Connecting Past to Present and Watersheds to Ocean

Modeling 165 Years of Incremental Changes to Flows into the San Francisco Bay Delta System

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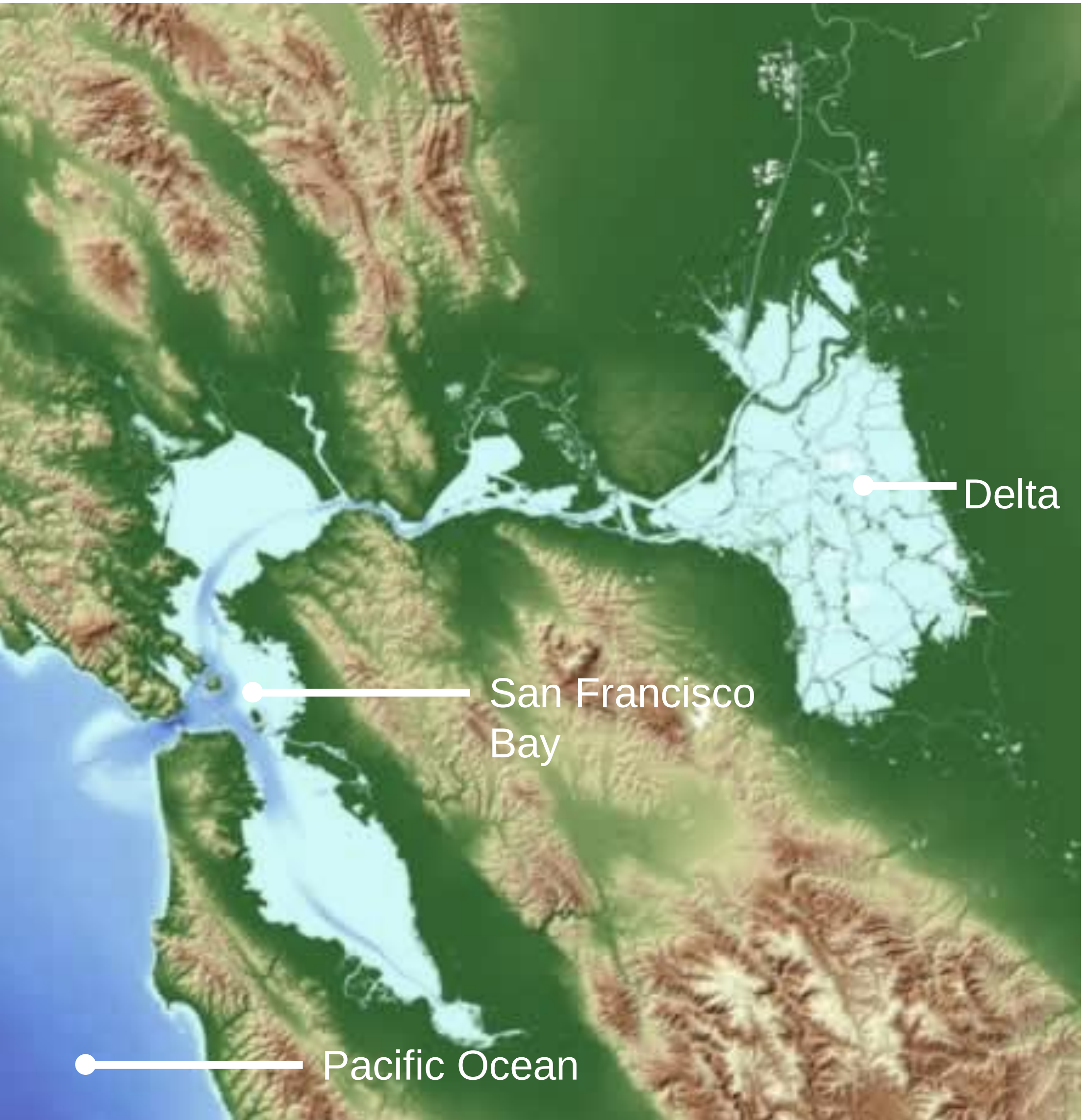
Shifting baselines

Daniel Pauly, 1995.

Anecdotes and the shifting baseline syndrome of fisheries

- **Failure to notice change**
- Coined in the context of fisheries, these baselines serve as "reference points for evaluating economic losses resulting from overfishing, or **for identifying targets for rehabilitation measures**"

What are natural flows into the Delta?



Our research focus: 1850-1921 Delta inflows

Minor emphasis on reproducing measurements; robust model verification

Major emphasis on understanding processes

- What was the annual cycling of water through the Delta watersheds?
- How did flood control levees function differently than natural ones?
- What was the role of vegetation?

Our research approach

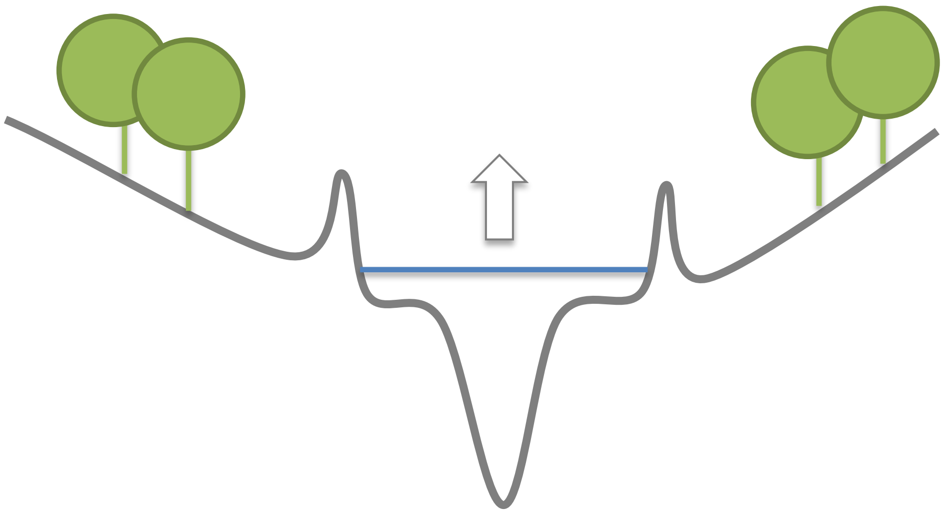
Idealized; process-based numerical model

- Explicit Moisture Accounting within watersheds (water balance)
- Flow routing between watersheds
- Python engine, GIS database, Matlab visualization

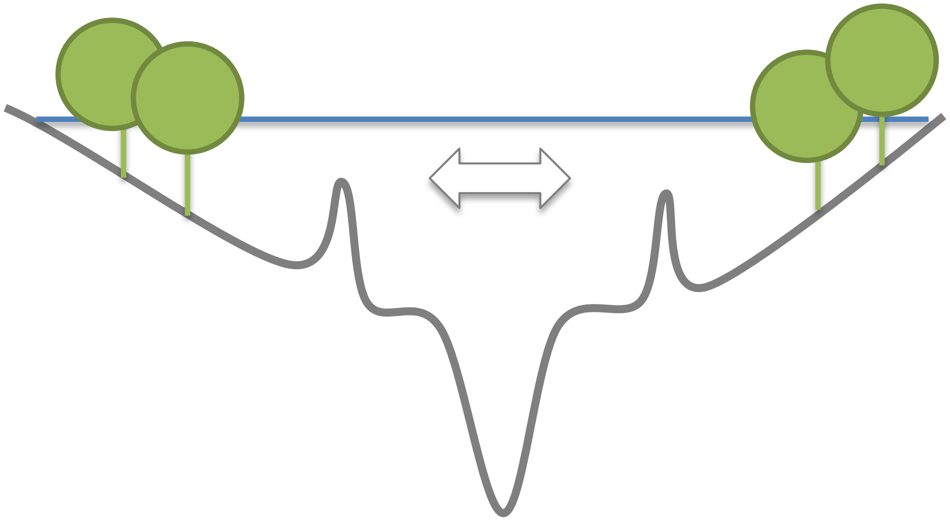
Vary levels of development and land use conversion to produce snapshots

Force with reconstructed meteorology 1850-2015

Conceptual model: flooding in natural system



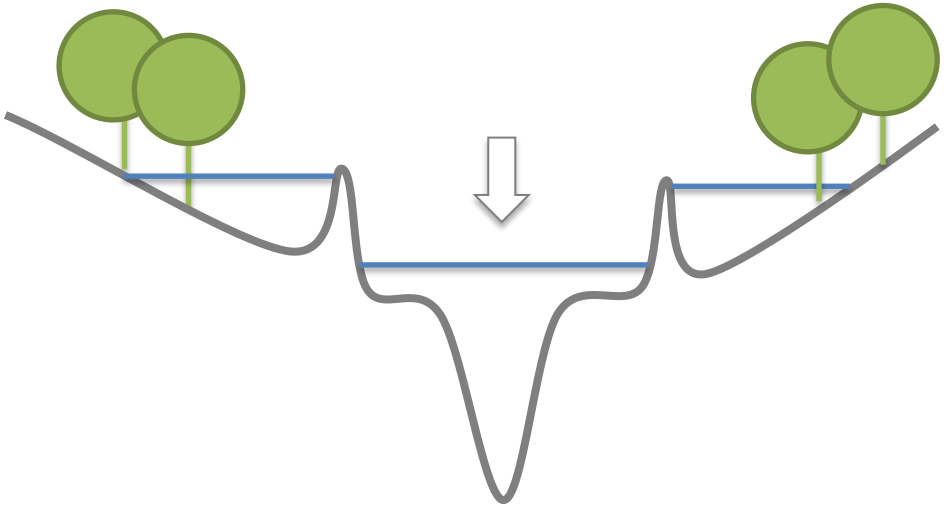
Conceptual model: flooding in natural system



Frequent floods inundated the low-lying riparian forests and tule marshes behind the levees multiple times per year.

