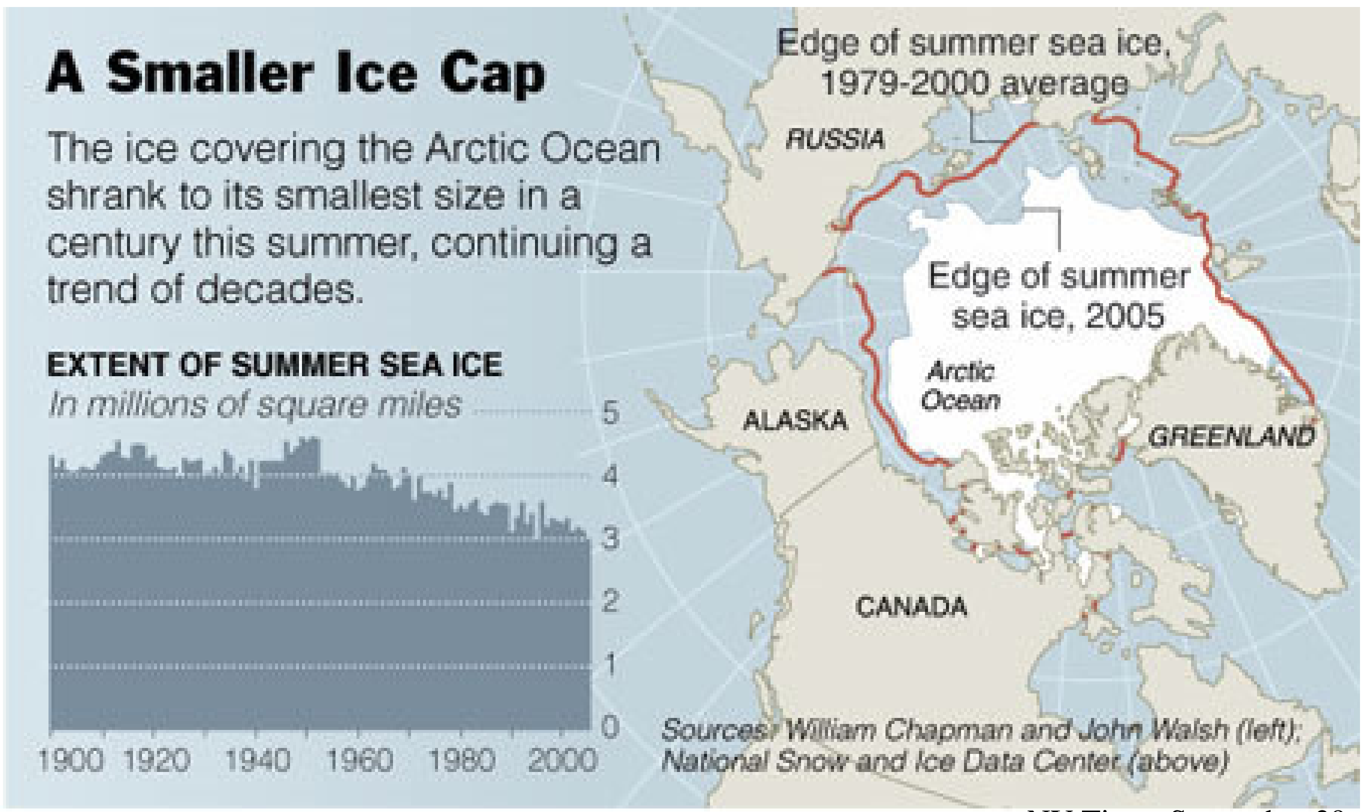
Climate Change and Cape Cod: Impacts on Water Resources and Planning Implications

David Ahlfeld, PhD, PE

Dept. of Civil and Environmental Engineering, UMass, Amherst

December 4, 2007



NY Times September 29, 2005

Impacts of climate change on water resources

Climate Change produces:

- changed precipitation, temperature, evaporation, streamflow… changed hydrology

Hydrologic changes can produce

- Threaten sustainability of human water supply
- Damage to aquatic ecosystems
- Shift in return periods for extreme events
- Agricultural and forestry patterns disrupted

New to Being Dry, the South Struggles to Adapt
Published: October 23, 2007

The New York Times October 23, 2007

John Bazemore/Associated Press

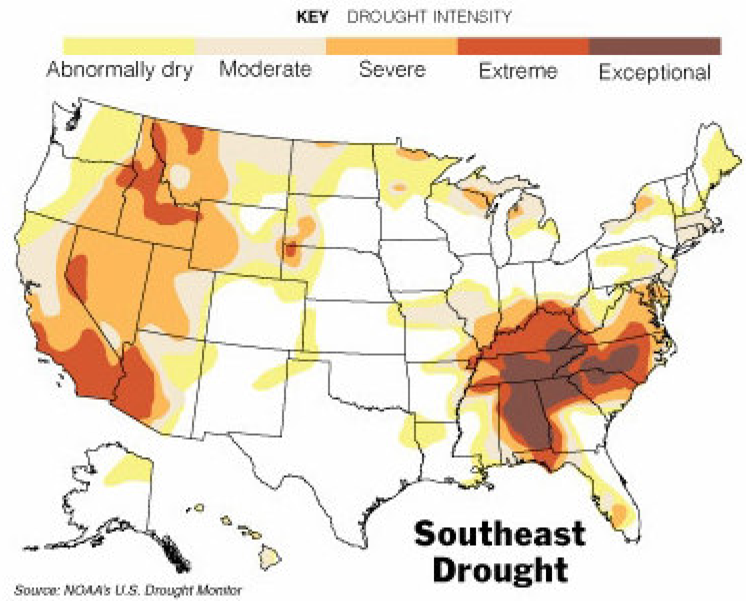
Low levels this month at Lake Lanier, which supplies water to Atlanta. The Southeast has been slow to respond to its drought.

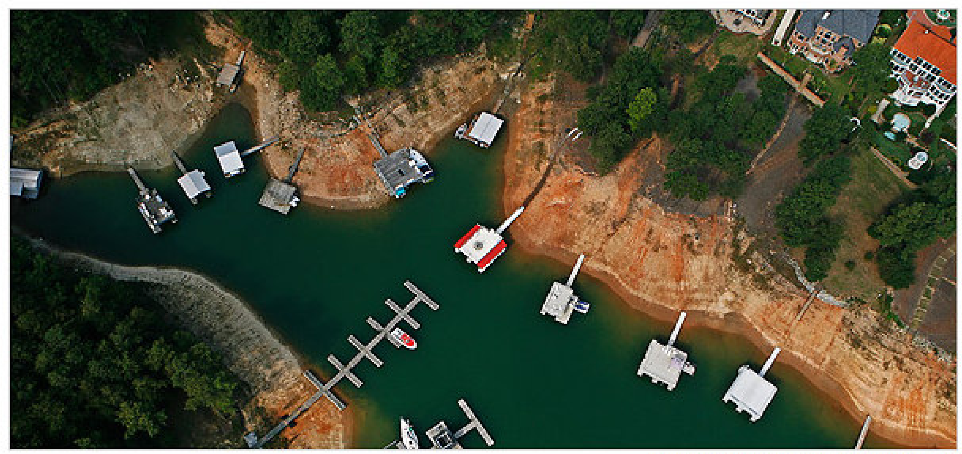
U.S. Acts to Bolster Supply of Water for Atlanta
Published: November 17, 2007

Georgia: Governor Orders Cuts In Water Use
Published: October 24, 2007

Drought-Stricken South Facing Tough Choices
Published: October 16, 2007

The New York Times October 15, 2007





Pouya Dianat/The Atlanta Journal-Constitution

Worst-case analyses indicate that Lake Lanier, the main water source for Atlanta, could be drained dry within four months.

