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An open-source implementation of California’s hydroeconomic model

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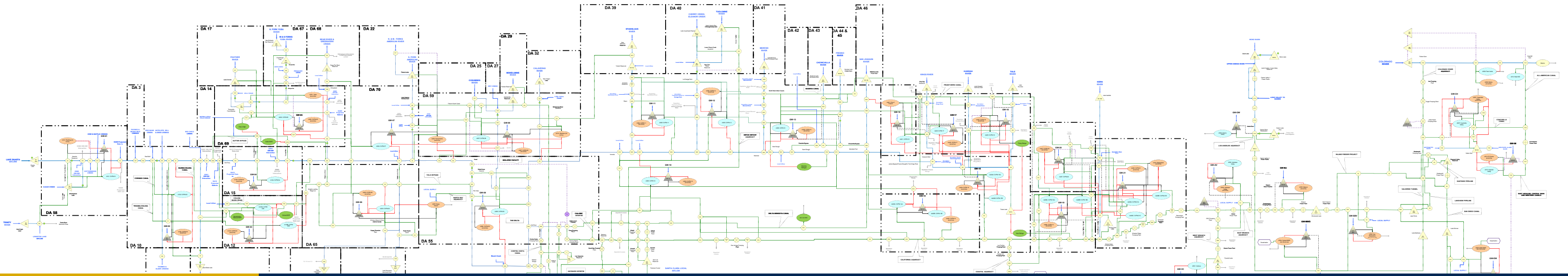


Summary

Improve hydroeconomic model, CALVIN, & turn into open-source

- Modeling (structural) improvements
- Database improvements
- Open-source implementation
- Runtime benchmarks
- Some results

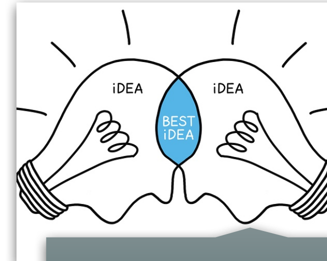
Goals

cross-platform

open data formats

freely available

separation of model & data



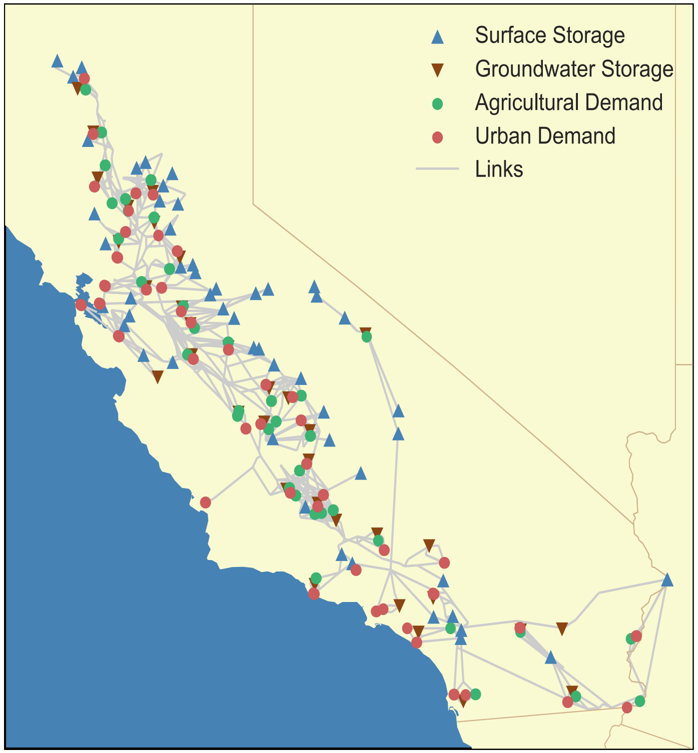
collaboration

- Model should run on Windows/OSX/Linux
- Use only common formats such as CSV & JSON
- Programming language & solvers should be free and open-source
- Dataset independent from any particular model
- Model & modeler communication

CALVIN

- Hydroeconomic optimization model for California's water infrastructure
- ~90 % of urban & agricultural activities
- Environmental requirements
- Groundwater & surface water used conjunctively
- Optimize water allocation to users
- Minimize statewide operating & scarcity costs

Network flow model



(CALifornia Value Integrated Network)

