

CALVIN

Fall 2018 Workshop

Mustafa Dogan

Center for Watershed Sciences

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msdоган@ucdavis.edu

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

CALVIN

- 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

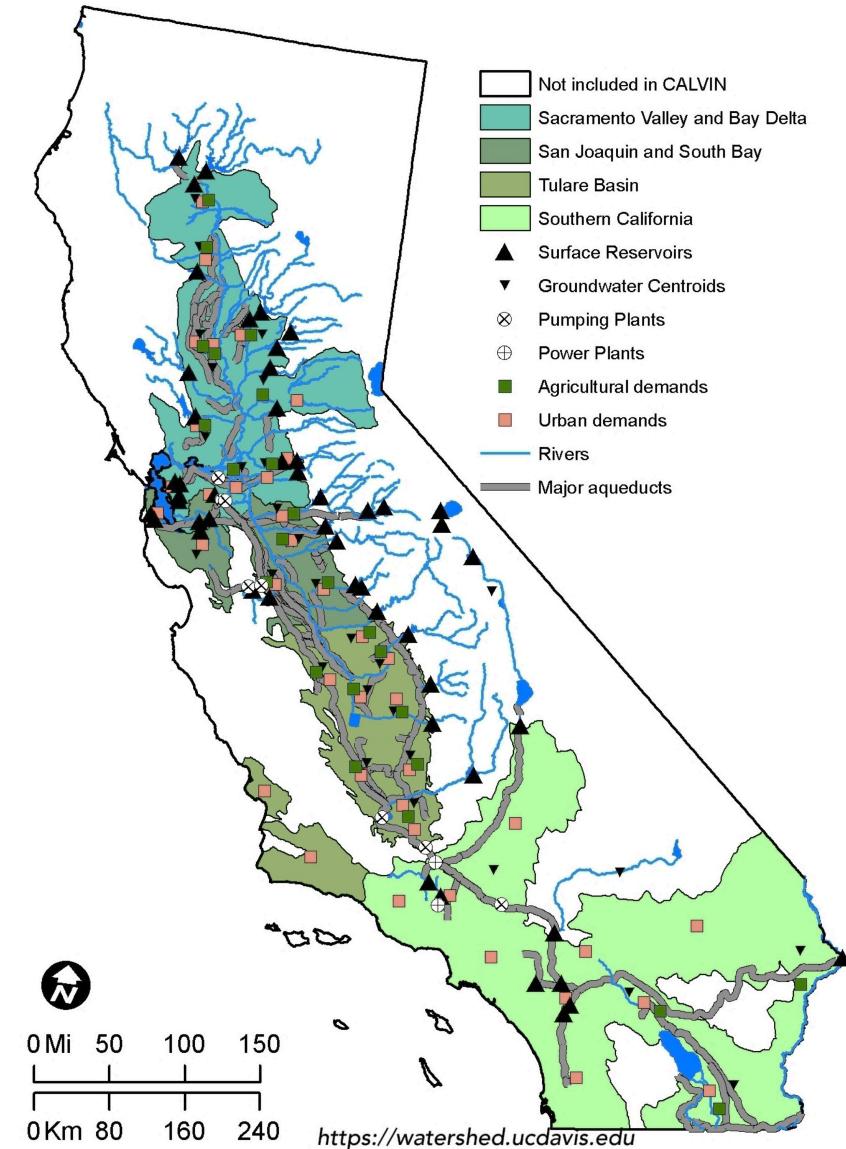
An integrated model

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)