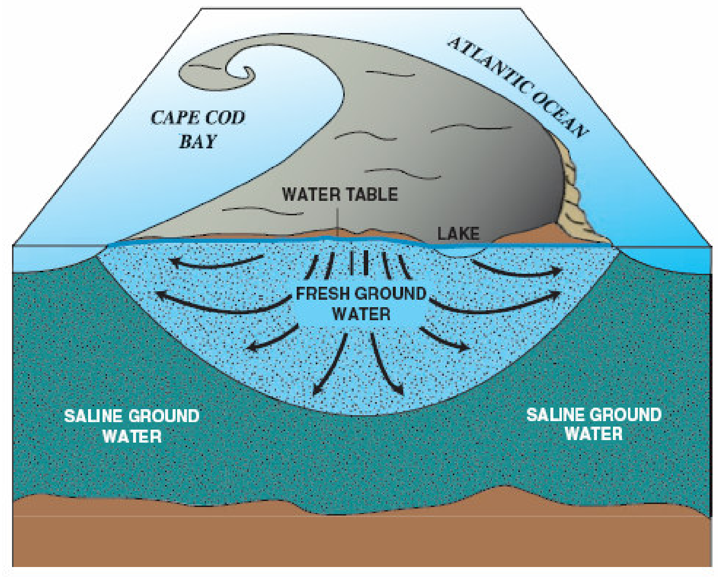
Drought Saps the Southeast, and Its Farmers
Published: July 4, 2007

Georgia: Water Cutbacks
Published: October 25, 2007

Can it happen here?

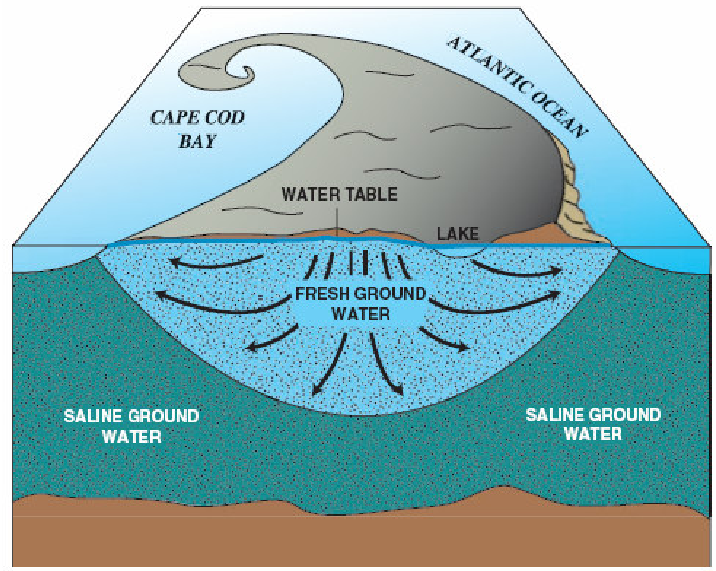
- Cape Cod water sources are groundwater wells
- Cape Cod water supply depends on precipitation and infiltration
- Cape Cod water “reservoir” is the aquifer beneath the Cape
- Understanding climate risk requires understanding risks to the aquifer.

Cape Cod Groundwater



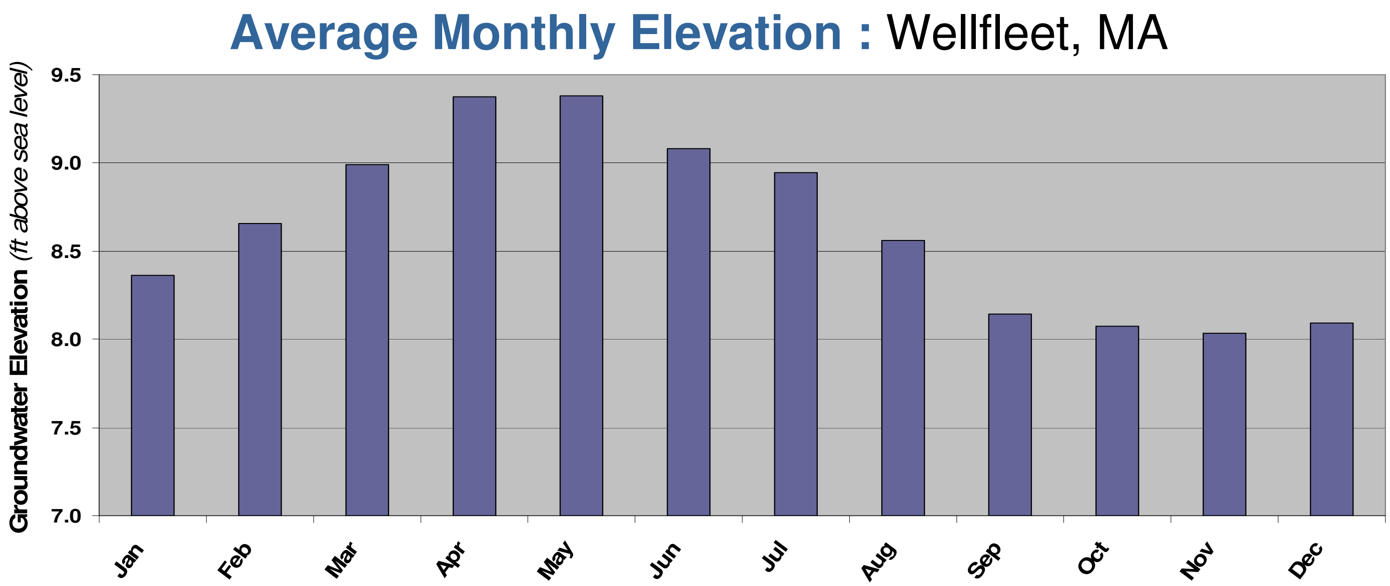
- Geology
  - Glacial Outwash sands and gravels: 50 to 200 feet thick
  - Underlain by bedrock, till and silts/clays

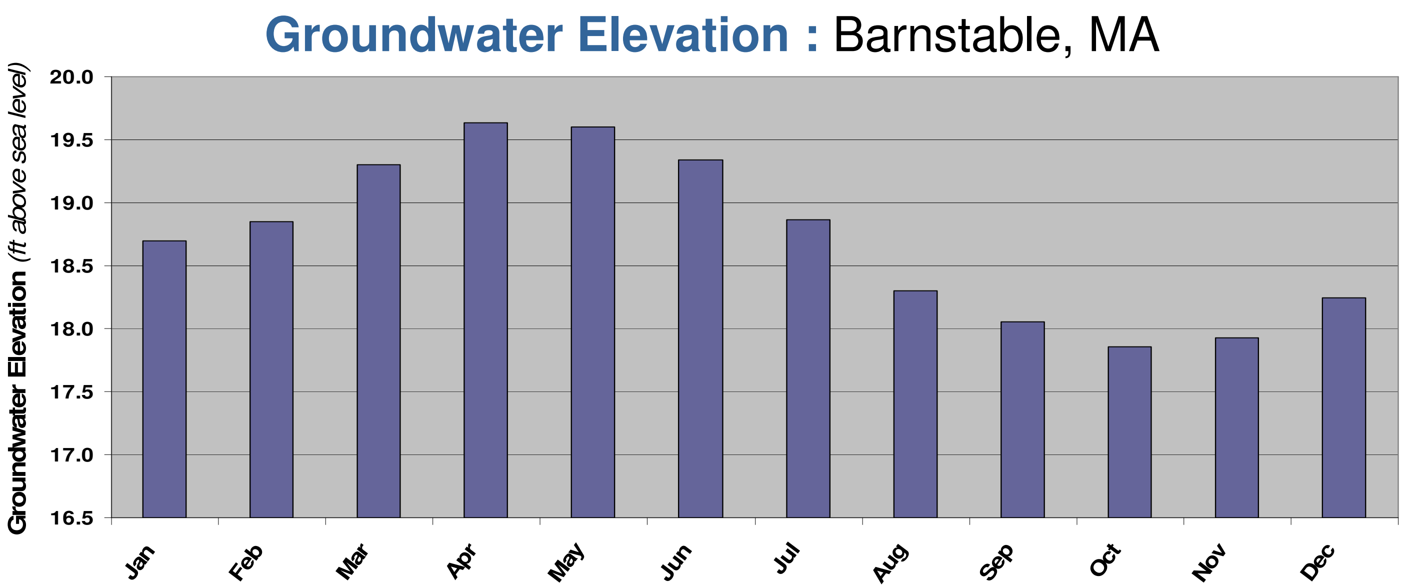
Cape Cod Groundwater



- Average Annual Water Balance
  - Precipitation: 40 inches
  - Recharge to Aquifer: 18 inches
  - Evapotranspiration: 22 inches
  - Annual flow-through 270 MGD (million gallons per day)
  - Freshwater stored in lens above salt-water