Flood control levees prevented frequent inundation.

Conceptual model: flooding in natural system

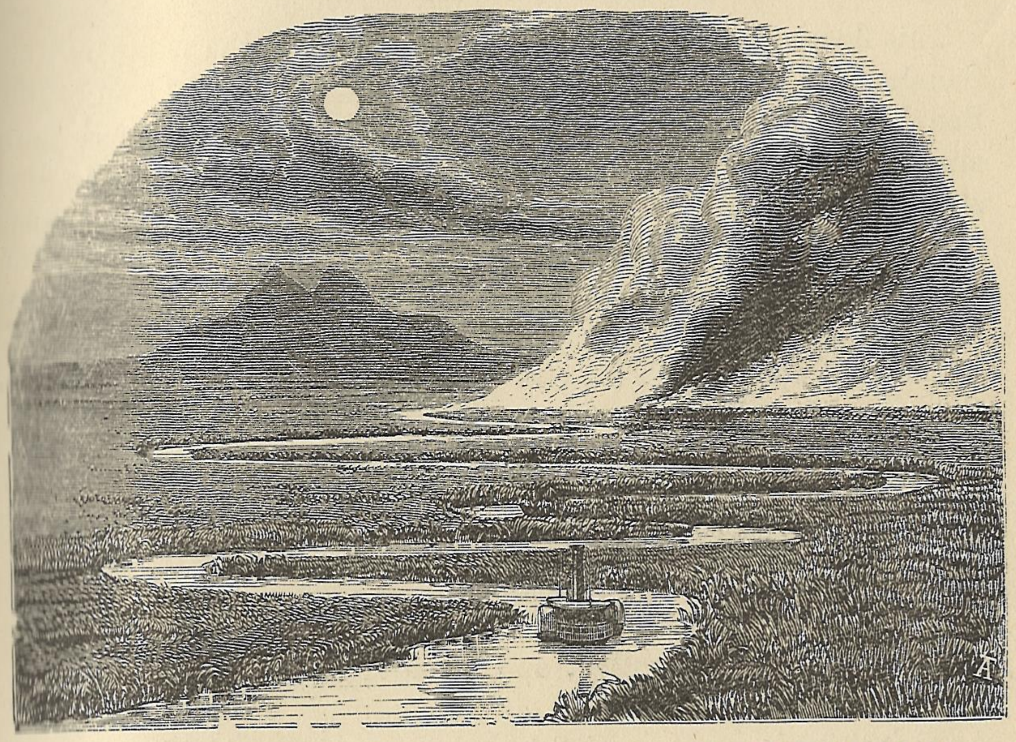


Water was retained behind the levees for weeks or months, allowing it to infiltrate and be used for ET by plants.

Hypothesis: vegetation dominates

Dr. Phyllis Fox, 1987 California Water Resources Control Board's Bay-Delta Hearings:

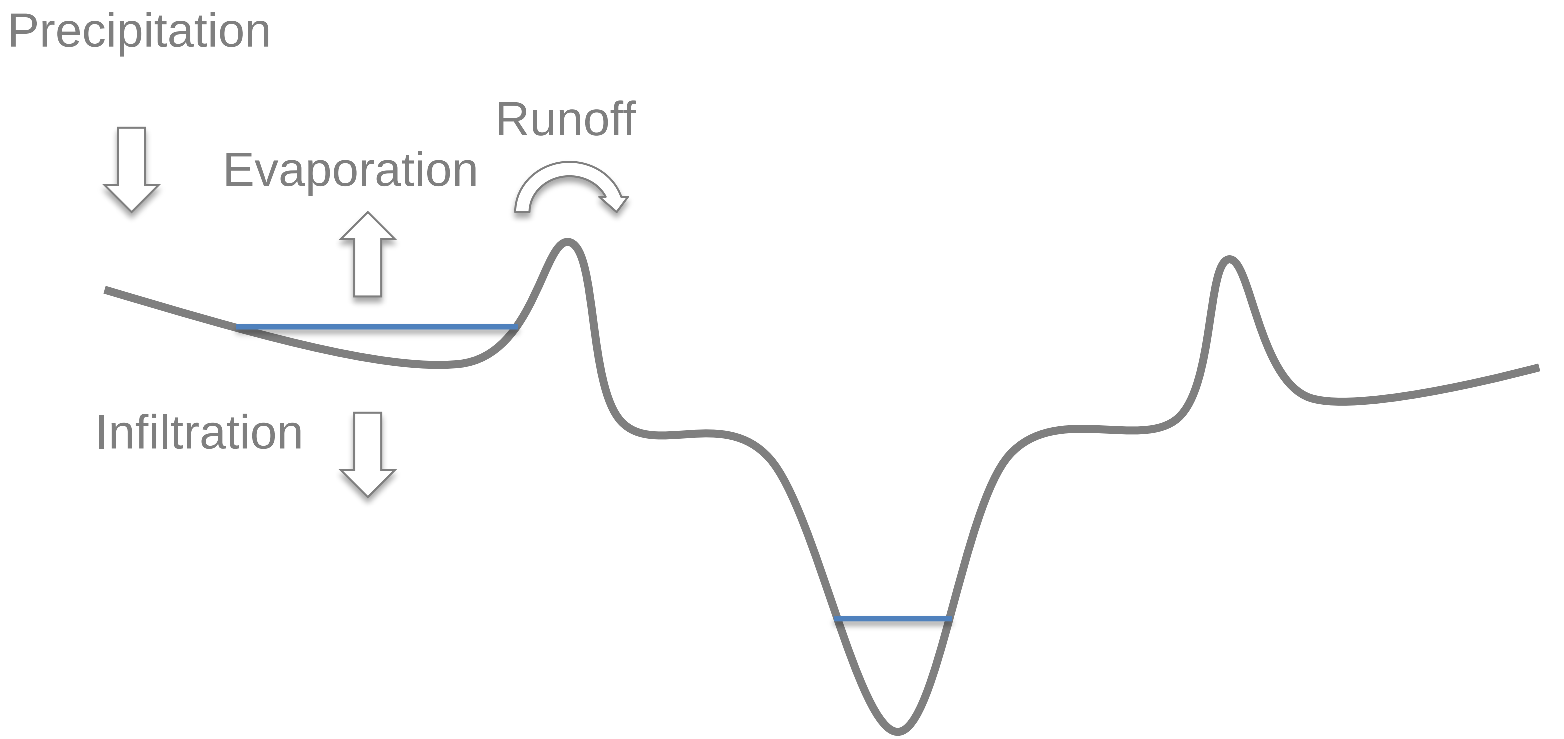
Water consumption by native vegetation in the Delta's watersheds (54% - 72%) equaled or exceeded current water use (62%), including exports, implying no significant change in freshwater inflows to the Delta



NIGHT SCENE ON THE SAN JOAQUIN RIVER—MONTE DIABLO IN THE DISTANCE.

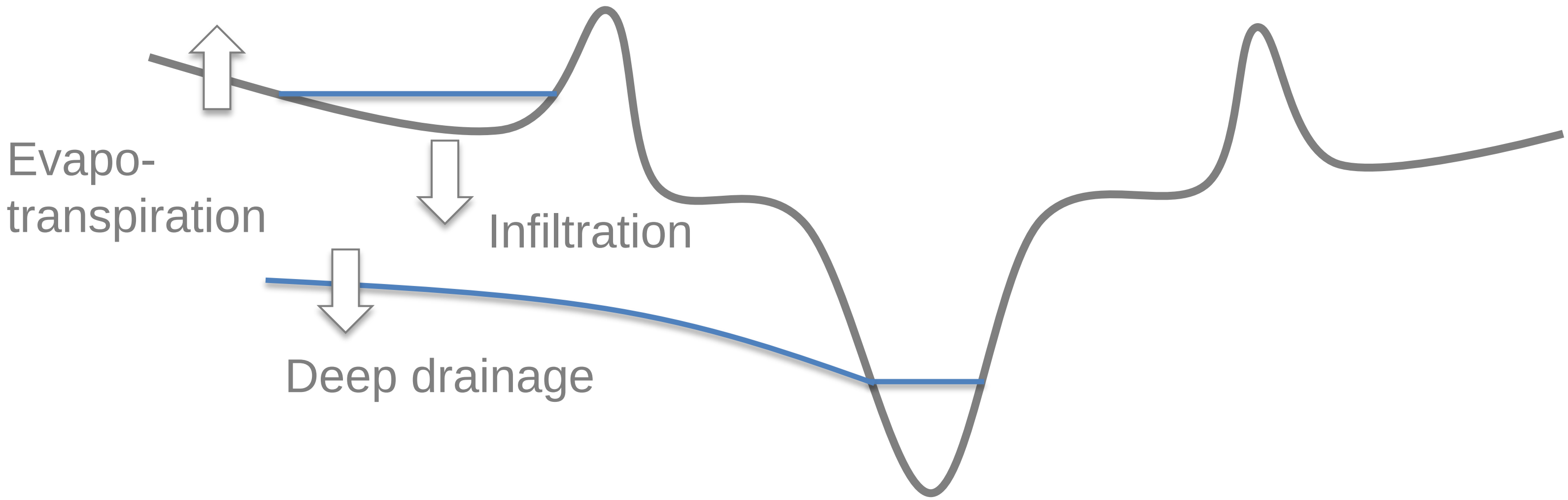
This contradicts the widely-held assumption that flows to the Delta have decreased over time due to exports and diversions.

