# CI-WATER Component 2

## Enhance Access to Data- and Computationally-Intensive Modeling

BYU
BRIGHAM YOUNG
UNIVERSITY

UtahState
University

THE
UNIVERSITY
OF UTAH

UNIVERSITY
OF WYOMING
*New Thinking*

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- Steve Burian, Court Strong, Christine Pomeroy, Erfan Goharian, Adam Kochanski
- Fred Ogden, Scott Miller

CI-WATER

http://www.ci-water.org

NSF
EPS-1135482
EPS-1135483
2011-2014

# Questions

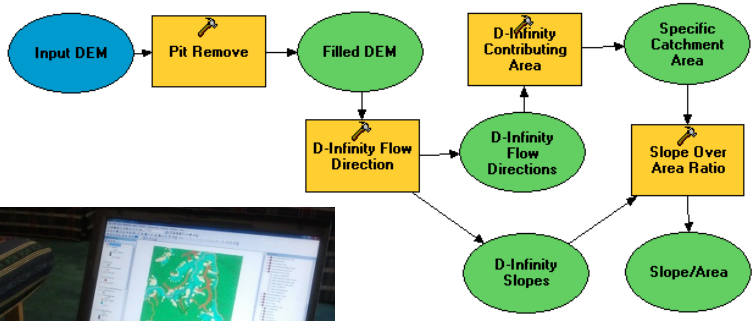
- *How are the quality and availability of water resources sensitive to climate variability, watershed alterations, and management activities?*

- ***How can we best structure data and computer models to address this scientific problem through the use of high-performance and data-intensive computing by discipline scientists coming to this problem without extensive computational knowledge and algorithmic experience?***

# A Digital Divide

Researchers

- Experimentalists
- Modelers




HPC Specialists

#!/bin/bash vi chmod

#PBS -l nodes=4:ppn=8

grep awk mpiexec

```
-bash-3.2$ ls tddata
logan           LoganOutlet.sbn  LoganOutlet.shp      LoganOutlet.shx
LoganOutlet.dbf  LoganOutlet.sbx  LoganOutlet.shp.xml
-bash-3.2$ ls tddata/logan
logan.tif
-bash-3.2$ ls
eric    logMPfel        run.bash        taudem.bash     taudem_submit.sh
logMPI  run_all.bash    run_taudem.sh   taudem.o41959   tddata
-bash-3.2$ run_taudem.sh pitremove -z logan -fel loganfel
43058.ib-net
-bash-3.2$
```

# Challenges

- Provide scientists and water managers access to HPC resources without requiring they become HPC experts
- Reduce the time and effort to organize data for modeling and analysis
- Enable data intensive HPC for mere mortals

# Problem / Prototypical Use Cases

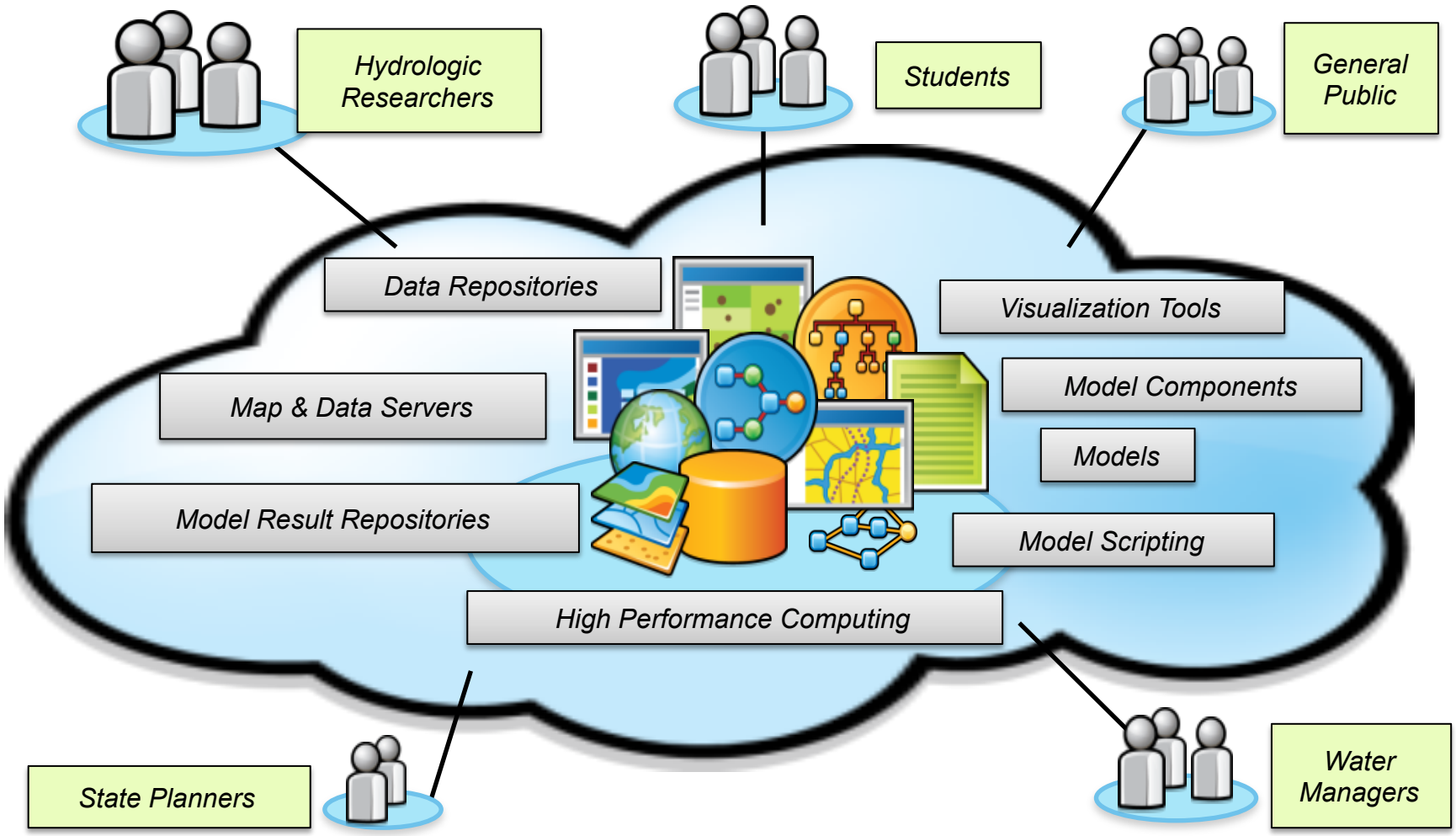
- Use the Utah Energy Balance (UEB) snowmelt model to examine the impacts of land cover change on watershed snowmelt inputs
- Overlay this with projected climate change from an IPCC scenario downscaled using WRF
- Examine the impacts on urban infrastructure and water resources management facilities

# Ultimate Endpoint

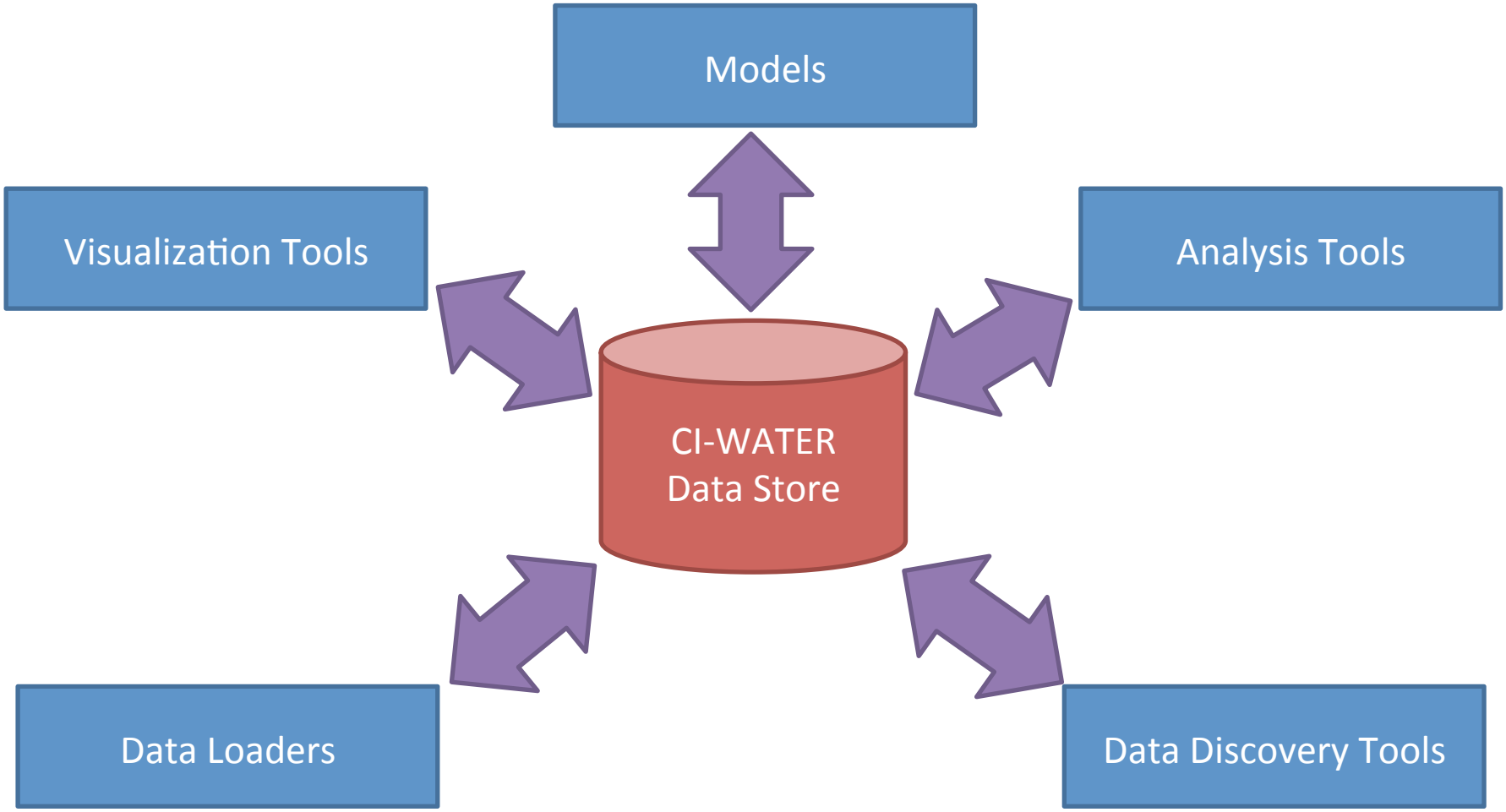
- **A web-based system that enables Utah and Wyoming water researchers + practitioners to:**
  - Access data to run hydrologic and water resources models
  - Execute tools to define modeling domains and configure model inputs
  - Execute models on HPC resources
  - Download and visualize the results

To the Cloud!!!!

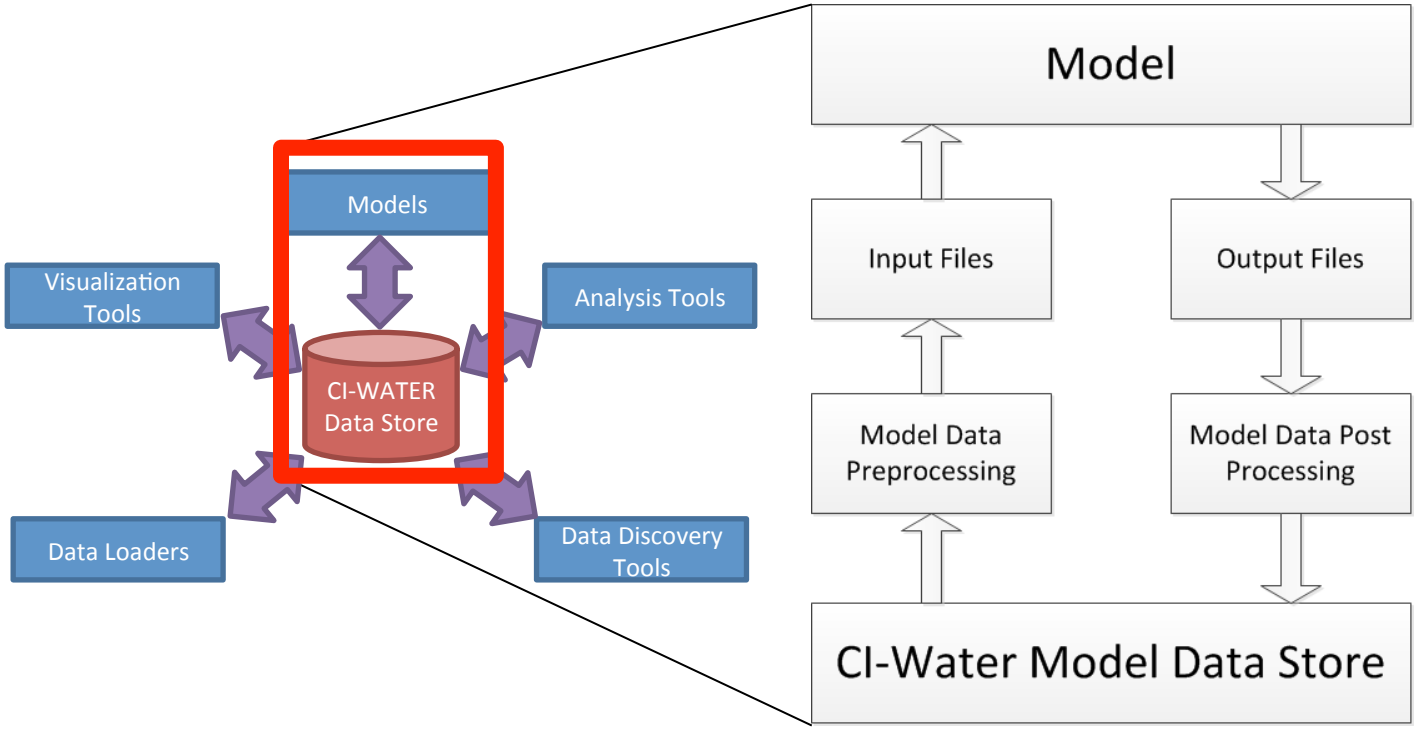
# CI-WATER System



# Data Store Centric Paradigm for Modeling and Analysis



# Model Pre and Post Processing Workflow

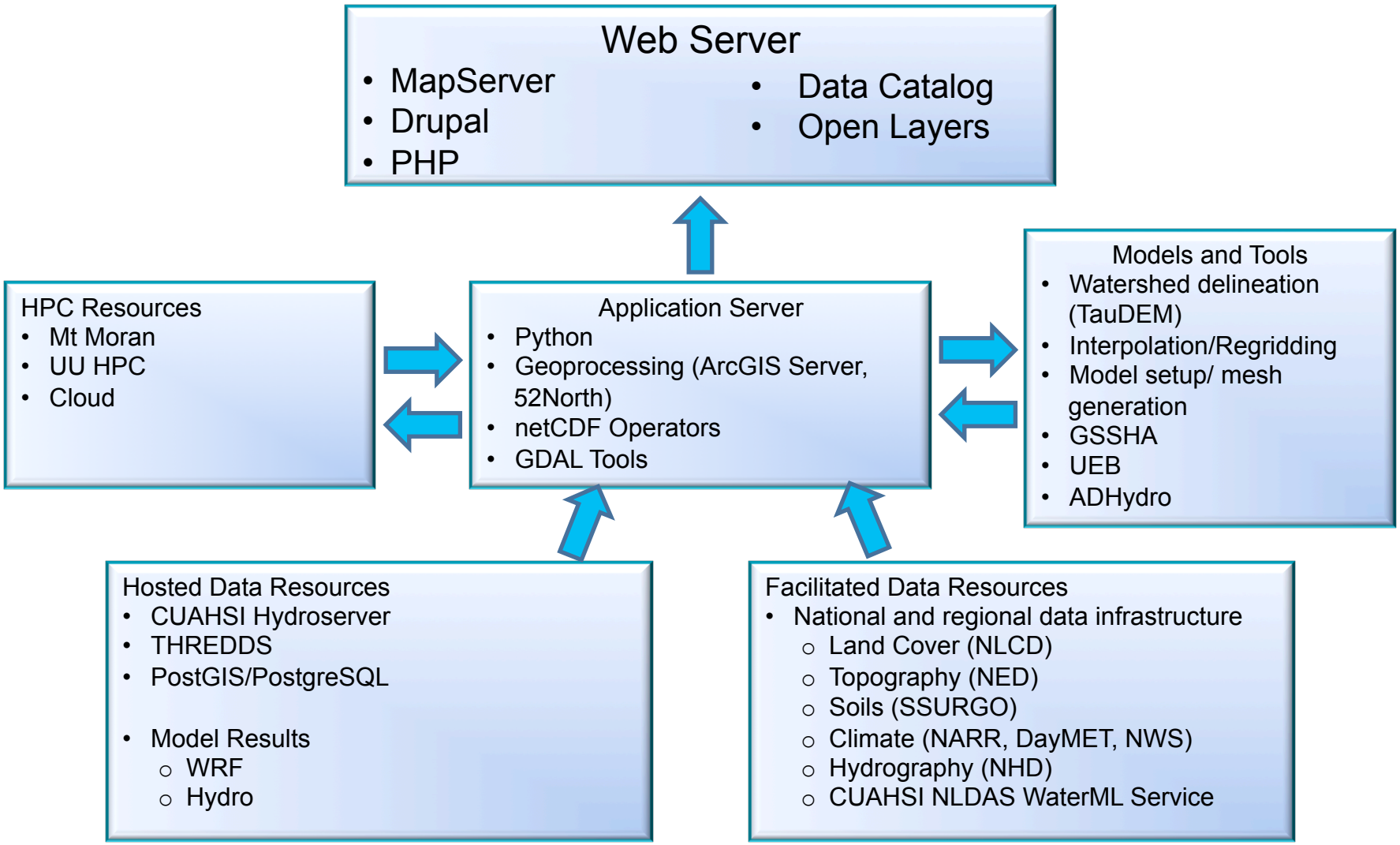



- Each model interacts with information in the common data store
- The modeler does not need to be concerned with and can take advantage of standardized analysis, visualization loading and discovery tools

