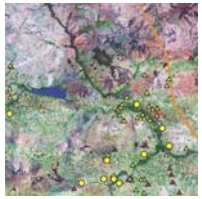

Modeling the Impacts of Municipal Consumption Rates, Outflow Regulations, and Climate Change on a Small Water Supply in North-Central Vermont

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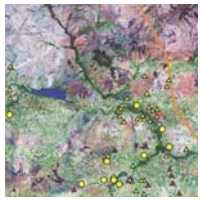
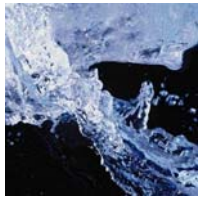


1 Background

2 Data



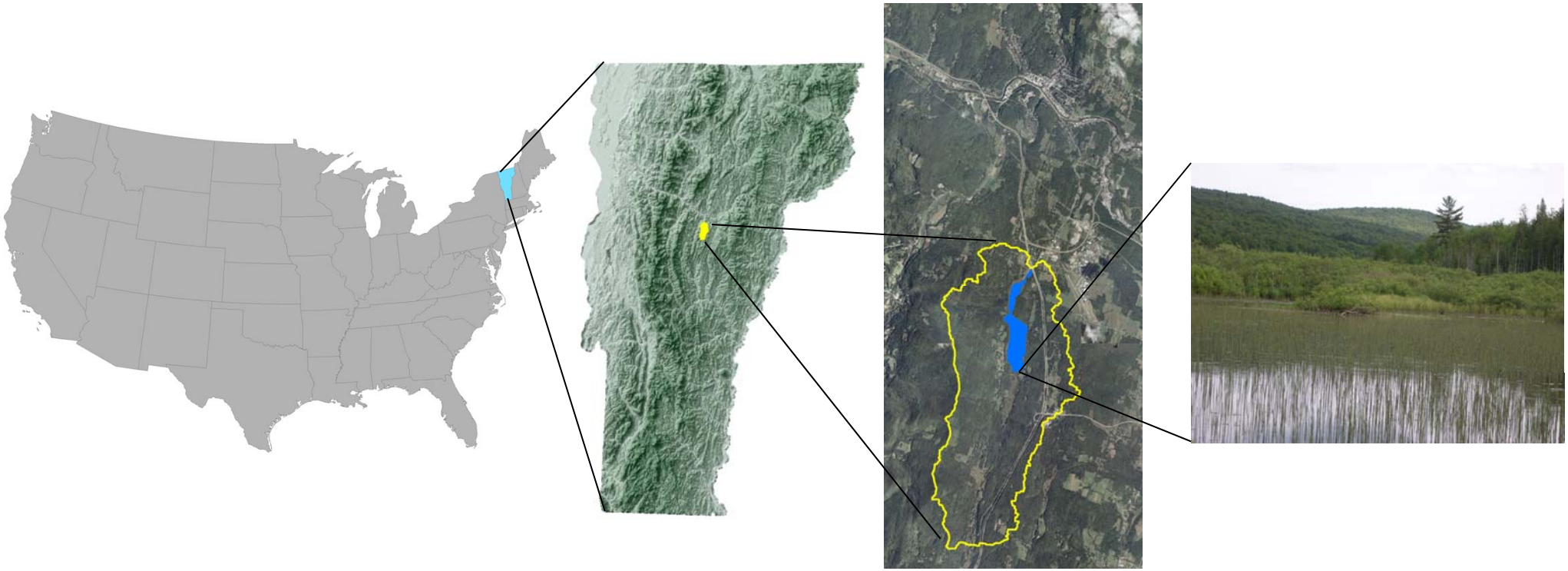
3 Model Development

4 Pond Management Scenarios

5 Evaluation of Results

Background: Berlin Pond … a Natural Resource

- Berlin Pond, located in North-Central Vermont, is a 103 hectare pond draining an area of approximately 26.8 km^2.
- The pond and its adjacent wetlands support abundant wildlife and provides recreational opportunities for local residents.



Background: Berlin Pond … a Municipal Resource

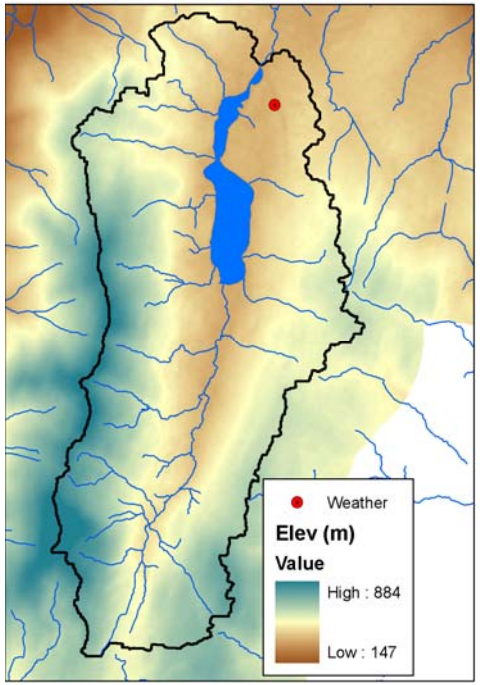
- Berlin Pond is the primary water supply for the City of Montpelier, serving approximately 2,600 customers including 327 businesses and a local fire district.
- Current water demand requires approximately 5,413 m^3/d from the Pond. The City Water Department would like to increase its customers, requiring greater withdrawals from the Pond.