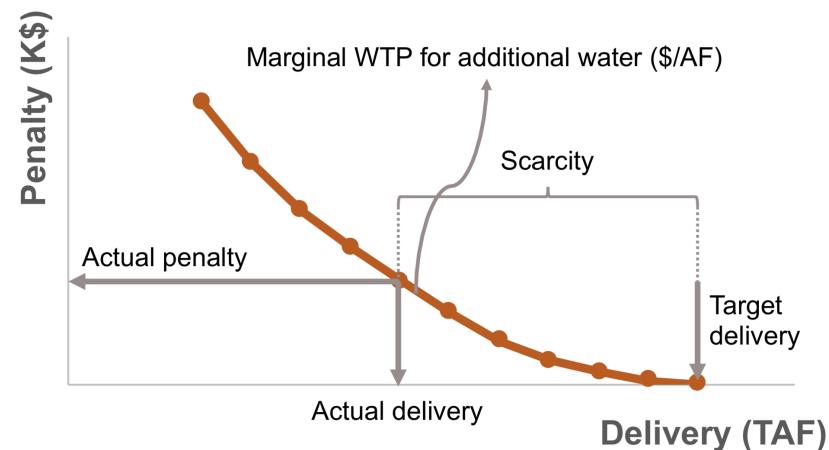
Model coverage

- 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

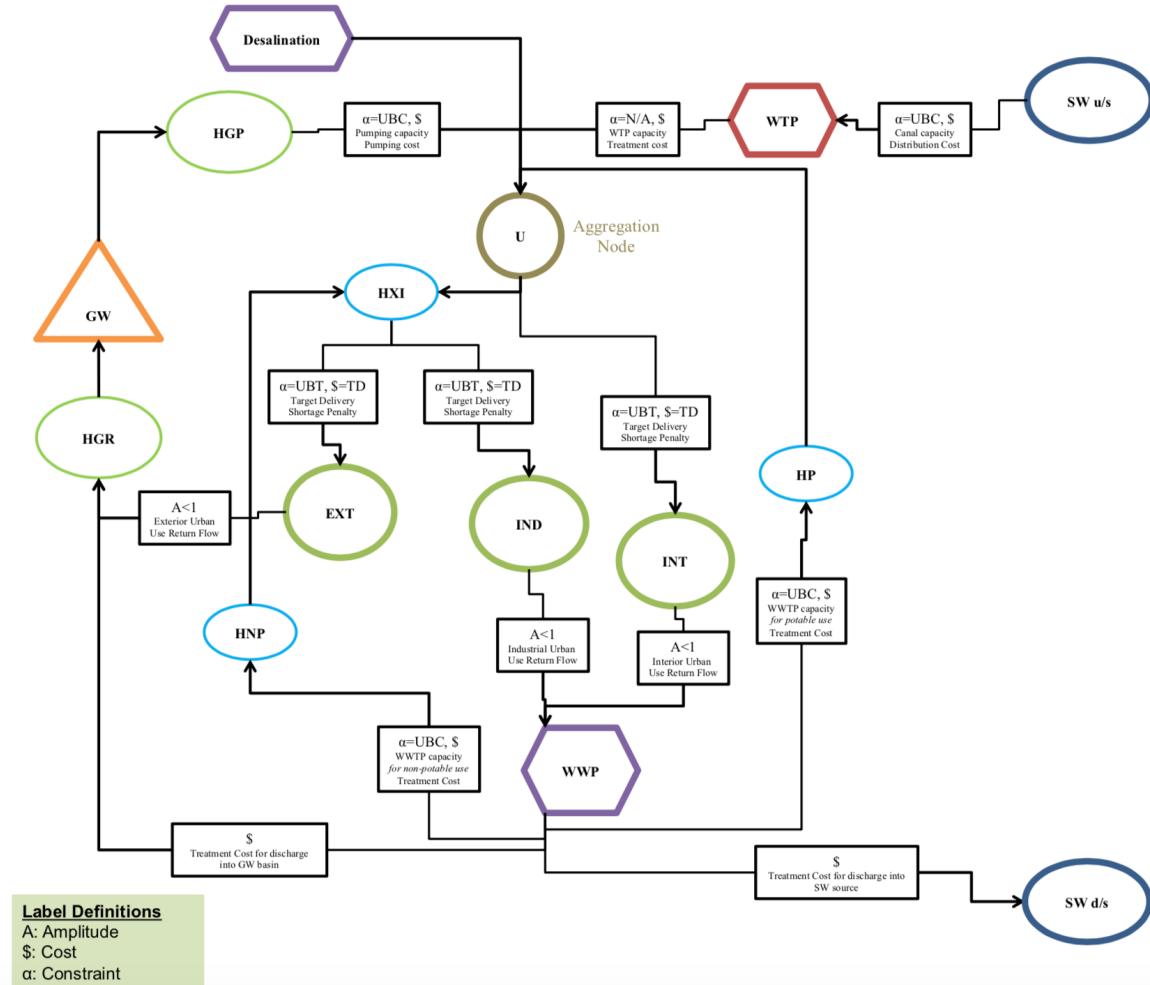


Agricultural demand

- 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
 α : Constraint

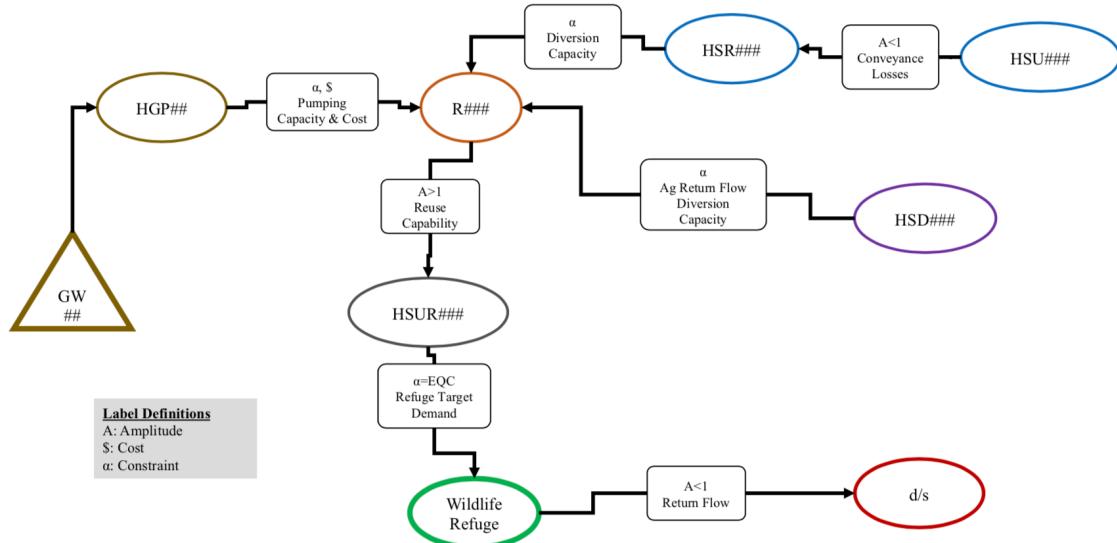
Urban demand

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



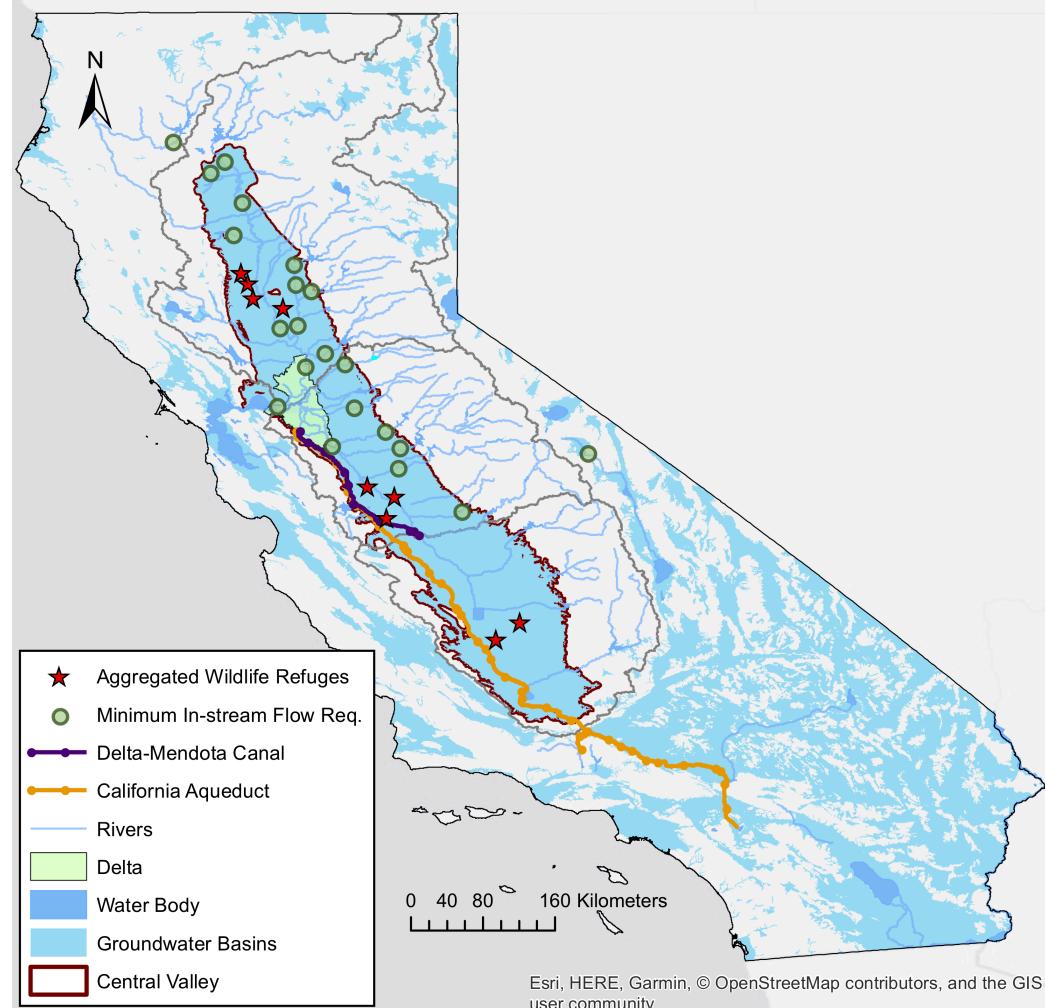
