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Refinement and further evaluation of the Massachusetts Firm-Yield-Estimator model version 2.0

In cooperation with
Mass DEP

April, 12, 2012

U.S. Department of the Interior
U.S. Geological Survey

Firm Yield Estimator development history

1996	Mass DEP guidance document detailing procedures for estimating the firm yield of reservoirs in MA
2000	Firm Yield Estimator (FYE) version 1.0 software and documentation released
2006	Two USGS reports* published which investigate sensitivity of the FYE to various basin characteristics and develop methodology for estimating groundwater contributions to the firm yield
2011	Firm Yield Estimator version 2.0 software includes several significant model refinements and new simulation options and user interface
	USGS Scientific Investigations Report 2011-5125 applied the FYE v 2.0 at 71 reservoirs in MA, tested several management scenarios, completed model uncertainty analysis, and model validation

*Waldron, M.C., and Archfield, S.A., 2006, Factors affecting firm yield and the estimation of firm yield for selected streamflow-dominated drinking-water supply reservoirs in Massachusetts: U.S. Geological Survey Scientific Investigations Report 2006-5044, 39.p

*Archfield, S.A., and Carlson, C.S., 2006, Ground-water contributions to reservoir storage and the effect on estimates of firm yield for reservoirs in Massachusetts: U.S. Geological Survey Scientific Investigations Report 2006-5045, 27.p

Project Objectives

Refinements to the model

- Model runs at a daily time step
- Improved calculation of ground-water contribution to reservoir storage in the FYE model.
- New features: user-defined demand management scenarios and reliability criteria

Additional Analyses

- Expand the study area to include 25 additional reservoirs in MA
- Uncertainty analysis of model predictions
- Model validation with observed data
- Evaluate the effect of drought severity on the calculation of firm yield.
- Evaluate the effects of controlled releases, reservoir reliability, and demand management on firm-yield estimates

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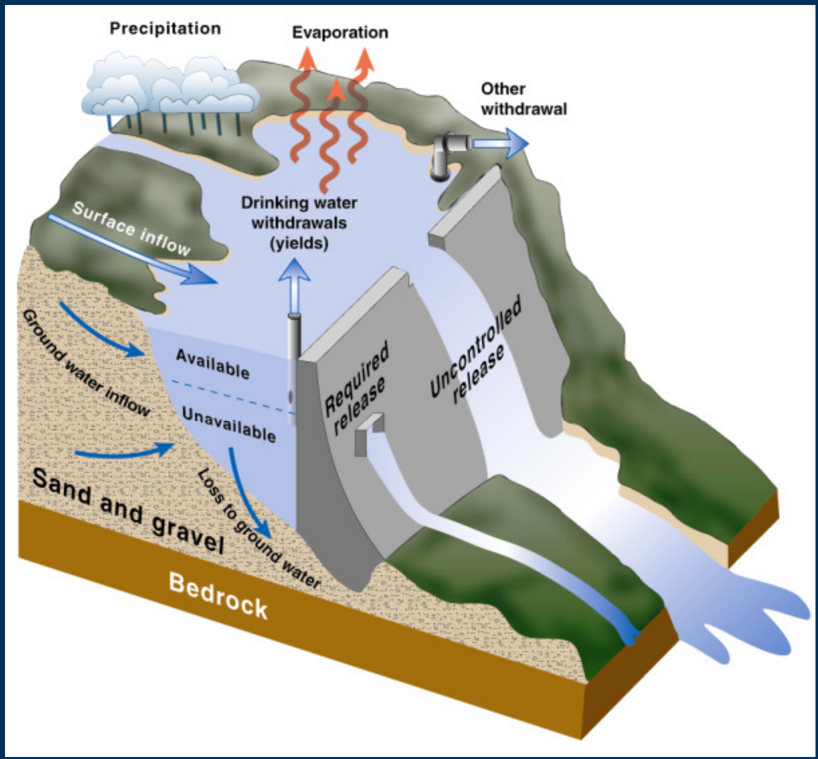
Firm Yield Estimator v 2.0

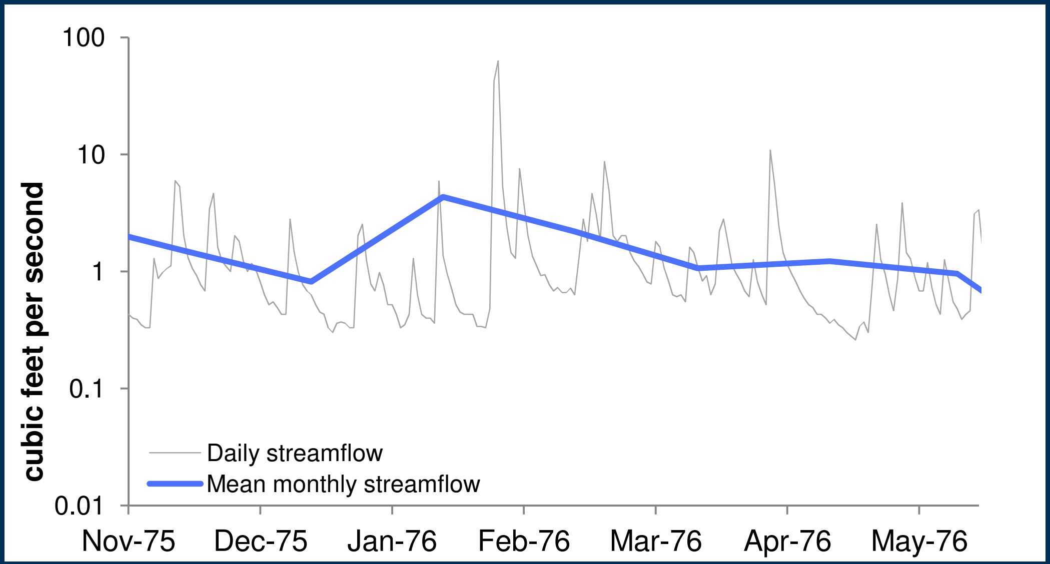
- Firm yield is calculated by iteratively solving the water balance each day over the entire period of record.
- With each iteration, withdrawals are increased until the reservoir fails.
- The firm yield is the highest withdrawal rate that can be used without causing a reservoir failure during the simulation.



