CALIFORNIA DEPARTMENT OF WATER RESOURCES
&
RESOURCE MANAGEMENT ASSCOIATES

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Delta Emergency Response Tool

Machine Learning Module

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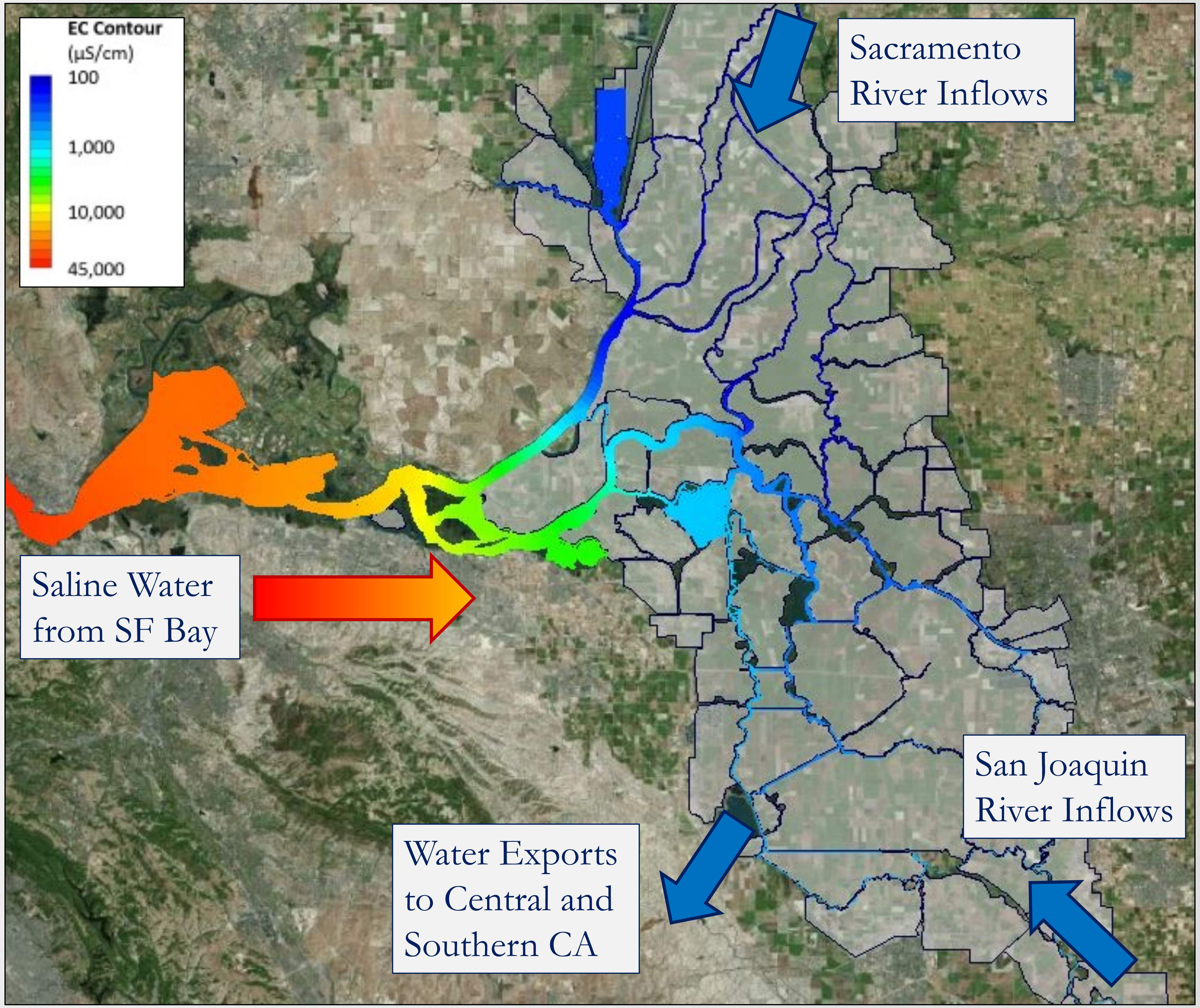
Outline

- Background
- Model Overview
- Machine Learning Module

Delta Normal Conditions

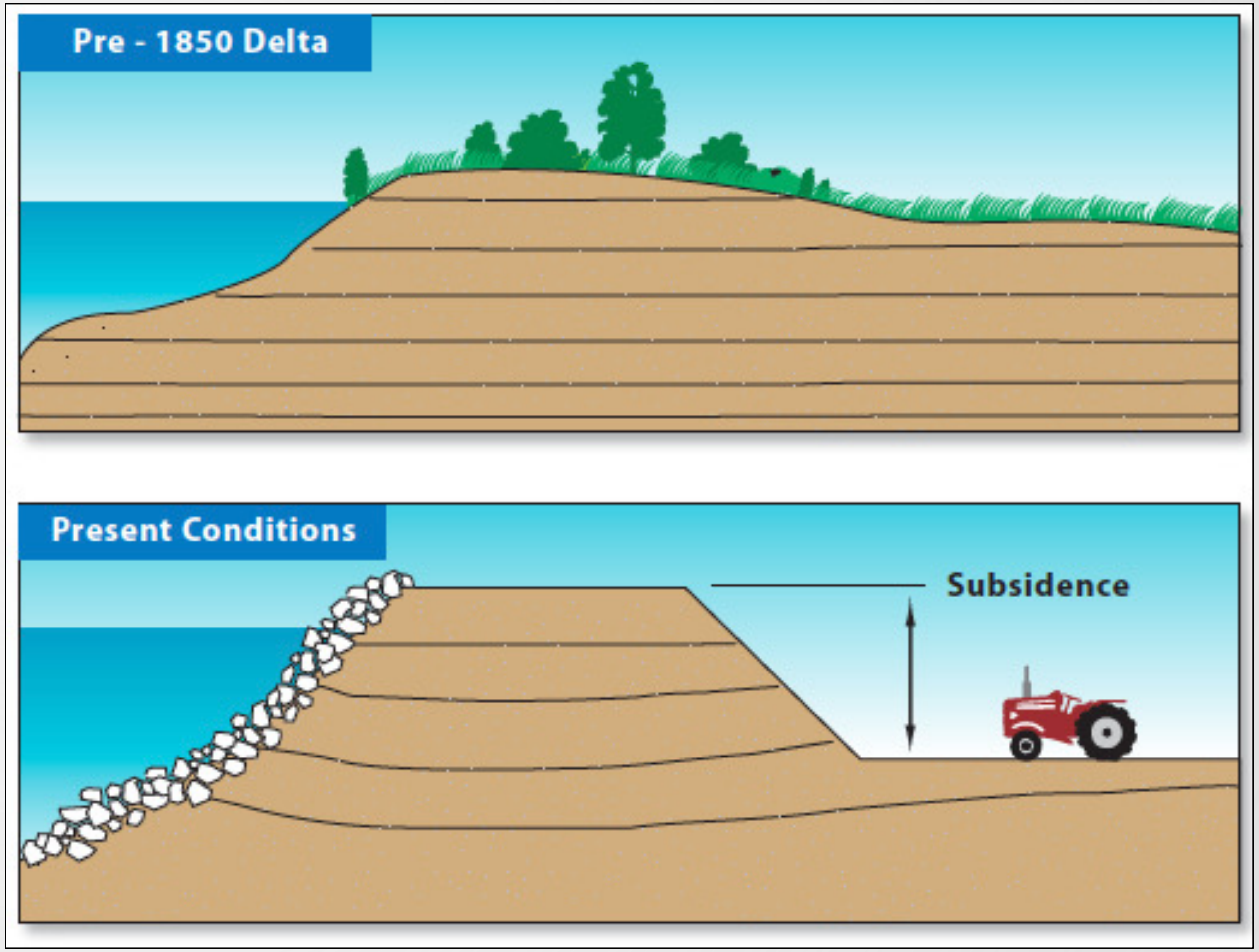
Delta ERT

- Sacramento & San Joaquin River Inflows
- SWP & CVP Exports
- Western Delta Saline
- Eastern Delta Fresh



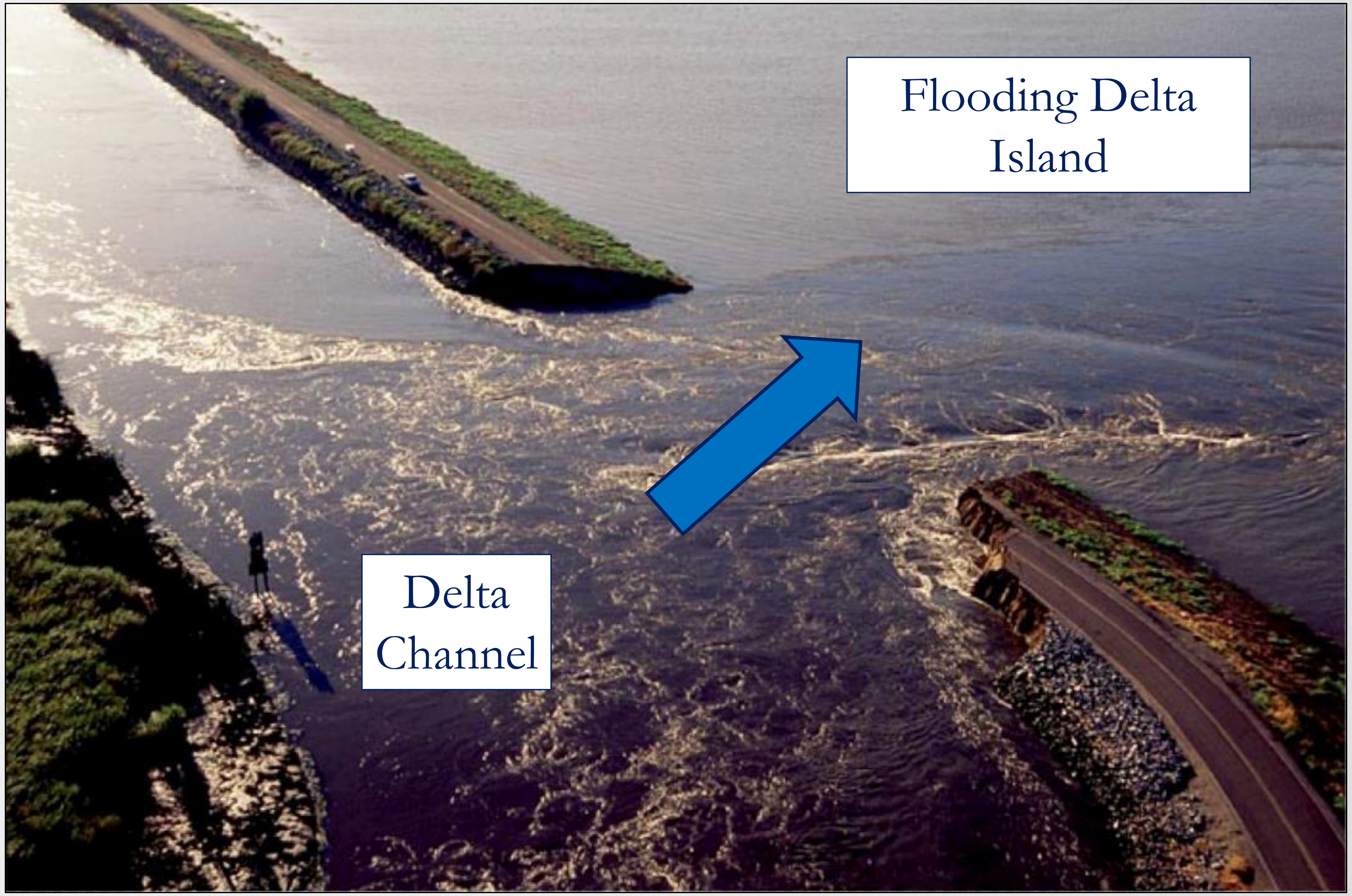
Delta Subsidence

- Land surface below sea level
- Water in Delta Channels much higher than adjacent land
- “Bowl” like islands create large voids in Delta terrain



