The Santa Cruz River through Tucson

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About the Authors

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This Codger Klatch has a combined 260 years of professional experience.
The 1983 Flood

It’s the Water, Stupid
Santa Cruz River Watershed
Tucson, View East on Congress Street from Powderhouse Hill

1981

2007
1700: Father Eusebio Kino in Tucson Basin

1800:

1850:

1900:
- Streamflow gaging begins
- Arroyo downcutting begins
- First photographs
- First ornithologist

Rainfall records begin

Mormon Battalion
A Timeline

Ornithologists flock to Tucson

Arroyo widening

First aerial photo

Turbine pumps

Mid-century drought

Ground water use peaks

Satellites

1983 flood

1993 flood

1983 flood

Drought

Soil cement installed
Environmental History

• The Santa Cruz River is one large uncontrolled experiment

• Cause – effect: equifinality in landform development?

• An array of evidence, ranging from anecdotal (descriptions) to visual (photographs) to quantitative (measurements)

• Putting the pieces together is always a difficult task
1889 headcut starts at Sam Hughes Intercept Ditch
Solomon Warner's Mill
Solomon Warner's Lake
Silver Lake

West Branch of Santa Cruz River
Dry pre-1871 headcut intersects water table by 1882
Martinez Hill
San Xavier Mission
Punta de Agua Spring
Agua de Mision cienega
Martinez Hill

• Discontinuous channel incision
• Alternating perennial – ephemeral reaches
• Generally high ground water levels in basin
• Large cienega south of Martinez Hill

1915 Olberg & Schenck channel
Before 1878, the river had alternating perennial – ephemeral reaches related to groundwater discharge points where riparian vegetation established.

The river was ephemeral, Continental to Pima Mine Road, and downstream from Marana.

Headcuts were present, indicating a discontinuous arroyo.

The reach through Tucson was unincised with high groundwater levels.
Santa Cruz River at 22nd Street
The Santa Cruz River in the Tucson Basin Had Perennial Reaches in the 1800s

- The river flowed at Mission San Xavier and A Mountain from springs arising from high groundwater tables.
- The river supported discrete, discontinuous riparian forests.
- The river had a clam, fish, and extensive waterbird populations.
- The riparian zones had Wild Turkey and numerous other, now rare birds.
- Beaver were not in the Tucson Basin, but muskrat may have been.
Santa Cruz River between 22\textsuperscript{nd} and Congress Streets
It’s the Water, Stupid

• The Santa Cruz River began downcutting and coalescing in the 1880s.
• Channel downcutting and widening was associated with large and(or) frequent floods.
• Paleoarroyos developed many times in the past, most recently during the height of Hohokam/Sobaipuri settlement.
• In 1890, downcutting was focused on Sam Hughes Ditch, designed to erode during floods and create an irrigation canal.
• Abundant evidence remains of Hohokam canals in the Tucson Basin, indicating floodplain water diversions did not guarantee channel erosion.
August 1890 – “Sam Hughes’ headcut taking a walk to Silver Lake”
0. Initial conditions (<1862)

1. Arroyo downcutting (1889-1914)

2. Widening (1914-1930)
Cause of Arroyo Downcutting

- Climatic variability
- Livestock grazing
- Groundwater declines due to drought

It takes water to transport sediment
The Groundwater – Drought Hypothesis

Hypothesis: groundwater table lowers during drought, killing riparian vegetation

Flow roughness is decreased, and the same size flood is more erosive to the floodplain

Plant-killing groundwater lowering (ca 1920s) occurred well after arroyo downcutting began (1878)
Hypothesis: overgrazing destroyed rangeland vegetation, causing increased watershed and erosion, leading to arroyo downcutting.

Problems: what about paleoarroyos (no livestock present)?

Problems: increased runoff and sediment should lead to sedimentation, not erosion.

Problem: livestock were on the watershed in 1700, in large numbers in the 1860s.

Land Use and Livestock

Really large numbers of livestock in the watershed were well after the arroyo downcut
Arroyo downcutting occurred during a time of unusual floods, large size, and persistent occurrence (1880-1915).

Arroyo widening also occurred during persistent flooding (1915-1929).

The arroyo was stable through the mid-century drought.

Renewed channel erosion occurred during renewed flooding.
The Great Mesquite Forest

- A major riparian area we call the Great Mesquite Forest occurred upstream from Martinez Hill and Mission San Xavier.

