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Simulation-Optimization Modeling: A Tool for Improved Understanding of Ground-Water Systems and Their Management

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Overview of Presentation

- Background on Simulation-Optimization Modeling:
  - What is it?
  - Why use it?
- Example Application
- Optimization-Modeling Resources

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Example Ground-Water Management Problems

- Maximize ground-water yields from a basin
- Control water-level declines
- Control saltwater intrusion
- Conjunctively use ground-water and surface-water resources

Center pivot irrigation system, High Plains aquifer

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General Issue

- Numerical models are powerful tools for simulating complex hydrogeologic and water-resource management systems

- Trial-and-error approach for determining ‘best’ operating policies is difficult:
  - complexity of ground-water systems
  - large number of engineering, legal, and economic facts that can affect water-resource management

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Alternative Approach: Simulation-Optimization Modeling

Combines ground-water modeling with management-modeling techniques to determine optimal ground-water management strategies given a specific management objective and set of management constraints

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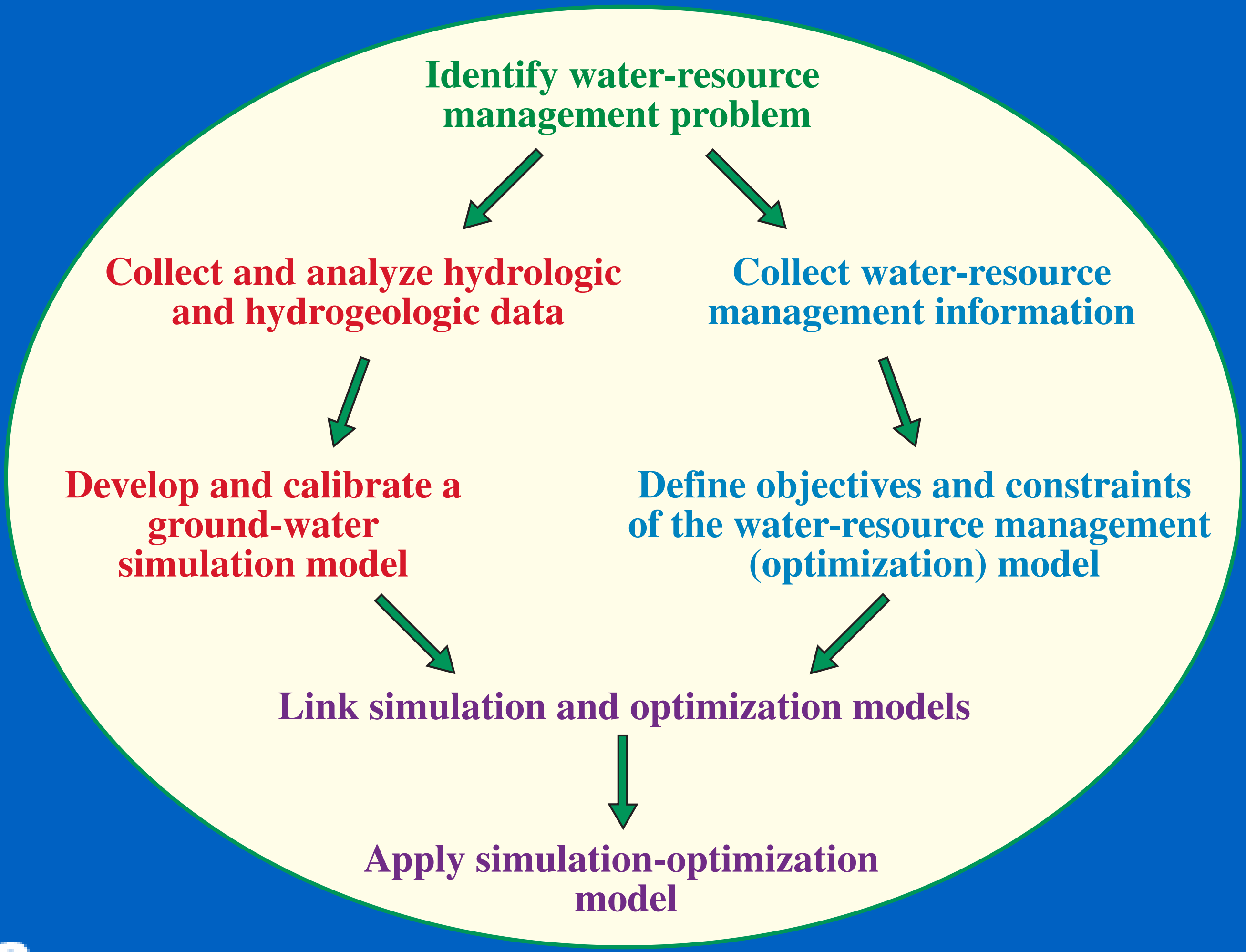
General Approach for Simulation-Optimization Modeling



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Components of an Optimization Model

- Objective Function
  - Maximize withdrawals
  - Minimize drawdowns
- Constraints
  - Upper and lower bounds on pumping rates
  - Maximum drawdowns; maximum rates of streamflow depletion
  - Meet minimum water-supply demands
- Decision Variables
  - Quantifiable controls (decisions) whose values are determined by solution of the model

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Outputs of an Optimization Model: Values for the Decision Variables

- Timing, rates, and locations of withdrawals at wells
- Timing, rates, and locations of injection at wells or discharge to artificial-recharge basins
- Timing, rates, and locations of interbasin transfers

- In simulation modeling alone, these variables are *specified*

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Why is Optimization Modeling Useful?

