UU Team 2 Integrated Modeling Updates

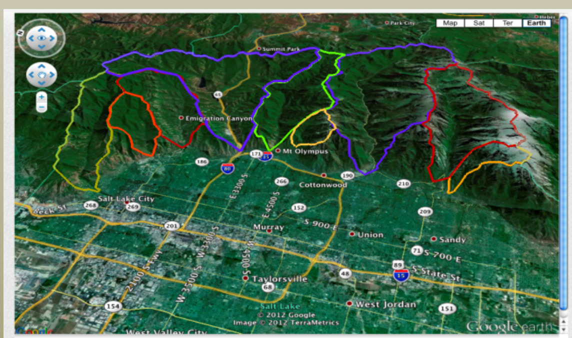
Climate Modeling
Web Interface
Wasatch Integrated Water Model
Climate Data Access Tool

Steven Burian, Court Strong, Erfan Goharian, Adam Kochanski, and Debadrita Das

Use future climate modeling and downscaling to inform probabilistic scenario development (Strong/Kochanski, UU)

Natural system hydrologic and hydraulic modeling (Burian, UU)

streamflow forecasts

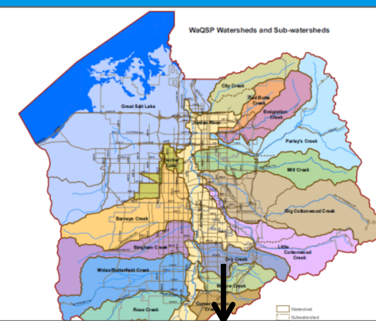


http://www.hiddenwaters.org/

climate change flows

Urban watershed and green infrastructure modeling (SWMM-ET, Pomeroy/Burian, UU)

Hydrologic Models



Water Quality Modeling (SL County, Potential iUTAH)

Operations model (Potential iUTAH)

Planning model (Burian, UU; SLC PU)

Water System Models

Demand scenarios (Tim Bardsley, WWA; SLC PU)

Outcomes

Expanded information for:

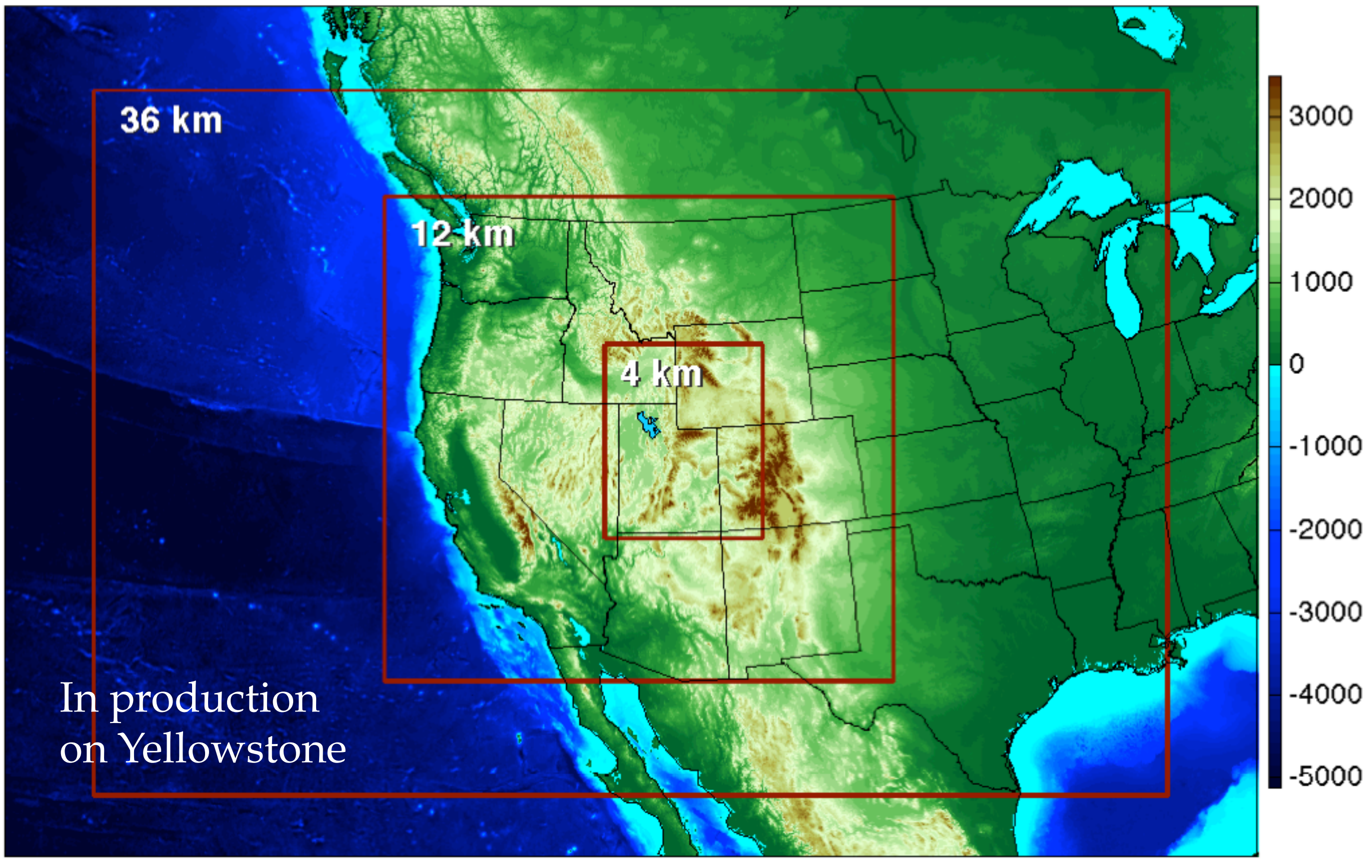
- climate-water science
- water operations
- long-term planning
- infrastructure upgrades

Dynamical downscaling

- WRF customized with Great Salt Lake model and urban irrigation scheme

Boundary conditions:
6-hourly NCEP Climate Forecast System Reanalysis (CFSR)
~38 km resolution
1985-2004,
2007-2009

CMIP5 (~1°)
2025-2035
2055-2065
2085-2095



Dynamical downscaling

- WRF Great Salt Lake “slab” model

Differential equation at each grid point

$$\frac{\mathrm{d}T_\mathrm{L}}{\mathrm{d}t} = -\frac{1}{\rho_\mathrm{w} c_\mathrm{w} h} F$$

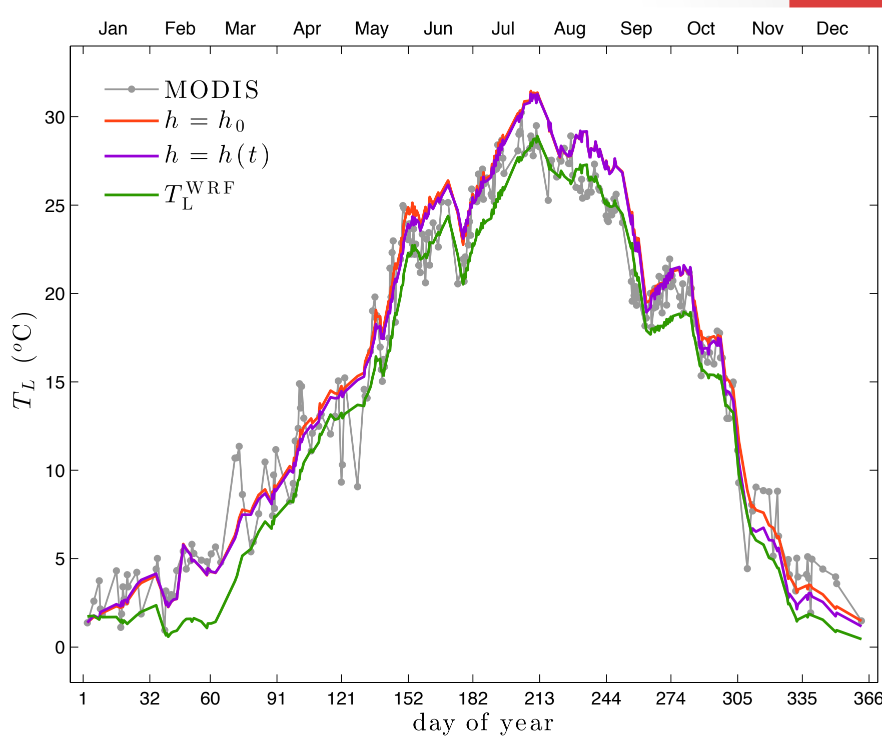
Cost function

$$J(h) = \left\{ \frac{1}{n_\Gamma} \sum_{t\in\Gamma} \left[T_\mathrm{L}^o(t) - T_\mathrm{L}^b(t,h) \right]^2 \right\}^{1/2}$$

Numerical optimization

$$\arg\min_h J(h);\ \text{subject to}: h \in [0, \infty]$$

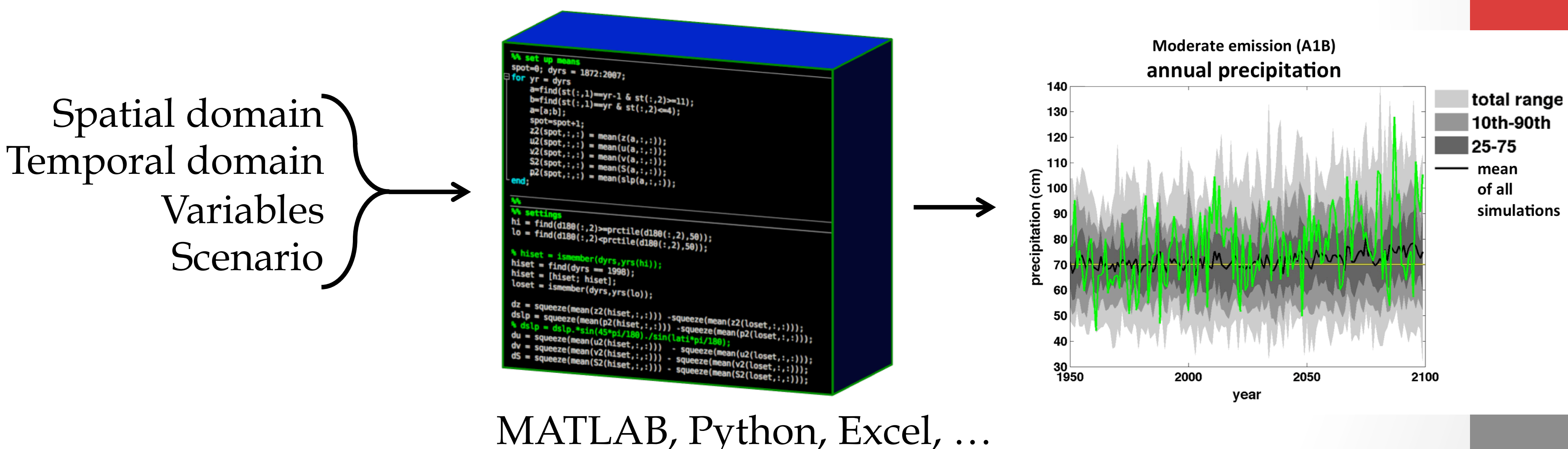
$$h = 5.1\ \mathrm{m}$$



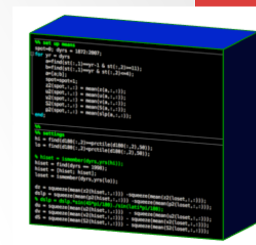
Strong et al. (2013), *JAMES*, in prep.

CSmod

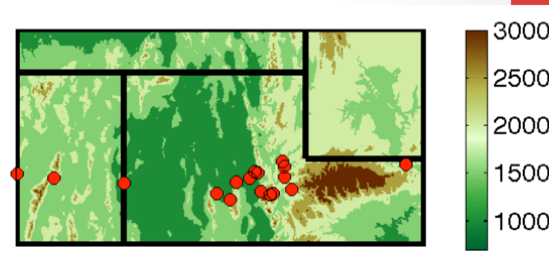
- **Developing a "Climate Scenario module" (CSmod) to generate on-demand, stochastic realizations of climate**



Statistical downscaling



CSmod engine:



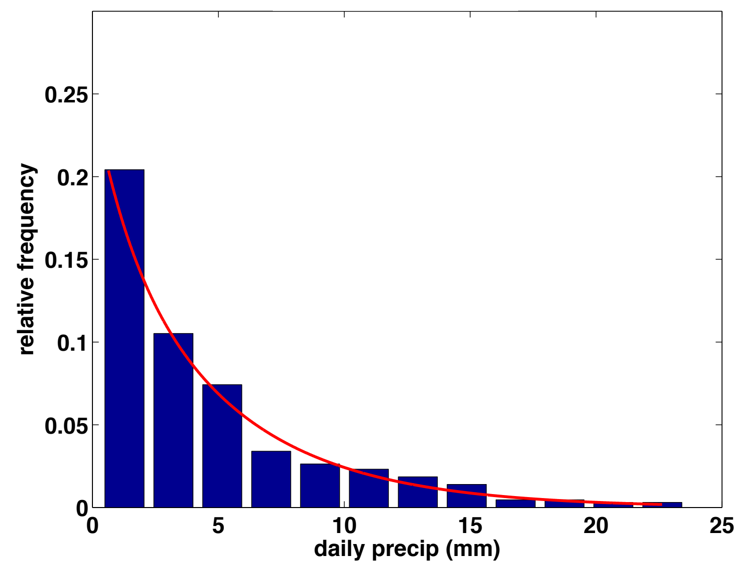
Occurrence: two-state, 2nd-order Markov chain process

$$p_{000}(k);\ p_{100}(k);$$

$$p_{010}(k);\ p_{110}(k);$$

$$k = 1, \ldots, K$$

KSLC March



Amount: fit mixed exponential

$$f\left[r(k)\right] = \frac{\alpha(k)}{\beta_1(k)} \exp\left[\frac{-1 r(k)}{\beta_1(k)}\right] + \frac{1-\alpha(k)}{\beta_2(k)} \exp\left[\frac{-1 r(k)}{\beta_2(k)}\right]$$