# Supported Tools and Models

- **Tools**
  - Watershed delineation (TauDEM)
  - Data access
  - Model element and mesh generation
  - Rescaling data in space/ time
  - Results visualization
- **Models**
  - ADHydro integrated distributed hydrologic and water resources model (Task 3)
  - UEB Snowmelt
  - TOPNET hydrologic and watershed management
  - GSSHA gridded surface subsurface hydrologic models
  - Others

# Overall Architecture



# Accomplishments

- Developed driving use cases
  - Snowmelt – Utah Energy Balance (UEB)
  - Semi-distributed, integrated hydrologic and water management model (TOPNET)
  - Gridded surface/subsurface hydrologic model (GSSHA)
  - Terrain analysis and pre-processing toolset (TauDEM)
  - Urban watershed and water management models (SWMM, Goldsim)

- CI-WATER climate simulations under way

# Accomplishments

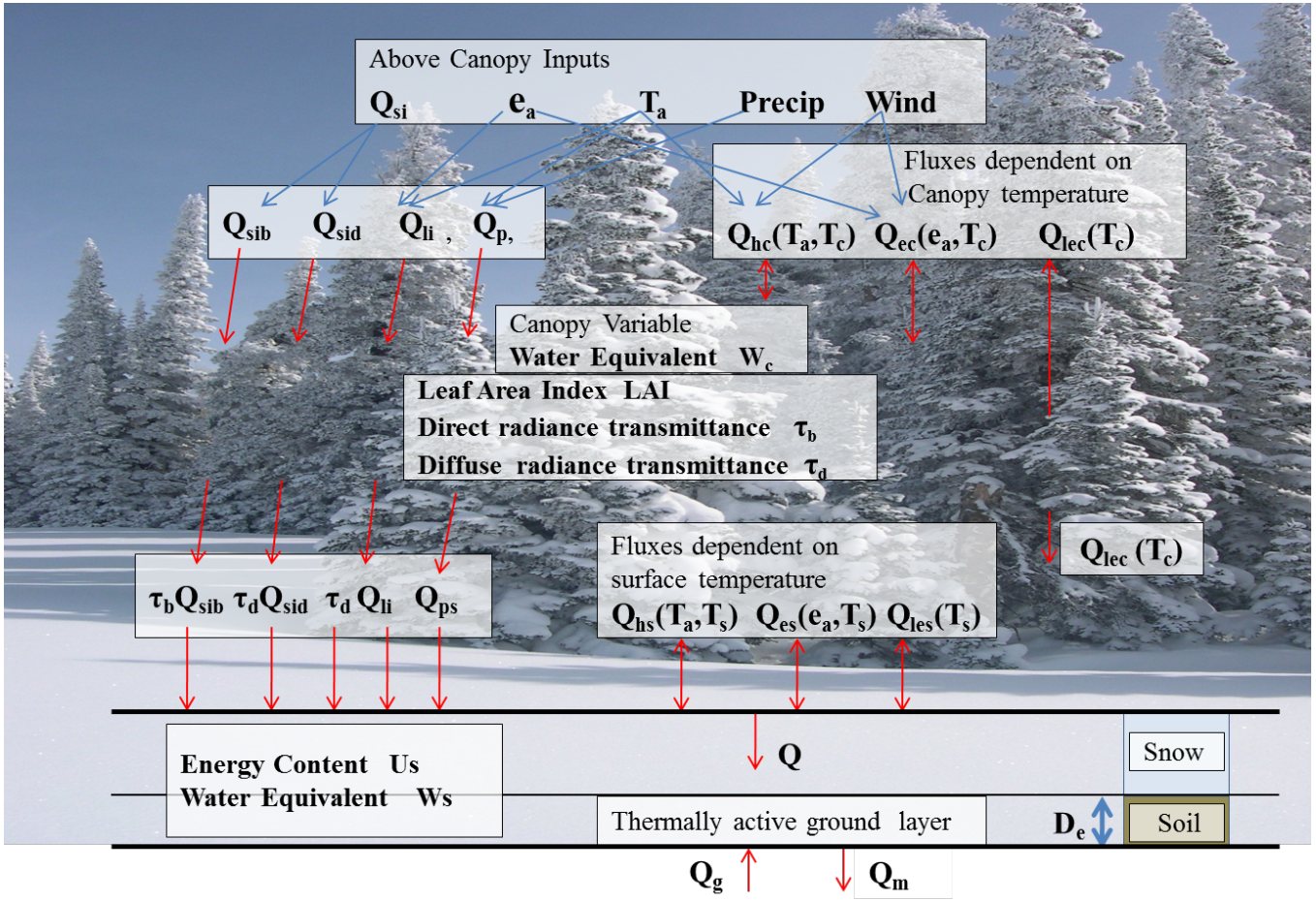
- Reviewed available server-based geospatial software stacks
  - Map servers
  - Geoprocessing
  - Geospatially enabled database systems
- Selected potential platforms and software stacks
  - Open Source: MapServer, 52North geoprocessing, PostgreSQL/ PostGIS, Python, Open Layers
  - Proprietary: ArcGIS Server, Microsoft SQL Server
- Developed prototype implementations of the platforms for testing in our virtualization environment (underway)

# Recent Progress and Next Steps (Outline)

- Modeling and pre-processing prototypes (UEB, TOPNET, TauDEM) - Tarboton
- Water management representations - Rosenberg
- Cloud-based modeling - Nelson
- Climate modeling and making projections available – Strong
- Urban water systems - Burian

# UEB Snowmelt Model Use Case

- What are the impacts of land cover change on watershed snowmelt inputs?




Mahat, V. and D. G. Tarboton, (2012), "Canopy radiation transmission for an energy balance snowmelt model," Water Resour. Res., 48: W01534, http://dx.doi.org/10.1029/2011WR010438.

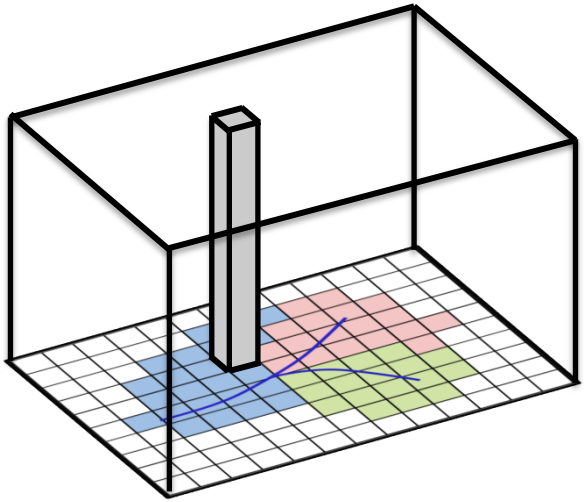
# Common Hydrologic Model Data Requirements
(UEB subset)

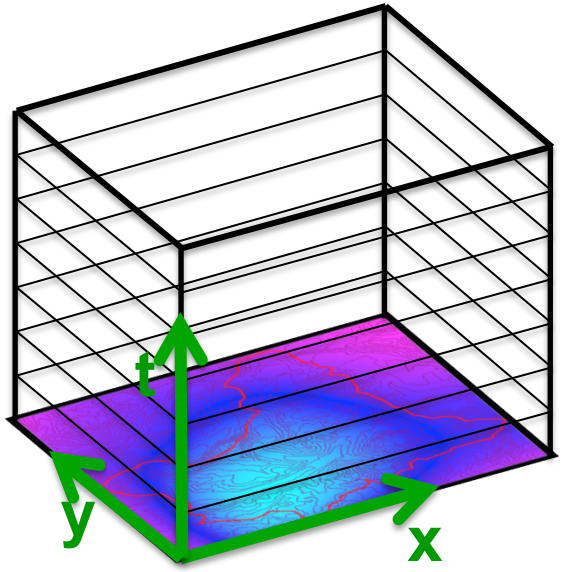
- Digital Elevation Model (and derivatives)
  - Slope, Watersheds, ...
- Soils (and pedotransfer functions)
- Geology (and hydrogeological parameters)
- Vegetation (and parameter mapping tables)
- Streams
- Water Management Infrastructure
- Dynamic input Variables
  - Precipitation, Humidity, Wind, Radiation, Temperature
- Water Use and Management process parameters

UEB subset serves as a simplified first use cas

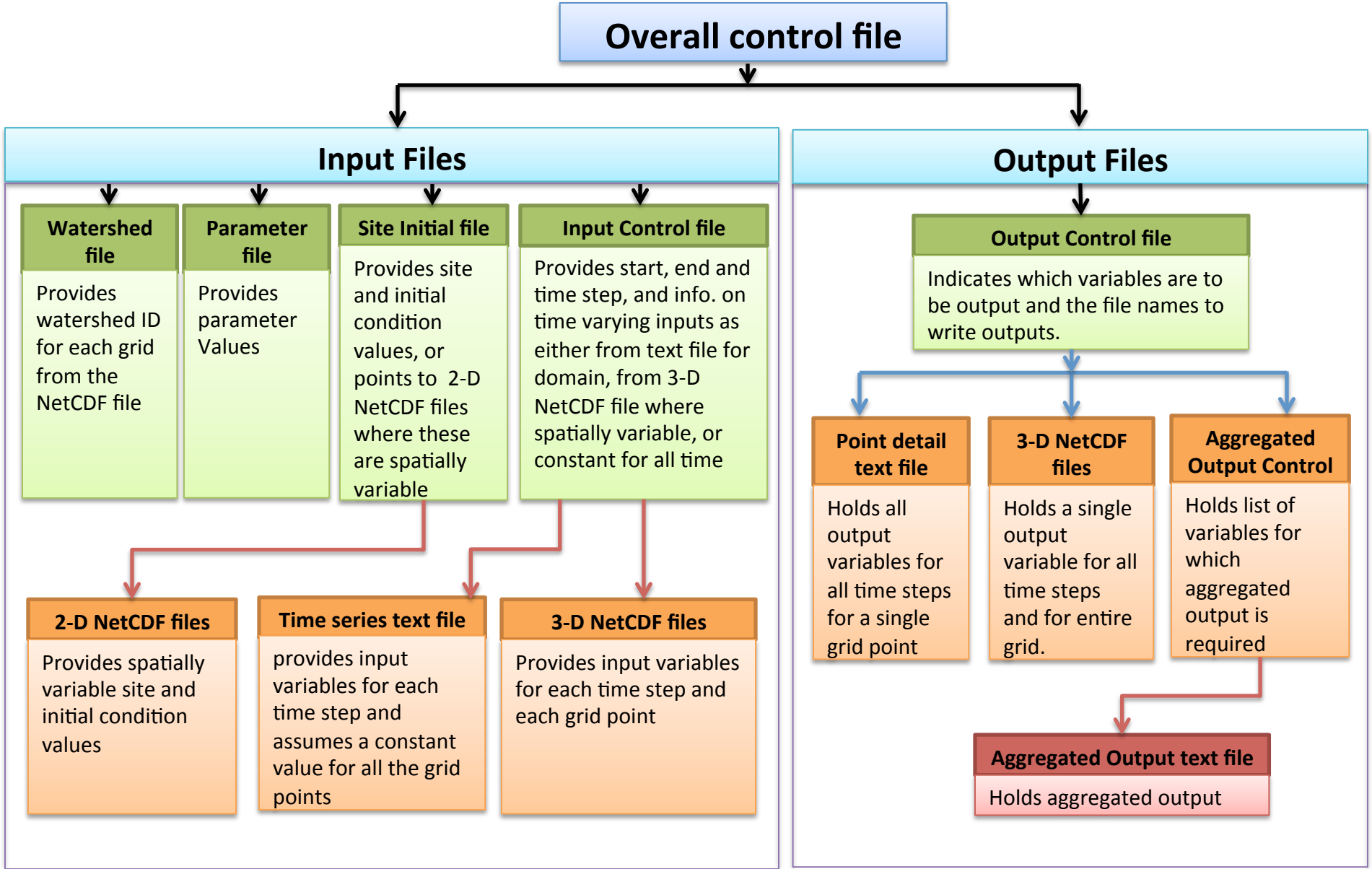
# UEB Grid Implementation

- Model run separately at each active grid cell
- Melt outputs aggregated for subwatersheds
- Structured File based IO for linking with EPA BASINS
- ASCII for non spatial data
- NetCDF for geospatial data





# File-Based Input-Output System



# Motivating Problem

- Compiling the data and formatting model input requires months of graduate student work

# Automatically Create UEB Model Package

1. User defines outlet point for model domain
2. CI-WATER extracts model domain watershed from terrain (TauDEM)
3. CI-WATER extracts necessary input data for model domain
4. CI-WATER packages model and inputs
5. CI-WATER ships package to a computational resource and executes it
6. CI-WATER retrieves model output and enables visualization and analysis

Automagically…

# Accomplishments

- Documentation of use case steps
- Design of prototype

# Recent Progress

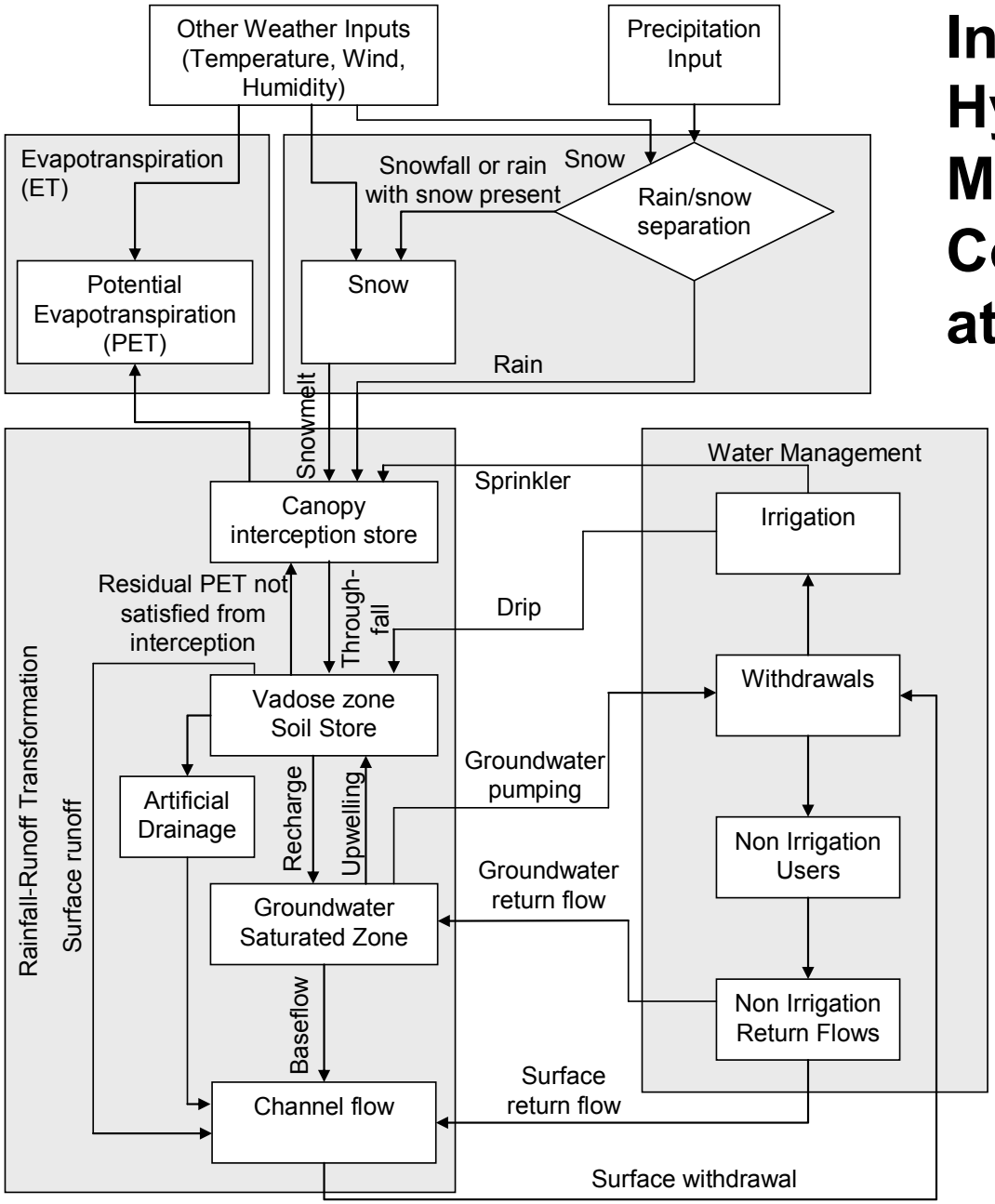
## Automatically Create UEB Model Package

- Development of map based web interface
  - Automatic watershed delineation to define the model domain
  - EPA delineation web service
- Automated extraction of datasets for model domain
  - NLCD land cover
  - Daymet time series datasets (1 km x 1 km)
  - DEM derived terrain variables
- Data processing steps
  - Space and time rescaling
  - Generation of model input files in correct format