Aquifer recharged by precipitation, drawn down by human use and evapotranspiration

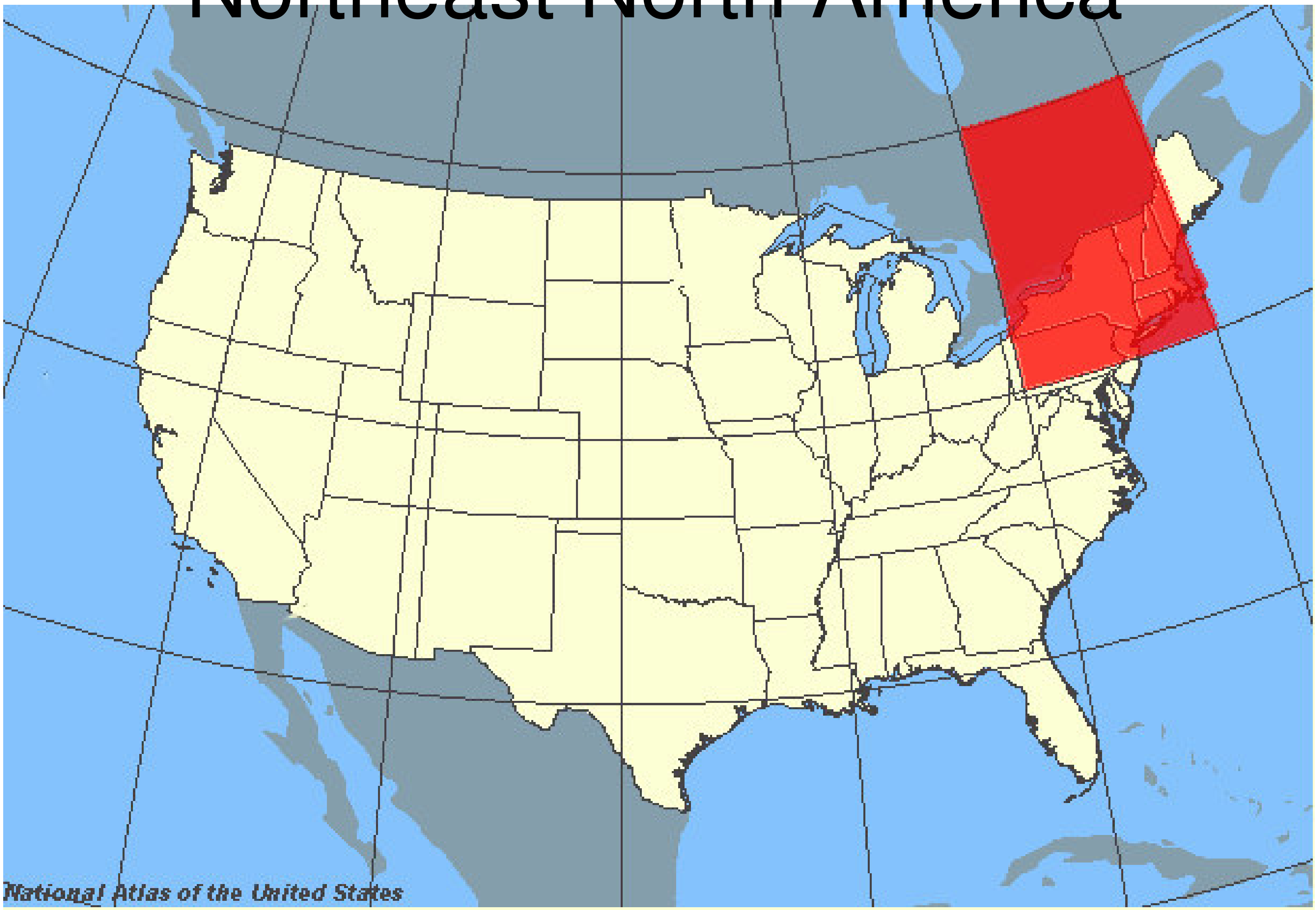




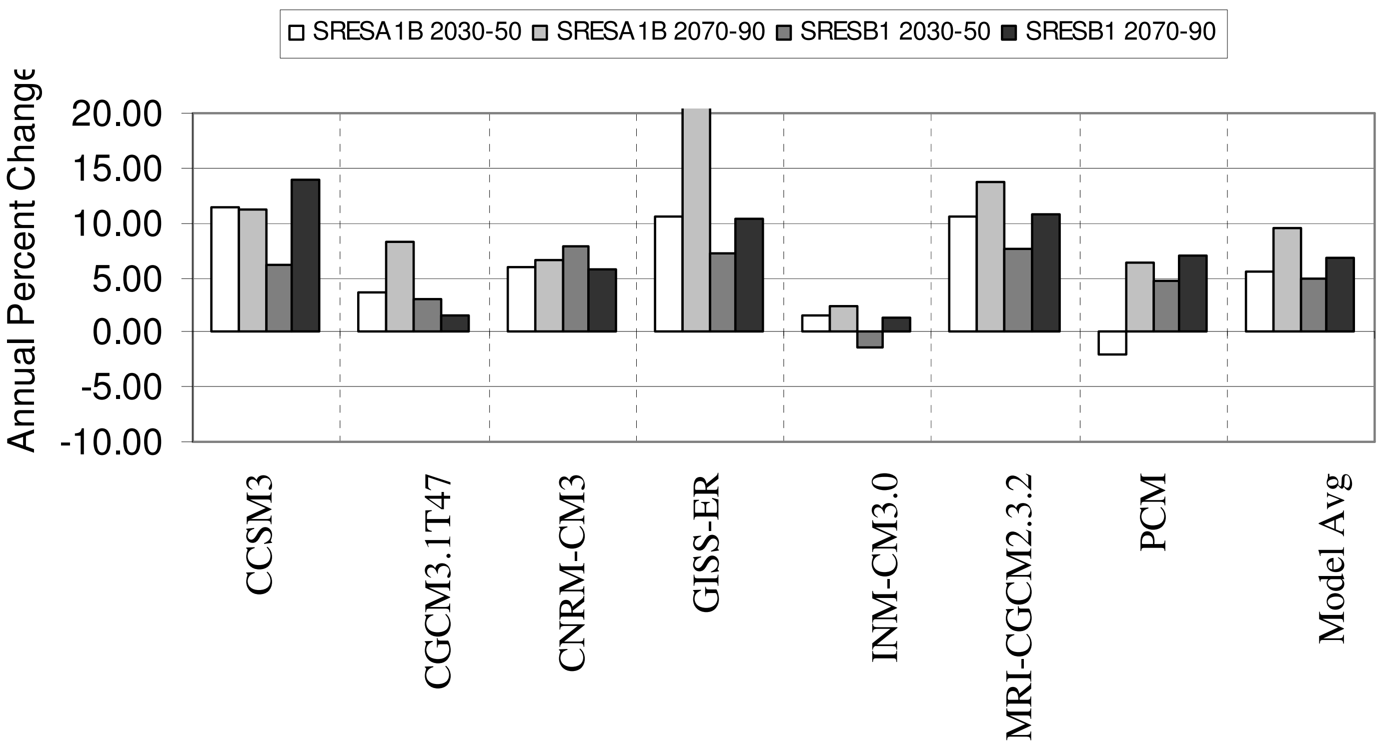
Major Threats to Groundwater

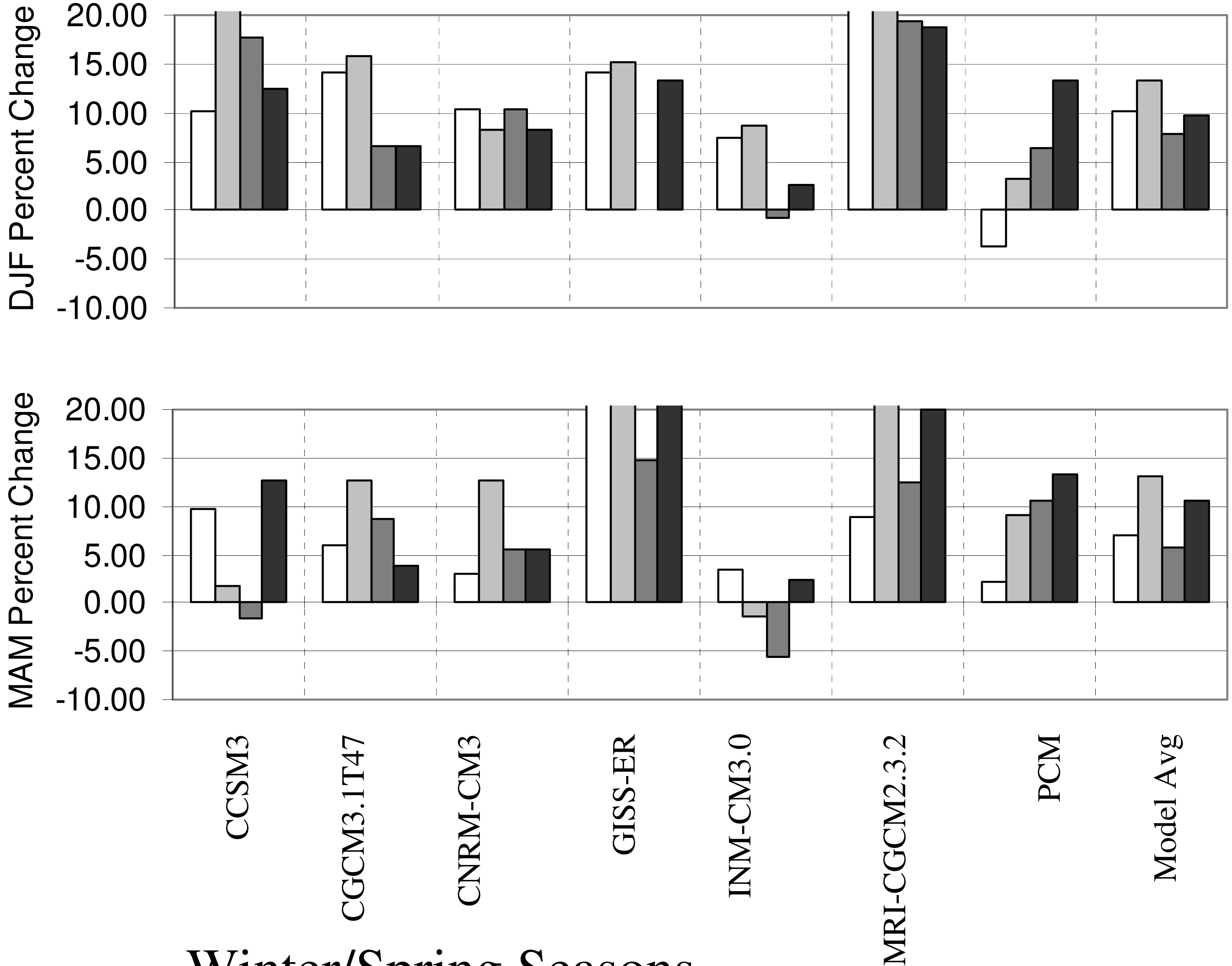
- Decrease in recharge to groundwater
  - Decreased precipitation
  - Increased evapotranspiration/runoff
- Decrease in storage volume
  - Rising sea level
- Degradation of water quality