Processes accounted for in the water balance include precipitation, evaporation, inflowing streamflow, groundwater flows, withdrawals, controlled releases and uncontrolled releases.

Refinements to the model

- Monthly time step used in the FYE 1.0 can lead to over-estimation of firm yield due to reduced variability in monthly streamflow and climate inputs.
- FYE 2.0 runs at a daily time step in order to more accurately represent the range and variability of daily streamflow and climate inputs.
- Daily streamflow is estimated using newly available Sustainable Yield Estimator*



Monthly and daily input streamflow for Belmont Reservoir used in the FYE 1.0 and FYE 2.0, respectively

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*Archfield, S. A., Vogel, R.M., Steeves, P.A., Brandt, S.L., Weiskel, P.K., and Garabedian, S.P., 2010, The Massachusetts Sustainable-Yield Estimator: A decision-support tool to assess water availability at ungaged stream locations in Massachusetts: U.S. Geological Survey Scientific Investigations Report 2009-5227, 41 p.

Management Scenarios

- Controlled releases
  - User-defined controlled releases for each month
- Reliability
  - Default setting defines the firm yield using 100% reliability (no-fail). Towns with alternative or emergency water sources may wish to operate at a lower reliability.
- Demand Management
  - Water-use restrictions during drought periods may be set by the user. These scenarios reduce the yield during periods when the reservoir storage falls below a user-specified threshold.

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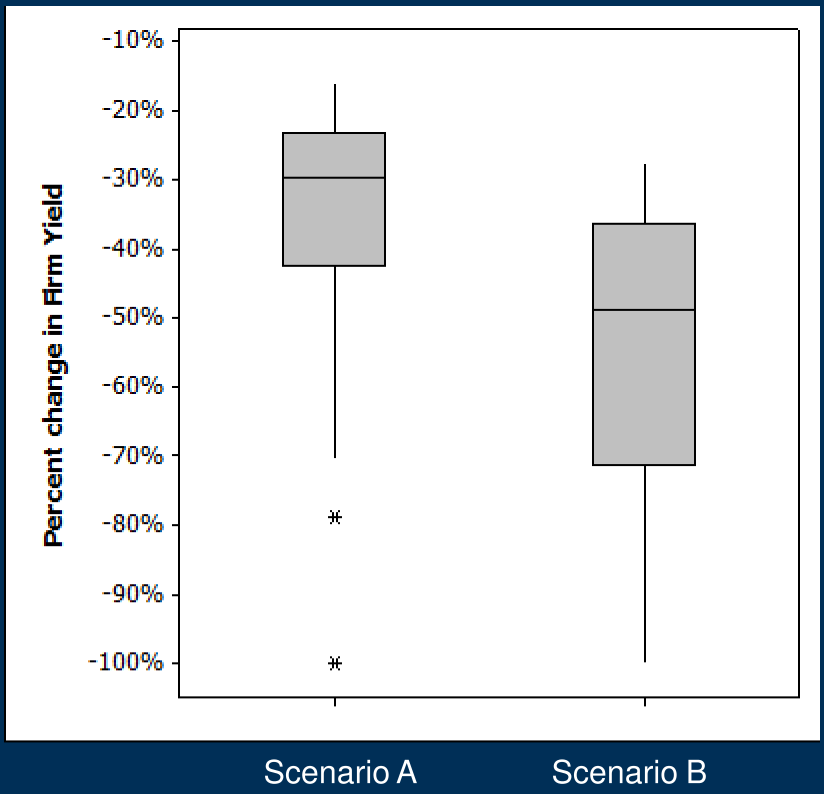
Controlled releases

- Two hypothetical controlled release scenarios examined
  - Scenario A: daily controlled releases equal to the 10th percentile monthly streamflow
  - Scenario B: daily controlled releases equal to the 25th percentile monthly streamflow
- Reservoirs with low storage capacity relative to their average streamflow had greater decreases in firm yield when controlled releases were imposed.