# Next Steps

- TOPNET Use Case
- TauDEM Use Case

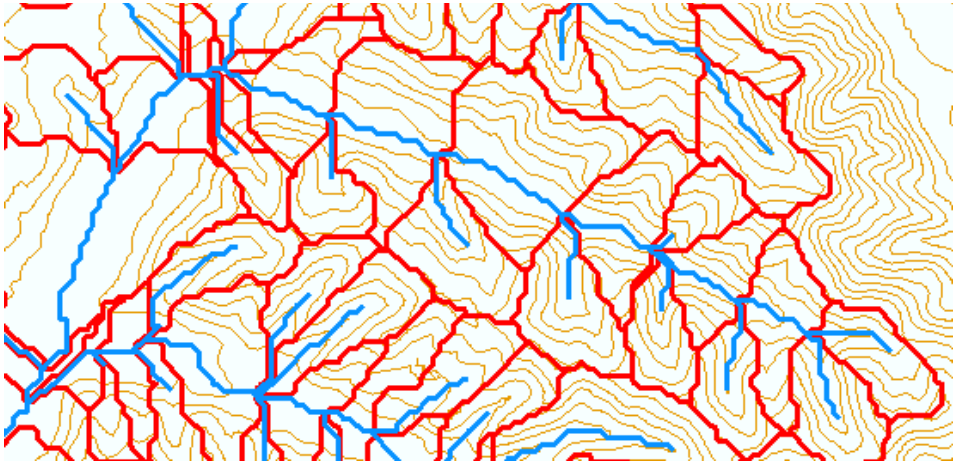
# TOPNET



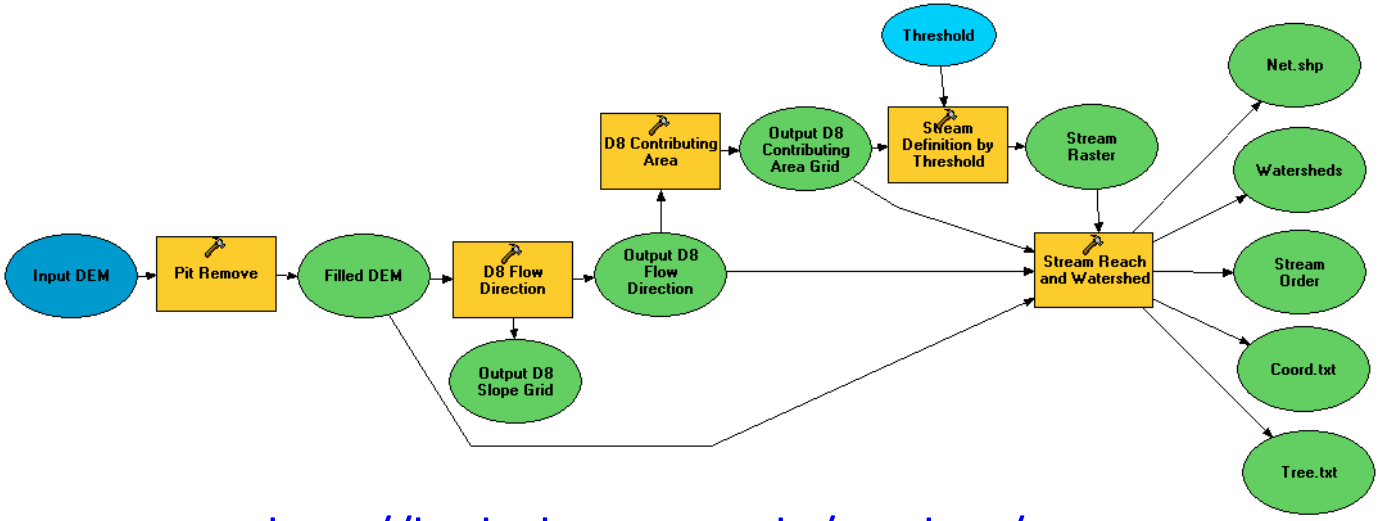

**Integrated model of Hydrologic, Water Management and Consumption processes at each "catchment"**

- Competition for water resources among users
- Human activities can alter water balance having effects on stream ecosystems and water quality
- Simulation modeling used to quantify the likely impacts of water management choices

# TauDEM Channel Network and Watershed Delineation Software



- To be deployed in web based environment
- Multi-file parallel approach to enable pre-processing of large DEMs and generation of subwatershed model elements




http://hydrology.usu.edu/taudem/

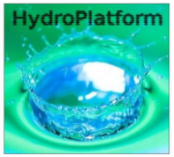
David Rosenberg – Utah State University

# WATER MANAGEMENT MODELS

# Motivating problem

- Automatically transfer water management data across models and platforms
- Communicate reservoir, diversion, demand, infrastructure, and operational data among nearly 30 agencies
- Consistent, descriptive, and integrated data model to share, prepare, and publish water management data



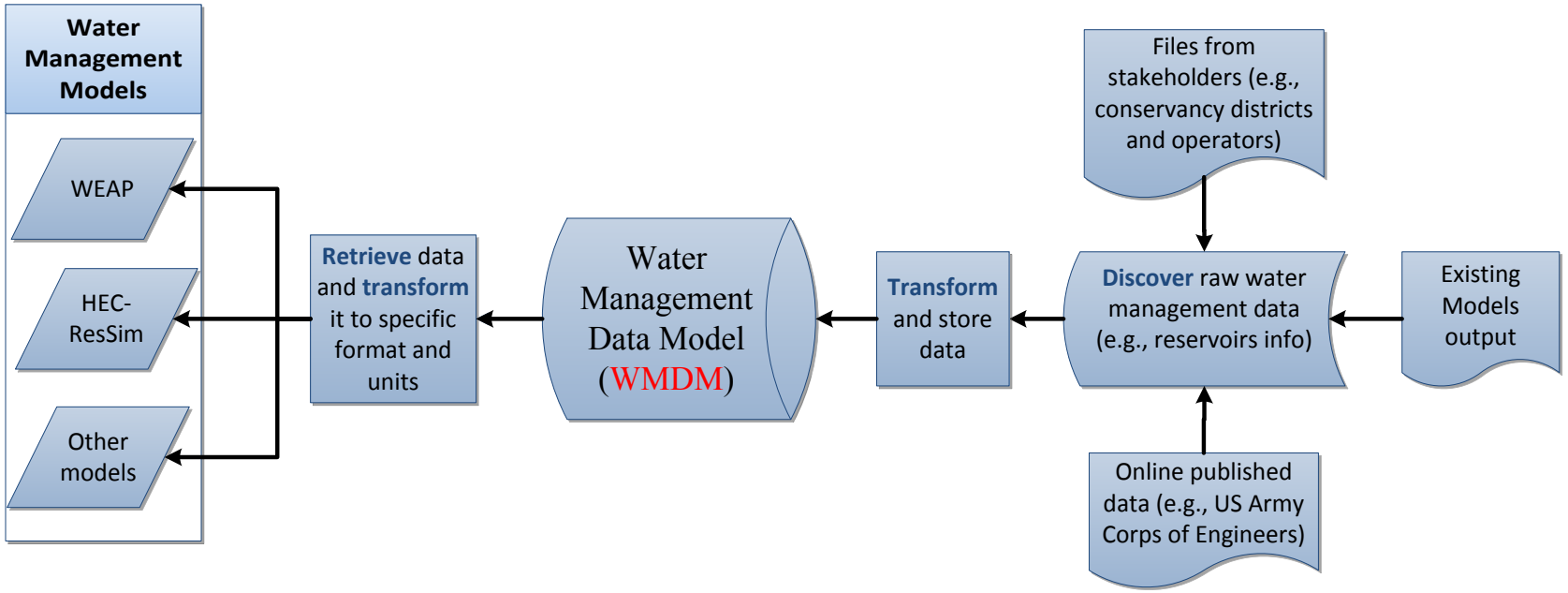


# Objectives/Workflow

- Review data requirements and formats for several common water management models (e.g., WEAP, HEC-ResSim, Hydroplatform)
- Identify similarities and differences in capabilities, scales, data formats, and semantics among the models.
- Reconstruct the data models for the common models
- Incorporate the data models into a generic relational data model for water management data

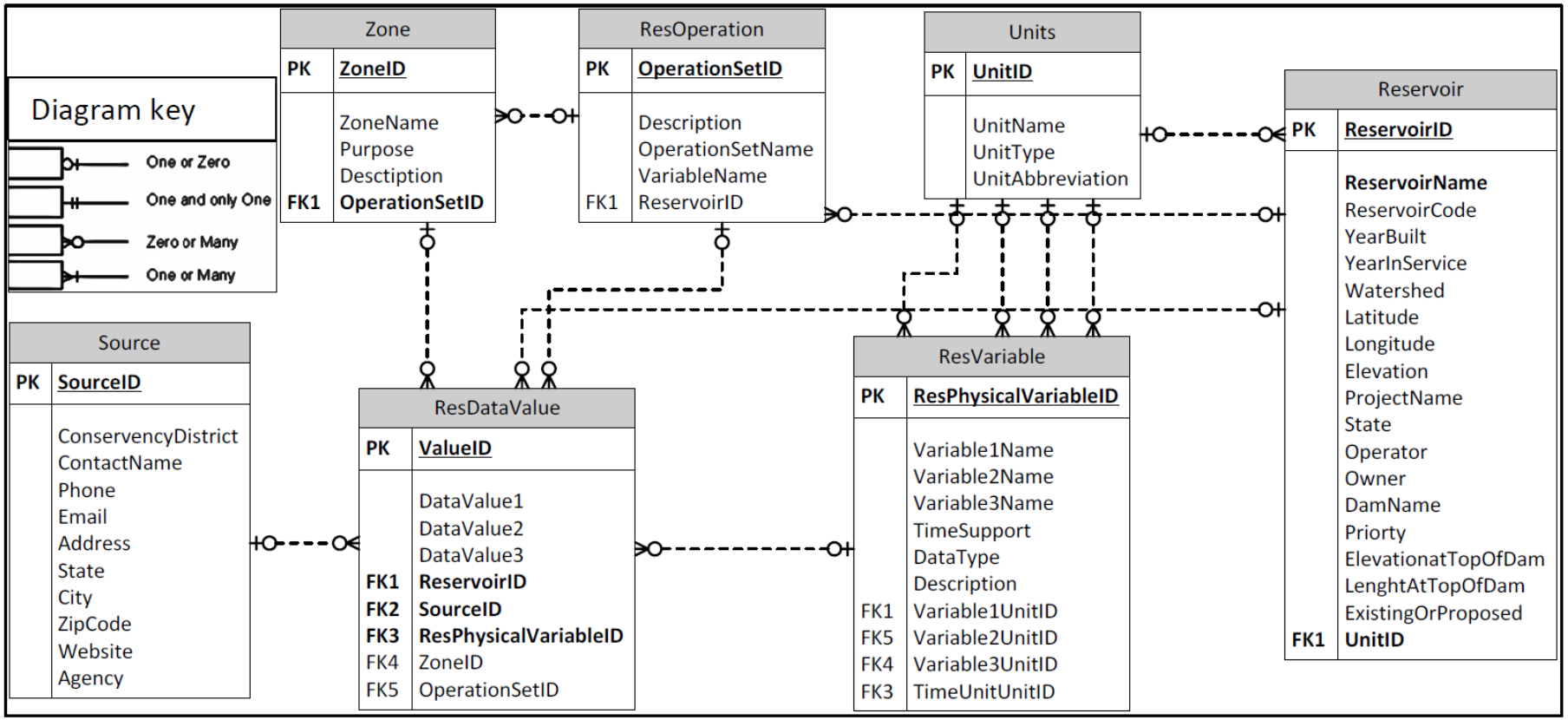
# Past Accomplishments

1. Developed a conceptual Water Management Data Model (WMDM)



# Past Accomplishments (Cont.)

## 2. Developed a generic reservoir data model



# Recent Progress

- Met with WEAP, HEC-ResSim, and Hydroplatform developers
- Reconstructed relational data models for Hydroplatform and WEAP
- Adopted node and link entities to represent spatial attributes of water management data.

# Next Steps

- Link in the Observational Data Model (ODM) to accommodate time-series data
- Develop controlled vocabulary lists of terms for water management data
- Seek feedback from the water management community on a draft version of the WMDM
- Use the WMDM as the core and specifications for a generic, open-source data management system to enter, manage, and serve water management data to models (HydroPlatform extension)

Jim Nelson – Brigham Young University

# CLOUD-BASED MODELING

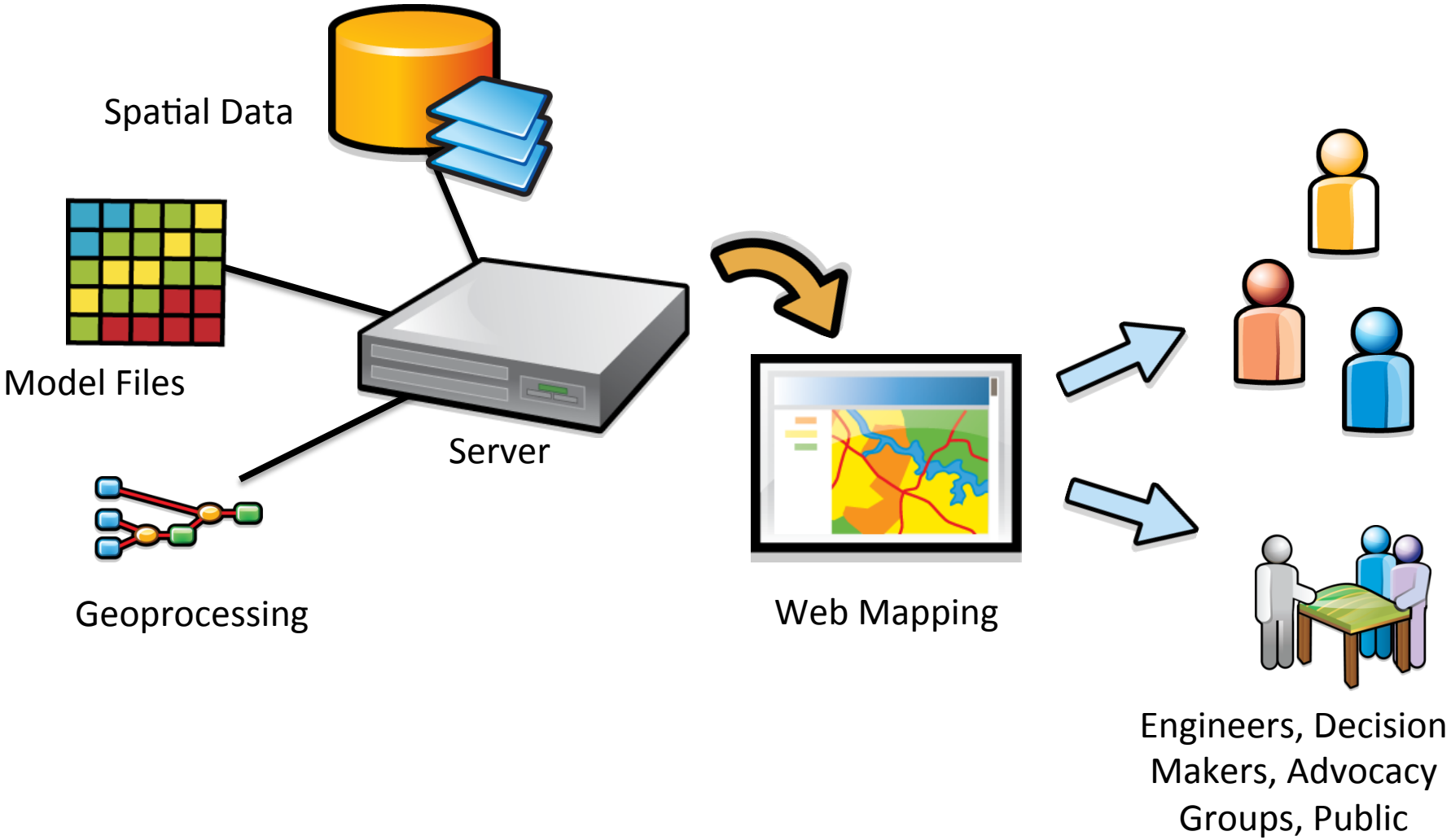
# Motivating Problem

"Currently, there exists a **digital divide** among most hydrologic researchers (experimentalists and modelers who have process-based modeling expertise) and HPC experts who have technical hardware and programming knowledge to efficiently use HPC resources and the resource managers who need to translate the outcomes to practical planning. **This divide limits comprehensive modeling** and the greater understanding of integrated hydrologic-human processes that we believe it would provide."

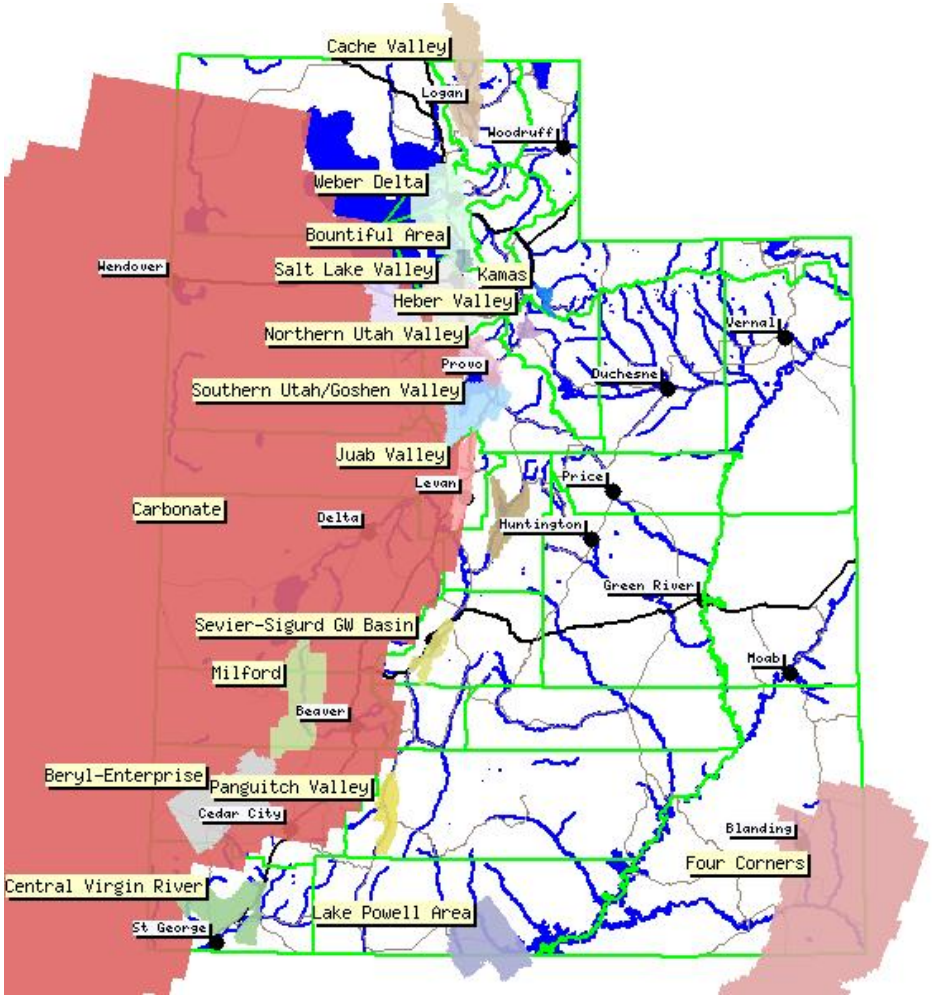
# Objectives

**“Proposed Activities:** To address these challenges, we will develop easy-to-use model and data interfaces that link integrated system models running within an HPC environment to multiple data sources, allow users to efficiently and effectively explore alternative physical representations of study systems, and describe the sensitivity to and consequences of alternative representations on the integrated system represented by the models. Additionally, we will develop user interfaces that summarize and visualize data and model outputs to support research, hypothesis testing and inform water management decisions.”

