A Novel Approach in Determining Changes in Consumptive Use for River Basins

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Objective: To understand hydrologic changes over time in a River Basin and to answer questions:

- Has there been a net water loss or gain over the period of record?
- If so, by how much and why?
- What caused the greatest impacts?
- Separate rainfall variability from other inputs to determine “consumptive use”

What is “consumptive use”?

- “Consumptive Use” defined as: Difference between water withdrawn from a basin and withdrawn water returned

Potential sinks for consumptive use?

- Water plant withdrawals and discharges to septic tanks (varies as percentage)
- Evaporative losses for chillers, cooling towers for institutional buildings; large use for large cities
- Example: “guest-imate” for Charleston Metro: 1-2 MGD; for NYC, think 30 MGD

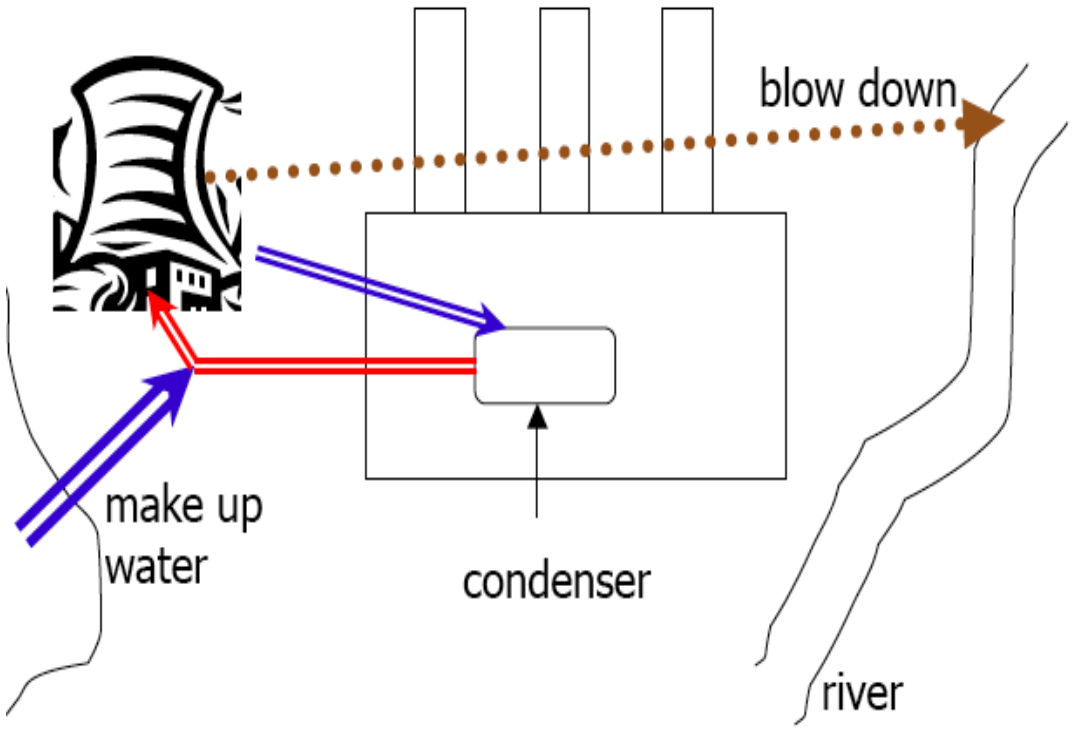
Potential consumptive use, cont…

- Historic changes to hydrologic patterns due to changes in land use
- Irrigation of lawns and agricultural ET losses
- A special case: Inter-basin transfers usually defined as separate impact item

Potential consumptive use, cont…

- Power plant cooling by evaporation
- Many MGDs
- Can be huge losses—

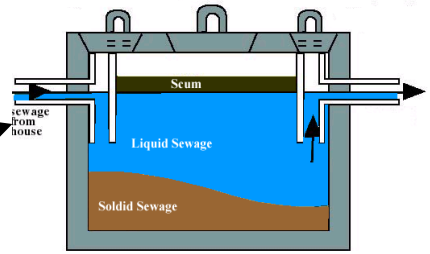
  15,000 gpd per 1 MW



Schematic of river basin Example Segment

Q_{in}

tributary



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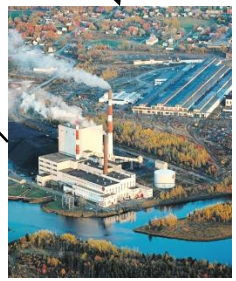


Q_{out}

WTP

WWTP

GAGE

Potential hydrological data sources to be mined

- USGS gaging stations
- Numerous weather stations in and contiguous to basin--more are better
- Known interbasin transfers
- The longer the record, outcomes more robust

Proposed Approach

- Divide the river basin into segments (segments determined by available flow gages) and calculate a flow difference for each segment
- Determine effects of weather on flow variability using artificial neural networks (ANNs); remove rainfall effects
- Calculate change in consumptive use over period of record

Nomenclature for process

- Qout = Flow measured at the output of the segment
- Qin = Flow measured at the input of the segment
- ΔQout = Change in segment discharge flow over historical record; calculated using linear regression

Nomenclature, cont…

- Qdiff = Qout - Qin
- ΔQdiff = Change in difference over historical record, Delta (Qout – Qin) determined using linear regression
- ΔRain = Change in rainfall over period of record, calculated using linear regression
- ΔQrain = Drainage area x ΔRain