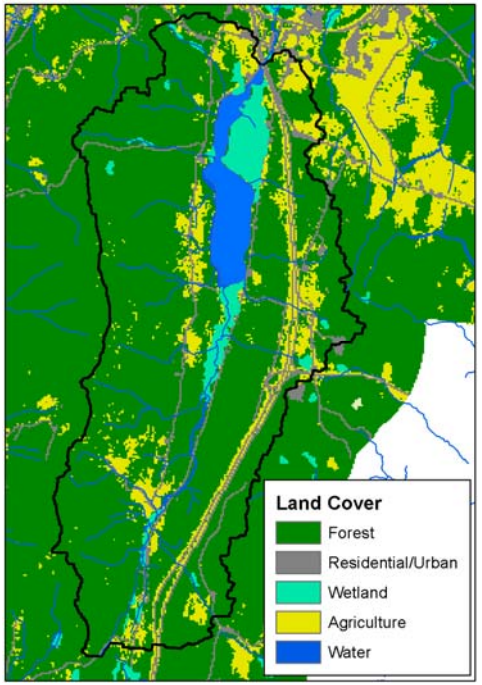
Background: The Challenge and the Approach

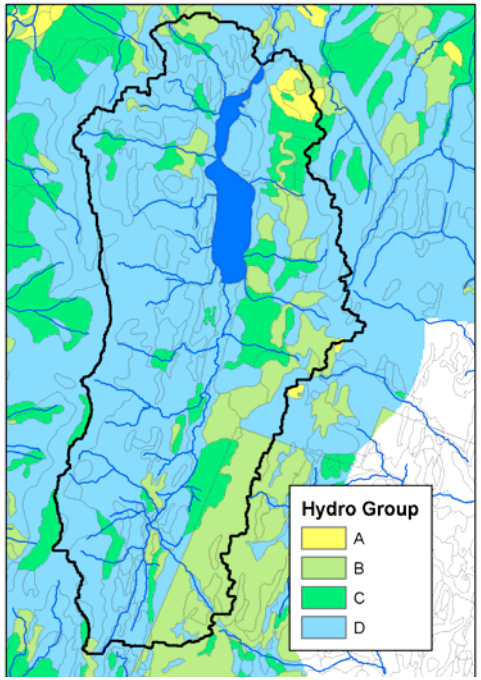
- The Challenge:
  - By court order, the City is required to “minimize potential negative impacts on Berlin Pond” by implementing water restrictions when the Pond falls below critical ecological levels.
  - Environmental regulators may require Montpelier to regulate outflow from the pond to support stream ecology (conservation flows).
  - Climate change may impact water balance of the pond.
- The Approach:
  - Develop a model to simulate a range of scenarios describing possible municipal use increases, conservation flows, and climate conditions.
  - Determine probability of pond levels dropping below critical levels under different scenarios.

Data: GIS and Weather

- DEM: 10-m DEM from USSG (NED)
- Hydrography: 1:5,000 local scale NHD (VHD)
- Land Use: 30-m Land cover/Land Use for VT
- Soils: SSURGO, 1:25,000 scale
- Weather: 30 years of daily temp and precipitation

