CALVIN Winter 2024 Workshop

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GitHub repo: https://github.com/msdogan/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

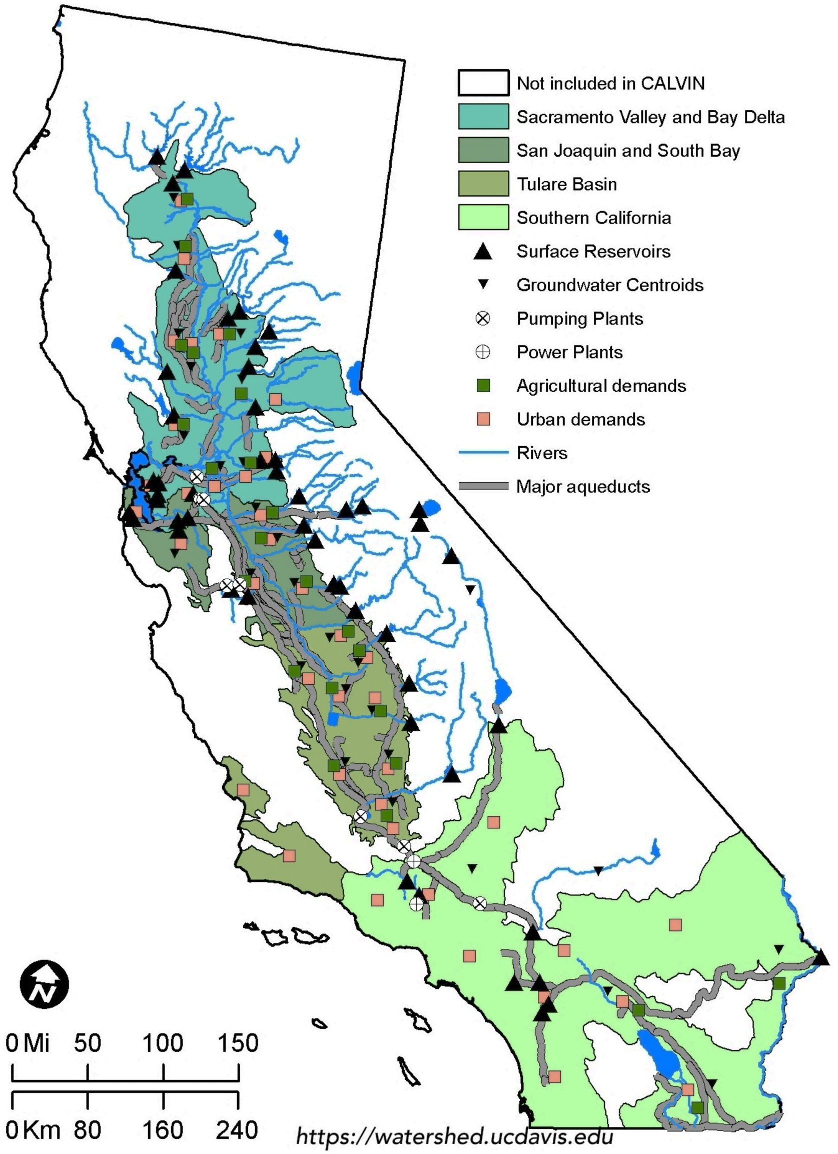
CALVIN limitations

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

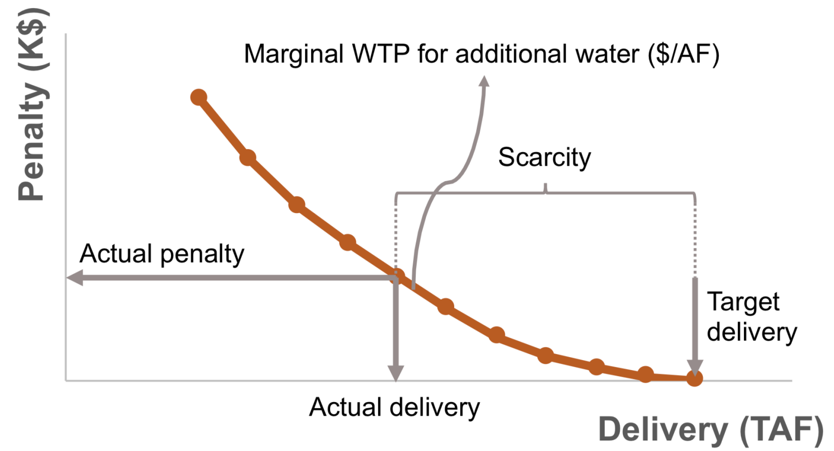
Model coverage

- 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

