

# CALVIN

# Fall 2018 Workshop

**Mustafa Dogan**

Center for Watershed Sciences

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[msdоган@ucdavis.edu](mailto:msdоган@ucdavis.edu)

GitHub repo: <https://github.com/msdоган/CALVIN-shortcourse>

# Hydroeconomic modeling

- Combines water resources systems & economics
- Water allocations are driven by economic value of water
- Economic costs & benefits are constrained by hydrology (water availability) & policies
- Useful for water resources planning & management decisions

# CALVIN model

- CALVIN = California Value Integrated Network
- Hydroeconomic optimization model
- Economics driven water allocation operations
- Optimizes deliveries to users (minimizing total operating and scarcity costs)
- Represents California's water infrastructure
- Historical monthly hydrology to represent hydrologic variability (Oct. 1921 to Sep. 2003)
- 2050 urban and agricultural demands

# An integrated model

CALVIN is an integrated model

- Surface water & groundwater resources are used conjunctively
- Aggregated environmental, agricultural & urban demands are represented
- The physical system is connected via rivers, canals, aqueducts, & reservoirs
- Reservoirs carry water across time-steps (multi-period model)

# CALVIN studies

CALVIN has been used in numerous studies:

- Climate change & adaptation
- Groundwater overdraft
- Effects of removing a dam
- Marginal value of expanding storage
- Marginal value of adding/expanding infrastructure

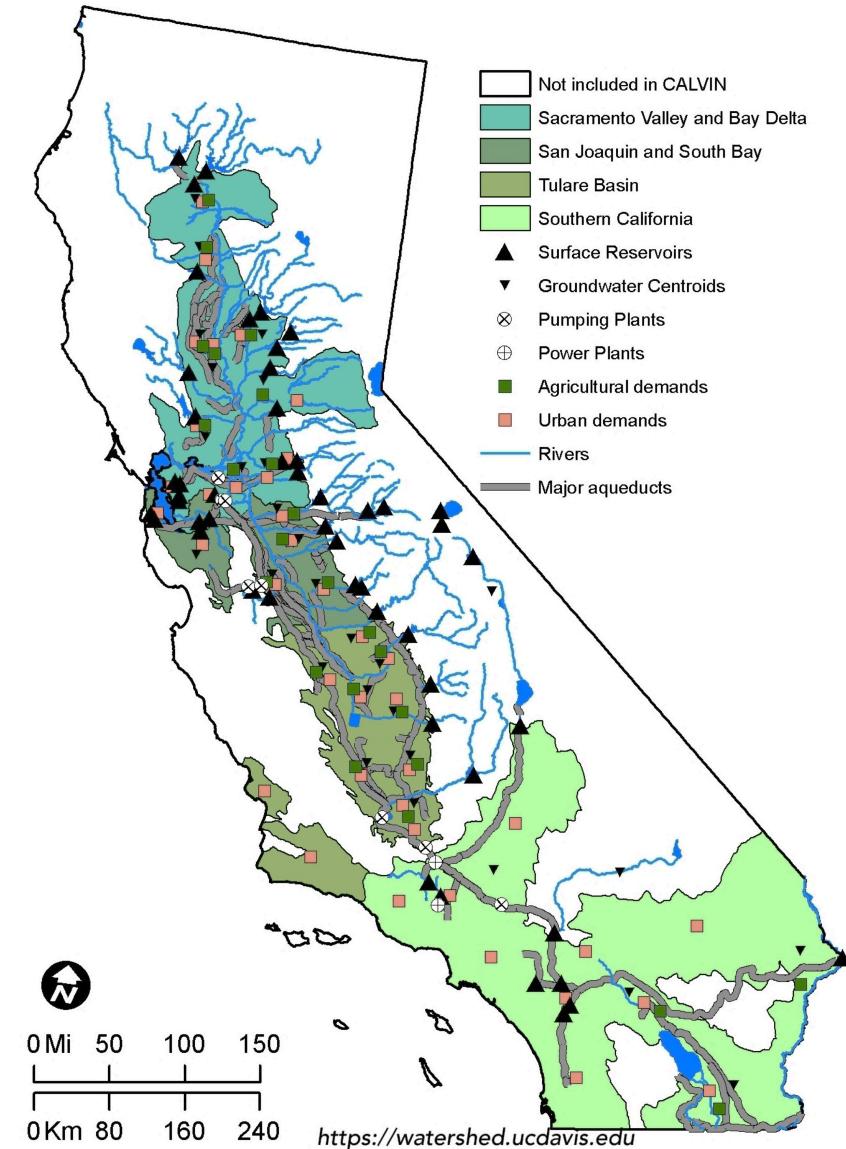
# CALVIN limitations

CALVIN has several limitations:

- Perfect hydrologic knowledge (limited in limited foresight model)
- Simplified groundwater representation (unit fixed pumping cost)
- Linearized cost curves (piecewise linear)
- Simplified hydropower representation due to linear programming (LP) framework

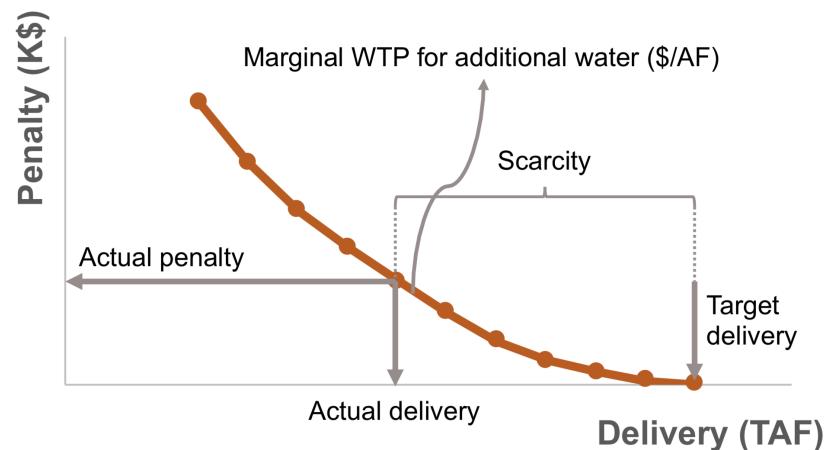
# Model coverage

- Most agricultural activities & urban population (~90%)
- 35 agricultural & 30 urban demand locations
- 9 wildlife refuge demands & 21 MIF requirements
- 33 groundwater basins, 53 surface reservoirs



# Economic value of water

- Monthly varying total cost curves derive operations for agricultural & urban deliveries & hydropower
- Whenever a user's total demand (target delivery) is not met, scarcity occurs
  - The difference between target & actual deliveries = scarcity
  - The scarcity cost (penalty) is total loss due to lack of water related activities