Land surface



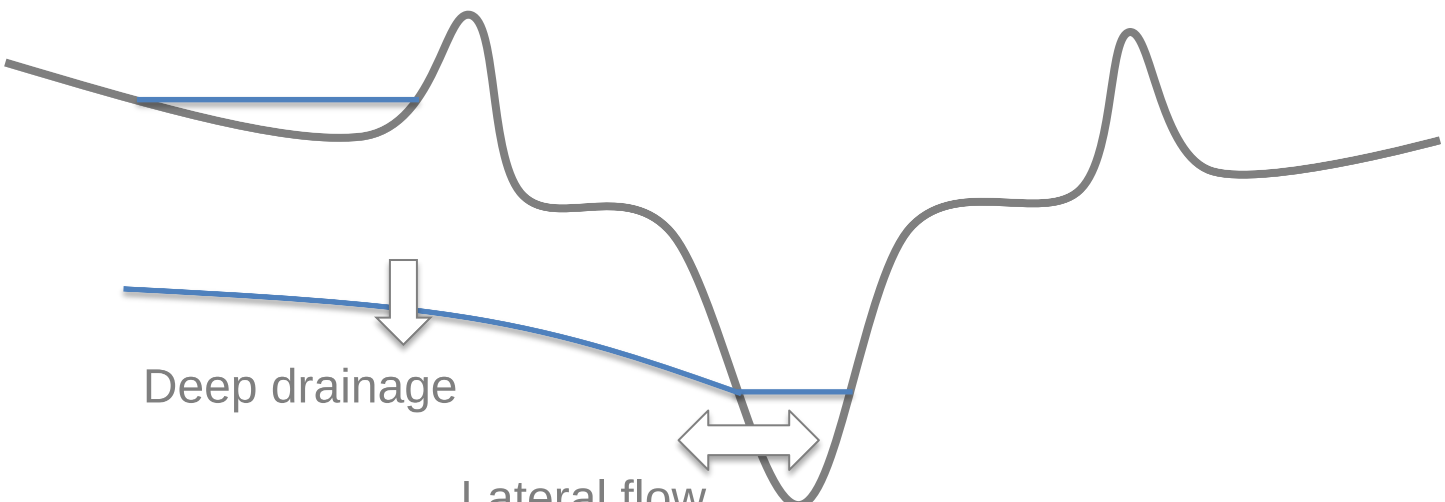
Control volume: surface ponding

Land surface Root zone



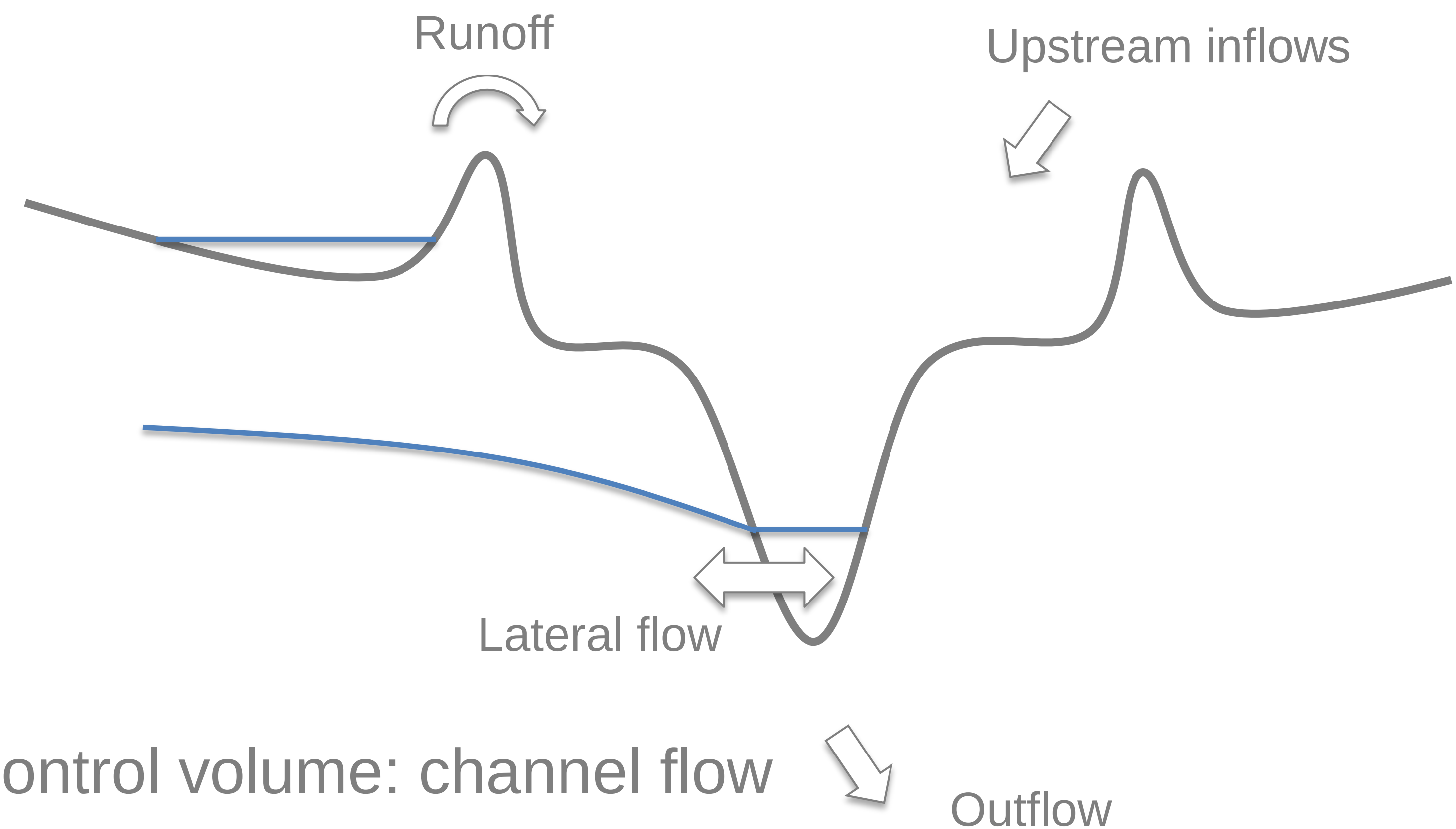
Control volume: soil moisture

Land surface Root zone **Groundwater**



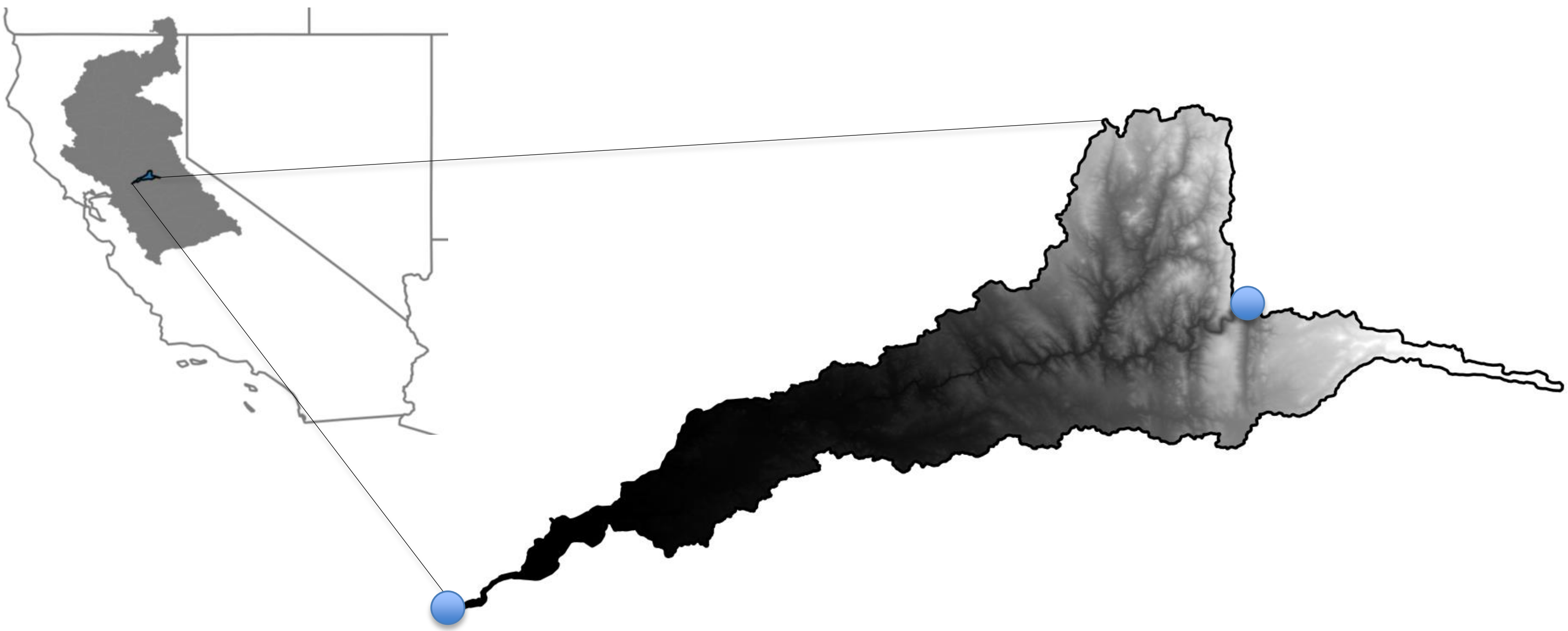
Control volume: groundwater table

Land surface Root zone Groundwater **Channel**



Control volume: channel flow