# Cloud-Based Modeling and Visualization Tools

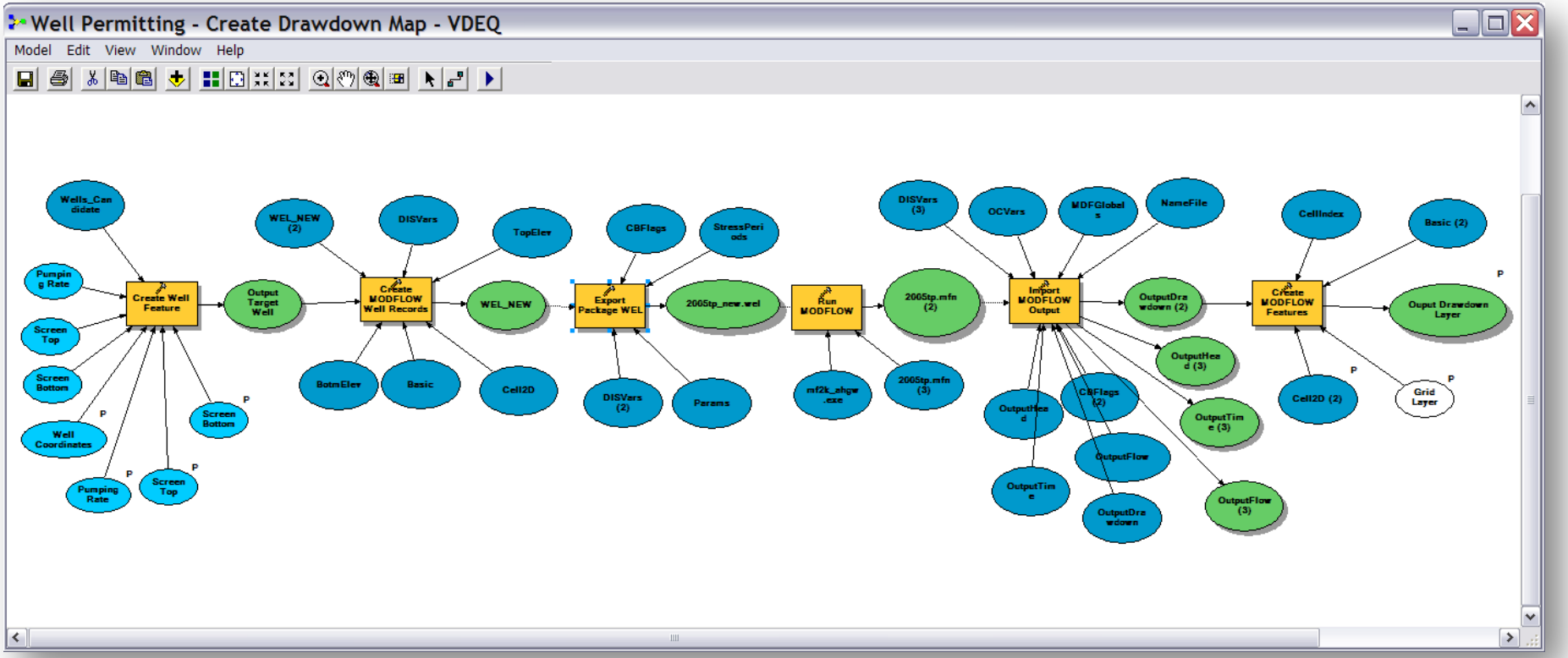


# Prototype: Utah Division of Water Rights



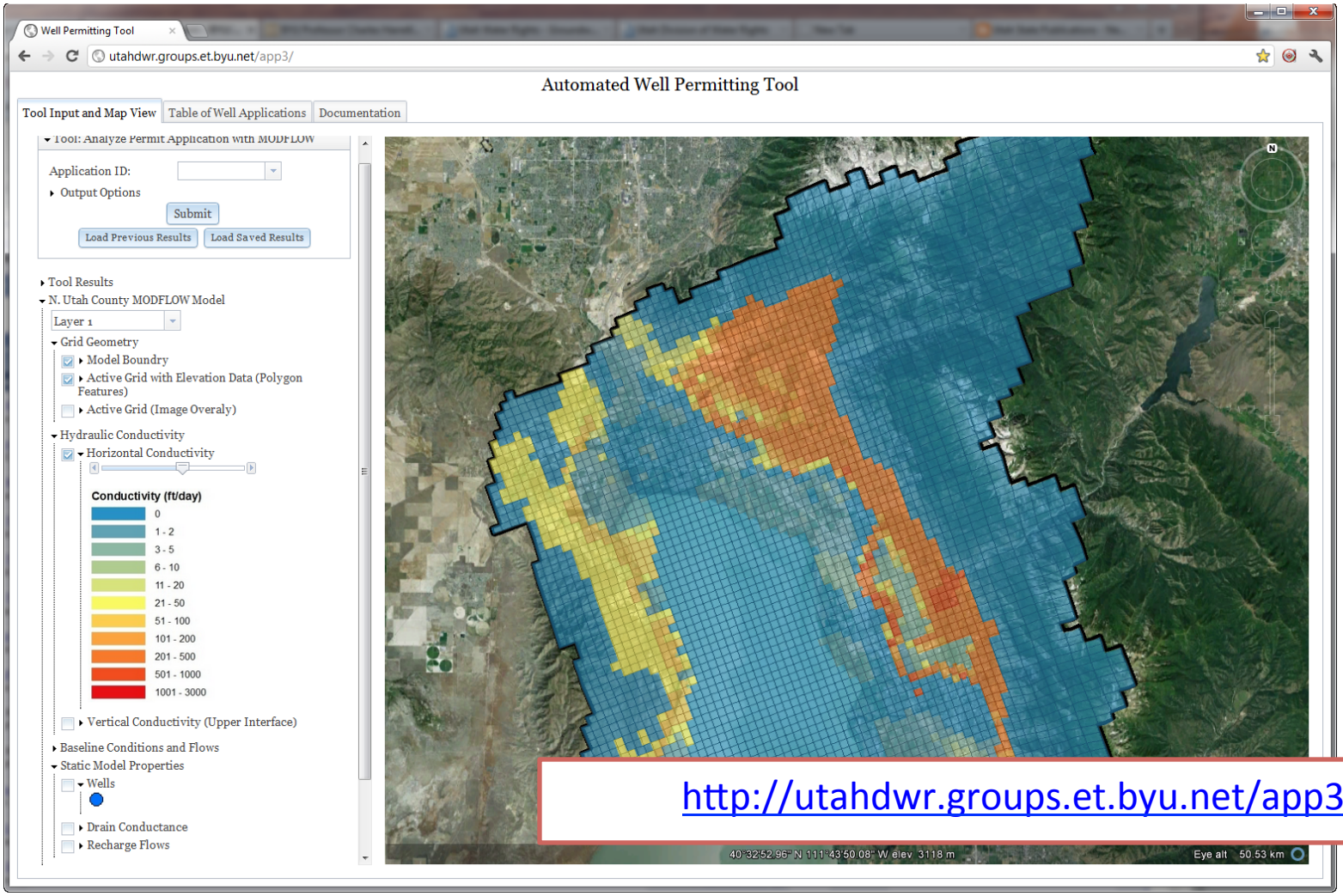

- 31 MODFLOW models used for impact analysis
- Challenges
  - Modeling expertise
  - Software installation and maintenance
  - User error
  - Cost

# Well Permitting Workflow



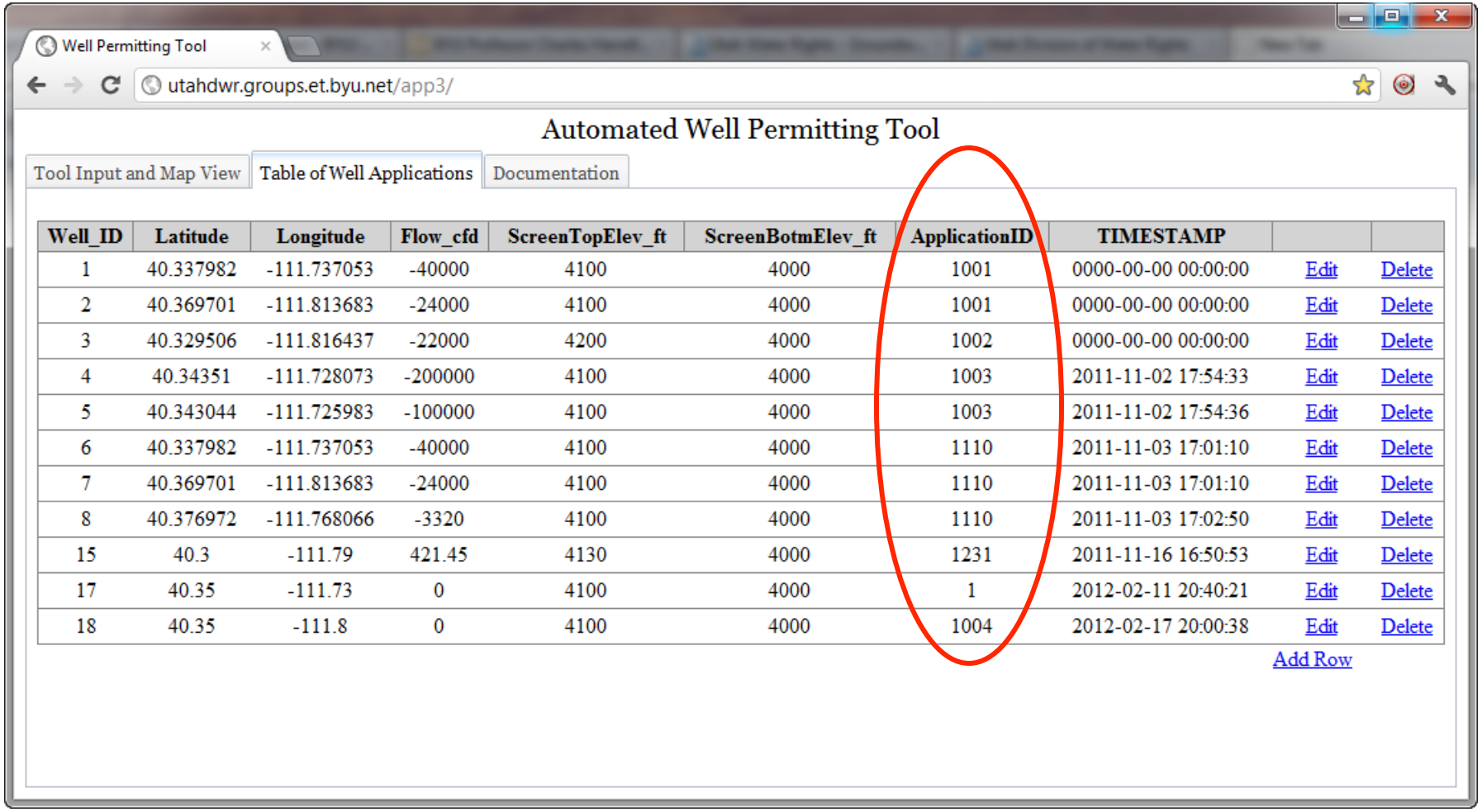

Create new well → update well table → export well package file → run MODFLOW → import solution → build drawdown map layer

# Web Interface




http://utahdwr.groups.et.byu.net/app3/

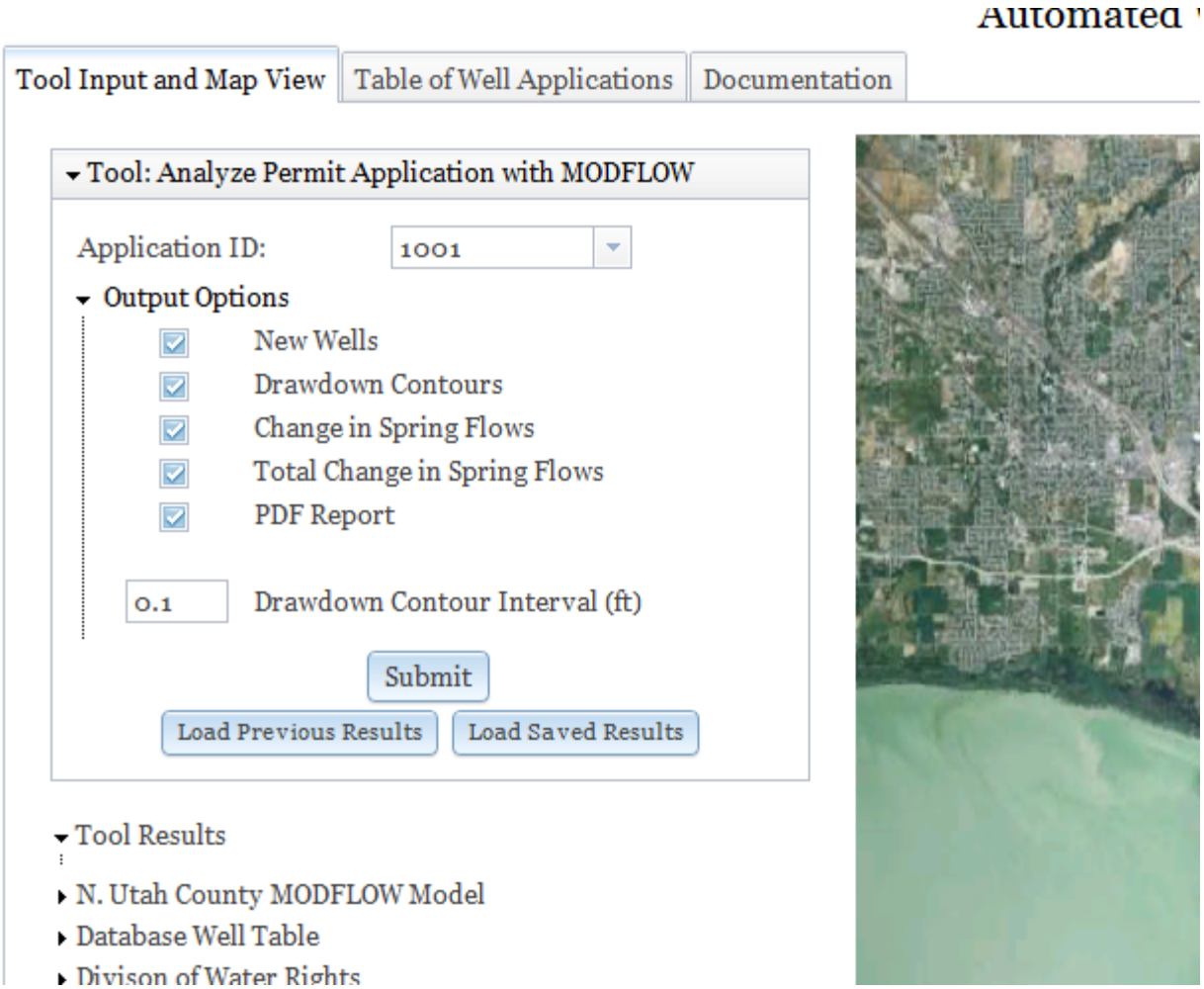
# Table of Well Applications



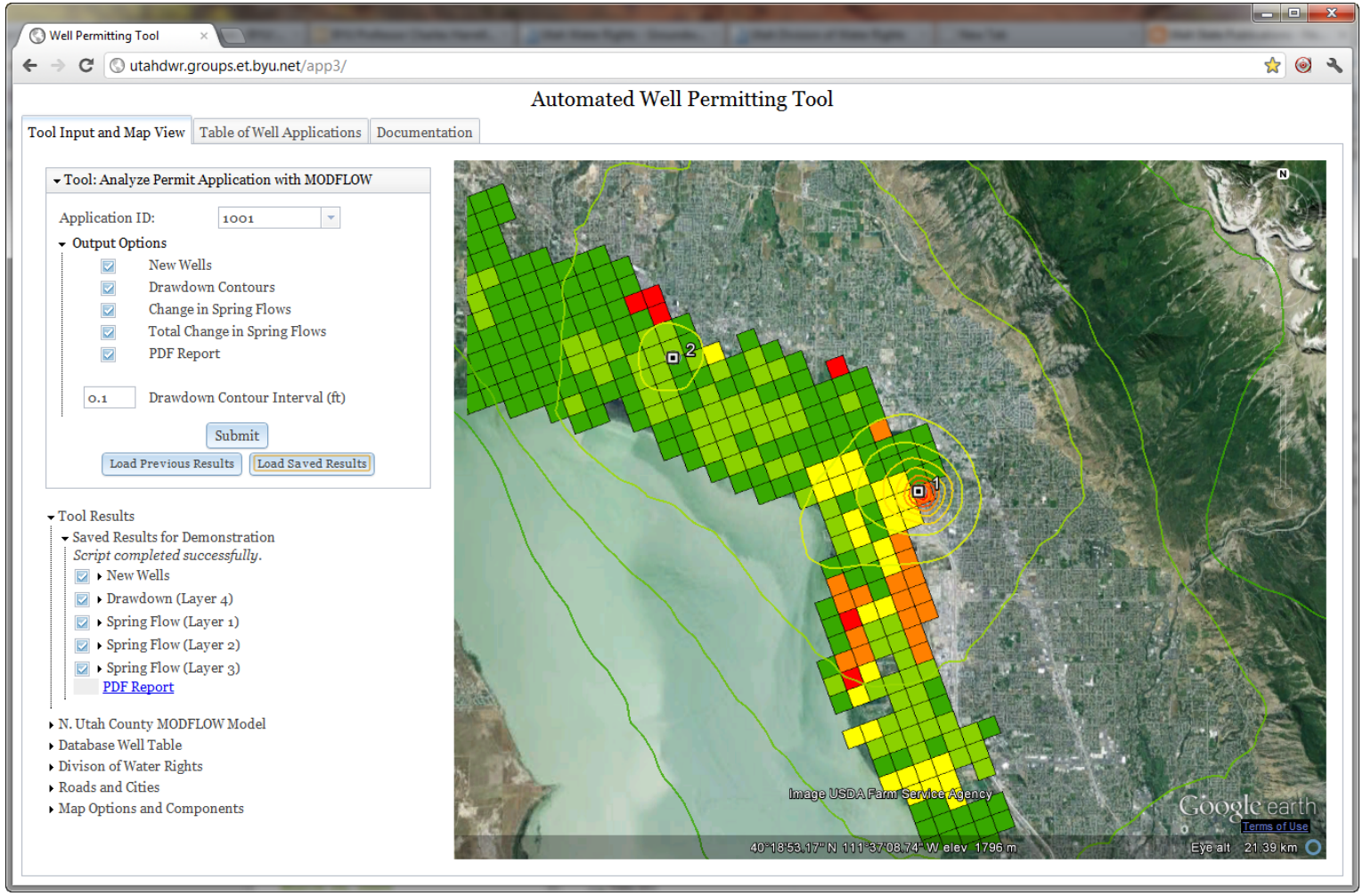

| Well_ID | Latitude | Longitude | Flow_cfd | ScreenTopElev_ft | ScreenBotmElev_ft | ApplicationID | TIMESTAMP | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 40.337982 | -111.737053 | -40000 | 4100 | 4000 | 1001 | 0000-00-00 00:00:00 | Edit | Delete |
| 2 | 40.369701 | -111.813683 | -24000 | 4100 | 4000 | 1001 | 0000-00-00 00:00:00 | Edit | Delete |
| 3 | 40.329506 | -111.816437 | -22000 | 4200 | 4000 | 1002 | 0000-00-00 00:00:00 | Edit | Delete |
| 4 | 40.34351 | -111.728073 | -200000 | 4100 | 4000 | 1003 | 2011-11-02 17:54:33 | Edit | Delete |
| 5 | 40.343044 | -111.725983 | -100000 | 4100 | 4000 | 1003 | 2011-11-02 17:54:36 | Edit | Delete |
| 6 | 40.337982 | -111.737053 | -40000 | 4100 | 4000 | 1110 | 2011-11-03 17:01:10 | Edit | Delete |
| 7 | 40.369701 | -111.813683 | -24000 | 4100 | 4000 | 1110 | 2011-11-03 17:01:10 | Edit | Delete |
| 8 | 40.376972 | -111.768066 | -3320 | 4100 | 4000 | 1110 | 2011-11-03 17:02:50 | Edit | Delete |
| 15 | 40.3 | -111.79 | 421.45 | 4130 | 4000 | 1231 | 2011-11-16 16:50:53 | Edit | Delete |
| 17 | 40.35 | -111.73 | 0 | 4100 | 4000 | 1 | 2012-02-11 20:40:21 | Edit | Delete |
| 18 | 40.35 | -111.8 | 0 | 4100 | 4000 | 1004 | 2012-02-17 20:00:38 | Edit | Delete |