Delta Levee Failure

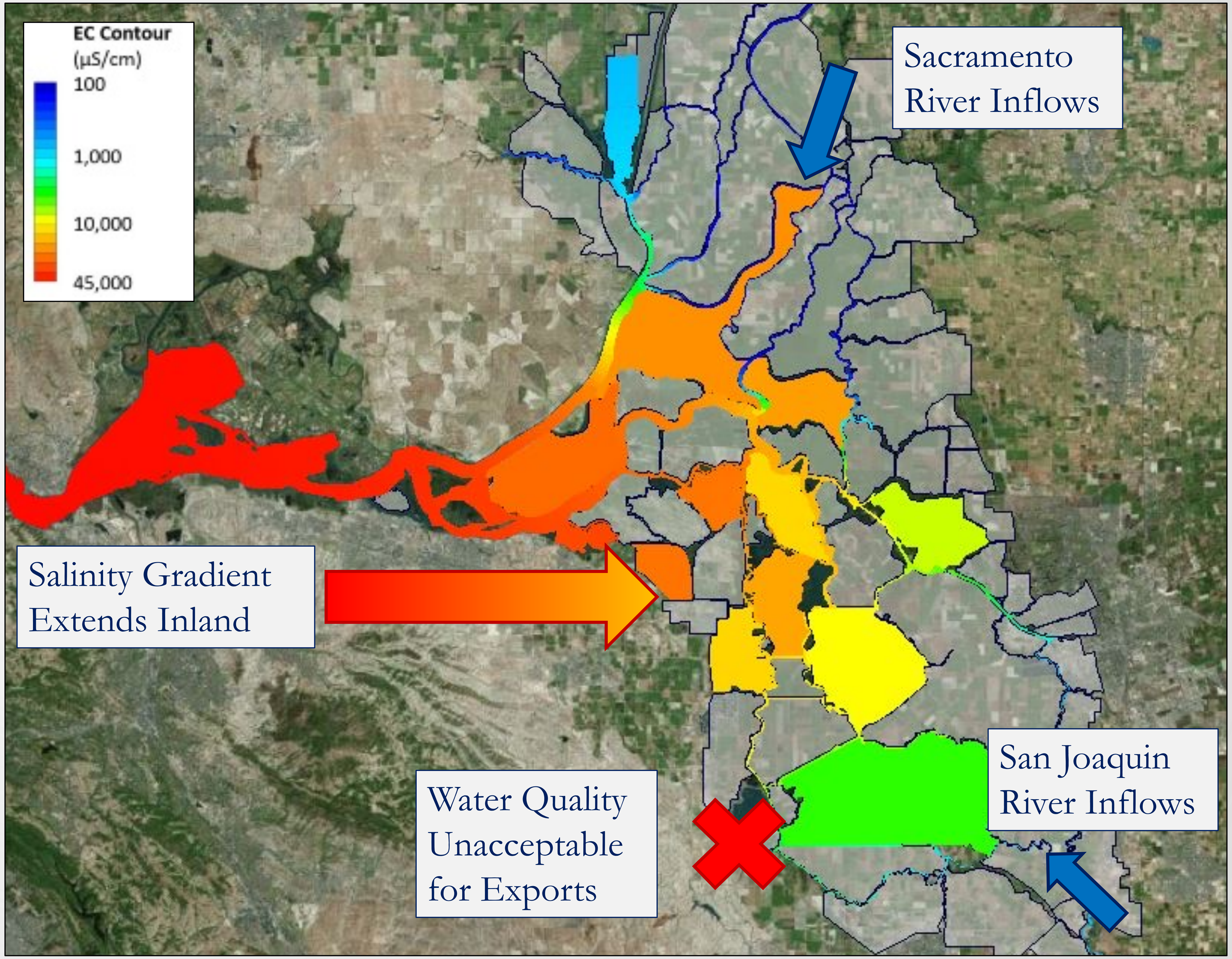
- Levee breach results in complete flooding of island
- Flooding island displaces large volume of water from Delta channel



Delta Post Levee Failures

Delta ERT

- Seismic event causes multiple levee breaches
- Flooding islands pulls saline water from bay
- Saline water fills islands and export corridors
- Exports halted



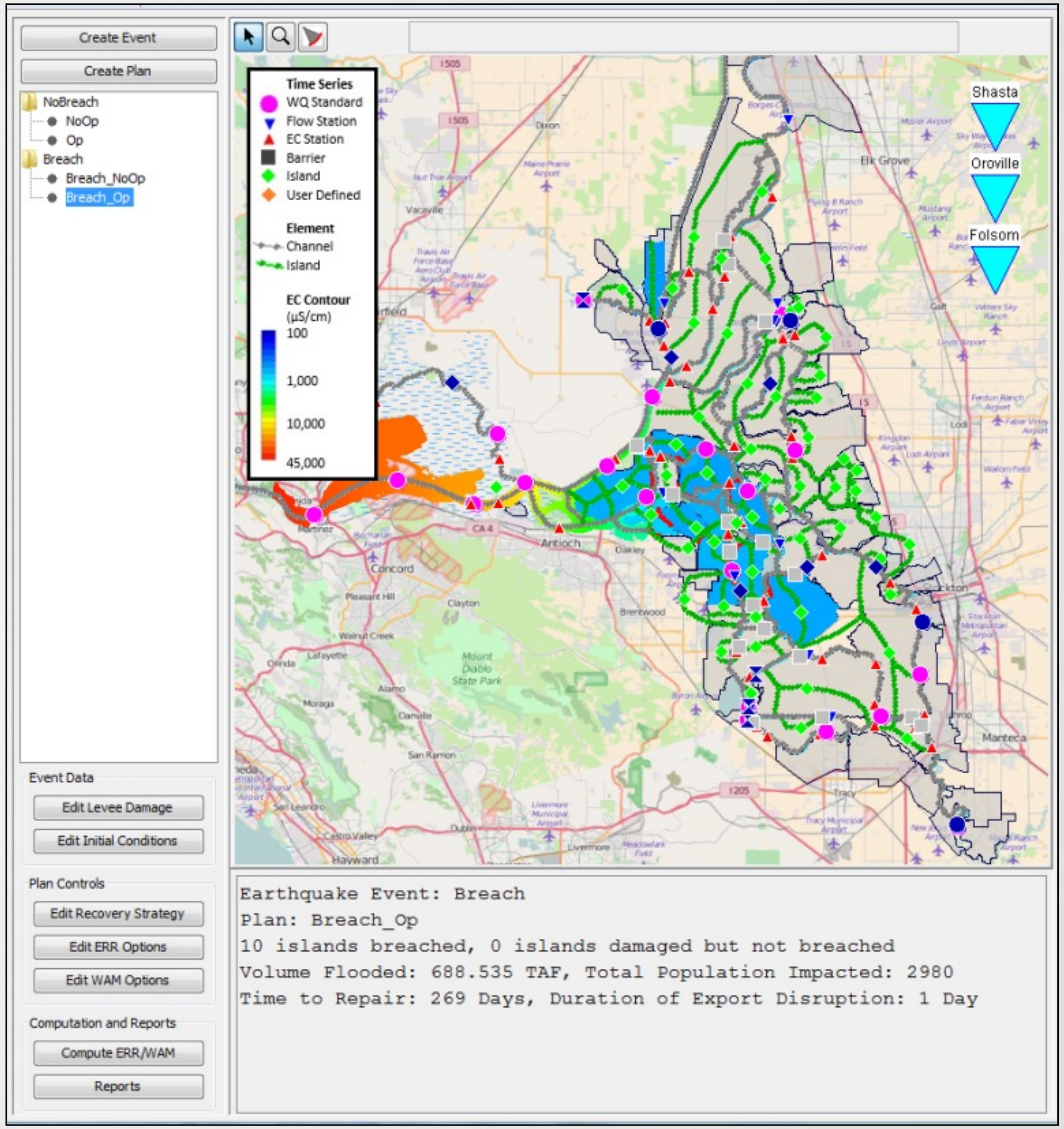
Recovery Actions

Delta ERT

- Channel Barriers
- Reservoir Releases
- Levee Repair
- Delta Cross Channel
- SWP Operations
- Island Pump Out
- Timing/Ordering