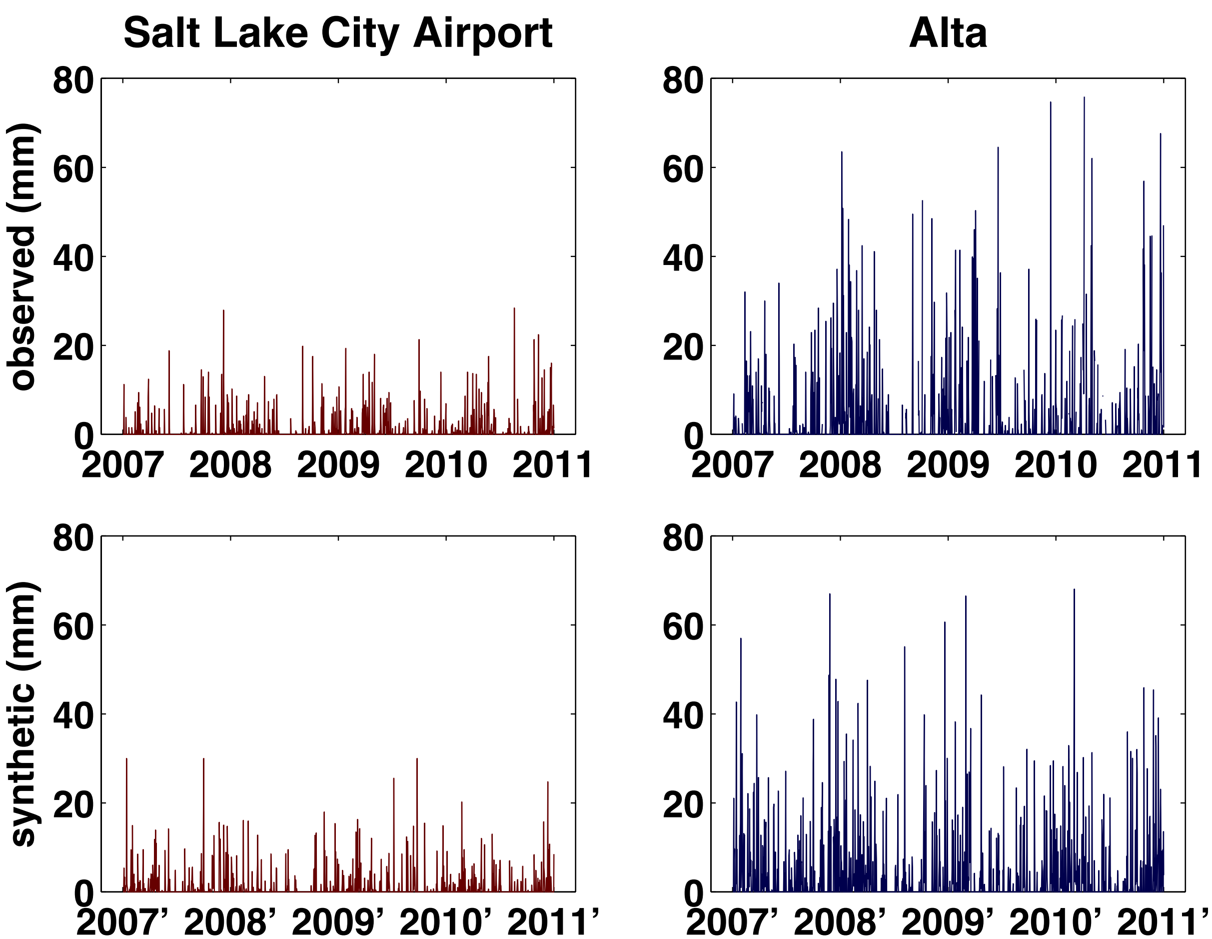
Stochastic driver: spatially-correlated multivariate Gaussian

$$g(\mathbf{x}) = \frac{1}{(2\pi)^{K/2}\sqrt{\det \boldsymbol{\Sigma}}} \exp\left[-\frac{1}{2}(\mathbf{x}-\mu)^T \boldsymbol{\Sigma}^{-1}(\mathbf{x}-\mu)\right]$$

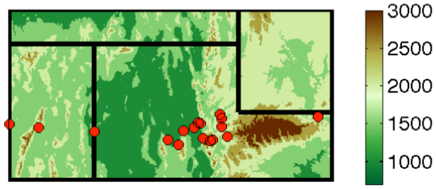
Wilks (1999,2009)

Climate Scenario module

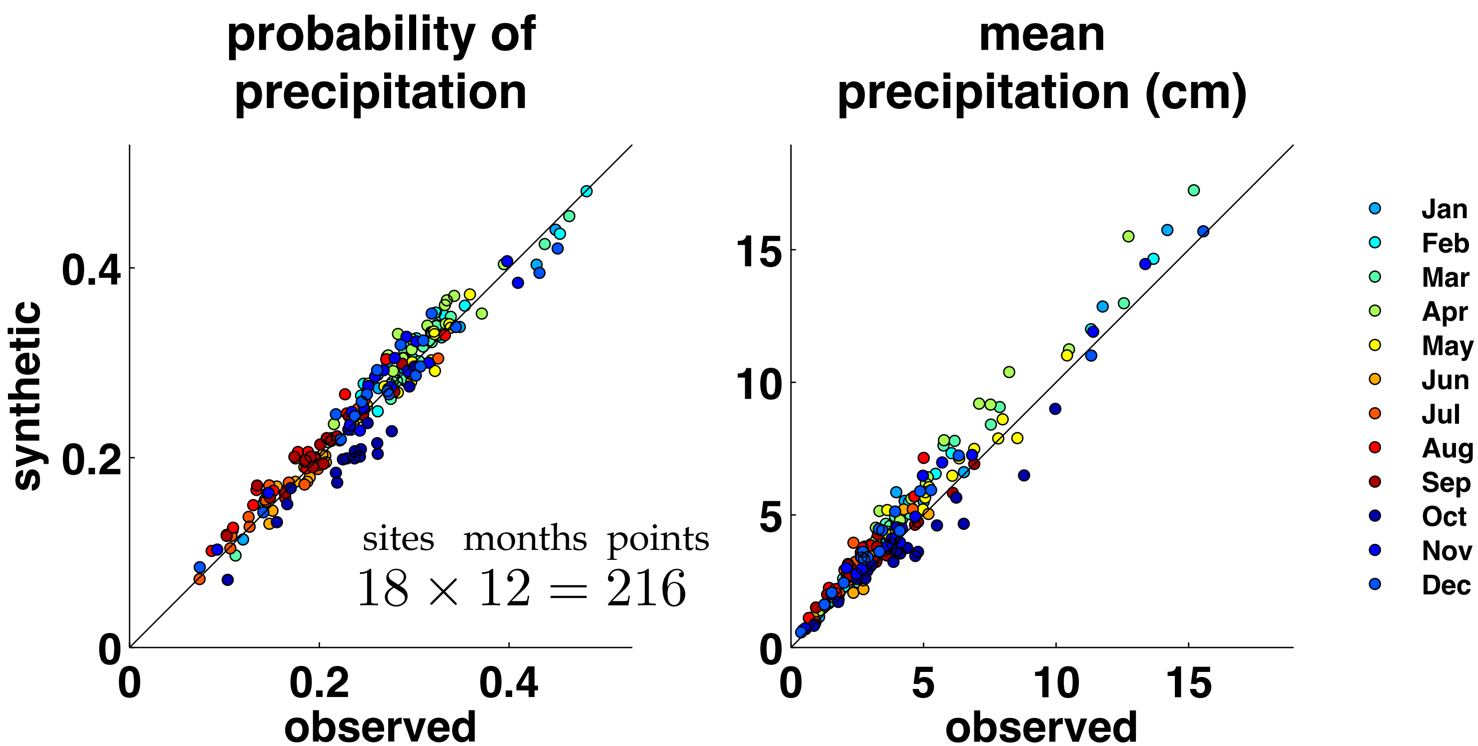
CSmod test: generate synthetic historical precipitation data



Climate Scenario module

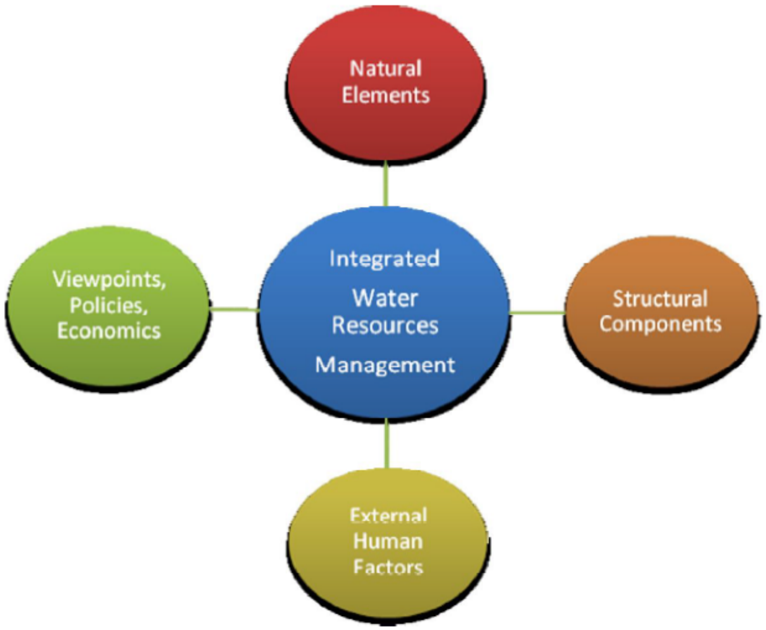


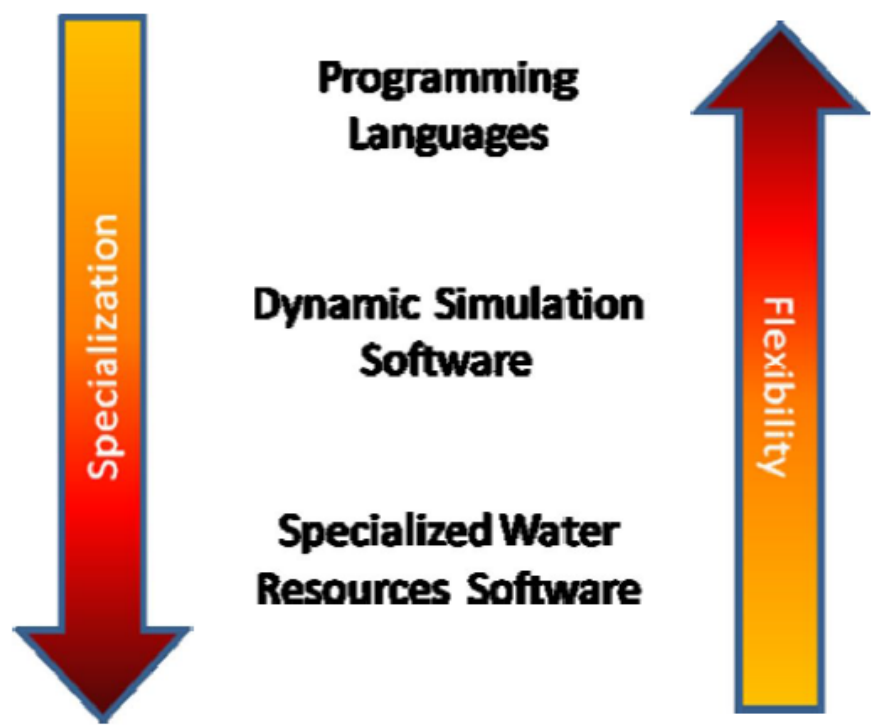
CSmod test: generate synthetic historical record (1958-2012)