Nomenclature, cont…

- ΔQconsumptive = Change in flow (Qout – Qin) that is not attributable to weather, i.e., change in “consumptive use”

- Data record = period of record for a particular segment/gage within the period of record

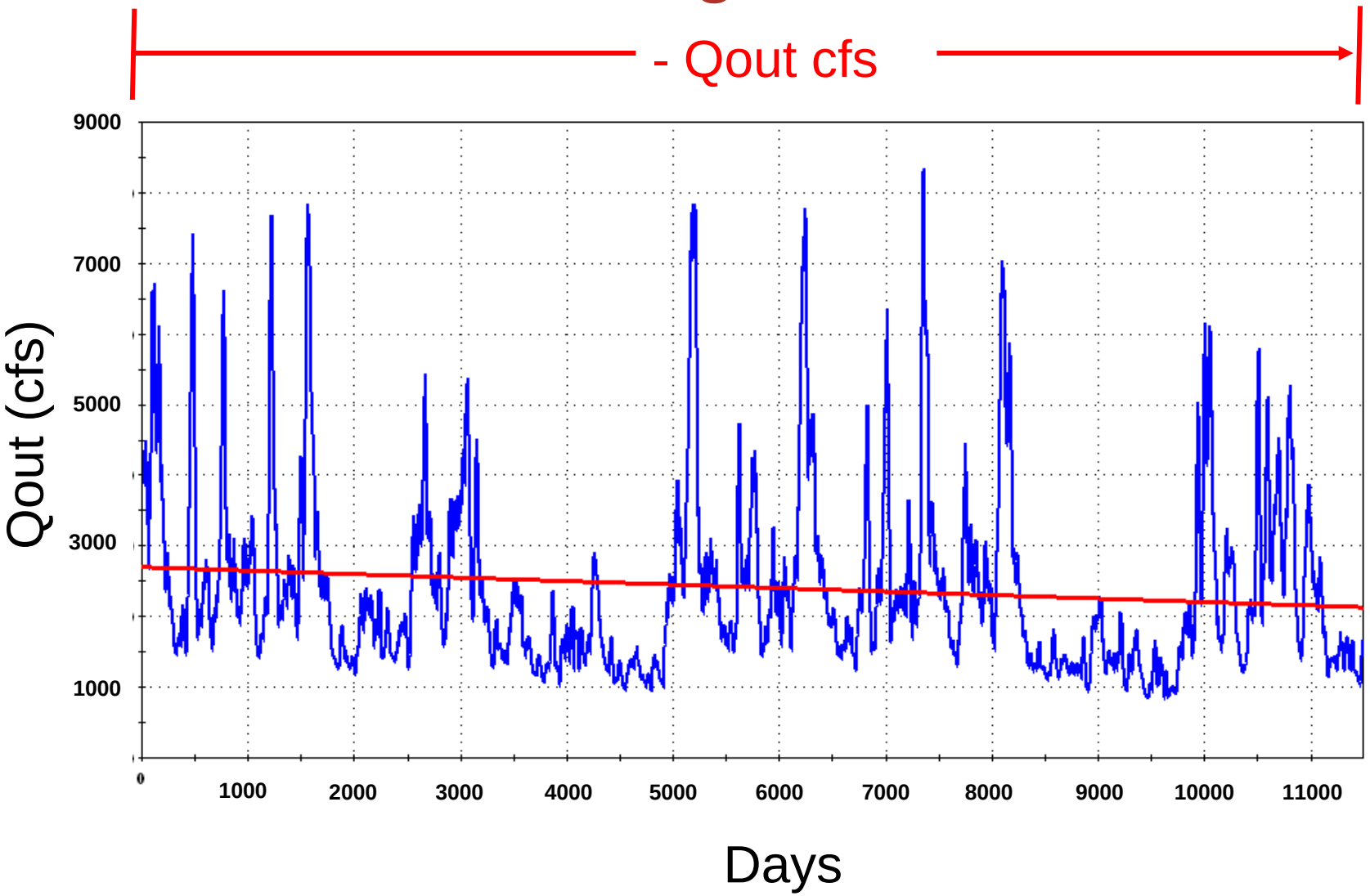
Raw flow data includes:

- Effects on flow from changes in rainfall over time
- Effects on flow from consumptive use over time
- Therefore, must determine way to remove effects from changes in rainfall and groundwater on basin flows