Wildlife refuge demand

- 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

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

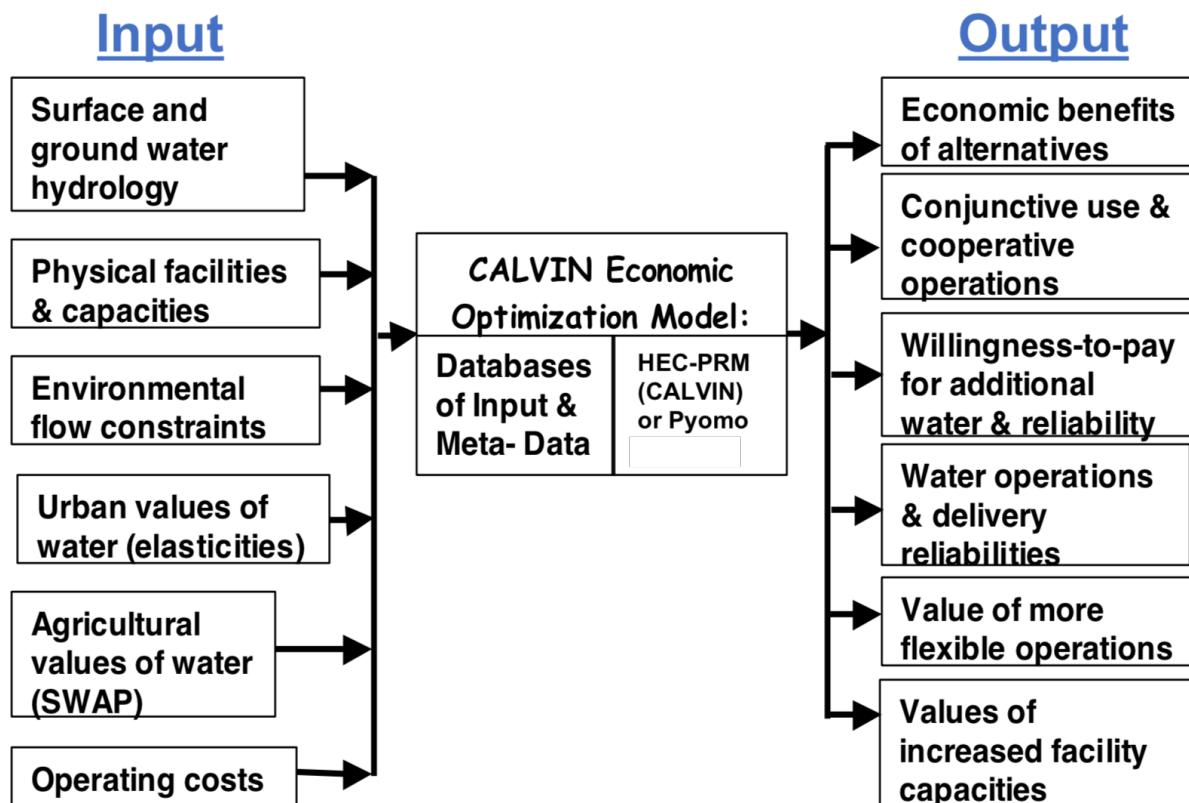
Mass balance constraint

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

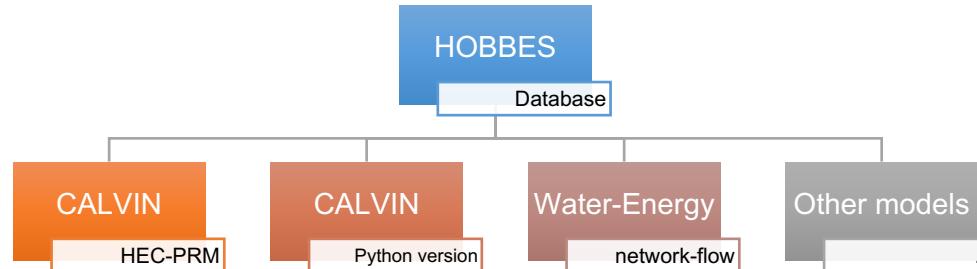
- Water operations are driven by economic value of water: Hydrologic data + economic data



HOBBES database