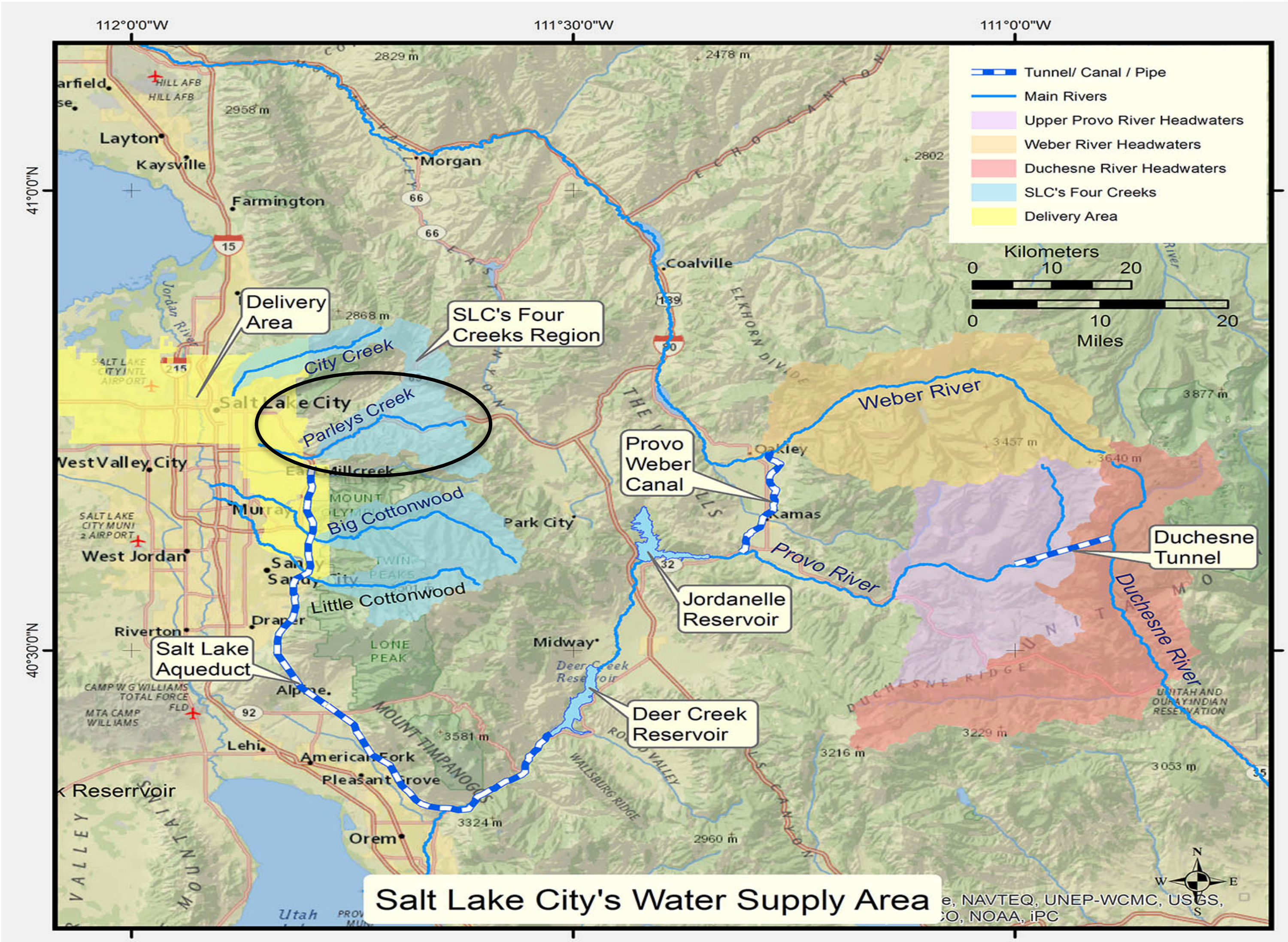
CSmod future climate: amount and occurrence functions are re-fit allowing nonstationarity if justified by change in log-likelihood

Integrated Water Resources Management (IWRM)





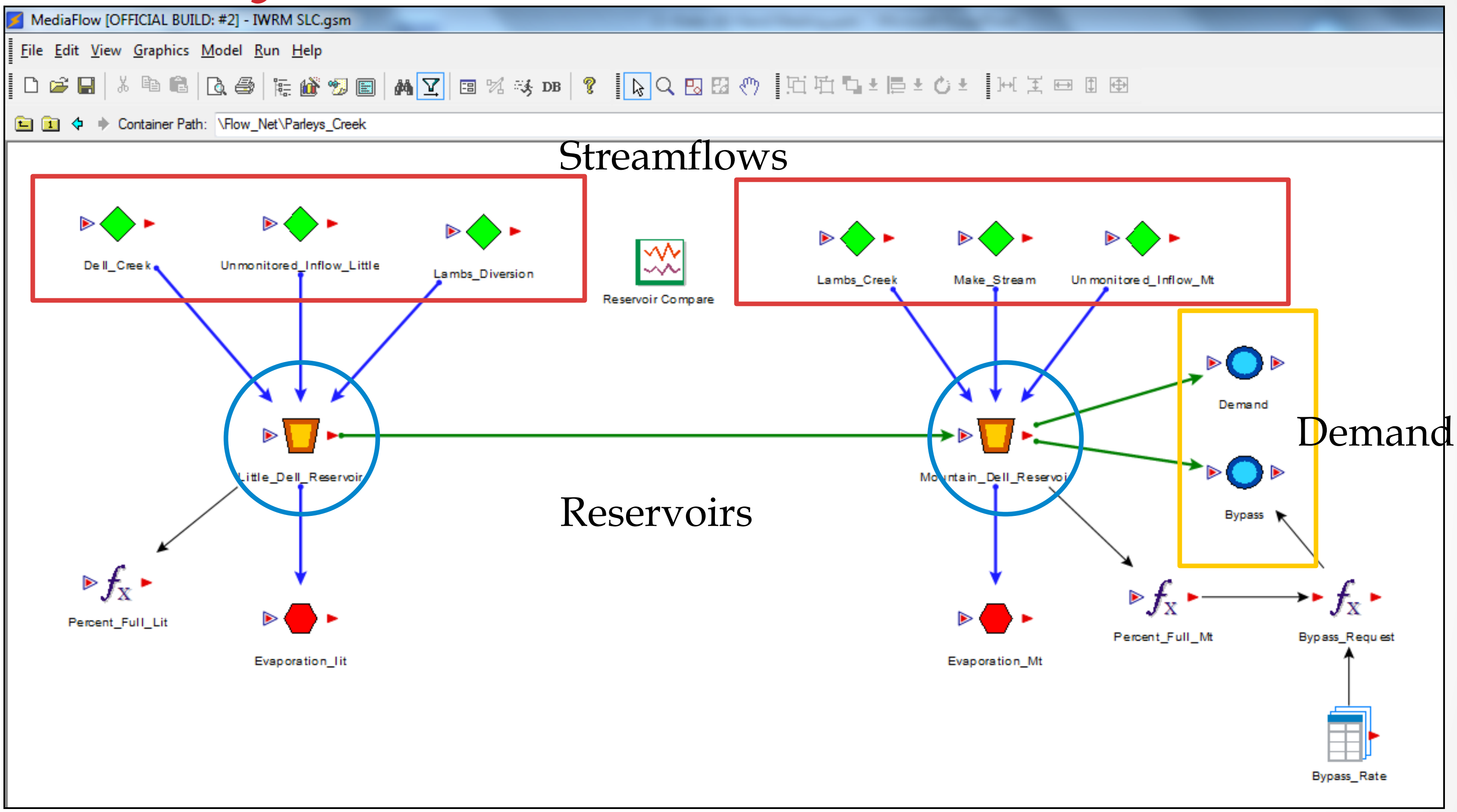
Case Study



Tunnel/ Canal / Pipe
Main Rivers
Upper Provo River Headwaters
Weber River Headwaters
Duchesne River Headwaters
SLC's Four Creeks
Delivery Area
Kilometers
Miles
Delivery Area
SLC's Four Creeks Region
City Creek
Parleys Creek
Big Cottonwood
Little Cottonwood
Salt Lake Aqueduct
Provo Weber Canal
Jordanelle Reservoir
Deer Creek Reservoir
Duchesne Tunnel
Weber River
Provo River
Duchesne River
Salt Lake City
Morgan
Coalville
Park City
Kamas
Oakley
Midway
Orem
Salt Lake City's Water Supply Area

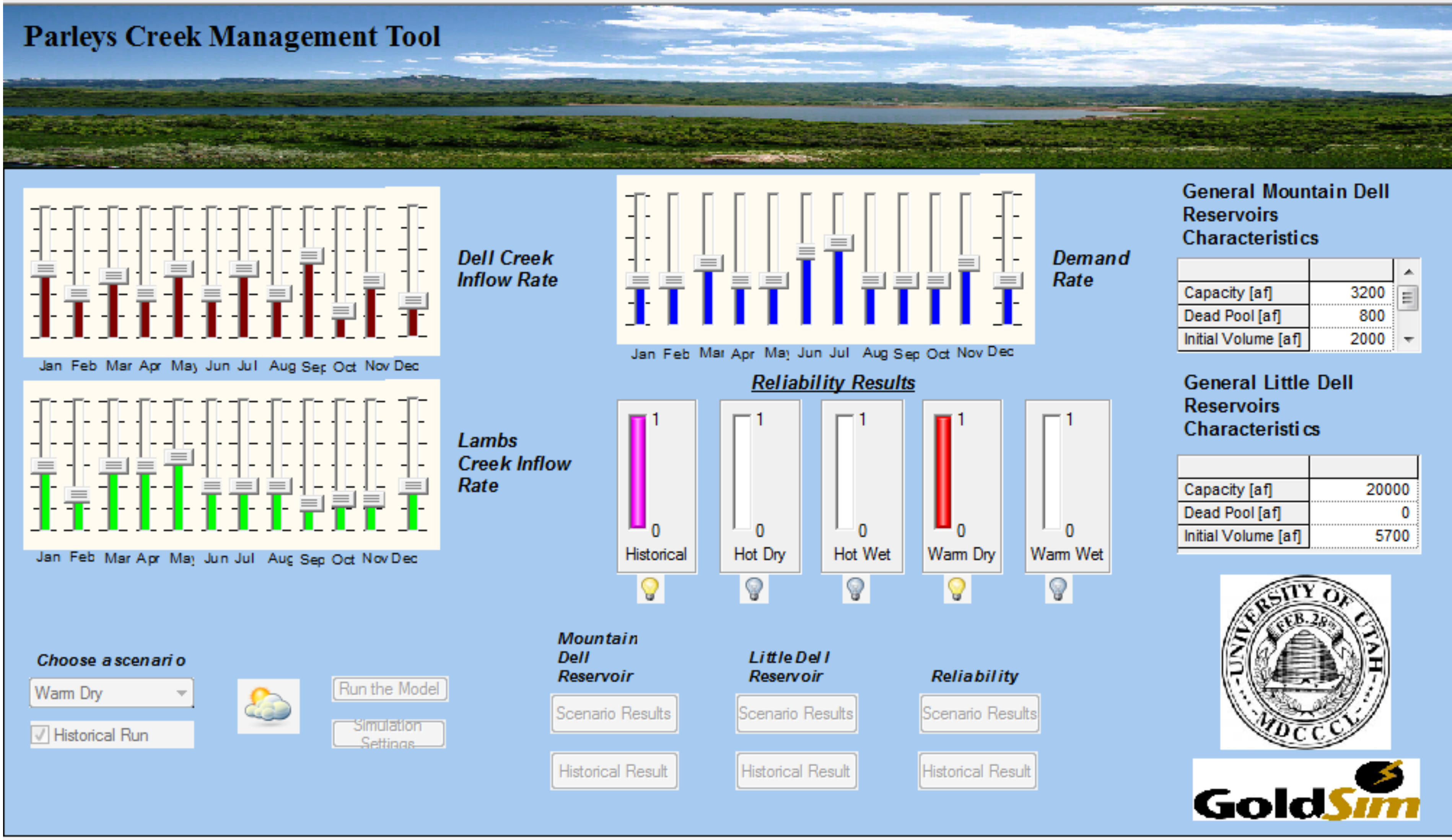
Parley's Water System

Parleys GoldSim model



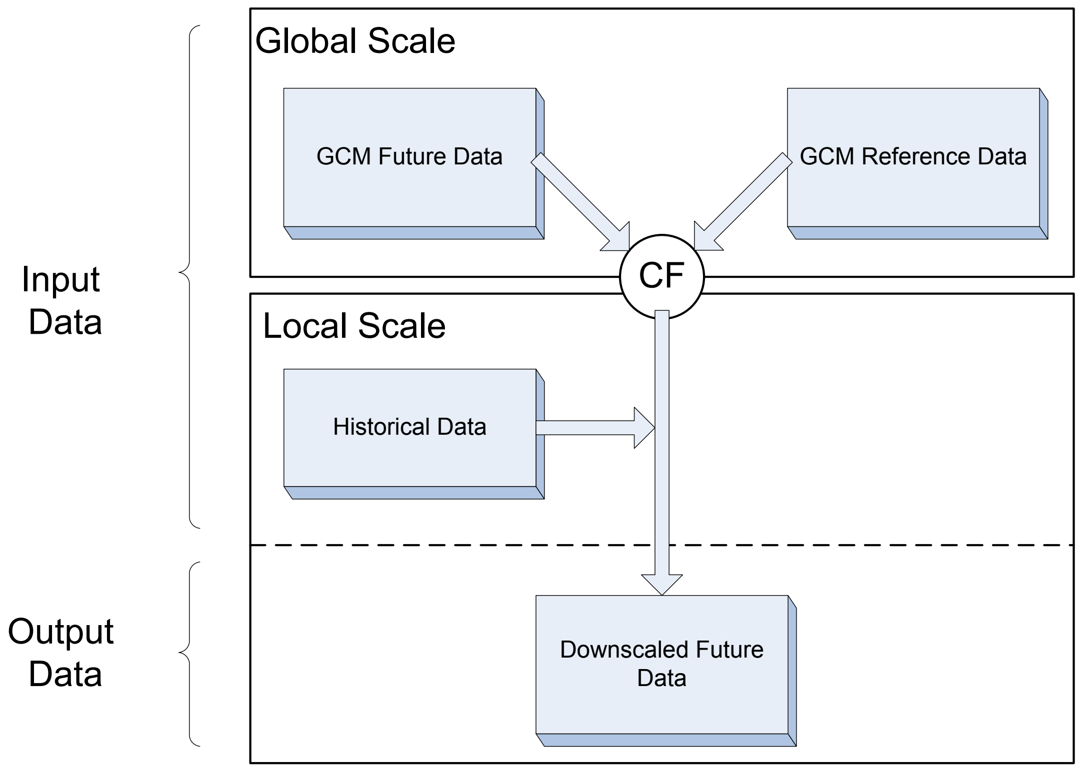
GoldSim Player allows you to view, navigate, and run an existing GoldSim model without having to purchase GoldSim Pro.