Add Row

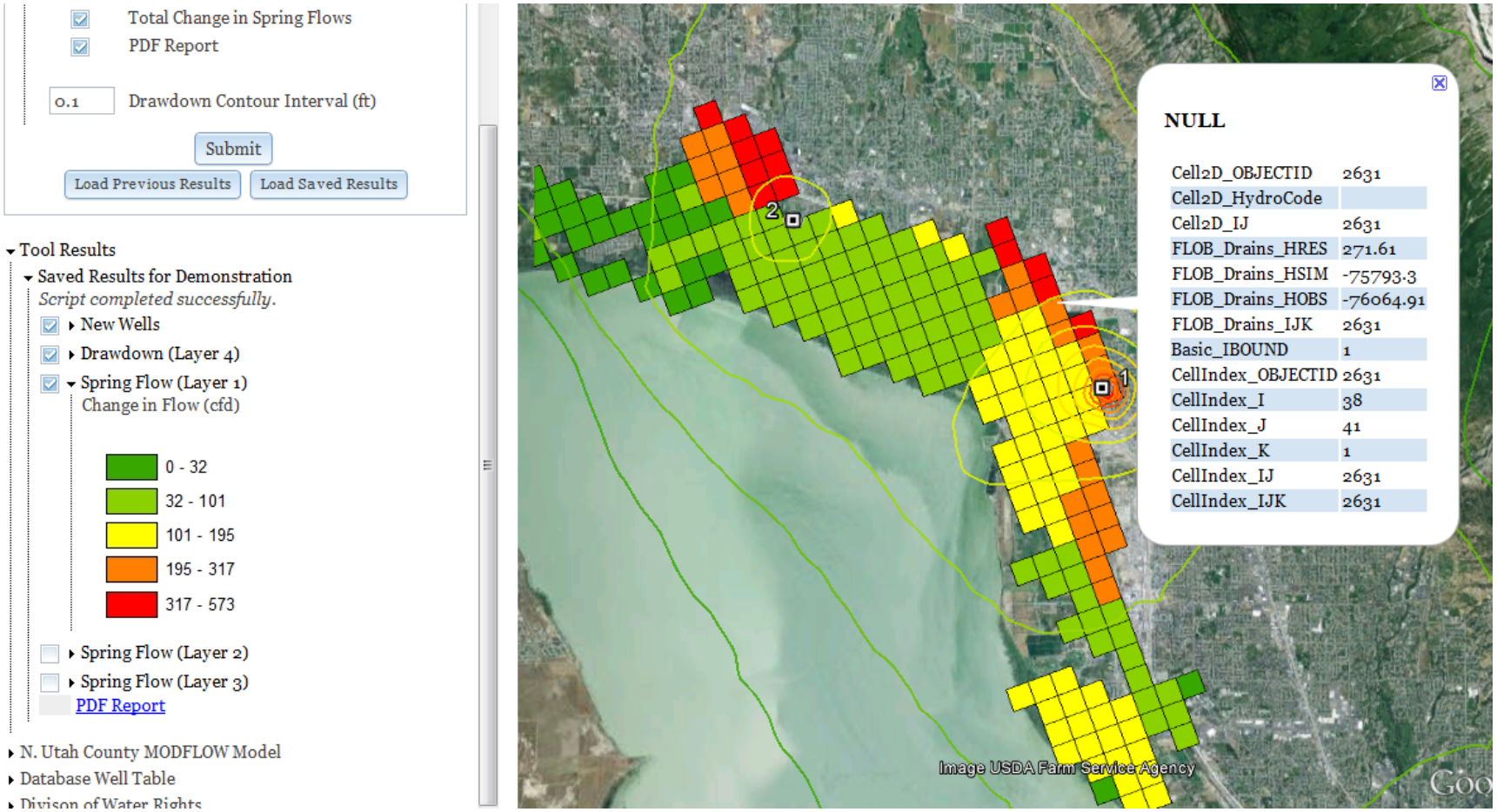
# Submitting a Model Run



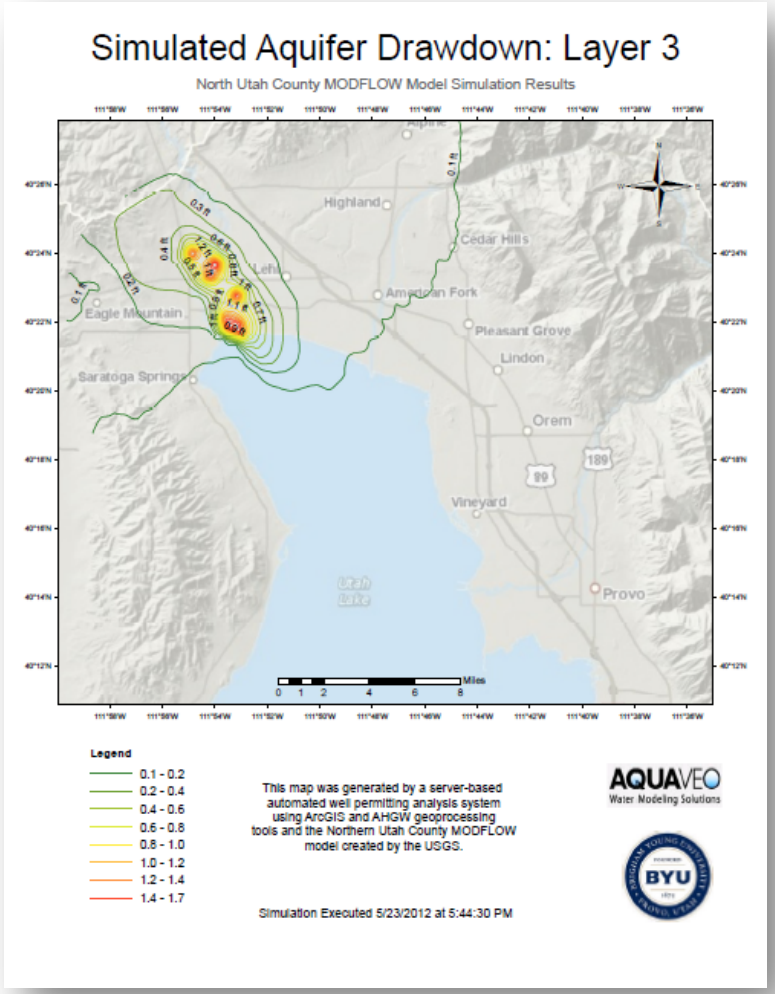
# Model Results

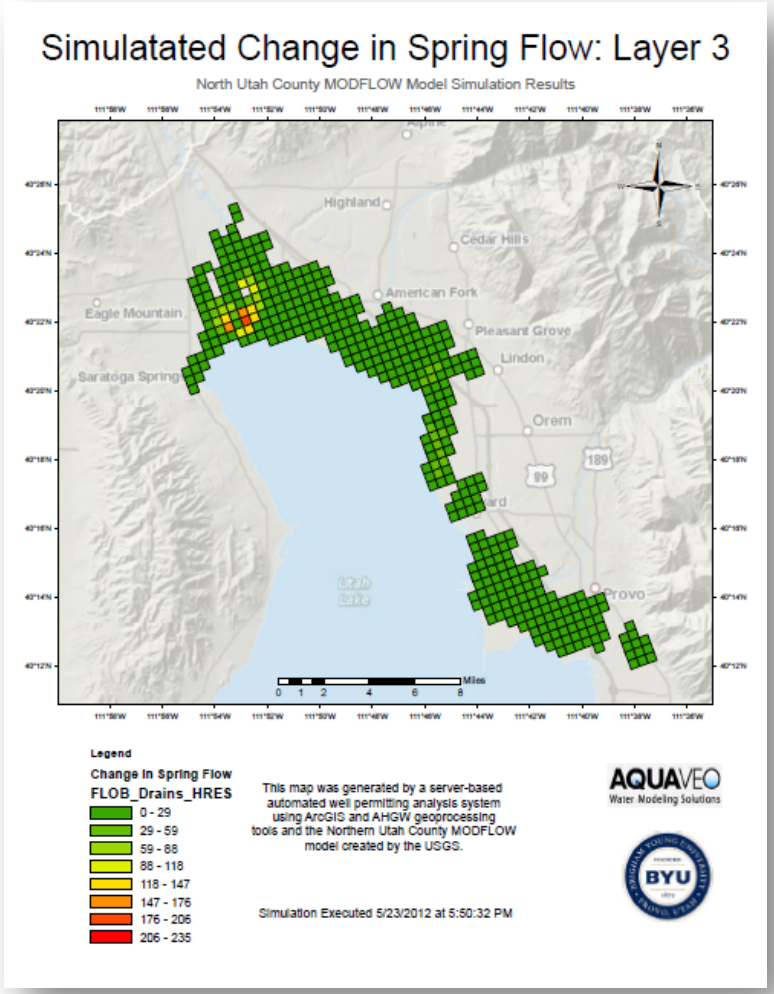


# Impact on Springs



# PDF Output


Simulated Aquifer Drawdown: Layer 3
North Utah County MODFLOW Model Simulation Results
Highland
Cedar Hills
Lehi
American Fork
Eagle Mountain
Pleasant Grove
Lindon
Saratoga Springs
Orem
Vineyard
Provo
Utah Lake
Miles
Legend
0.1 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1.0
1.0 - 1.2
1.2 - 1.4
1.4 - 1.7
This map was generated by a server-based automated well permitting analysis system using ArcGIS and AHGW geoprocessing tools and the Northern Utah County MODFLOW model created by the USGS.
Simulation Executed 5/23/2012 at 5:44:30 PM
AQUAVEO
Water Modeling Solutions
BYU


Simulatated Change in Spring Flow: Layer 3
North Utah County MODFLOW Model Simulation Results
Highland
Cedar Hills
American Fork
Eagle Mountain
Pleasant Grove
Lindon
Saratoga Springs
Orem
Provo
Utah Lake
Miles
Legend
Change in Spring Flow
FLOB_Drains_HRES
0 - 29
29 - 59
59 - 88
88 - 118
118 - 147
147 - 176
176 - 206
206 - 235
This map was generated by a server-based automated well permitting analysis system using ArcGIS and AHGW geoprocessing tools and the Northern Utah County MODFLOW model created by the USGS.
Simulation Executed 5/23/2012 at 5:50:32 PM
AQUAVEO
Water Modeling Solutions
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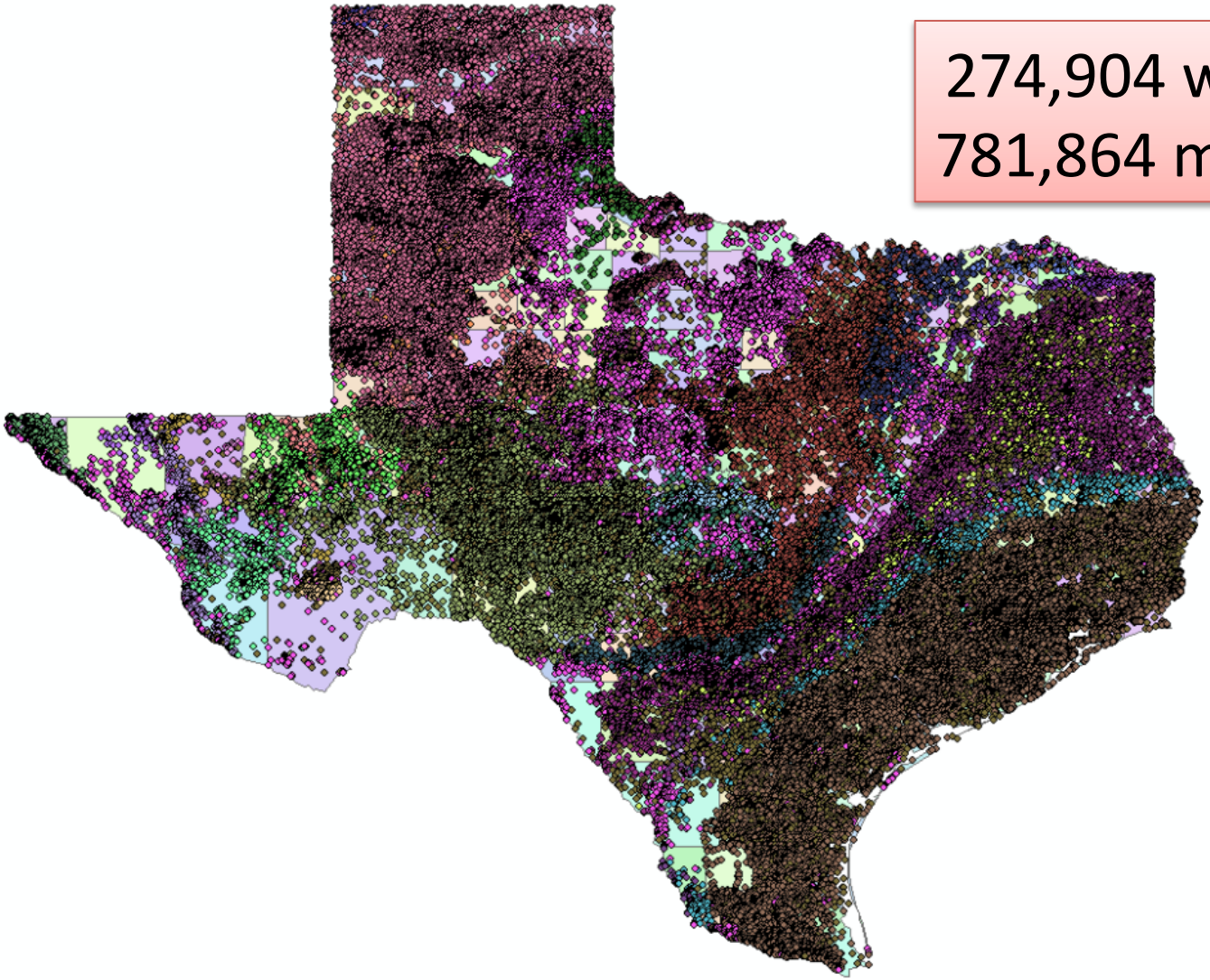
# Prototype: TWDB Well Database



274,904 wells w/meas.
781,864 measurements

Firefox

Water Table Mapping Tool

ci-water.groups.et.byu.net/watertable/

does the scout app use google search?