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

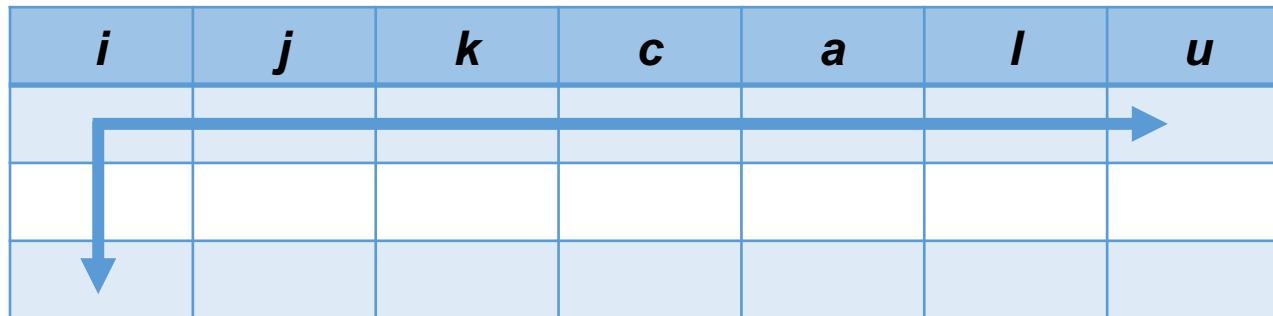
- A web-based open-source data storing and sharing platform
- Stores California's water network data
- Documentation and change tracking via GitHub
- Data visualization and animation
- Several models can be built around HOBBES, where built-in tools convert and export network data in the desired format