- Nodes
  - Reservoir, demand location, pumping & power plant, or joint
- Links
  - Canal, aqueduct, stream
- Linear programming model

$$\underset{X}{minimize}\, Z = \sum_i \sum_j \sum_k c_{ijk} \cdot X_{ijk}$$

subject to:

$$\sum_i \sum_k X_{ijk} - \sum_i \sum_k a_{ijk} \cdot X_{ijk} = 0, \forall (i,j,k) \in A$$
$$X_{ijk} \le u_{ijk}, \forall (i,j,k) \in N$$
$$X_{ijk} \ge l_{ijk}, \forall (i,j,k) \in N$$

where
Z: total cost
X: flow on the link (arc)
c: unit cost (or penalty)
a: amplitude
l: lower bound
u: upper bound

Components

- Large-scale model (~5 million decision variables)
- +1000 nodes, +600 conveyance links, 82-year time horizon with monthly time-step

Inputs:

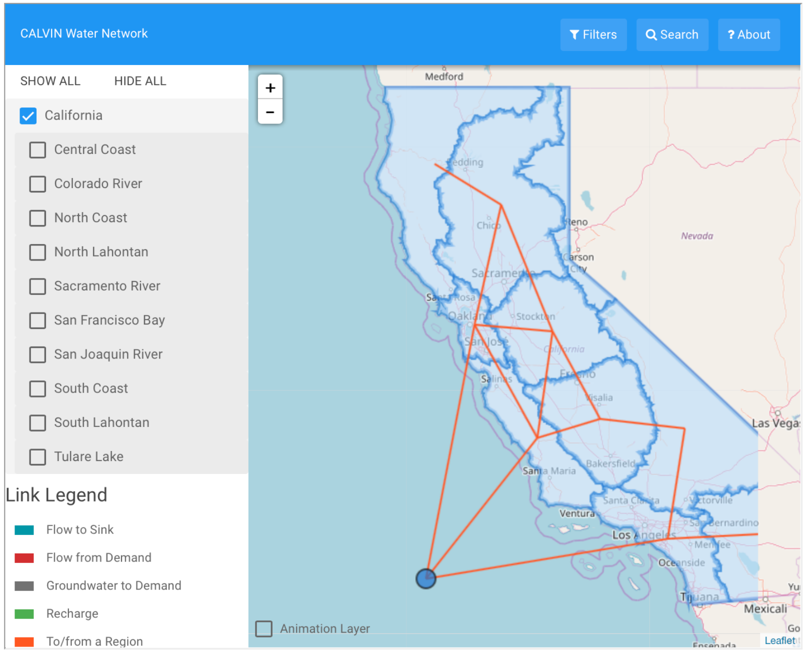
- Hydrology, water demands, operating costs & capacities

Key outputs:

- Water deliveries, shortage costs, reservoir storage, marginal values of water & increasing capacity

Web-based database: HOBBES

- Database for California's water supply network
- Data independent from model
- Store hydrology time-series, demand curves, & physical properties of network
- Tools can export the network in desired format
- Visualize & animate input & output data

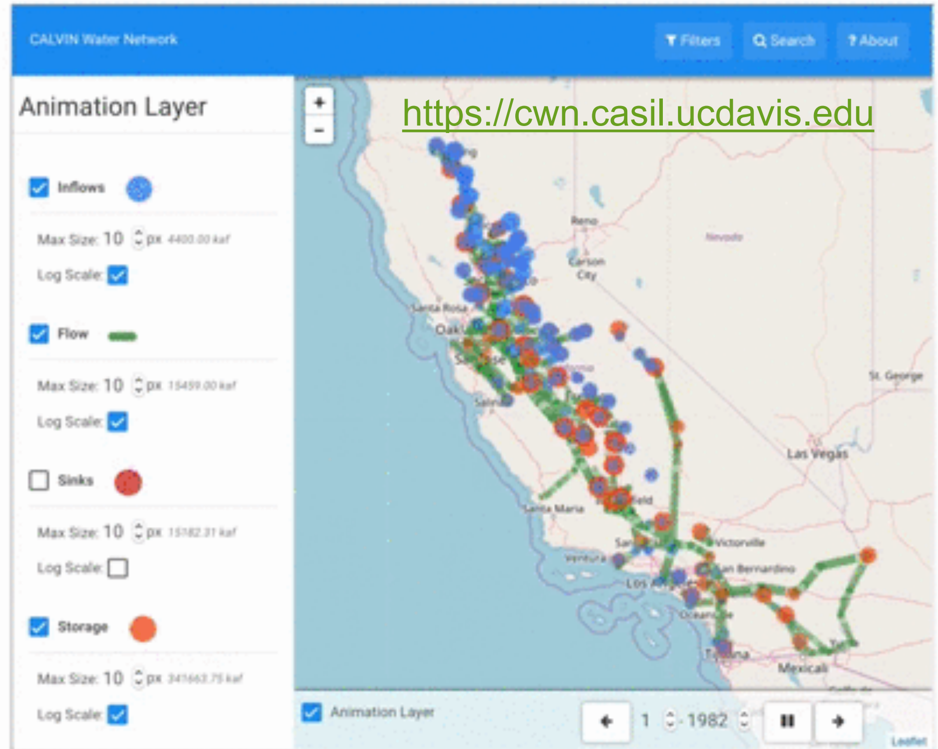


https://hobbes.ucdavis.edu/cwn

Visualization

- Animation layer to visualize inputs (inflow) and outputs (storage, demand & flows on conveyance links
- Size of nodes & links change depending on magnitude of flow & storage
- Your own visualization?