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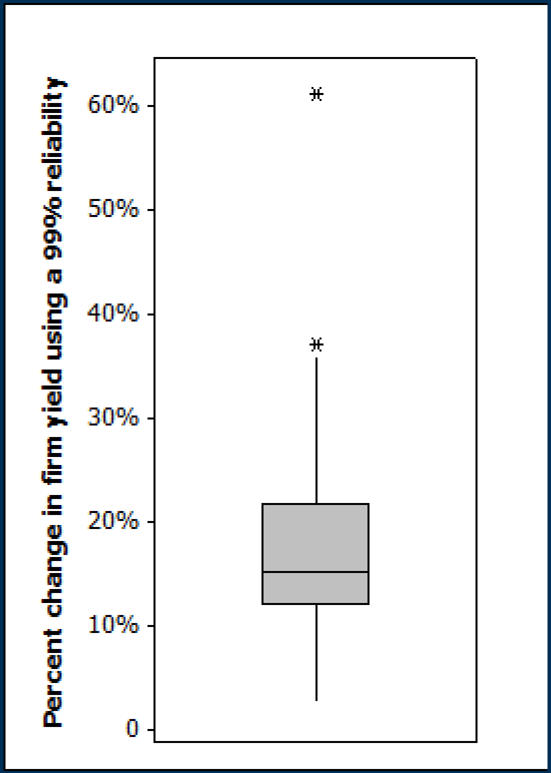
Reservoir reliability

- Some towns may wish to operate at a higher failure rate if they have alternative or emergency sources they can use during extreme droughts

- Users may specify the number of allowable failure days in the simulation. The firm yield will then be calculated as the highest yield possible without exceeding the allowable failure rate.

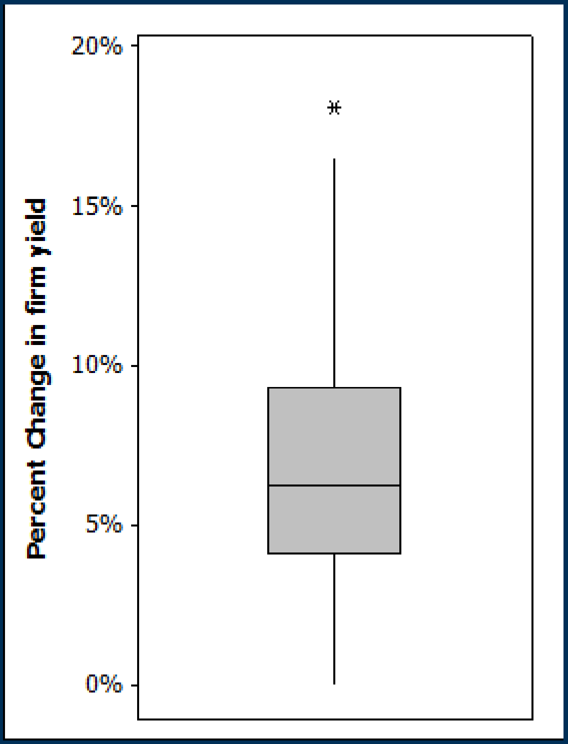
- 99% reliability scenario (1% failure rate) increased reservoir yields by 10 – 25%



Demand Management

Demand management hypothetical scenario

Percent Reduction in Demand	Reservoir storage depletion threshold
15%	40% depleted
25%	60% depleted
35%	80% depleted