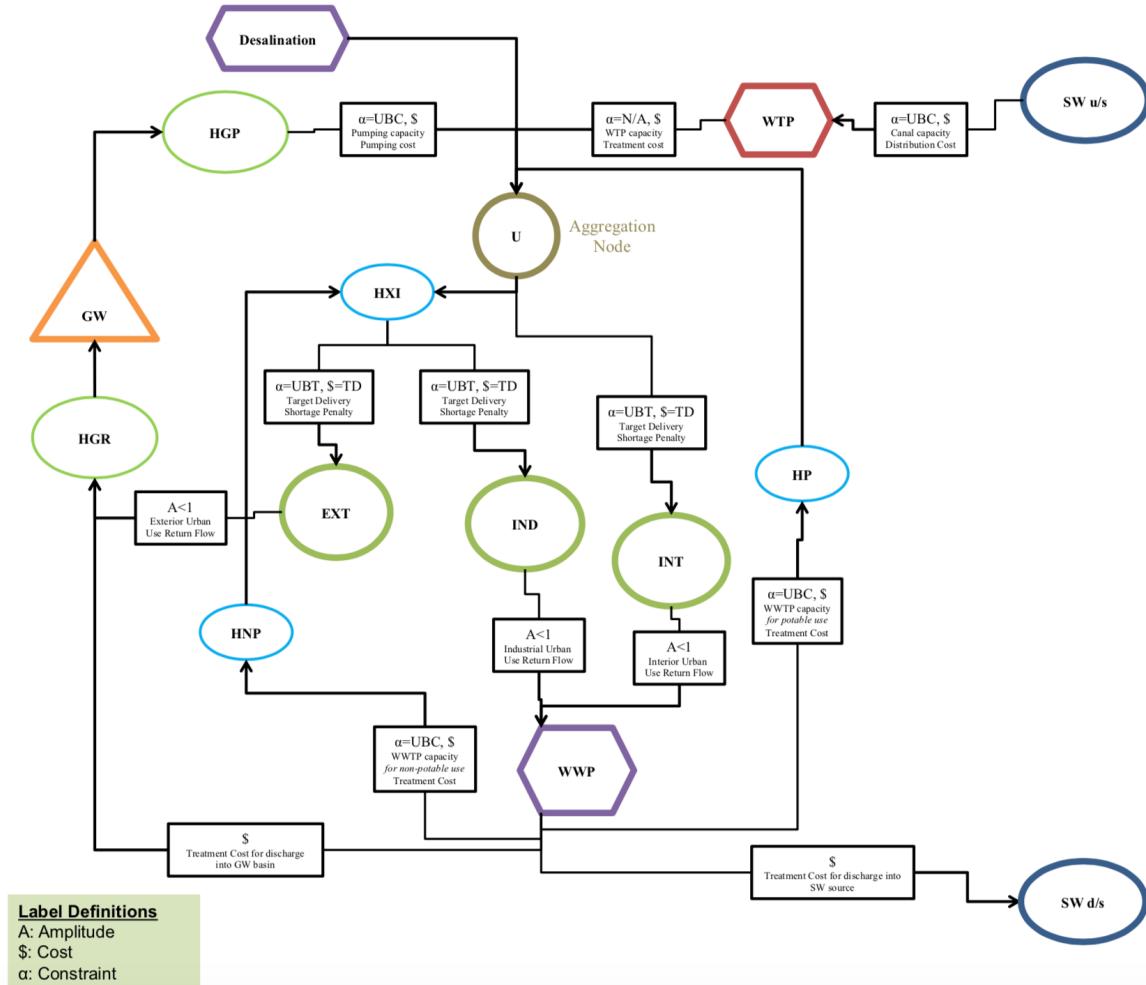


# Agricultural demand

- SWAP model is used to create penalty curves
  - Two supply sources: groundwater & surface
  - Aggregated demand is divided into two parts based on return flow to groundwater or surface water
- 
- Label Definitions**
- A: Amplitude  
\$: Cost  
 $\alpha$ : Constraint

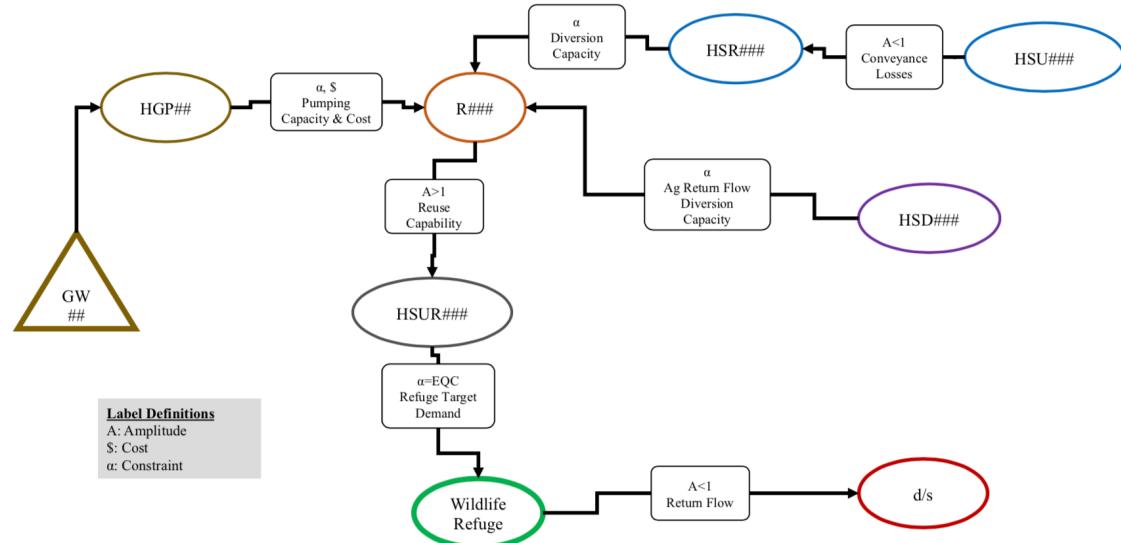
# Urban demand

- Interior & exterior residential, & industrial demands
- Water sources:
  - Surface water
  - Groundwater
  - Desalination
  - Potable & non-potable recycled water