# Automated Water Table Mapping Tool

CI-WATER

A Utah-Wyoming Cyberinfrastructure Water Modeling Collaboration

Tool Input and Map View | New

**Tool: Generate Water Table Maps**

Select By: Aquifer

Area:

Start Date:

End Date:

Output Options

Submit

For generating new maps

Tool Results

Water Table Maps

- Texas: depth to groundwater, 12/25/2008
  - Value
  - High : 1096.48
  - Low : 8.23723
- Texas: depth to groundwater, 12/25/2009
- Texas: water elevation, 12/25/2008
- Texas: water elevation, 12/25/2009
- Lower Colorado: depth to groundwater, 12/25/2008
- Lower Colorado: water elevation, 12/25/2008
- Ogallala Aquifer: depth to groundwater, 12/25/2008
- Ogallala Aquifer: water elevation, 12/25/2008

Archive of existing maps

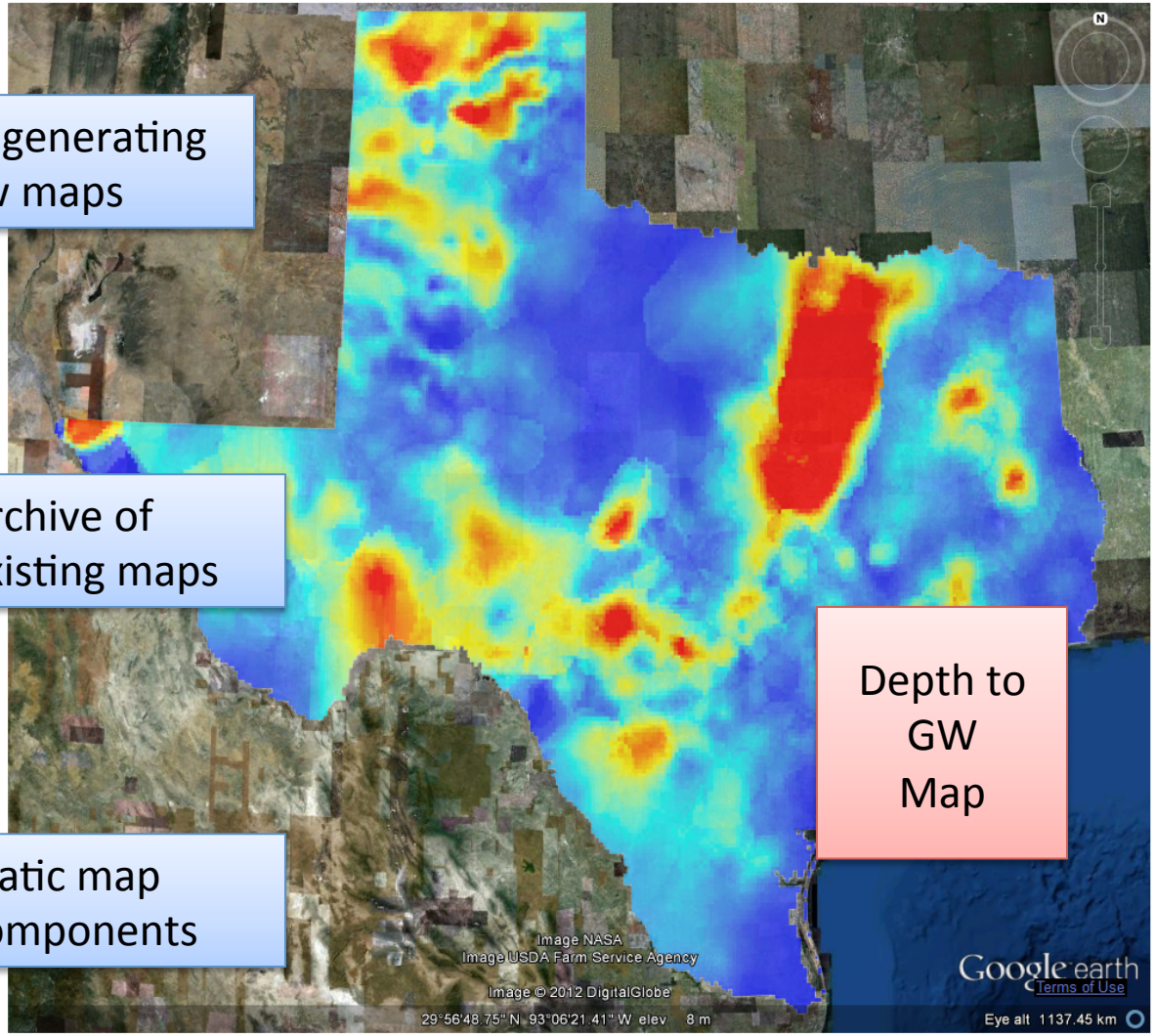
Boundaries

- Major Aquifers
- State Boundary
- Counties
- Water Planning Areas

Roads and Cities

Map Options and Components

Static map components



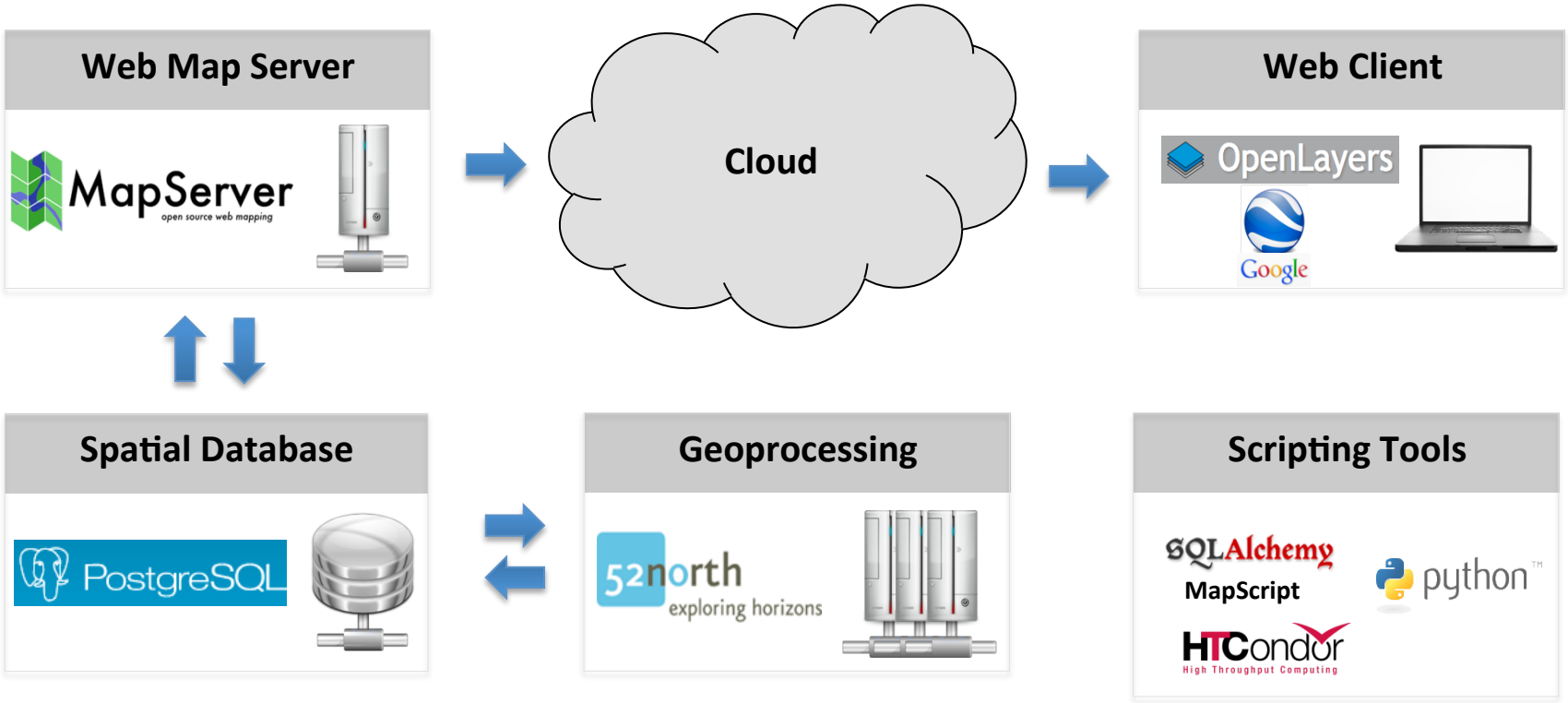

Depth to GW Map

Find: Next Previous Highlight all Match case

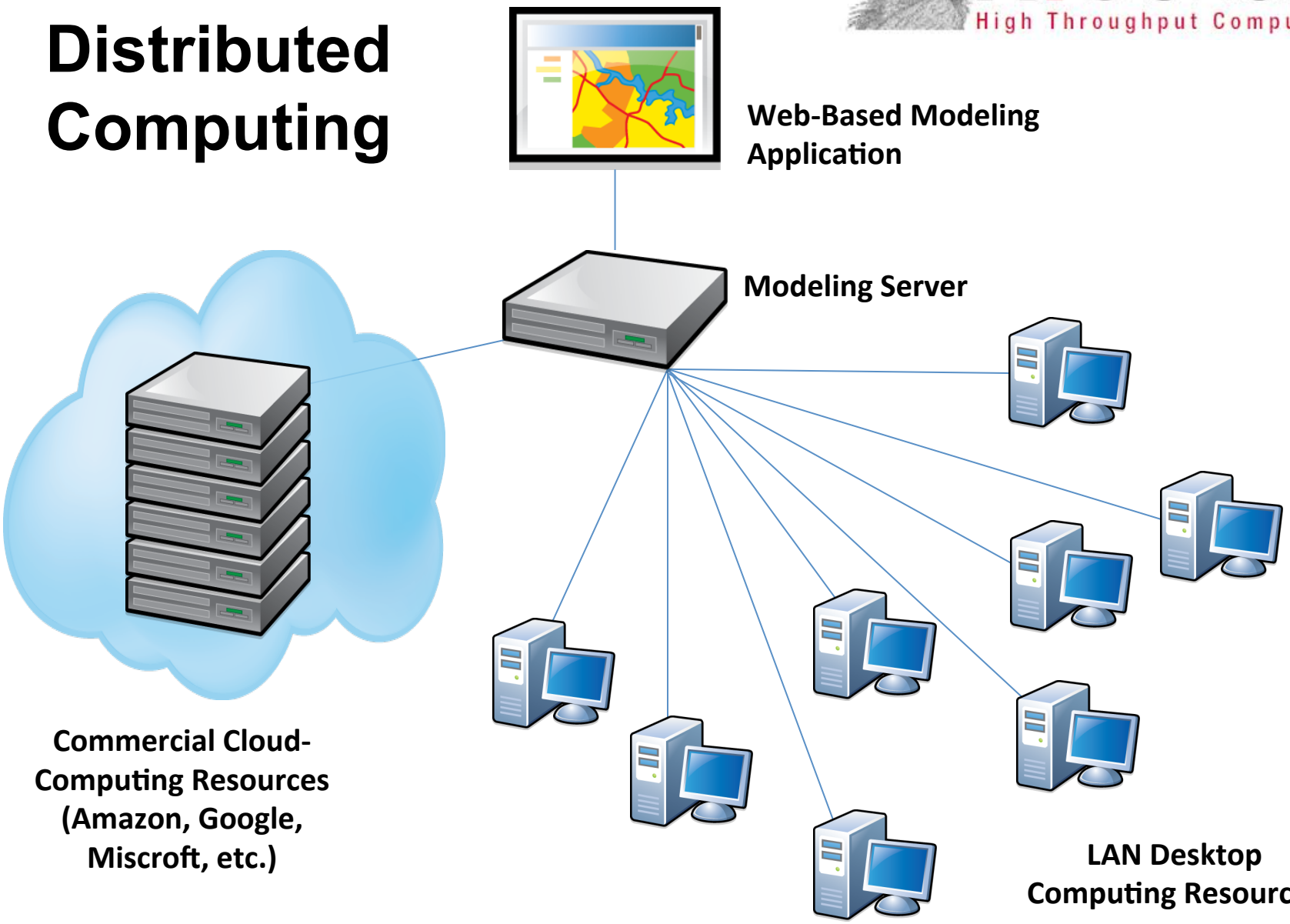
# Objective

- Develop infrastructure to support rapid development of Cloud-based tools for surface water modeling applications
- Components
  - Software stack for scripting and application development
  - GIS interface data models (schema) for selected models
  - Geoprocessing library for selected models

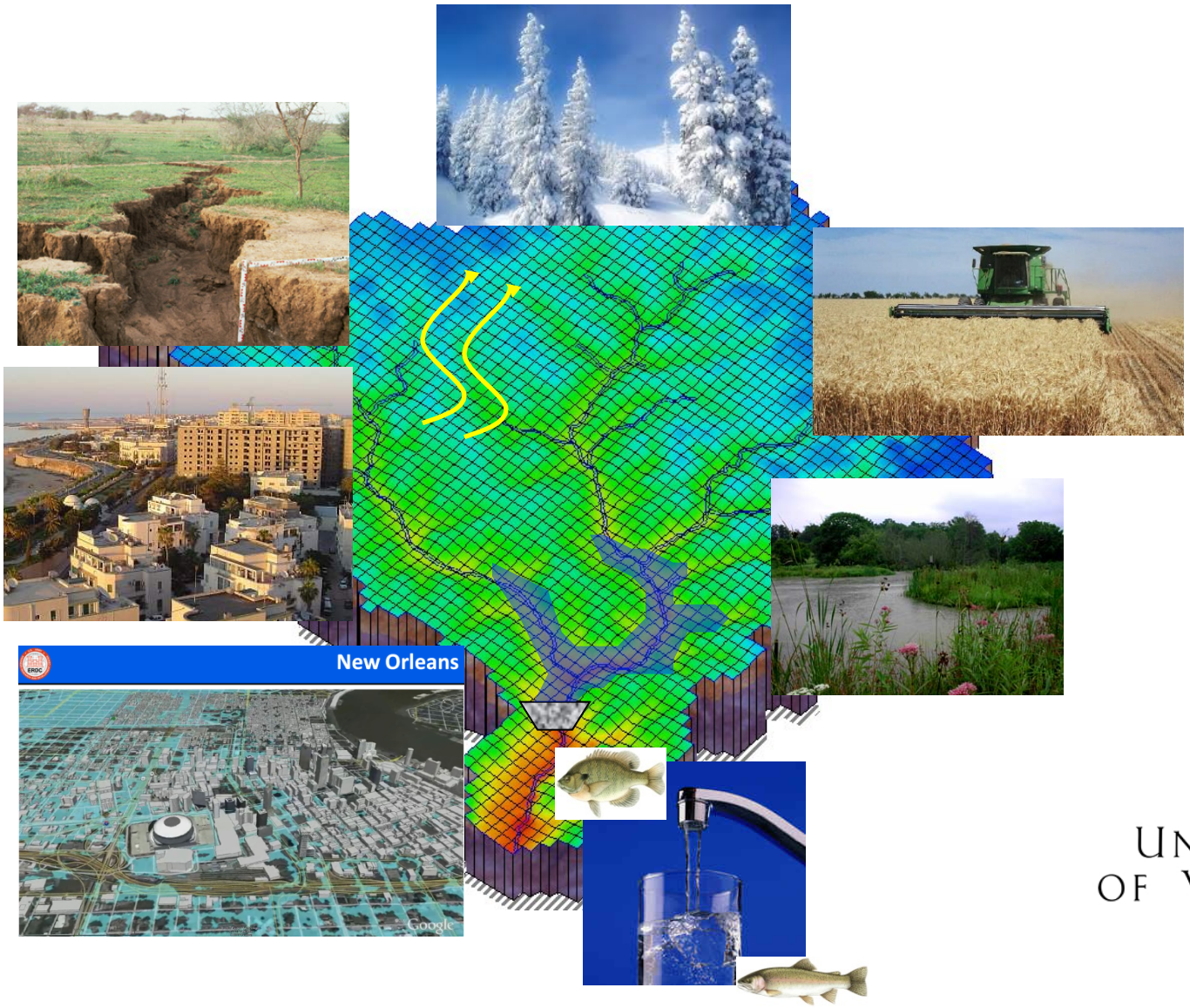
# Software Stack



# Automated Distributed Computing



# Gridded Surface Subsurface Hydrologic Analysis (GSSHA)

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CHL GSL EL TEC CRREL ITL

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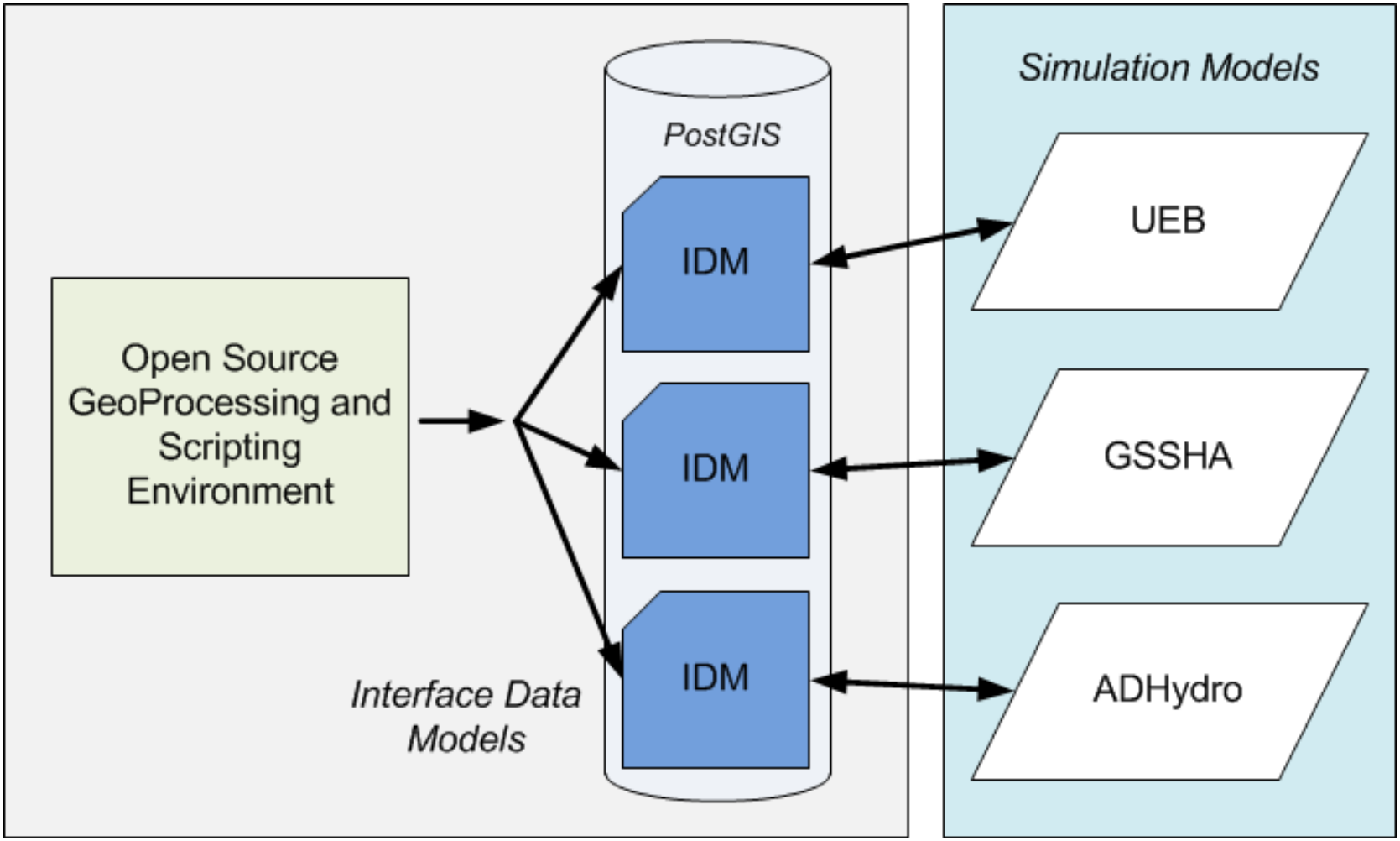
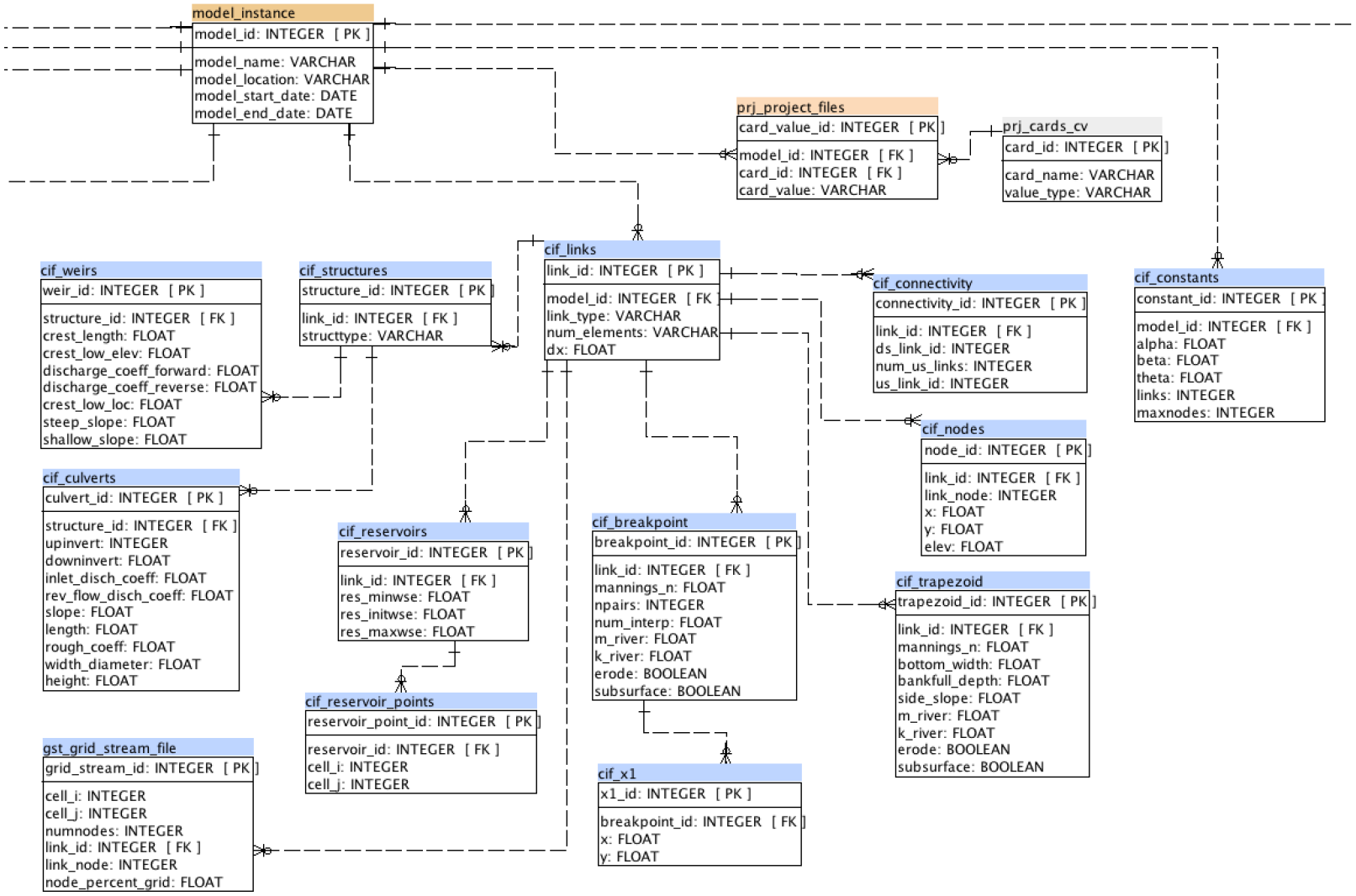
New Thinking