California Water Network



Change in total groundwater storage (MAF)

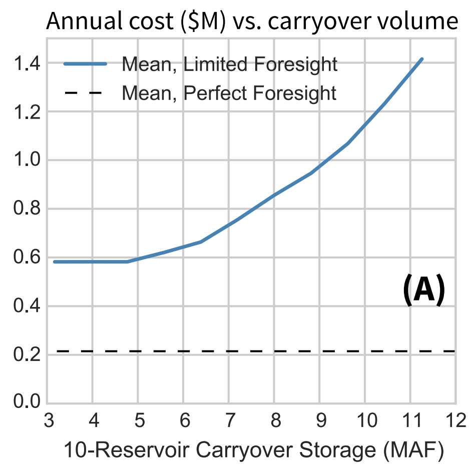
Dependencies

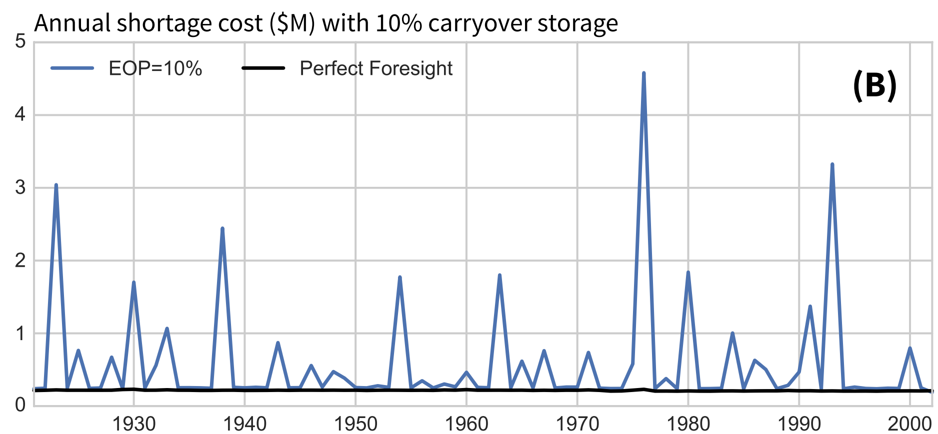
- Python programming language & its standard scientific libraries
- Pyomo library, a Python-based, open-source optimization modeling language
- Solvers
  - `GLPK` } Freely available
  - `CBC` }
  - `CPLEX` } Free for academic use only
  - `Gurobi` }
- CALVIN model repository from GitHub

Limited foresight

- Linear programming drawback: perfect foresight
  - Model knows all hydrologic events
  - Optimistic (low) shortage costs
- Sequential annual optimization
- Constrained or penalized end-of-period storage

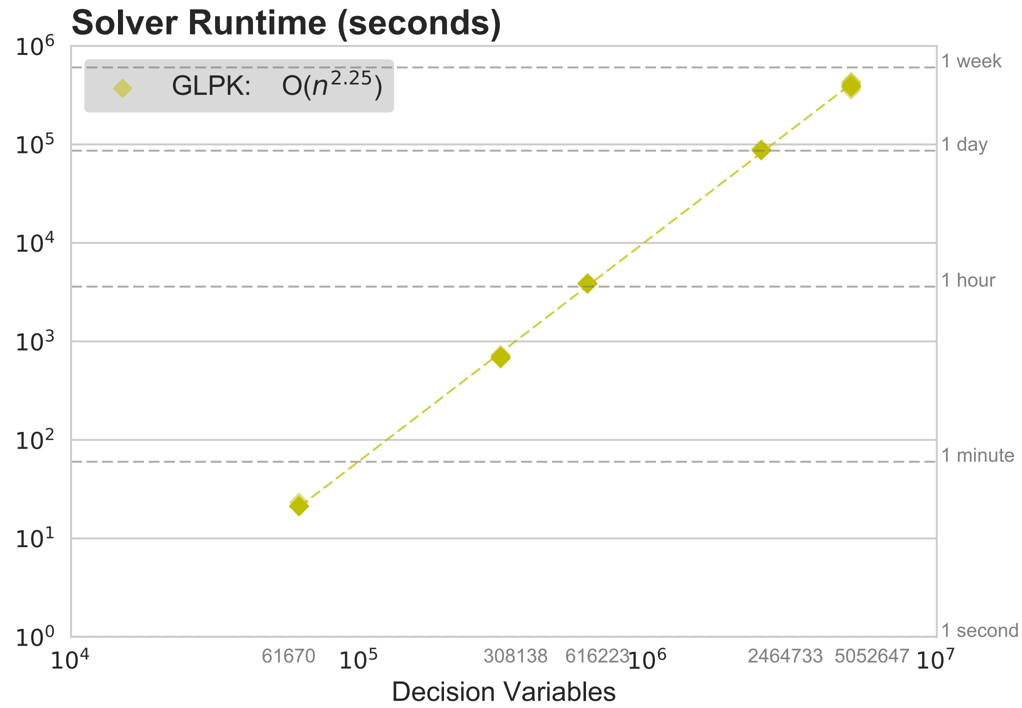
(A) Annual avg. scarcity cost for different carryover storage
(B) Time-series of shortage cost for 10% of capacity as carry over storage