- Explicitly accounts for management/policy objectives and constraints within the modeling process
- Provides a means to understand tradeoffs between various constraints and possible uses of ground-water resources
- Improves the understanding of the hydrogeologic system

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Example Application:

Evaluation of Tradeoffs Between Instream-Flow Criteria and Ground-Water Development, Big River Basin, Rhode Island

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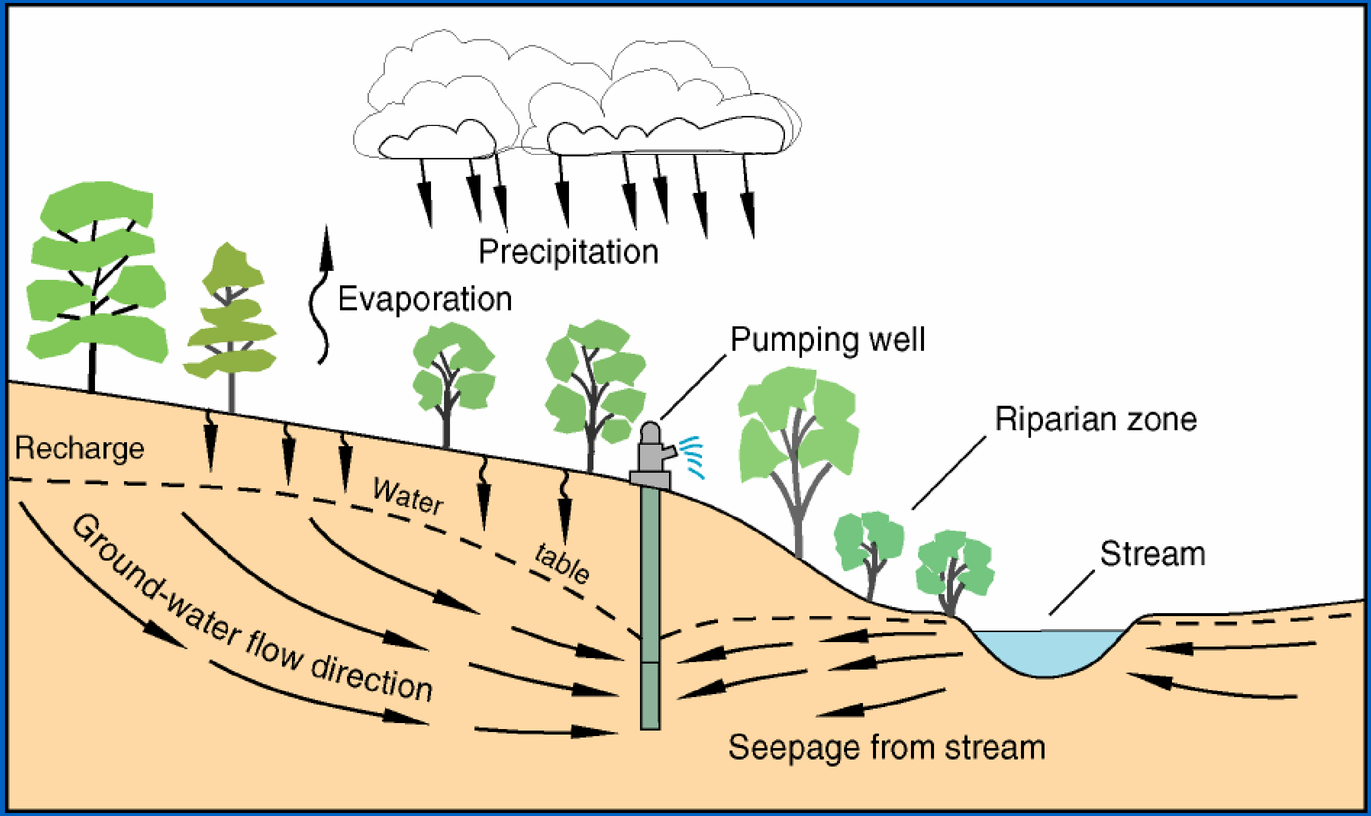
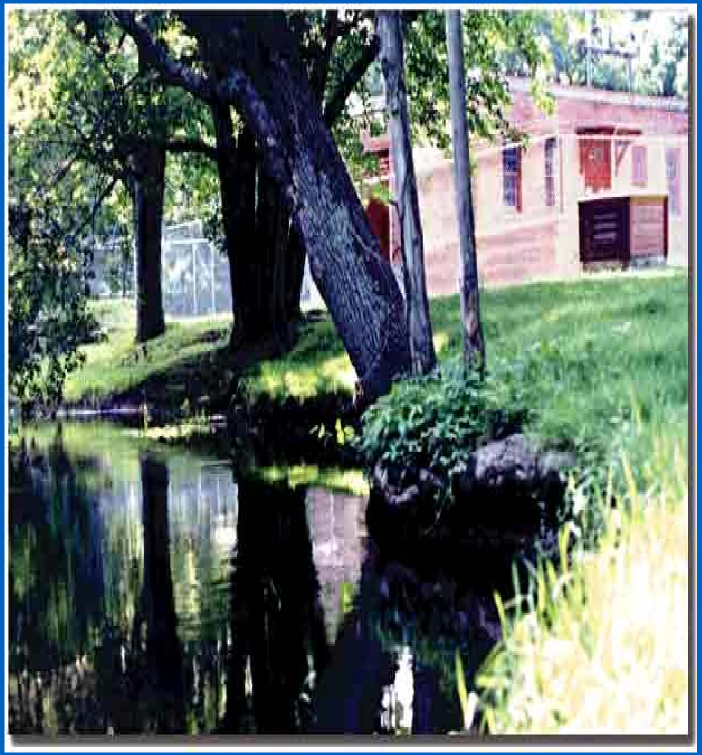
Common Water-Resource Issue: How to increase gw withdrawals while minimizing the effects of gw development on instream flows?