Firm yields for most reservoirs increased between 5-10% under this scenario

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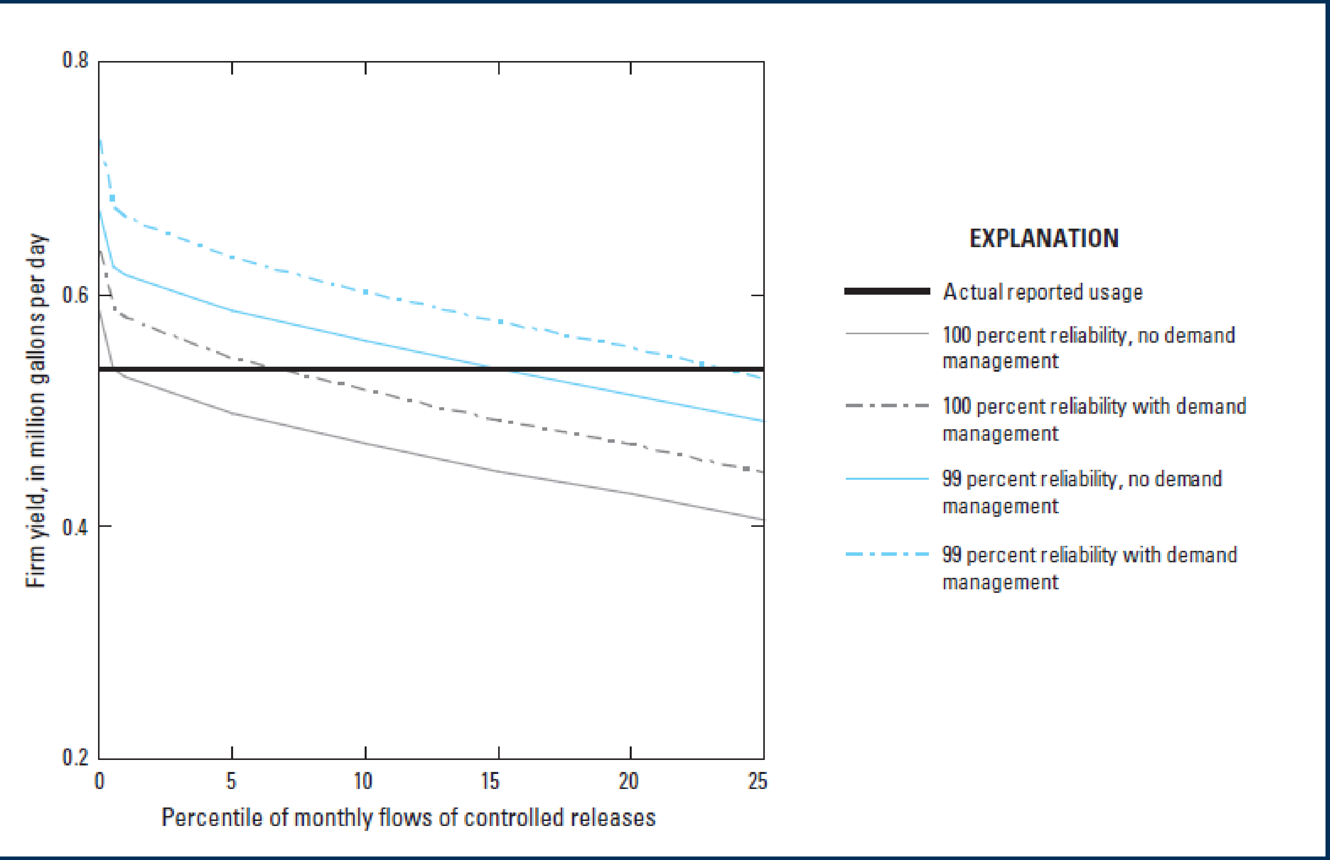
Complex management scenarios

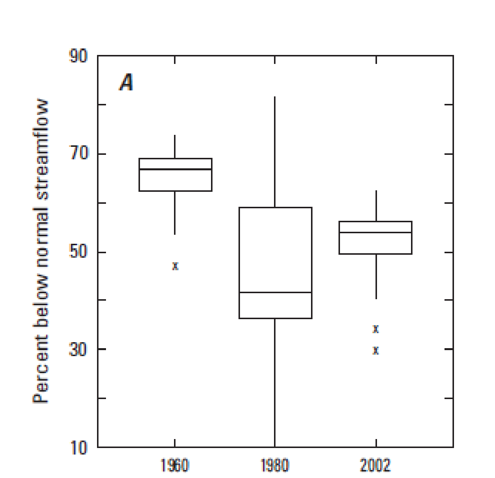
- Trade-offs between different management scenarios can be examined by simulating a reservoir system using different combinations of management scenarios.



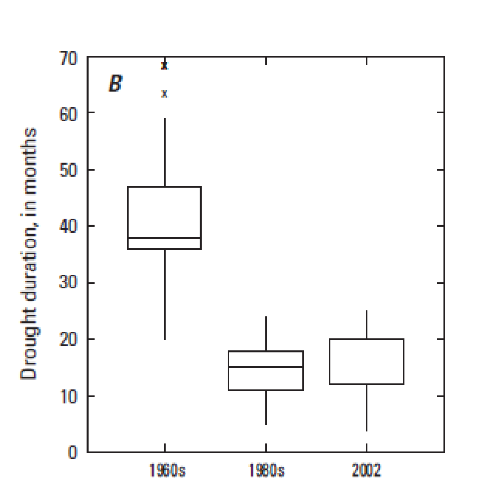
Effect of drought severity on firm yield

- Firm yields are based on the 1960's drought which was the longest and most severe drought on record
- Droughts in the 1980's and 2002 were shorter in duration and had less severe water shortages in most places compared to the 1960's drought
- Estimating firm yields based on droughts other than the 1960s drought increased firm yield estimates by 20 – 60%

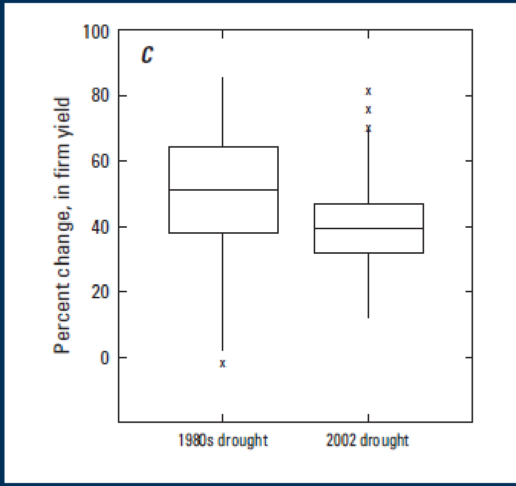
Drought severity of 1960's, 1980's and 2002 droughts



Drought duration of 1960's, 1980's and 2002 droughts



Percent change in Firm Yield based on 1980's and 2002 droughts



Model Uncertainty

- Streamflow inputs
  - Firm Yields increased by 2-10% in after accounting for errors in streamflow time series. Reservoirs with low storage ratios are more sensitive to errors in streamflow.
- Climate inputs
  - Because precipitation and evaporation are generally small volumes compared to streamflow, errors in these data are not expected to affect firm yield estimates greatly.
- Bathymetric maps
  - Bathymetric maps are used to estimate reservoir storage capacity and stage-storage tables. Maps created from too few survey points cause an underestimation of reservoir capacity and firm yield. Analysis in the report suggests these errors are minor (1-5%) for most reservoirs in the study.