Model Overview *Delta ERT*

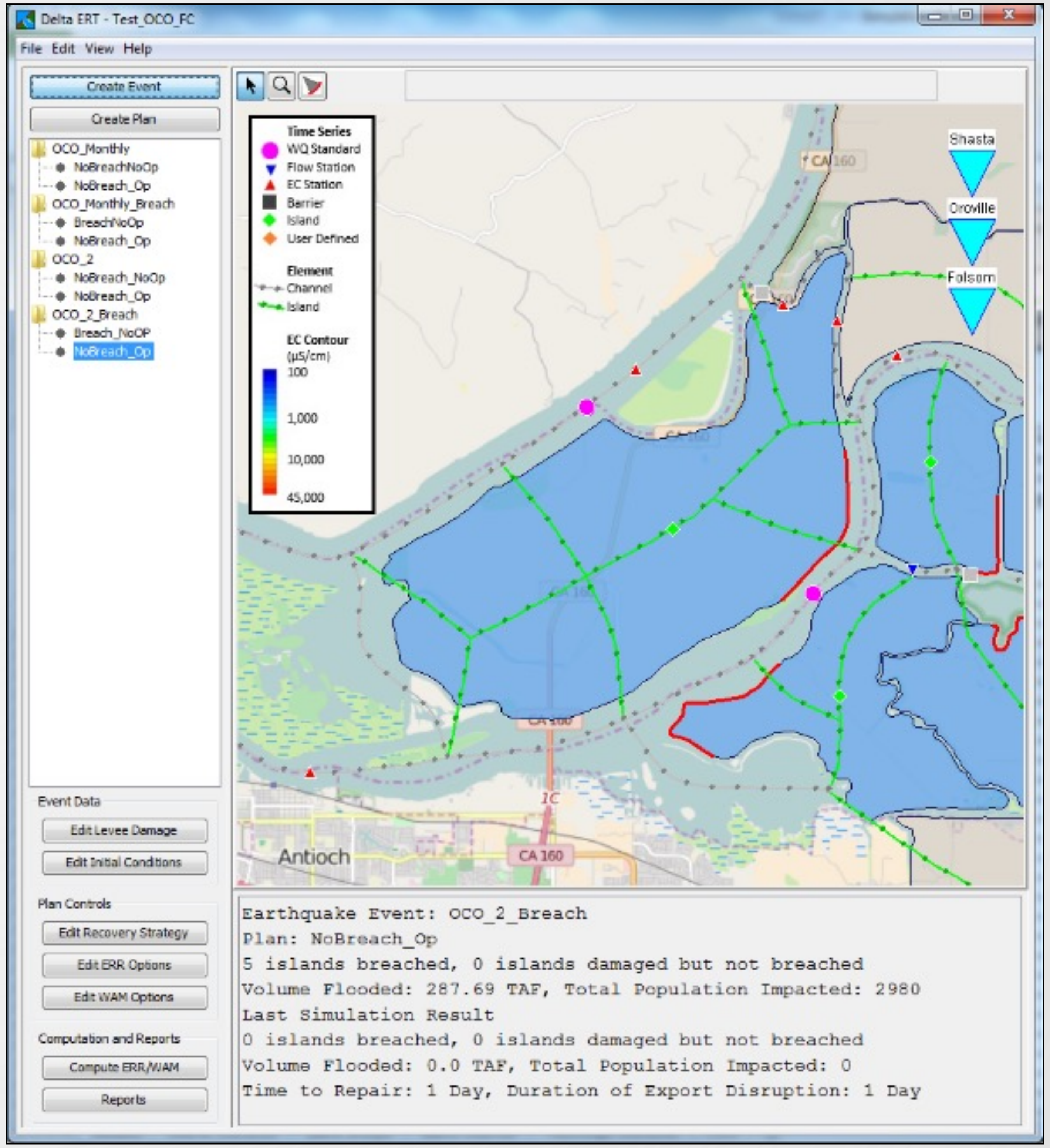
- Test various response strategies quickly
- Provide preliminary estimates of cost and time for repairs
- Computes water quality impacts due to levee failures and response
- Determine optimal suite of response actions



Model Inputs

Delta ERT

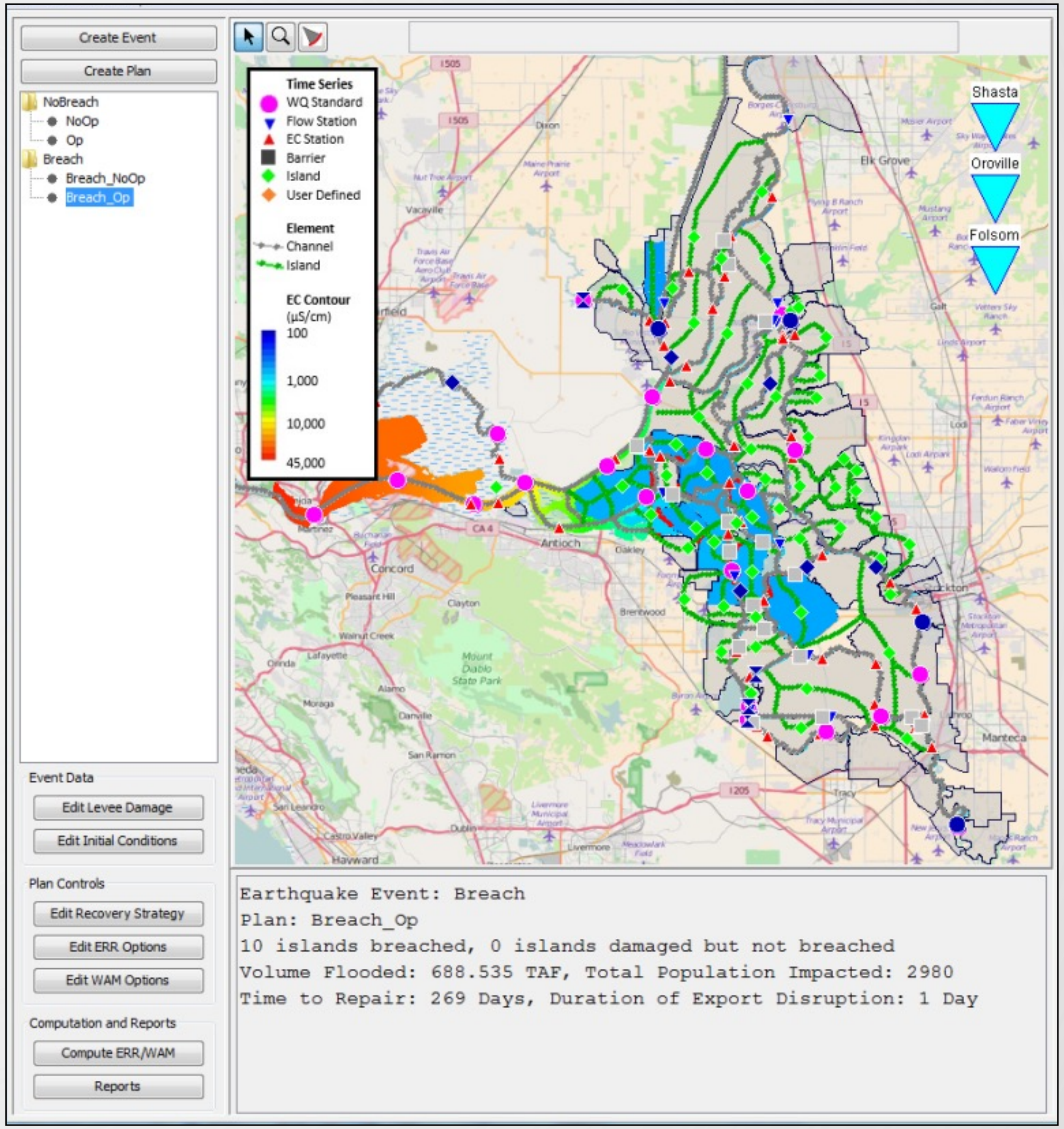
- Levee damage
- Current conditions & forecasted inflows
- Recovery strategy:
  - Repair Priorities
  - Barrier Placement
  - Reservoir releases
  - Delta Cross Channel
  - SWP Operations



Simulation Process

Delta ERT

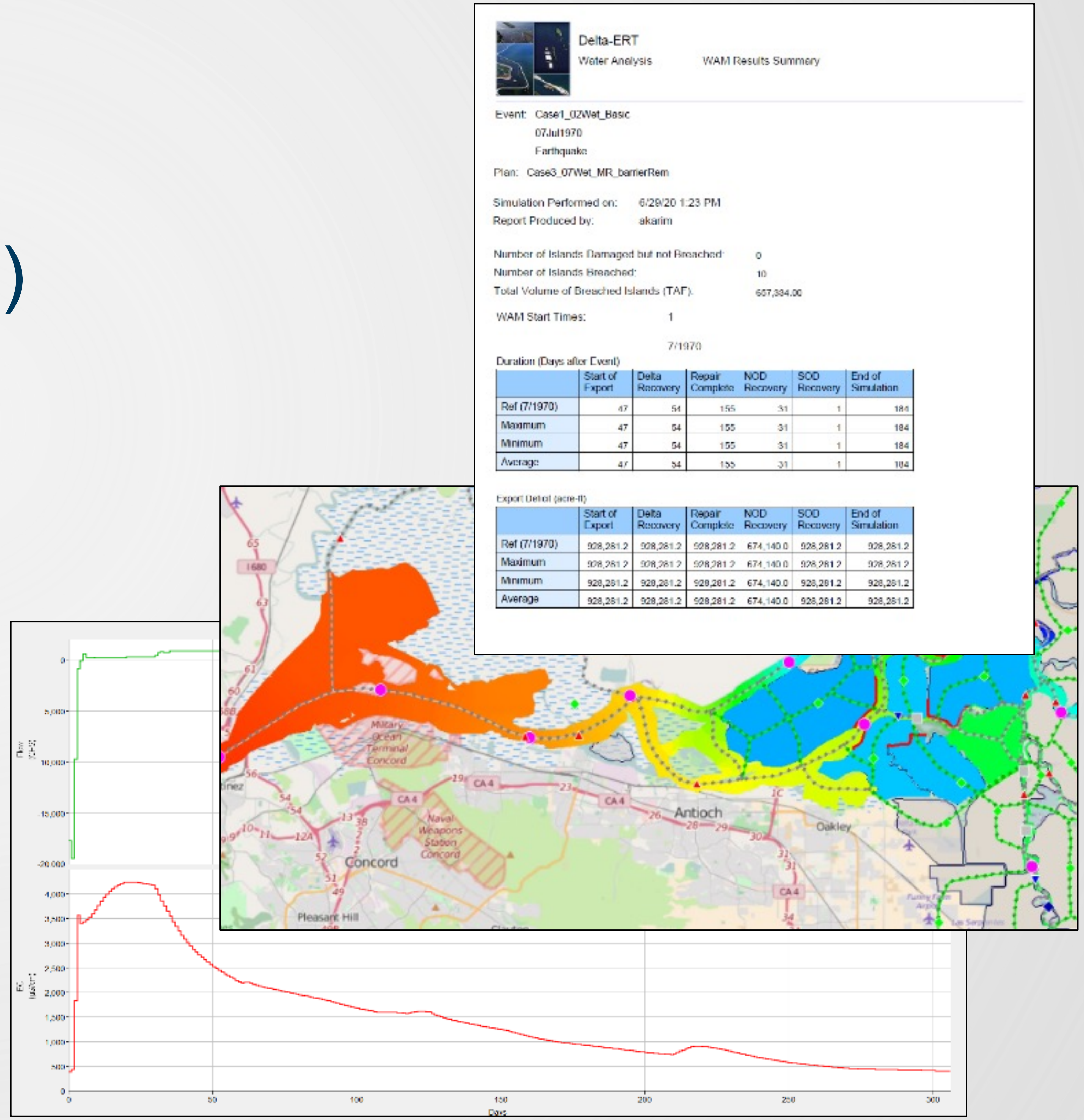
- **Phase 1 – Physical Repairs**
  - Levee Repairs
  - Channel Barriers
  - Calculates Time and Cost
- **Phase 2 – Hydrodynamics**
  - Dynamic Geometry
  - Forecasted Inflows
  - Additional Response Actions
  - Computes Salinity



Model Outputs

Delta ERT

- High-level Output
  - Time to complete repairs
  - Cost (levees, barriers, dewatering)
  - Export disruption time
  - Export deficit
- Detailed Output
  - Timeseries
  - Salinity contour animations



Delta-ERT
Water Analysis WAM Results Summary

Event: Case1_02Wet_Basic
07Jul1970
Earthquake
Plan: Case3_07Wet_MR_barrierRem

Simulation Performed on: 6/29/20 1:23 PM
Report Produced by: akarim

Number of Islands Damaged but not Breached: 0
Number of Islands Breached: 10
Total Volume of Breached Islands (TAF): 657,384.00

