CALVIN (Python Version)
Fall 2018 Shortcourse

Prepared by

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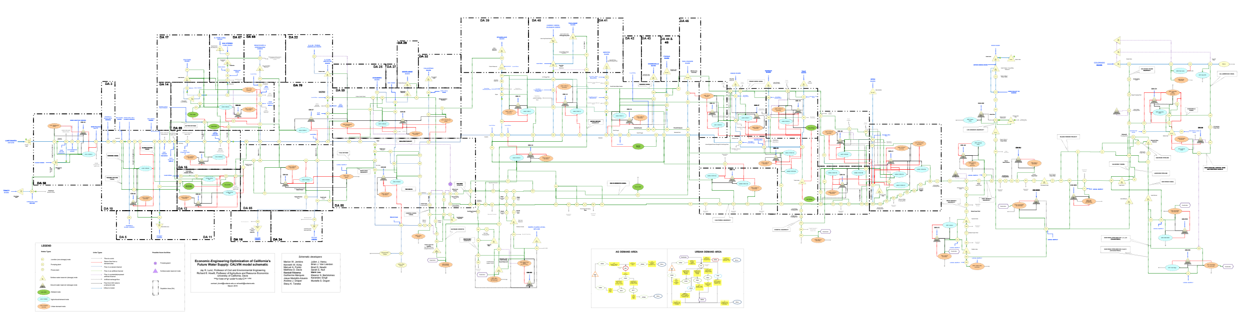
Date: October 5, 2018

Location: Center for Watershed Sciences Conference Room



Date: Friday, October 5, 2018

Location: UC Davis, Center for Watershed Sciences Conference Room

Registration: https://goo.gl/forms/6nUVGddb8xhUOSVn1

Shortcourse GitHub Repo: https://github.com/msdogan/CALVIN-shortcourse

Tentative Agenda and Topics

10.00 – 10:05 am	-	Introduction
10:05 – 10:30 am	-	Set-up required software
10:30 – 11:15 am	-	CALVIN Theory
11:15 – 12:00 pm	-	HOBBES overview and exporting network data
12:00 – 01:00 pm	**-**	**Lunch break**
01:00 – 01:15 pm	-	CALVIN Python version updates and Pyomo
01:15 – 02:15 pm	-	“Abstract model”: run and analyses
02:15 – 03:15 pm	-	“Concrete model”: run and analyses
03:15 – 03:30 pm	**-**	**Break**
03:30 – 04:30 pm	-	Postprocessing and analyzing results

Summary

This shortcourse is intended for those who are interested in California's water supply system and large-scale water optimization modeling. Mechanics of the CALVIN model will be covered. This crash course introduces open-source CALVIN version modeled in Python-based Pyomo environment, employing faster solvers and giving an opportunity for better representation of the system. It walks through steps for required software installation process for the CALVIN model, as well as creating a model run and postprocessing results.

Recommended readings

- **Original publication of CALVIN** (Draper et al., 2003):

Draper, A. J., Jenkins, M. W., Kirby, K. W., Lund, J. R., & Howitt, R. E. (2003). Economic-Engineering Optimization for California Water Management. *Journal of Water Resources Planning and Management*, *129*(3), 155–164. https://doi.org/10.1061/(ASCE)0733-9496(2003)129:3(155)

- **Open-source Python version of CALVIN** (Dogan et al., 2018):

Dogan, M. S., Fefer, M. A., Herman, J. D., Hart, Q. J., Merz, J. R., Medellín-Azuara, J., & Lund, J. R. (2018). An open-source Python implementation of California's hydroeconomic optimization model. *Environmental Modelling & Software*, *108*, 8–13. https://doi.org/10.1016/j.envsoft.2018.07.002

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Required Software

Several different installations are required in order to export network data from HOBBES, and then create and run CALVIN model. CALVIN is an open-source project, so all installations are free of charge! CALVIN can connect to commercial solvers, some of which are free for academic purposes, but there we will use open-source solvers for the purposes of this shortcourse. Required installations are cross-platform, so they (should) run on Windows or Mac OS.

GitHub account

Model data and components are hosted in GitHub, a web-based data and code hosting service with version control. So, having a GitHub account and downloading GitHub desktop is strongly recommended but files can be downloaded from hosted repositories as zip files without an account.