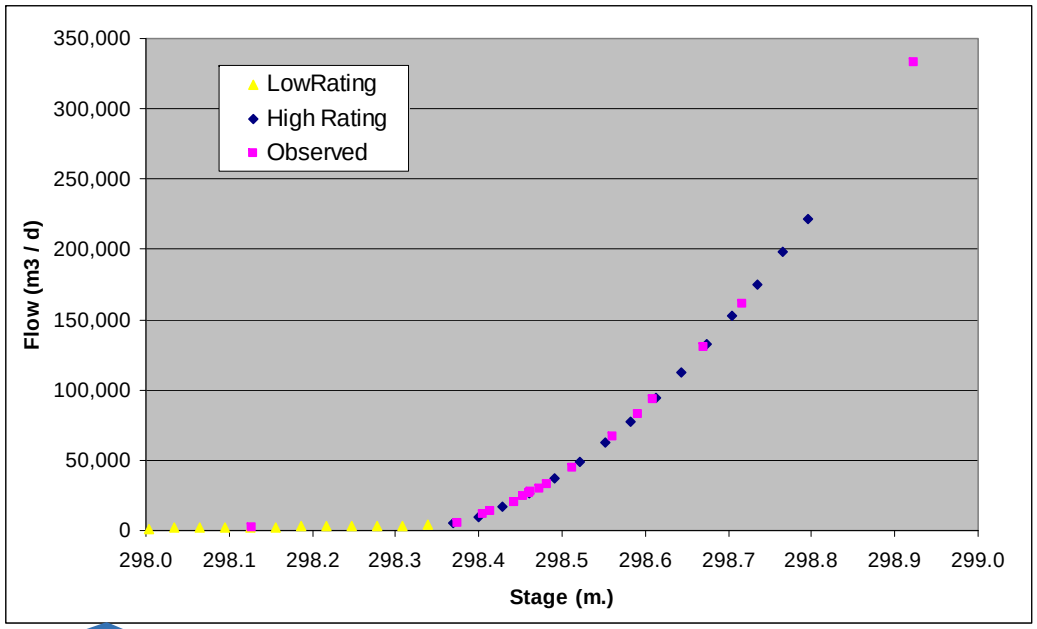






Data: Pond Characteristics

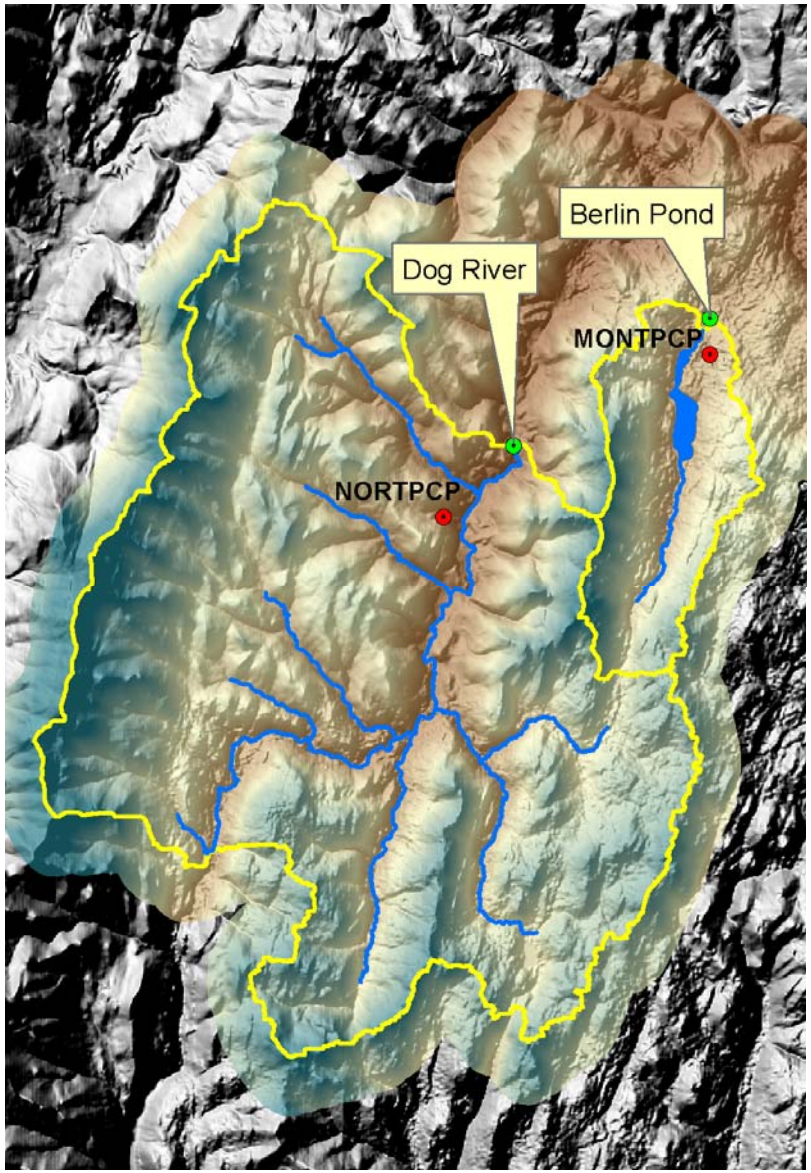
- Pond bathymetry: Elevation/storage curves developed
- Pond regulation/outflow characteristics:
  - Pond is regulated by several culverts and an uncontrolled dam.
  - A rating curve was developed to determine the relationship between pond stage and outflow.



Data: Calibration Data

- Flow: Observed streamflow data for the stream feeding Berlin Pond was not available. Daily streamflow for the adjacent 197 km^2 Dog River watershed was available and used for initial estimation of Berlin Pond parameters.

- Pond Levels: Observed pond level data was available from May 1993 through December 2004. These data were taken nearly daily, with some periods of missing data, particularly during winter.