WAM Start Times: 1

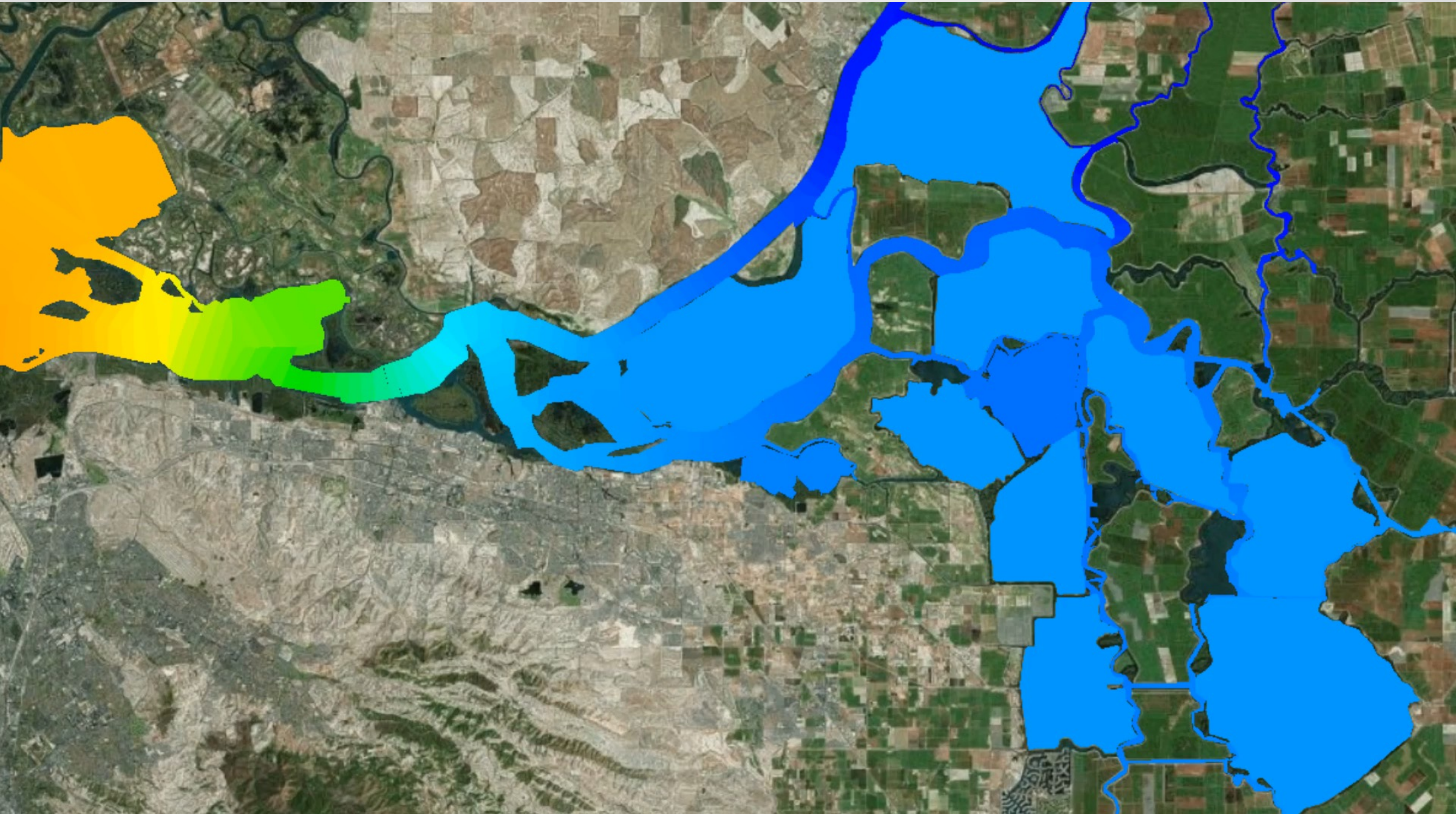
7/1970

Duration (Days after Event)

	Start of Export	Delta Recovery	Repair Complete	NOD Recovery	SOD Recovery	End of Simulation
Ref (7/1970)	47	54	155	31	1	184
Maximum	47	54	155	31	1	184
Minimum	47	54	155	31	1	184
Average	47	54	155	31	1	184

Export Deficit (acre-ft)

	Start of Export	Delta Recovery	Repair Complete	NOD Recovery	SOD Recovery	End of Simulation
Ref (7/1970)	928,281.2	928,281.2	928,281.2	674,140.0	928,281.2	928,281.2
Maximum	928,281.2	928,281.2	928,281.2	674,140.0	928,281.2	928,281.2
Minimum	928,281.2	928,281.2	928,281.2	674,140.0	928,281.2	928,281.2
Average	928,281.2	928,281.2	928,281.2	674,140.0	928,281.2	928,281.2



Delta ERT Machine Learning Module

Barrier Strategy Optimization

Objective for Machine Learning

- Suggest Good Repair Strategies for simulated Breach Events
  - Suggestions need to be generated quickly
  - Suggestions should be approximately optimal
  - Suggestions should be unique and tailored
  - Suggestions should be novel
- Similar to a Search Engine

Basic Search Engine

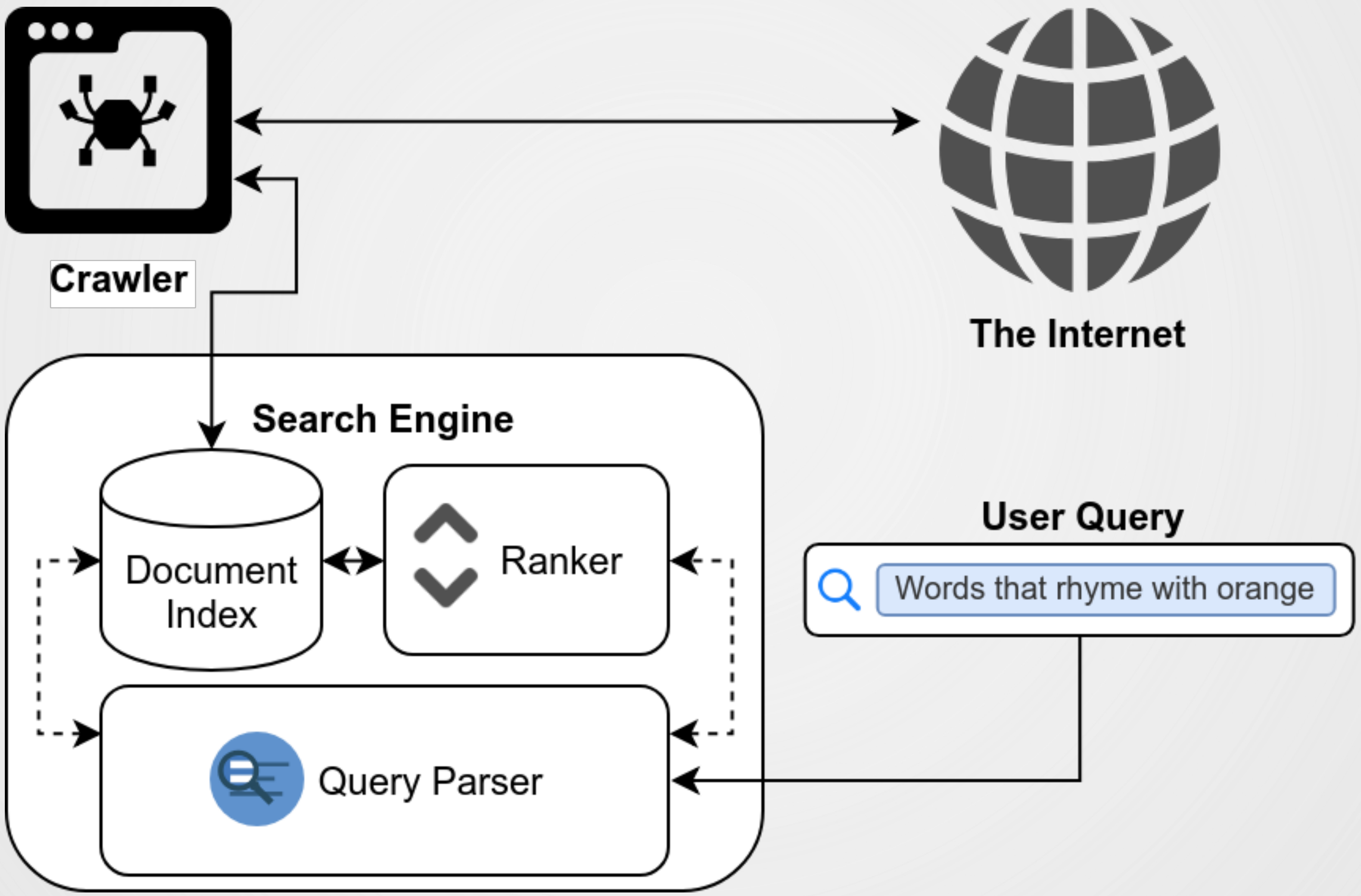


*Image Courtesy Muuo Wambua

What Determines Magnitude of Disruption to Water Supply Systems?

- Hydrology
  - River inflows for upcoming months
- Current salinity field
  - X2 location
- Islands that have breached

Given Conditions:
we know or can estimate these

- Installation of temporary barriers
- Island repair order
- Reservoir pulse releases

Repair/recovery strategies:
we can try different things to flush the salt out faster

Recommendations as Information Retrieval

- The set of **Given Conditions** is the query
- The suggested **Repair Strategies** are the query results
- Results to be sorted from best to worst
  - In Machine Learning this type of sorting problem is called "Learning to Rank" (LTR)