Case Study: The Cosumnes River



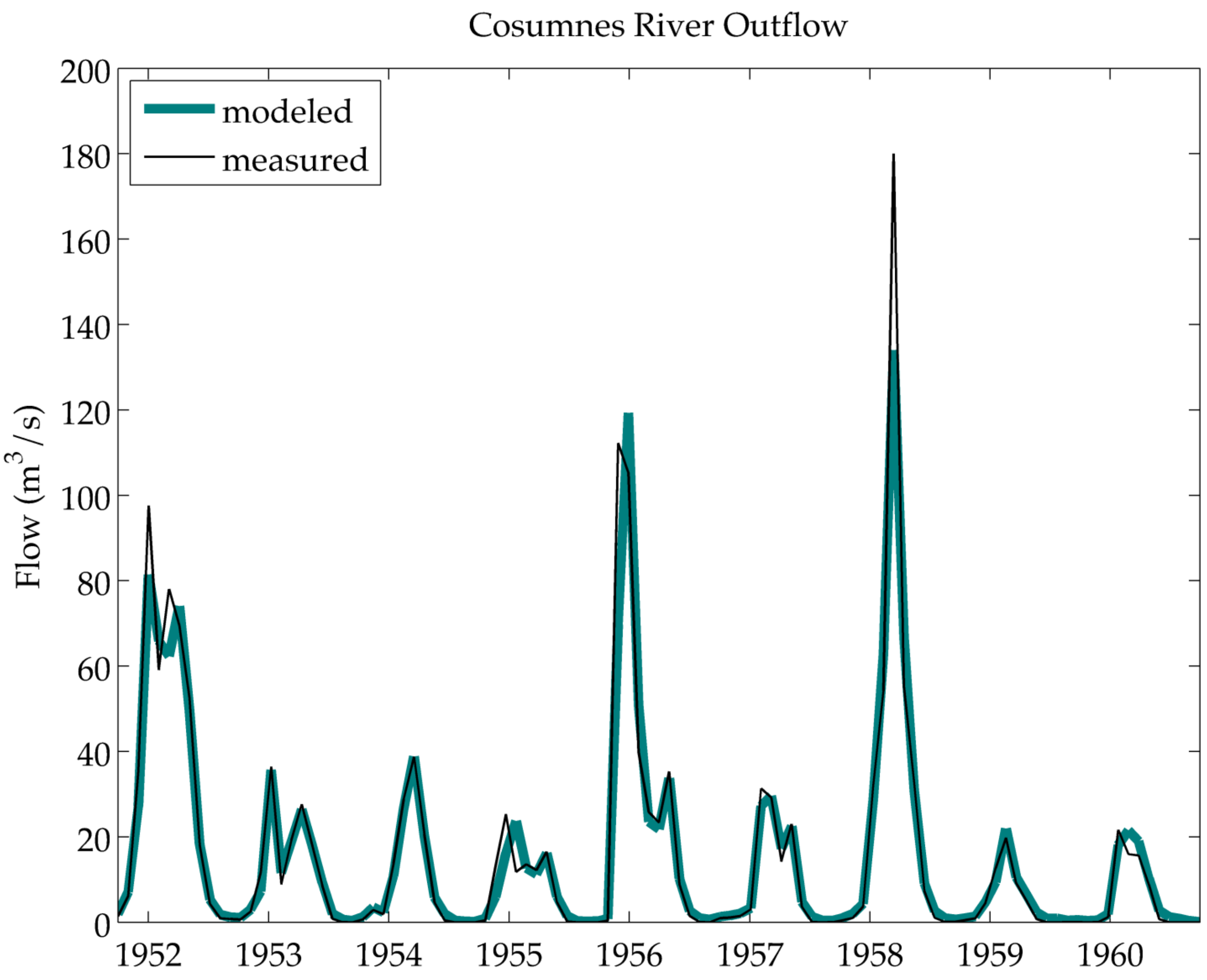
Only undammed large northern CA river (no exports)

Tributary to Mokelumne River, then San Joaquin River

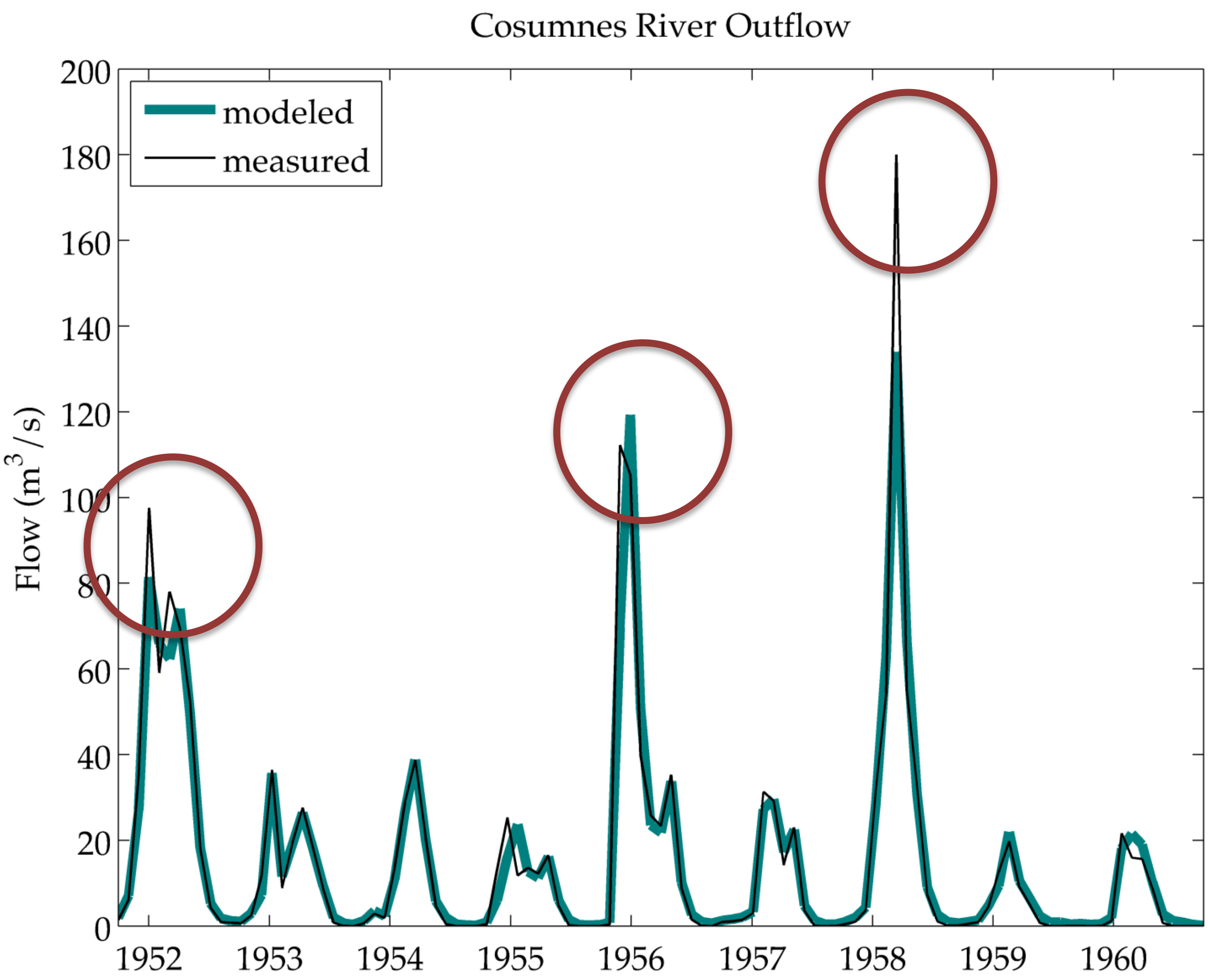
USGS gaging stations at inlet and outlet for WY 1952-1960

Channel lined with flood-control levees; land use: agricultural (vineyards)

