UMassAmherst

Water Management and Climate Change in the Connecticut River Basin

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WSCAC – 11/29/2011

UMass Research Team

- Dr. Richard Palmer (Department Head and Professor)
- Dr. Casey Brown (Assistant Professor)
- Dr. David Ahlfeld (Professor)
- Jessica Pica (MS Research Assistant)
- Scott Steinschneider (PhD Research Assistant)
- Brian Pitta (Former MS Student – now CDM)
- Many Others

Current Projects

- Climate Change and the Connecticut River Basin
- Evaluation of Climate Impacts on Boston Water Supply
- Water Management and the Connecticut River

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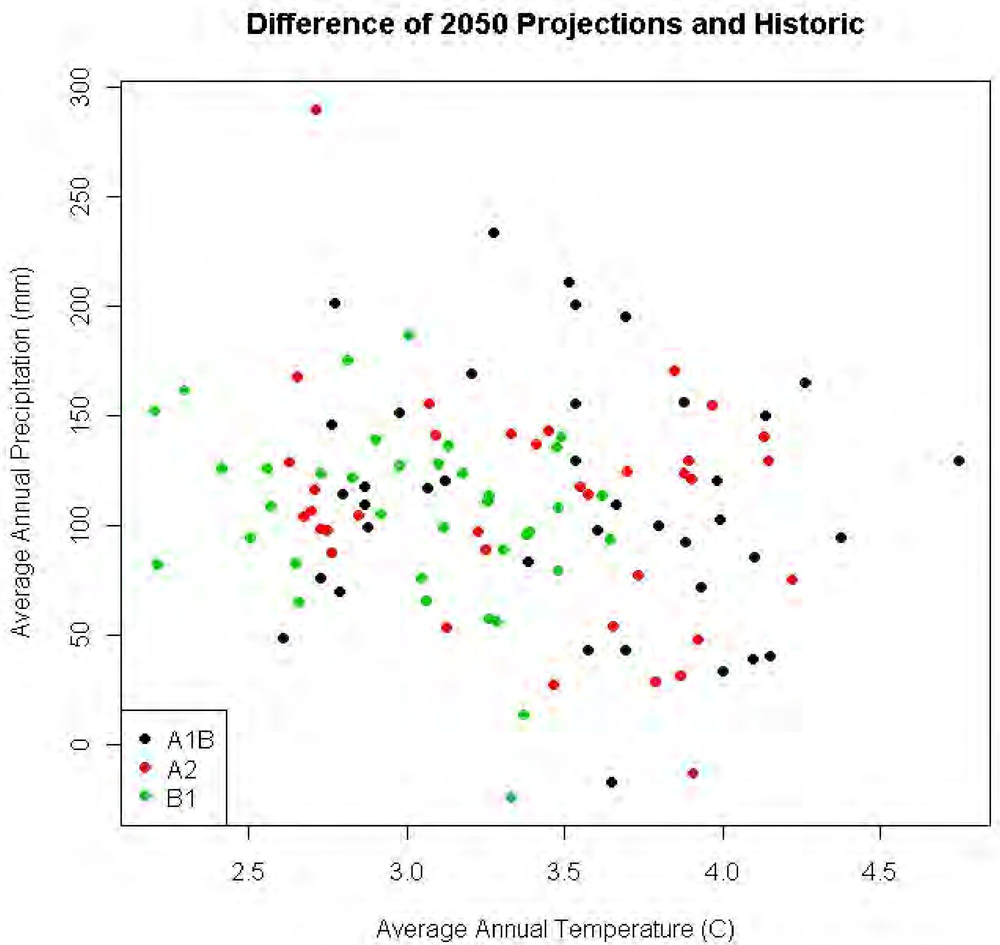
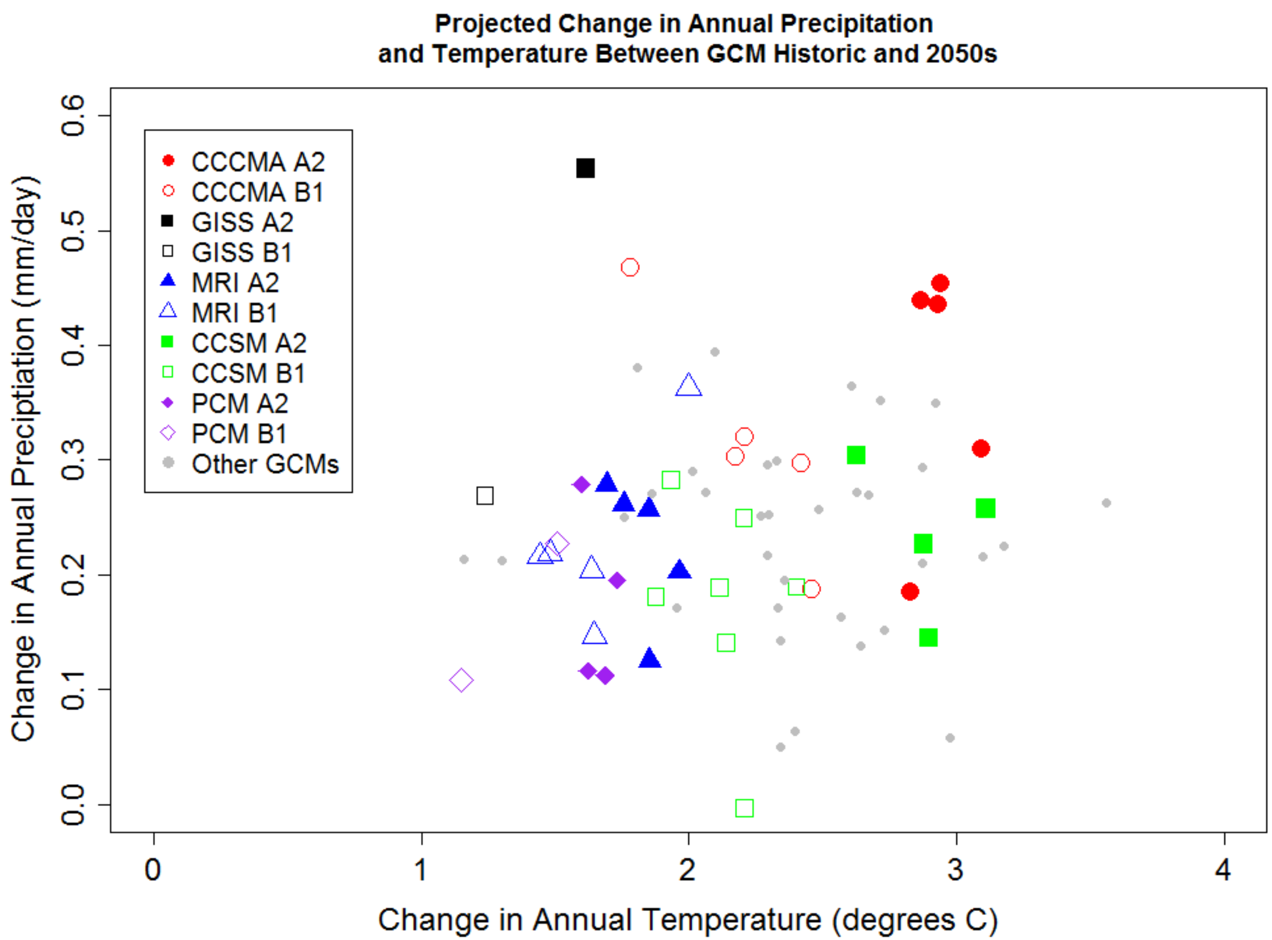
Future Climate by Emission Scenario (All)

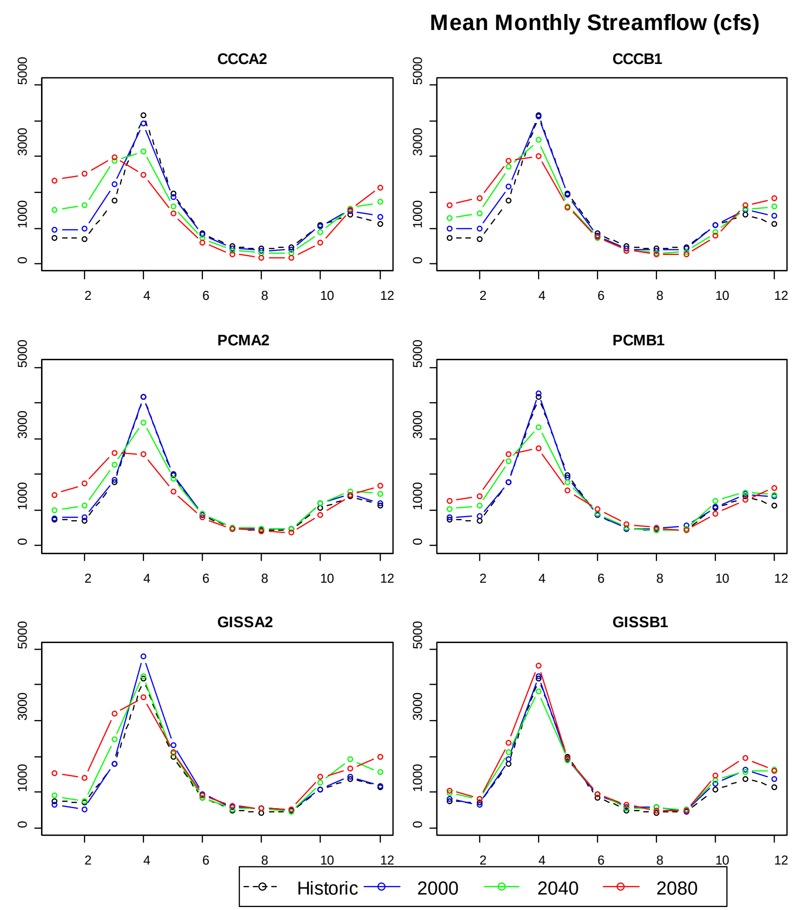


Projections of 2050 Climate



Climate Impacts on Hydrology

- Shift in hydrograph from spring peak to muted winter peak
- Less precipitation falling as snow, more as rain (warmer)
- Potentially lower summer streamflow