Learning to Rank

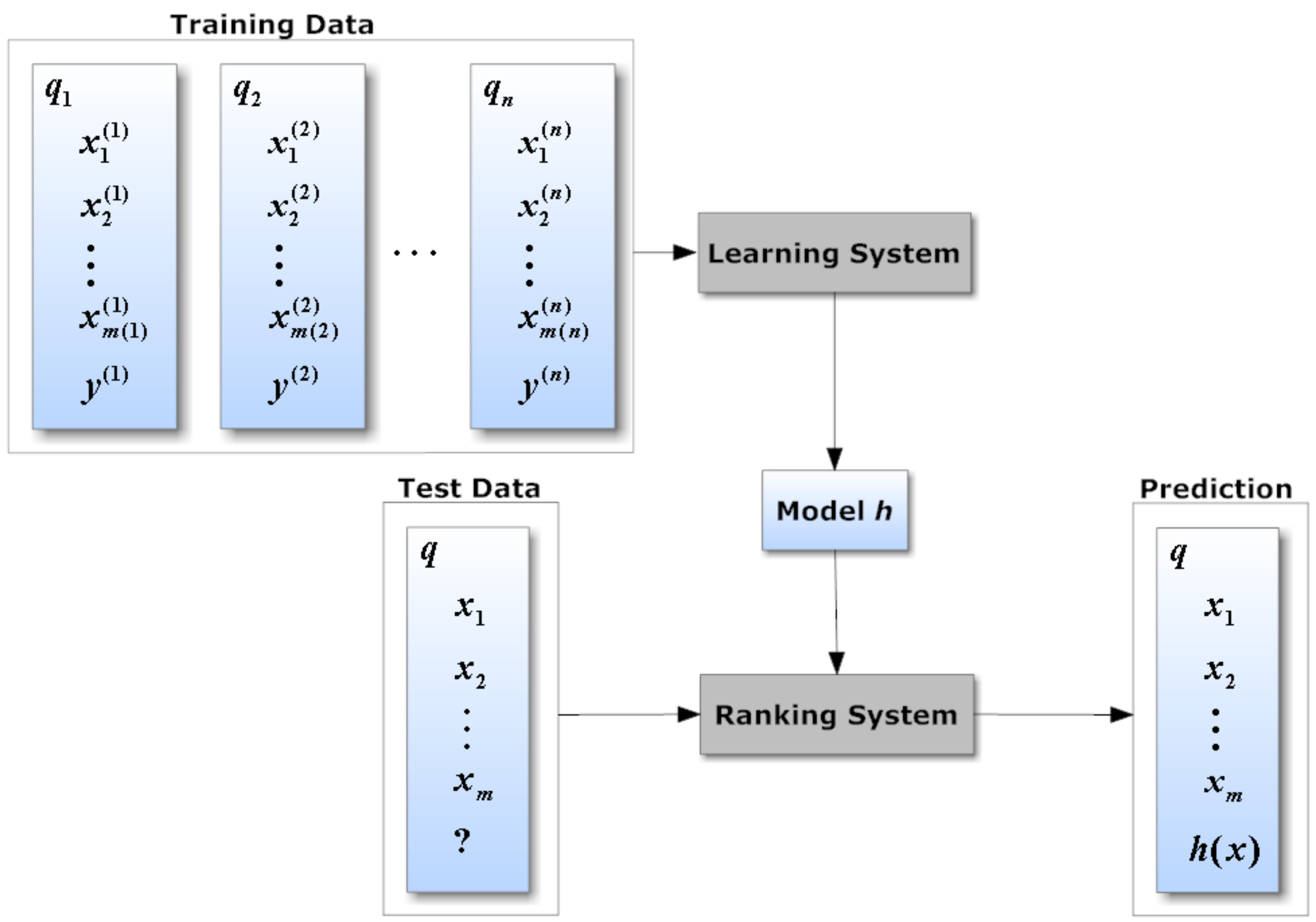


Image courtesy: [Catarina Moreira]

Q are the queries

X are the documents

The X are ordered (1-m) and grouped by query

The model is trained on a dataset of queries with ordered results

At prediction time the model is given a new query and a set of documents and it predicts the relevance of each document

Building a Training Dataset

- Select Breach Events
  - Include a range of breach sizes
  - Include a variety of hydrologies
- Select Repair Strategies
  - Needs to include near optimal strategies
  - Needs to include variety, unusual and novel strategies
- Save and tabulate input to each simulation
  - Initial salinity field, hydrology, breached islands, repair order, barrier configuration
- Run the model
- Order by the Days of Export Disruption

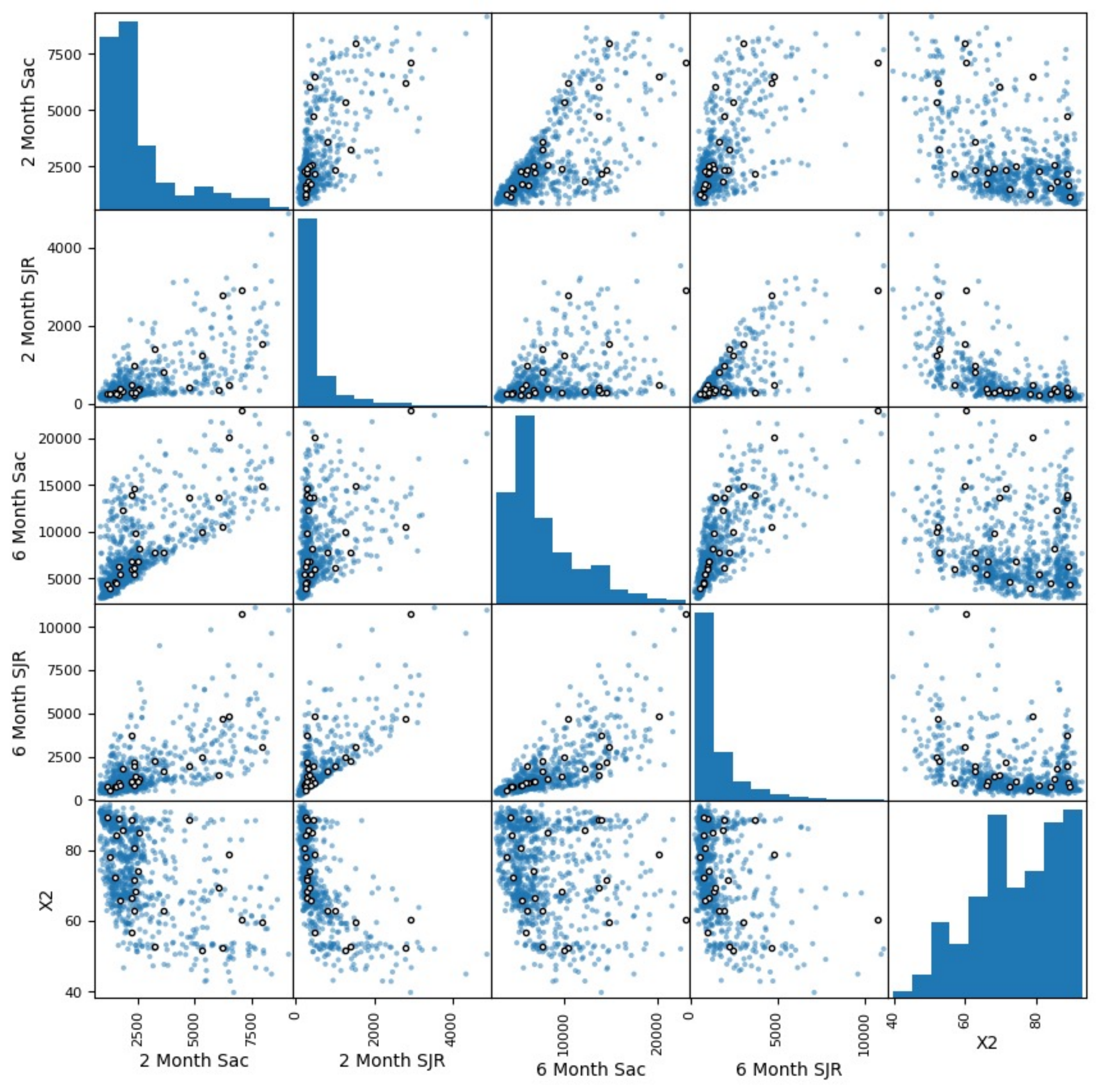
Dataset Size

- How many can we run?
  - Each simulation takes ~1 minute
  - 1 week ≈ 600,000 simulations
  - 8 Amazon cloud compute instances ≈ 5M simulations
- Unfortunately the problem is very, very large.
  - 81 years (972 months) of available start times (hydrology, initial conditions)
  - 53 possible islands to breach
  - 21 possible barrier locations to use
  - For a 10 island breach event:
    - "53 choose 10" ≈ 1.9 x 10^{10} island breach combinations
    - "21 choose 5" ≈ 20,000 combinations of 5 barriers
    - 10! = 3.6M repair orders