Player File Dashboard



Adjustment

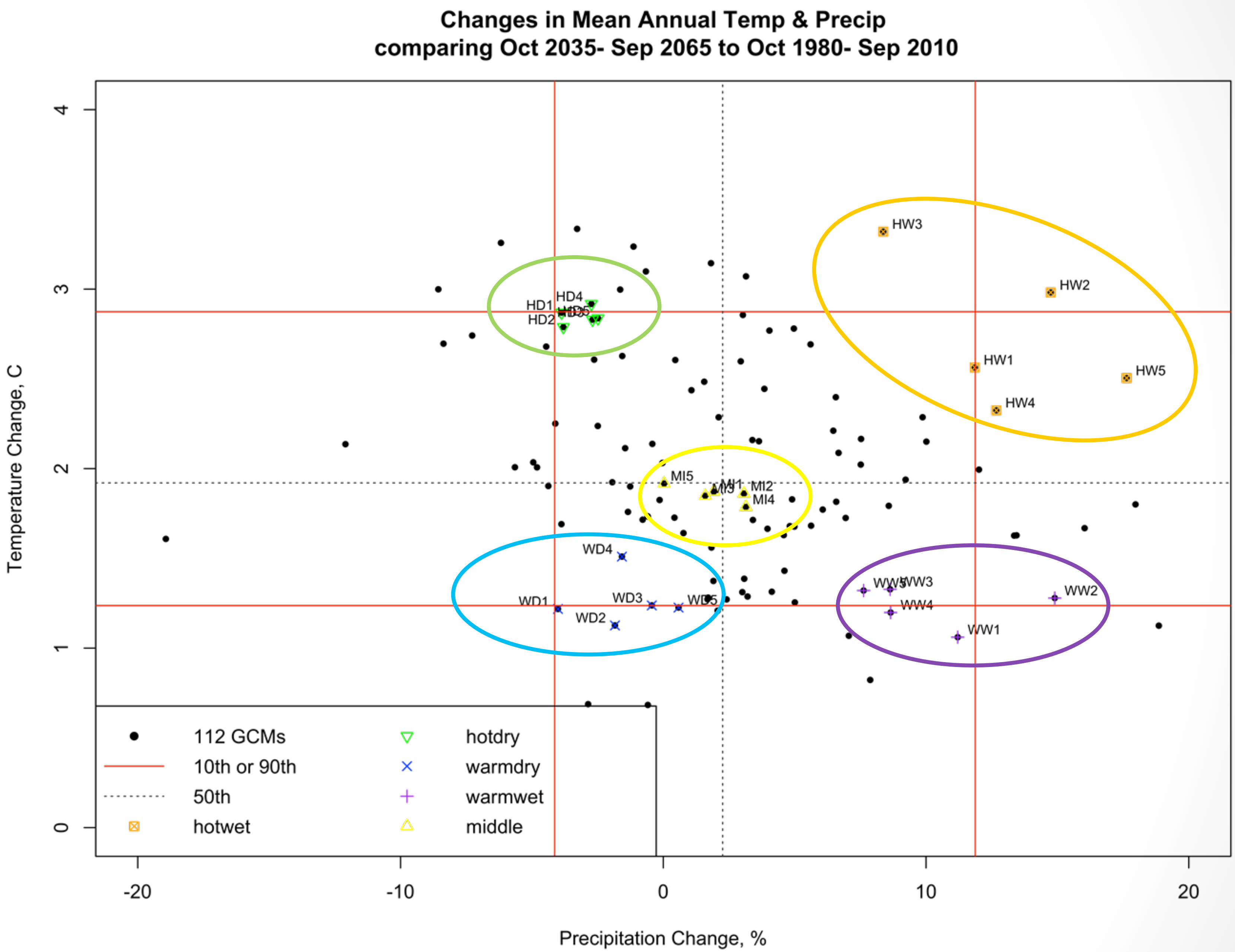
❑ **Change factor approach (CFA):**



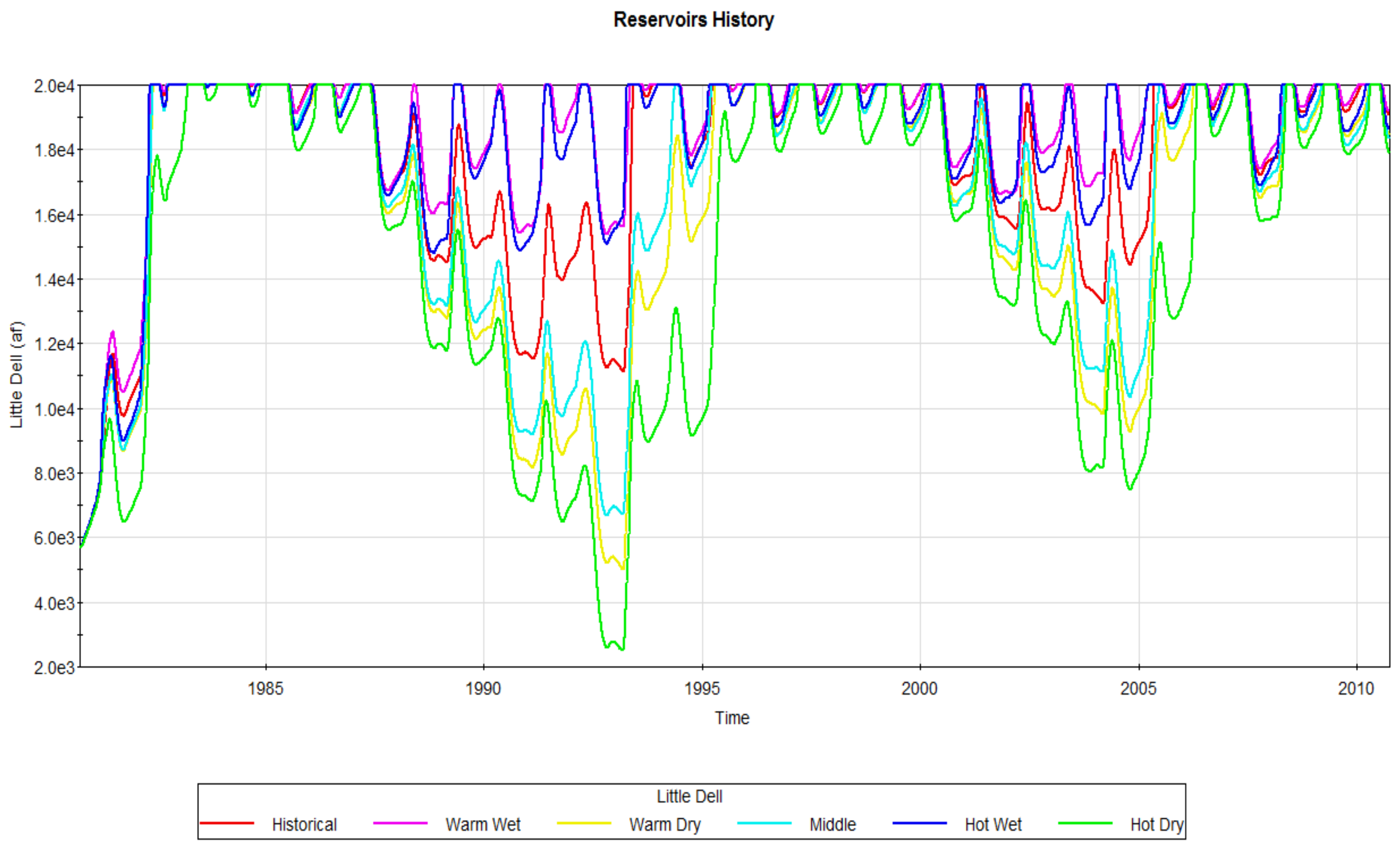
$$\begin{cases} P_{sim} = P_{obs}.\Delta P \\ \Delta P = \left(\dfrac{P_{GCM,fut}}{P_{GCM,base}}\right) \end{cases}$$

$$\begin{cases} T_{sim} = T_{obs} + \Delta T \\ \Delta T = \left(T_{GCM,fut} - T_{GCM,base}\right) \end{cases}$$

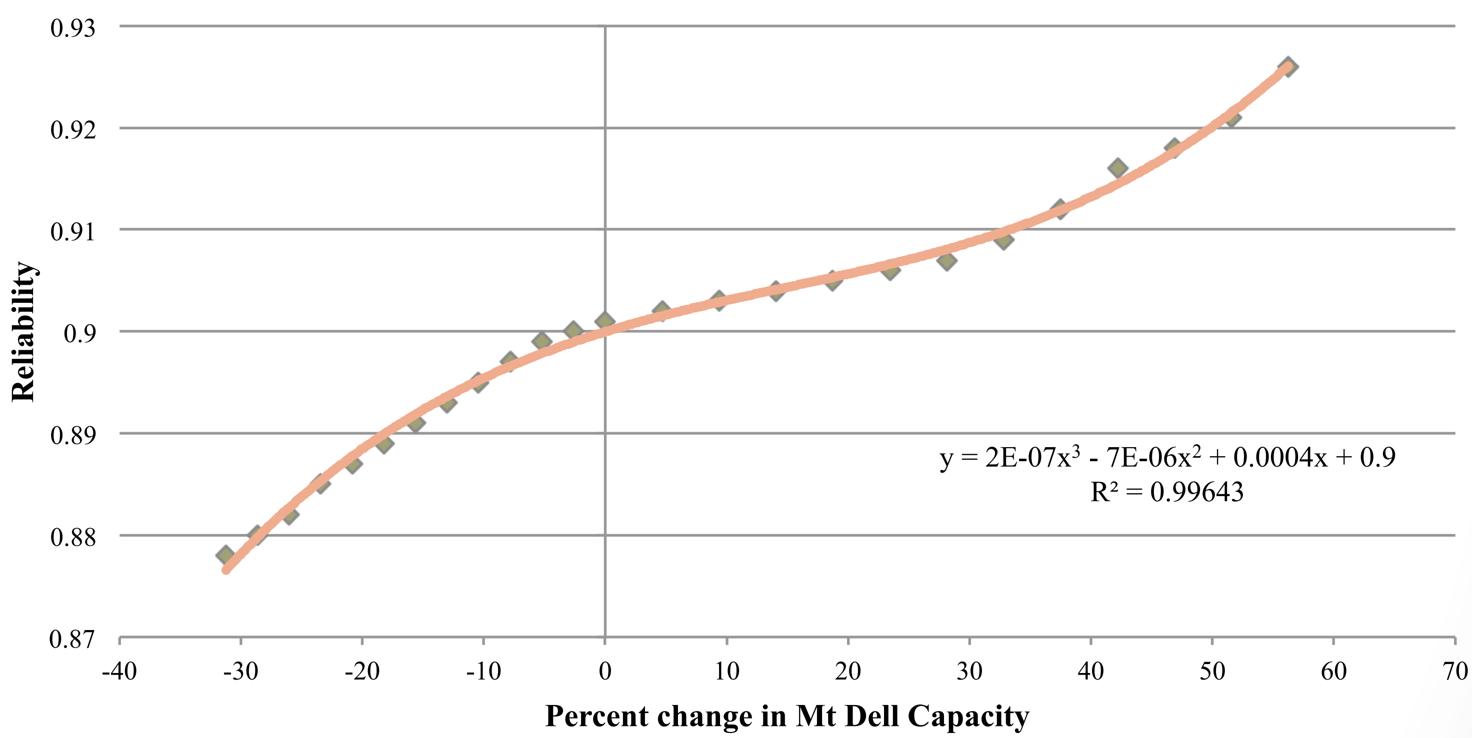
- ΔT and ΔP are monthly change factors (CFs) of temperature and precipitation


Changes in Mean Annual Temp & Precip
comparing Oct 2035- Sep 2065 to Oct 1980- Sep 2010
Temperature Change, C
Precipitation Change, %
0
1
2
3
4
-20
-10
0
10
20
HD1
HD2
HD4
HD5
HW1
HW2
HW3
HW4
HW5
MI1
MI2
MI3
MI4
MI5
WD1
WD2
WD3
WD4
WD5
WW1
WW2
WW3
WW4
WW5
112 GCMs
10th or 90th
50th
hotwet
hotdry
warmdry
warmwet
middle