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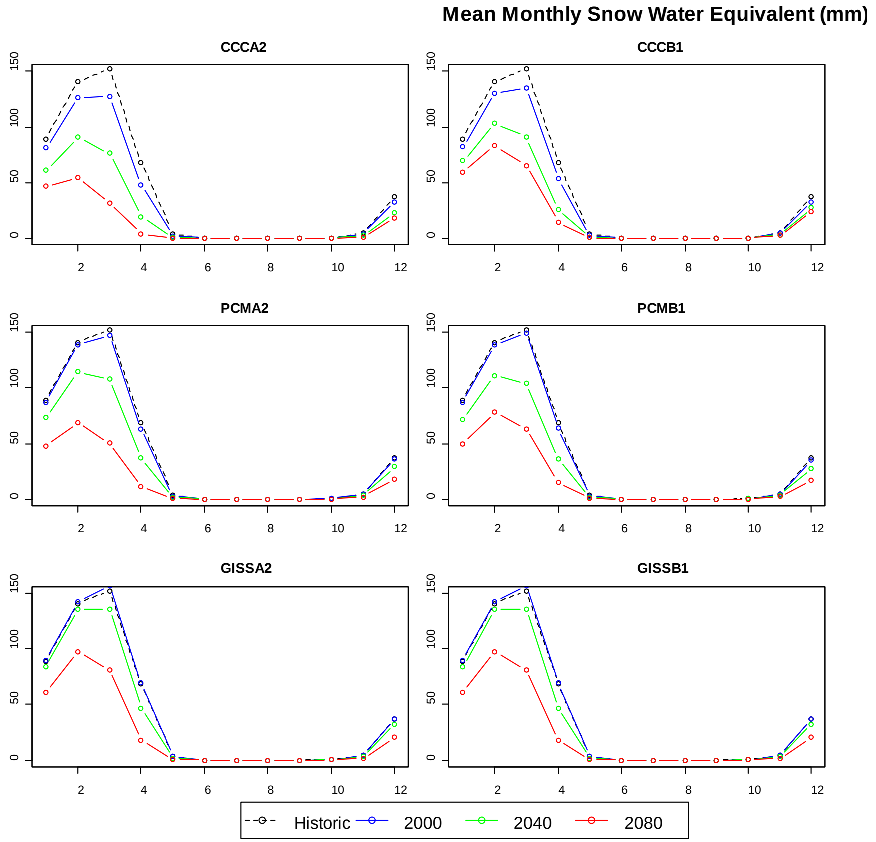

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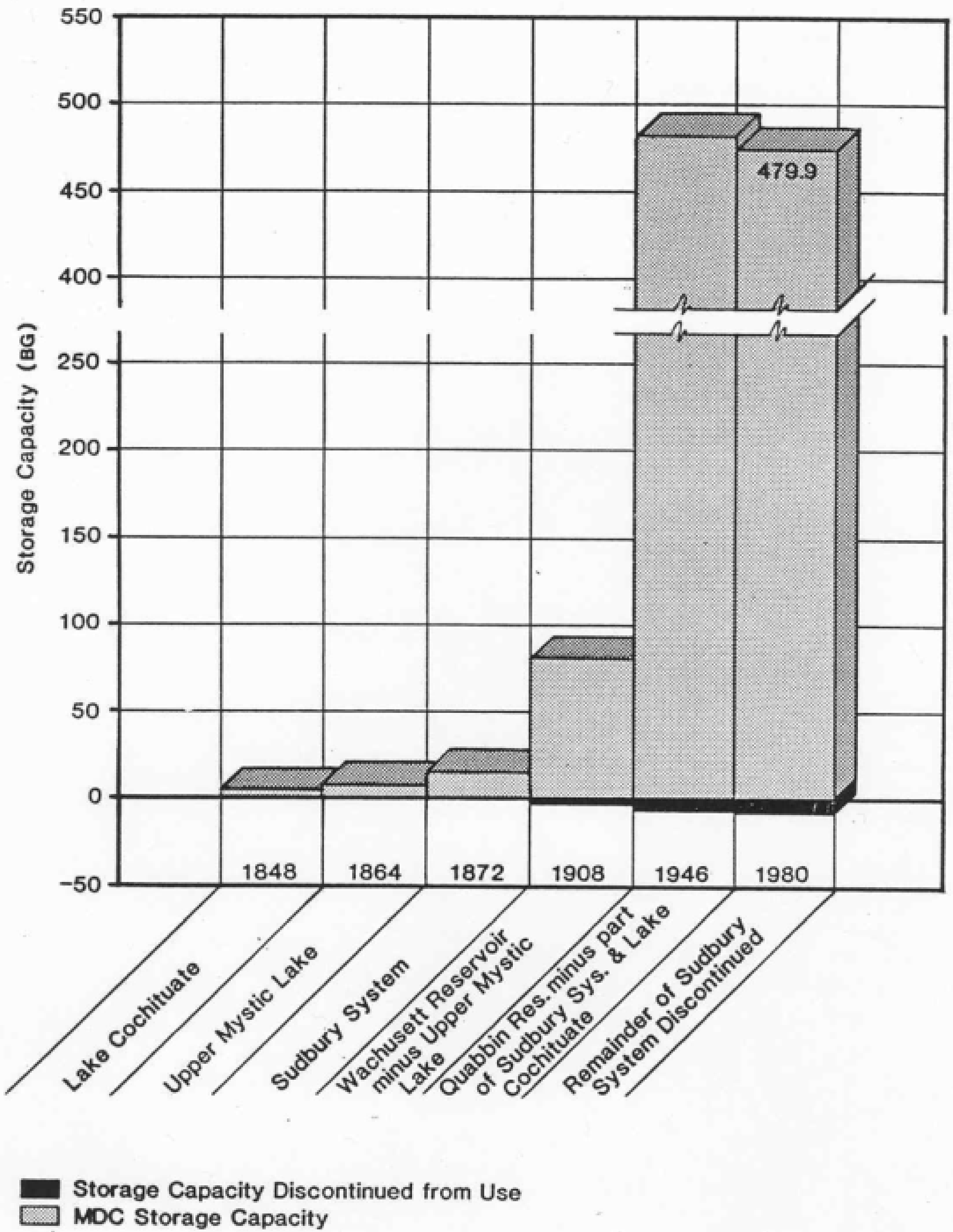
Massachusetts Water Resources Authority

- MWRA’s Director of Planning
  - Stephen Estes-Smargiassi
- Senior Program Manager
  - Daniel Nvule
- Study Requests
  - Investigate multiple emission scenarios
  - How well does their ABCD hydrology model compare with historic data? Are other models better?
  - Can they assist other utilities in meeting their future demands?