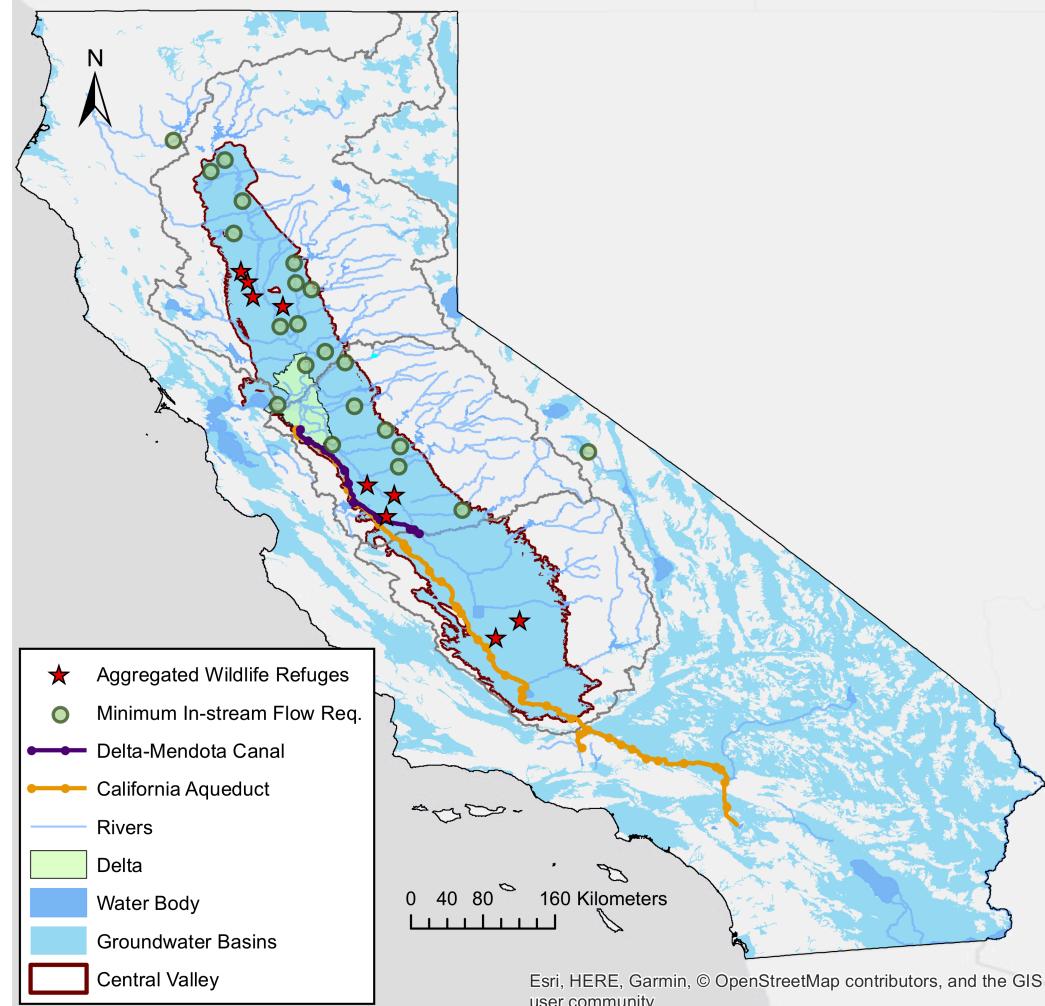
# Wildlife refuge demand

- 9 wildlife refuge demand locations
- No economic representation
- Constrained water deliveries
- Supply sources:
  - Surface water
  - Groundwater
  - Agricultural return flow