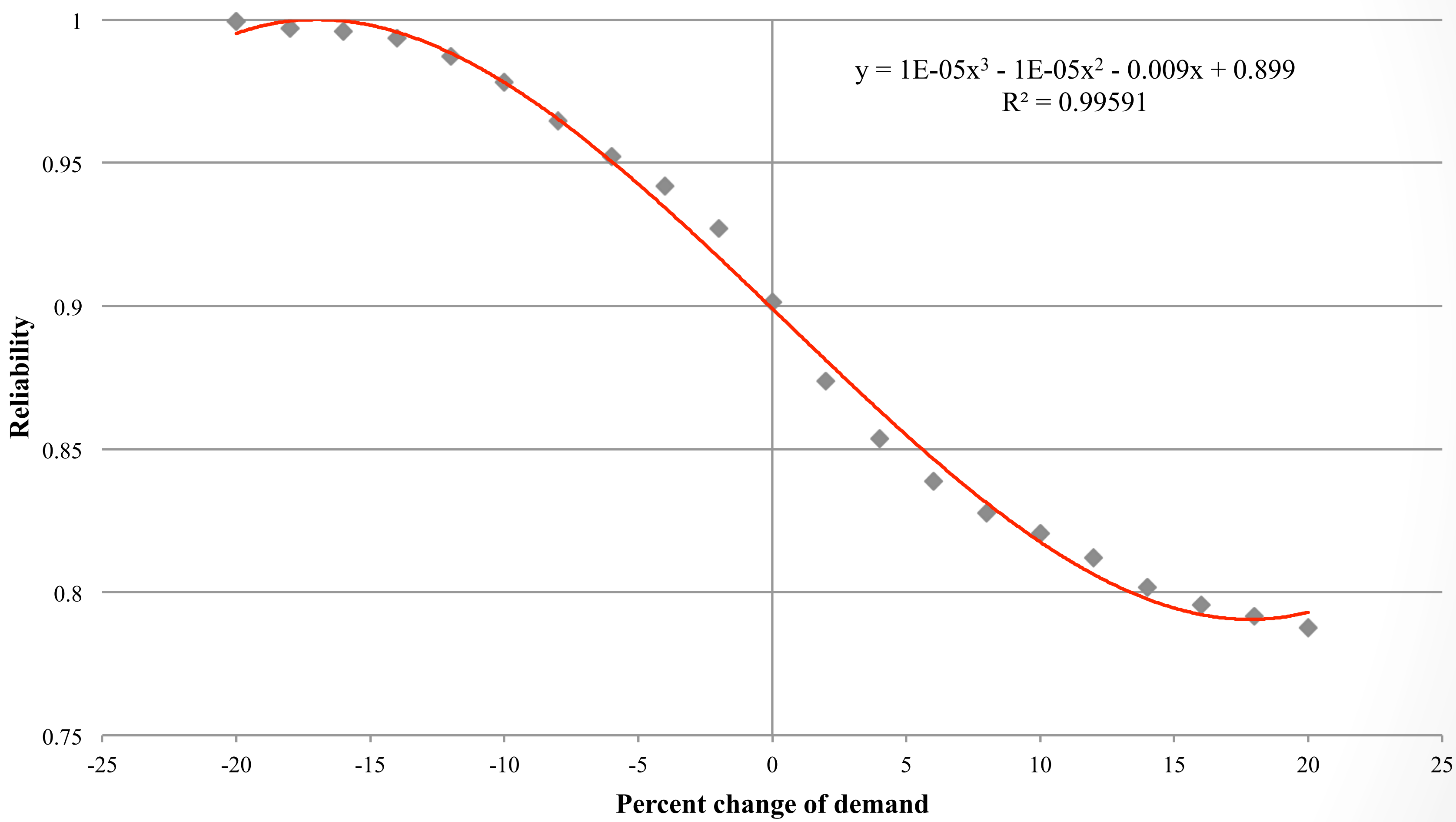
Climate Scenario results

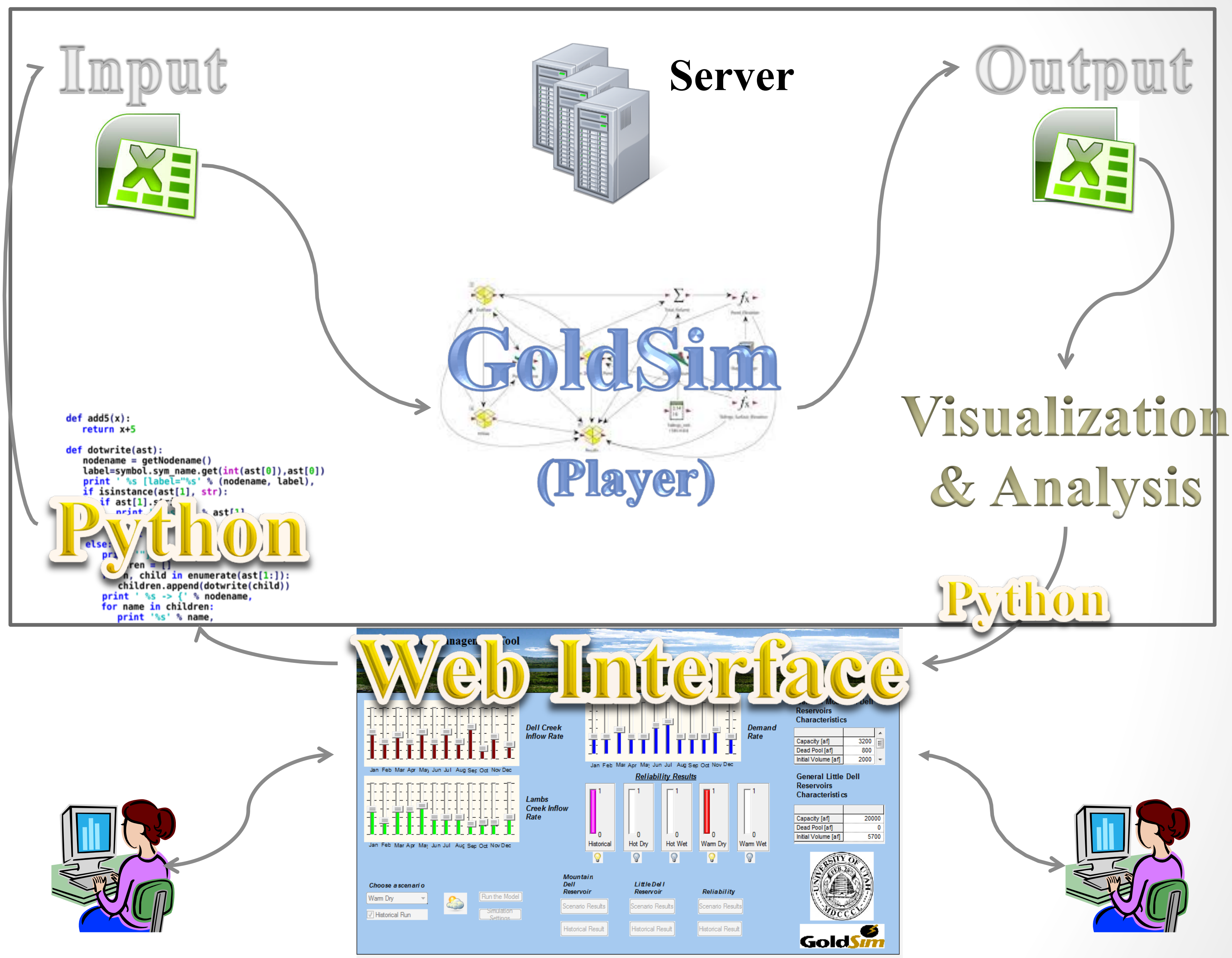


Development Plans

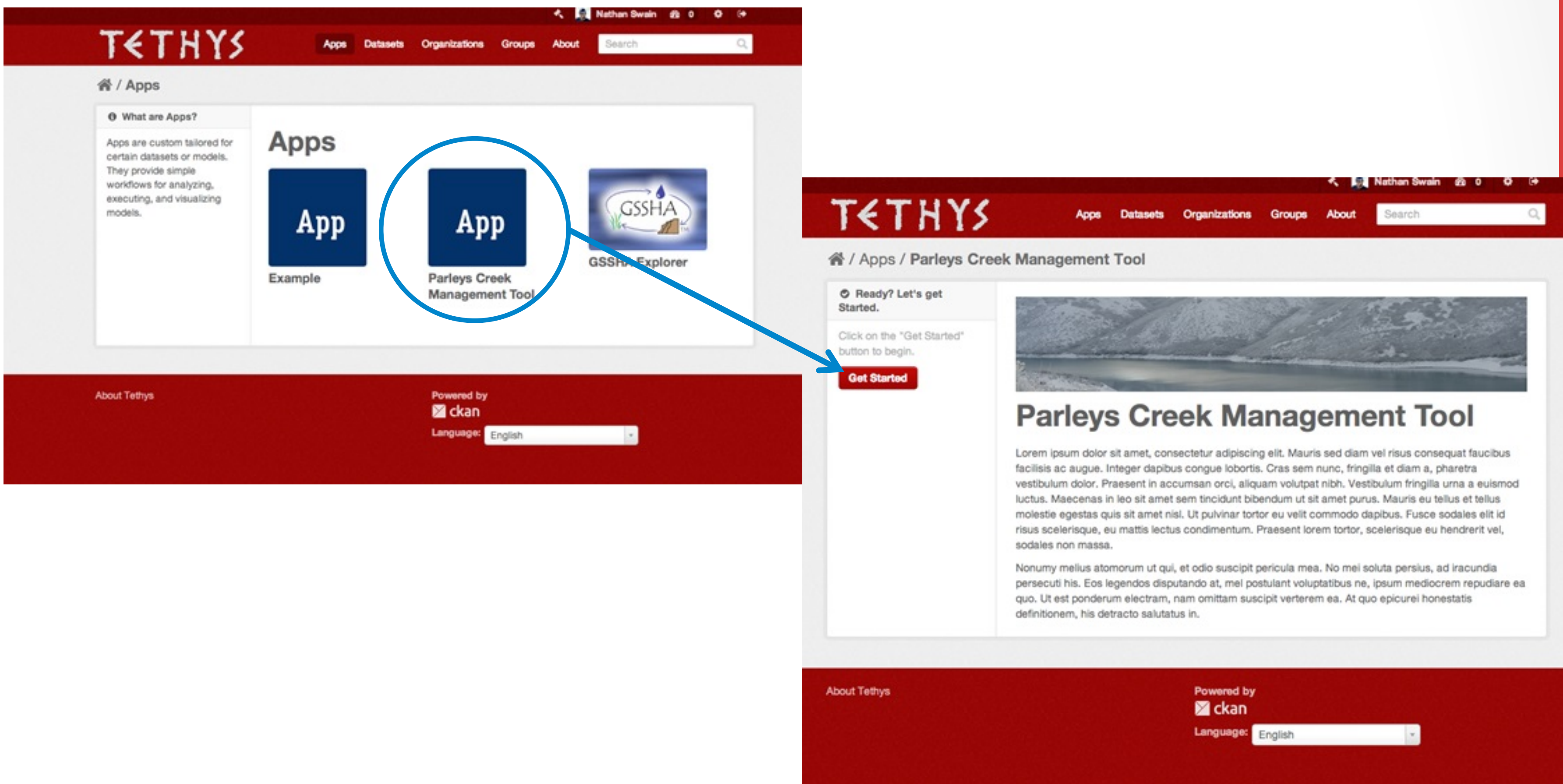


Water Conservation or Population Growth?

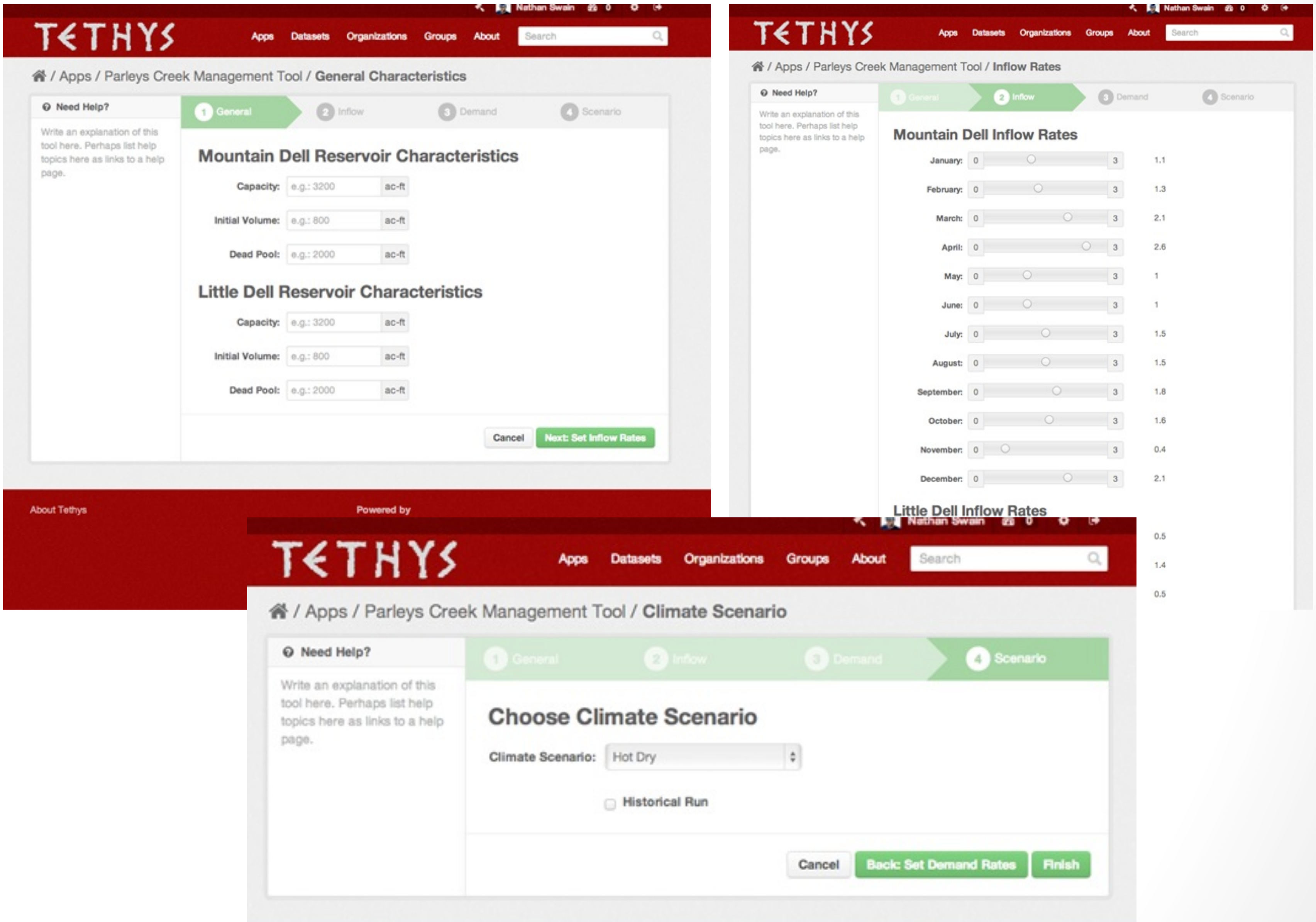



Input
Server
Output
GoldSim
(Player)
Visualization
& Analysis
Python
Python
Web Interface