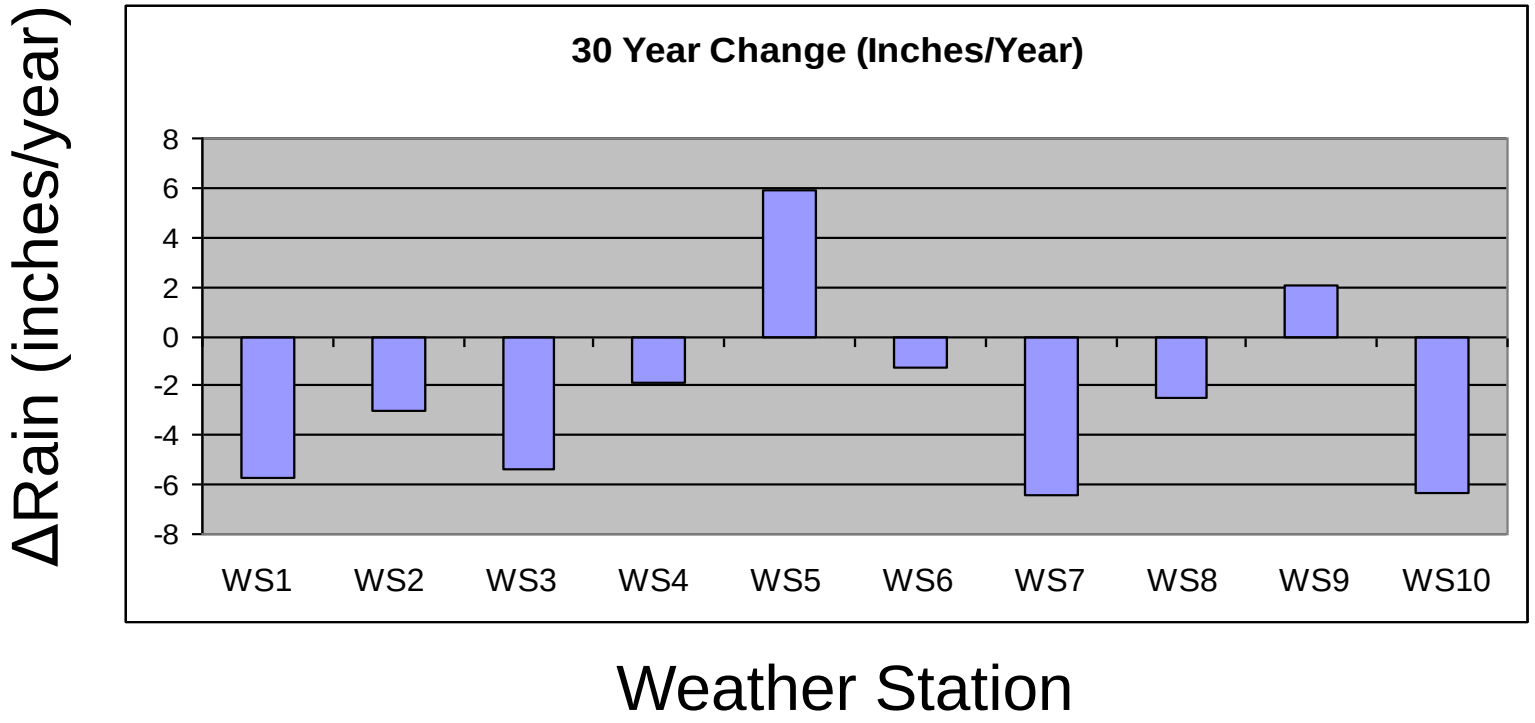
Example Segment Qout:

- In the Example Segment, monitoring data shows flow out of Segment
- For many possible reasons, Qout has diminished over period of concern

Qout over data record for Example Segment



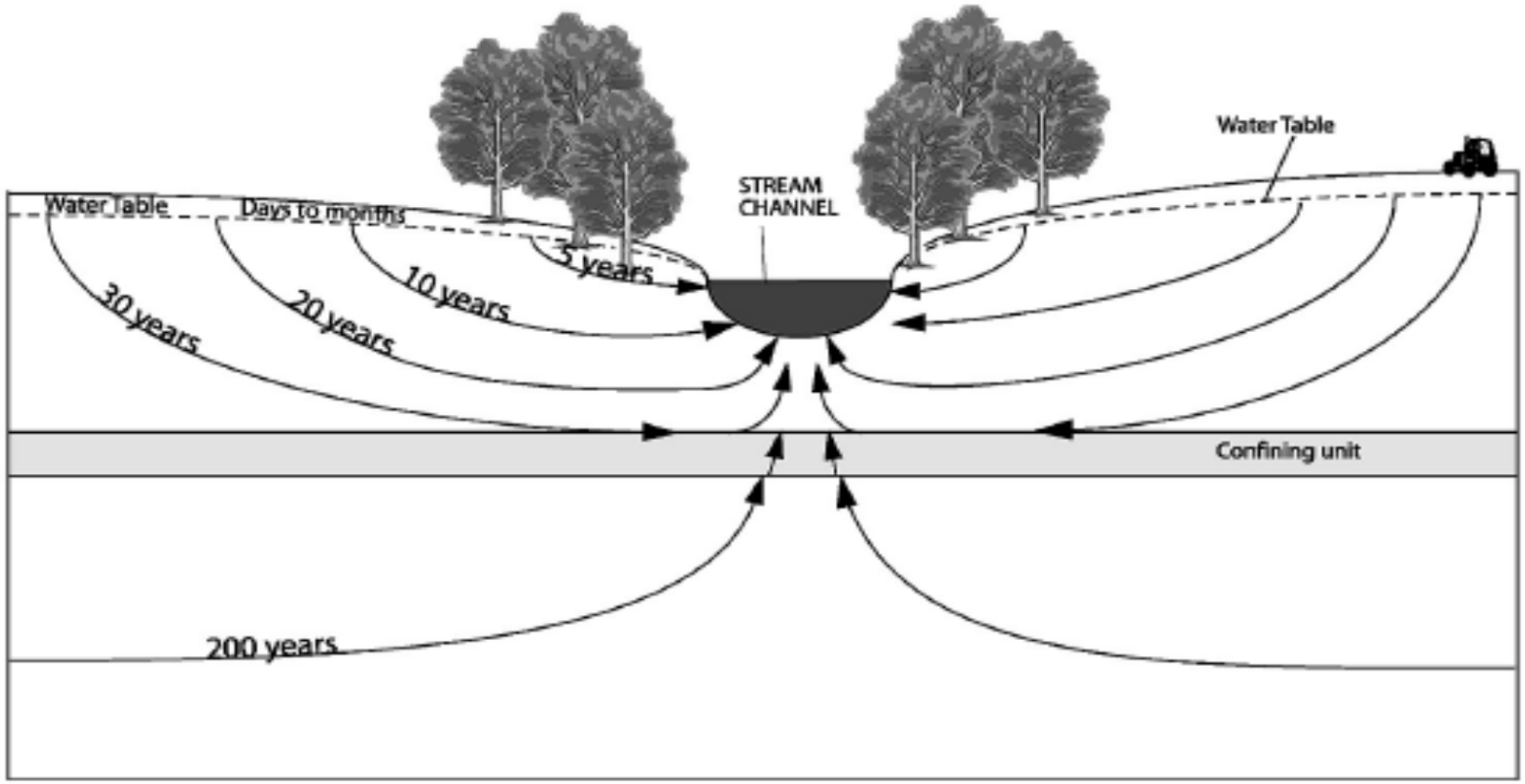
Example: rainfall summary for 10 weather stations (WS) in the southeastern United States, inches/year