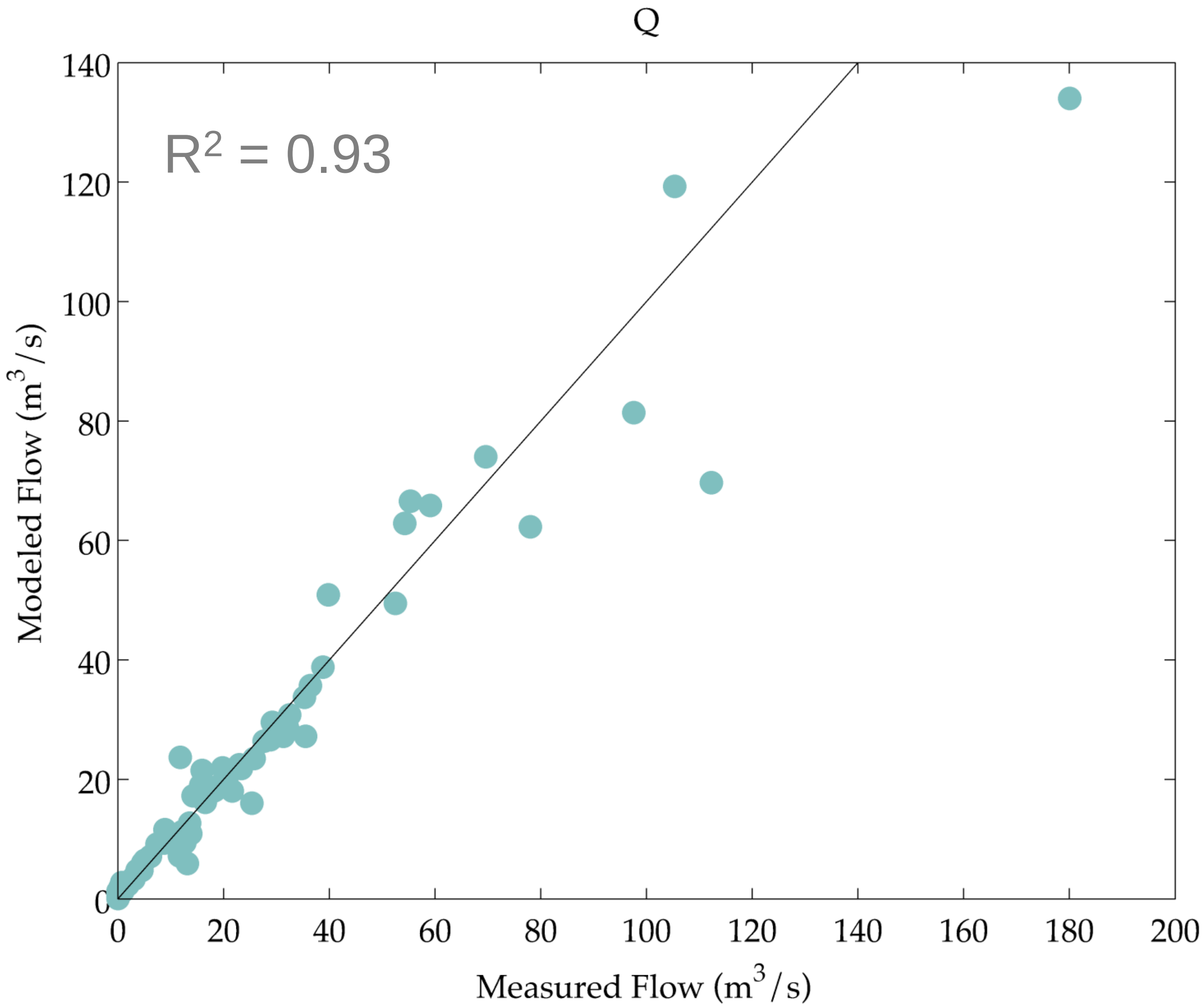
Model testing: watershed outflow



Model testing: watershed outflow

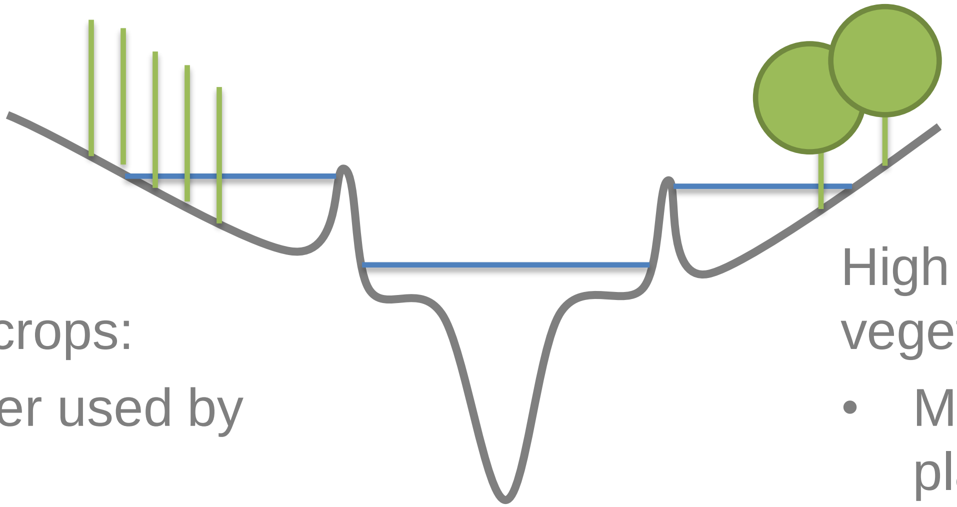


Model testing: watershed outflow



Exploring watershed outflows: ET and stream flow

- Vary key parameters in the model, one at a time
  - Land use, vegetation type
  - Flood frequency, levees
  - Topography
  - Ground water exchange
  - Climate: water supply versus water demand
- The base case
  - Crop coefficient: 1
  - Loam soils over clay aquifer
  - 2-m high levees; 20-m wide floodplain
  - Forced with P and ET_0 from Cosumnes, 1952-1960
  - Hypothetical topography



Low K_c for agricultural crops:

- Less water used by plants
- More available for streamflow

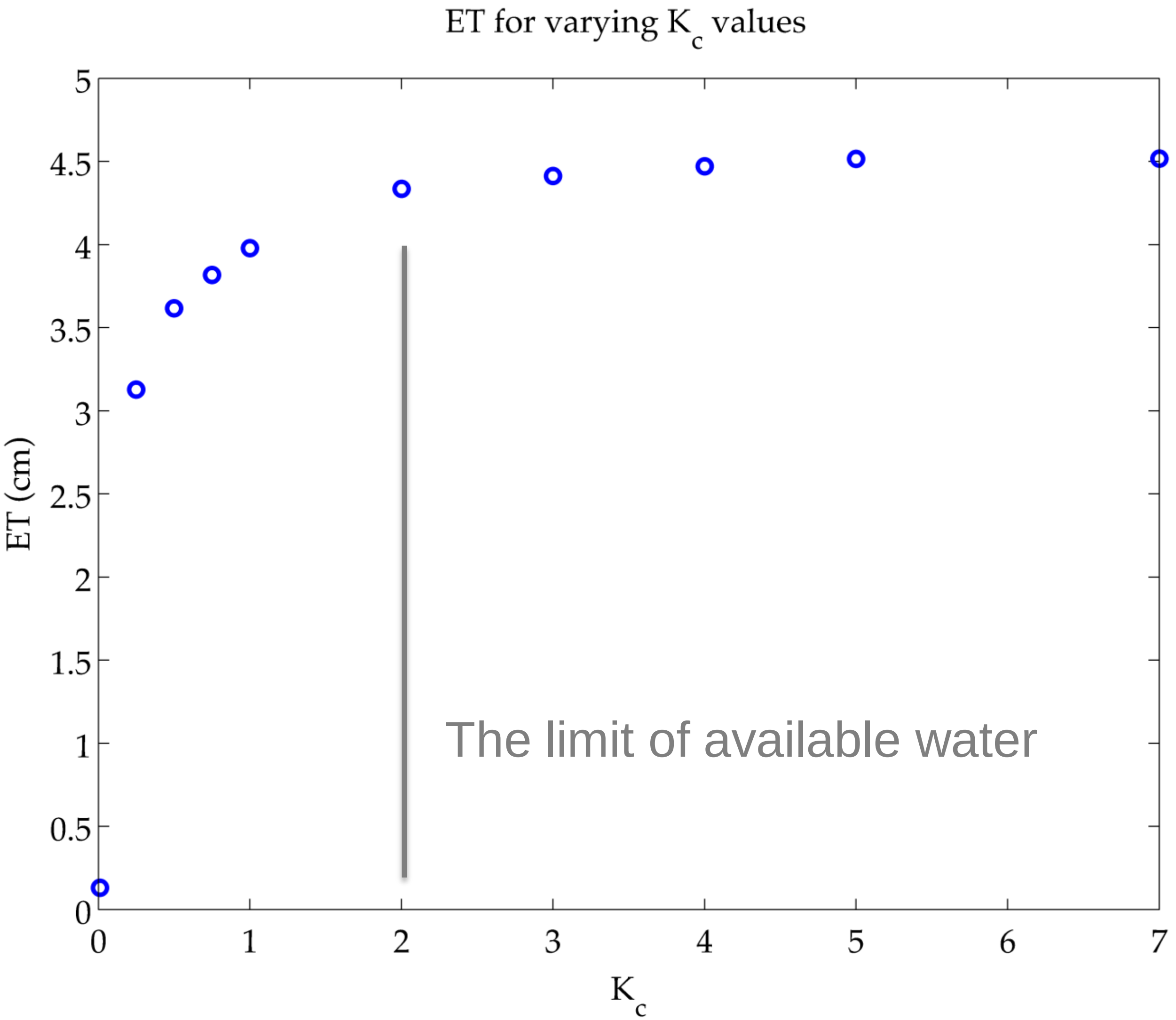
High K_c for native vegetation:

- More water used by plants
- Less available for streamflow

Land use:

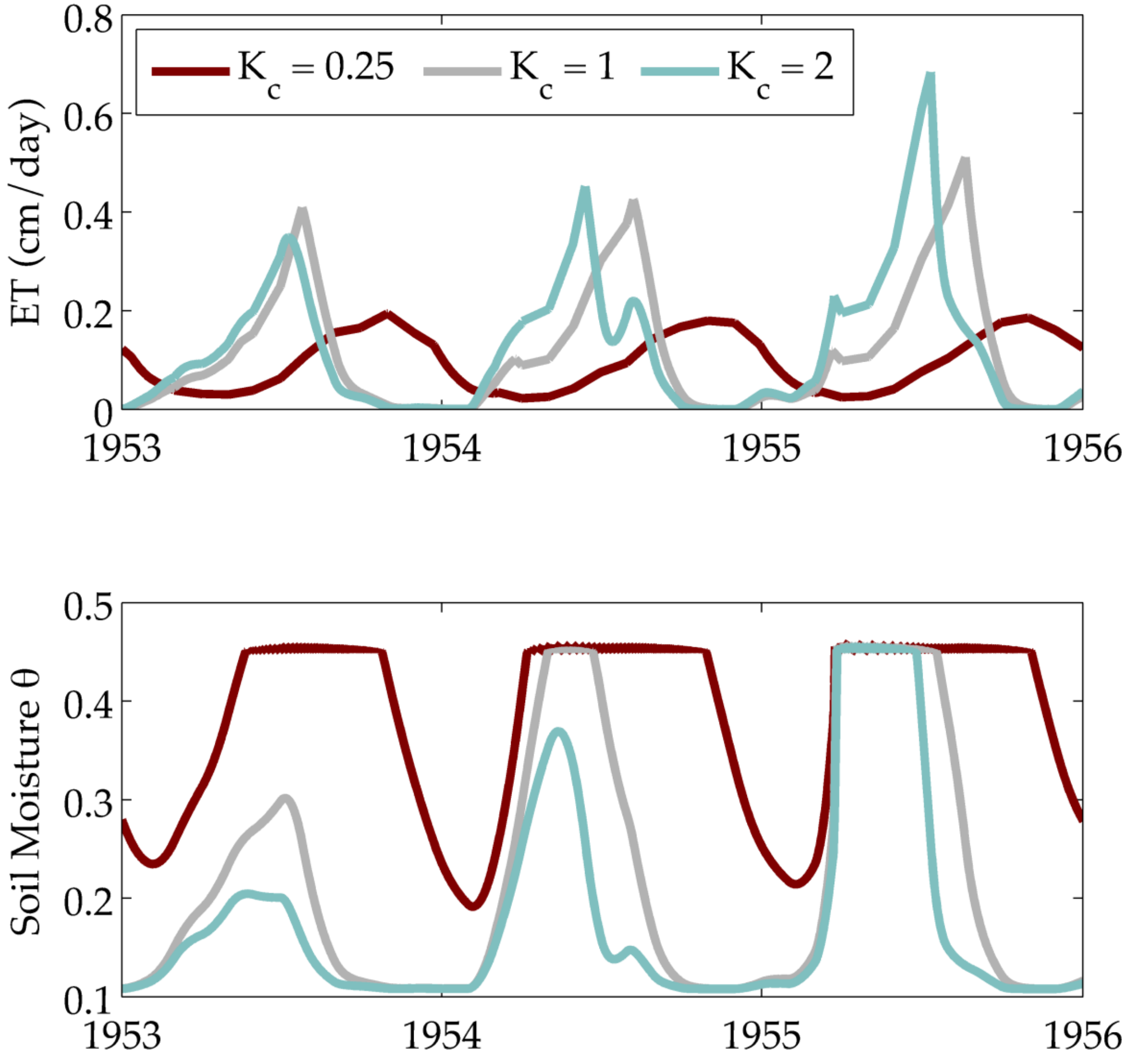
Water use by plants (*ET*) = K_c *PET*

ET by different vegetation types



- ET: cm over watershed area (465 km^2)
- K_c varies from 0.01 to 7
- For $K_c > 2$, ET fairly constant
- *The soil runs out of water*

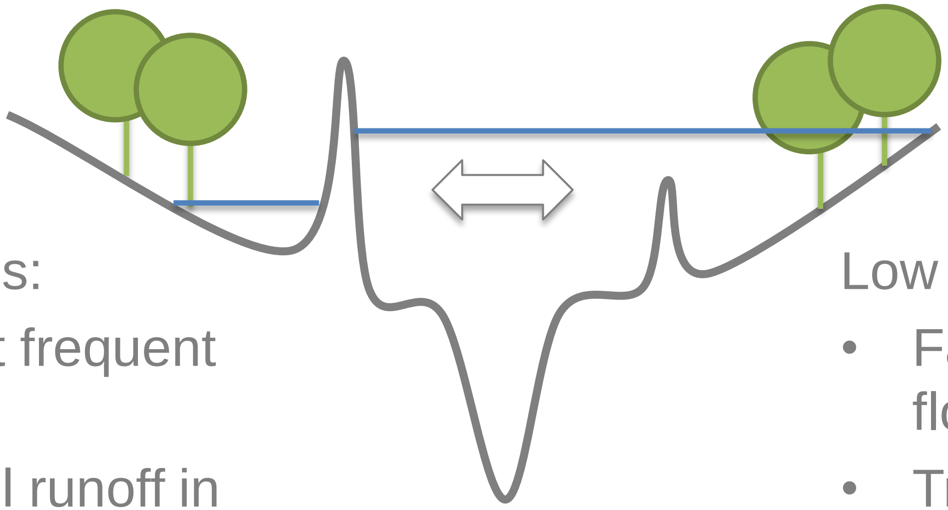
ET limited by water supply



- Higher K_c: more ET earlier in the wet season
- Lower K_c: soil moisture sustained for later ET → *not exiting via stream flow*

High levees:

- Prevent frequent floods
- Keep all runoff in valley: ET, infiltration



Low levees:

- Facilitate frequent floods
- Trap water in valley: ET, infiltration

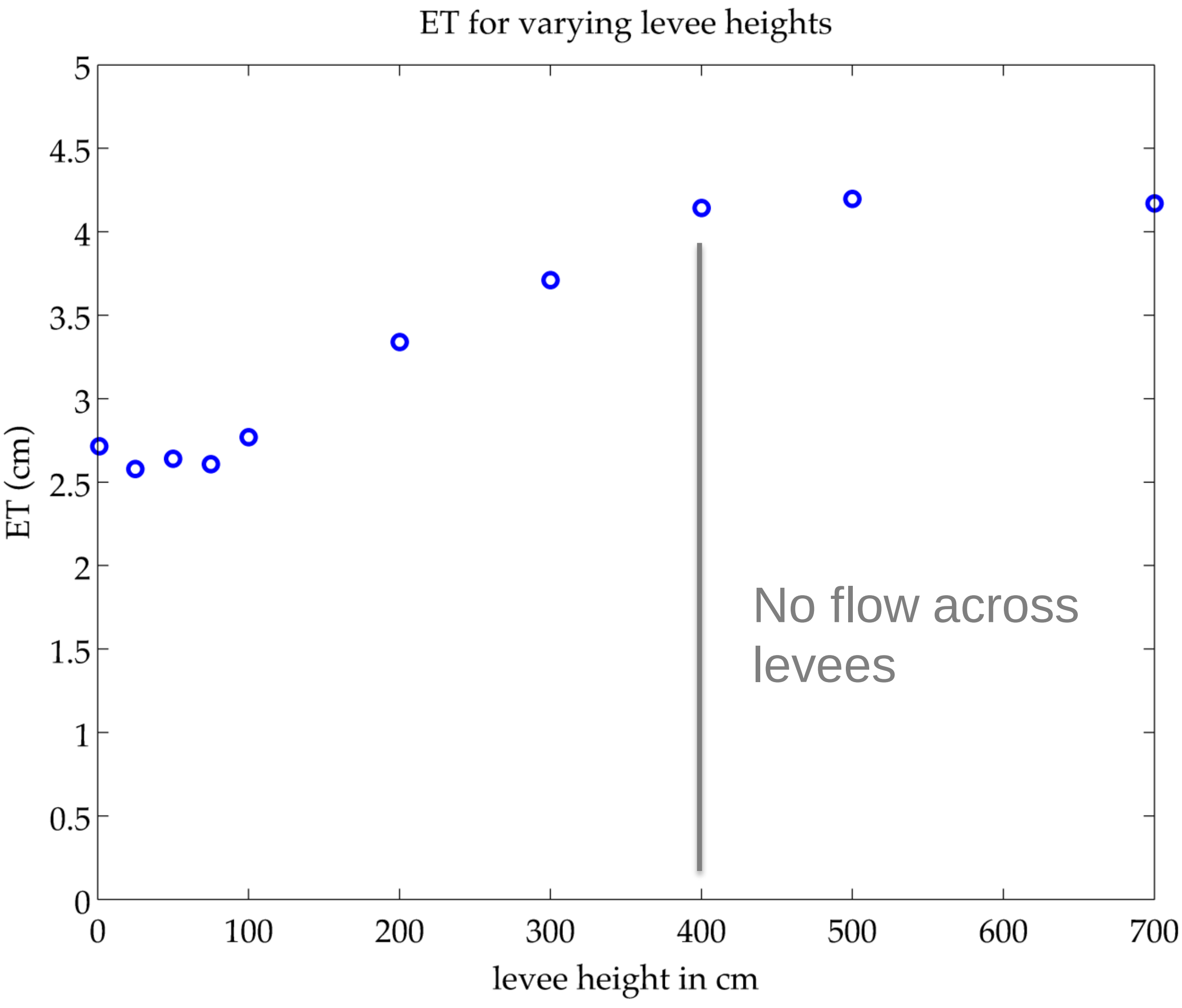
Frequency of flooding:

Channel dimensions, levee height, floodplain width

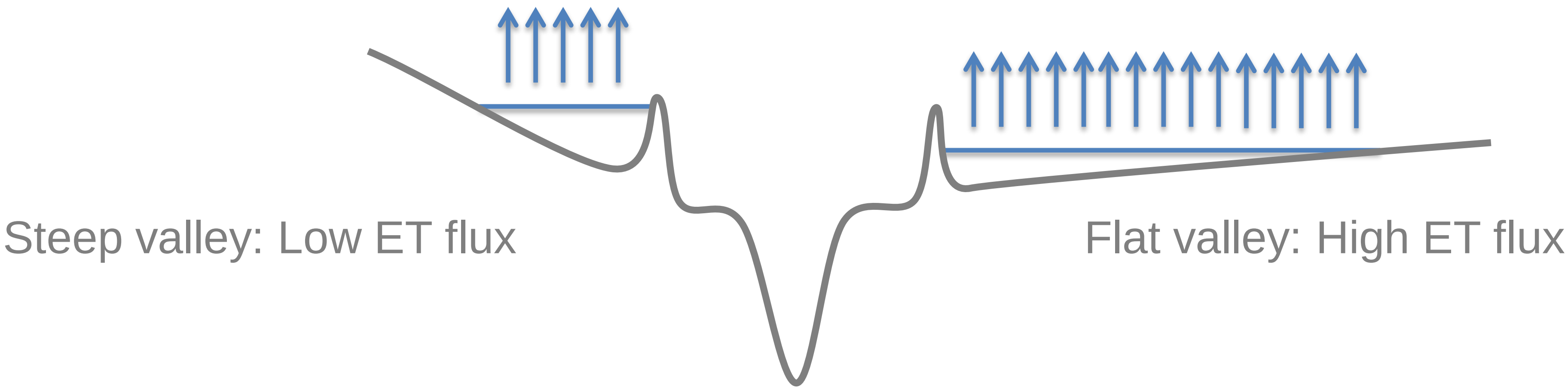
Impeding runoff from watershed to channel:

Levee height

Flooding & detention



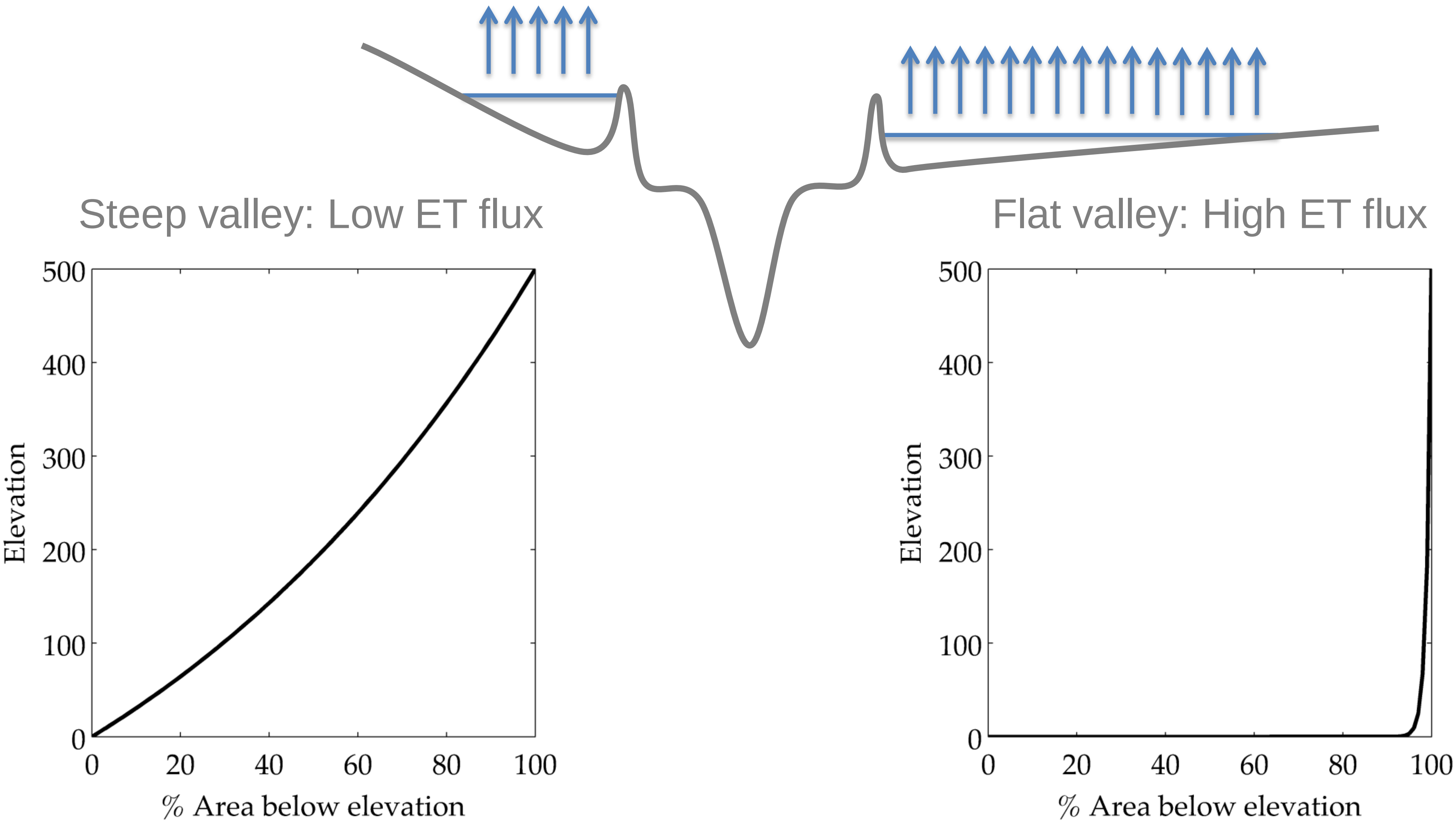
- Lower levees → more flooding
- Higher levees → runoff detained on valley floor
- *For this channel cross-section, ET is greatest when runoff is detained*



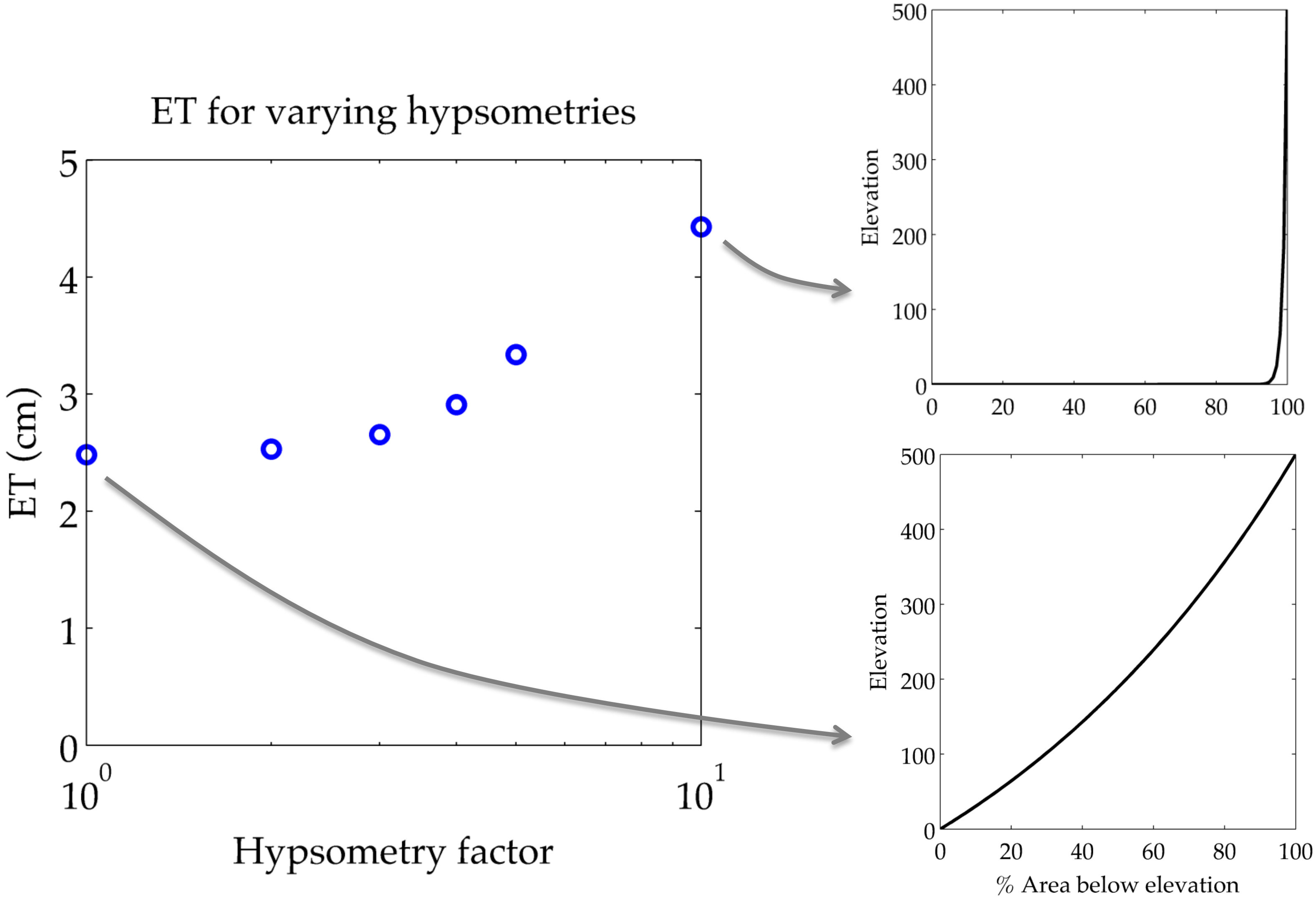
Topographic limits on ET:

Area of low-lying regions: surface of open water or root zone moisture that can lose water to ET