- First observations indicate an open cienega with alkali sacaton grasslands rimmed with a mesquite bosque and trees of enormous size (4-foot diameter, 65-75 feet tall).

- The arroyo downcut and drained the cienega, encouraging mesquite growth in the now unsaturated soils.

- Massive mesquites supported a world-class avian ecosystem, attracting the top ornithologists in the US, 1900-1940.
Drain the Cienega, Grow Trees

**Before 1878**
- Prehistoric terrace
- Grasses, shrubs
- Cottonwood
- Emergent aquatic species, water
- Willows, emergent aquatic species
- Settlement terrace
- Hohokam cultural remains

**After 1890**
- Groundwater table
- Cottonwood with crown dieback
- Barren, water
- Mesquite
Open water behind the Indian Dam

Arroyo walls

Agricultural clearing

The Great Mesquite Forest (1912)
In 1936, the bosque occupied an area of about 7 square miles.

Historically, five fish species, two frogs, one turtle, several snakes, and one clam were known from the perennial reaches.

Mammals are less certain, but probable loss of mesquite mouse, gray wolf, and jaguar.

The Great Mesquite Forest (1936)

- This mesquite bosque was famous among ornithologists at the turn of the 20th century.
- More than a hundred species of neotropical migrant birds, waterbirds, and residents.
- Many of these birds no longer occur in the United States or are threatened or endangered species.
White-winged Dove

• White-winged Dove was perhaps the most common species of the Great Mesquite Forest

• In 1922, A.C. Bent wrote: “White-winged doves fairly swarmed through the thickets, and their tiresome notes were the dominant sounds...”

• Now, Arizona Game and Fish maintains tamarisk reserves on the Gila River for this species
The Developing Bosque

- 1700-1850: cienega rimmed with mesquite, large trees in this outer halo
- 1860s: a herd of 500 cattle in the cienega, no changes
- 1880s-1890s: arroyo downcut, lowering water table to bottom of the channel. Mesquite encroaches on former marsh
- 1880s-1920s: intensive woodcutting in bosque supplies Tucson fuelwood, secondary growth of mesquites occurs
- 1900-1940: Great Mesquite Forest may have been at its zenith
Before the US Senate in 1931, C. K. Smith, mayor of Tucson, testified:

“The city of Tucson has been scouting for some time to get a larger and more available water supply for the city. Our engineer employed for the purpose of finding what the available sources of water were came to the conclusion that the Santa Cruz Valley carries from its watershed the largest and most valuable source of water for Tucson. We are a growing community. We have an adequate supply for the present but we must look forward to the future. Eight or nine miles up the river is the Indian Reservation. . . . It is the most available place for water in the entire river course. Now, I want to offer a tentative plan that might be of benefit to the Indian Service and also to Tucson. Our engineers have investigated the claim that there is more water than the Indians can ever use and more than Tucson can use for 50 years to come.”
From *Requiem for the Santa Cruz*

“The bosque withstood arroyo downcutting, clearing, and woodcutting, but this unique ecosystem could not withstand those stresses combined with the lowering of the underlying water tables.” (p. 172)
It’s the Groundwater, Stupid

Hypothesis: groundwater table lowers during drought, killing riparian vegetation

Flow roughness is decreased, and the same size flood is more erosive to the floodplain

Tipping Point: About 1970

Possible Zenith

Channel Bottom

Limit of Riparian Roots
Lower Groundwater, Kill Trees

1940
- Cottonwood
- Channel
- Mesquite
- Groundwater table

1959
- Mesquite dying
- Groundwater table lowered 50 feet

1972
- Stumps
- Groundwater table lowered >90 feet
Who Dunnit: Who Killed the Great Mesquite Forest?

• Was it Mahlon E. Layne, who invented the vertical turbine pump in the 1902, allowing aquifers to be pumped from below instead of from the surface?

• Was it Tucson Mayor C.K. Smith, who proposed to pump water out of the San Xavier District in 1931?

• Or was it our predecessors, the citizenry of Tucson, who thirsted for more and more water without understanding the consequences to a priceless ecosystem?
Santa Cruz River at Martinez Hill

2002
Santa Cruz River at Martinez Hill (1942)
Santa Cruz River at Martinez Hill (1989)
Requiem for the Great Mesquite Forest

- ±85 species of summer birds, ±73 species nesting (early 20th century). No estimates of density.
- Now ±75 species, ±66 nesting at Sweetwater Wetlands, density has to be far lower.
- In 1940, 31 species of amphibians and reptiles. Now, 21 have been recorded, including different species.
- In 1940, 39 species of mammals, present number is unknown.
Other Equivalent Bosques?