# Interface Data Models



# GSSHA Data Model (PostGSSHA)



# Recent Progress

- GSSHA data model designed
- GSSHA geoprocessing library under development
- 52 North server installed and functional
- Developing models for prototype applications
- Developed water table mapper as exercise to test web mapping and scripting tools

# Next Steps

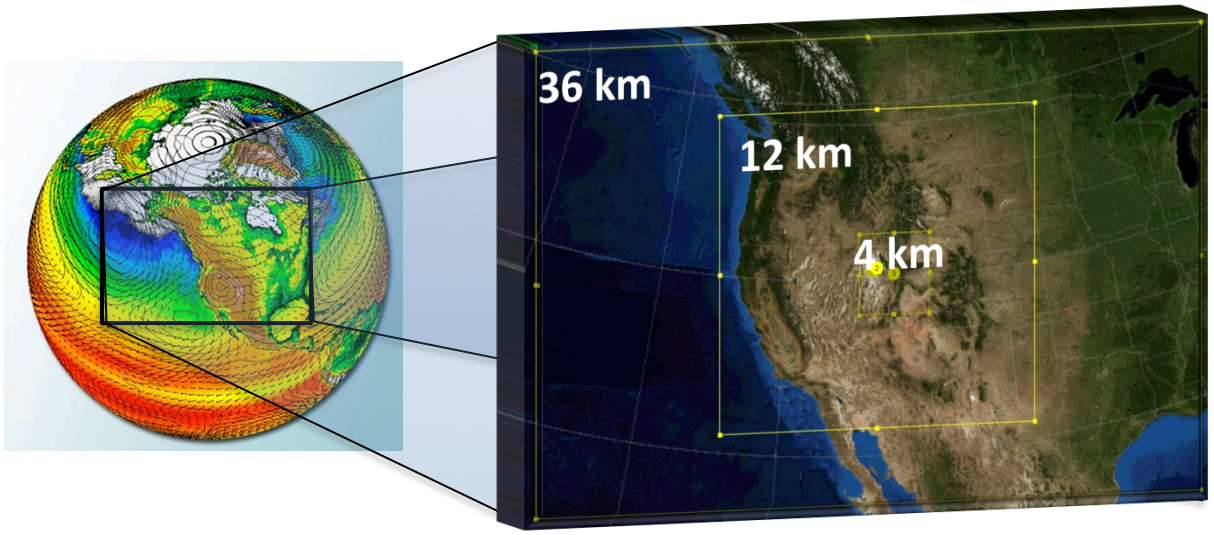
- Complete GSSHA geoprocessing library
- Develop cloud-based GSSHA modeling applications
- Assist with data model and tools for UEB and ADHydro
- Continue to develop reusable tools for web mapping and model visualization/ management

Court Strong – University of Utah

# CLIMATE MODELS

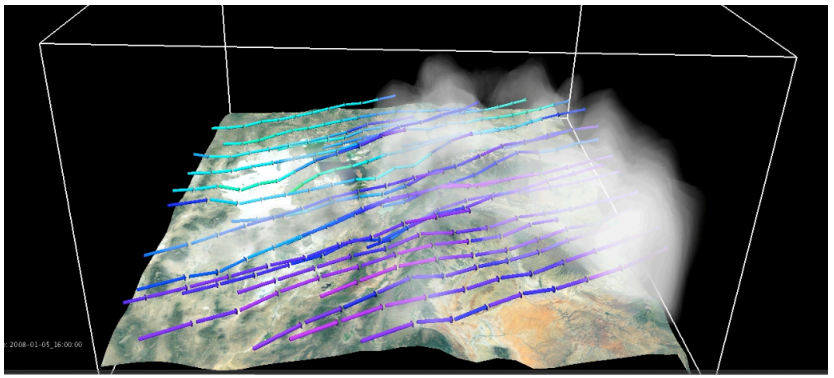
# Climate Modeling and Data Access

- **Problem:** the hydrology community needs high-resolution data representing the range of possible future climate conditions
- **Objective:** progressively increase the resolution of climate model output to 4 km using a physically-based regional model (WRF)



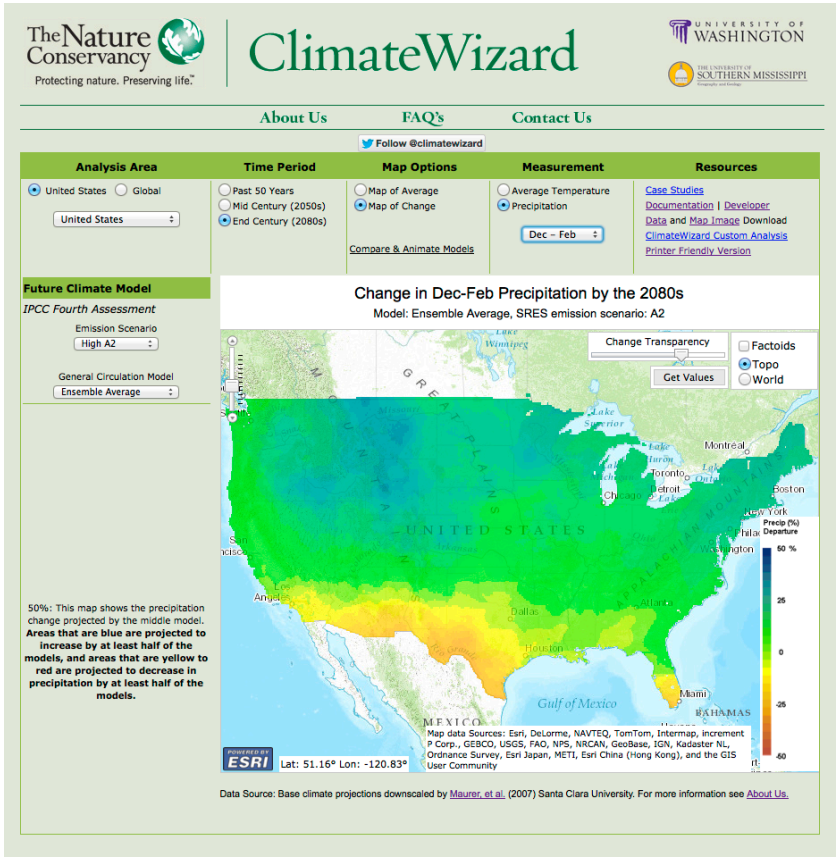
# Climate Modeling and Data Access

- **Accomplishments:**
  - Corrected land cover in WRF input fields
  - Prepared boundary conditions for 20-year historical period and three future decades
  - Introduced a model of the Great Salt Lake
  - Modified evaporation formulas over saline water
  - Introducing an irrigation scheme for urban areas

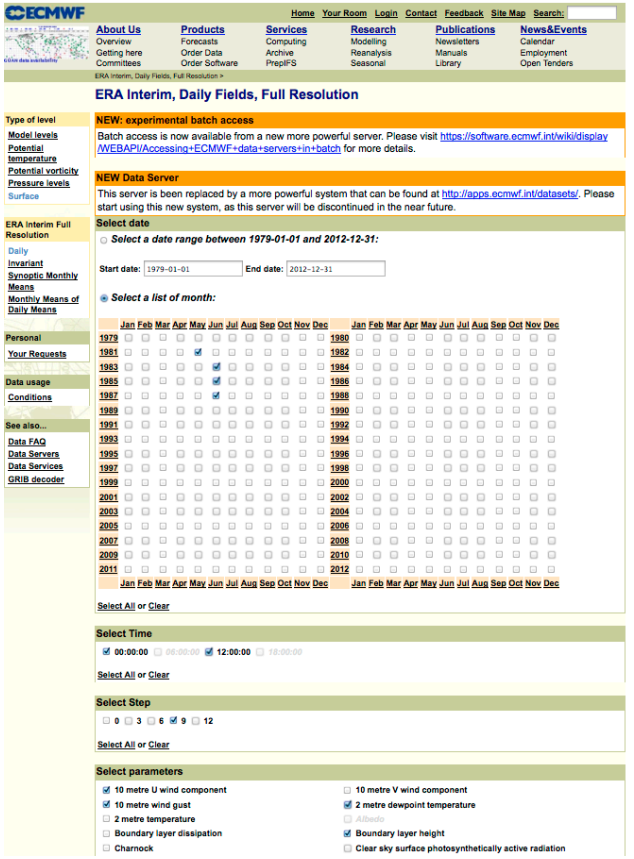


# Climate Modeling and Data Access

- **Next steps:** interactive access to simulations




Visualization for outreach and community users

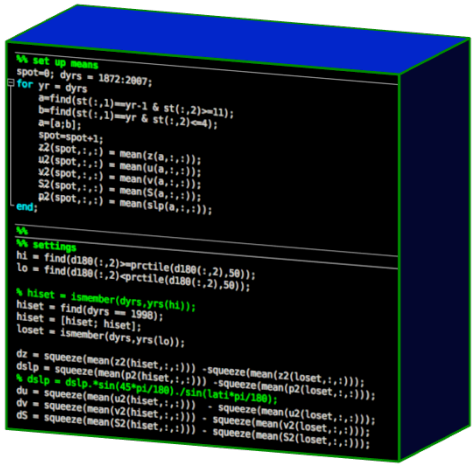


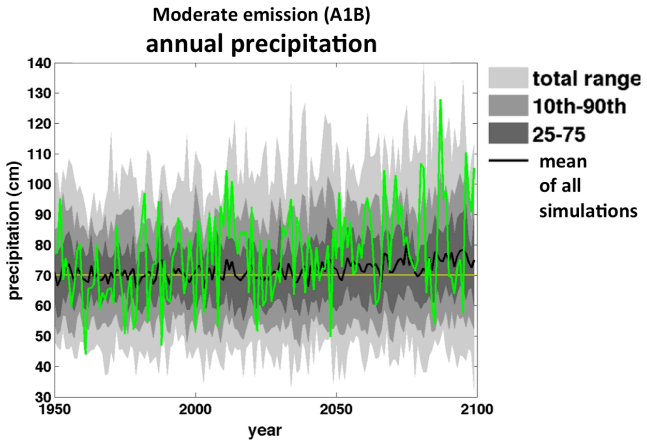

Customized data download for researchers

# Climate Modeling and Data Access

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

Spatial domain
Temporal domain
Variables
Scenario






MATLAB, Python, Excel, …

Use cases include historical and future modeling of hydrology, land use impacts, air quality, and ecology.

# Climate-urban water system modeling

- Slides by Burian following general pattern
  - Problem
  - Objectives
  - Accomplishments
  - Recent progress
  - Next steps

Steve Burian – University of Utah

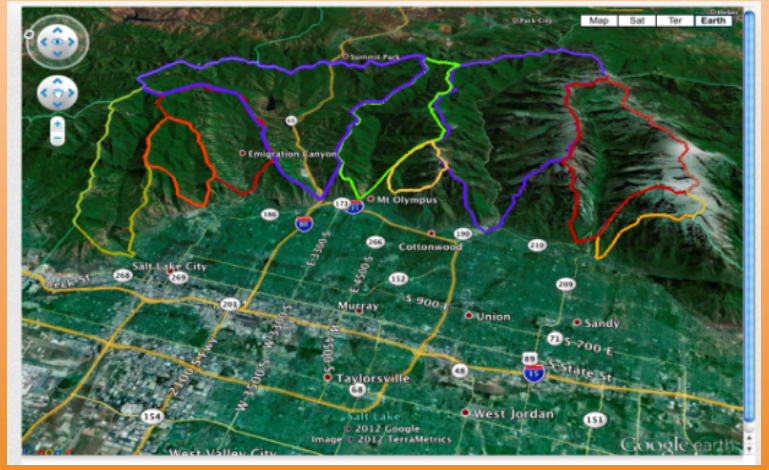
# URBAN WATER SYSTEM MODELS

# Climate-Urban Water System Modeling

- **Opportunity:** advance understanding of urban water system vulnerabilities to climate variability and extremes
- **Objective:** create access, connectivity, and analysis tools to bring climate modeling and high-performance computing resources to study climate impacts on urban water systems

# Climate Modeling and Data Access

**Hydrologic Model**

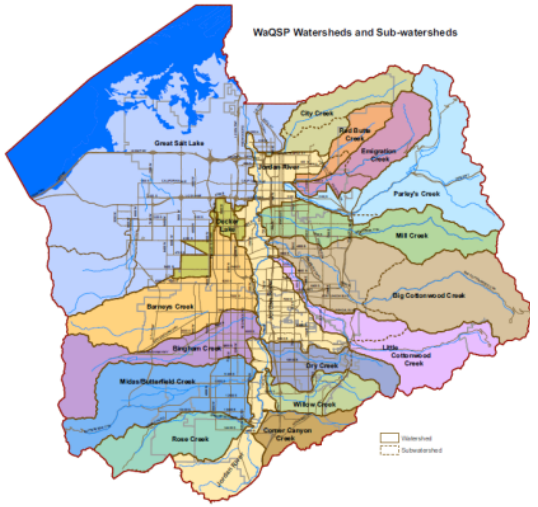



http://www.hiddenwaters.org/

climate impacted flows

**Water System Model**

**Urban Stormwater Model**




**Water Quality Model**

**Demand Scenarios**

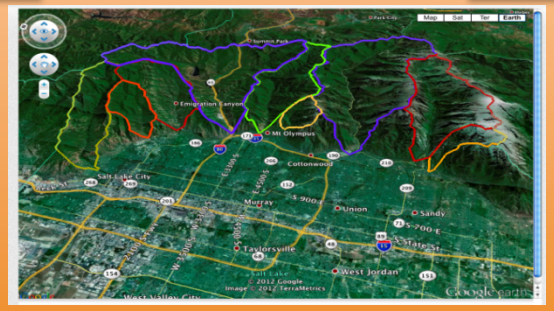
# Climate Modeling and Data Access

Hydrologic Model (CBRFC, RHESSys)

Hydrologic Model (BYU, USU, WYO)

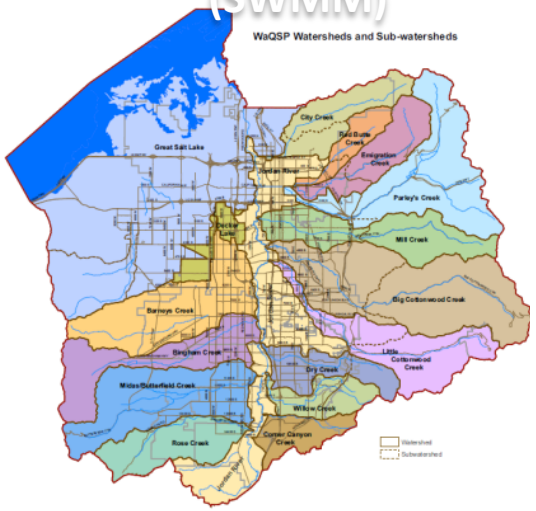
Stormwater Model (SWMM)

climate impacted flows




http://www.hiddenwaters.org/

climate impacted flows




Urban Water Supply System Model (Goldsim)