Runtime benchmarks

- Important for large-scale models
- 5 model sizes: 60K to 5M decision variables
- 10 runs for each
- High performance computing cluster
- 4 installed solvers
  - `GLPK`



- Time marks (1 second, 1 day … etc.)
- Log-log scale
- Exponential increase of runtime

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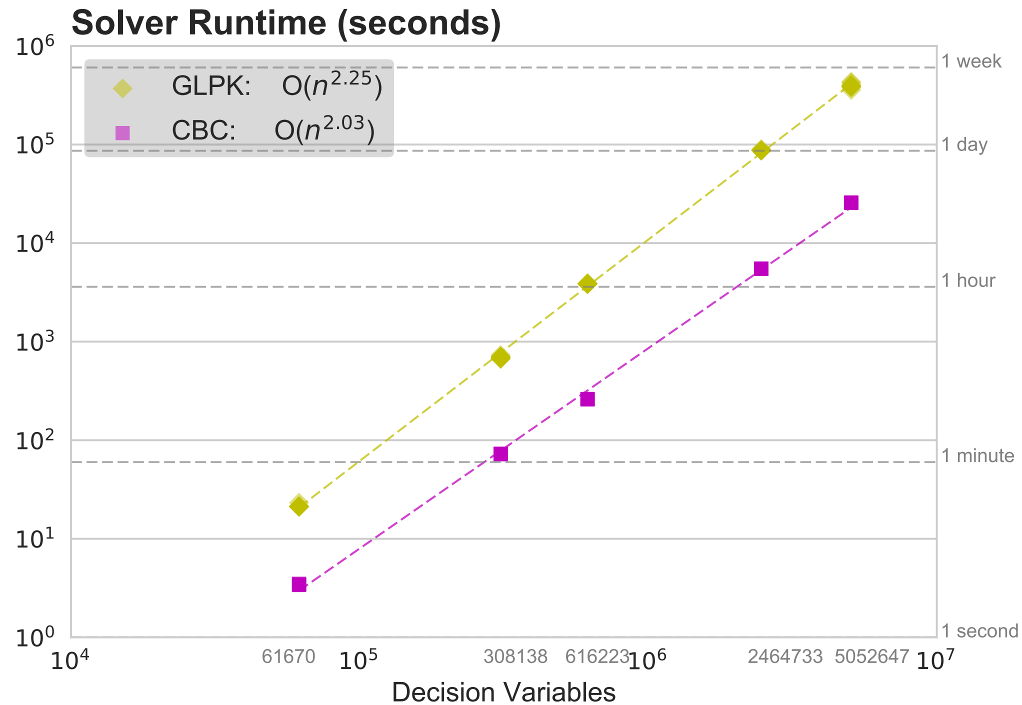