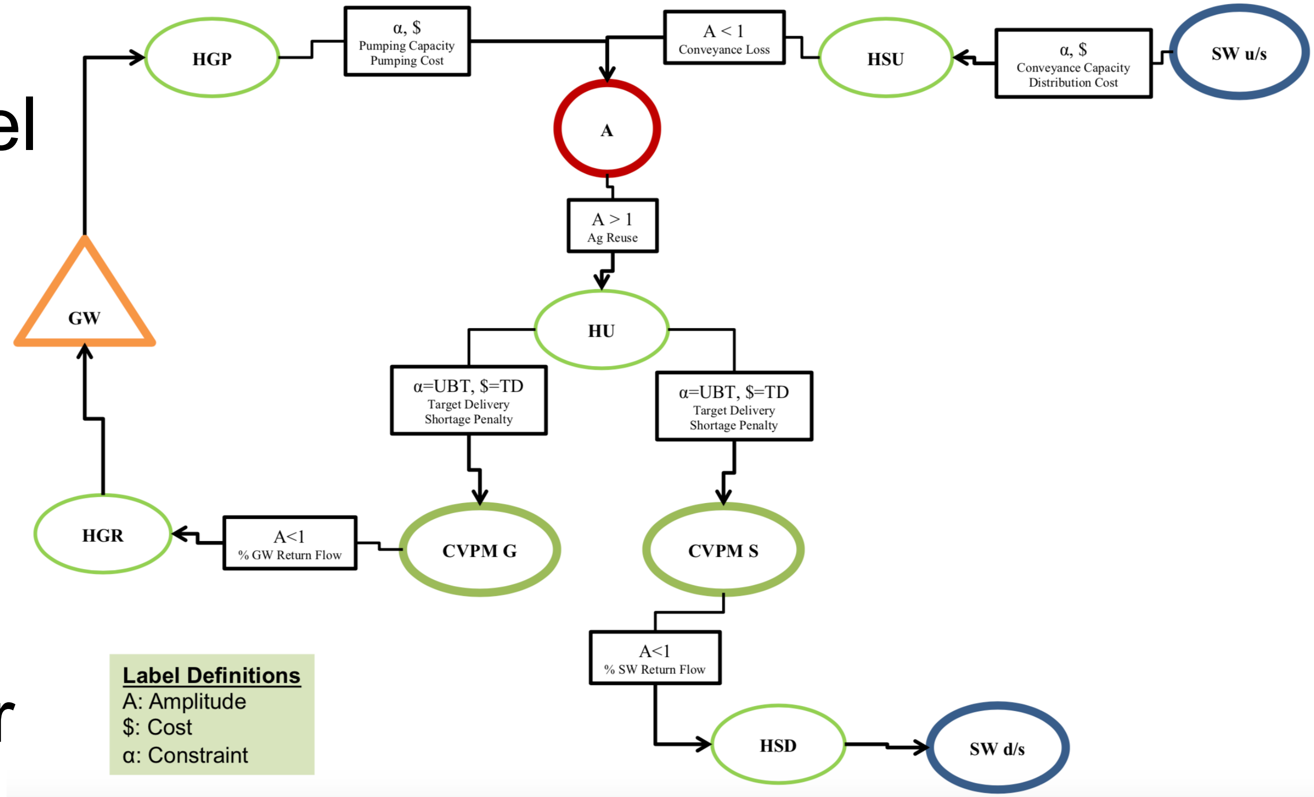
- Monthly varying total cost curves derive operations for agricultural & urban deliveries & hydropower
- Whenever a user's total demand (target delivery) is not met, scarcity occurs



- The difference between target & actual deliveries = scarcity
- The scarcity cost (penalty) is total loss due to lack of water related activities