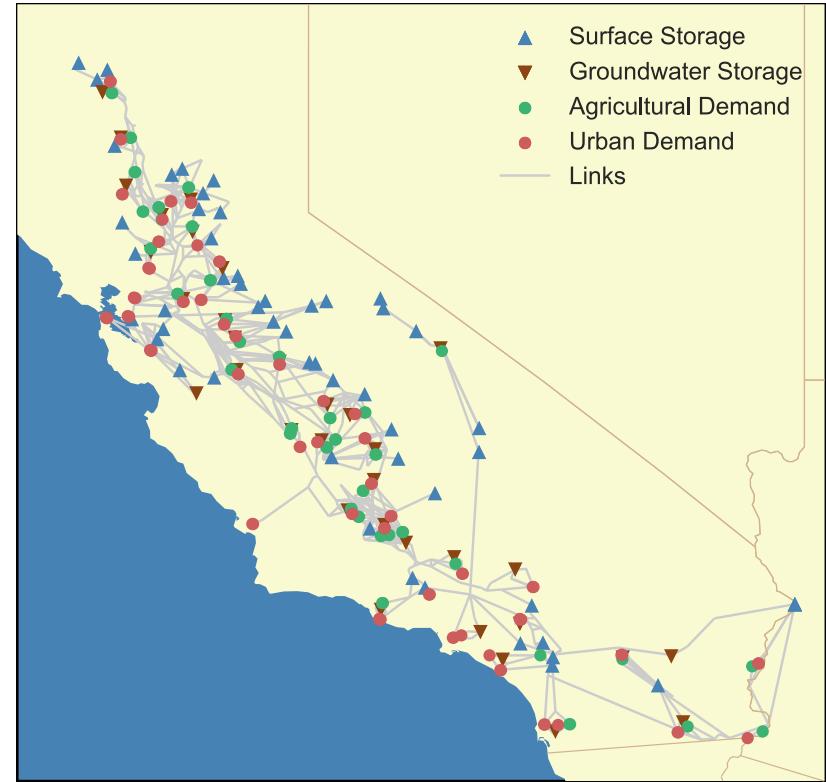
# MIF Requirements

- Minimum in-stream flow requirements due to aquatic habitat needs
- Represented as lower bound constraints
- Mostly time-series obtained from CALSIM II model



# Network-flow model

- CALVIN represents the physical system with nodes and links
- Nodes represent reservoirs, demand locations, power and pumping plants and junctions
- Links only connect nodes to each other
- All network parameters are applied to links: amplitude (loss factor)  $a$ , unit cost  $c$ , lower bound  $l$ , & upper bound  $u$



# Linear Programming model

- As an network-flow LP model, CALVIN minimizes statewide water scarcity and operating costs within constraints