  - Salt-water intrusion

GCM Analysis for Northeast North America



Percent change in Annual Precipitation from model predicted 20th century values averaged over the 20 year period



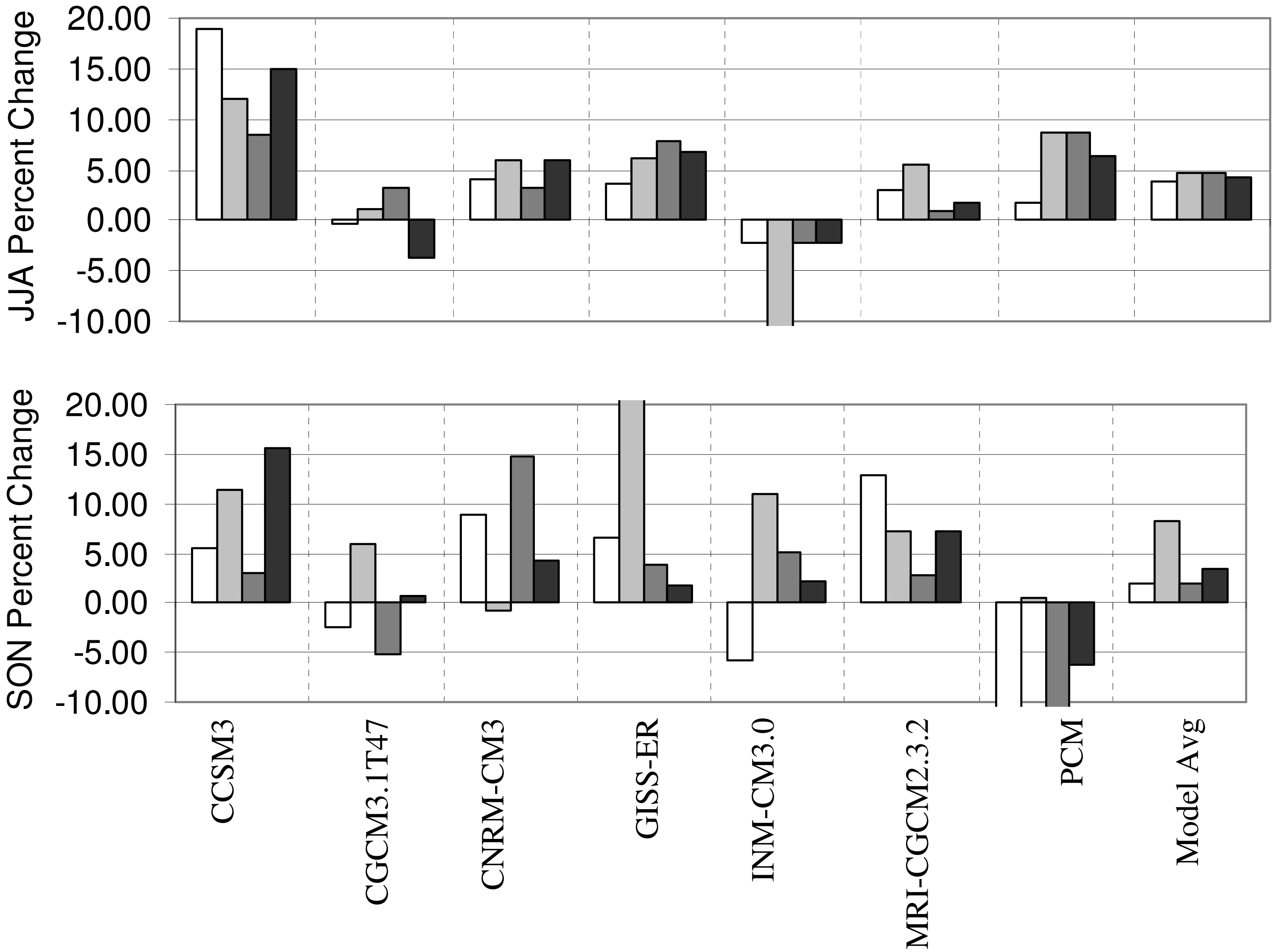


Winter/Spring Seasons

Percent change from 20th century model result

Averaged over 20 years

Summer/Fall Seasons
Percent change from 20th century model result
Averaged over 20 years