Water System Model

Water Quality Model

Demand Scenarios

# Climate Modeling and Data Access

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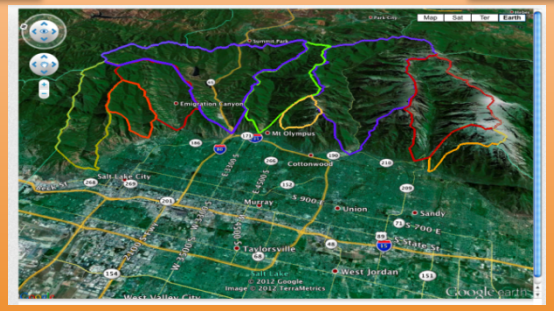
Hydrologic Model (BYU, USU, WYO)

Stormwater Model (SWMM)

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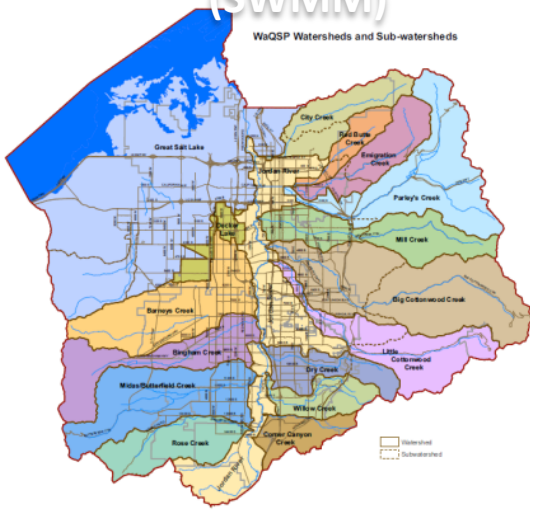


climate impacted flows

climate impacted flows

Urban Water Supply System Model (Goldsim)

Water System Model

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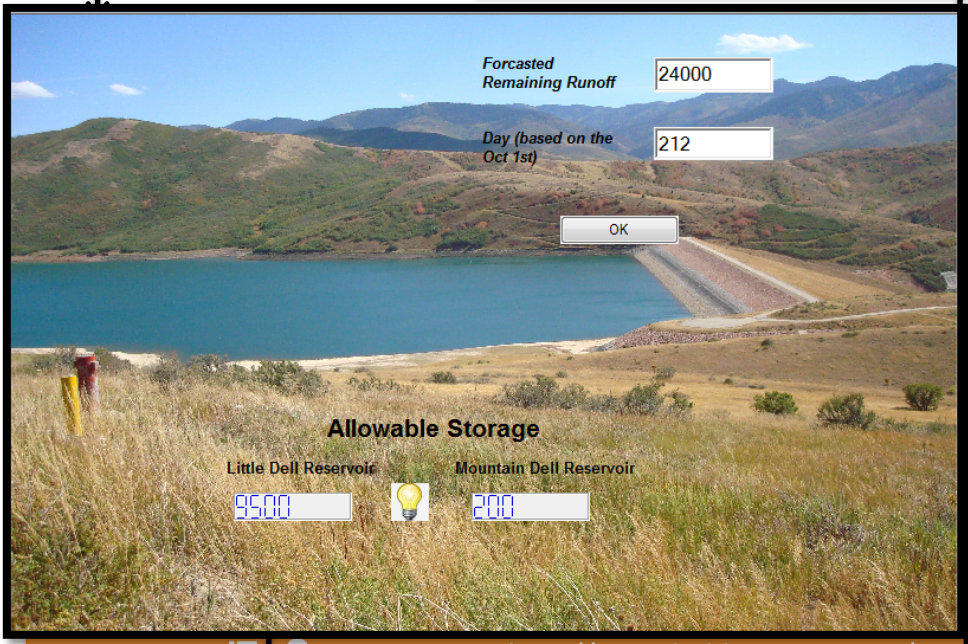
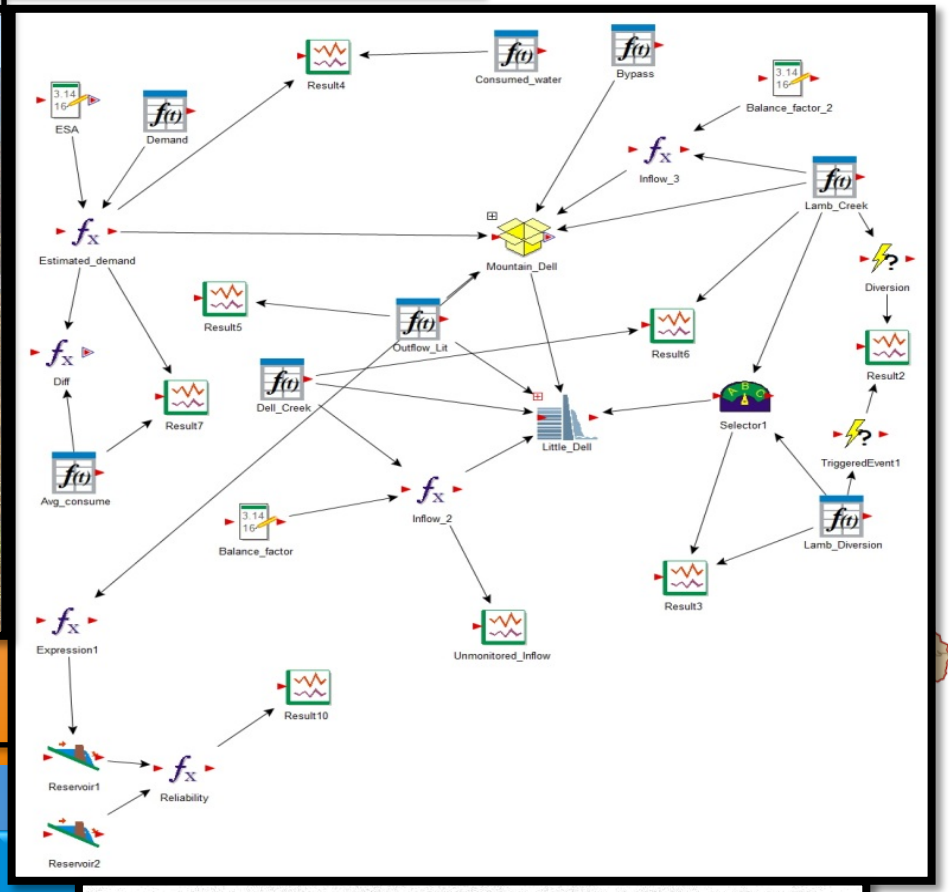
Demand Scenarios

# Climate Modeling and Data Access

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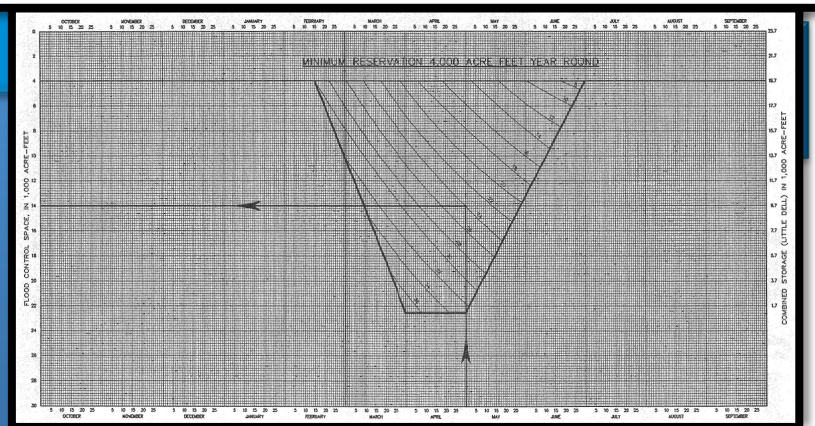
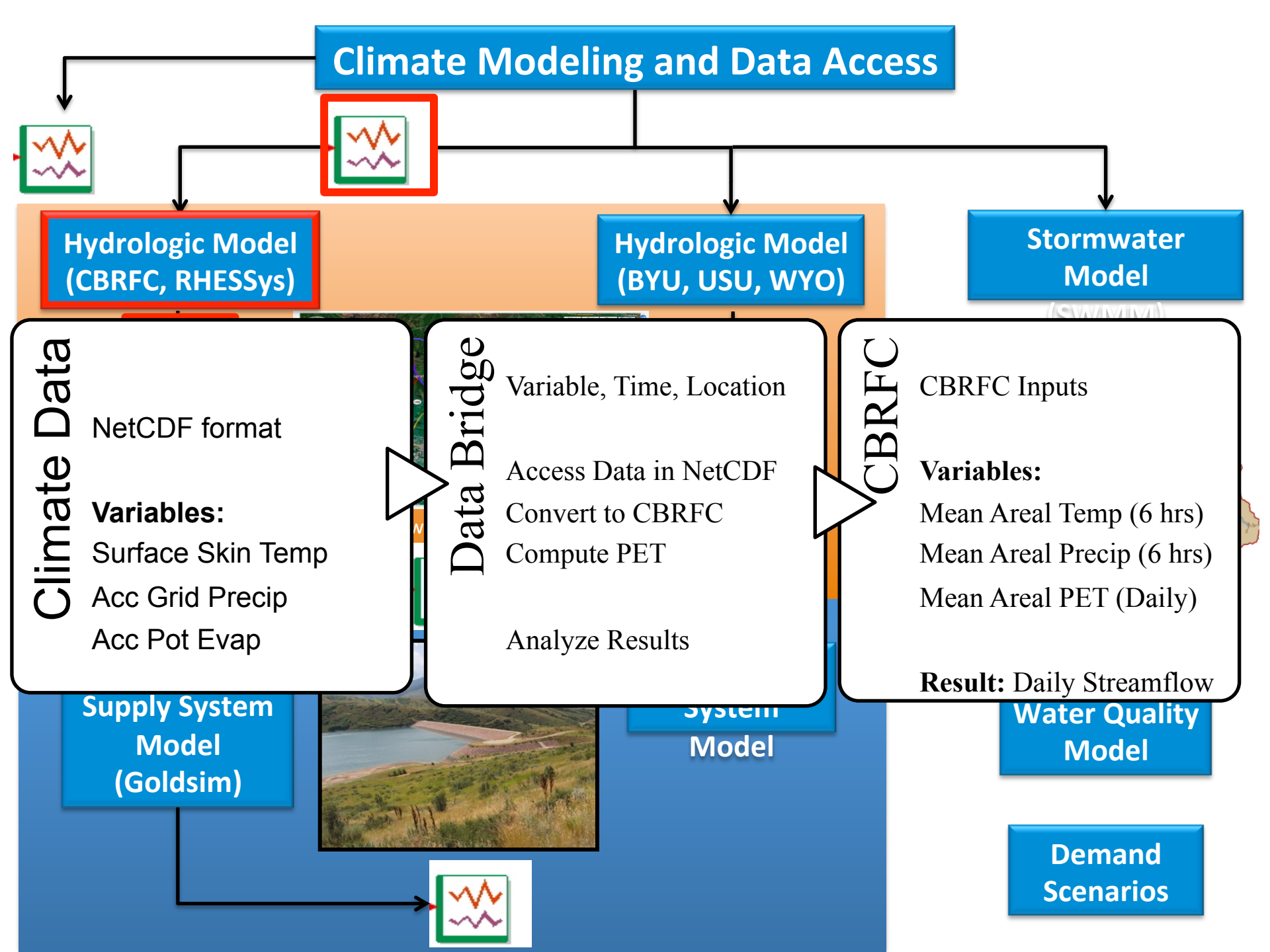
**Urban Water Supply System Model (Goldsim)**



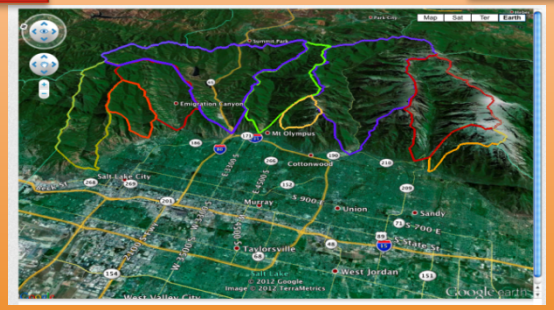

Climate Modeling and Data Access
Hydrologic Model (CBRFC, RHESSys)
Hydrologic Model (BYU, USU, WYO)
Stormwater Model
(SWMM)
Climate Data
NetCDF format
Variables:
Surface Skin Temp
Acc Grid Precip
Acc Pot Evap
Data Bridge
Variable, Time, Location
Access Data in NetCDF
Convert to CBRFC
Compute PET
Analyze Results
CBRFC
CBRFC Inputs
Variables:
Mean Areal Temp (6 hrs)
Mean Areal Precip (6 hrs)
Mean Areal PET (Daily)
Result: Daily Streamflow
Supply System Model (Goldsim)
Water Quality Model
Demand Scenarios

# Climate Modeling and Data Access

**Hydrologic Model (CBRFC, RHESSys)**

**Hydrologic Model (BYU, USU, WYO)**

**Stormwater Model (SWMM)**



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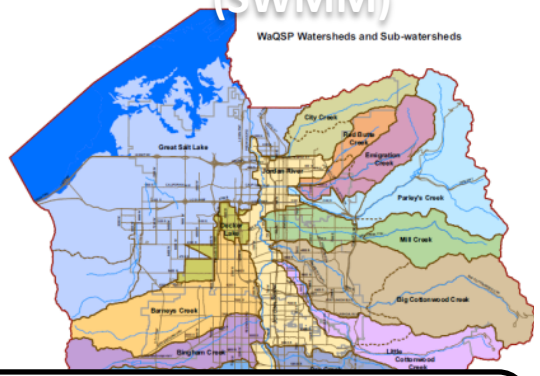


climate impacted flows

climate impacted flows

## CBRFC

CBRFC Inputs

**Variables:**

Mean Areal Temp

Mean Areal Precip

Mean Areal PET

## Data Bridge

Daily Streamflow

Location

Daily Time Step

Analyze Results

## Goldsim

Pre-processed CBRFC Output

**Result:** Daily Streamflow

- **Intensity:** Mean, Maximum, Moving Average, …
- **Events and Duration:** Avg Duration, Interevent, mean Event Depth, …
- **Frequency Analysis:** Probability distribution, return period, Exceedence probability, …
- **Spatial Analysis**

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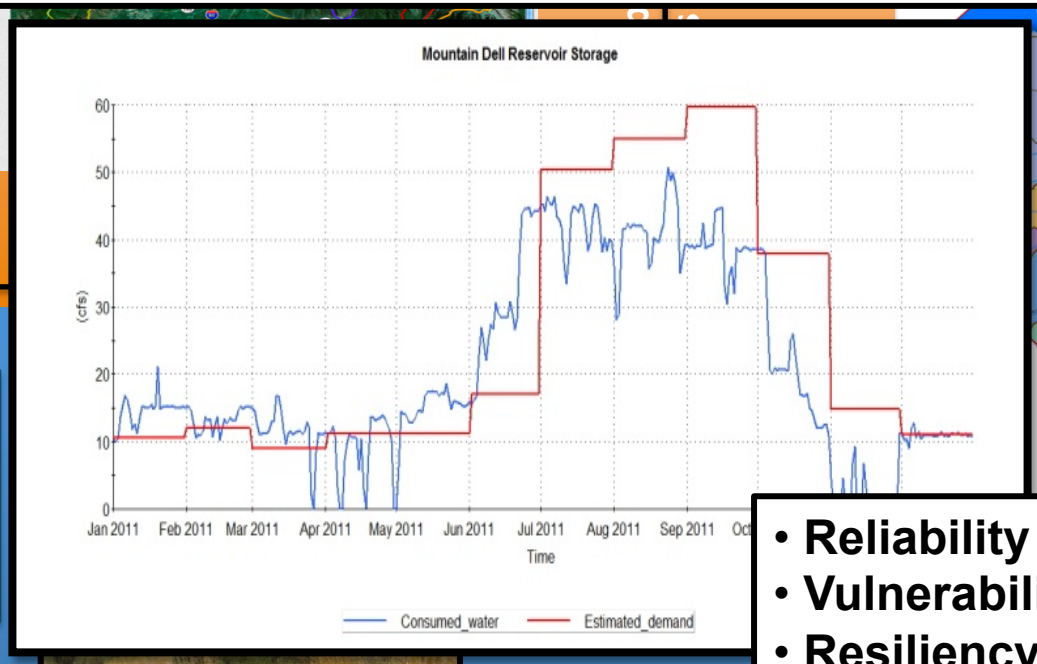
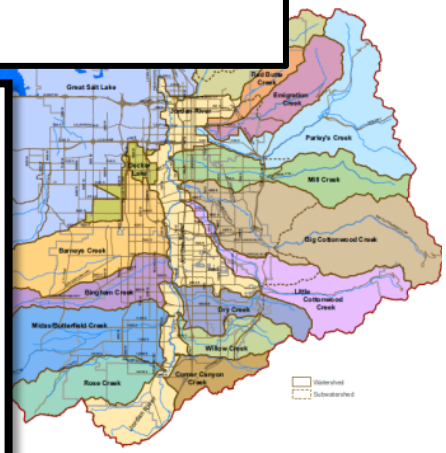
(CBR

er

climate impacted flows




Urban Water Supply System Model (Goldsim)

Water Quality

- **Reliability**
- **Vulnerability**
- **Resiliency**
- **System Readiness Index**
- **Sustainability Index**

# Climate Modeling and Data Access

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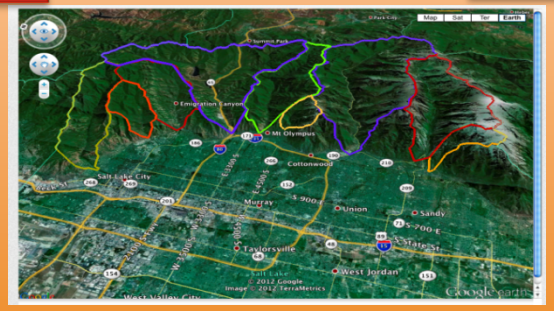

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Urban Water Supply System Model (Goldsim)

Water System Model

Water Quality Model

Demand Scenarios