- Sign up for a GitHub account: https://github.com/
- Download GitHub desktop: https://desktop.github.com

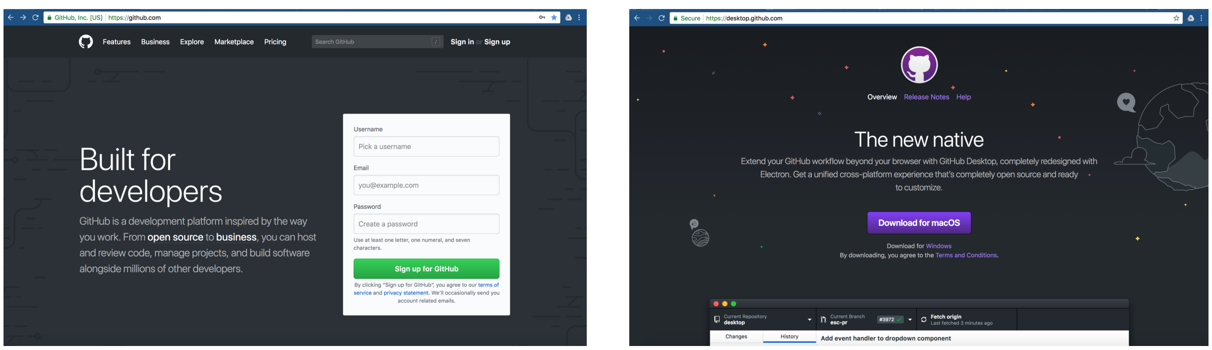

Figure 1. GitHub sign-up page and desktop

Cloning or downloading required GitHub repositories

After signing up and installing GitHub desktop, go to each of these following repositories and clone them, or if you can download as zip file as shown below. Please read “Readme” files by scrolling down in each repository. Required repositories:

- https://github.com/ucd-cws/calvin-network-data
- https://github.com/ucd-cws/calvin-network-tools
- https://github.com/ucd-cws/calvin

Bonus

- https://github.com/msdogan/CALVIN-shortcourse

Cloning steps (repeat this for each repository):

1. Go to repository link (above)
2. Click on green “Clone or download” button.
3. “Open in Desktop” or if you do not have account or GitHub desktop, click on “Download ZIP”

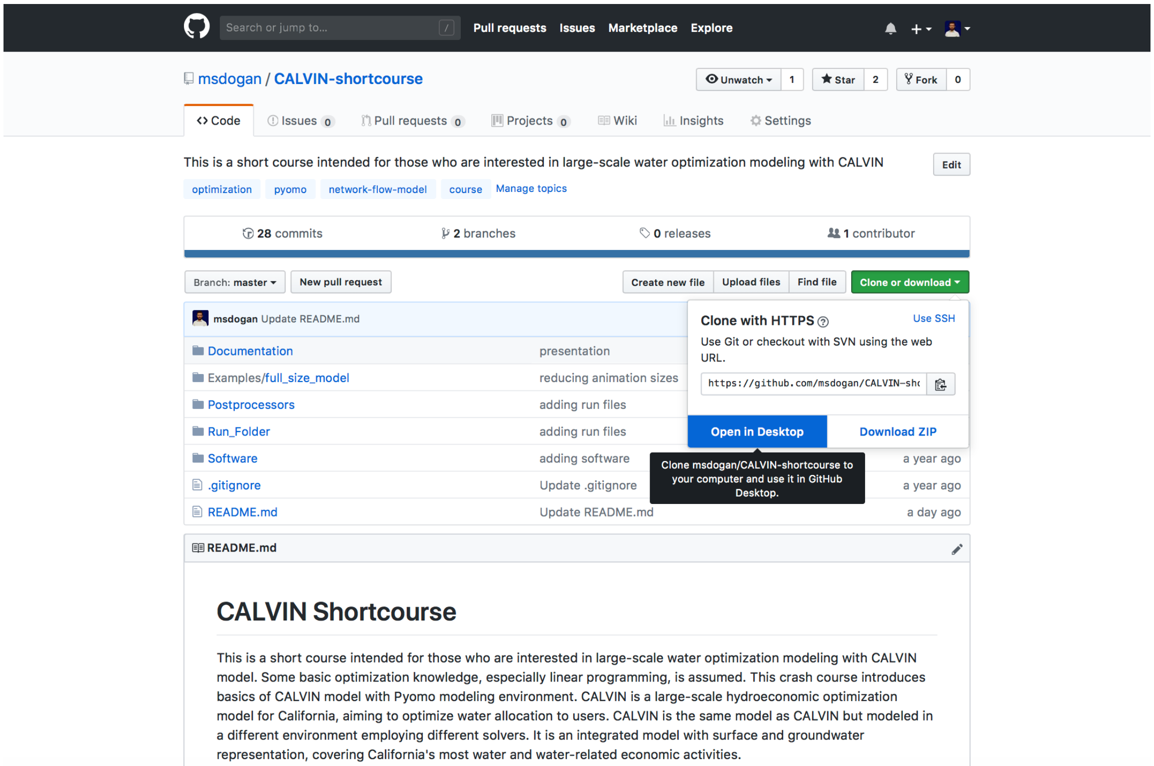

Figure 2. Cloning a repository

Installing CALVIN network tools to export input data

We will use command line to install required software (Node.js) and export network. Instructions on how to use command line for Windows and Mac OS are provided. CALVIN network tools (https://github.com/ucd-cws/calvin-network-tools) has several feature, such as exporting network, running HEC-PRM (old solver), updating database with a new run. However, we will only use matrix feature, which exports water network as a matrix. This matrix is used as input for Pyomo model.