Agricultural demand

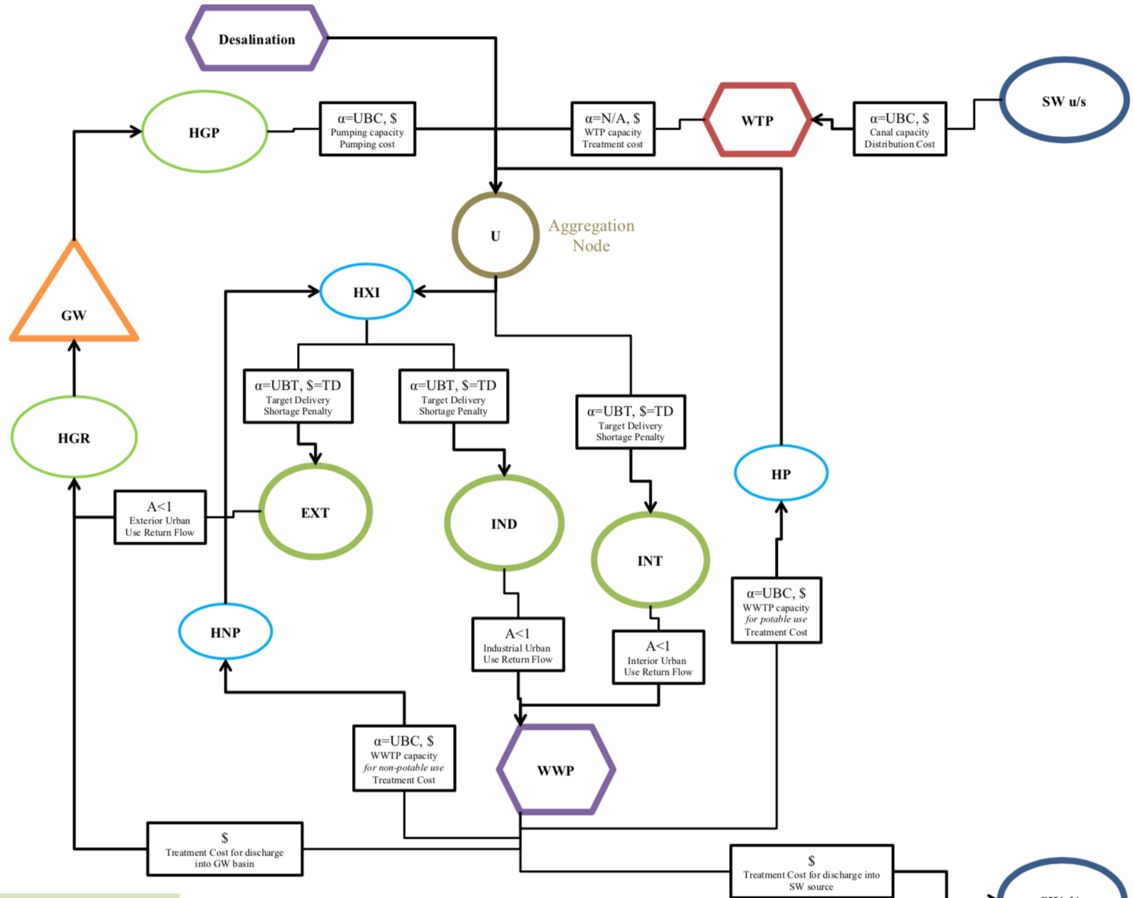
- SWAP model is used to create penalty curves
- Two supply sources: groundwater & surface



- Aggregated demand is divided into two parts based on return flow to groundwater or surface water

Urban demand

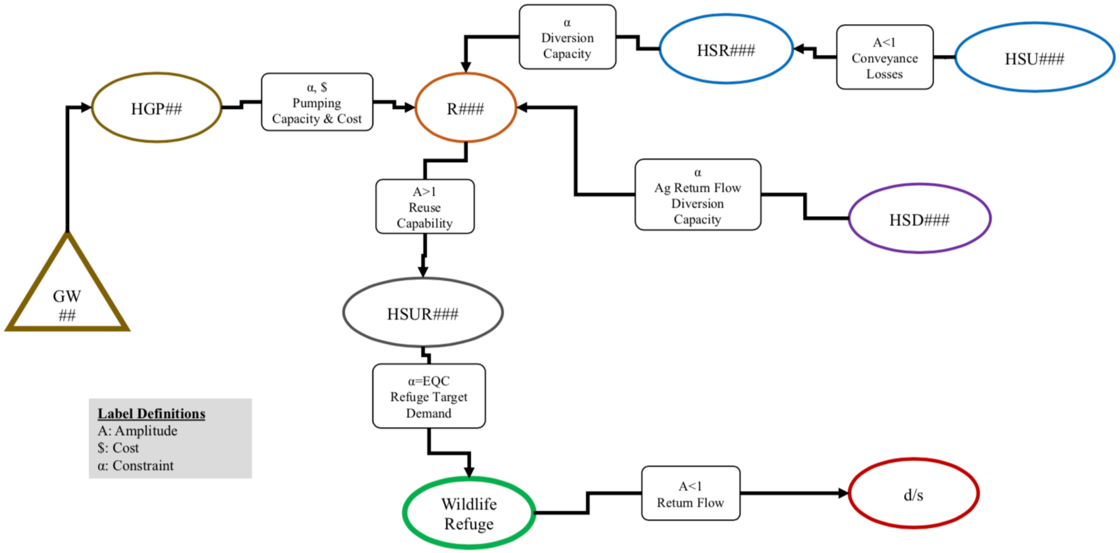
- Interior & exterior residential, & industrial demands
- Water sources:
  - Surface water
  - Groundwater
  - Desalination
  - Potable & non-potable recycled water