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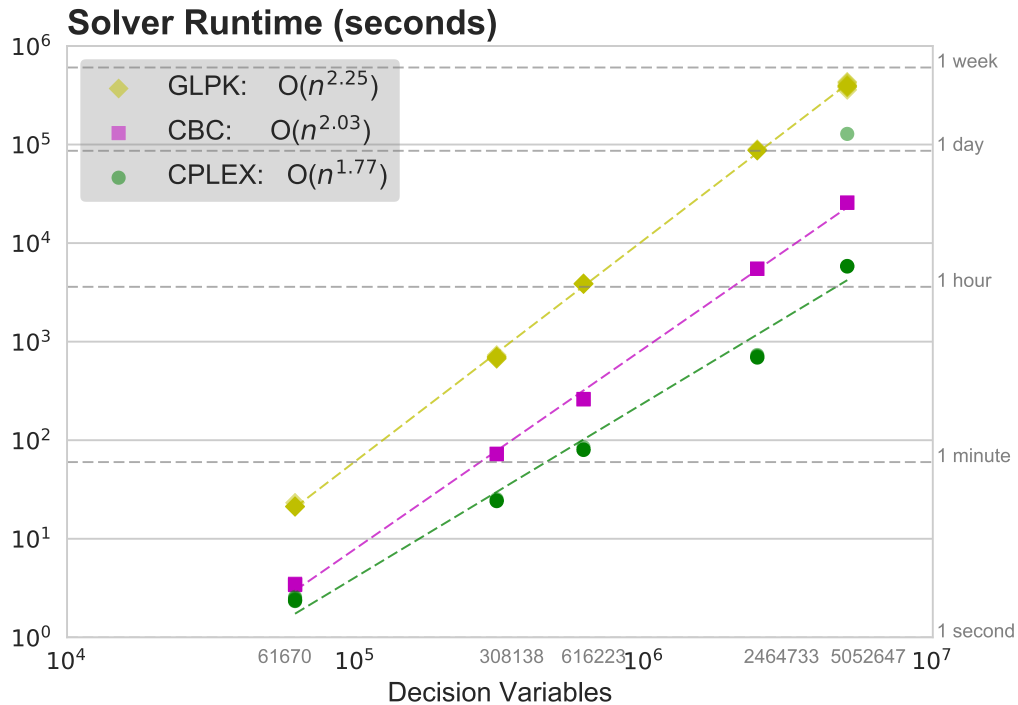

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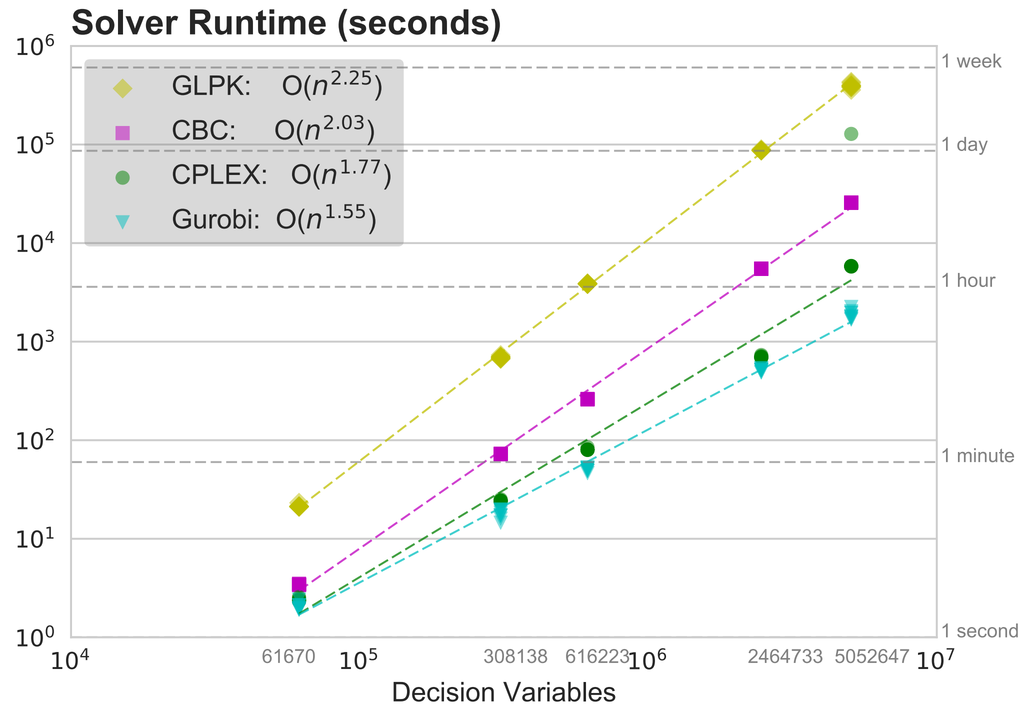