Instructions for Mac OS

Step 1: Download and install Node.js from https://nodejs.org/en/

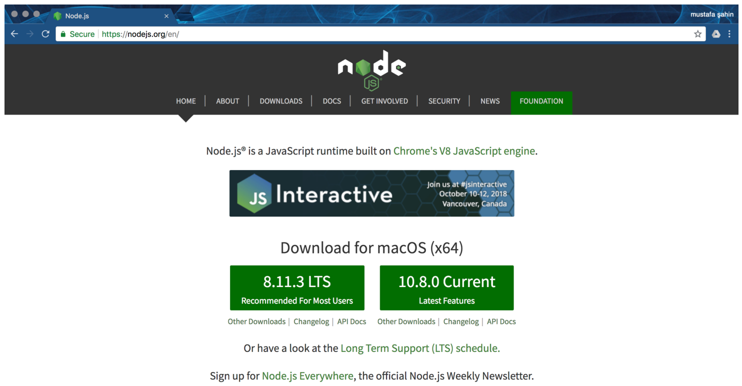

Figure 3. Node.js installation page

Step 2: Open Terminal and run following command to install calvin-network-tools via npm. If you do not know how to open Terminal on your Mac, just google it.

Type this command and hit enter.

```
npm install -g calvin-network-tools
```

if you get a permission error, try sudo running and enter your Admin password:

```
sudo npm install -g calvin-network-tools
```

Figure 4. Installing calvin-network-tools via npm on Mac Terminal

Step 3: Specify data location. Data is calvin-network-data cloned or downloaded from its repository. Run following command and enter path to data file when prompted. Path is folder location where you cloned calvin-network-data. Example:
`/Users/msdogan/Documents/github/calvin-network-data`

```
sudo cnf library init
```

```
[campus-041-215:~ msdogan$ sudo cnf library init
[Password:

Please enter the full path of your data directory
(be sure and include /data, so will look something like /path/to/repo/calvin-network-data/data ):
/Users/msdogan/Documents/github/calvin-network-data

Runtime download complete.
Runtime extraction complete.
All set.

Help:           cnf hec-prm --help
Example build:  cnf hec-prm build --prefix test
More Info:      https://github.com/ucd-cws/calvin-network-tools
campus-041-215:~ msdogan$
```

Installing Python and other libraries via Anaconda package

We will use Anaconda, a free and open source distribution of the Python programming language for data science and machine learning related applications (large-scale data processing, predictive analytics, scientific computing), that aims to simplify package management and deployment. Anaconda distribution has several packages, including Numpy, Scipy and Pandas. If you already have Anaconda with Python 3.0+, you do not need to install again, you can proceed to Pyomo and solver installations. Otherwise, if you use Python only purposes of this course, I recommend installing miniconda with Python 3.0+ as it includes less but enough packages for this shortcourse.

Download link: https://conda.io/miniconda.html

Installing Pyomo and its solver

Pyomo is a high level Python optimization modeling library. Pyomo is like a interface between your data and solver in a sense that it prepares your parameter data, decision variables, objective function, and constraints in way that solvers can understand and solve. Pyomo then gets raw results from solvers and organizes for us to Postprocess. Pyomo simply communicates between data and solvers. CALVIN can connect to several solvers but we will use GLPK, an open-source linear programming (LP) solver.

After installing miniconda v3 (or Anaconda v3), installing pyomo and GLPK solver are straightforward. We will use command line to install required packages.

```
conda install -c conda-forge pyomo pyomo.extras glpk
```

Mac OS Pyomo and solver installation

Open Terminal (you can search for “Terminal” in your Spotlight Search if it is not in your Dock), and **type** the following command and hit **enter** to run.

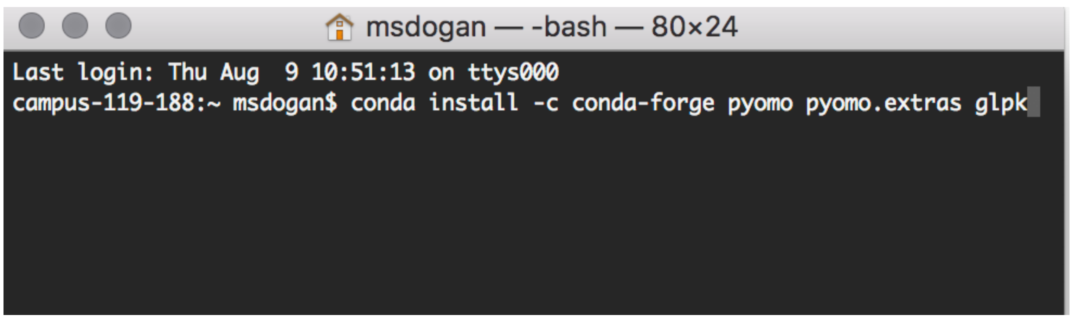

Figure 5. Mac OS Terminal Pyomo and GLPK solver installation

Windows Pyomo and solver installation

You can open command line by searching “Command Prompt” in your Windows search. **Type** command above in your command line console and hit **enter** to run.