Minimum Instream-Flow Requirements

- Protect aquatic and riparian ecosystems
- Ecological requirements have been difficult to define
- Regional, long-term streamflow statistics



Water-supply well house near the Hunt River, Rhode Island

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Approach: Simulation-Optimization Modeling

- Link transient, numerical ground-water flow models with optimization methods to evaluate hydrologic, hydrogeologic, and proposed instream-flow policies on ground-water development options

- Approach for linking simulation and optimization models is known as the ‘response-matrix approach’

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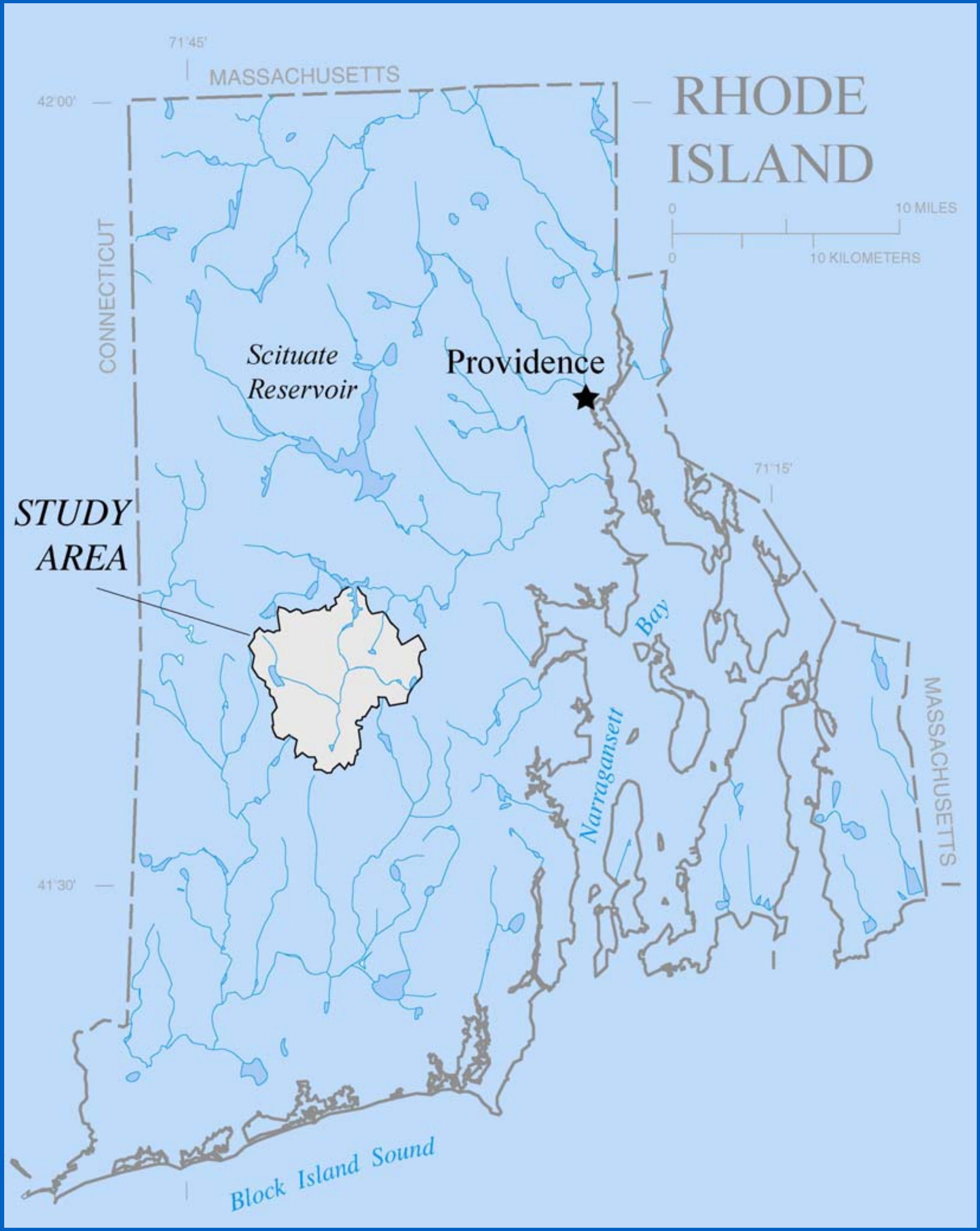
Big River Basin, Rhode Island