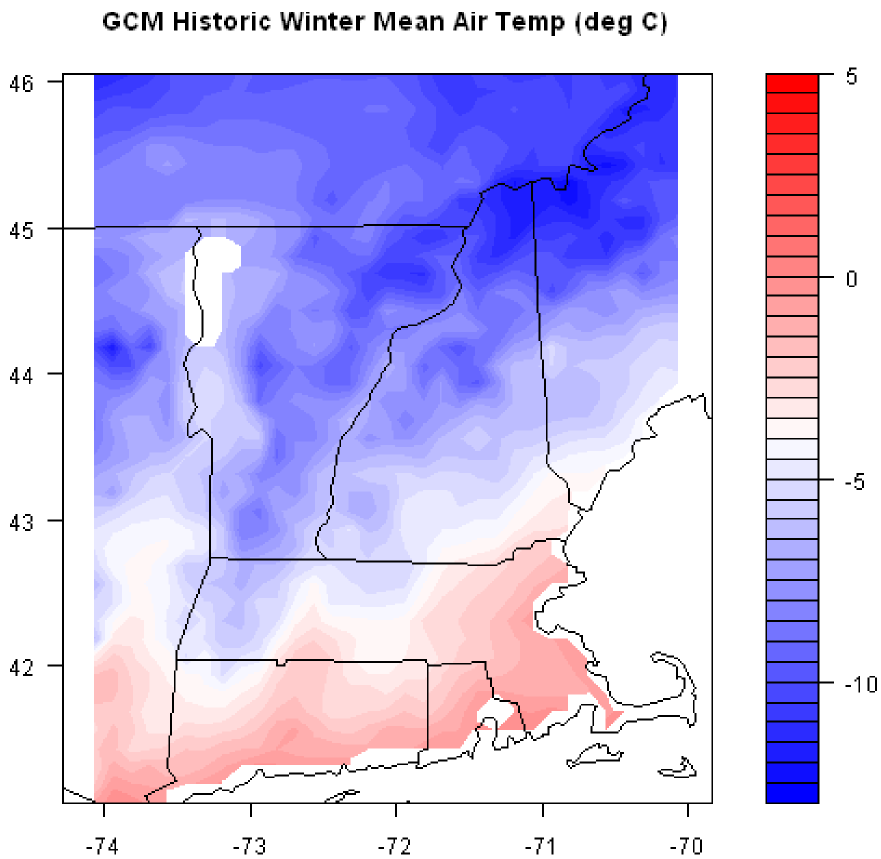
Cistern, circa 1600’s


550
500
450
400
250
200
150
100
50
0
-50
Storage Capacity (BG)
479.9
1848
1864
1872
1908
1946
1980
Lake Cochituate
Upper Mystic Lake
Sudbury System
Wachusett Reservoir minus Upper Mystic Lake
Quabbin Res. minus part of Sudbury Sys. & Lake Cochituate
Remainder of Sudbury System Discontinued
Storage Capacity Discontinued from Use
MDC Storage Capacity

The Study

- Investigate the impacts of climate change and climate variability on MWRA water supply.
- This study emphasizes the use of a variety of emission scenarios and climate models to determine the uncertainty of future climate on water management.
- A previous study (1999) indicated slight **decreases** in yield, but selection of climate models and emission scenarios limited. More recent studies have shown **increases** in reliability.
- **Reliability** is determined by percent of time below **pool elevation 490'** in the model

Climate Change Assessment: Methodology



Global Circulation Models

Projections of **Meteorology** Under Climate Change

Hydrology Models of Basin

Projections of **Streamflow** Under Climate Change

Simulation and Optimization Models

Impacts of Climate Change on all Watershed Objectives

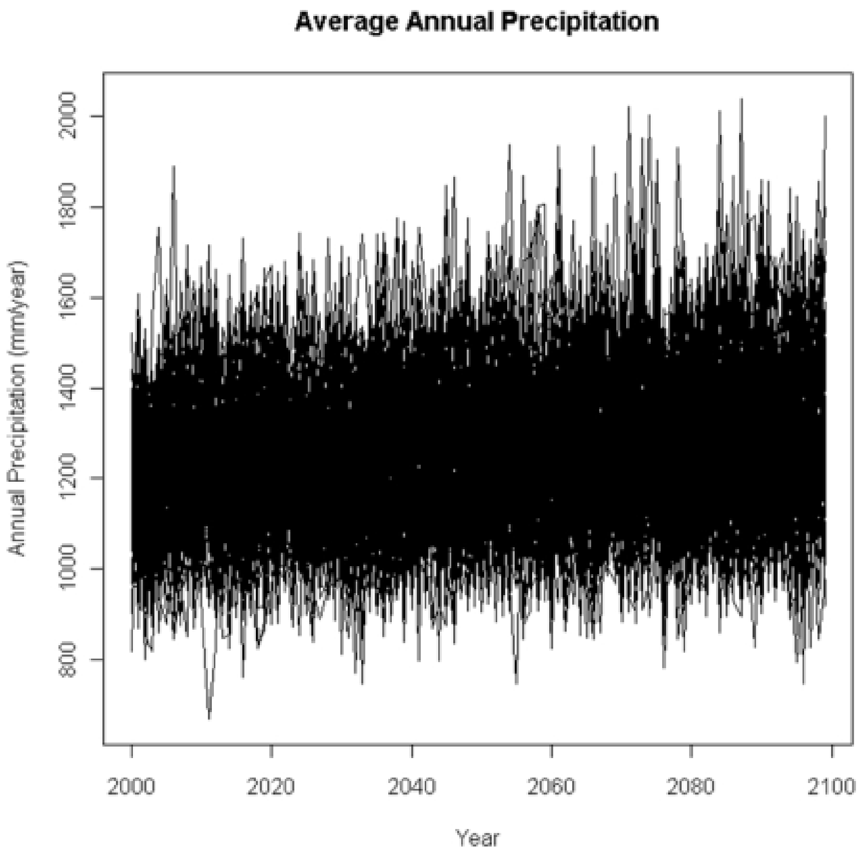
The Climate Data

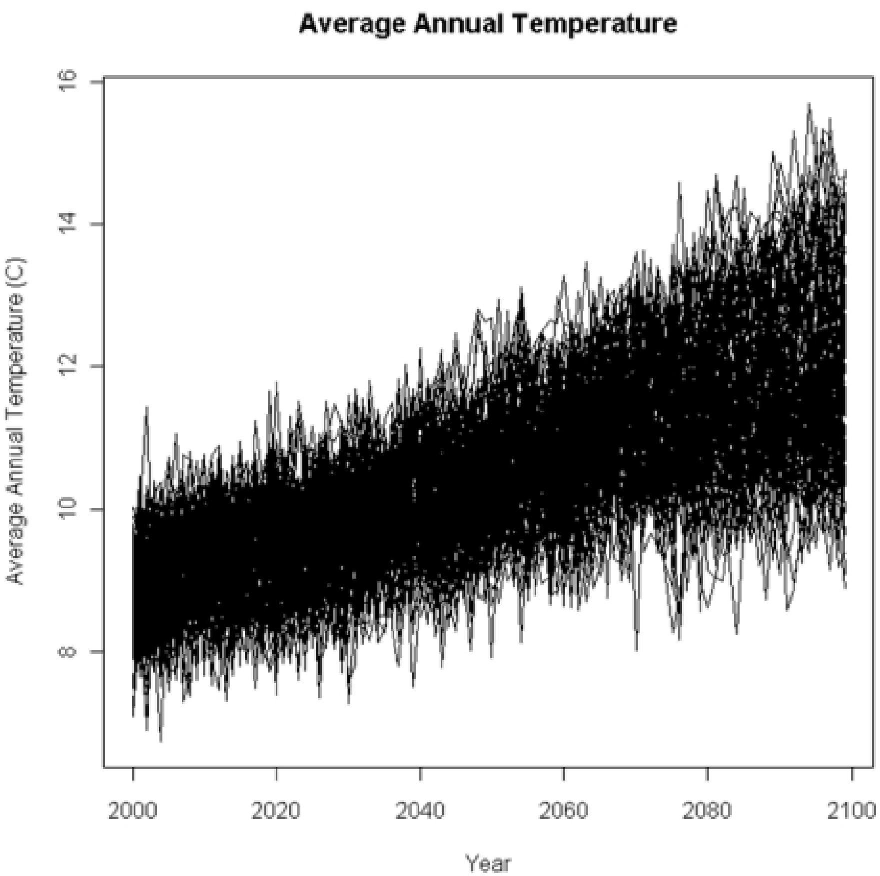
- 112 downscaled projection-specific datasets
  - 16 CMIP3 models
  - 3 scenarios for future greenhouse gas emissions (A2, A1B and B1)
  - One or more simulations featuring unique initial conditions
  - Time frame 2000-2099

The Climate Data

Modeling Group, Country	WCRP CMIP3 I.D.	SRES A2 runs	SRES A1B runs	SRES B1 runs
Bjerknes Centre for Climate Research	BCCR-BCM2.0	1	1	1
Canadian Centre for Climate Modeling & Analysis	CGCM3.1 (T47)	5	5	5
Meteo-France / Centre National de Recherches Meteorologiques, France	CNRM-CM3	1	1	1
CSIRO Atmospheric Research, Australia	CSIRO-Mk3.0	1	1	1
US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory, USA	GFDL-CM2.0	1	1	1
US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory, USA	GFDL-CM2.1	1	1	1
NASA / Goddard Institute for Space Studies, USA	GISS-ER	1	2, 4	1
Institute for Numerical Mathematics, Russia	INM-CM3.0	1	1	1
Institut Pierre Simon Laplace, France	IPSL-CM4	1	1	1
Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC), Japan	MIROC3.2 (medres)	3	3	3
Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA	ECHO-G	3	3	3
Max Planck Institute for Meteorology, Germany	ECHAM5/ MPI-OM	3	3	3
Meteorological Research Institute, Japan	MRI-CGCM2.3.2	5	5	5
National Center for Atmospheric Research, USA	CCSM3	4	1-3, 5-7	7
National Center for Atmospheric Research, USA	PCM	4	4	2, 3
Hadley Centre for Climate Prediction and Research / Met Office, UK	UKMO-HadCM3	1	1	1