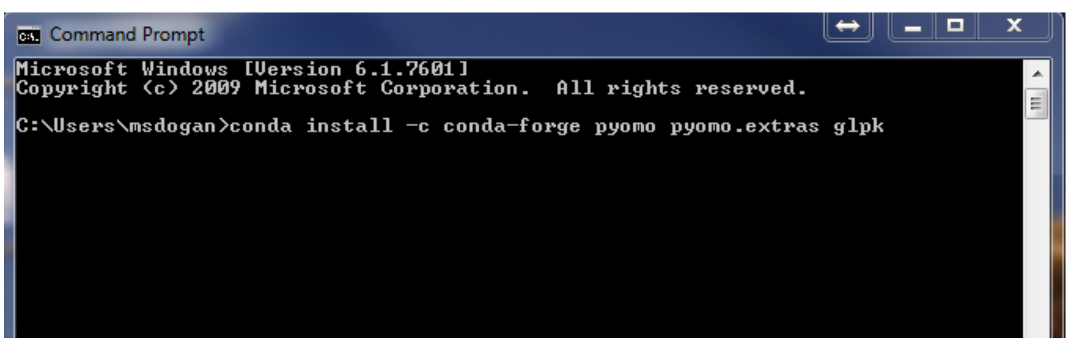

Figure 6. Windows Command Prompt Pyomo and GLPK solver installation

Here is a successful installation of Pyomo and GLPK solver

```
campus-119-188:~ msdogan$ conda install -c conda-forge pyomo
pyomo.extras glpk
Solving environment: done

## Package Plan ##

  environment location: /Users/msdogan/anaconda

  added / updated specs:
    - glpk
    - pyomo
    - pyomo.extras

The following packages will be downloaded:
    package                |  build
    ---------------------------|-----------------
    pyutilib-5.6.3         |  py27_0          333 KB  conda-forge
    glpk-4.65              |  h16a7912_1      1.0 MB  conda-forge
    pyomo.extras-3.3       |  py27_0          3 KB  conda-forge
    pyomo-5.5.0            |  py27_1          2.7 MB  conda-forge
    ------------------------------------------------------------
                              Total:          4.1 MB
The following packages will be UPDATED:

glpk:    4.61-0 conda-forge --> 4.65-h16a7912_1 conda-forge
pyomo:    5.1.1-py27_0 conda-forge --> 5.5.0-py27_1 conda-forge
pyomo.extras: 3.2-py27_0 conda-forge --> 3.3-py27_0 conda-forge
pyutilib: 5.4.1-py27_0 conda-forge --> 5.6.3-py27_0 conda-forge

Proceed ([y]/n)? y

Downloading and Extracting Packages
Pyutilib 5.6.3: ######################################## | 100%
glpk 4.65: ############################################# | 100%
pyomo.extras 3.3: ###################################### | 100%
pyomo 5.5.0: ########################################### | 100%
Preparing transaction: done
Verifying transaction: done
Executing transaction: done
```

Optional: Text editor

If you do not have a text editor, I recommend Sublime Text https://www.sublimetext.com or Notepad++ https://notepad-plus-plus.org. Text editor can be used to open data file. With Sublime Text you can also run Python.

CALVIN Theory and Background

Developed in early 2000s, **CAL**ifornia **V**alue **I**ntegrated **N**etwork model (CALVIN) combines ideas from economics and engineering optimization with advances in software and data to suggest more integrated management of water supplies regionally and throughout California. CALVIN is a hydro-economic optimization model for California's advanced water infrastructure that integrates the operation of water facilities, resources, and demands, and it aims to optimize surface and groundwater deliveries to agricultural and urban water users. It allocates water to minimize water scarcity and operating costs (maximize statewide agricultural and urban economic value), considering physical and policy constraints. It replicates water market operations transferring water from users with lower willingness-to-pay (WTP) to users with higher WTP. CALVIN uses historical hydrology and 2050 water demand projections for its operations.

CALVIN forces quantitative understanding of integrated water and economic sys- tem. Motivation for the CALVIN effort include:

- making better sense of integrated system and operations
- seeking ways to improve system management
- quantifying user willingness to pay for additional water
- finding insights into changes in physical capacities and policies

CALVIN is a network-flow model over a physical network represented by a set of nodes N and links A. Links are defined by $(i, j, k) \in A$, where i is the origin node, j is the terminal node, and k is piecewise component used to represent nonlinear penalty (or cost) curves with a convex piecewise delineation. The component k creates multiple links from origin node i to terminal node j with monotone decreasing unit costs. Each link has the following properties: flow X_{ijk}, which is the decision variable; unit cost c_{ijk}; lower bound l_{ijk}; upper bound u_{ijk}; and amplitude or loss factor a_{ijk}. The objective function and constraints are:

$$\min_{X} z = \sum_{i} \sum_{j} \sum_{k} c_{ijk} X_{ijk} \qquad \text{Equation 1}$$

$$X_{ijk} \geq l_{ijk}, \forall (i, j, k) \in A \qquad \text{Equation 2}$$

$$X_{ijk} \leq u_{ijk}, \forall (i, j, k) \in A \qquad \text{Equation 3}$$

$$\sum_{i} \sum_{k} X_{jik} - \sum_{i} \sum_{k} a_{ijk} X_{ijk} = 0 , \forall j \in N \qquad \text{Equation 4}$$

The objective function (*Equation 1*) is a summation over all links (i, j, k) and represents the total cost of flow conveyed in the network. *Equation 2*, *Equation 3*, and *Equation 4* represent the lower bound, upper bound, and mass balance constraints, respectively.