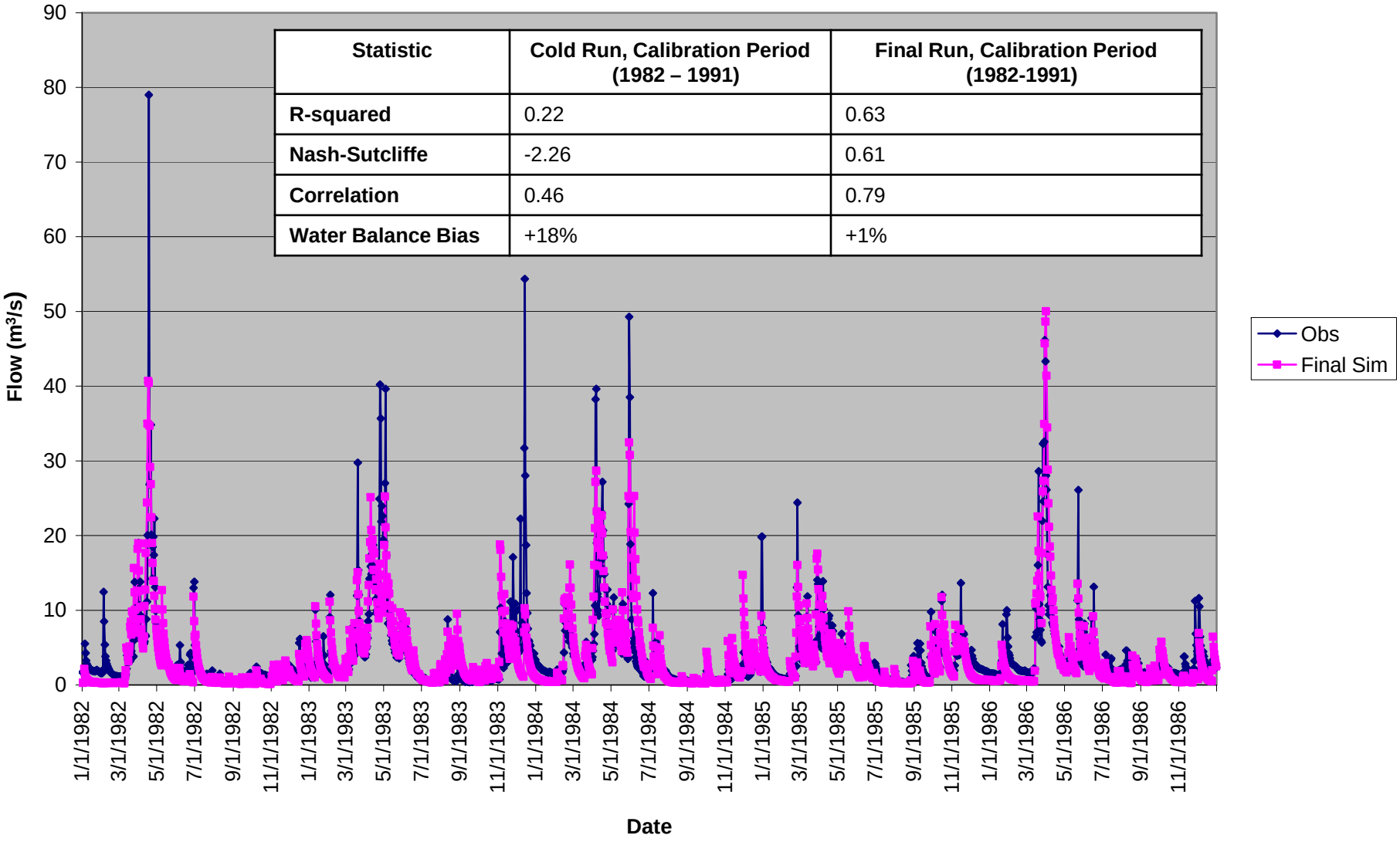
Model Development: Dog River Model

- Calibration Period: 1982-1991 with a 1-year warm up.
- Biggest Challenge: Too little baseflow in the winter and early spring. Unable to parameterize to obtain observed streamflow behavior.
- Solution: Small changes to model for winter conditions
  - Modified snowmelt model to contain ground melt and a snowfall adjustment factor, similar to the U.S NWS SNOW-17 model.
  - Modified percolation from soil to shallow groundwater with temperatures below 0 Celsius.
  - Justified this change based on the deep, early snow packs that can occur in this basin resulting in shallower penetration of frozen soil

Model Development: Dog River Calibration

Calibration Period, Years Shown (1982 – 1986)

Statistic	Cold Run, Calibration Period (1982 – 1991)	Final Run, Calibration Period (1982-1991)
R-squared	0.22	0.63
Nash-Sutcliffe	-2.26	0.61
Correlation	0.46	0.79
Water Balance Bias	+18%	+1%