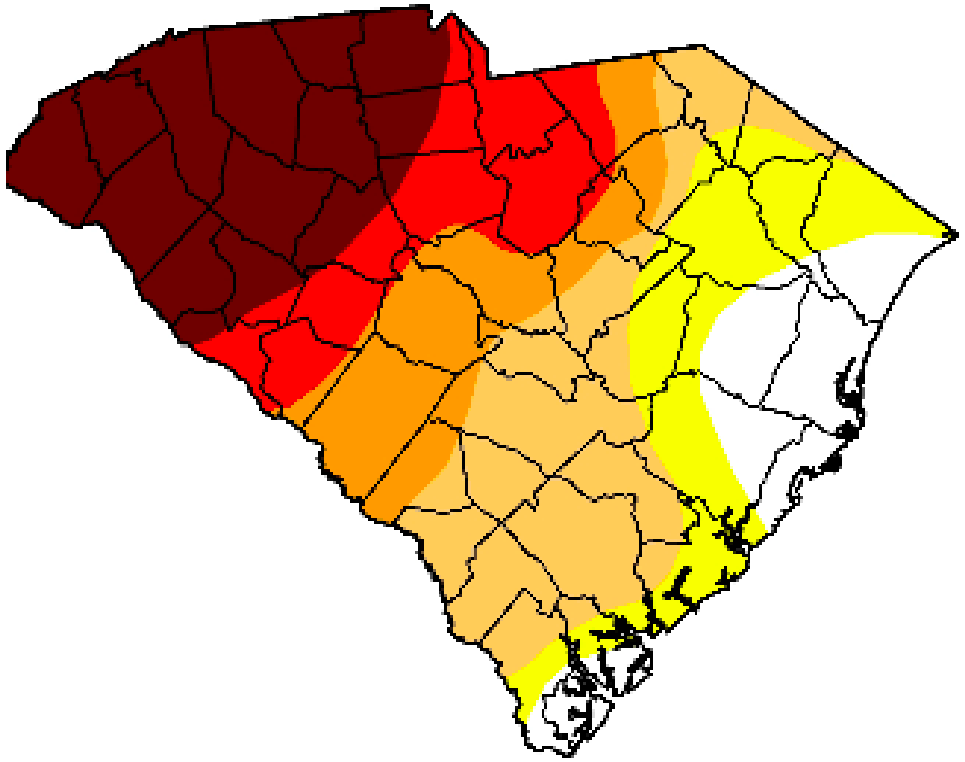
Practical issues to overcome

- Temporal variability in rainfall
- Travel time of rainfall and groundwater

Rainfall takes different time-steps to become river flow, with many losses along the path to river



Another problem: rainfall is very erratic across any area, not falling uniformly over space or time