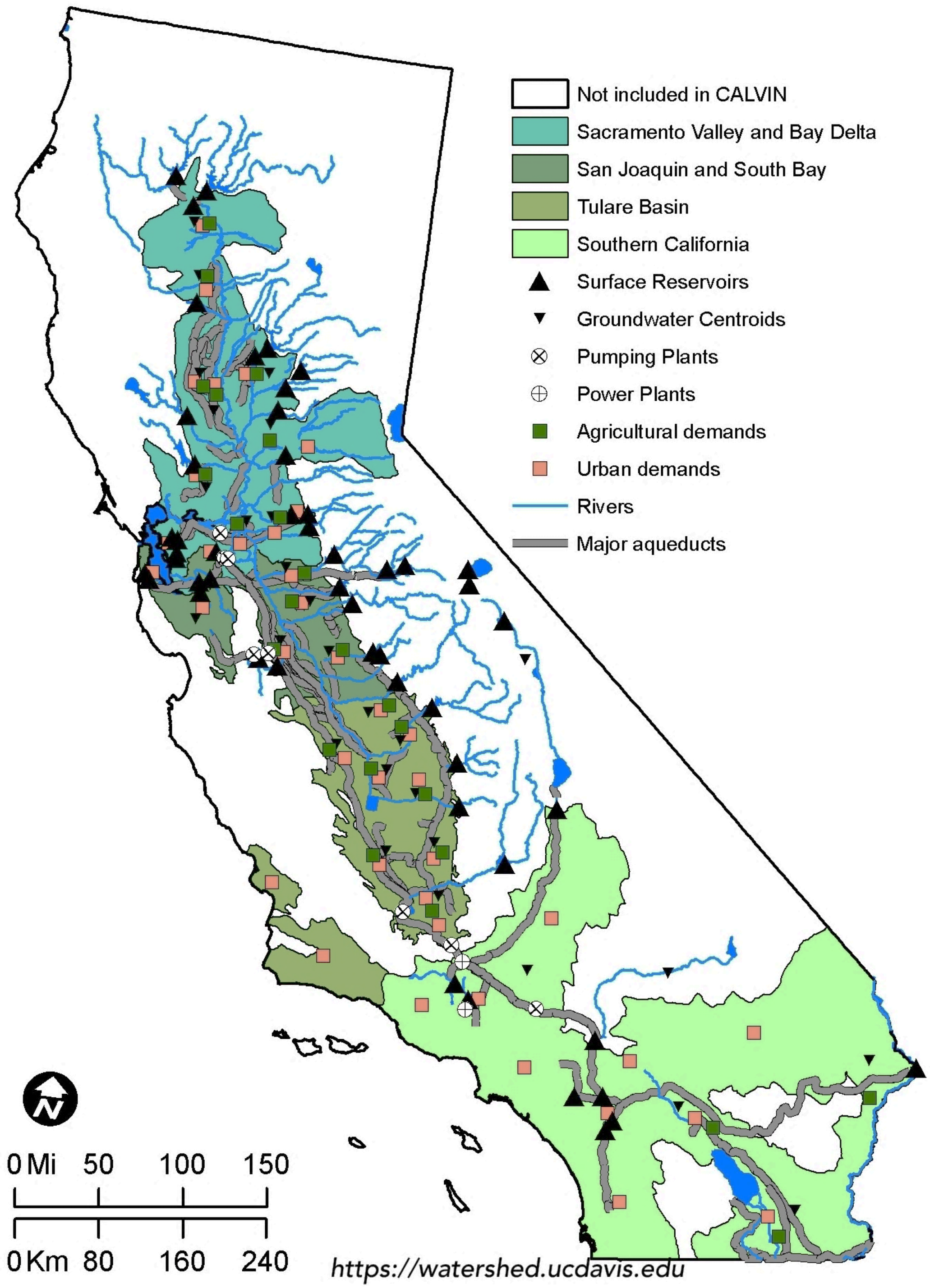

Figure 7. California's water infrastructure and CALVIN coverage

CALVIN online schematic and visualization tool

This tool shows schematic of georeferenced nodes and links on a California map by reading data from HOBBES database. Regions and network features can be filtered through its interface. You can see information about the feature (node or link) by clicking. If there is any time-series or cost data, plots will be shown. Visualization tool also has an animation layer, which shows already optimized flow and storage operations. Animation layer can be active by checking box on the bottom of page.