Model Development: Berlin Pond Model

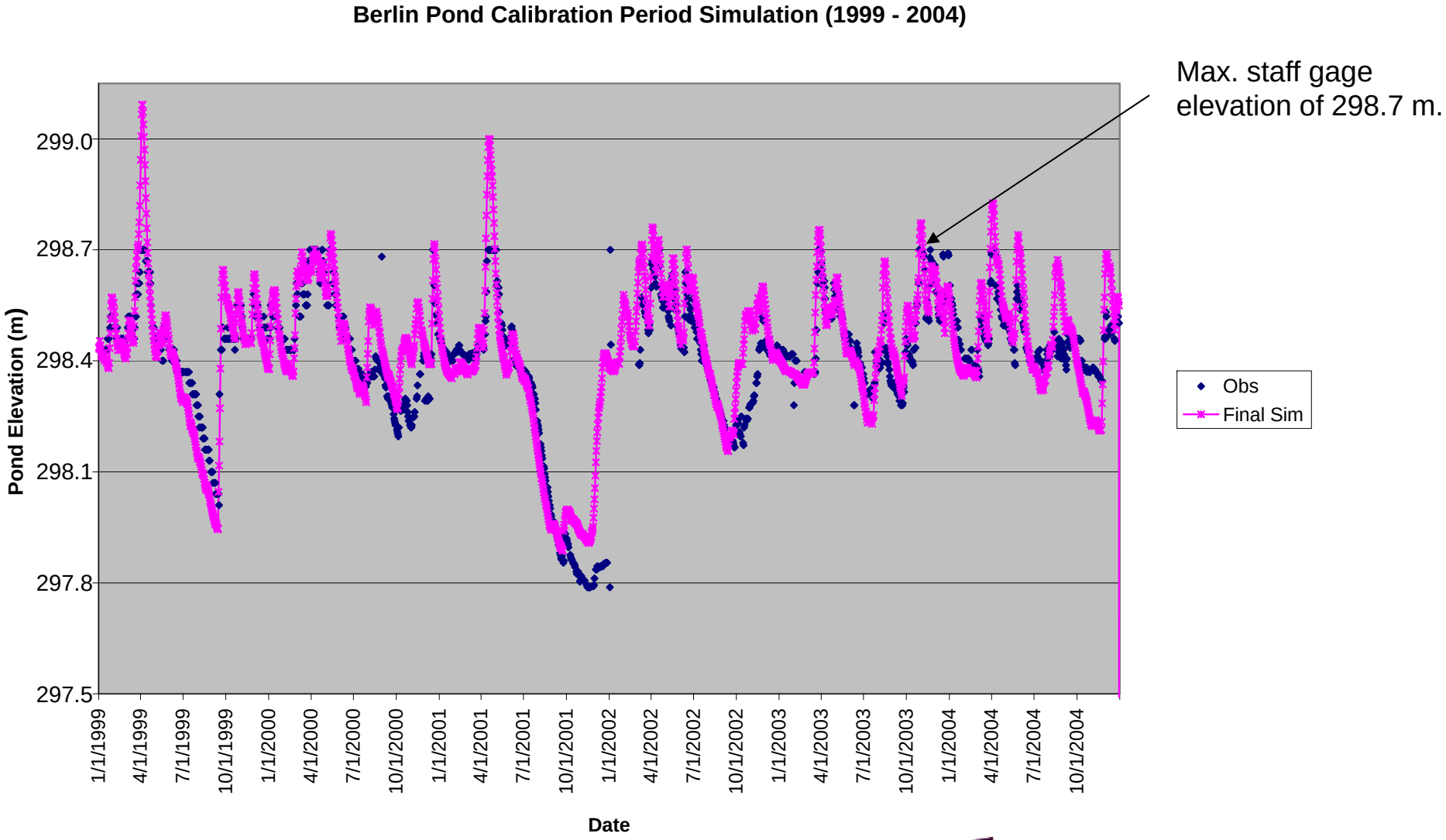
- Calibration Period: 1999-2004 with a multi-year warm up.

- Model Notes:
  - Utilized same model modifications as for Dog River (snow model, frozen soil)
  - Implemented custom reservoir regulation model

- Reservoir Model Components:
  - Outflow as a function of pond stage (low and high end rating curves)
  - Seasonal low end rating curve adjustment (account for ice and vegetation)
  - Municipal withdrawal reductions when pond falls below action levels
  - Adjustment of outflows to account for conservation flow requirements

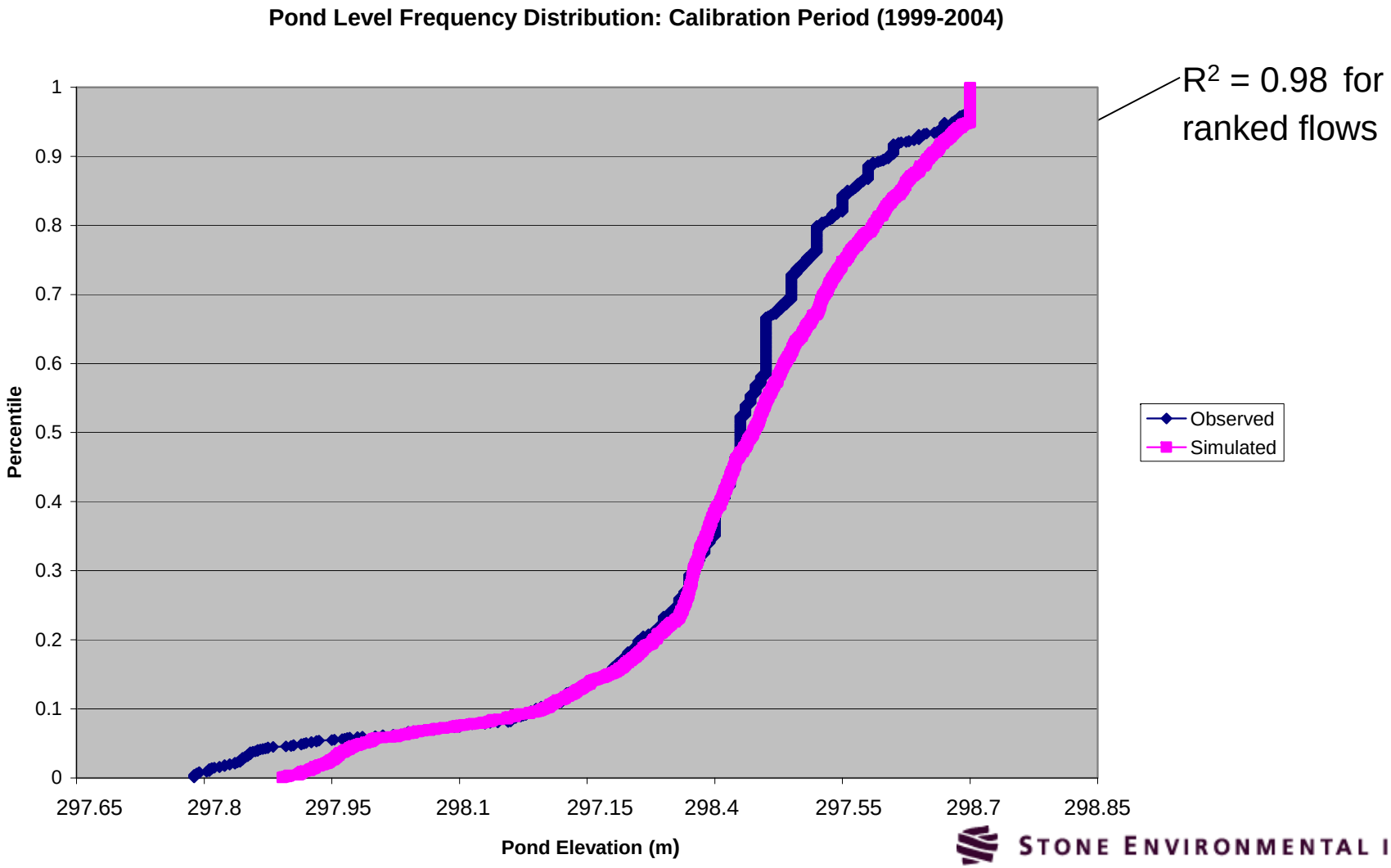
Model Development: Berlin Pond Model Calibration