Label Definitions
A: Amplitude
$: Cost
α: Constraint

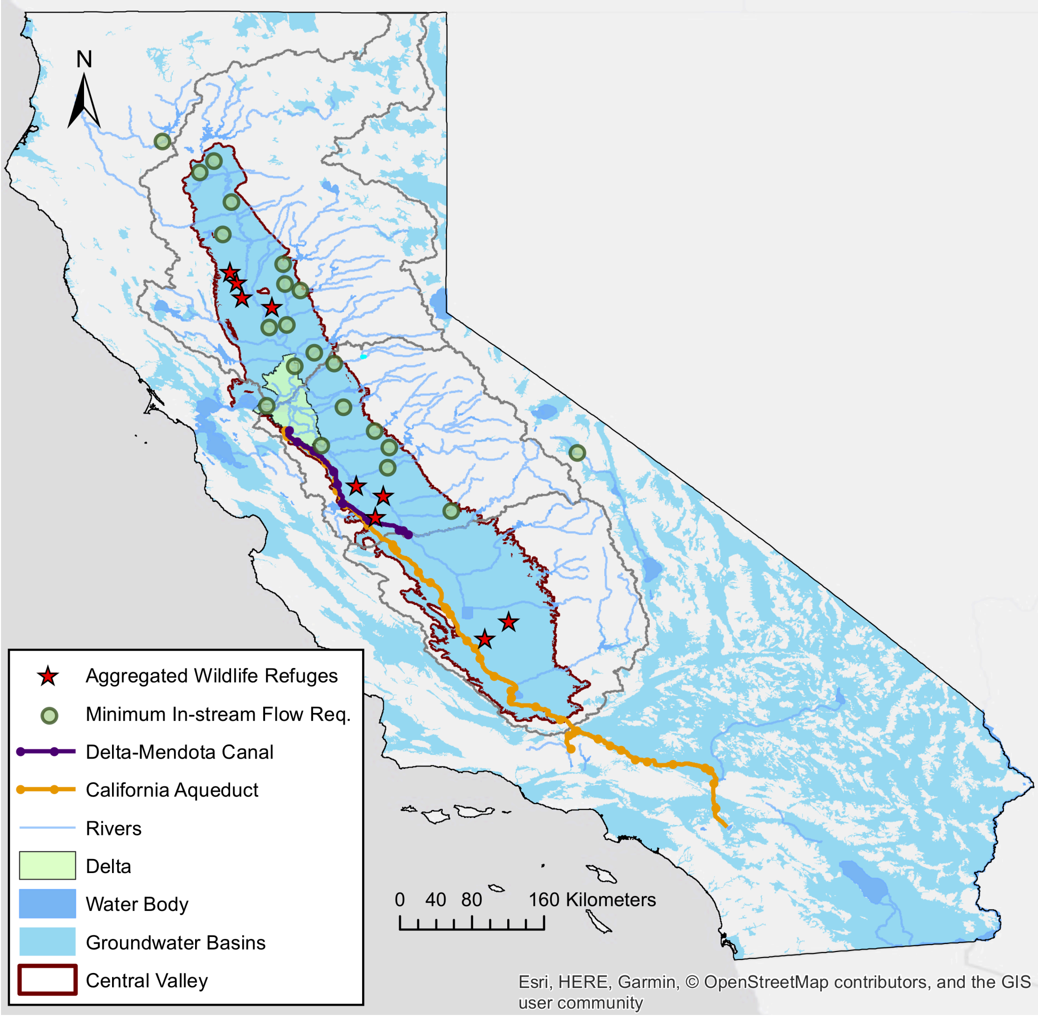
Wildlife refuge demand

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

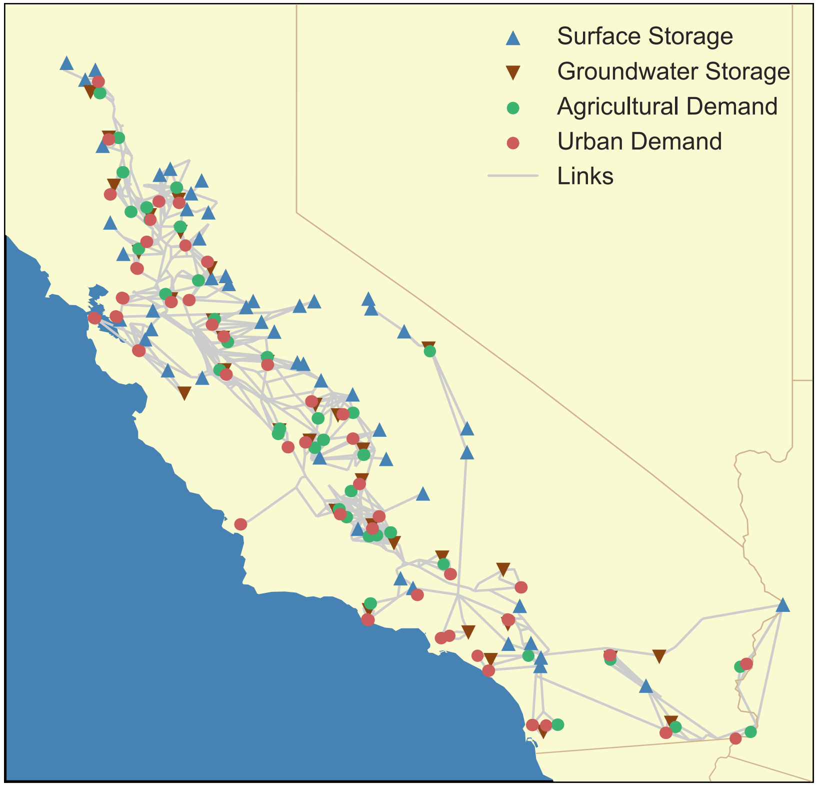


MIF Requirements

- 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

$$\sum_{i}\sum_{k} X_{jik} - \sum_{i}\sum_{k} a_{ijk} X_{ijk} = 0, \forall j \in N$$