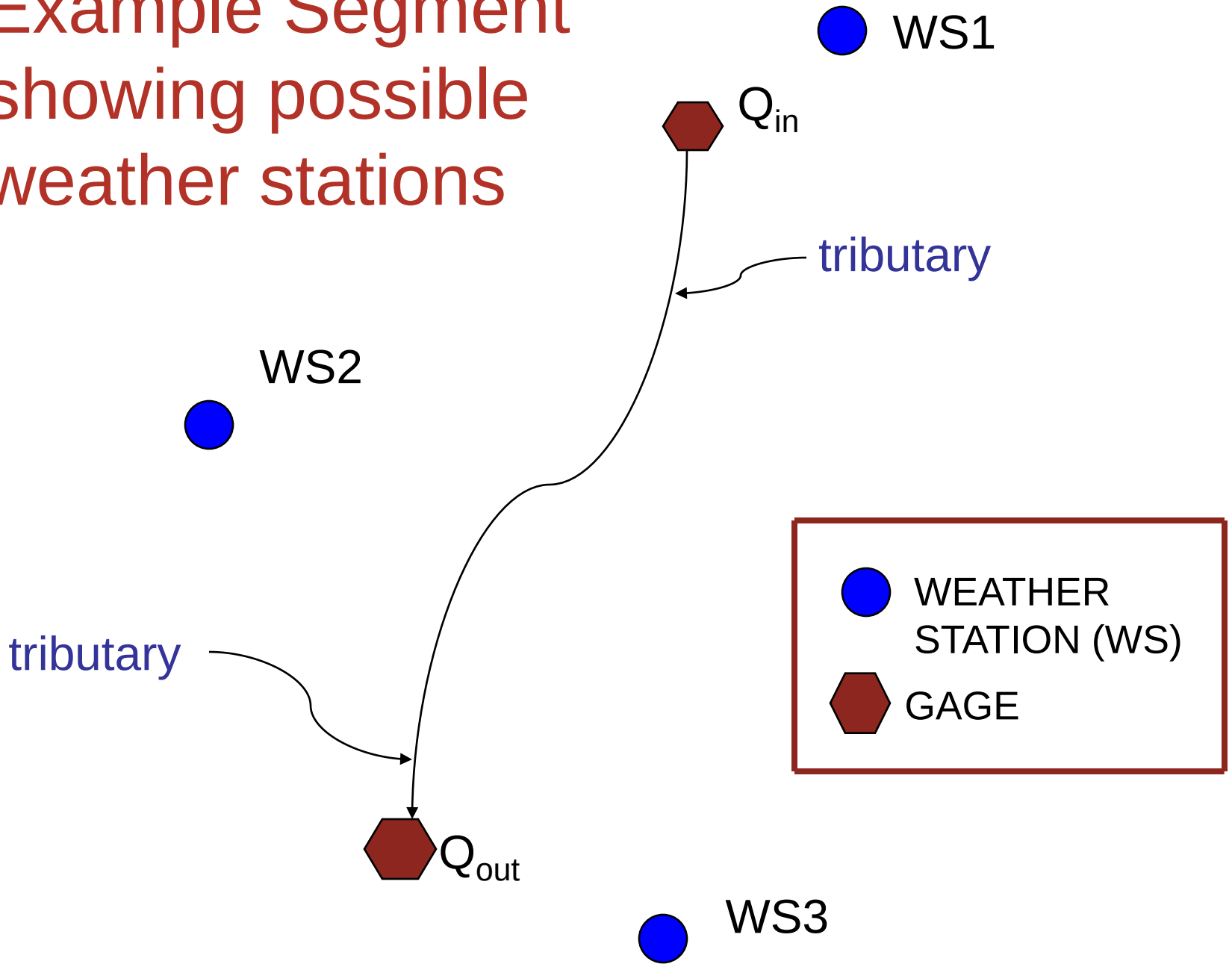
Dealing with spatial variability

- Spatial variability
  - Multiple weather stations
  - Correlation analysis of rainfall stations and river flows is used to select stations with strongest correlation using ANNs
  - Weather data is decorrelated from each other using ANNs

Dealing with temporal variability

- Time variability
  - Include varying sizes of moving window averages and derivatives; use signal processing

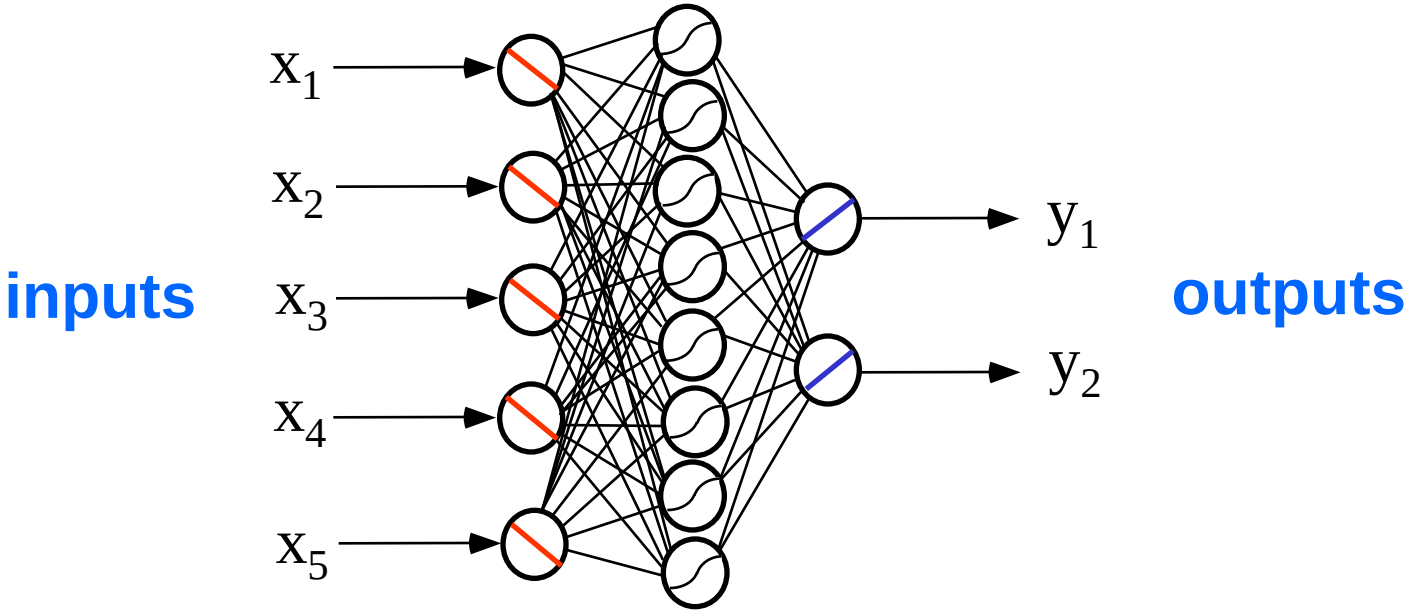
Example Segment showing possible weather stations