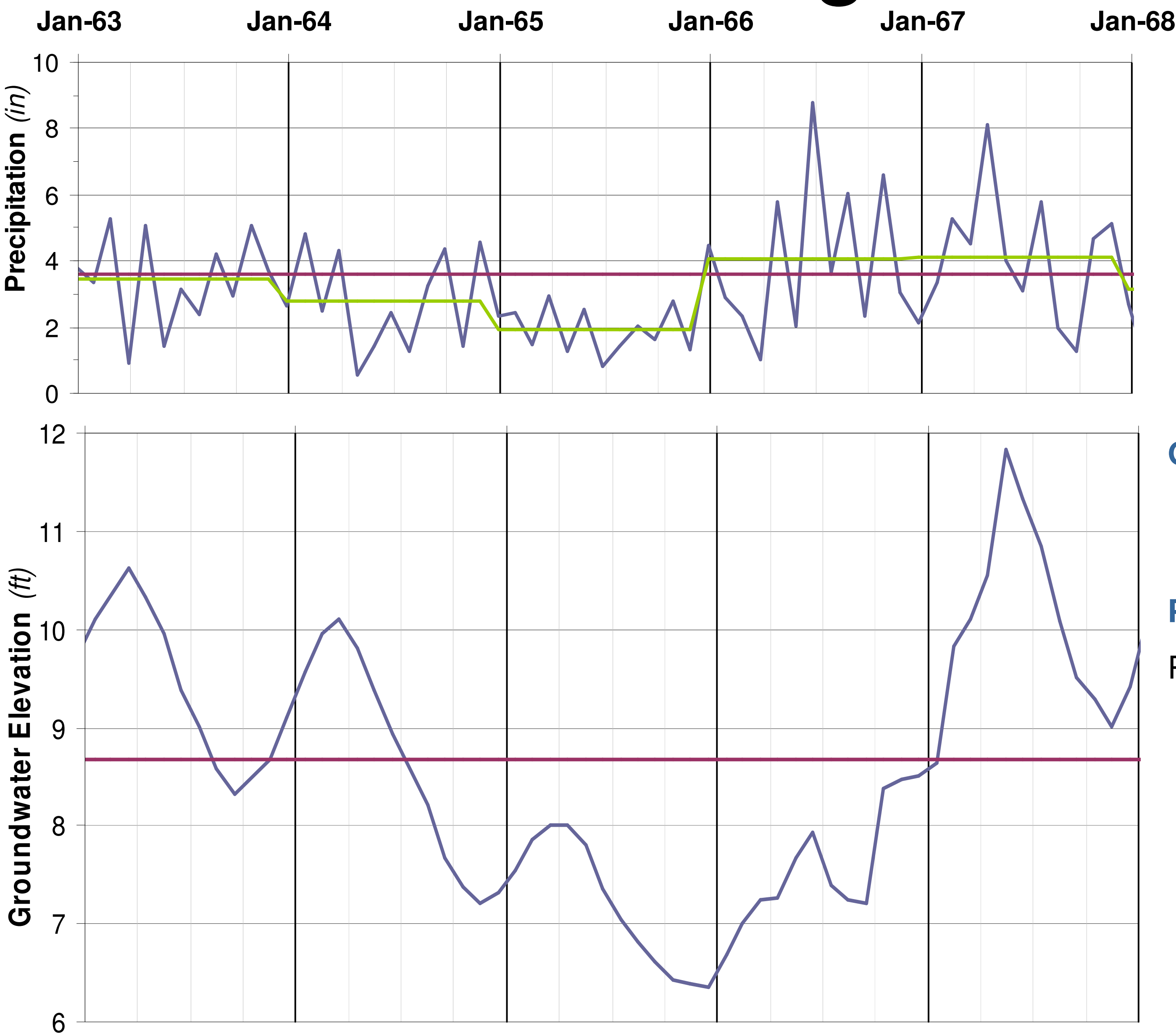
Observations for Northeast North America

- Models are generally consistent that climate change will include:
  - More precipitation
  - Precipitation changes are highest in winter and smallest in fall.
  - Temperatures increase by one to two degrees Centigrade during 21st century.
  - Temperature increases distributed across seasons.

Implications for Water Supply

- More precipitation => Good!
- Higher temperatures:
  - More evaporation
  - Lengthened growing season
  - More transpiration
- More intense storms
  - More direct runoff
  - Less infiltration
- More frequent droughts

1960's Drought



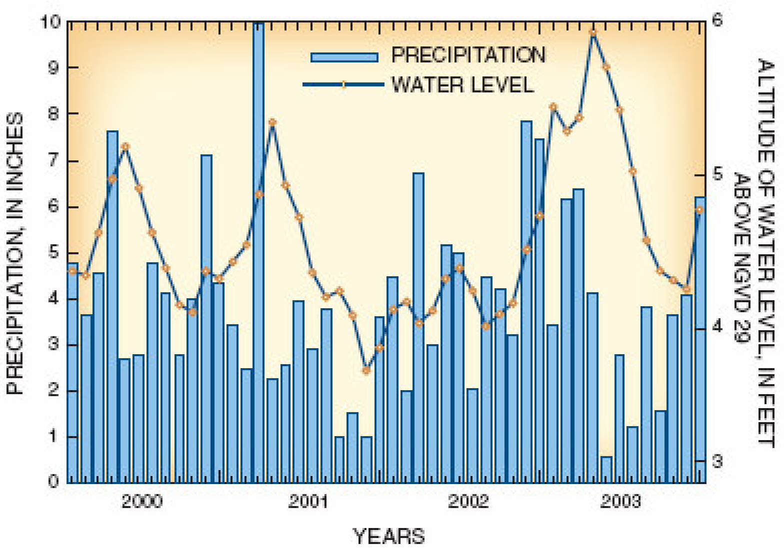
Groundwater Elevation :

Wellfleet, MA

Precipitation :