HOBBES for CALVIN (Python)

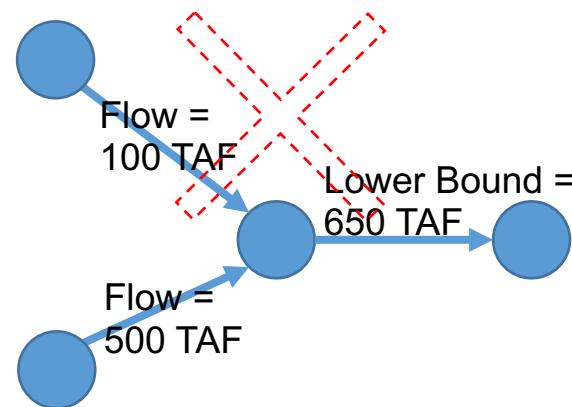
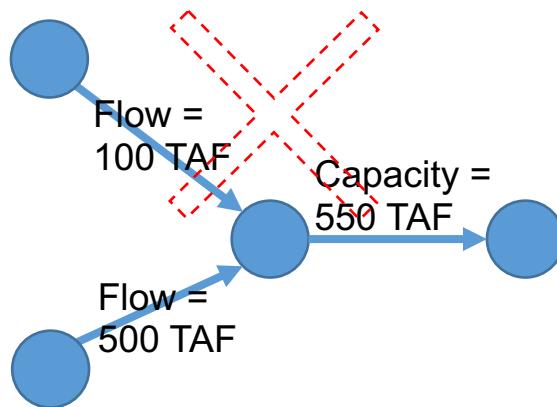
- CALVIN Python version uses matrices for all parameters: c , a , I , u
- Calvin-network-tool in HOBBES converts input data into a network matrix
- The network matrix is input to CALVIN (Python)
- Each of network matrix lines correspond to a link – decision var. (full size model has 6 millions)