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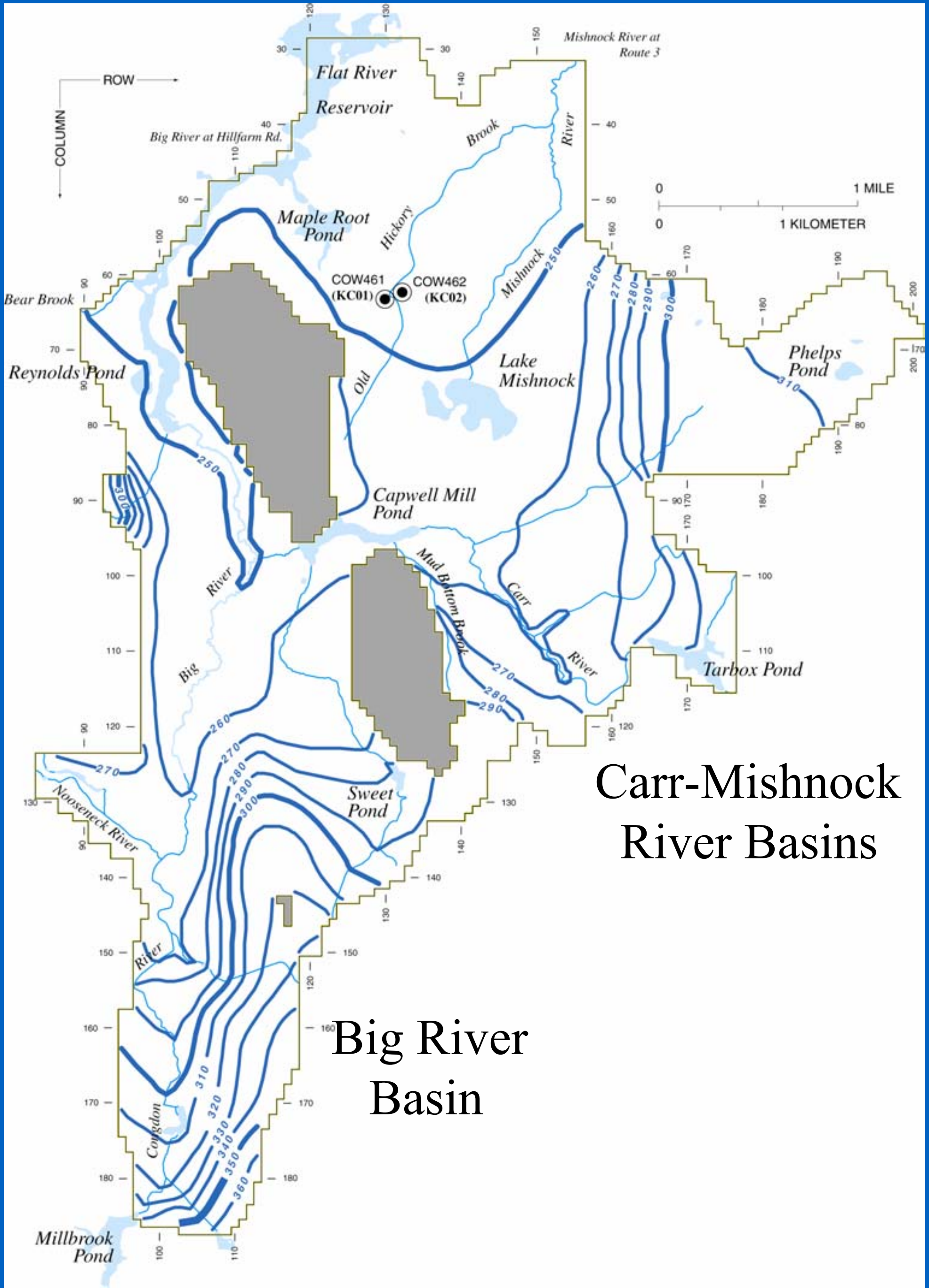
Simulated Water Table



Carr-Mishnock River Basins

Big River Basin

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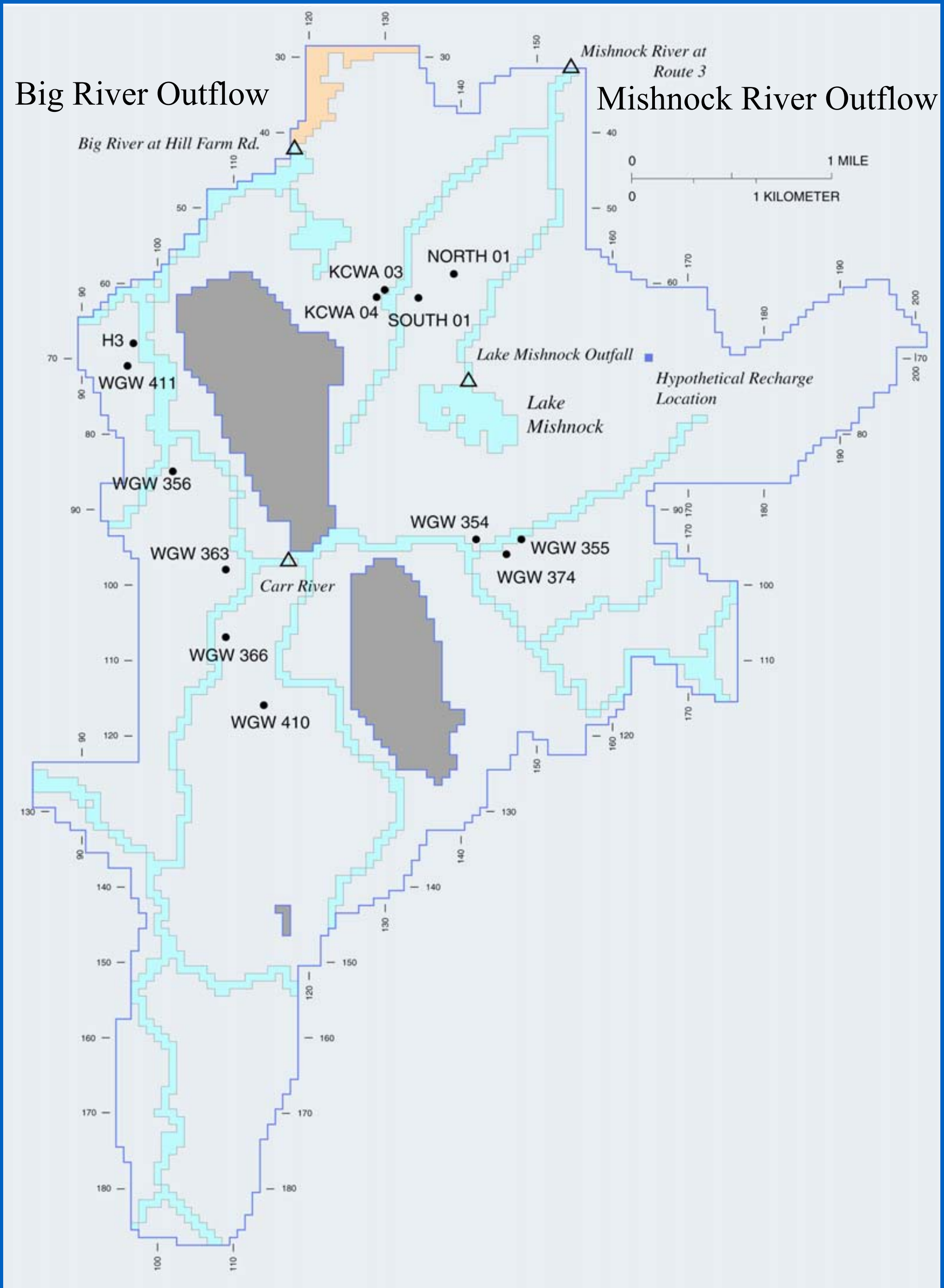
Existing and Potential Well Sites and Streamflow-Constraint Locations