Link here: https://cwn.casil.ucdavis.edu

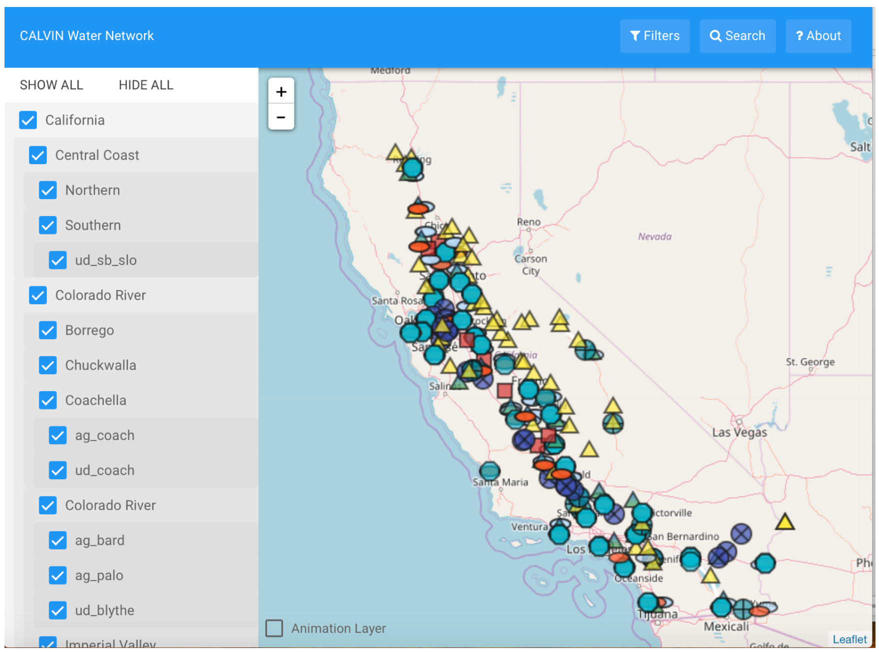

Figure 8. CALVIN visualization tool

Agricultural Demand

CALVIN optimizes reservoir and water supply operations to minimize water scarcity and operating costs. Water scarcity and economic costs occur when a user's total is not met. As a result, agricultural production losses occur. Demand and penalty curves quantifying how much loss occur depending on water delivery differ for each subregion and are obtained from Statewide Agricultural Production (SWAP) model (Howitt et al., 2012).

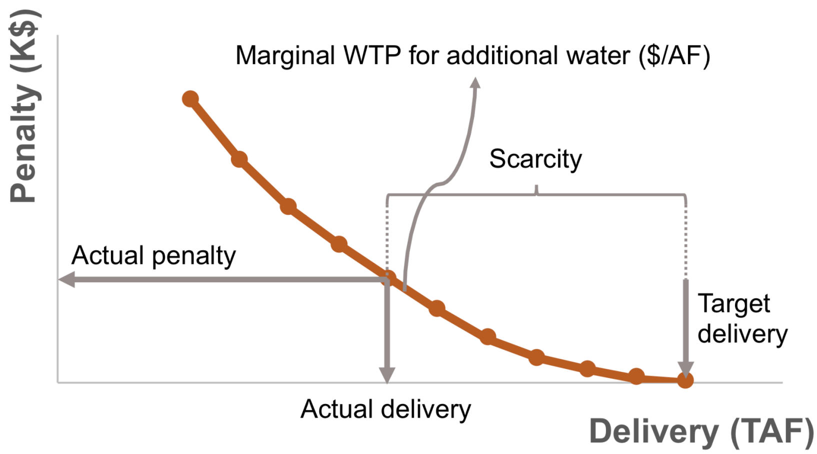

Figure 9. Typical penalty curve for water delivery

In CALVIN, there are two water sources available for agricultural users: groundwater and surface water. Both supplies are aggregated in one node (A###) and after applying reuse multiplier on link (A###-HU###), demand penalties and delivery targets are applied on HU###-CVPMG and CVPMS links. Agricultural demand areas are divided into two parts based on their return flow to either groundwater (CVPMG) or surface water (CVPMS). After that consumptive use ratios (amplitudes) are applied and remaining water goes back to network.