$$\min_X z = \sum_i \sum_j \sum_k c_{ijk} X_{ijk}$$

*Objective Function*

$$X_{ijk} \geq l_{ijk}, \forall (i, j, k) \in A$$

*Lower bound constraint*

$$X_{ijk} \leq u_{ijk}, \forall (i, j, k) \in A$$

*Upper bound constraint*

$$\sum_i \sum_k X_{jik} - \sum_i \sum_k a_{ijk} X_{ijk} = 0, \forall j \in N$$

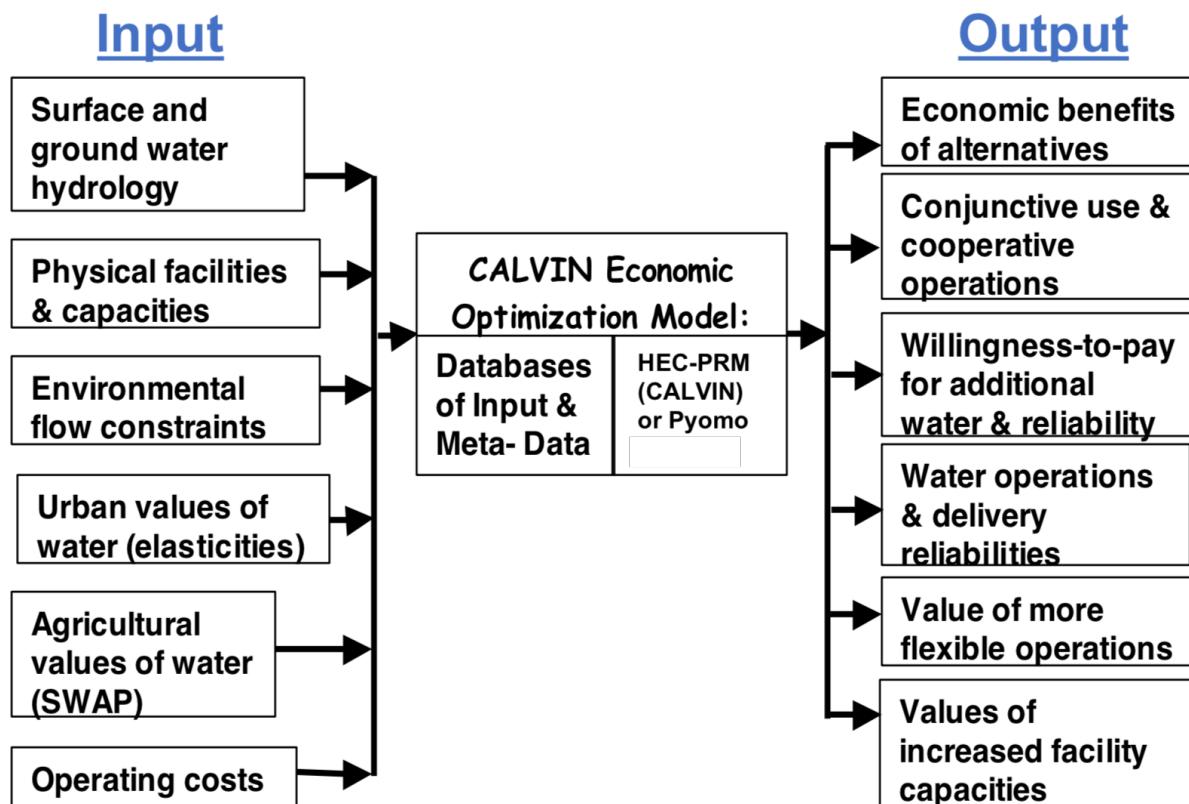
*Mass balance constraint*

where  $X$  is flow (decision variable);  
 $c$  is unit cost;  $l$  is lower bound;  $u$  is  
upper bound;  $a$  is amplitude

index  $i$  represents origin node;  
 $j$  is terminal node;  $k$  is a  
piecewise component

# Data overflow

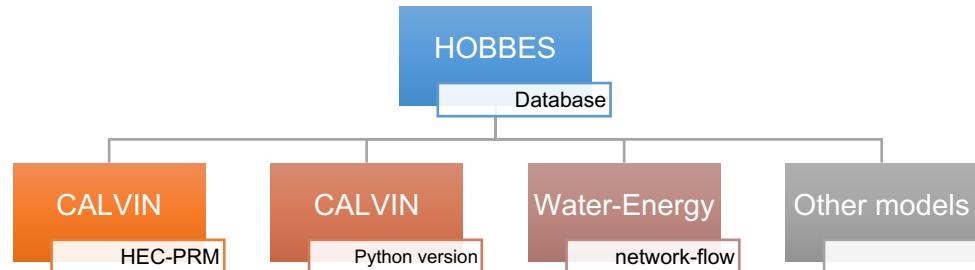
- Water operations are driven by economic value of water: Hydrologic data + economic data



# HOBBES database

<https://cwn.casil.ucdavis.edu>

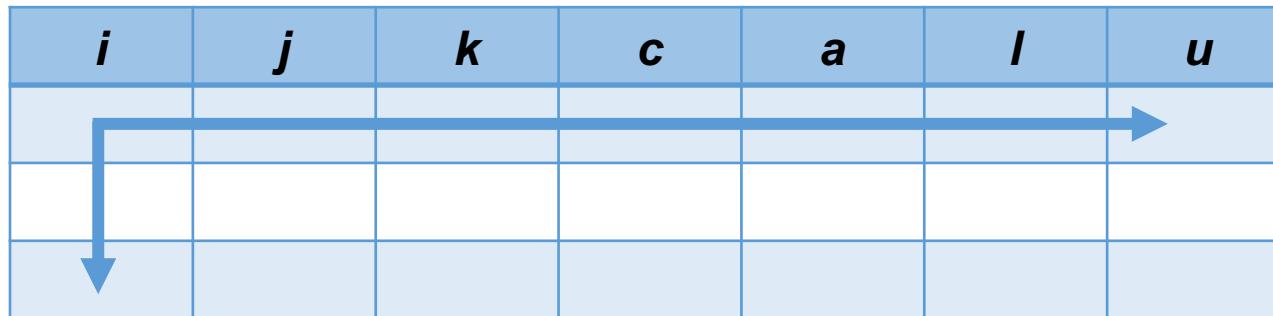
- A web-based open-source data storing and sharing platform
- Stores California's water network data
- Documentation and change tracking via GitHub
- Data visualization and animation
- Several models can be built around HOBBES, where built-in tools convert and export network data in the desired format