- Emphasis on matching dry periods



Model Development: Berlin Pond Model Calibration

- Predicted water levels within 6 cm. of observed from 5th through 99th percentiles.



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Pond Management Scenarios: Water Use and Outflow Regulation

- Water Use: Evaluated 5 municipal withdrawal rates: 3785, 5413, 6435, 7570 and 9463 m^3/day

- Outflow Regulation: Evaluated unregulated outflow and a conservation flow requirement scenario.

- Conservation Flow Scenario:
  - For Jun 1 – Sep 30, minimum flow = 0.0367 m^2/sec-km^2
  - For Oct 1 – May 31, minimum flow = 0.0734 m^2/sec-km^2
  - If pond inflow < conservation flow, pond outflow = pond inflow

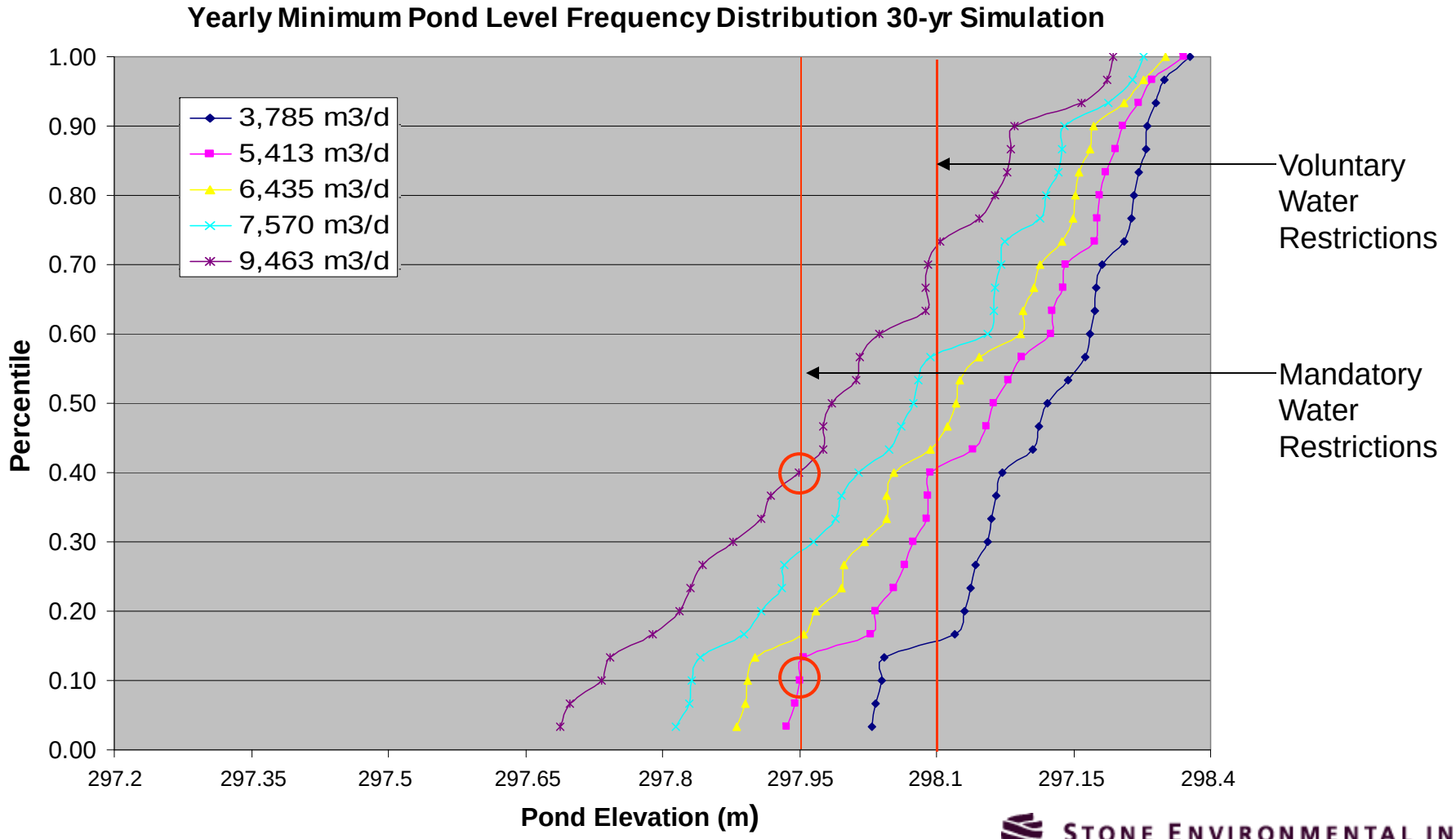
Pond Management Scenarios: Climate Change