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Optimization (Management) Model

- Decision variables
  - Monthly withdrawal rates at wells
- Objective function
  - Maximize total annual withdrawals
- Constraints
  - Specified streamflow requirements during some or all months of the year
  - Water-supply demands
  - Maximum/minimum withdrawal rates at wells

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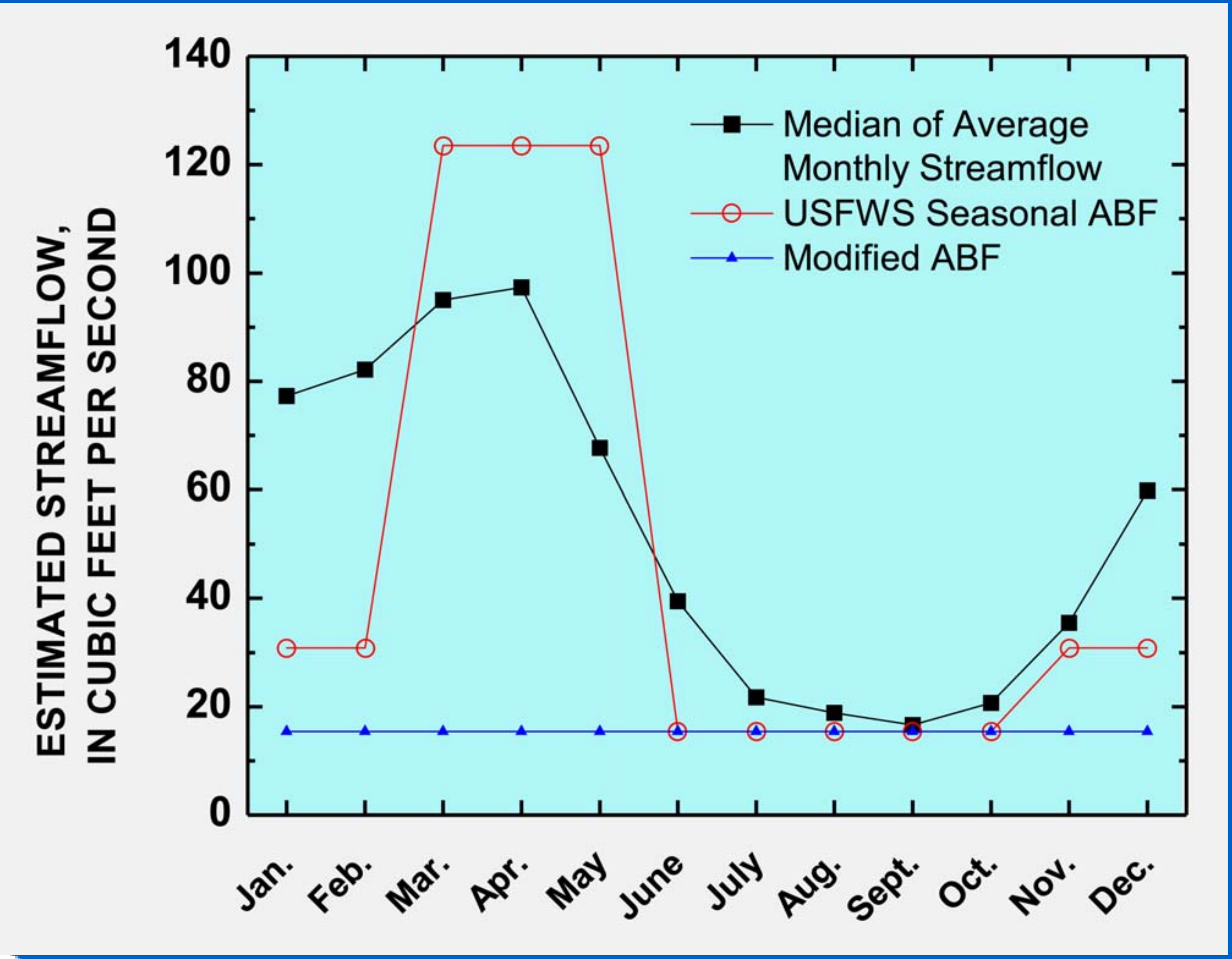
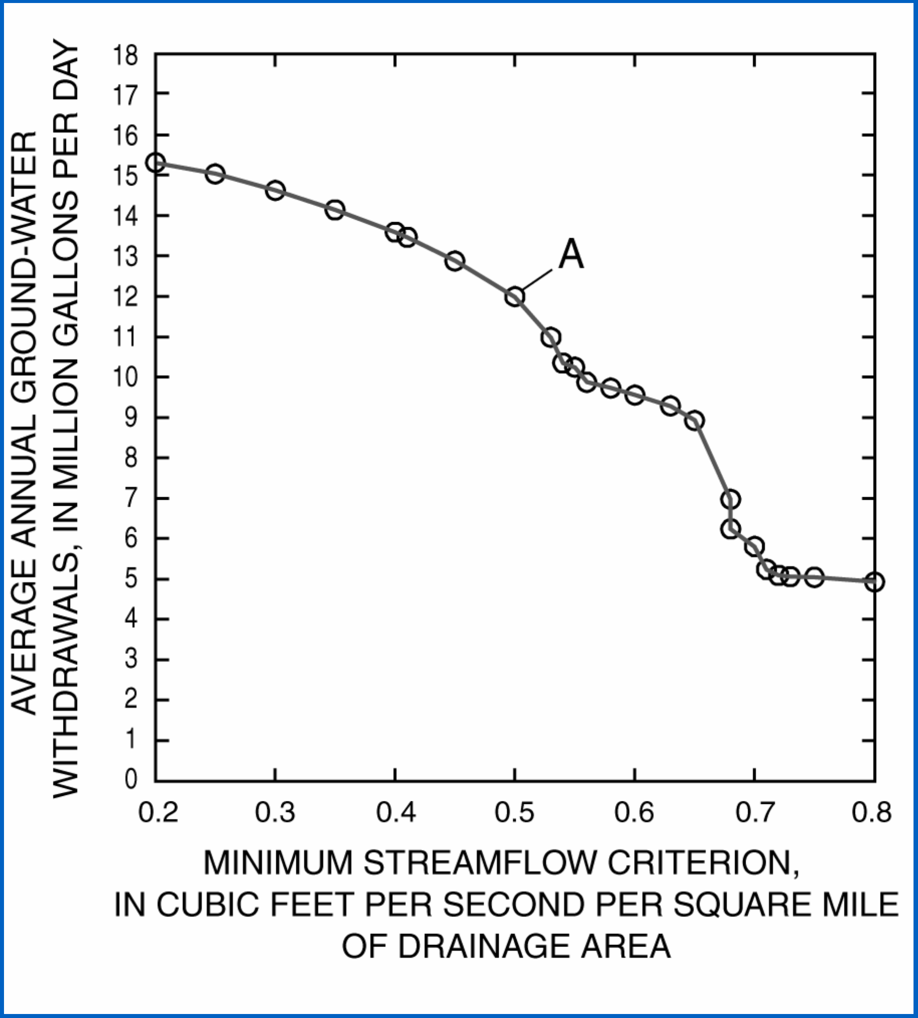
Example Streamflow and Instream-Flow Criteria for Big River at its Outflow