# HOBBES for CALVIN (Python)

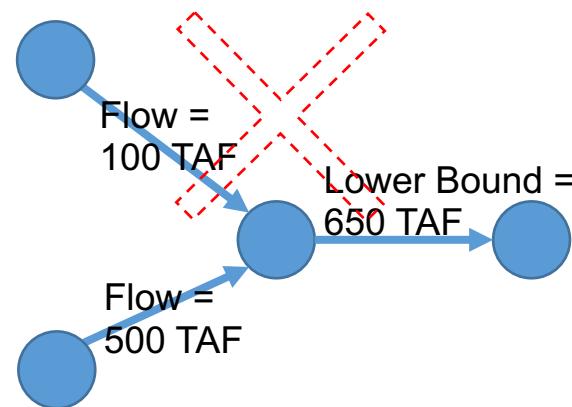
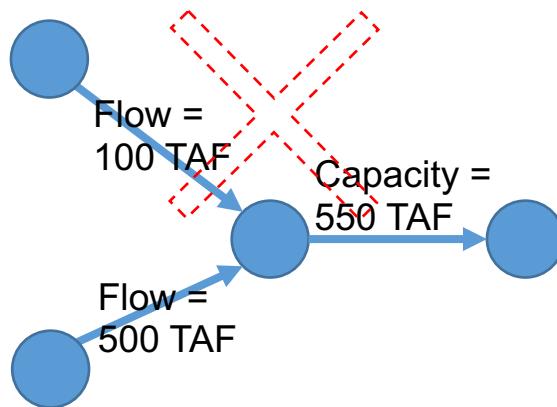
- CALVIN Python version uses matrices for all parameters:  $c$ ,  $a$ ,  $I$ ,  $u$
- Calvin-network-tool in HOBBES converts input data into a network matrix
- The network matrix is input to CALVIN (Python)
- Each of network matrix lines correspond to a link – decision var. (full size model has 6 millions)

$i$	$j$	$k$	$c$	$a$	$I$	$u$



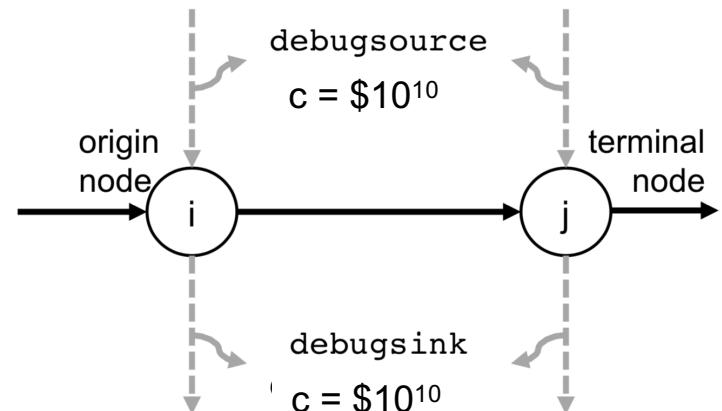
# Resolving infeasibilities

- When a mass-balance constraint at any location is not met, the model results in infeasible solution
- Due to size of the model, in case of infeasibility, you never know where the problem is



# Debug mode

- When network is modified (climate change, adding a new requirement or element etc.), first run in debug mode
- Debug mode adds two links (debug source & debug sink) at very high cost ( $\sim 10^{10}$ )
- The debug cost is much higher than any other cost in CALVIN to make sure it is not used unless there is infeasibility
- Then postprocess to eliminate debug flow