Use Artificial Neural Networks (ANNs) to determine non-linear relationships

Inspired by the Brain

get complicated behaviors from lots of “simple” interconnected devices - neurons and synapses

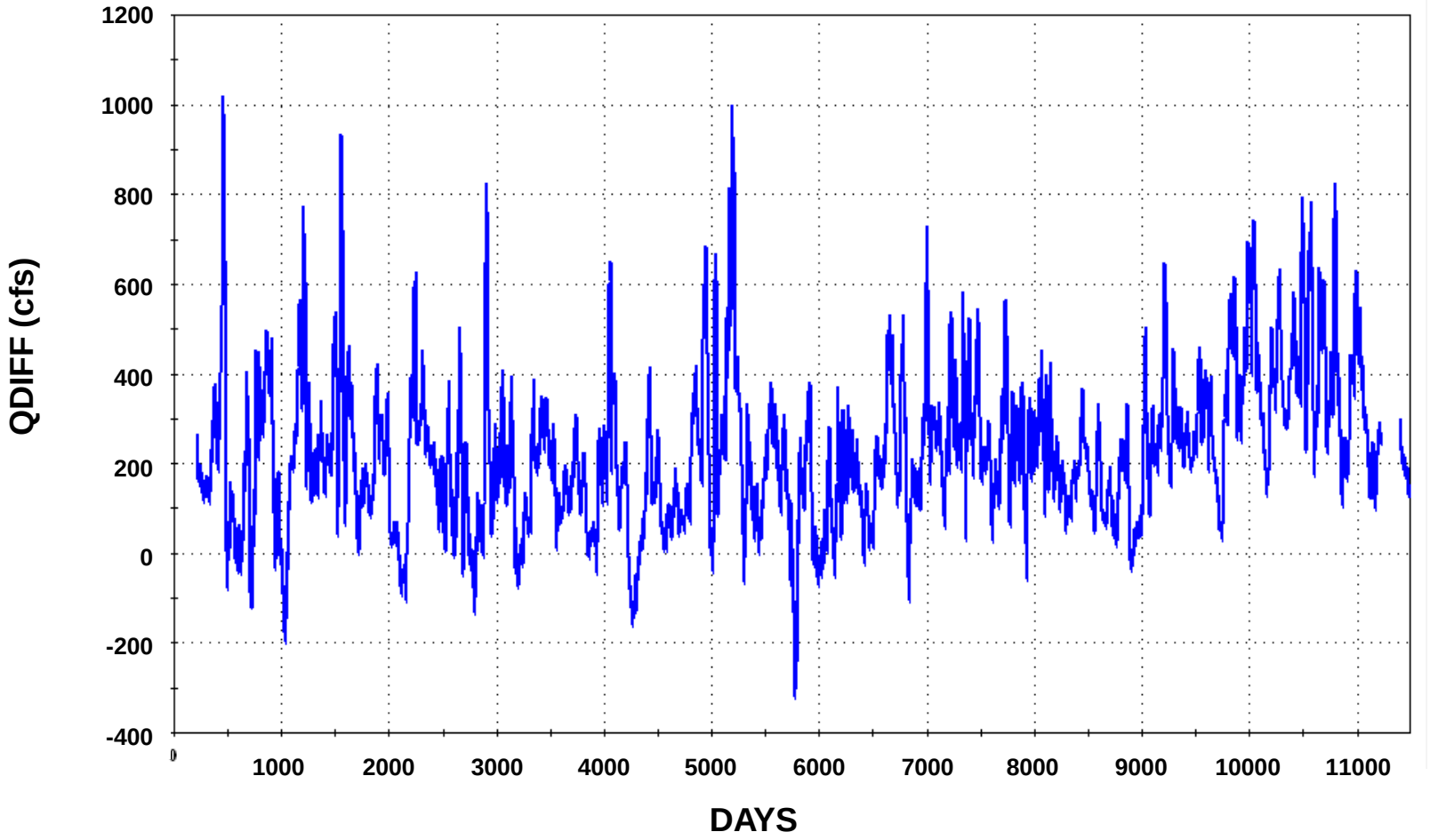


non-linear, multivariate curve fitting

models are synthesized from historical data

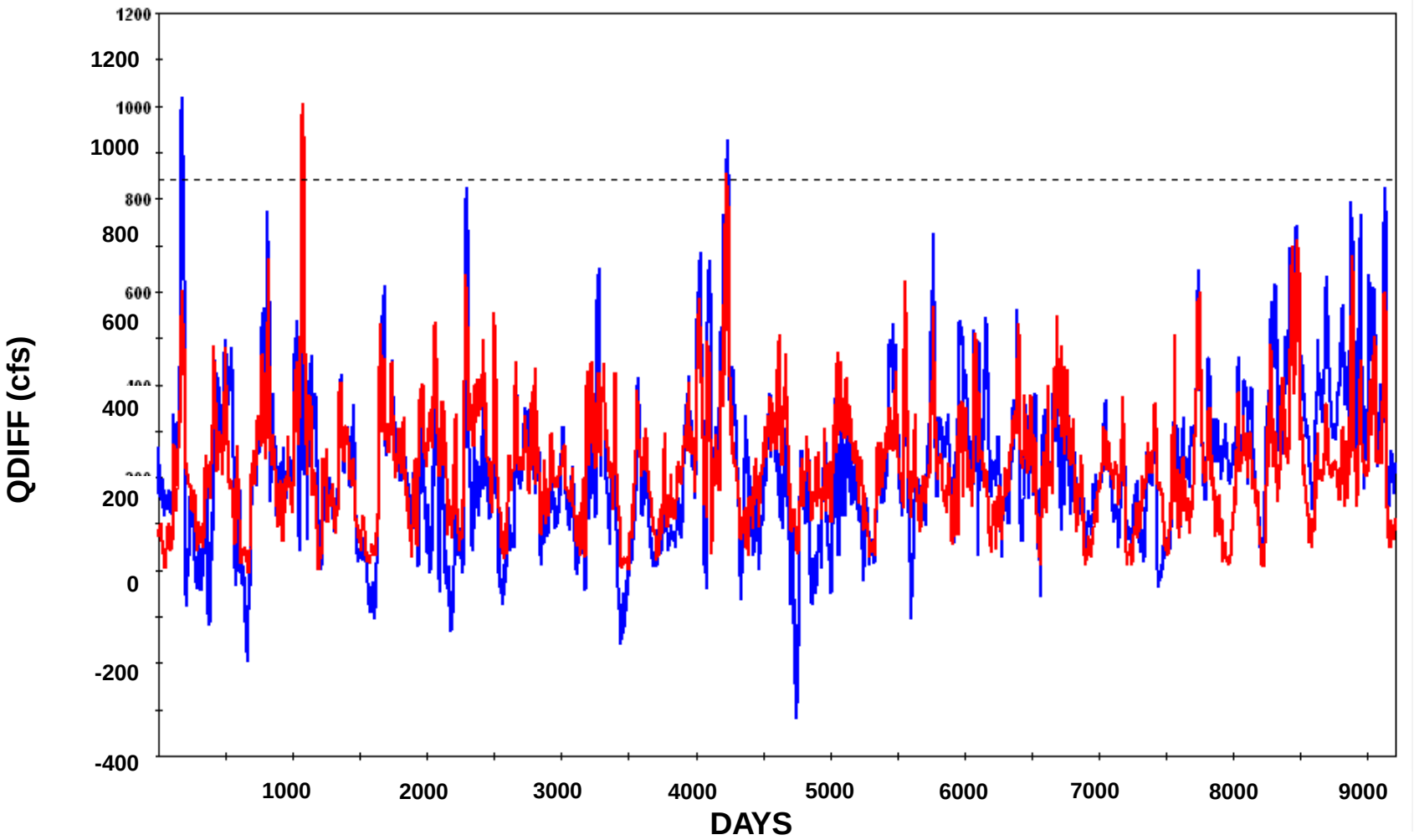
Example Segment–Qdiff v. time

Qout - Qin = Qdiff



Model Qdiff with ANN for Example Segment using rainfall variability over time and space and drainage basin areas