Web Interface (Collaboration with BYU)



Management Tool for Users

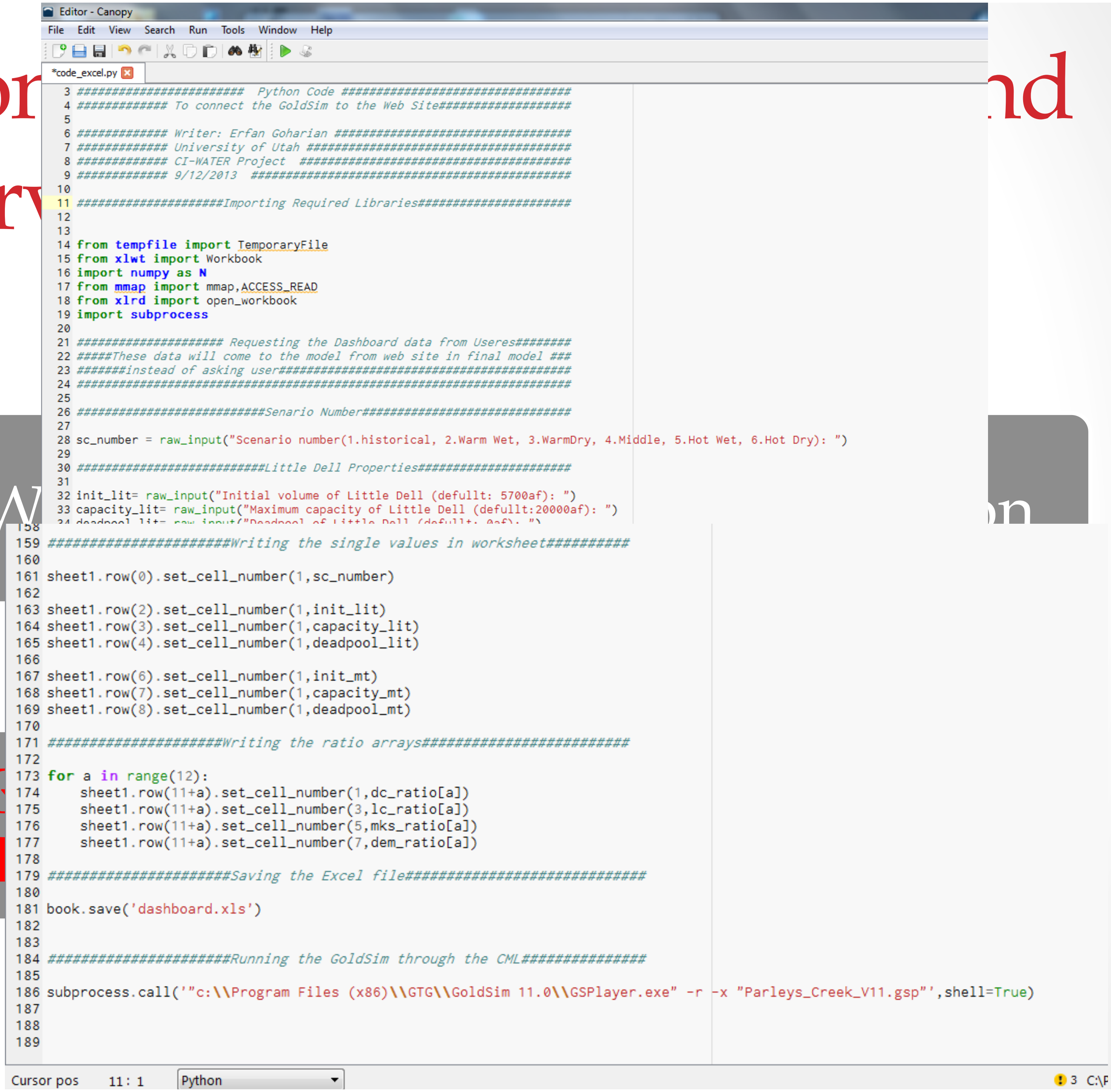


Cor ... nd Serv

W ... on

I

M




```python
######################### Python Code ##################################
############# To connect the GoldSim to the Web Site####################

############# Writer: Erfan Goharian ###################################
############# University of Utah #######################################
############# CI-WATER Project  ########################################
############# 9/12/2013  ###############################################

#####################Importing Required Libraries######################


from tempfile import TemporaryFile
from xlwt import Workbook
import numpy as N
from mmap import mmap,ACCESS_READ
from xlrd import open_workbook
import subprocess

###################### Requesting the Dashboard data from Useres########
#####These data will come to the model from web site in final model ###
#######instead of asking user##########################################
#######################################################################

###########################Senario Number##############################

sc_number = raw_input("Scenario number(1.historical, 2.Warm Wet, 3.WarmDry, 4.Middle, 5.Hot Wet, 6.Hot Dry): ")

###########################Little Dell Properties######################

init_lit= raw_input("Initial volume of Little Dell (defullt: 5700af): ")
capacity_lit= raw_input("Maximum capacity of Little Dell (defullt:20000af): ")
```

```python
#######################Writing the single values in worksheet##########

sheet1.row(0).set_cell_number(1,sc_number)

sheet1.row(2).set_cell_number(1,init_lit)
sheet1.row(3).set_cell_number(1,capacity_lit)
sheet1.row(4).set_cell_number(1,deadpool_lit)

sheet1.row(6).set_cell_number(1,init_mt)
sheet1.row(7).set_cell_number(1,capacity_mt)
sheet1.row(8).set_cell_number(1,deadpool_mt)

#####################Writing the ratio arrays##########################

for a in range(12):
    sheet1.row(11+a).set_cell_number(1,dc_ratio[a])
    sheet1.row(11+a).set_cell_number(3,lc_ratio[a])
    sheet1.row(11+a).set_cell_number(5,mks_ratio[a])
    sheet1.row(11+a).set_cell_number(7,dem_ratio[a])

######################Saving the Excel file###########################

book.save('dashboard.xls')


######################Running the GoldSim through the CML###############

subprocess.call('"c:\\Program Files (x86)\\GTG\\GoldSim 11.0\\GSPlayer.exe" -r -x "Parleys_Creek_V11.gsp"',shell=True)
```

Comprehensive Knowledge Archive Network (CKAN)

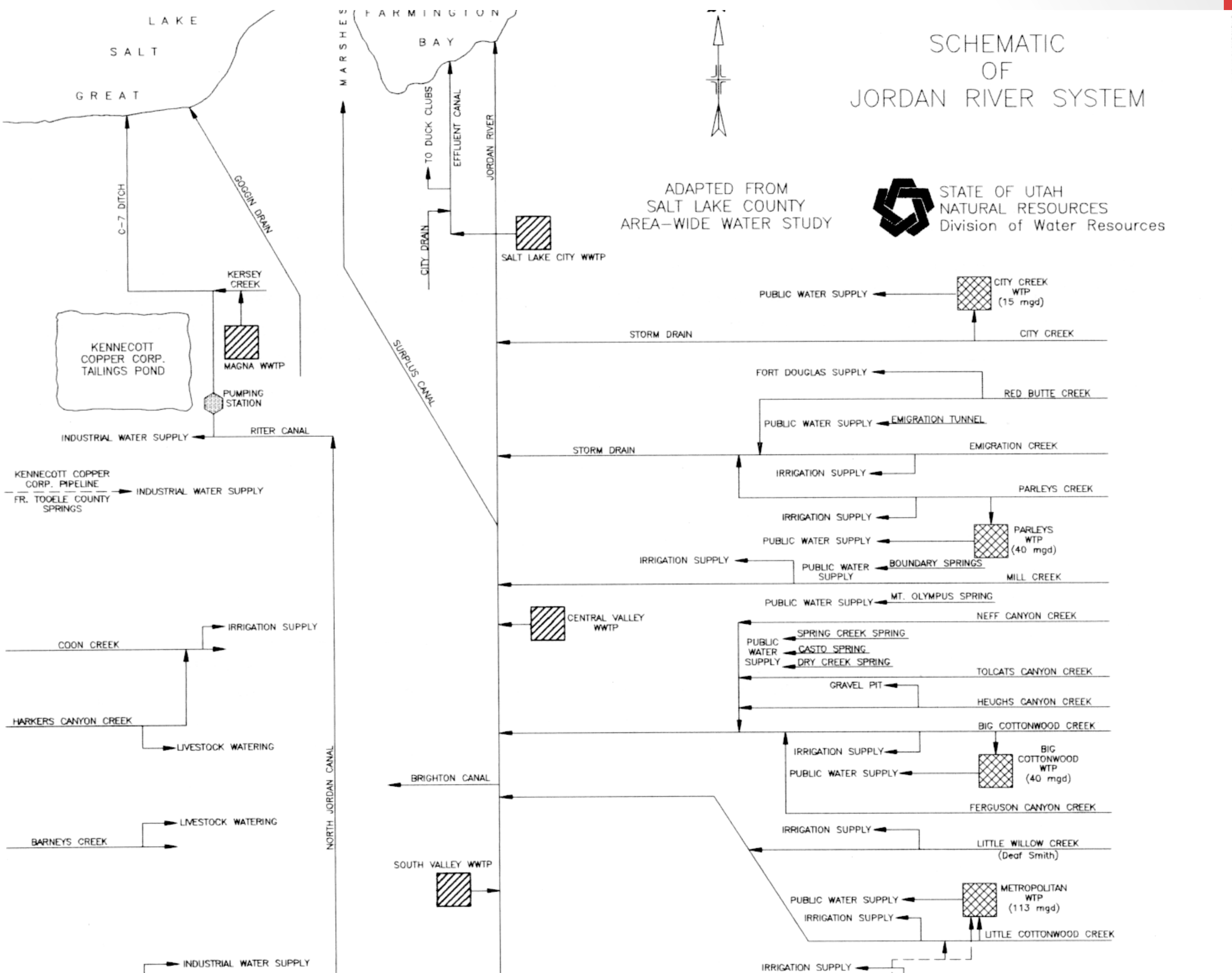
- Web-based open source data management system for the storage and distribution of data
- CKAN provides a rich API for querying and accessing dataset information.

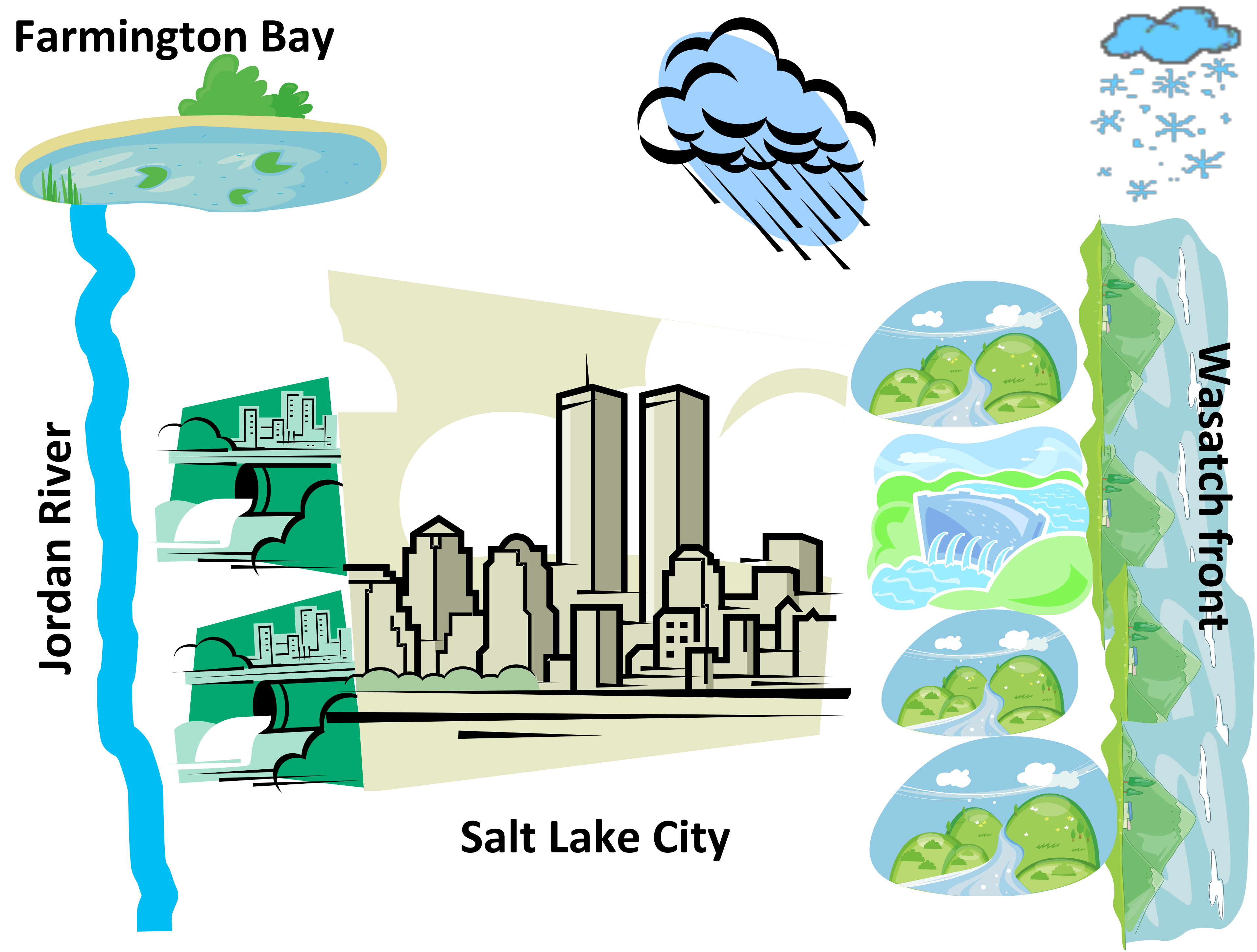
- Publish and Manage Data
- Search and Discovery
- Geospatial
- Community
- Visualize
- Themable
- Store
- History
- API