- Current Climate: represented by 30 years of observed climate records (1975 – 2004)
- 2050 Climate Scenario: Based on Hadley model output (HADCM2)
  - Extracted GCM grid cells for Berlin Pond climate region (7 grid cells) and created average values for region
  - Averaged monthly t-min, t-max, and precip. for 2045 – 2055
  - Calculate seasonal departures from current conditions (1975-2004)
  - Applied adjustments to historical 30-yr time series

Season	Precip Change (%)	TMax Change (C)	TMin Change (C)
Winter	4.81	1.34	1.97
Spring	-7.79	1.07	1.47
Summer	22.82	0.30	1.25
Fall	22.67	0.48	1.3

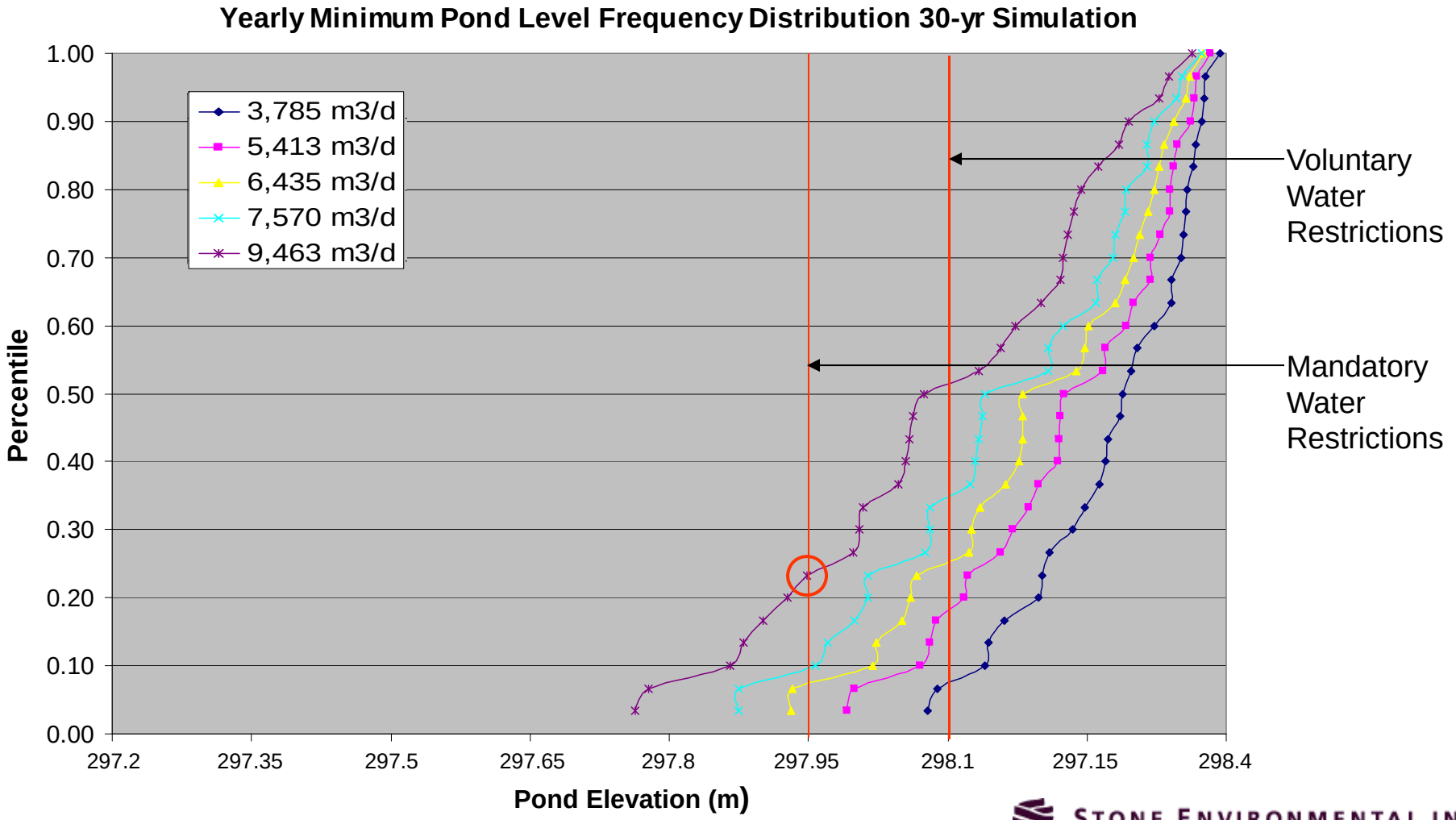
Evaluation of Results: Current Climate, Unregulated Outflow

- Probability of experiencing mandatory restrictions in any year increases from 10% (current use) to 40% under highest potential use.