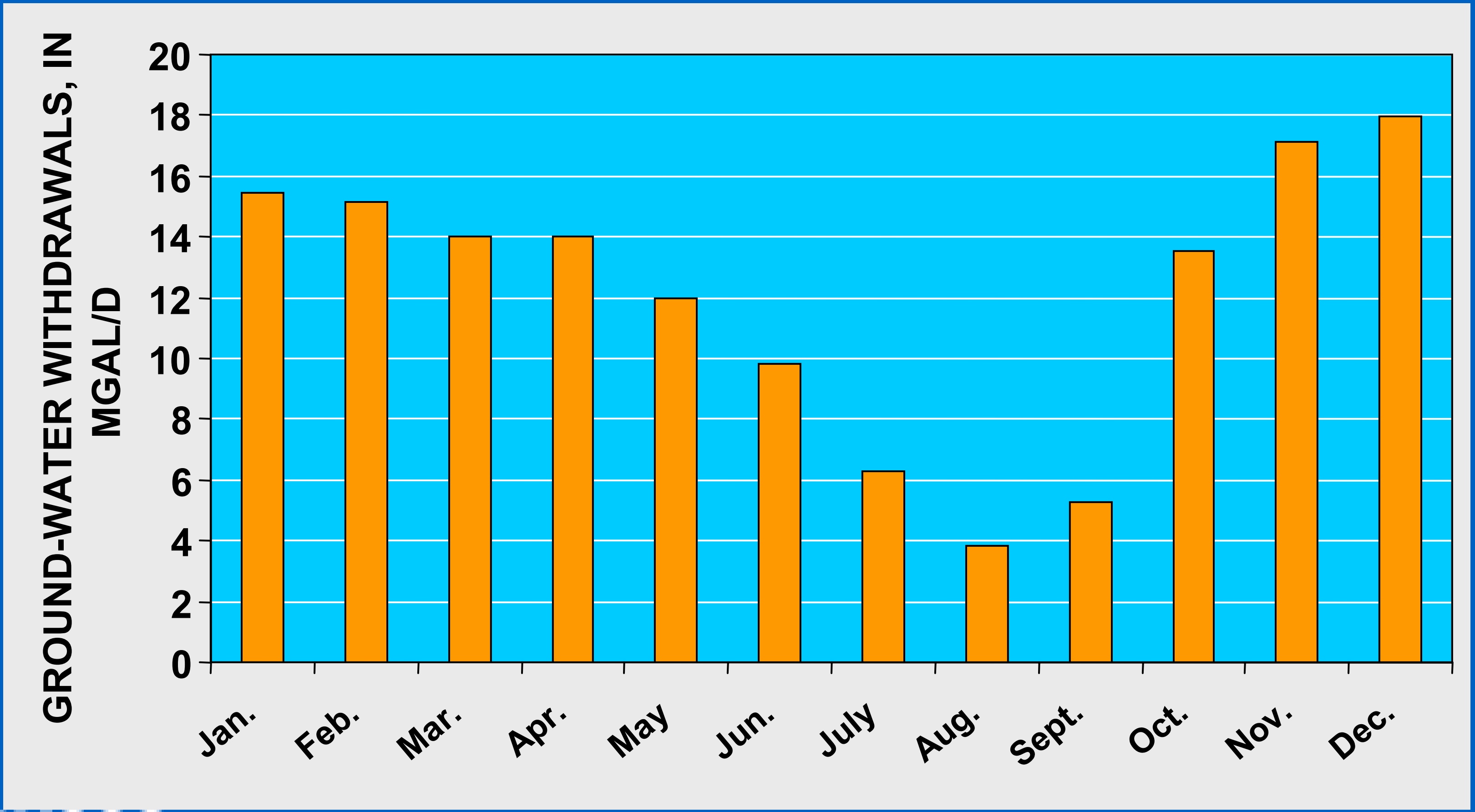


Results: Tradeoffs Between Instream-Flow Criteria and Ground-Water Withdrawals



Point A: Modified Annual Aquatic Base Flow (ABF) Criterion of 0.5 $ft^3/s/mi^2$

Monthly Withdrawal Pattern for Modified ABF Criterion (12 Mgal/d)



