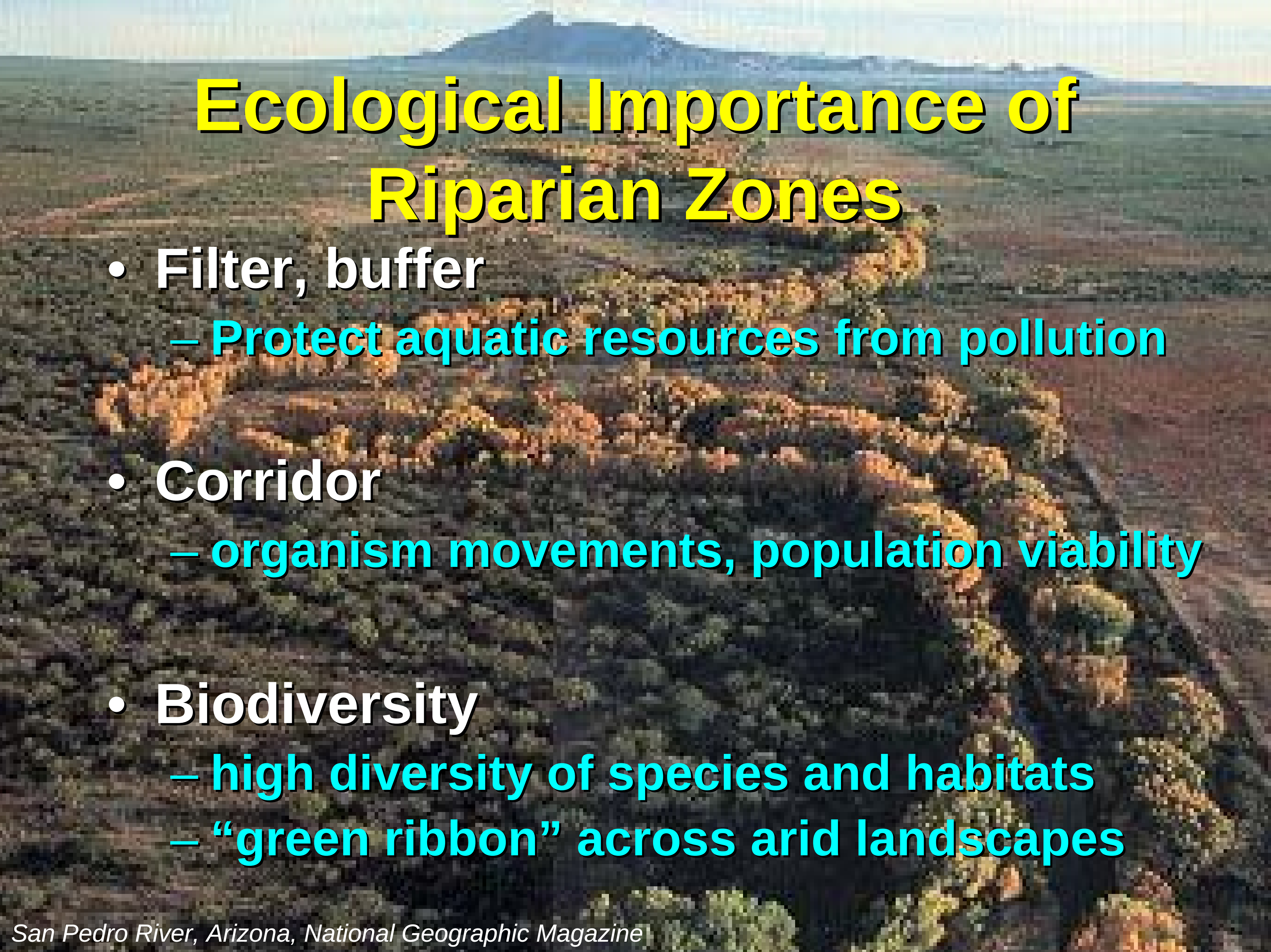
Photos by BLM

Following cattle removal in 1988…

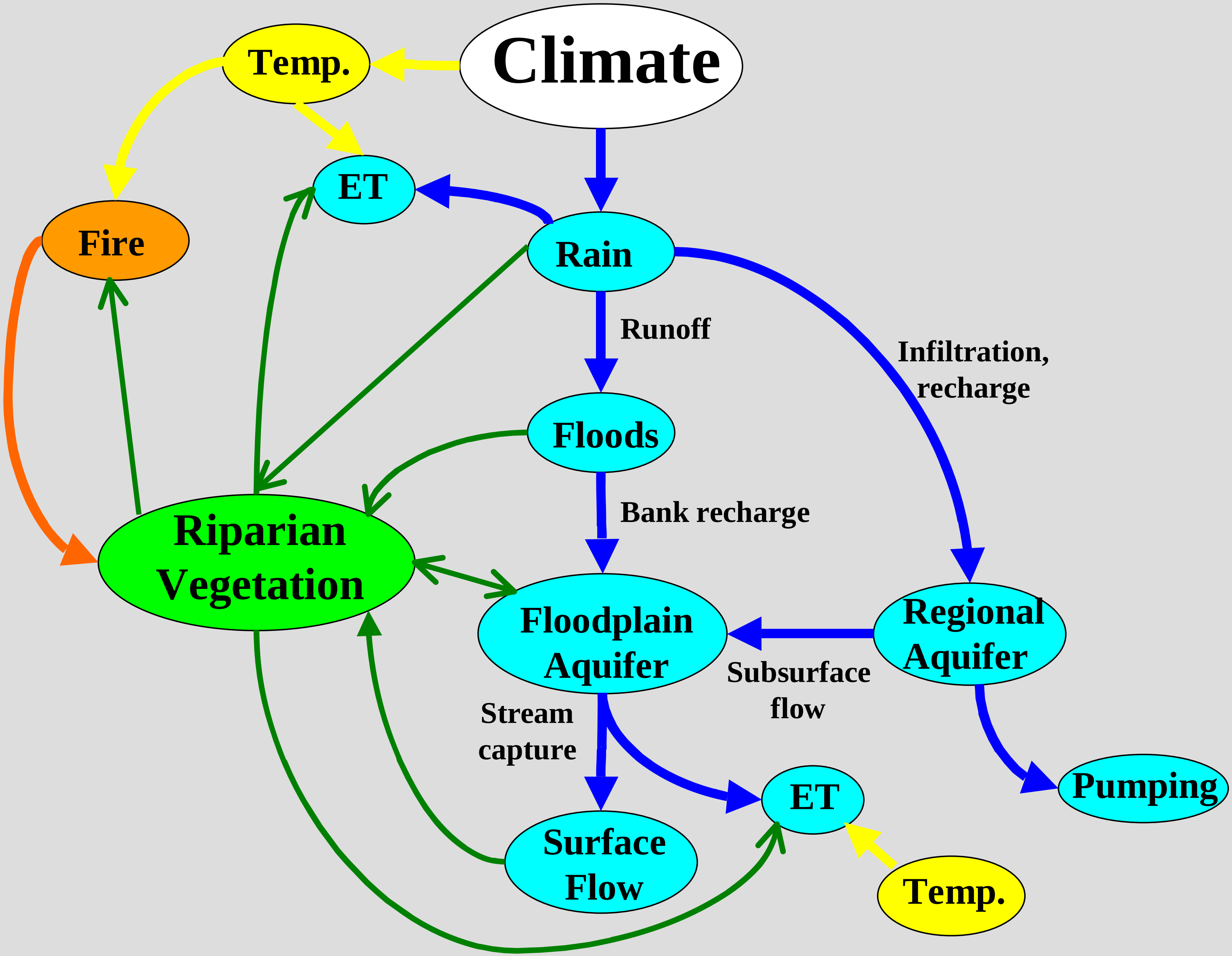
- Expansion of riparian vegetation
- Channel narrowing & stabilization

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



San Pedro River, Arizona, National Geographic Magazine


Climate
Temp.
ET
Fire
Rain
Runoff
Infiltration,
recharge
Floods
Bank recharge
Riparian
Vegetation
Floodplain
Aquifer
Regional
Aquifer
Subsurface
flow
Stream
capture
ET
Pumping
Surface
Flow
Temp.