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Model Uncertainty

- Groundwater parameters
  - Aquifer characteristics are estimated from existing maps which are not very precise. This would affect ~30% of reservoirs in the study that receive groundwater flows. Groundwater flows are generally small compared to streamflow inputs, so the effect of errors in these calculations should be minor in most caes.

- Reservoir operations
  - Many multi-reservoir systems have complex daily operations that cannot be adequately modeled using this approach

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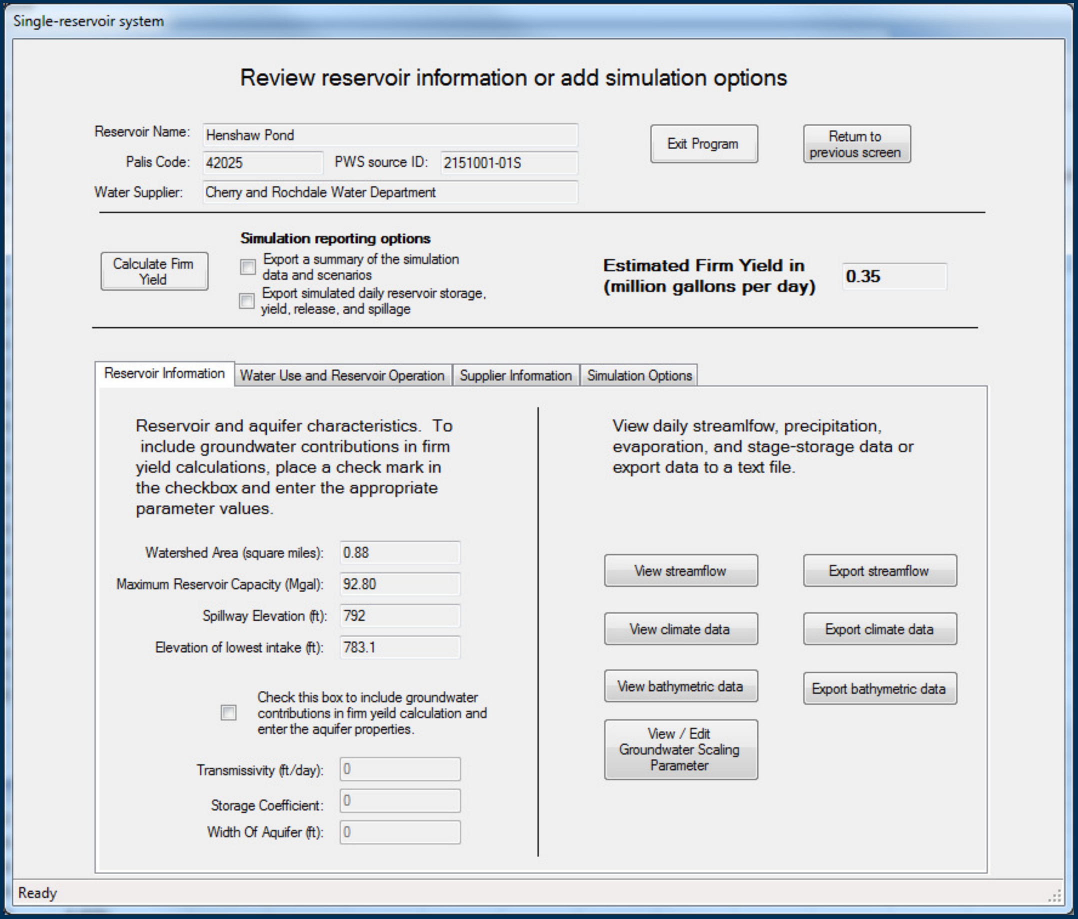
Model Release

- New user interface with pre-loaded data for 71 reservoirs in Massachusetts.
- Features include:
  - Simulations for single and multi-reservoir systems in a variety of configurations
  - View and export all streamflow, climate, and bathymetric reservoir data
  - Add new reservoir information to database
  - User-defined reliability criteria, demand management scenarios, and monthly controlled releases



Report and software available for download at:
http://pubs.usgs.gov/sir/2011/5125/