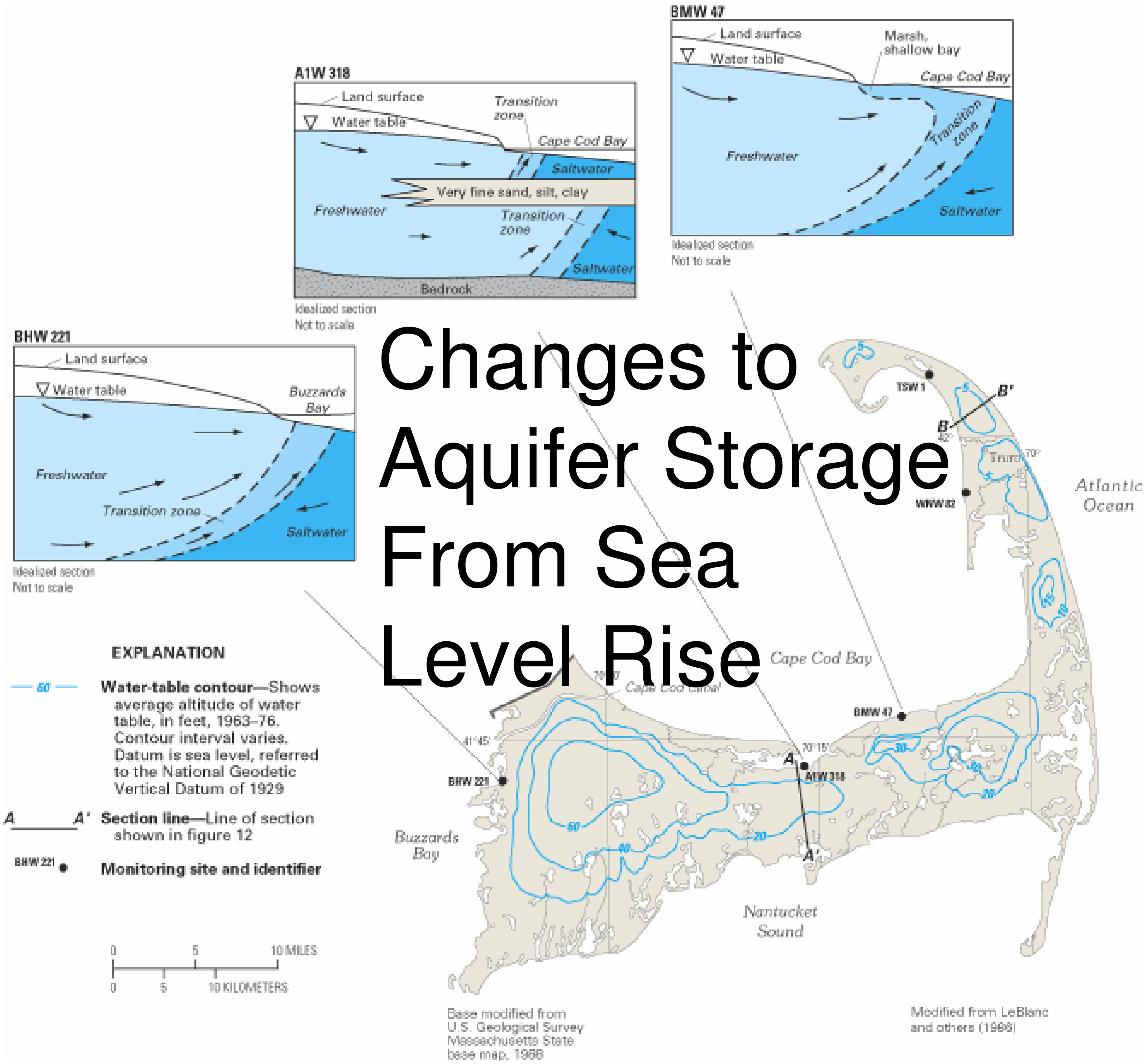
Provincetown, MA

Possible Impacts on Aquifer

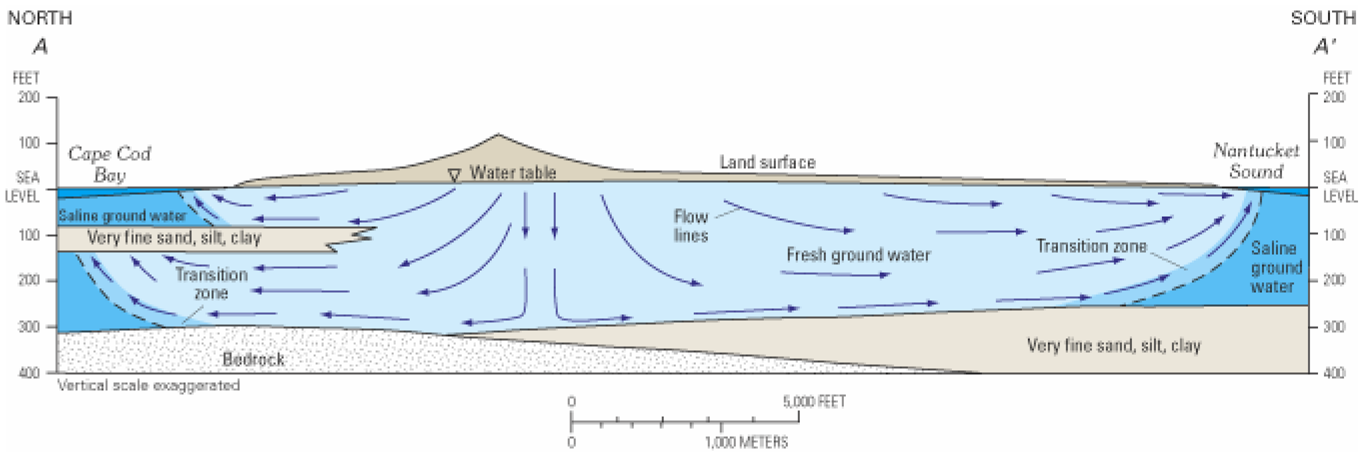


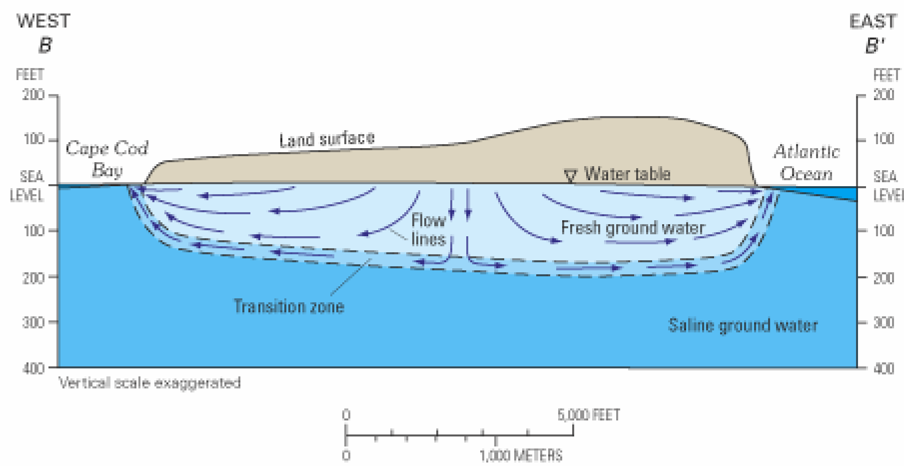
- More winter infiltration – higher winter rise in water table
- Less summer infiltration – larger summer drop in water table
- Larger changes in streamflow and pond elevations