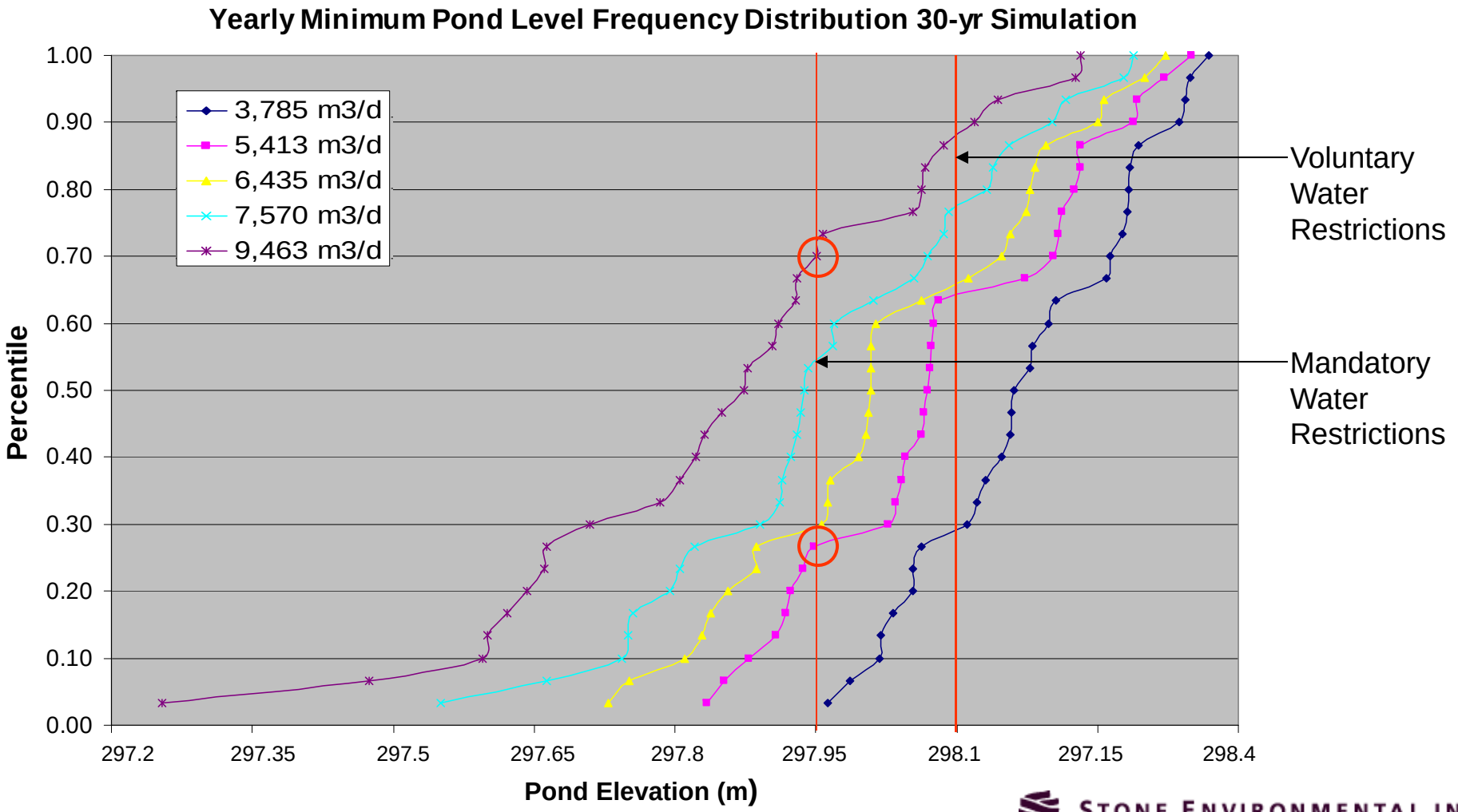
Evaluation of Results: 2050 Climate, Unregulated Outflow

- Probability of mandatory restrictions at highest use rate decreases to 23% under the projected 2050 climate (hooray … more water!).



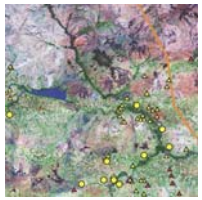
Evaluation of Results: Current Climate, Conservation Flows

- Probability of mandatory water restrictions increases significantly with conservation flow requirements (good for fish, not for the Water Dept.)



Summary and Conclusions

- SWAT was applied to a evaluate the impacts of water use, environmental regulation, and climate change on a small water supply reservoir.
- The modeling incorporated modifications to the SWAT model code to account for winter season runoff and a customized reservoir management scheme.
- Modeling of 20 different scenarios was performed to predict the probability of reaching ecologically critical water levels in Berlin Pond.
- Future climate conditions, with higher summer precipitation, resulted in greater water availability.
- Imposing conservation flow requirements to support downstream aquatic habitat resulted in considerably less water availability for municipal use.



Thank you!