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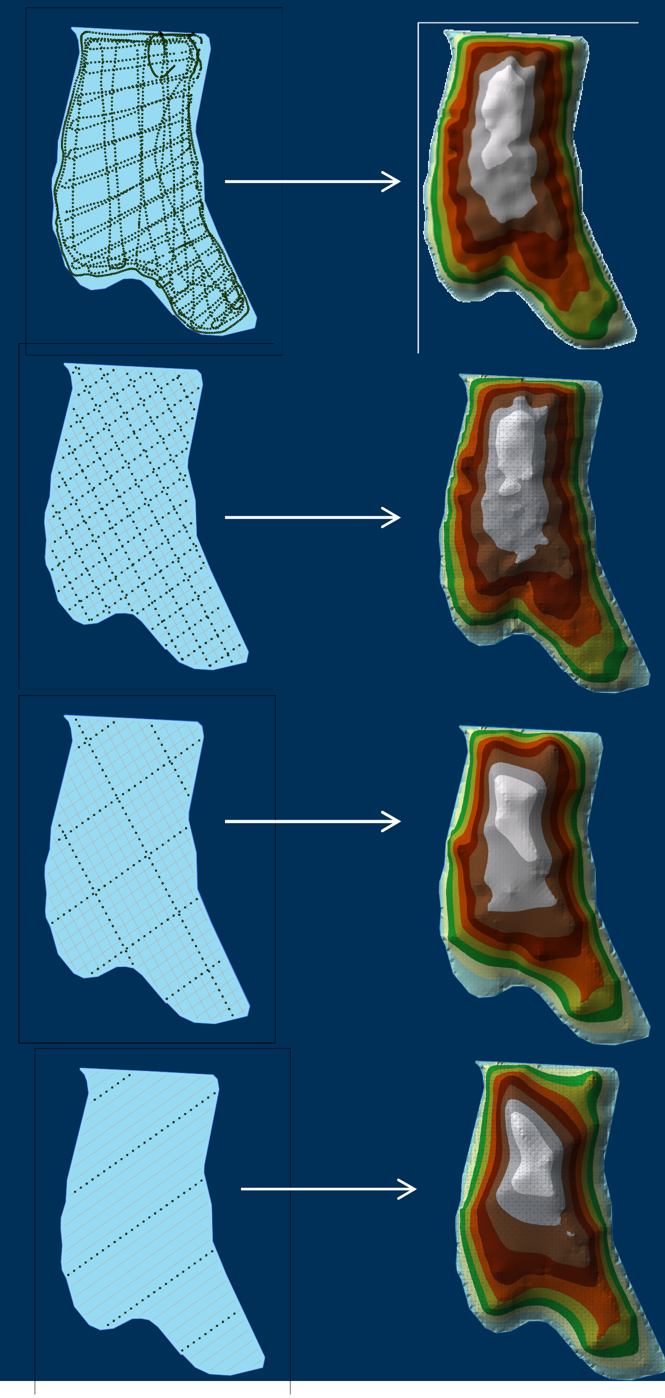
Model uncertainty

Effect of bathymetric survey accuracy on FirmYield

- Bathymetric maps from original depth profile data were resampled using several different transect widths and configurations
- New bathymetric profiles were created from the hypothetical transect depths
- Storage capacity and firm yield recalculated from new depth profiles.



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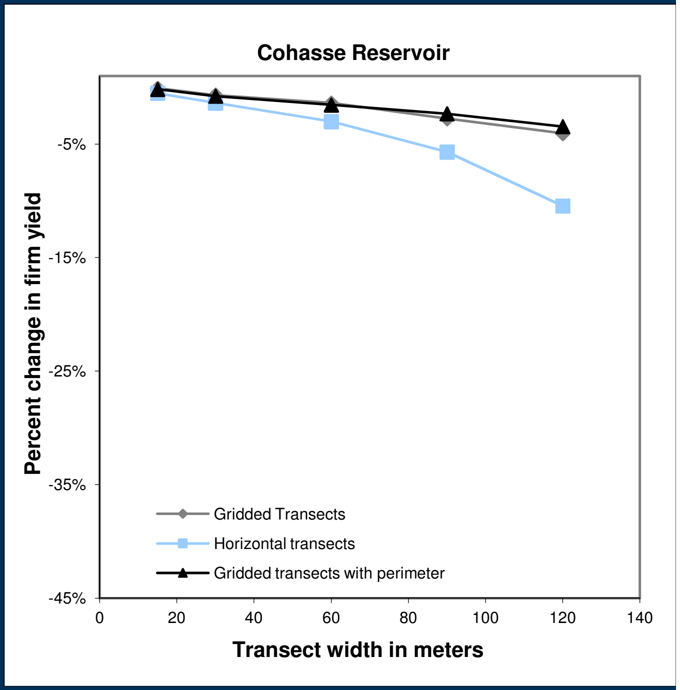
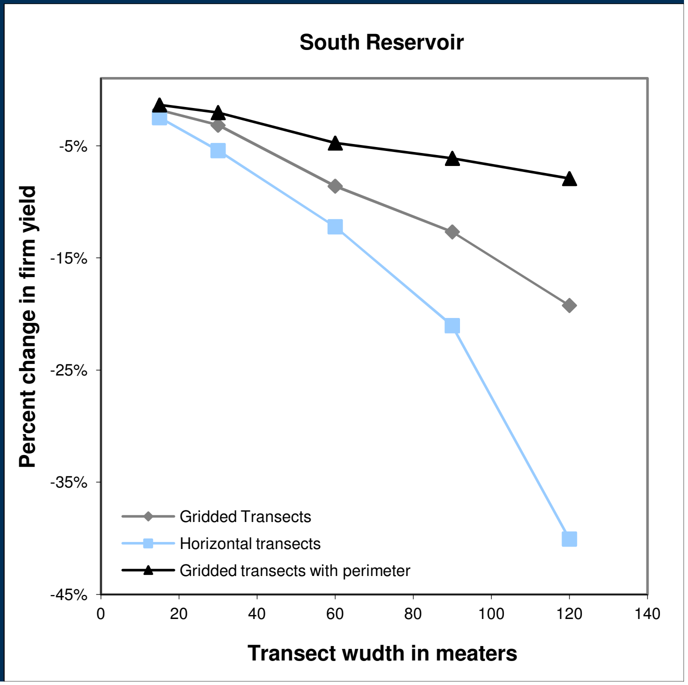
Model uncertainty