We can explore 3.6 x 10^{-13} % of the space

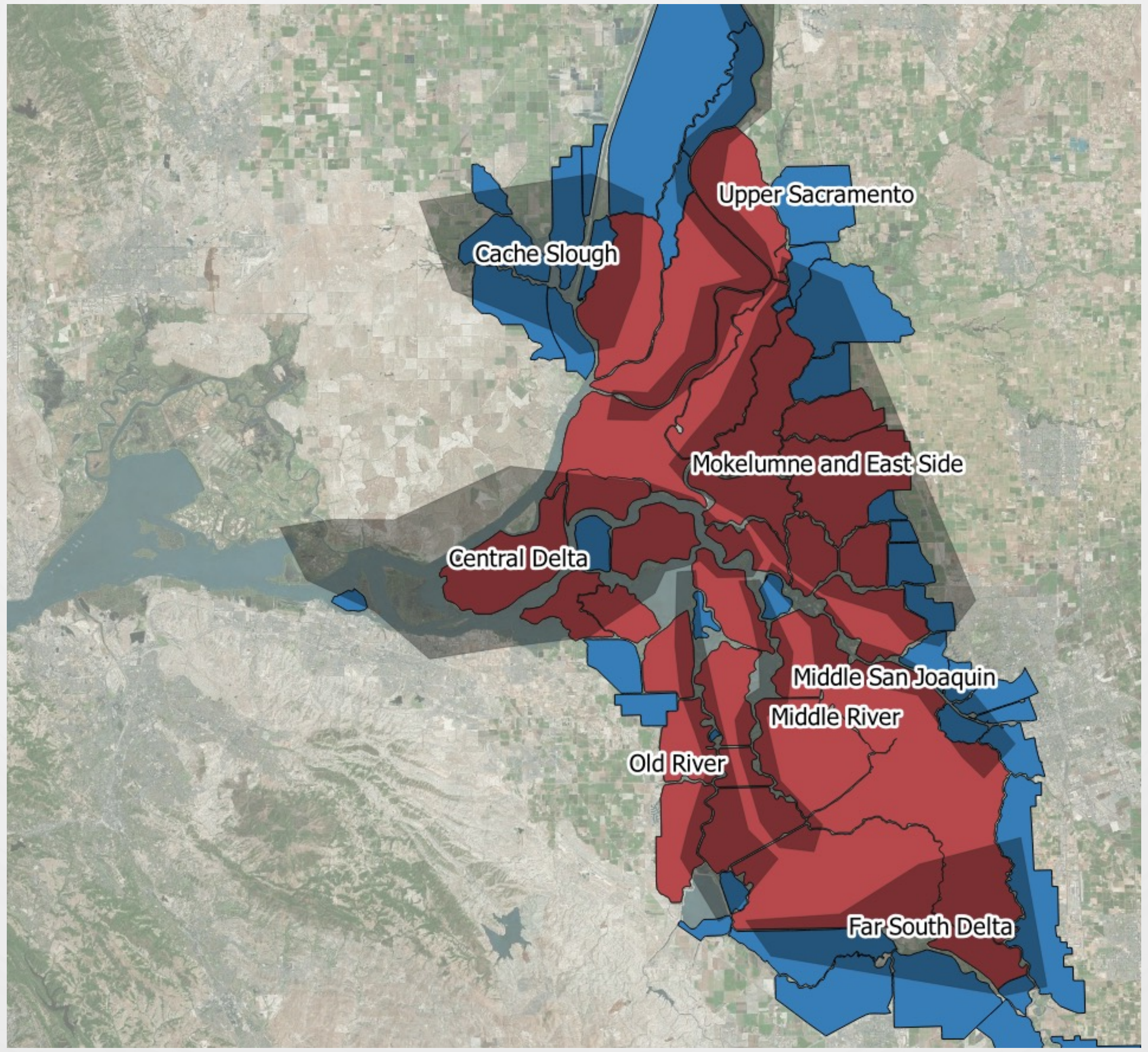
Hydrology Subsampling

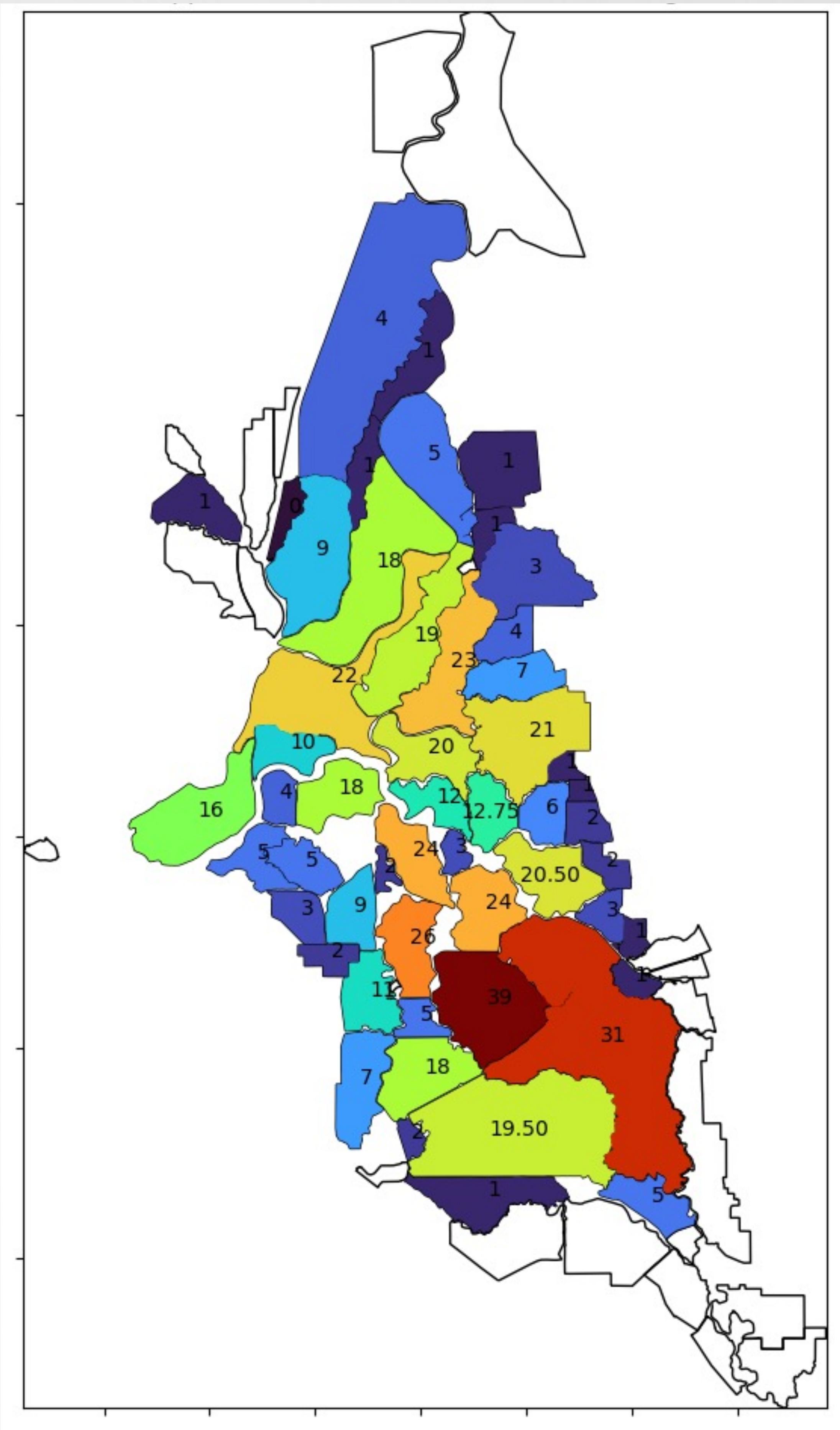
- Hydrology and initial salinity field (X2) broken down into 2-month and 6-month Sacramento and San Joaquin inflow volumes
- Cluster analysis to choose a representative subset of all the available conditions
  - Blue dots = all 972 start times
  - White dots = cluster centers



Breach Event Subsampling

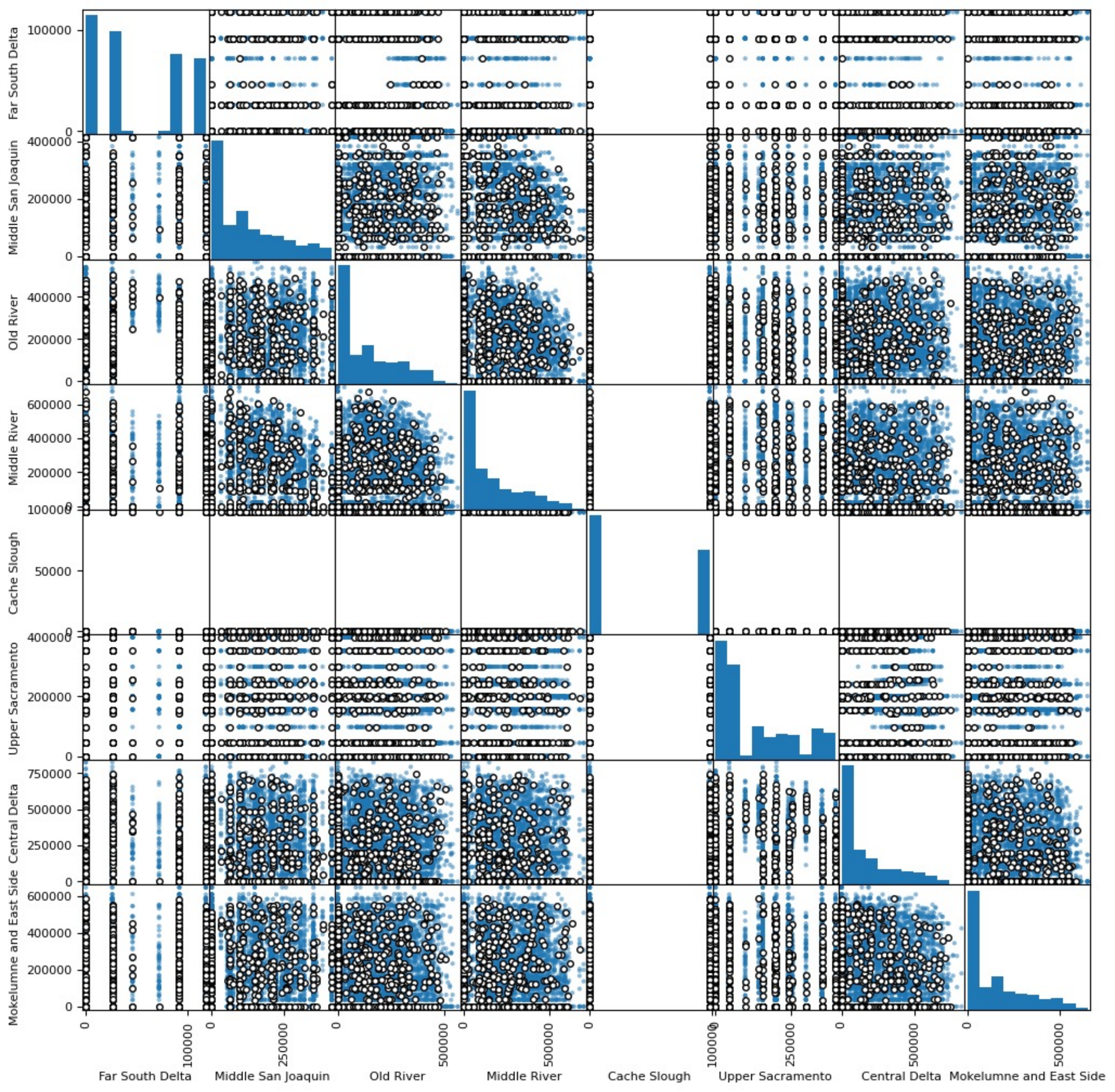
- Only consider islands large enough or who's geographical location causes it to have a large impact on exports
  - 53 islands down to 30
- Classify islands by volume located along each river corridor
  - Assume similar island volume along the same corridor gives a similar result