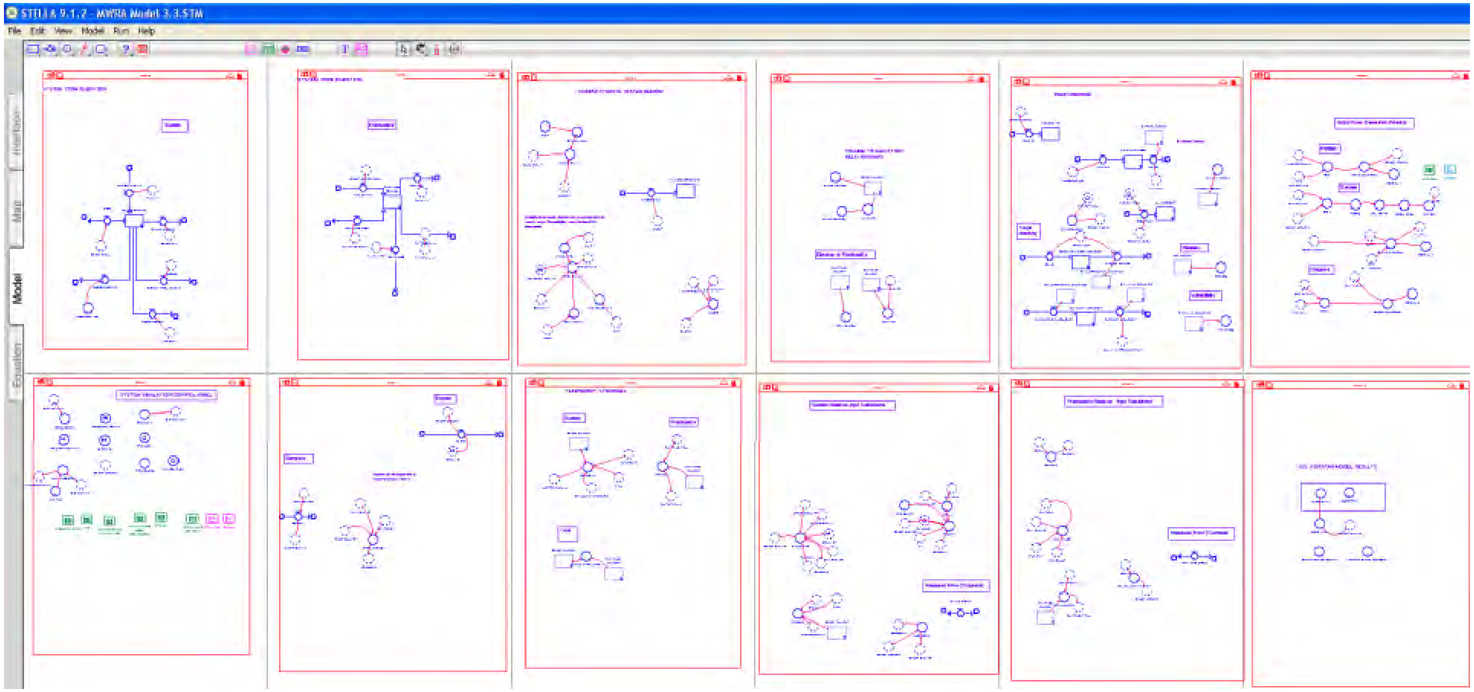
The Climate Data





The First Model

- An early water resource simulation model of the Boston water supply system was constructed with STELLA at a monthly time step

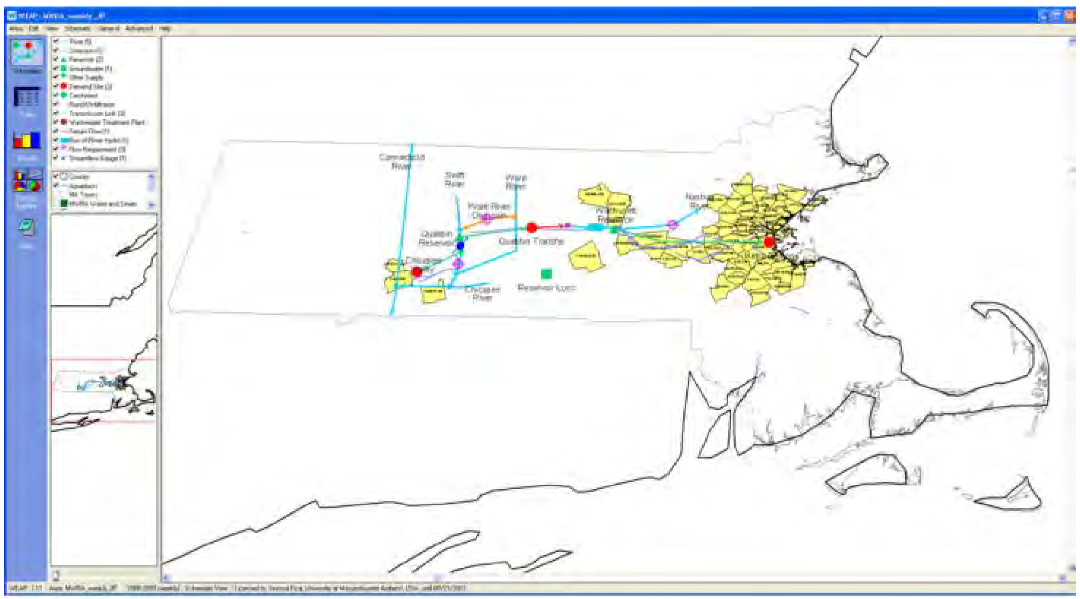


The Current Model

- The STELLA model was converted into another program, WEAP (“Water Evaluation And Planning” system) at a weekly time step
- WEAP is a user-friendly software tool that takes an integrated approach to water resource planning.
- Developed by the Stockholm Environment Institute’s U.S. Center.

The Current Model

- Aims to incorporate the integration of supply, demand, water quality, and ecological considerations.
- GIS-based interface

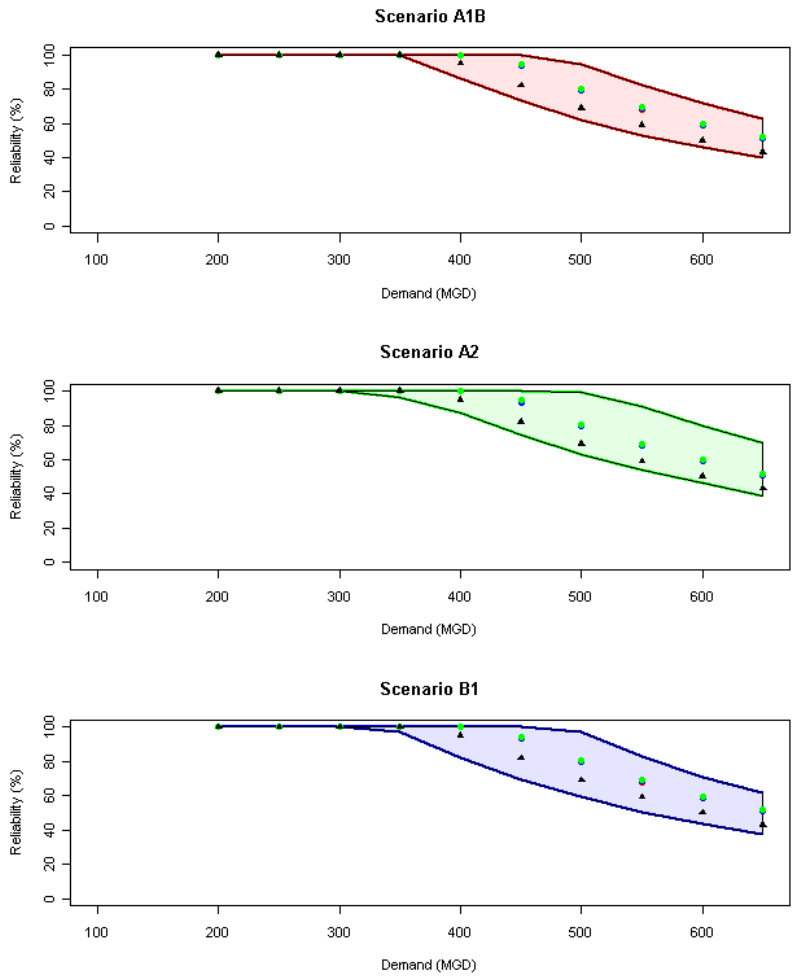


WEAP's ABCD Hydrology Model

- Inputs: weekly precipitation and minimum and maximum temperature values
- Fixed parameters include a, b, c, d, e, drainage area, latitude, melt temperature, maximum seepage rate, etc.
- Calculated variables include potential evaporation, snow accumulation, snow melt, effective precipitation, available water, etc.
- Outputs: weekly streamflow
- Usable in climate impact assessments!