- Widely spaced transect patterns resulted in an underestimation of storage capacity and a lower estimated firm yield.
- Actual bathymetric surveys for reservoirs in the FYE report generally had gridded transects between 30-60 meters wide and included a perimeter transect.
- Uncertainty in bathymetries of reservoirs used in this study are a minor source of error in resulting firm yields.





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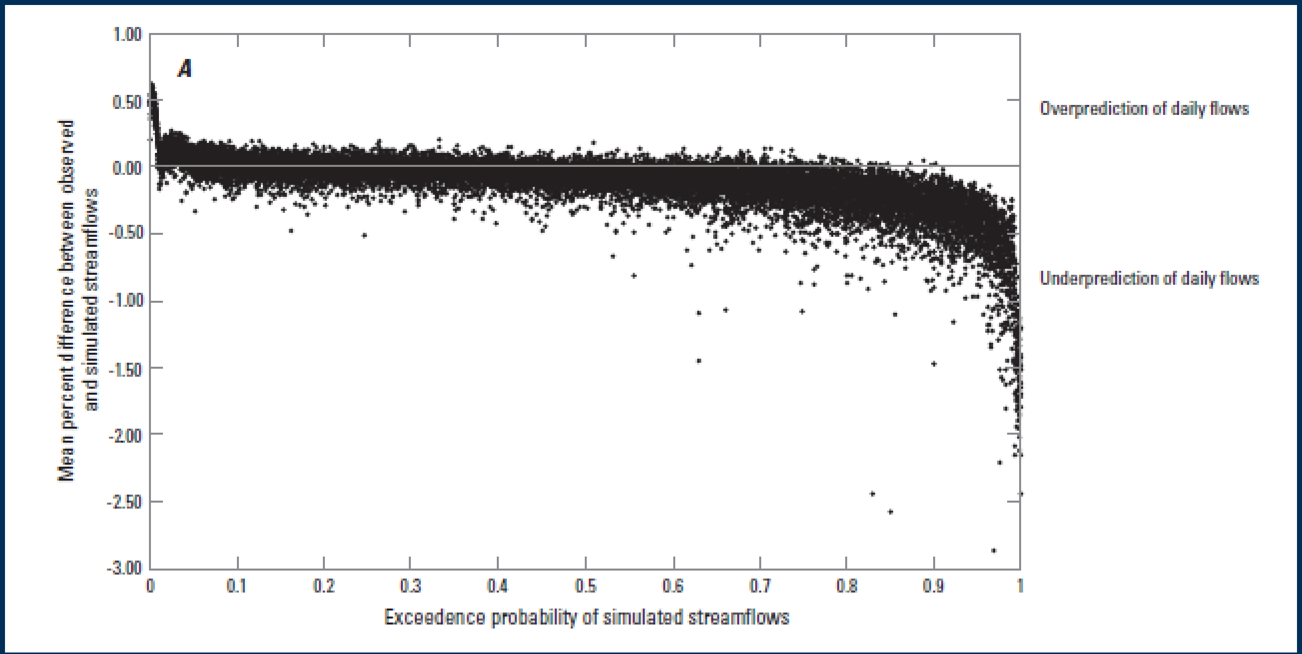
Model uncertainty

- Sensitivity of FYE to errors in streamflow was examined using Monte Carlo simulations.

- For each Monte Carlo simulation, daily streamflows were altered by a random error that was structured to match the uncertainty in the Sustainable Yield Estimator (SYE).

- Errors in streamflow estimation using the SYE were estimated by the difference between estimated and observed flows at 18 USGS gaged sites.