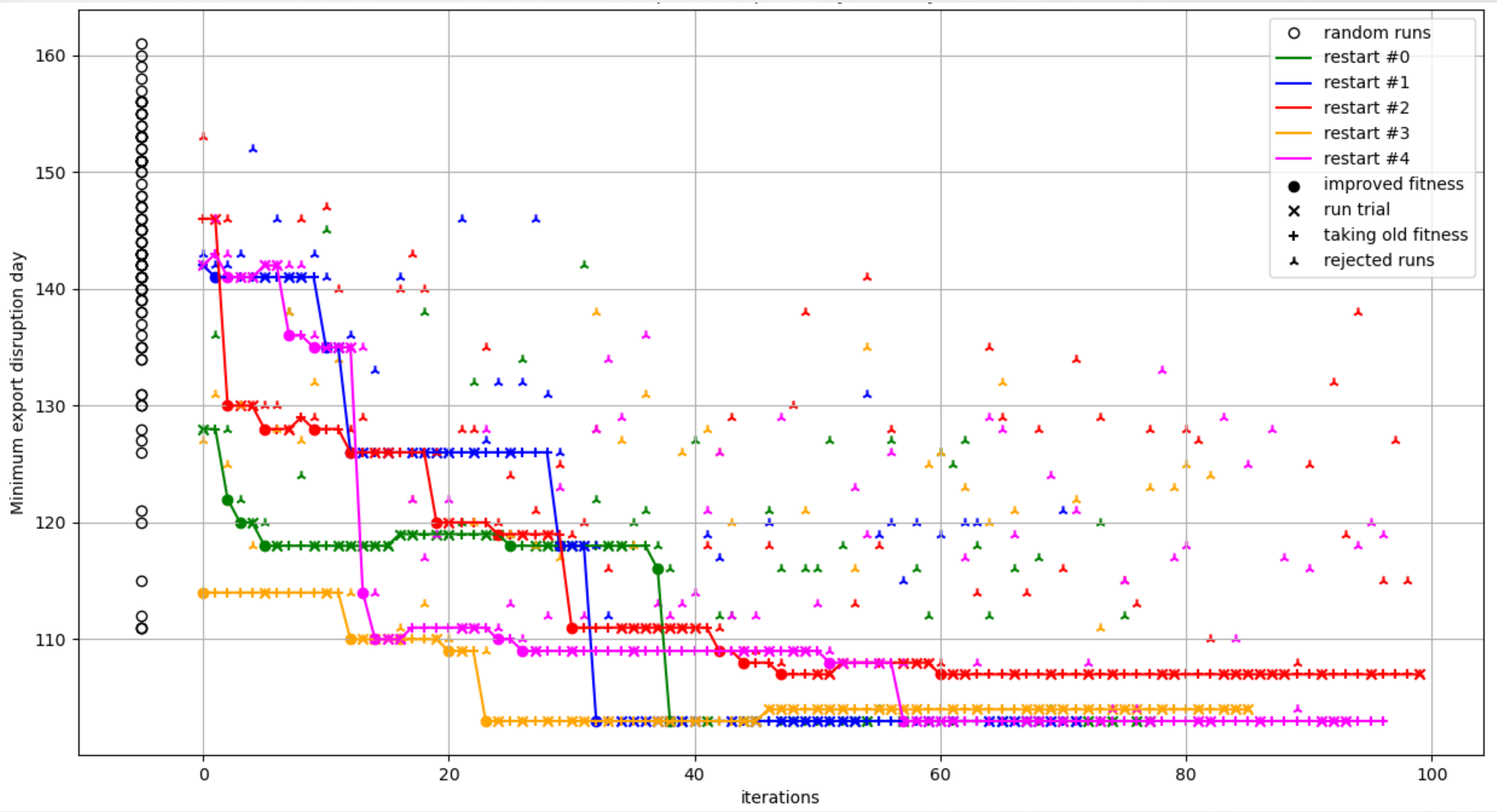
More Clustering to Subsample

- Choose 2,000 breach events
- Even distribution over river corridors so ML algorithm can be exposed to all manner of events
  - E.g., only South Delta islands
  - Only Central Delta islands
  - These combinations unlikely if breach events chosen at random



Randomized Optimization for Testing Barrier Strategies

- Simulated annealing method
- Given a breach event, start with a random set of barriers
- Swap one (barrier added or removed)
- Accept result if it's better, else reject



Ranker

Used LightGBM library from Microsoft

Uses Gradient Boosted Decision Trees

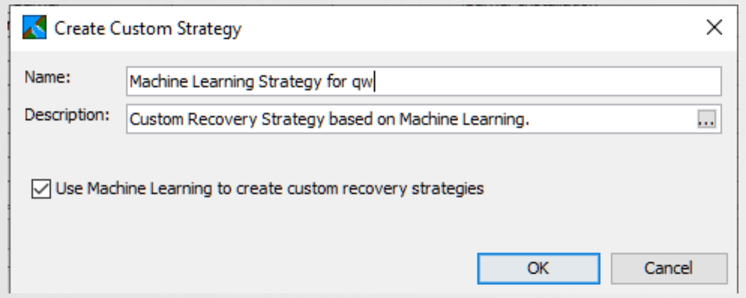
Review Methods Used

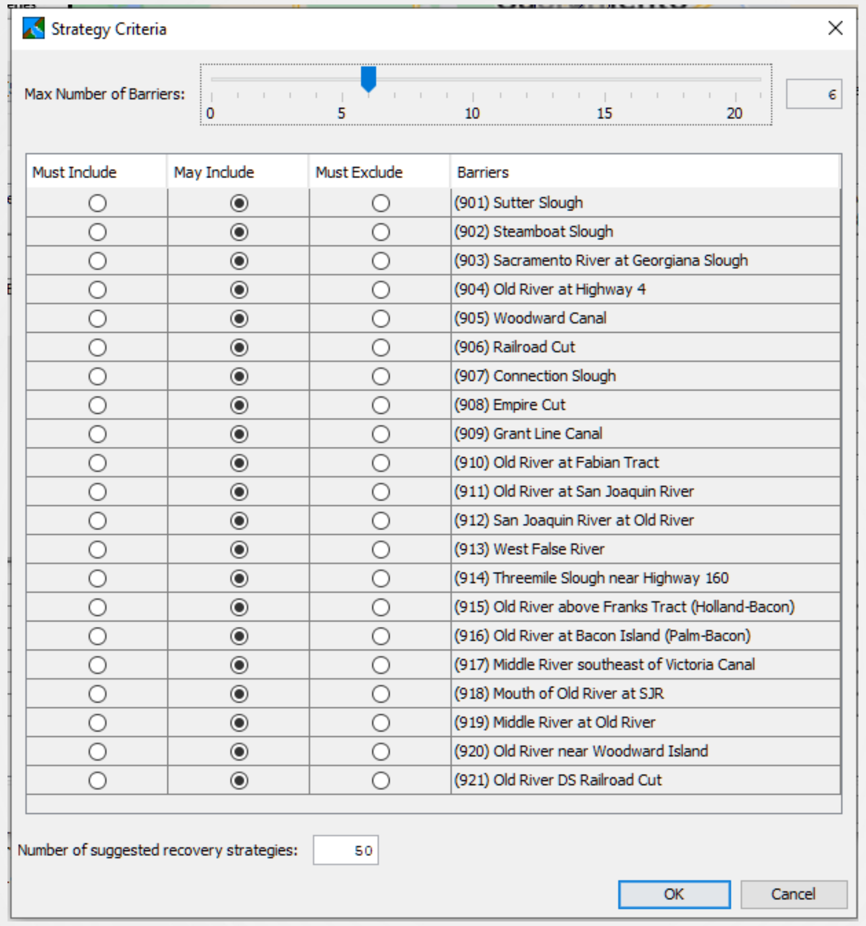
- Unsupervised Learning (Clustering)
  - Subsample problem space
- AI (Randomized Optimization)
  - Build training dataset
- Supervised learning (Learning To Rank)
  - Train model

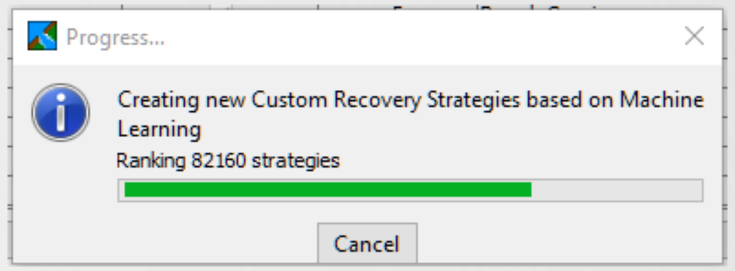
Feature Importance

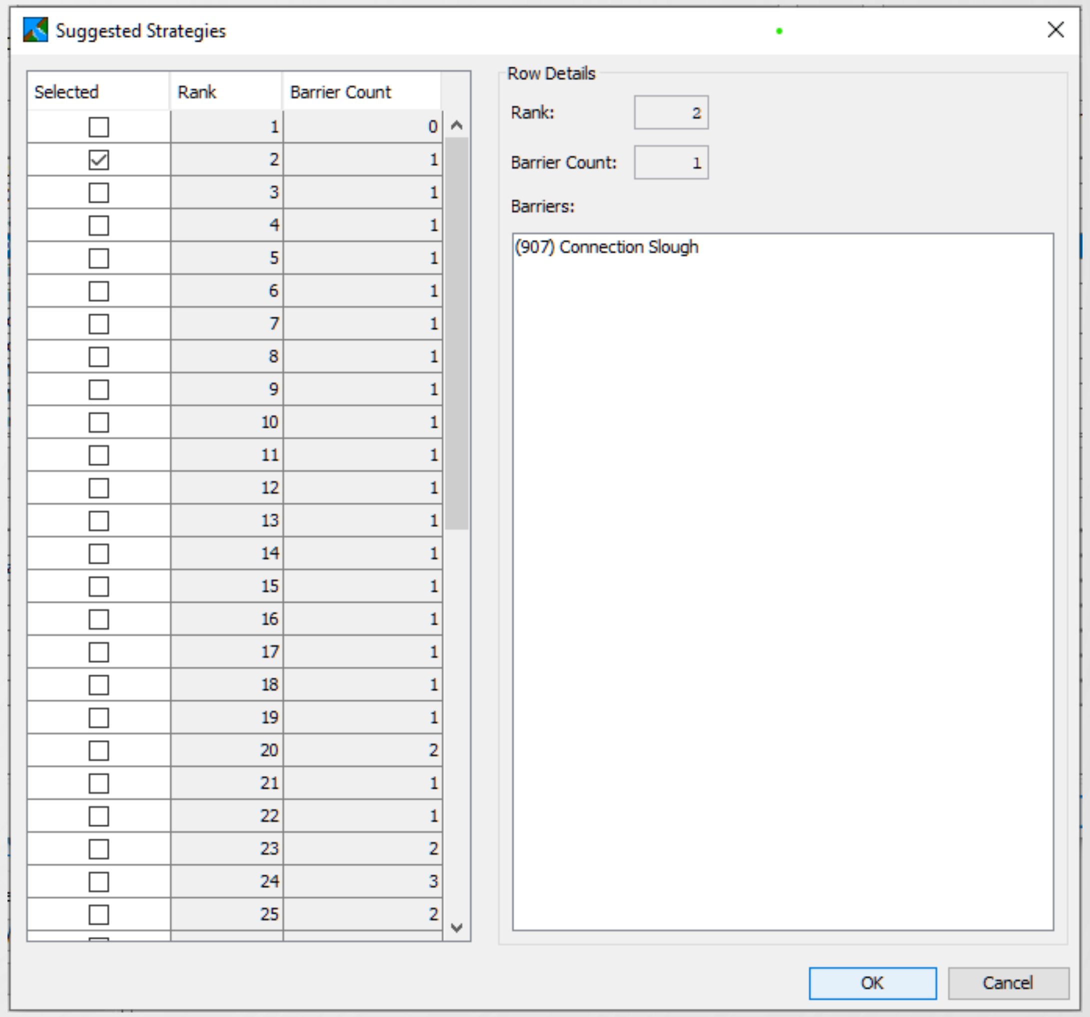
- A trained ML algorithm can give insight into the system
- Start time (future hydrology) is important!
- Barrier 912 = San Joaquin River downstream of head of Old River
  - Good
- Barrier 911 = Old River downstream of head of Old River
  - Bad
- Corridor 3 = Middle River