Changes to Aquifer Storage From Sea Level Rise



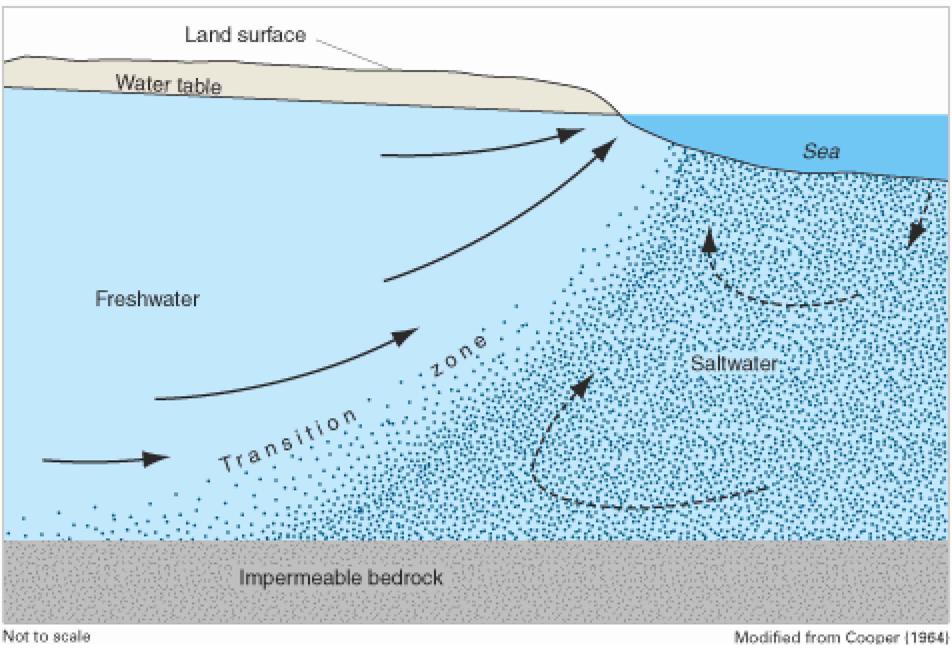
Cape Cod cross sections





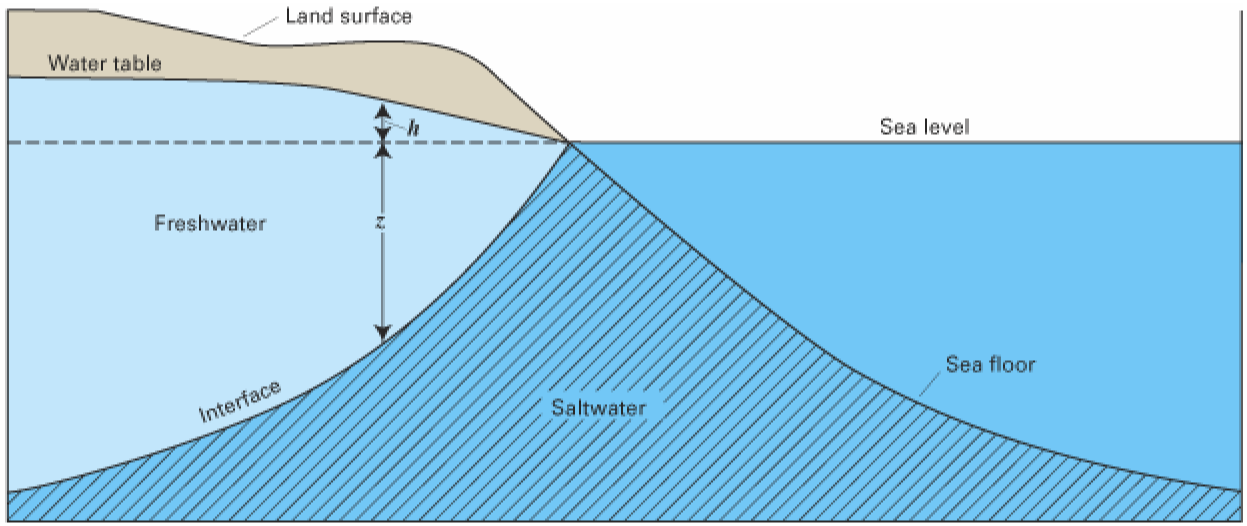
Figures modified from LeBlanc and others (1986); sea level refers to National Geodetic Vertical Datum of 1929

Coastal Fresh/Salt Grounwater



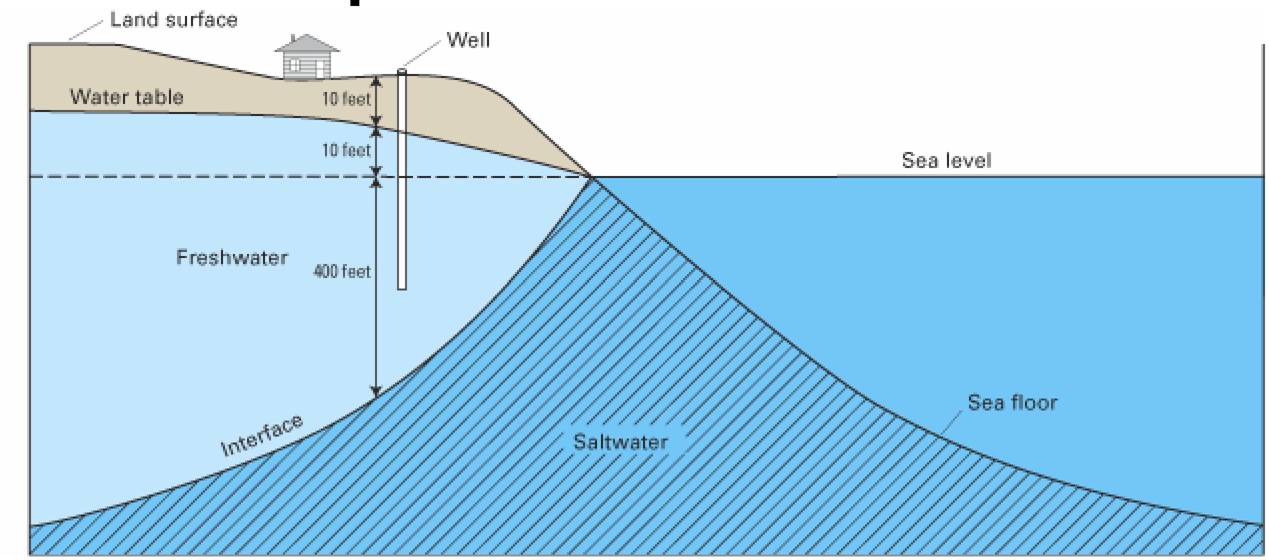
- Denser saltwater intrudes beneath freshwater
- Lighter freshwater maintained by pressure from water table
- In transition zone, freshwater degraded by high chloride levels

Simplified Freshwater/Saltwater



- Water table elevation above sea level influences depth to fresh/salt interface

Relationship of Head and Interface



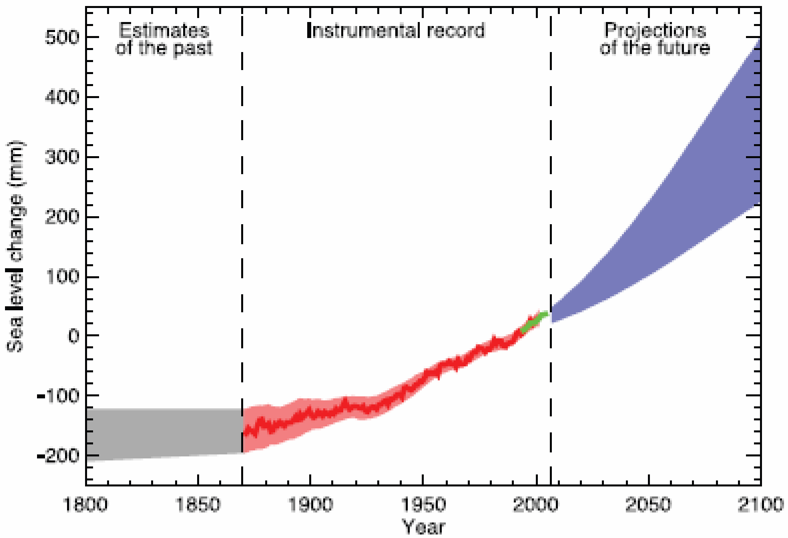
- Depth of interface below sea level is 40 times the water table elevation above sea level
- If head is 10 feet, freshwater interface about 400 feet below sea level.
- Based on density differences and pressure balance
- Transition caused by fluctuations in water table and sea level (tides)

Table TS.6. *Projected global average surface warming and sea level rise at the end of the 21st century. {10.5, 10.6, Table 10.7}*