Example Segment –Qdiff_Measured vs. Qdiff_Predicted using ANN



Take difference between modeled Qdiff and actual Qdiff to yield “residual Qdiff” (Qres)

Model “residual” = Qdiff_measured – Qdiff_predicted

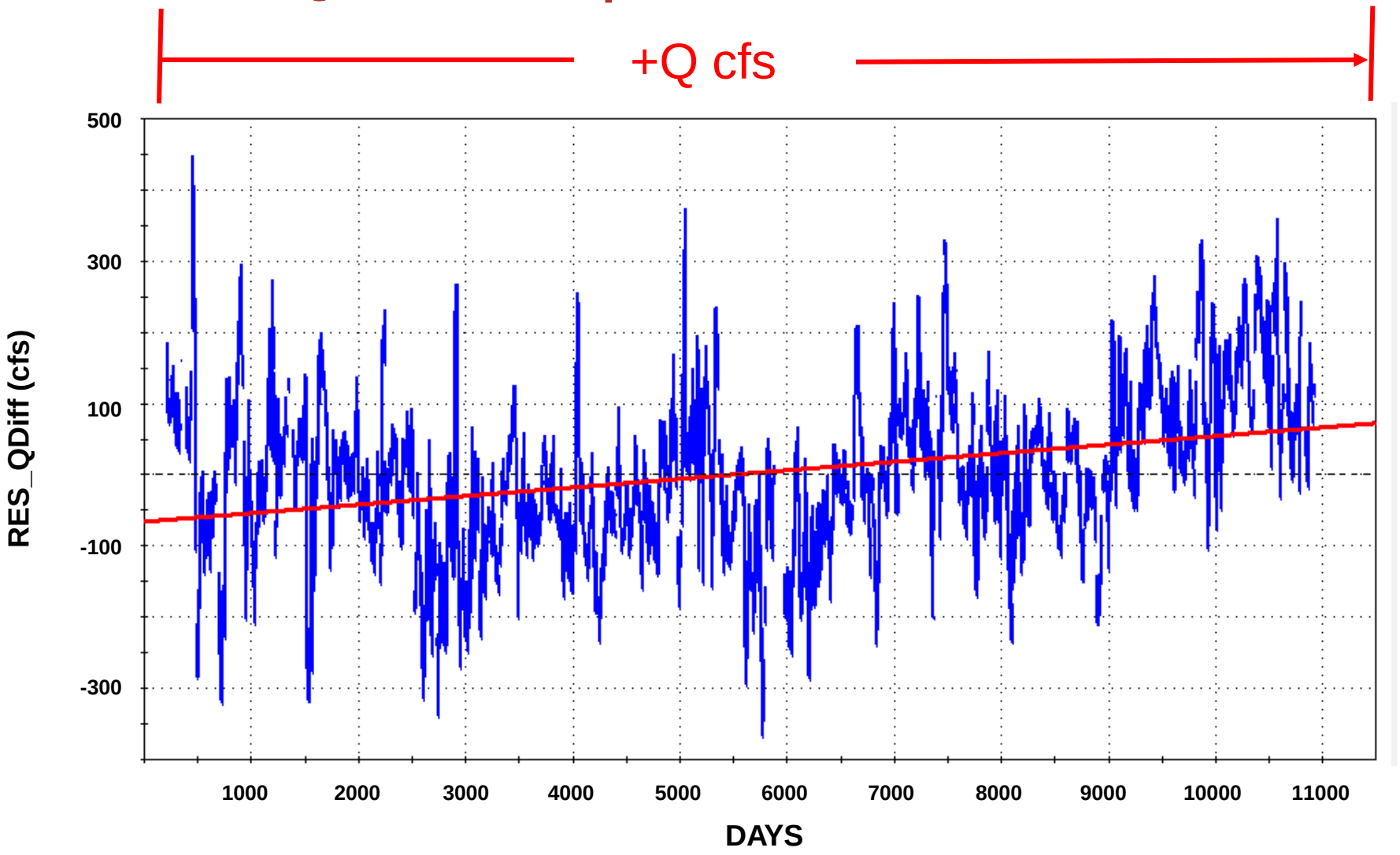
- Model residual is an estimate of the variability due to non-rainfall causes
- Other causes could include:
  - Measurement error
  - Noise (randomness)
  - “Other disturbances” = **consumptive use**