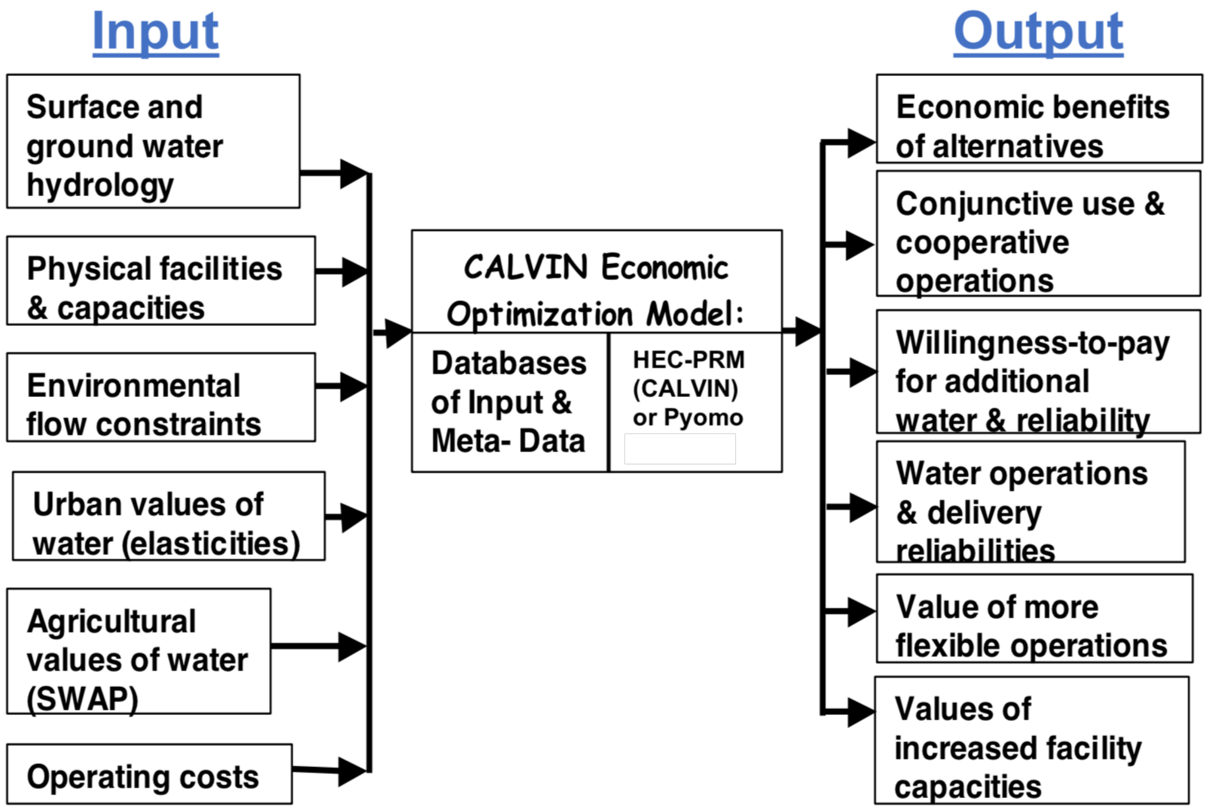
Mass balance constraint

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

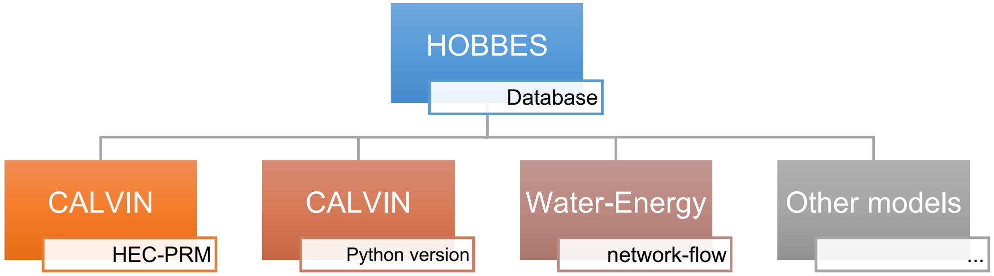
- Water operations are driven by economic value of water: Hydrologic data + economic data