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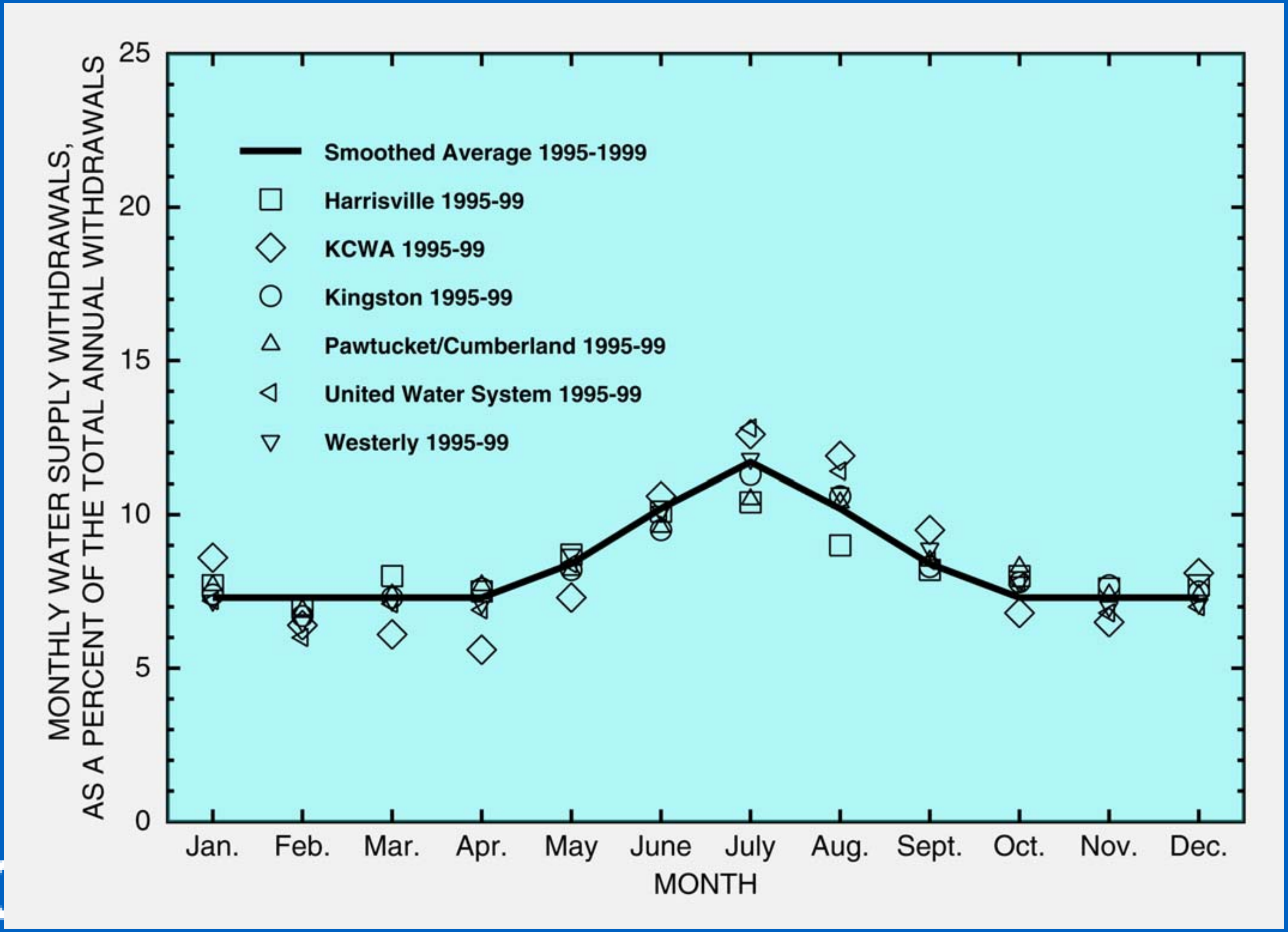
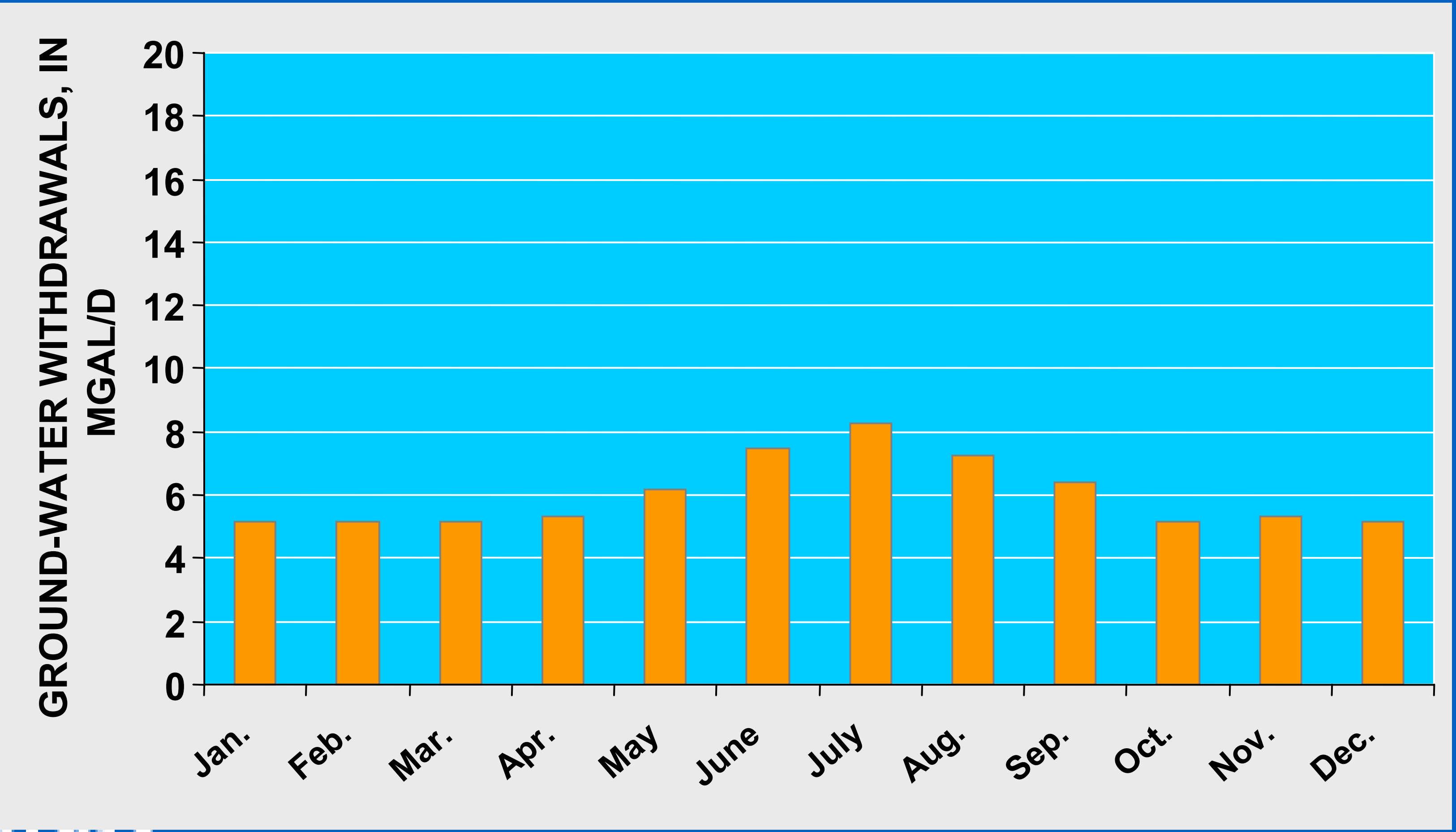
Typical Water-Supply Demand Patterns in Rhode Island



Withdrawals are Reduced to 6 Mgal/d if System Must Meet Typical Demand Pattern



Conclusions

- Simulation-optimization modeling
  - Provides effective means to determine tradeoffs between alternative instream-flow policies and sustainable levels of ground-water withdrawals
  - Provides insight into how the hydrogeologic system and water-supply demands affect management alternatives

Some Optimization-Modeling Resources

- USGS Fact Sheet:
  - “Use of Simulation-Optimization Modeling to Assess Regional Ground-Water Systems” (http://pubs.usgs.gov/fs/2005/3095/)
- GWM: a new process for MODFLOW-2000:
  - Available through USGS Ground-Water Software site:
    http://water.usgs.gov/software/ground_water.html
- Textbook by Ahlfeld and Mulligan (2000):
  - “Optimal Management of Flow in Groundwater Systems” (Academic Press)

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