CALIFORNIA DEPARTMENT OF WATER RESOURCES & RESOURCE MANAGEMENT ASSCOIATES

Delta Emergency Response Tool Machine Learning Module



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Outline

- Background
- Model Overview
- Machine Learning Module

Delta ERT

Delta Normal Conditions

- 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

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



Recovery Actions

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









Model Overview

- 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

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Model Inputs

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



Simulation Process

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

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Model Outputs

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



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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?



Given Conditions: we know or can estimate

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 \approx 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 $10'' \approx 1.9 \times 10^{10}$ island breach combinations
 - "21 choose 5" \approx 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 2month 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



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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

SOD Storage



Feature Importance

Screenshots

K Create C	ustom Strategy	×
Name:	Machine Learning Strategy for qw	
Description:	Custom Recovery Strategy based on Machine Learning.	
🔽 Use Mad	ine Learning to create custom recovery strategies	
	ОК	Cancel

Must Include	May Include	Must Exclude	Barriers
0			(901) Sutter Slough
0		0	(902) Steamboat Slough
0		0	(903) Sacramento River at Georgiana Slough
0	0	0	(904) Old River at Highway 4
0		0	(905) Woodward Canal
0	۲	0	(906) Railroad Cut
0	۲	0	(907) Connection Slough
0	۲	0	(908) Empire Cut
0	۲	0	(909) Grant Line Canal
0	۲	0	(910) Old River at Fabian Tract
0	۲	0	(911) Old River at San Joaquin River
0	۲	0	(912) San Joaquin River at Old River
0	۲	0	(913) West False River
0	۲	0	(914) Threemile Slough near Highway 160
0	۲	0	(915) Old River above Franks Tract (Holland-Bacon)
0	۲	0	(916) Old River at Bacon Island (Palm-Bacon)
0	۲	0	(917) Middle River southeast of Victoria Canal
0	۲	0	(918) Mouth of Old River at SJR
0	۲	0	(919) Middle River at Old River
0	۲	0	(920) Old River near Woodward Island
0	۲	0	(921) Old River DS Railroad Cut

Model

Rec Prog	gress ×
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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?

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Breach Event Number



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?

Contact Information

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