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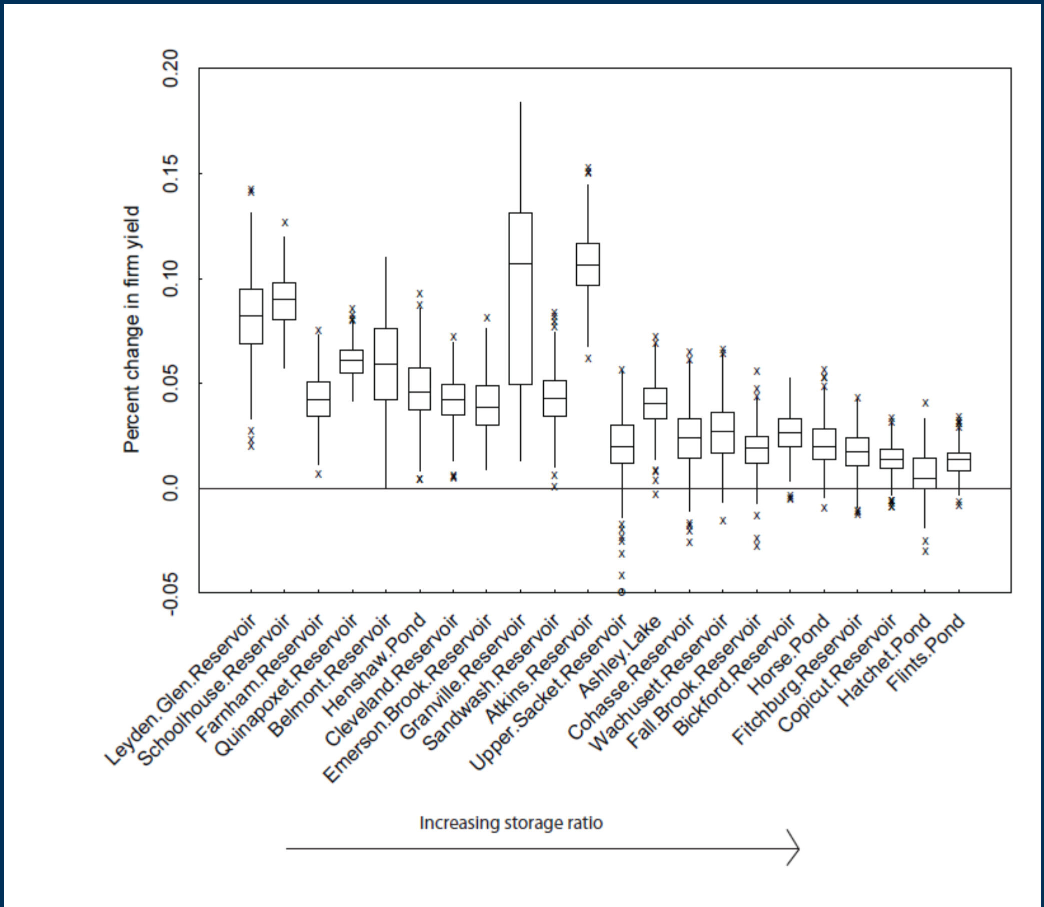
Model uncertainty

- Underestimation of low flows by the SYE may cause firm yields to be underestimated by 1-10%

- Reservoirs with low storage ratios were more sensitive to errors in streamflow inputs.



Percent change in firm yield of selected reservoirs after accounting for potential errors in daily streamflow in 500 Monte Carlo simulations.

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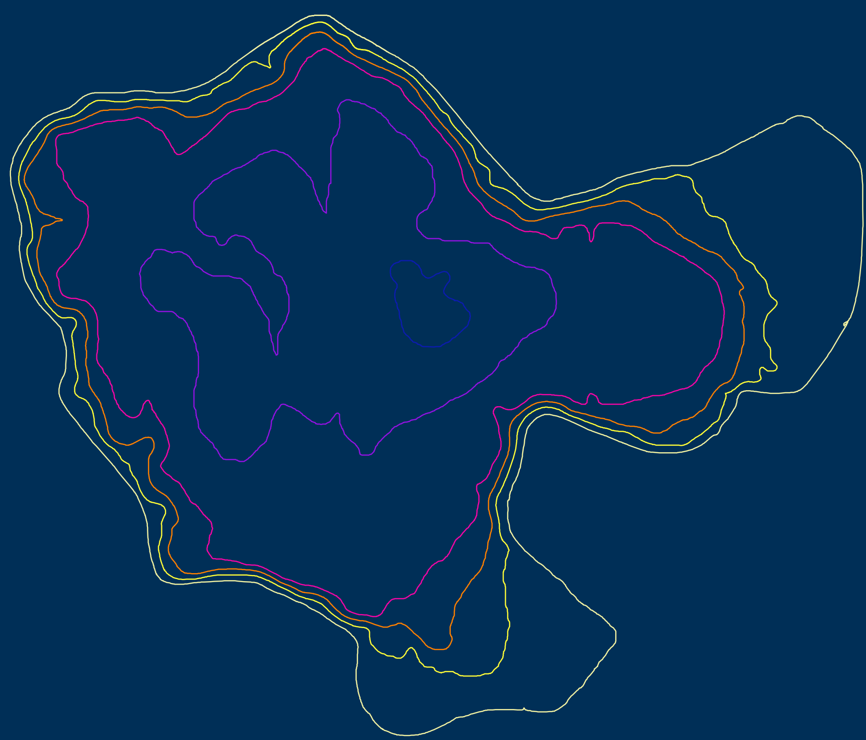
Refinements to the model

- Analytical solution to daily groundwater contributions is solved iteratively.
- In some reservoirs, groundwater contributions were overestimated during low storage periods leading to instability in the iterative solution.
- Equation was stabilized by re-parameterizing shoreline length based on lake elevation

Lake Level	Perimeter Length
Full Pool	12900 ft
45 ft	13700 ft
35 ft	10200 ft
25 ft	9700 ft
15 ft	8000 ft
5 ft	1200 ft



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