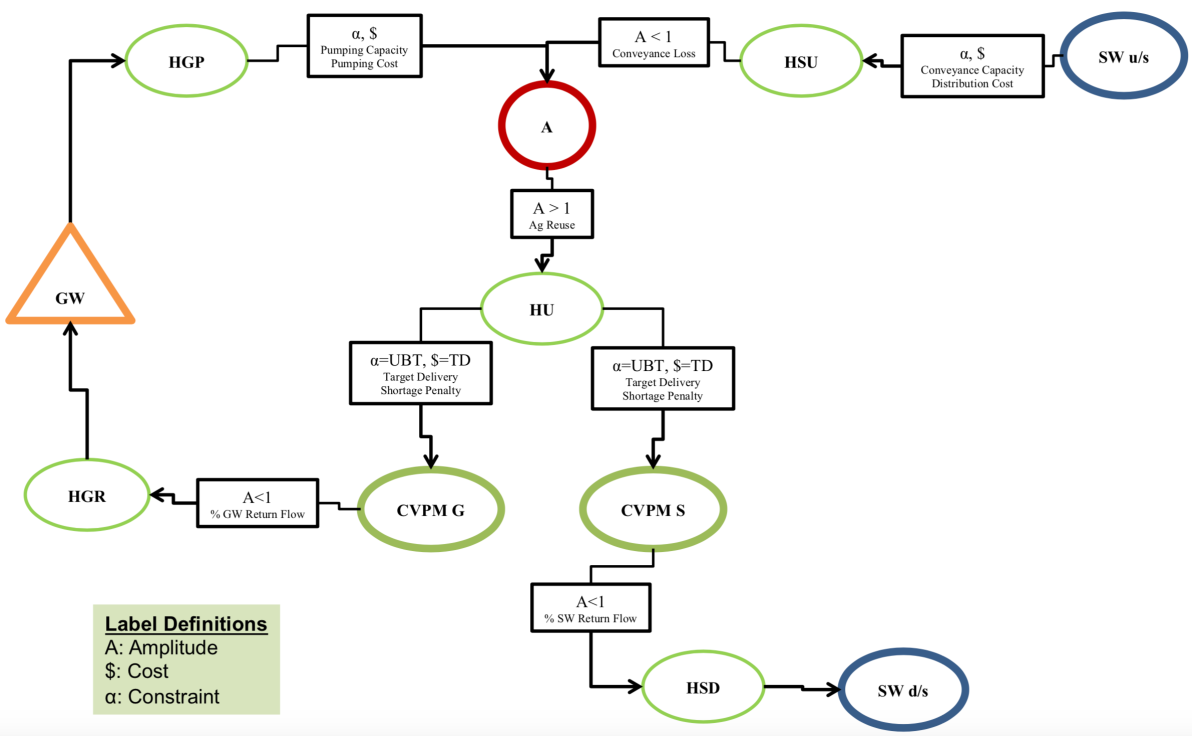

Figure 10. Generalized representation of agricultural demand in CALVIN

Urban Demand

Urban areas have more water supply sources available than agricultural users. In addition to groundwater and surface water, desalination, potable and nonpotable recycled wastewater are available for urban users. Surface water deliveries are treated in a water treatment plant node (WTP###) and all sources, except nonpotable recycled wastewater, are aggregated in U### nodes. CALVIN's urban areas split into three uses: exterior, interior, and industrial. While potable recycled wastewater is available for all three uses (HP###)), nonpotable recycled wastewater is available only for exterior and industrial uses (HNP###). After applying consumptive use ratios on return links, industrial and interior return flows are sent to wastewater treatment plant nodes (WWP###) and then returned to surface or groundwater.