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



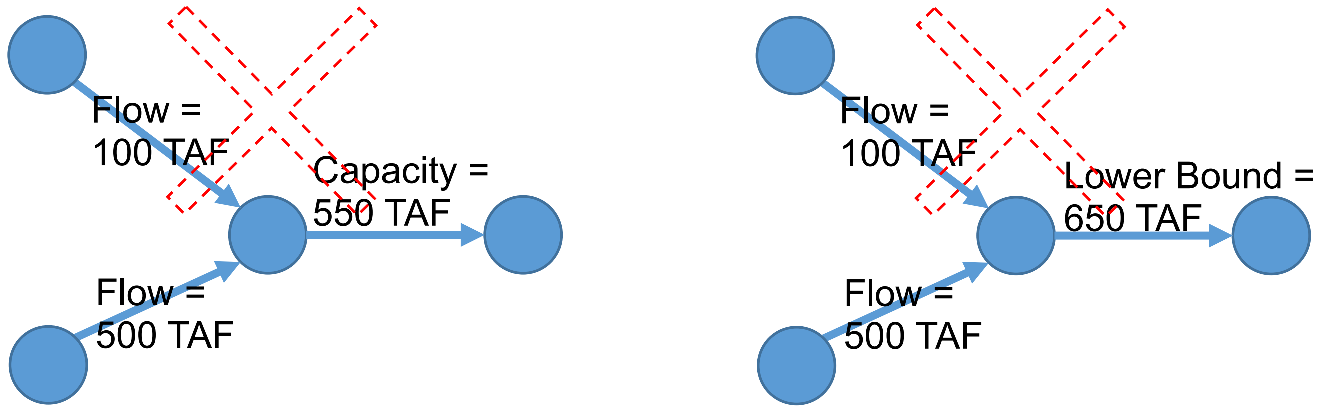
HOBBES for CALVIN (Python)

- CALVIN Python version uses matrices for all parameters: *c*, *a*, *l*, *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*	*l*	*u*