Visualize

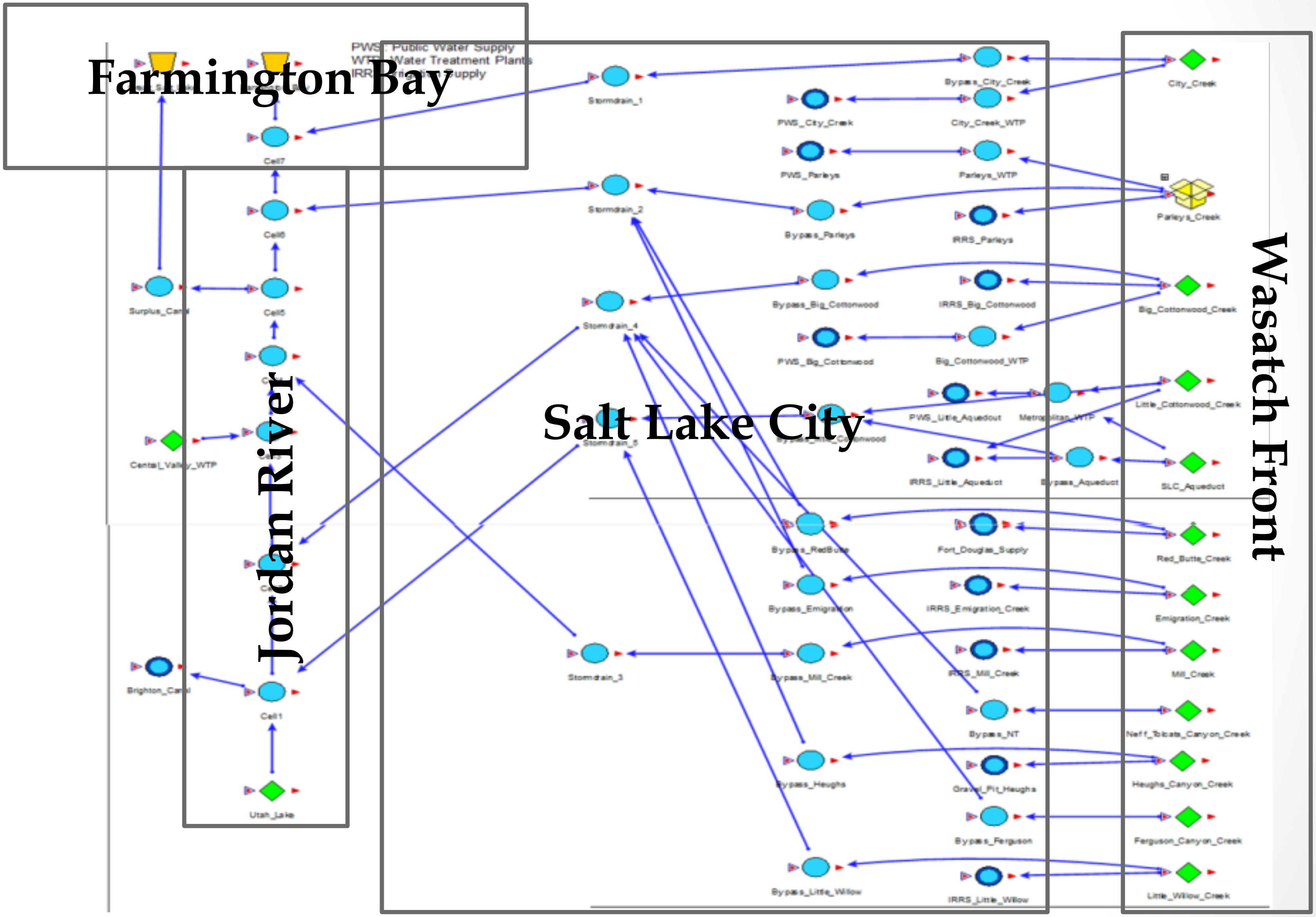
Supports:

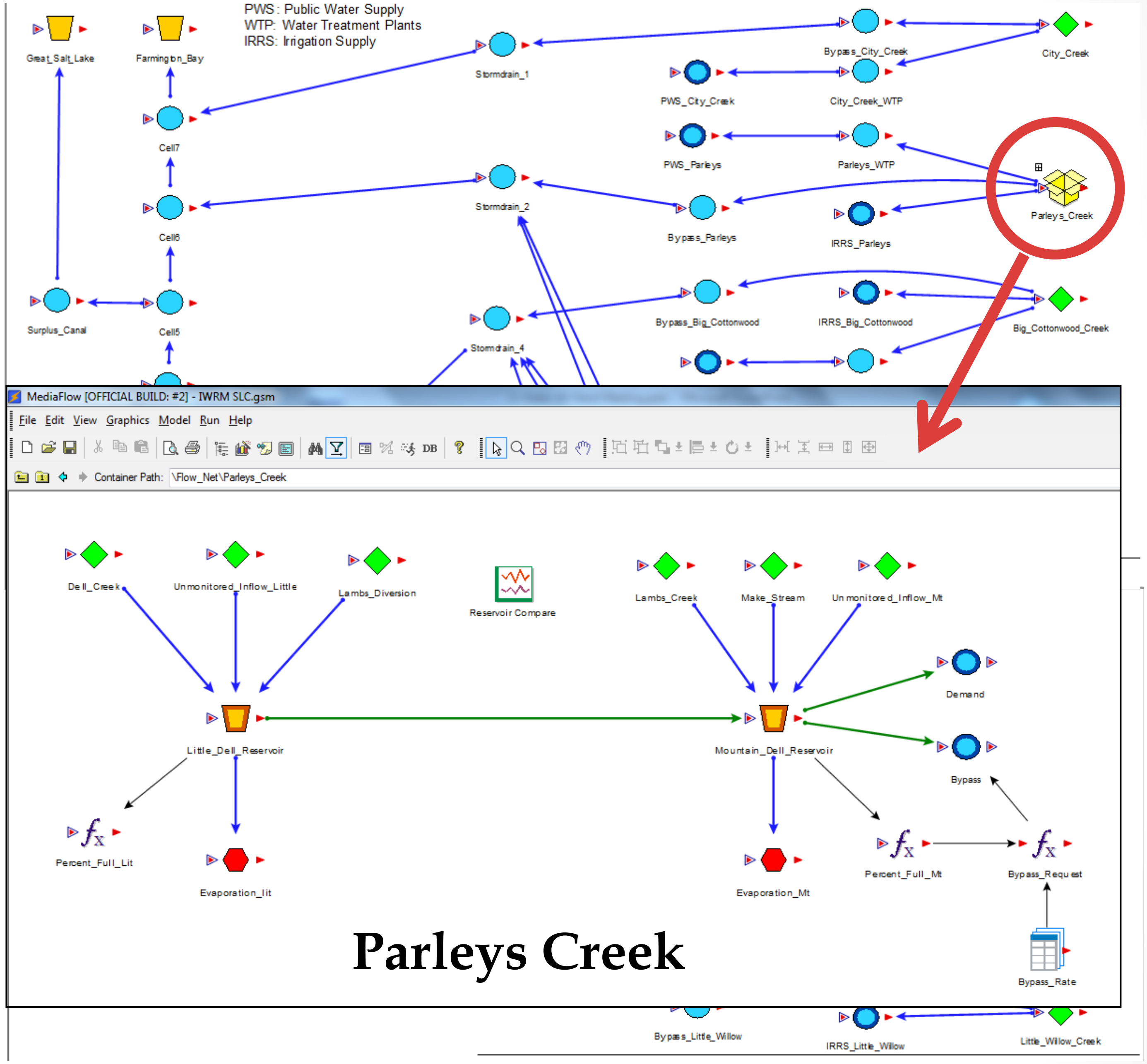
- line,
- spline,
- area,
- column,
- bar,
- pie,
- Scatter
- Etc…


SCHEMATIC OF JORDAN RIVER SYSTEM
ADAPTED FROM SALT LAKE COUNTY AREA-WIDE WATER STUDY
STATE OF UTAH NATURAL RESOURCES Division of Water Resources
GREAT SALT LAKE
FARMINGTON BAY
MARSHES
TO DUCK CLUBS
EFFLUENT CANAL
JORDAN RIVER
CITY DRAIN
SALT LAKE CITY WWTP
C-7 DITCH
GOGGIN DRAIN
KERSEY CREEK
MAGNA WWTP
KENNECOTT COPPER CORP. TAILINGS POND
PUMPING STATION
SURPLUS CANAL
INDUSTRIAL WATER SUPPLY
RITER CANAL
KENNECOTT COPPER CORP. PIPELINE
FR. TOOELE COUNTY SPRINGS
INDUSTRIAL WATER SUPPLY
PUBLIC WATER SUPPLY
CITY CREEK WTP (15 mgd)
STORM DRAIN
CITY CREEK
FORT DOUGLAS SUPPLY
RED BUTTE CREEK
PUBLIC WATER SUPPLY
EMIGRATION TUNNEL
STORM DRAIN
EMIGRATION CREEK
IRRIGATION SUPPLY
PARLEYS CREEK
IRRIGATION SUPPLY
PARLEYS WTP (40 mgd)
PUBLIC WATER SUPPLY
IRRIGATION SUPPLY
PUBLIC WATER SUPPLY
BOUNDARY SPRINGS
MILL CREEK
PUBLIC WATER SUPPLY
MT. OLYMPUS SPRING
CENTRAL VALLEY WWTP
NEFF CANYON CREEK
PUBLIC WATER SUPPLY
SPRING CREEK SPRING
CASTO SPRING
DRY CREEK SPRING
TOLCATS CANYON CREEK
GRAVEL PIT
HEUGHS CANYON CREEK
BIG COTTONWOOD CREEK
IRRIGATION SUPPLY
COON CREEK
HARKERS CANYON CREEK
LIVESTOCK WATERING
BIG COTTONWOOD WTP (40 mgd)
PUBLIC WATER SUPPLY
BRIGHTON CANAL
NORTH JORDAN CANAL
FERGUSON CANYON CREEK
IRRIGATION SUPPLY
LITTLE WILLOW CREEK (Deaf Smith)
BARNEYS CREEK
LIVESTOCK WATERING
SOUTH VALLEY WWTP
PUBLIC WATER SUPPLY
METROPOLITAN WTP (113 mgd)
IRRIGATION SUPPLY
LITTLE COTTONWOOD CREEK
INDUSTRIAL WATER SUPPLY
IRRIGATION SUPPLY