i	j	k	c	a	I	u



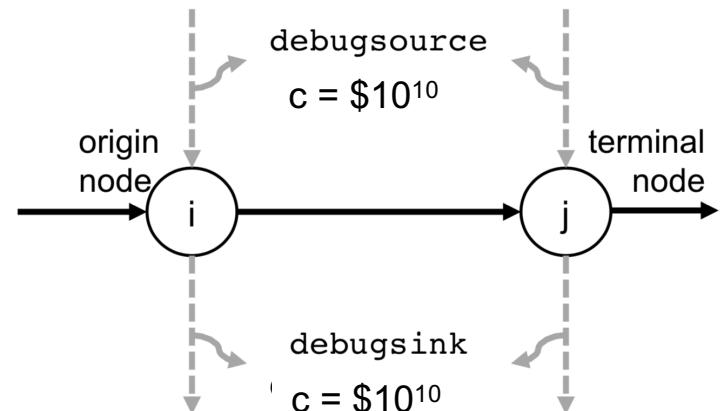
Resolving infeasibilities

- 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

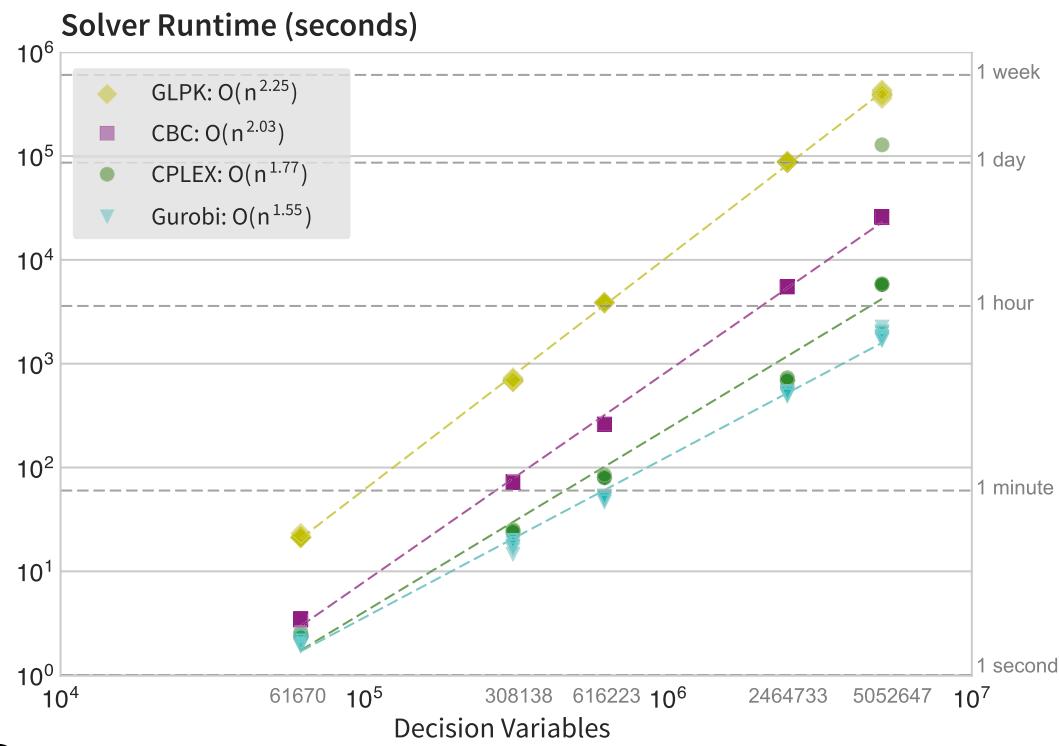
- Create a *cross-platform* model: MacOS, Windows
- Use *open data format*: csv, JSON
- Have *freely available*: data, code, modeling language & solvers are open-source or free of charge
- *Separate model & data*:
 - HOBBES is independent from any data
 - CALVIN's structure code is generalized (can solve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

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

Penalty curve (due to (lost) hydropower benefits)



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

Network-flow form