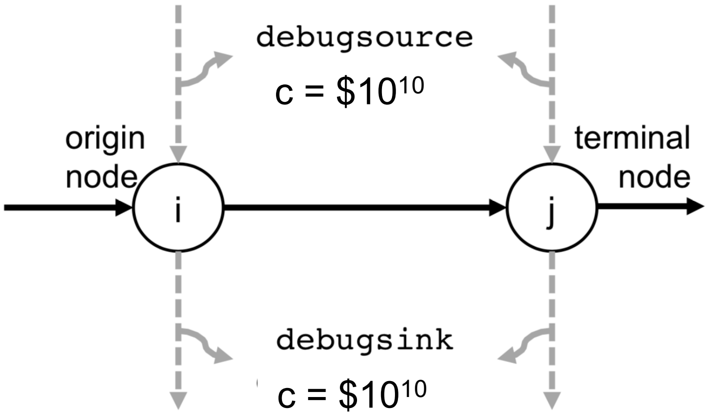
Resolving infeasibilities

- 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 (~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

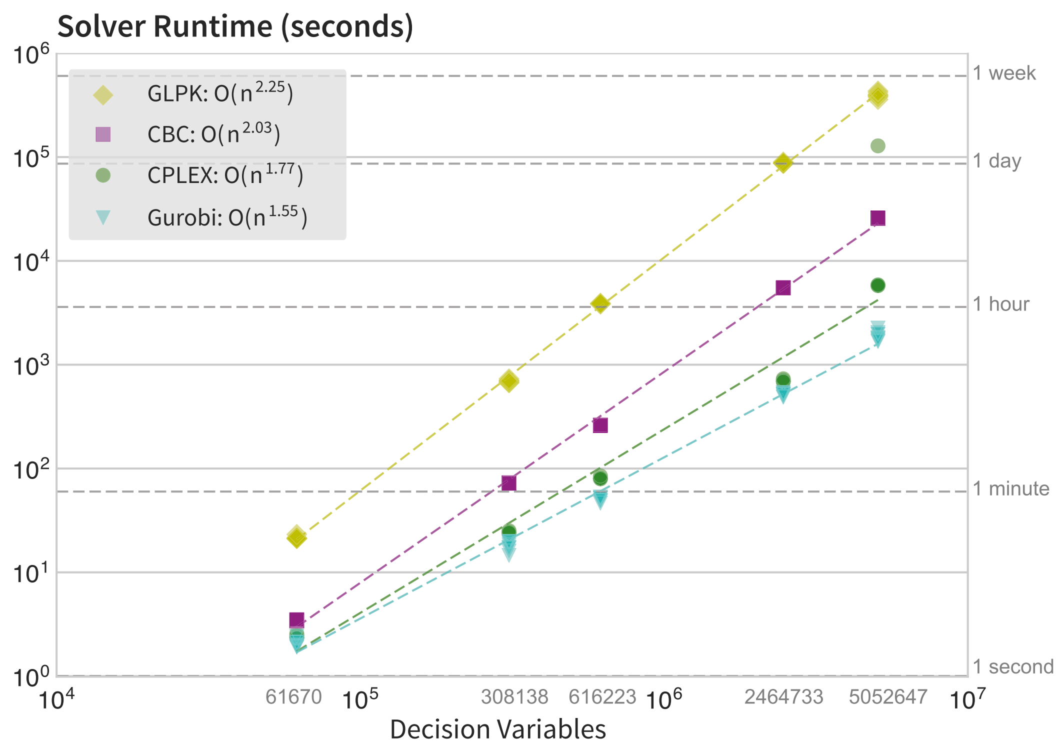
- Create a *cross-platform* model: MacOS, Windows
- Use *open data format*: `csv`, `JSON`
- Have *freely available*: data, code, modeling language & solvers are open-source or free of charge
- *Separate model & data*:
  - HOBBES is independent from any data
  - CALVIN's structure code is generalized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