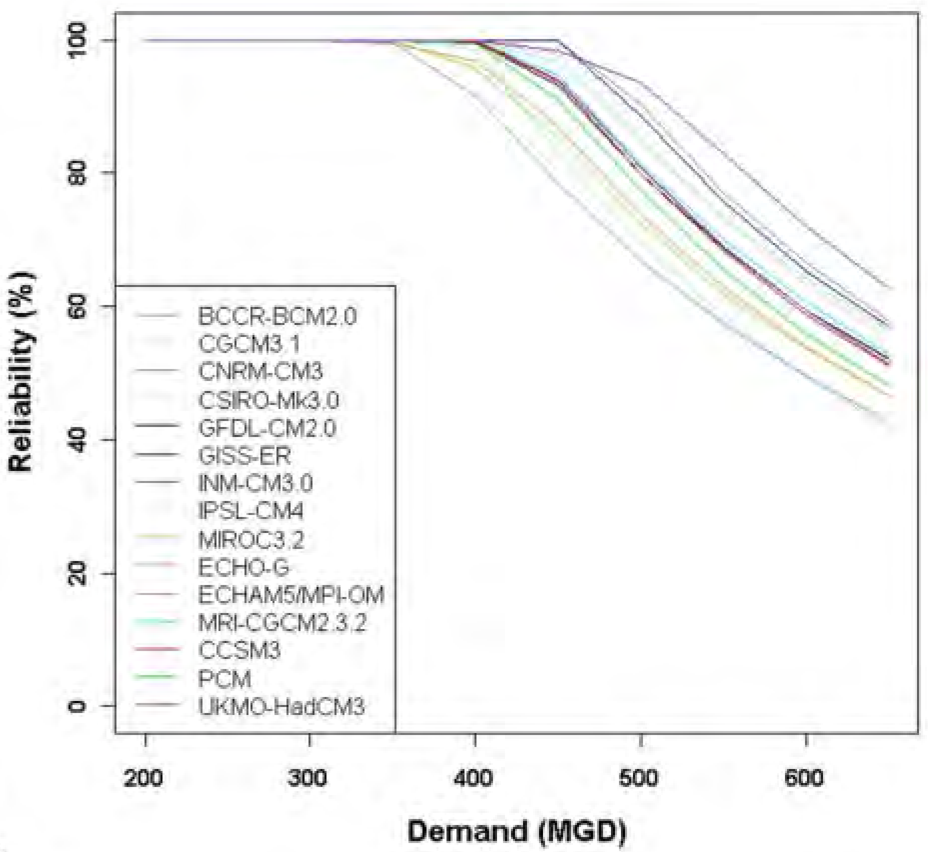
Reliability by Emission Scenario

- No significant differences in system reliability between emission scenarios
- Under most climate change scenarios, reliability goes up!



Reliability by Model

- More variability by climate model than scenario
- Additional research may focus on identifying models that perform best for NE climate
- NE CSC work!



The Next Steps

- Investigate more specific future time period
- Investigate any patterns in model results due to particular model or emission scenario
- Investigate different hydrology models
- Compare results with STELLA model results

Current Projects

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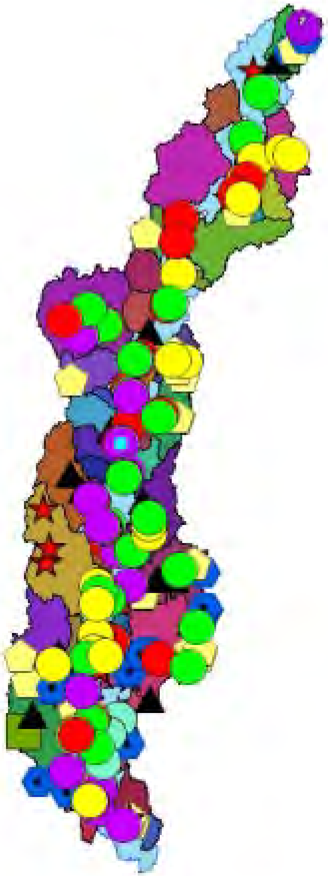
Study Goal

Create a **basin-wide decision support tool** that allows **water managers** and other **key stakeholders to evaluate environmental and economic outcomes** based on various management scenarios.

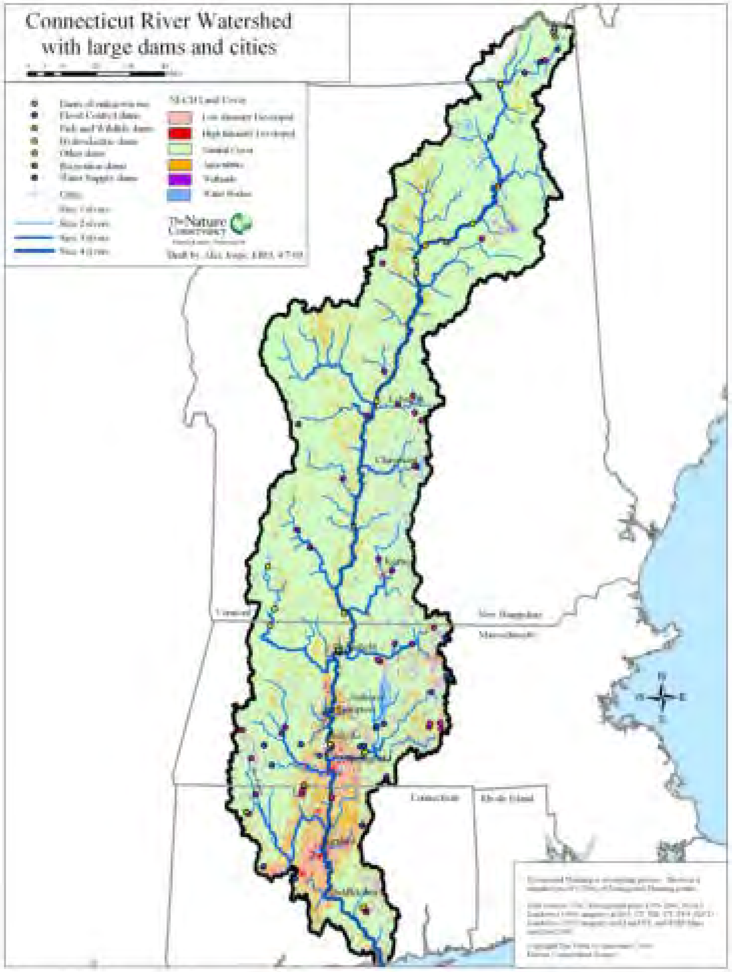


This goal is being achieved with:

- careful evaluation of current operations,
- interactions with stakeholders, and
- the generation of new operational alternatives that improve overall system performance.

Connecticut River

- Connecticut River
  - Connecticut Lake, NH to the Long Island Sound
  - 11,000 mi^2
  - >410 miles long
  - 44 major tributaries
  - regulated by >70 large dams, 14 USACE
  - 3.2 million people
- Once inaccurately called the “most highly regulated sewer in America”

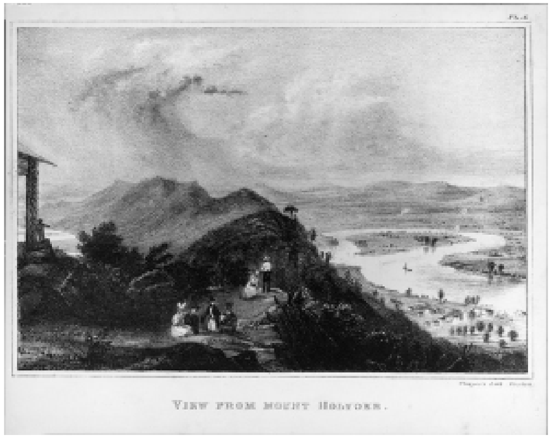


Study History

- TNC has 50 years of involvement CT River
- TNC has purchased over 250,000 acres
- 2004 TNC convened stakeholders and identified major issues:
  - Biodiversity
  - Threats
  - Strategies
- TNC and USACE developed the Connecticut River Ecosystem Flow Strategy Action Plan, 2007
- TNC and the USACE hired the Consensus Building Institute (CBI) to conduct a stakeholder engagement process in 2008