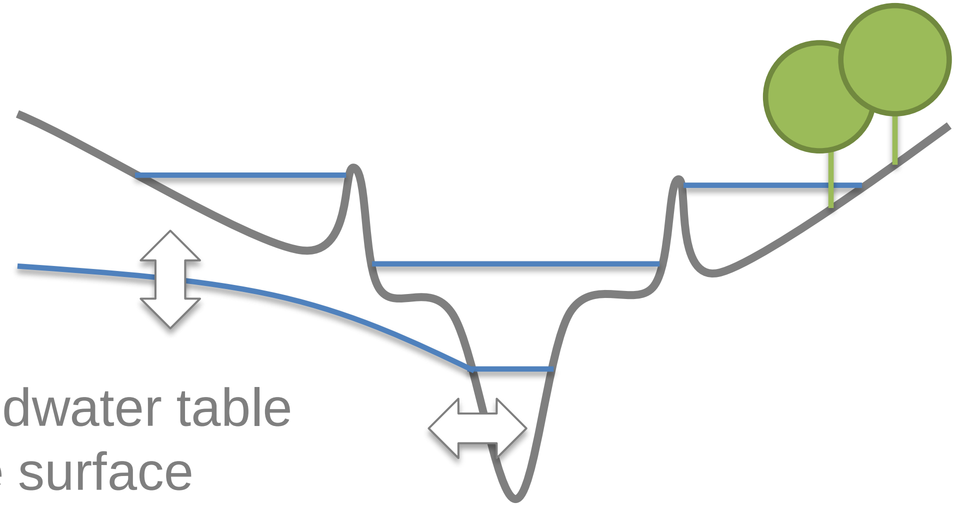
Hypsometry


Steep valley: Low ET flux
Flat valley: High ET flux
Elevation
0
100
200
300
400
500
0
20
40
60
80
100
% Area below elevation

Topography



ET for varying hypsometries
ET (cm)
5
4
3
2
1
0
10^0
10^1
Hypsometry factor
Elevation
500
400
300
200
100
0
0
20
40
60
80
100
Elevation
500
400
300
200
100
0
0
20
40
60
80
100
% Area below elevation



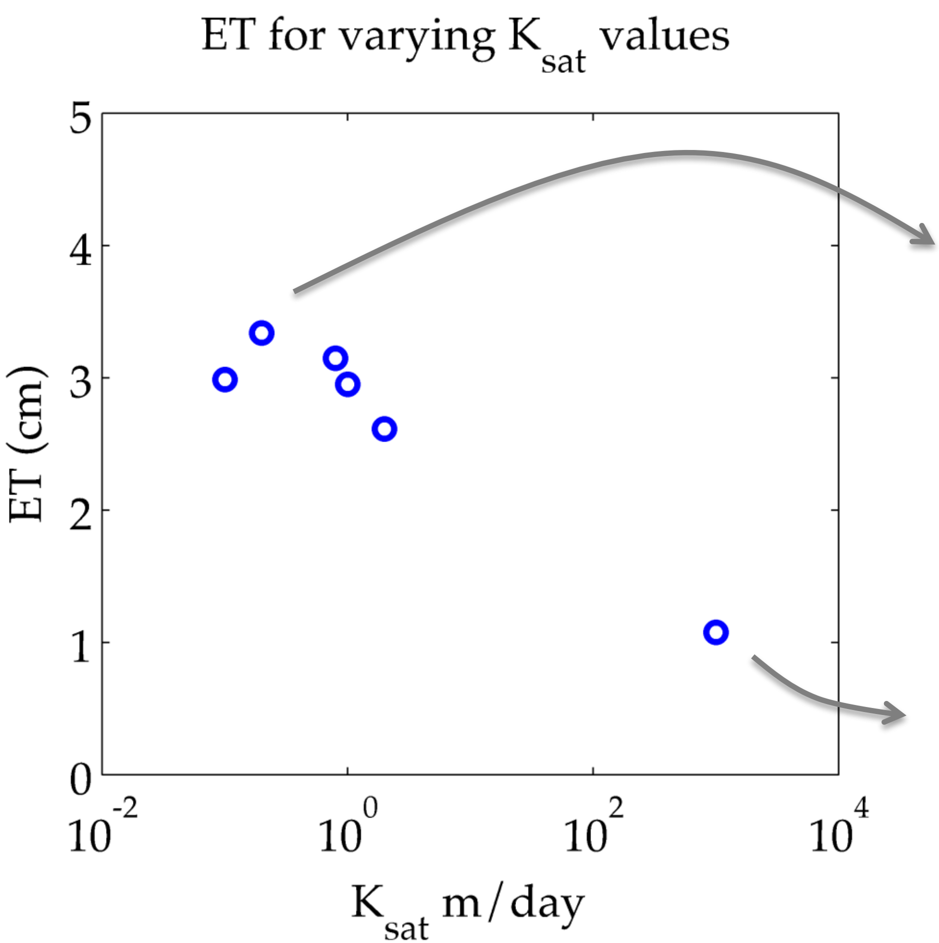
Allow groundwater table to reach the surface

A reservoir of water subject to ET after flood recedes

Exchange with groundwater:

Soil type: saturated hydraulic conductivity (K_{sat})

Ground water interactions

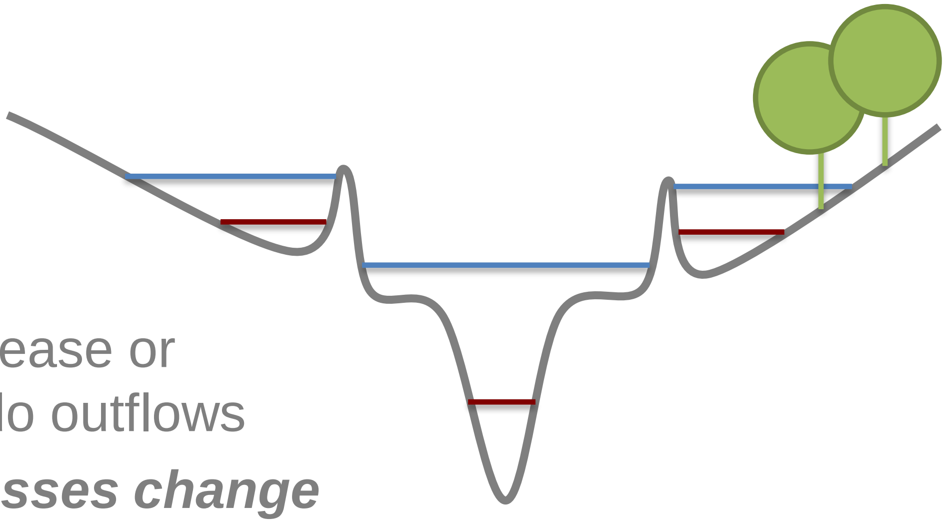


Low/intermediate K_{sat} strikes a balance:

- Allows GWT to gain water
- Retains it long enough to facilitate ET

Very high K_{sat} allows GWT to rise, but falls rapidly

The importance of climate



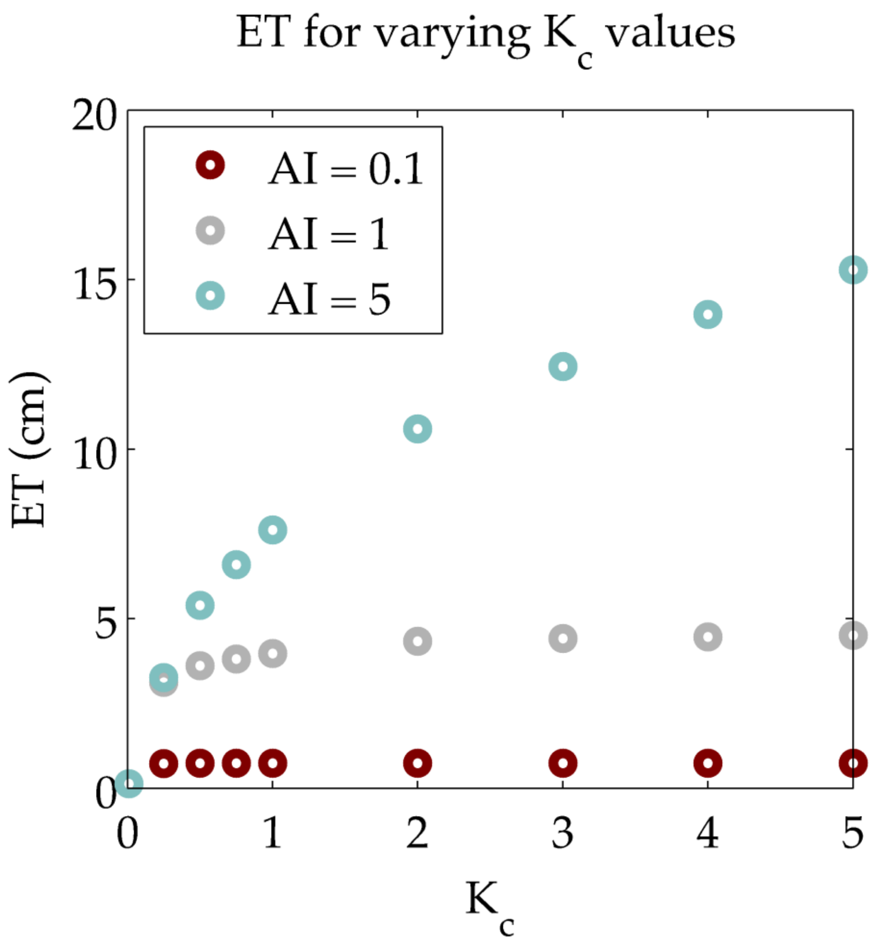
As inflows increase or decrease, so do outflows

But the processes change

Water supply versus water demand:

Aridity index (*AI*) = P/PET

The importance of climate



Higher inflows mean greater sensitivity of ET to vegetation type

Lower inflows mean ET is only sensitive to low values of K_c

Preliminary conclusions: controls on the ET flux

- Vegetation: differences are important when the soil is not water-limited
- Levees: impeding runoff is as important for ET as allowing the river to flood
- Ground water exchange: length of time water is held within the matrix is critical
- Topography: Steep watersheds limit surfaces for ET; flat watersheds enhance them
- Climate can change everything!