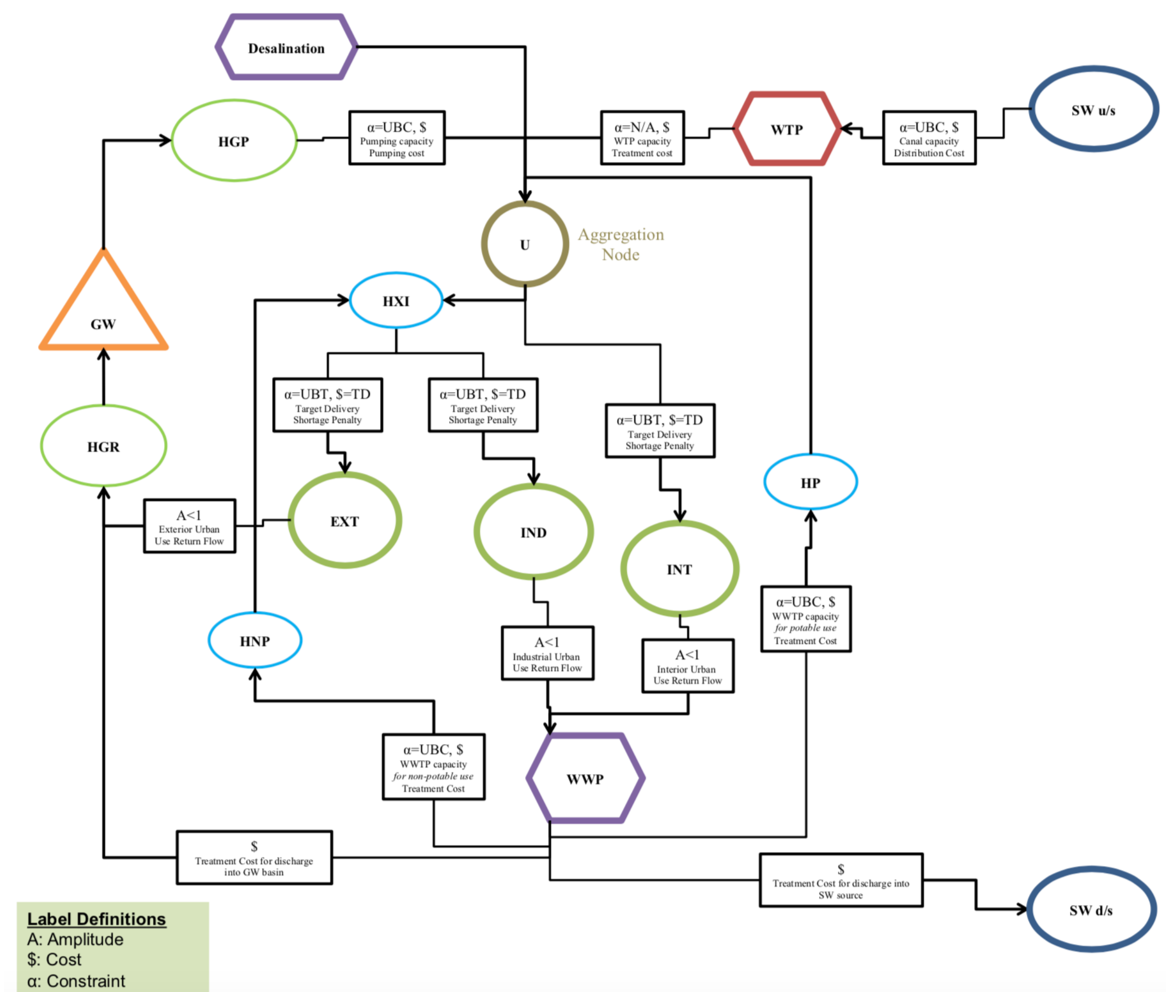

Figure 11. Urban water demand in CALVIN

Environmental Demand

Wildlife refuge areas do not have an economic representation in CALVIN. Deliveries are represented with constrained flows, which assures that environmental deliveries must be met before other deliveries. Groundwater, surface water and agricultural return flow supplies, which are aggregated in R### nodes, are available for wildlife refuge users and all return flows go to surface flow. In addition to wildlife refuge demands, CALVIN represents minimum in-stream flow requirements. These requirements are mostly on rivers (usually below reservoir releases or diversion points) and represented as lower bound constraints on the water network.

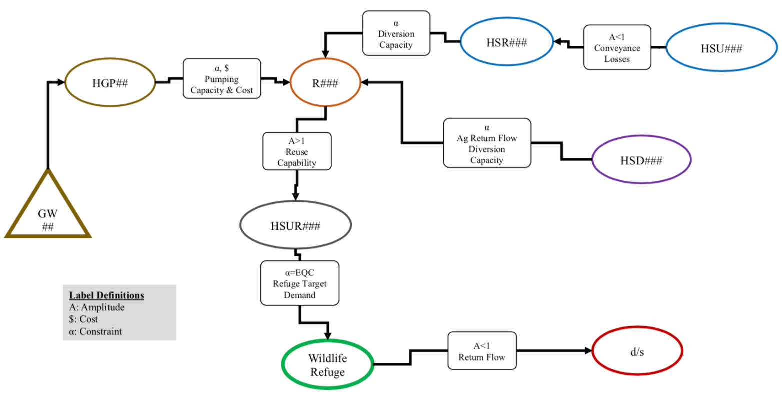

Figure 12.Wildlife refuge demand in CALVIN

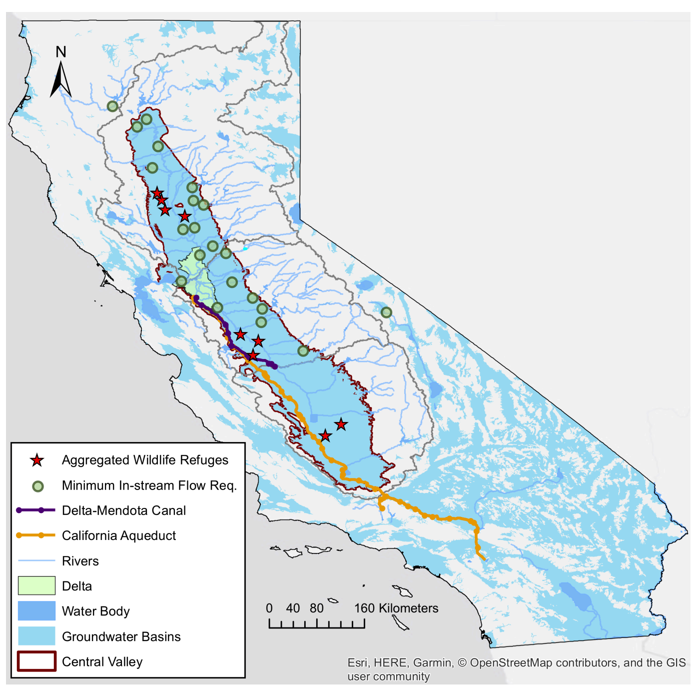

Figure 13. CALVIN's minimum in-stream flow locations and wildlife demands