Developing Decision Support Tools

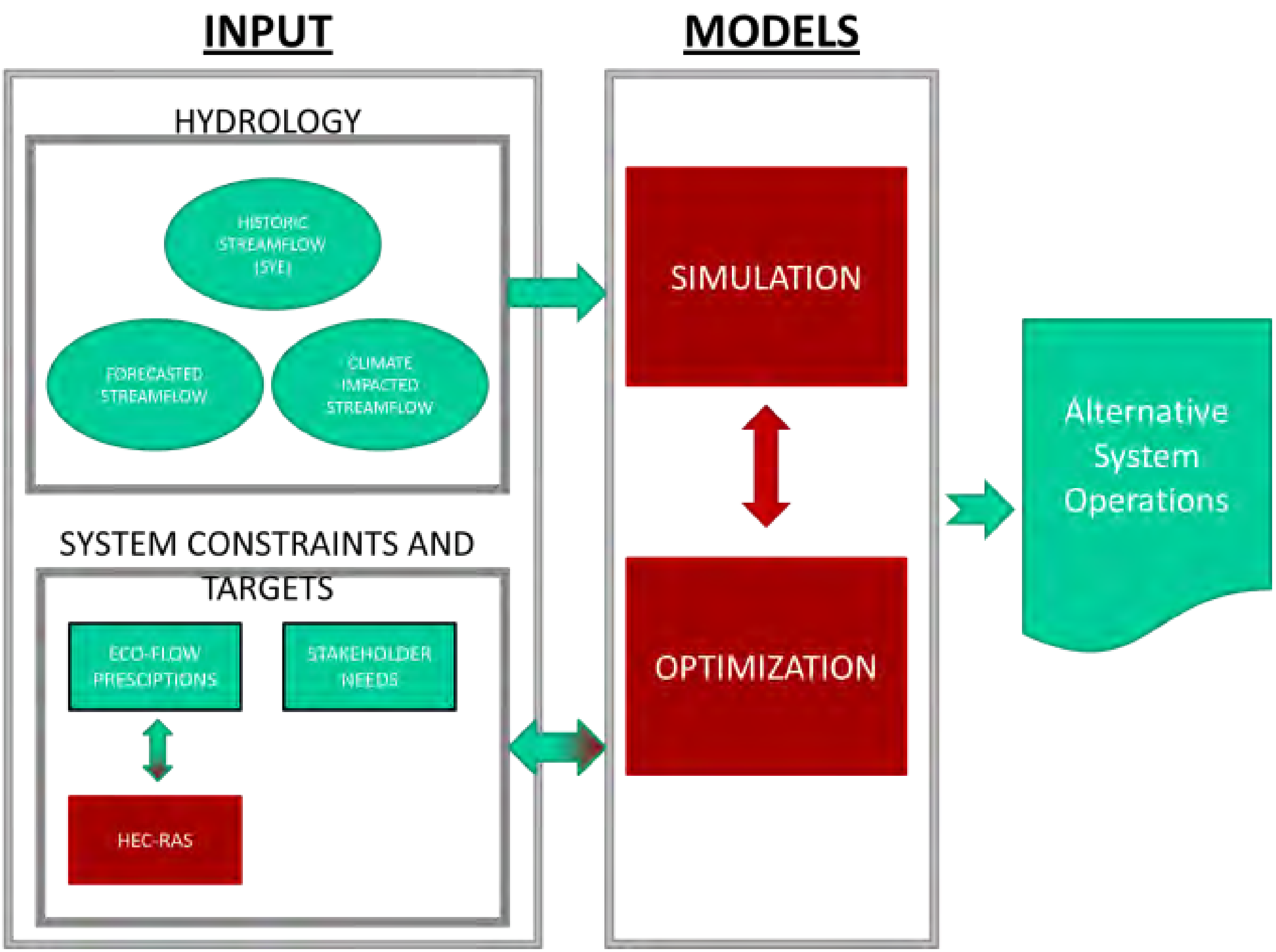
- Three different models have been created describing system management
  - RES-SIM – developed by HEC
  - Optimization model – by UMass
  - STELLA simulation model – by UMass



Developing Decision Support Tools

- Why three models?
  - RES-SIM has more hydraulic detail and appropriate for detailed time of flow studies
  - Optimization is our primary product
  - Simulation model fed insight into optimization model
    - We felt UMass building a simulation model, testing its validity and sharing it with stakeholders was the best way to gain support and understanding of existing operations

Model Schematic



Developing Decision Support Tools

- Optimization Model
  - Less of a shared vision, but built on trust
  - Daily time step– as is simulation
  - Can simulate 5 year operation with weighted objectives including
    - Fish targets
    - Hydropower
    - Water supply
    - Flood Control

Targets vs. Constraints

- **Targets**
  - Can be violated
  - Penalize the objective function as deviation from the target increases.

Example

Deviation from Release Target
= Actual Release
– Target Minimum Release

- The objective function minimizes the deviation below the target

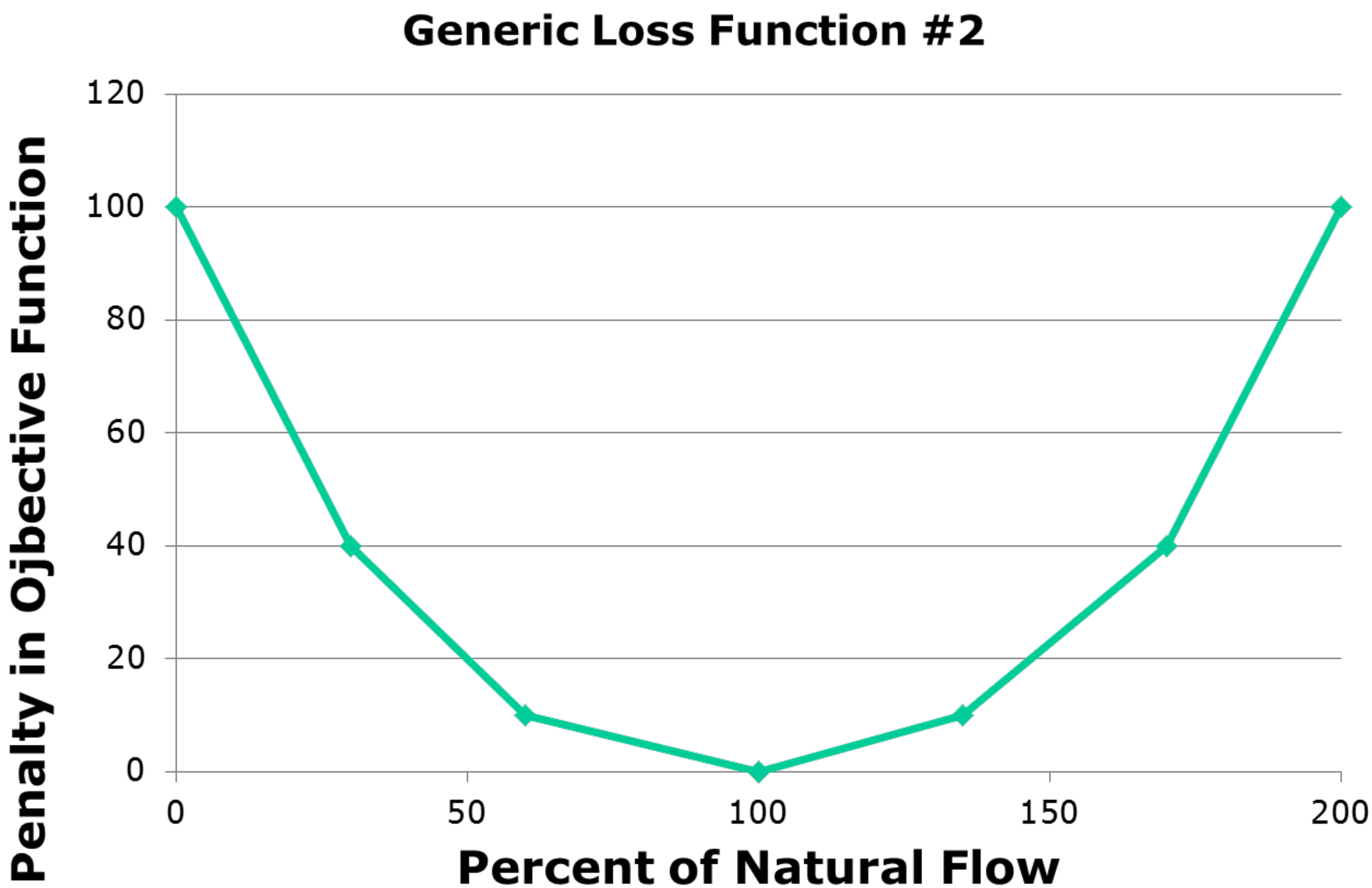
- **Constraints**
  - Cannot be violated
  - If the model cannot be satisfy the constraints the problem is infeasible