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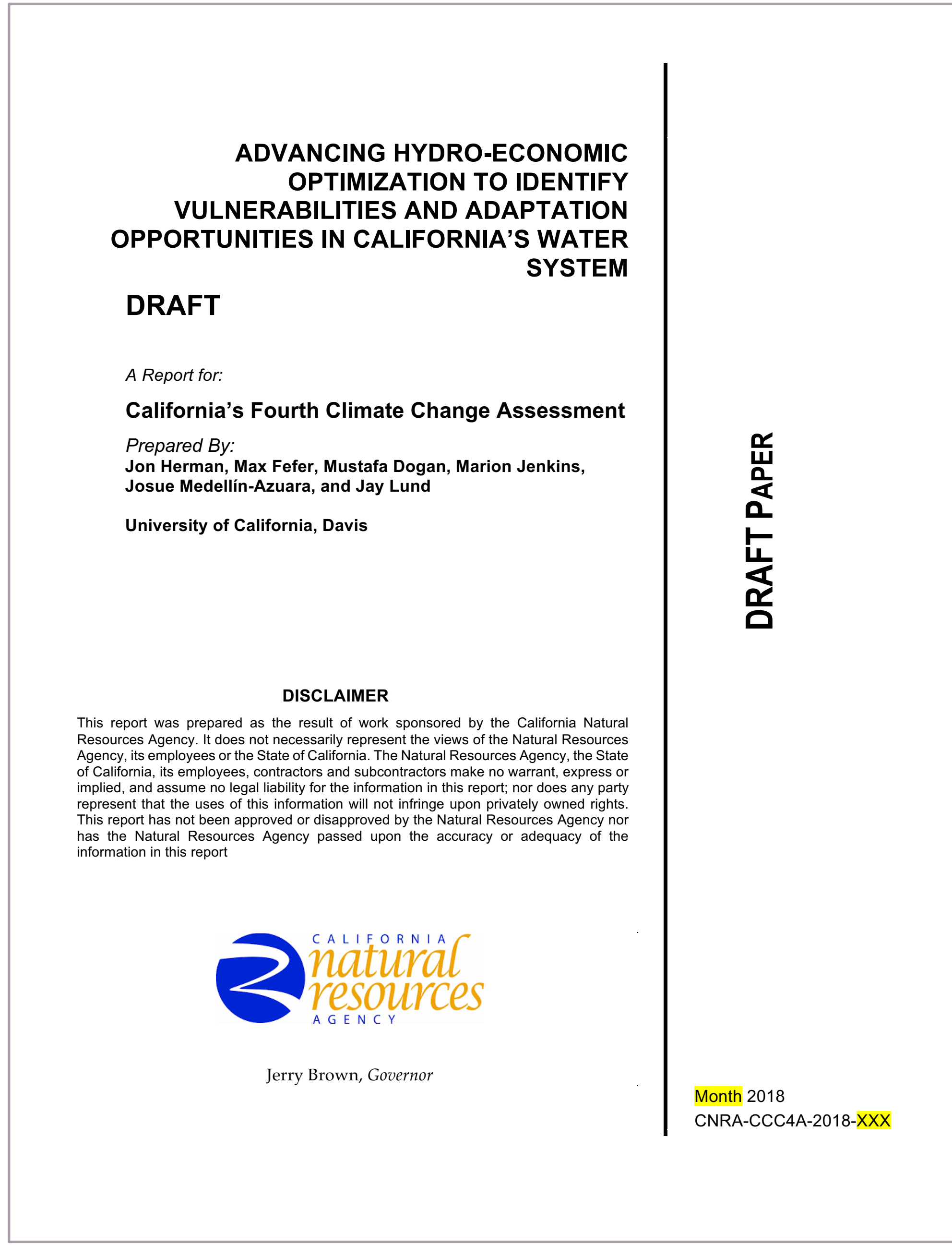
Some results

- Updated CALVIN is used in California's 4th Climate Change Assessment report
- Operations under different climatic conditions
- Identify vulnerabilities & adaptation opportunities


ADVANCING HYDRO-ECONOMIC OPTIMIZATION TO IDENTIFY VULNERABILITIES AND ADAPTATION OPPORTUNITIES IN CALIFORNIA'S WATER SYSTEM

DRAFT

A Report for:

California's Fourth Climate Change Assessment

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DISCLAIMER

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Jerry Brown, *Governor*

DRAFT PAPER

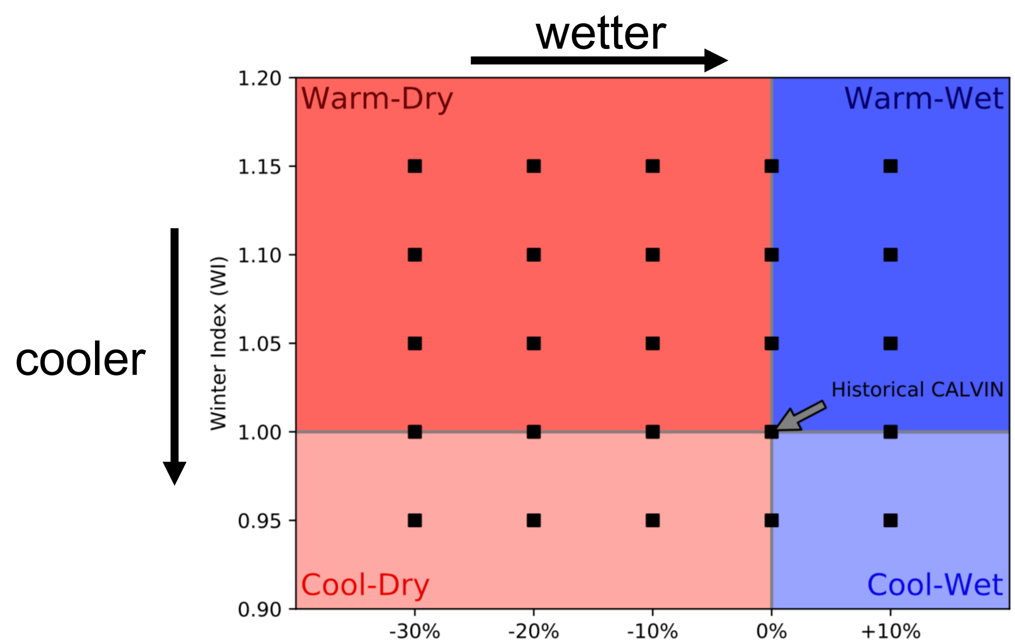
Month 2018
CNRA-CCC4A-2018-XXX

Matrix of scenarios

- Bottom-up vulnerability assessment using an ensemble of climate scenarios
- Create a matrix of WI & Water Availability (WA)

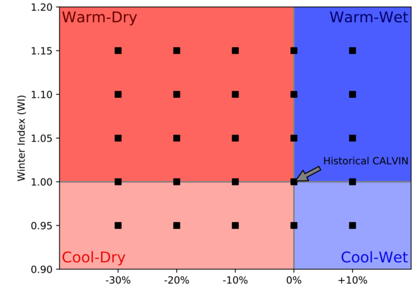
Winter Index (WI) for each climate scenario

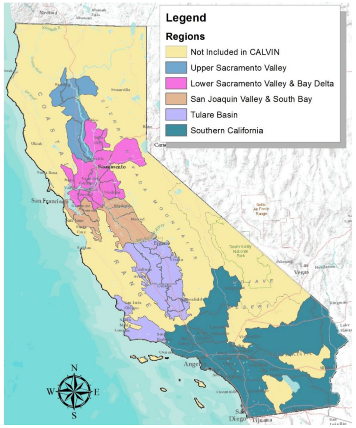
$$= \frac{\frac{Avg.Est.Flow\ Nov\ thru\ Apr}{Avg.Est.Flow}}{\frac{Avg.Hist.Flow\ Nov\ thru\ Apr}{Avg.Hist.Flow}}$$