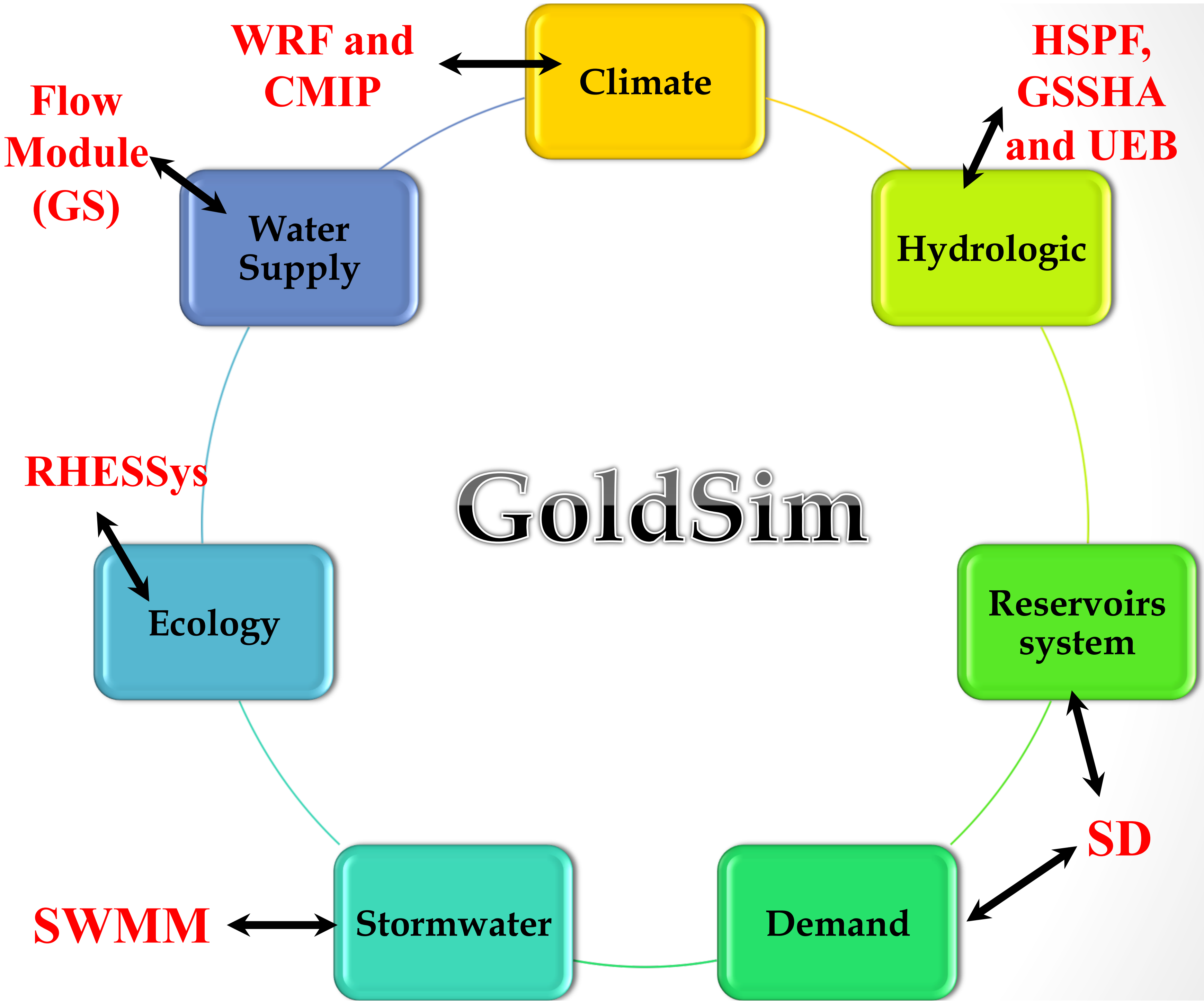

Farmington Bay
Jordan River
Salt Lake City
Wasatch front

Wasatch Integrated Water Model



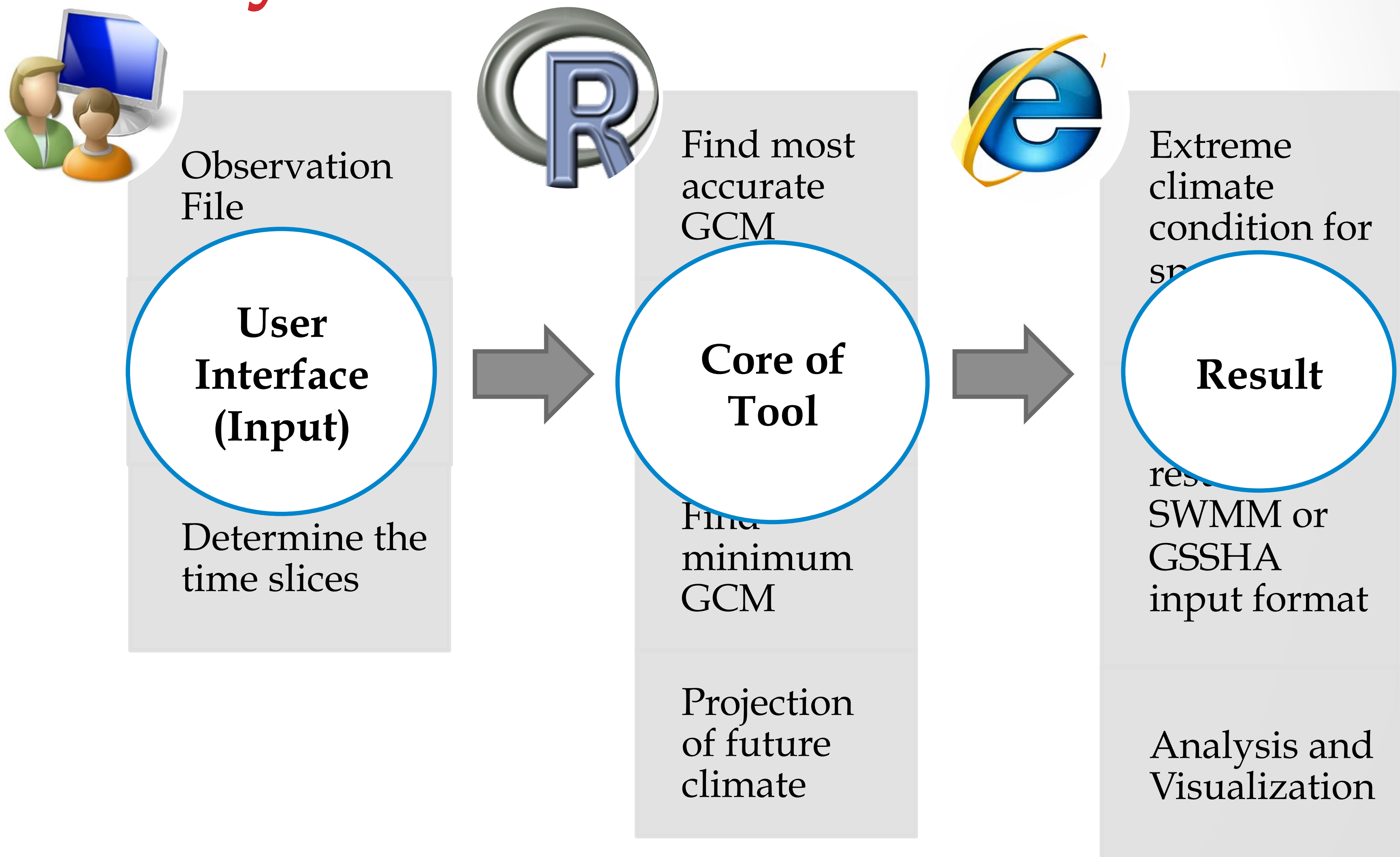


Parleys Creek



WRF and CMIP
Climate
HSPF, GSSHA and UEB
Hydrologic
Flow Module (GS)
Water Supply
GoldSim
RHESSys
Ecology
Reservoirs system
SD
SWMM
Stormwater
Demand

Climate Data Access Tool for Analysis of Water Resources



Method

- Download climate data for the required grids(daily and monthly) for all models in NetCDF (NOT AUTOMATED)
- Write R code to calculate which model predictions are closest to the observations
- Determine monthly change factors for every model
- Use these change factors to determine which models project extreme conditions

Potential Climate Analysis Tools

- Intensity : Mean, Maximum, Moving Average, …
- Events and Duration: Average Duration, Interevent, mean event Depth, …
- Frequency Analysis: Probability distribution, return period, Exceedence probability, …
- Drought: Dry proceeding days, longest drought, …
- Spatial Analysis
- Indices: Standard Precipitation Index, Palmer Drought Index, Extreme Precipitation Index
- etc

- Time series
- Hourly
- Weekday
- Monthly
- Annual

Main Idea

- This package can determine which model (GCM) is most appropriate (based on historical projection and observation) for each part of the USA and prepare an assembled model for future use

- This package can present a good estimation of future extreme climate condition for each part of the USA and prepare an assembled model for future use. (now we are working on three different parts: Salt Lake City, NYC and Toledo)

- The result can be used for different water models like SWMM, GSSHA and HSPF

R-Code

RGui (64-bit) - [R Console]

File Edit View Misc Packages Windows Help

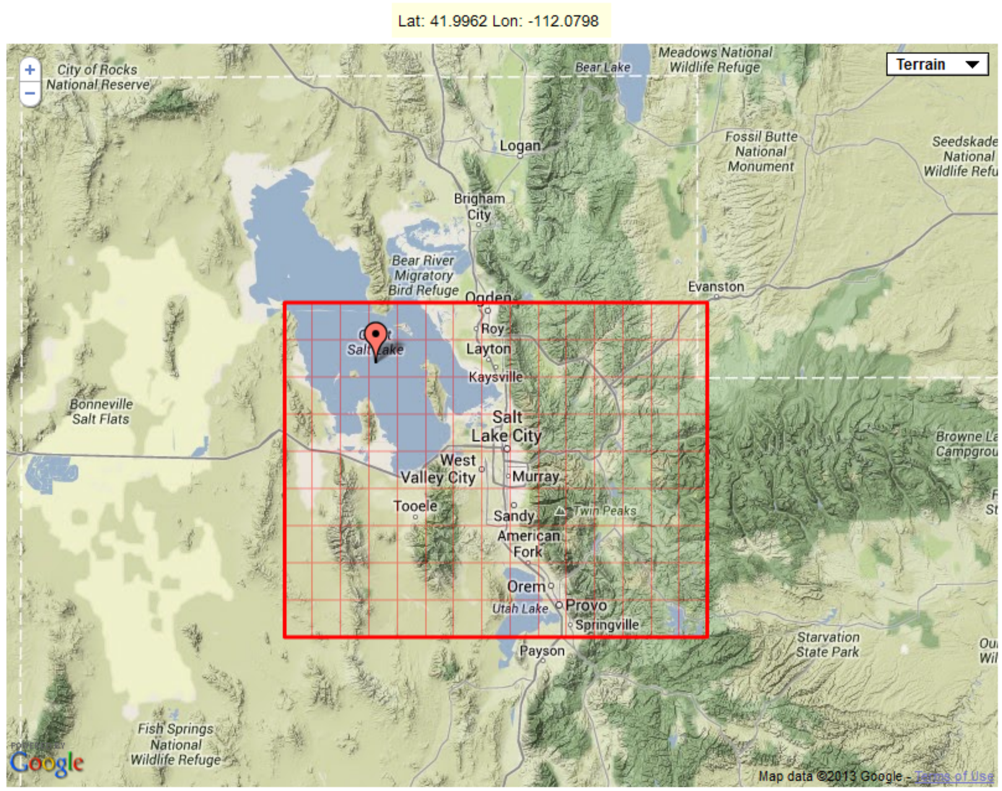
```
R version 3.0.1 (2013-05-16) -- "Good Sport"
Copyright (C) 2013 The R Foundation for Statistical Computing
Platform: x86_64-w64-mingw32/x64 (64-bit)

R is free software and comes with ABSOLUTELY NO WARRANTY.
You are welcome to redistribute it under certain conditions.
Type 'license()' or 'licence()' for distribution details.

  Natural language support but running in an English locale

R is a collaborative project with many contributors.
Type 'contributors()' for more information and
'citation()' on how to cite R or R packages in publications.

Type 'demo()' for some demos, 'help()' for on-line help, or
'help.start()' for an HTML browser interface to help.
Type 'q()' to quit R.

> library(ncdf)
> ncd1<-open.ncdf("ext_pr(1950-2099).nc")
> ncd2<-open.ncdf("obs_pr(1950-1999).nc")
> pr1<-get.var.ncdf(ncd1,"pr")
> pr2<-get.var.ncdf(ncd2,"Prcp")
> closest<- -999
> modelnumber<-0
> sum<-0
> dim(pr1)
[1] 1800  234
> dim(pr2)
[1] 600
> closestmodel<-function(pr1,pr2,n)
> for(i in 1:600)
+ sum<-(abs(pr1[n,i]-pr2[n][i]))
> if(sum<closest)
+ closest<-sum
+ modelnumber<-n
> changefactorfn<-function(pr1,noofyrs,startcurrent,starthistoric)
> arr<-c(12,2)
> for(i in startcurrent:noofyears)
+ arr[i,0]+=pr1
> for(i in starthistoric:noofyears)
+ arr[i,1]+=pr2
> arrcf<-c(12)
> for(i in 1:12)
+ arrcf[i]<-arr[0,i]/arr[1,i]
+ arrcf[i]
> for(j in 1:234)
+ closestmodel(pr1[j],pr2[j],j)
> changefactorfn(pr1[j],30,1980,2050)
> closest
[1] 14.562
> modelnumber
[1] 63
> close.ncdf(ncd1)
> close.ncdf(ncd2)
```

Results

Climate Tool

- Developing the Climate tool for the first case study, Salt Lake City for precipitation (1950-2100) in monthly and daily mode.

- Using disaggregation methods to produce result in hourly scale.



Accomplishments

Conferences:

- Evaluating the reliability of a water supply system based on system dynamics modeling: A Case Study of Salt Lake City, Utah. **EWRI Congress 2013 – Cincinnati, OH.**

- Assessing climate change risks to a municipal water supply: A pilot project incorporating downscaled climate projections, operational hydrologic modeling, and a systems planning model. **2013 Spring Runoff Conference.**

- Assessing climate change risks to a municipal water supply: A pilot project incorporating downscaled climate projections, operational hydrologic modeling, and a systems planning model. **2013 CPASW Climate Prediction Applications Sciences Workshop.**

- Strong C. Future precipitation and snowpack along the Wasatch Range, **American Water Resources Association Utah Section Annual Conference, Salt Lake City, Utah, 14 May 2013.**

Journal paper:

- Bardsley, T., Wood, A., Hobbins, M., Kirkham, T., Briefer, L., Niermeyer, J., and Burian, S. "Planning for an uncertain future: Climate change sensitivity assessment towards adaptation planning for public water supply." *Earth Interactions* (in press).

Future

Conferences:

- Web-Based Reservoirs System Management Tool based on Dynamic Simulation for Water Utilities in Salt Lake City, Utah - **EWRI Congress 2014 - Portland, Oregon. (Submitted)**

- Using Dynamic Simulation to Support Integrated Water Resources Management in Cities - **EWRI Congress 2014 - Portland, Oregon. (Submitted)**

- Integrated Water Resource Management Tool based on Extreme Climate Change Impact. **HIC 2014 - New York, USA. (Not submitted)**

Proposal:

- NSF Hydrologic Sciences, Fall 2013, Climate-Vegetation Impacts on Hydrologic Response

Journal paper:

- Strong C, Kochanski A, Crosman E. A slab model of the Great Salt Lake for regional climate simulation. *Journal of Advances in Modeling Earth Systems,* in prep.
- Impact of climate change on water resources (Salt Lake City, Utah). (in prep)

Any Question?

Thank you