Example

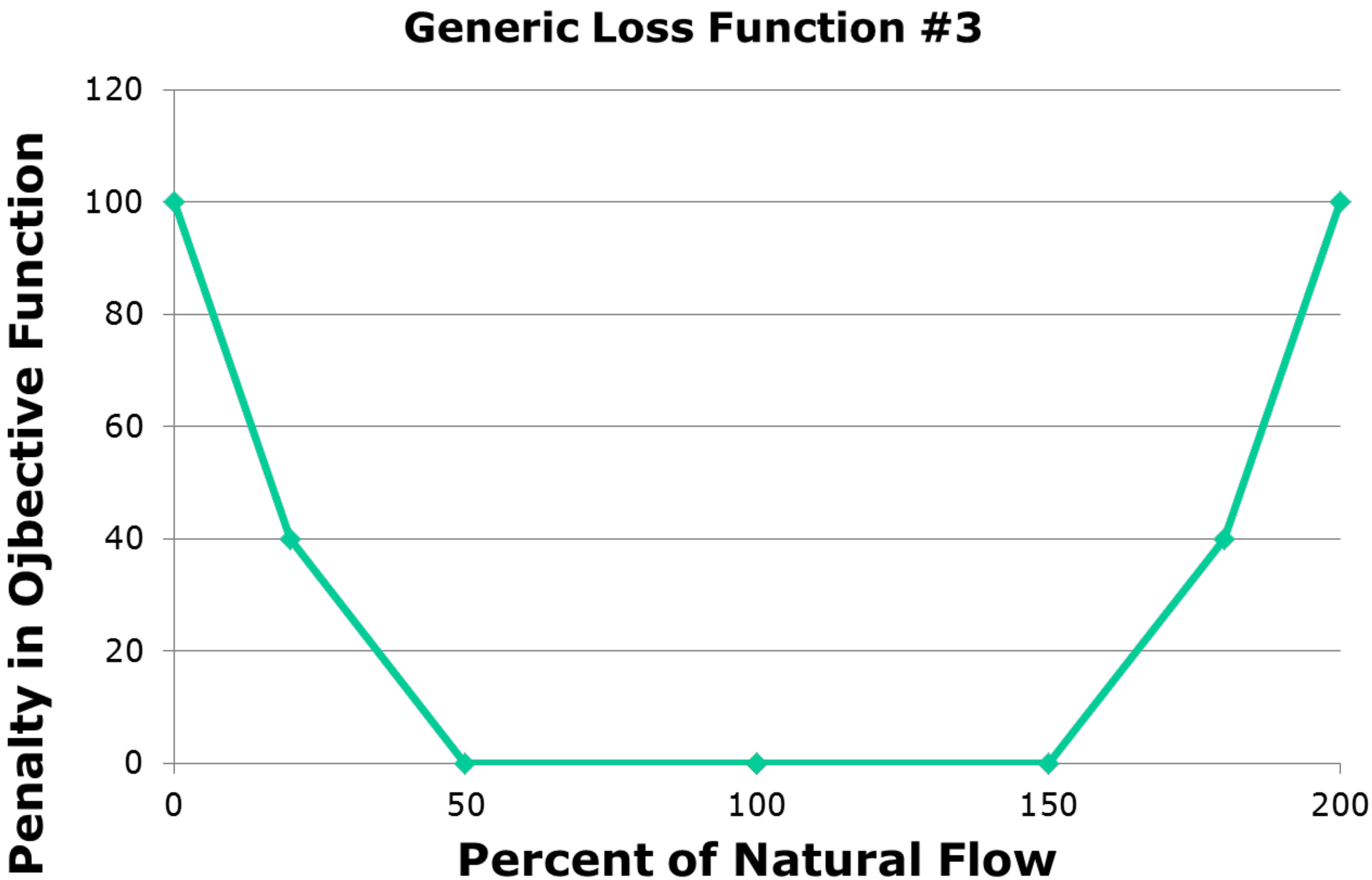
Reservoir Storage $\leq$ *50K acre-ft*

- The storage **must** be less than or equal to 50K acre-ft
- Optimization solver will report an infeasible result

Target with "No" Flexibility



Target with "Wide" Flexibility



Multiple Objectives and Trade-Offs

Minimize = Weight 1*Deviations from Target Storages +
Weight 2*Deviations below Min. Flow Targets at –
Weight 3*Income from power generation –
Weight 4*Deviations from water supply

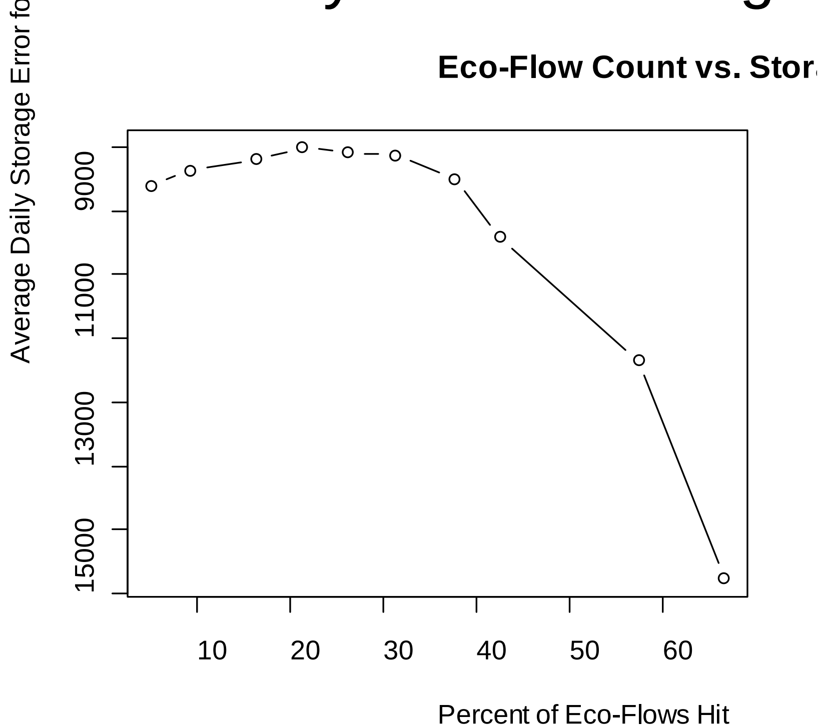
To prioritize an objective, increase it's respective weight.

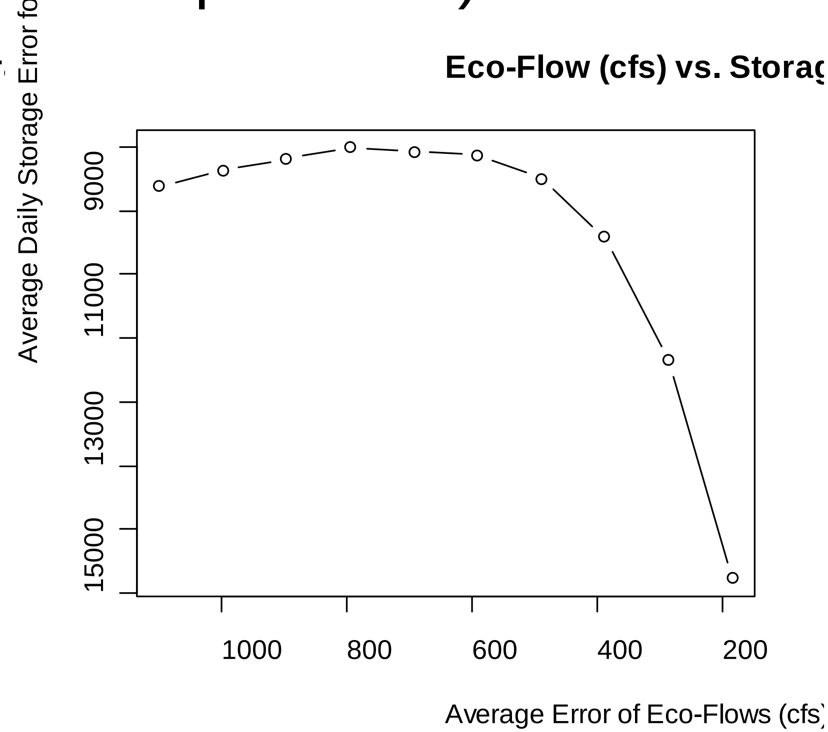
Develop Trade-Off Curves:

Run the model several times, each time changing the objective function weights.

Trade-Offs: What Do the Eco-Flows "Cost"

Cost can be evaluated in sacrificed income from hydropower or deviations from target storage (i.e. how much do they have to change their operations)





Modeling Process

Simulation Tool of the Basin → Optimization model With Current Operations as Targets → Introduce New Targets/Objectives in Optimization Model and Create Trade-Off Curves

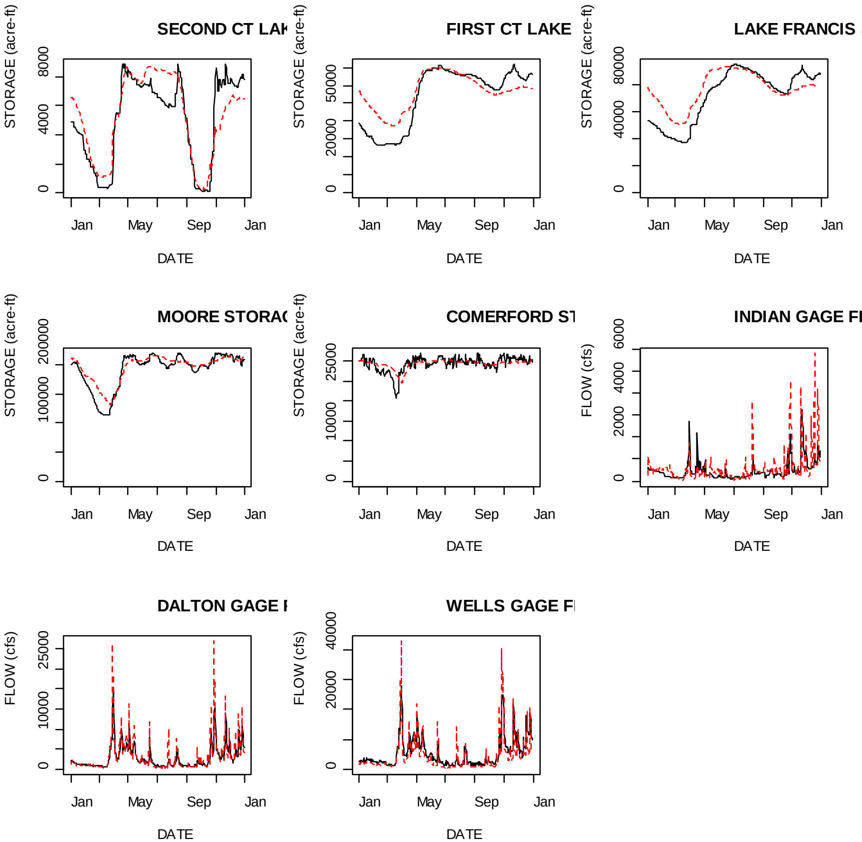
- Understanding of Current System
- Calibrated to historical release/storage data