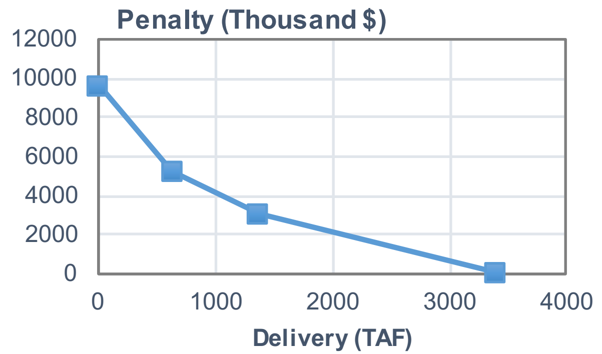
CALVIN runtime

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

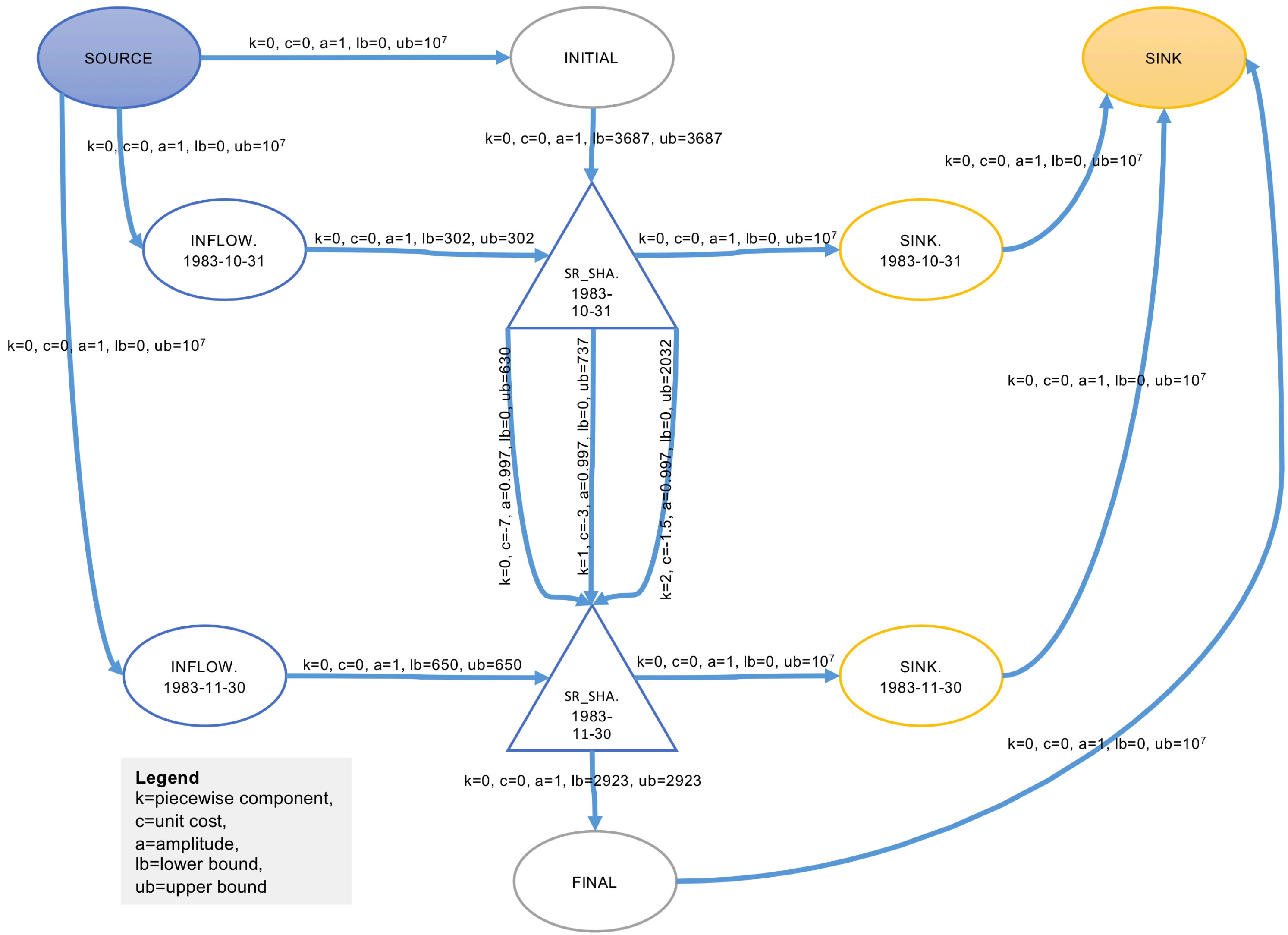


A small network example

- 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



Legend
k=piecewise component,
c=unit cost,
a=amplitude,
lb=lower bound,
ub=upper bound