Screenshots



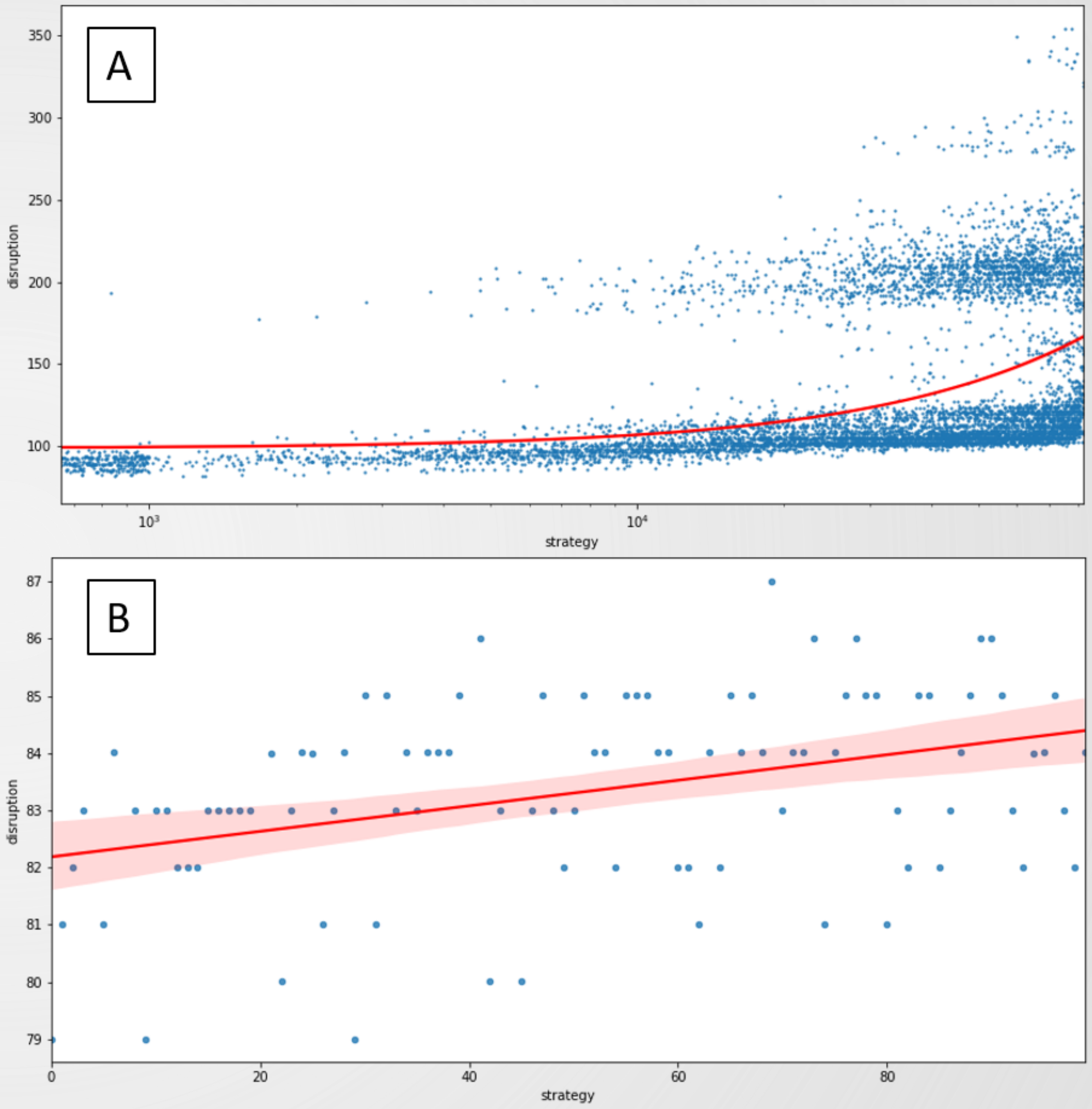






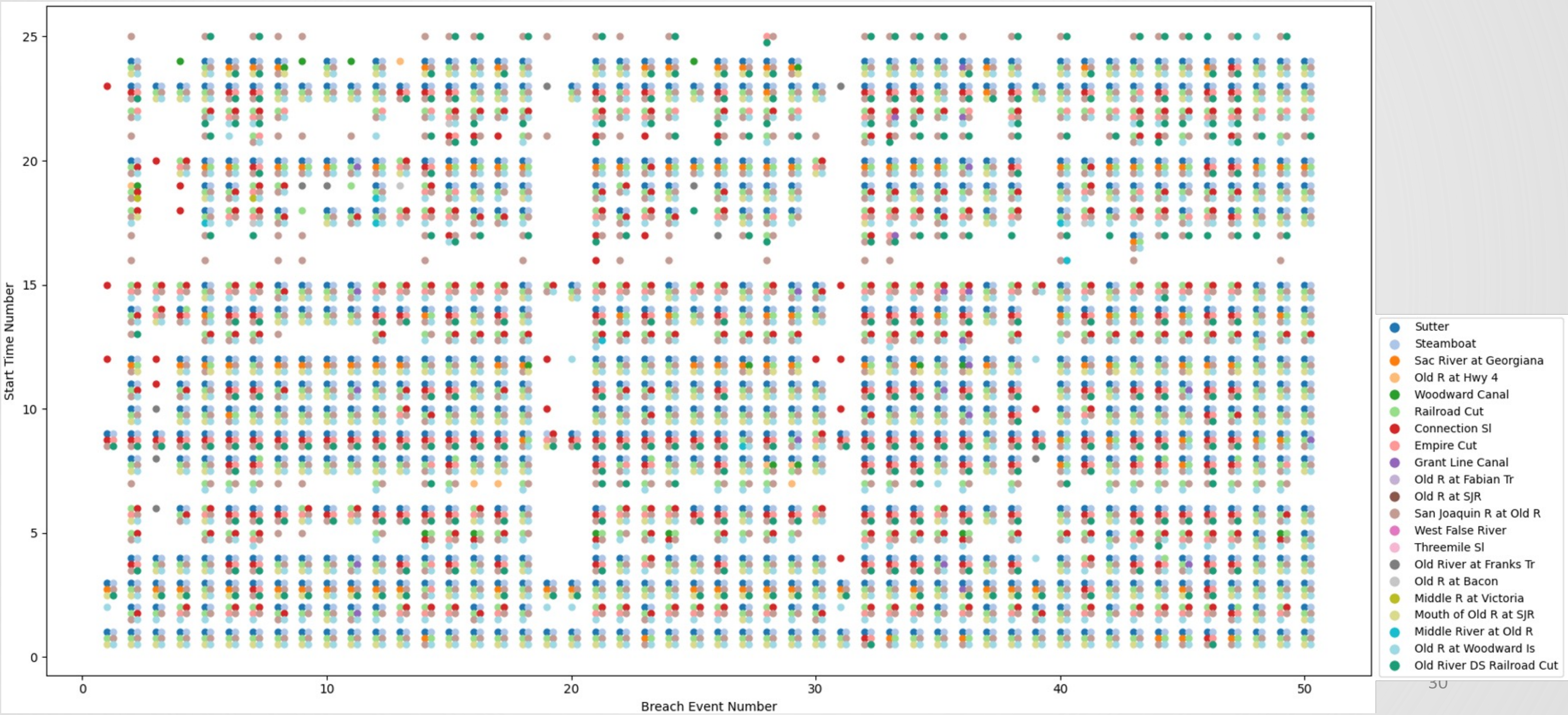
Model

Are the top barrier configurations suggested by the ranker actually the best ones?

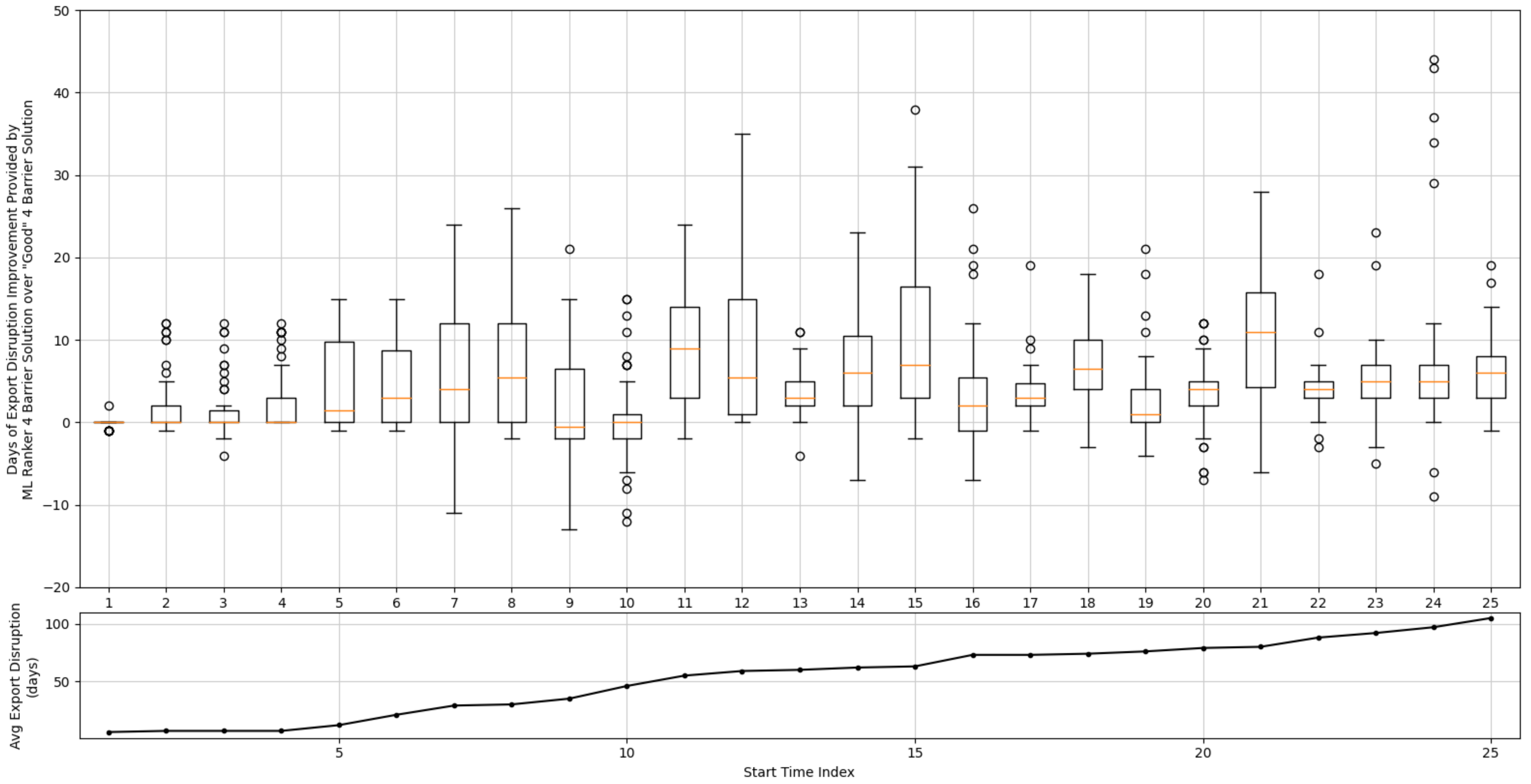


- Run one simulation with the top 1,000 ranked barrier configurations + 10% of the remaining possible combinations

Does the ranker generate tailored solutions?



Is the ranker better than a good guess?



Validation of Objectives

1. Is it quick?
    - Yes. 6s – 60s
2. Are the suggestions optimal ?
    - Approximately
3. Are the strategies tailored?
    - Yes
4. Are the suggest strategies novel?
    - Yes

Recap

- Multi-levee failure events in the Delta may occur
- They can cause significant disruptions to California’s water supply
- Effective response strategies can help mitigate impacts to water supply
- Delta hydrodynamics are complex – modeling can help
- Running many simulations and training a ML to look for patterns can help in an emergency as well as aid in our understanding of the system

Questions?

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