- Current operating rules as targets (some as constraints)
- Since there are no new objectives, it should yield similar results as simulation model

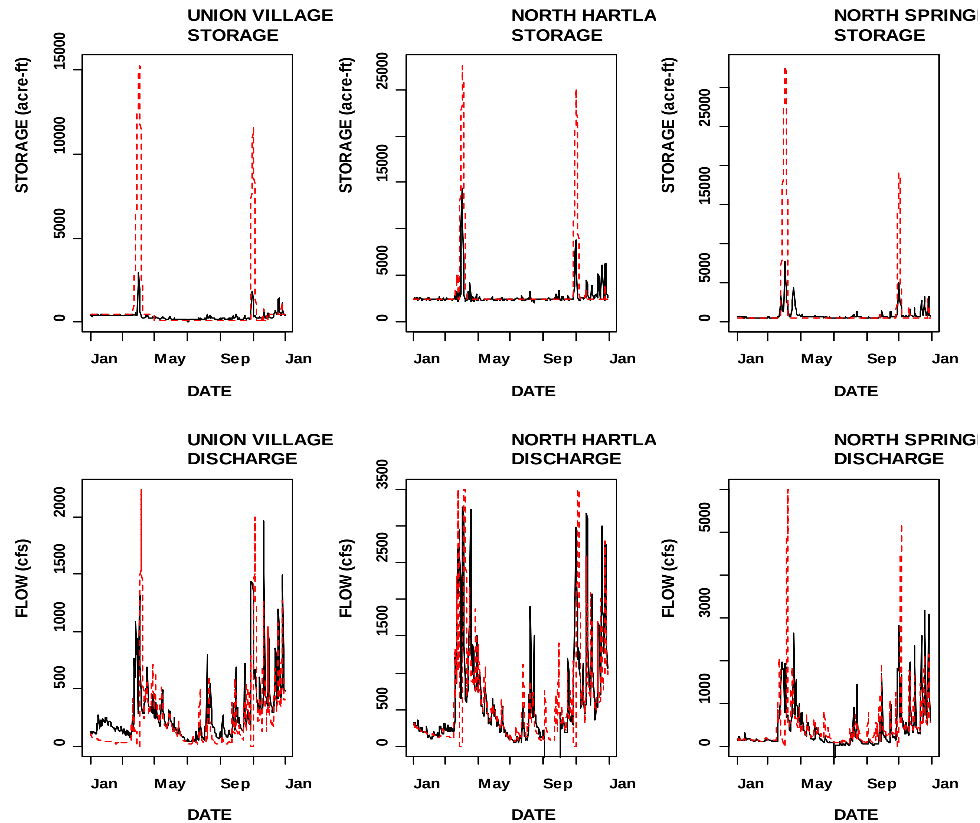
- New targets and objectives introduced
- Determine benefits gained from altering operations
- Trade-offs between competing objectives

Optimization Model Verification

Upper Third Mainstem Dams

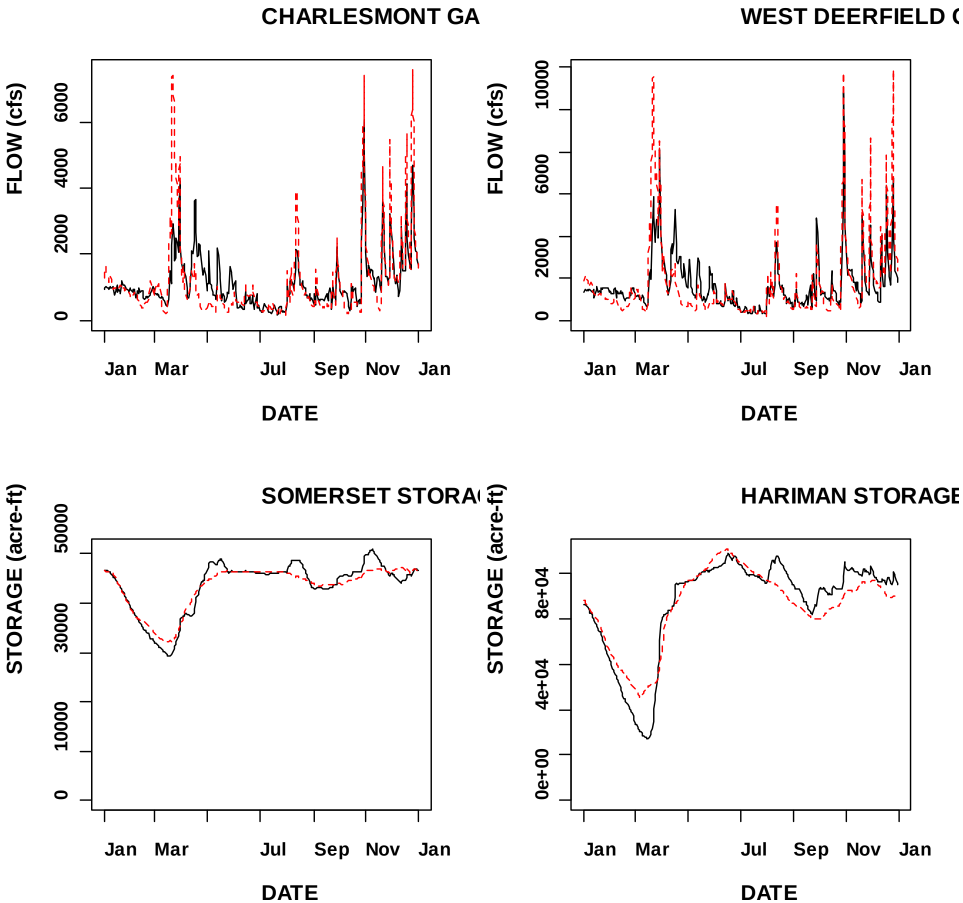


USACE Facilities in Upper Basin

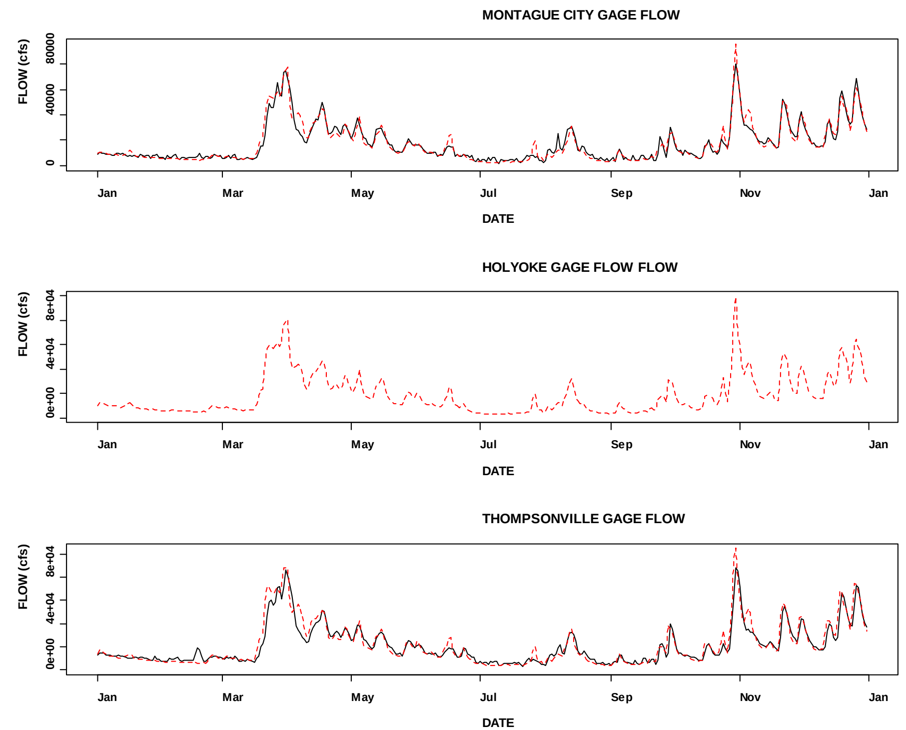


Optimization Model Verification

Deerfield River Basin



Mainstem Connecticut River



Next Steps

- Produce large scale simulation and optimization models of system (70 reservoirs)
  - Two Masters theses are complete
  - Optimization model will be finalized around beginning of next year
- Evaluate tradeoffs between ecological objectives and system functions
  - Use input from recent workshops to inform objectives
- Evaluate impacts of climate change on Connecticut River system
  - Have developed basin-wide hydrology model (VIC) to evaluate impacts of climate change on streamflow


Thank you!