# CALVIN goals

The recent updates aims to

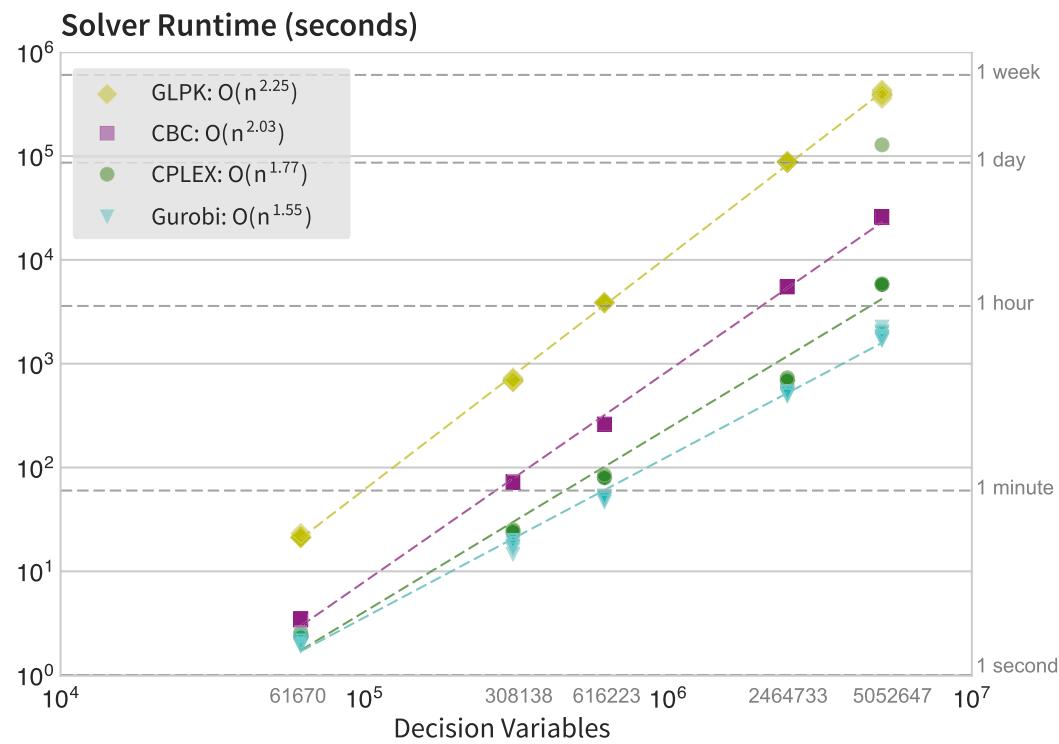
- Create a *cross-platform* model: MacOS, Windows
- Use *open data format*: csv, JSON
- Have *freely available*: data, code, modeling language & solvers are open-source or free of charge
- *Separate model & data*:
  - HOBBES is independent from any data
  - CALVIN's structure code is generalized (can solve any other network-flow problems)

# CALVIN improvements

- The original CALVIN uses HEC-PRM to solve its optimization problem
- With recent updates, CALVIN is moved to Python
- Pyomo library, a high level optimization modeling language in Python, is used
- Pyomo can connect to several freely available solvers
- Runtime is decreased from 2-5 days to 30min-1 hr, with parallelization in Pyomo.

# CALVIN runtime

- Solver wall clock runtime for different model sizes
- Installed solvers:
  - GLPK
  - CBC
  - Gurobi
  - CPLEX
- Log-log scale: exponential increase of runtime



# A small network example

- Modeling of a reservoir with following properties
- Two time-steps

<b>Initial storage (TAF)</b>	3686.84
<b>Ending period storage (TAF)</b>	2923.297
<b>Reservoir inflow 1983-10-31 (TAF/m)</b>	301.765
<b>Reservoir inflow 1983-11-30 (TAF/m)</b>	650.408
<b>Evaporation loss factor</b>	0.99716

**Penalty curve (due to (lost) hydropower benefits)**



<b>Reservoir storage capacity (TAF)</b>	3400 (less due to flood storage)
<b>Reservoir release capacity</b>	None (assumed for simplicity)

# Network-flow form