Calculating ΔQconsumptive over period of record

- ANN model predicts weather effects on flow using multiple weather stations
- Model Qdiff and calculate Qdiff "residual" between modeled and actual
- Linear regression of Qres is used to calculate Qres at the start and end of the data record
- $\Delta Q_{consumptive} = Qres_{end} - Qres_{begin}$

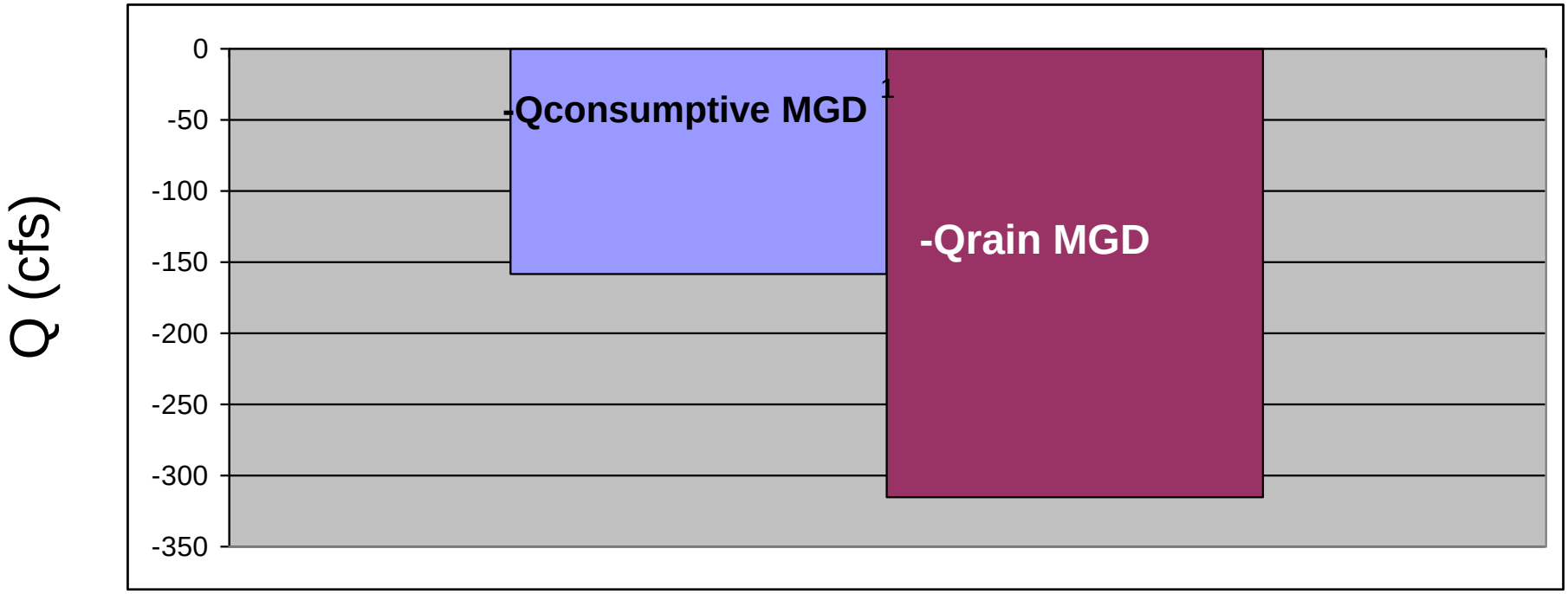
  [could be (+) or (-) over period of record]

Example Segment – residual change is ΔQconsumptive over data record



For river basin Example Segment, reduction of flow due to CU and rain

ΔQconsumptive v. ΔQrain



Thank you and questions…

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