- Bosque del Apache (Rio Grande, NM) – cottonwood-willow
- Komatke Thicket (Santa Cruz River at Gila confluence) – mesquite, unknown size
- Gila River at San Carlos River confluence (now under San Carlos Reservoir)
- Gila River at Colorado River confluence (now a tamarisk thicket)
- Colorado River delta
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<th>2004 (ha)</th>
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<td>SHRUBS AND HERBS</td>
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<td>TOTAL</td>
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Controlling the Raging River

• In the 1880s, the problem was damaged properties and flooded houses.
• Between 1890 and 1915, the problem was destroyed bridges and damaged properties.
• In 1977 and 1983, the problem was destroyed bridges and damaged properties.
• Flood control on the Santa Cruz River, not riparian ecosystems, has been a priority for 130 years.
East approach to Congress Street Bridge
20th Century Floods and Channel Change

- Channel widening occurred in the first third of the 20th century.
- Channel did not change much in the mid-20th century, mostly narrowed through reduced flow and trash dumping.
- Renewed widening/downcutting beginning in 1977 with Hurricane Heather, leading to installation of bank protection (soil cement).
- Large floods in 1983 and 1993 continued the widening in reaches without soil cement.
Santa Cruz River at Congress Street

1914

1926

1983

2008
Are Floods Related to Land Use?

[Graph showing population growth and annual peak discharge over time.]
DROUGHT  WET  DROUGHT  WET  DROUGHT

Pacific Decadal Oscillation (PDO)

Hurricanes in North Pacific Ocean

Floods in the Santa Cruz River

- Winter floods
- Summer monsoon floods
- Fall floods
The Concept of Nonstationarity

- In time-series analysis, statistics in the time domain (e.g., flood-frequency analysis) require the assumption of stationarity.
- Type 1 stationarity: time invariant mean and variance.
- When the mean and variance change with time, the assumptions of flood-frequency analysis are violated — and the results wildly vary based on data used.
Floods and Flood Frequency

The graph illustrates the 100-year flood discharge over time, along with the +95% and -95% confidence levels.
Is the Arroyo Filling?
The first data, other than the single cross section at the gaging station, was in 1982 (before soil cement).

The 1982 soil cement installation was designed.

We established 12 cross sections and surveyed in 1989.

We used the 2005 aerial Lidar to obtain cross sections at the 1989 sites.

We used Terrestrial Lidar in 2008.
Change in Cross Section 4
Evidence of Increased Flood Hazard in the Stage-Rating Curve

• 1992: channel contains 100-year flood
• 2008: channel contains 50-year flood
Oh The Irony of It All

Channel engineered to convey 60,000 ft$^3$/s, the post-1983 100-year flood

The channel now can convey about 30,000 ft$^3$/s, which is the drought-induced 100-year flood

Channel aggradation post-1993 encouraged growth of riparian vegetation, increasing channel roughness
WHAT DO WE WANT FROM OUR ARID-REGION RIVERS?

- Water for development
- Flood control for infrastructure
- Ecosystems for biodiversity
A Little Rant on Restoration

• “Restoration” is a euphemism for creation of designer ecosystems with little or no relation to what resources once were present

• “Restoration” typically has vaguely defined goals with little scientific basis

• If you hear the word “restoration” applied, immediately ask: “Restore to what and when?”
The Cottonwood Conundrum

• The common perception is that the big loss in riparian vegetation was cottonwood-willow forests.

• Moreover, avian studies emphasize cottonwood-willow resources as most important, de-emphasizing mesquite bosques.

• Until very recently, “restoration” focused on planting cottonwood and willow, not mesquite.
It’s the Groundwater, Stupid

Data Section, Tucson Water (2012)
It’s the Reclaimed Water Stupid

Narrow, linear riparian ecosystem

Santa Cruz River downstream from Ina Road
Santa Cruz River Upstream from Valencia Road
Santa Cruz River Downstream From Irvington Road

Trapezoidal cross section, conveys design flood
Santa Cruz River Upstream From Irvington Road

High banks, wide cross section prevent overbank inundation

Low soil cement
limits channel widening

Have your cake and eat it too: grow as much riparian vegetation as you want and still have flood control. But you have to water it.