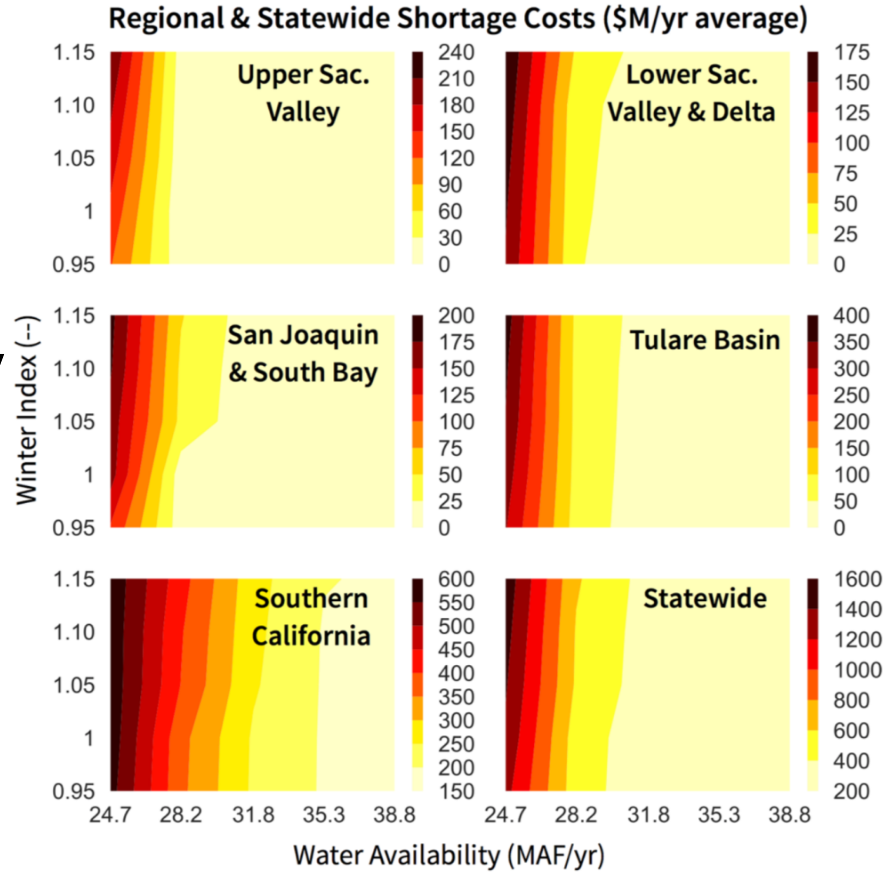


Shortage cost

- Cost of not delivering water
- Historical CALVIN
  - WI: 1
  - WA: 35.3 MAF/y
- Shortage cost significantly increase if water availability (WA) < ~30 MAF
- Shortage cost is higher Southern California: urban demand, high value crop

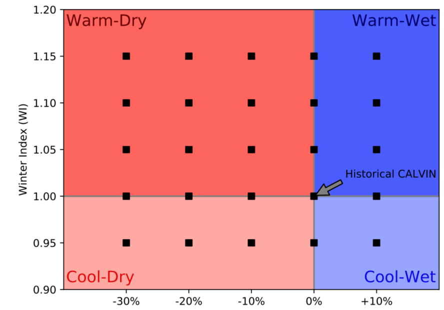




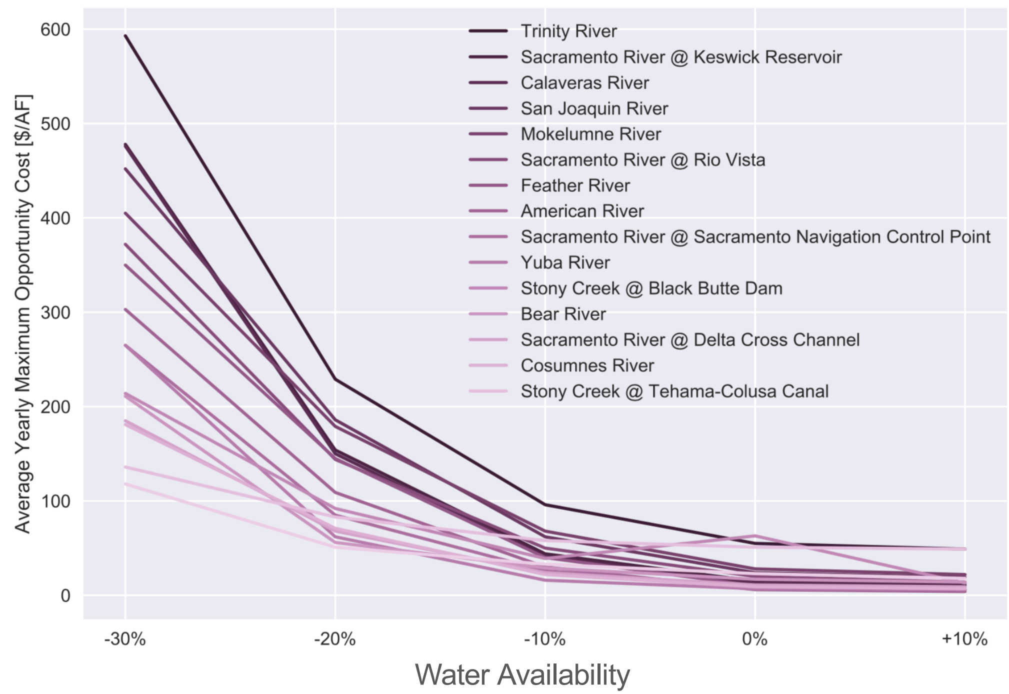


Value of environmental flows

- Environmental flows as minimum in-stream flow requirements
- Dual values of environmental flows



- Quadratic increase in value of environmental flows as water availability decrease
- Trinity River is most valuable (consumptive use in CALVIN)



Conclusions

- Keeping up with changing technology are key for better system representation and performance
- More flexibilities are added to CALVIN:
  - Limited foresight
  - Connection to several fast, state-of-the-art solvers
- Updated model enabled us to look at wide range of possible climate scenarios
- Open-source made version control, data sharing & data transparency easier

https://github.com/ucd-cws/calvin