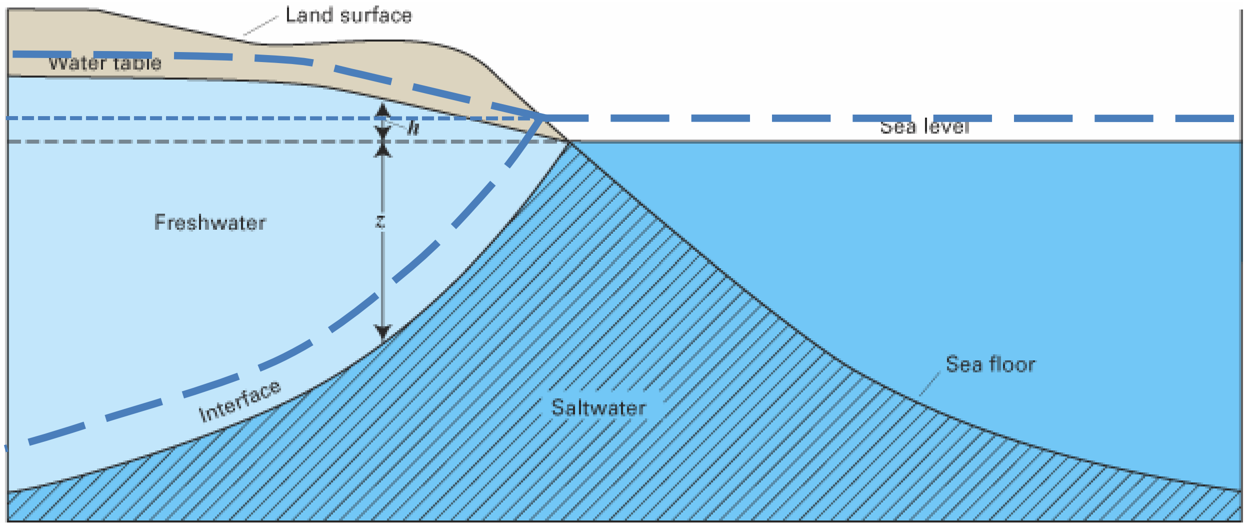
Case	Temperature Change (°C at 2090-2099 relative to 1980-1999)[a]		Sea Level Rise (m at 2090-2099 relative to 1980-1999)
	Best estimate	*Likely* range	Model-based range excluding future rapid dynamical changes in ice flow
Constant Year 2000 concentrations[b]	0.6	0.3 – 0.9	NA
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

Notes:
[a] These estimates are assessed from a hierarchy of models that encompass a simple climate model, several Earth Models of Intermediate Complexity (EMICs), and a large number of Atmosphere-Ocean Global Circulation Models (AOGCMs).
[b] Year 2000 constant composition is derived from AOGCMs only.

Projected sea level rise

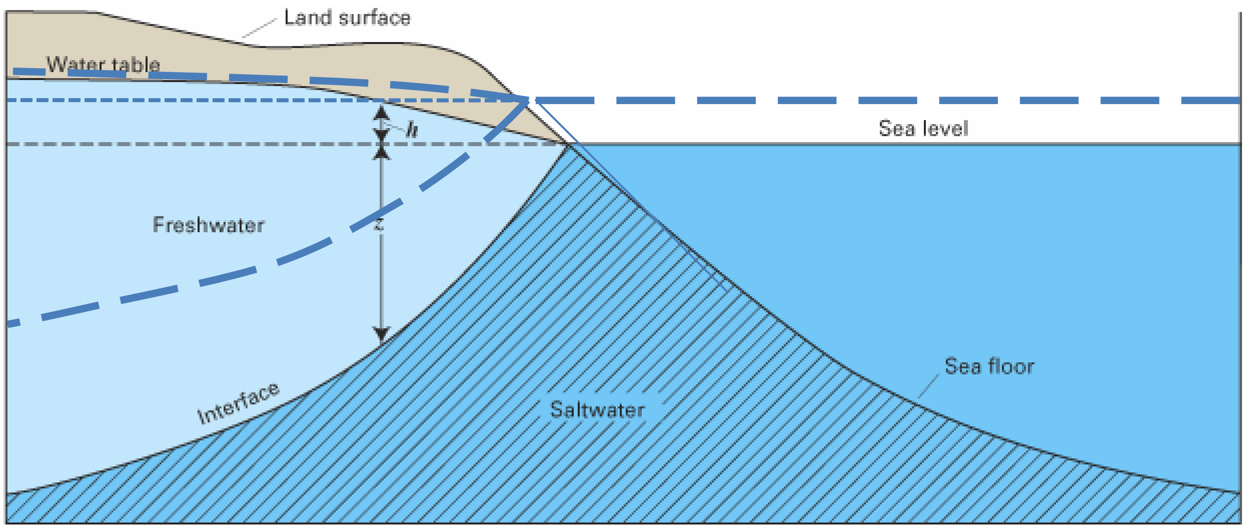


Impact of Sea Level Rise on Aquifer Storage

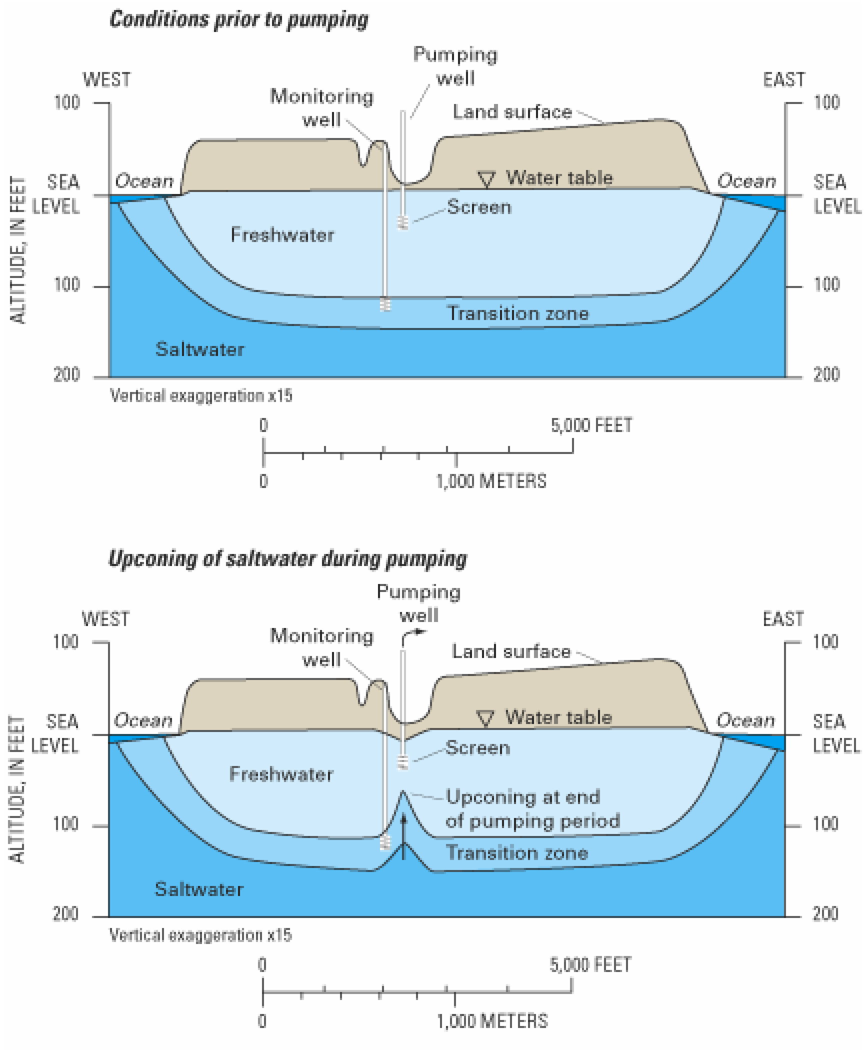


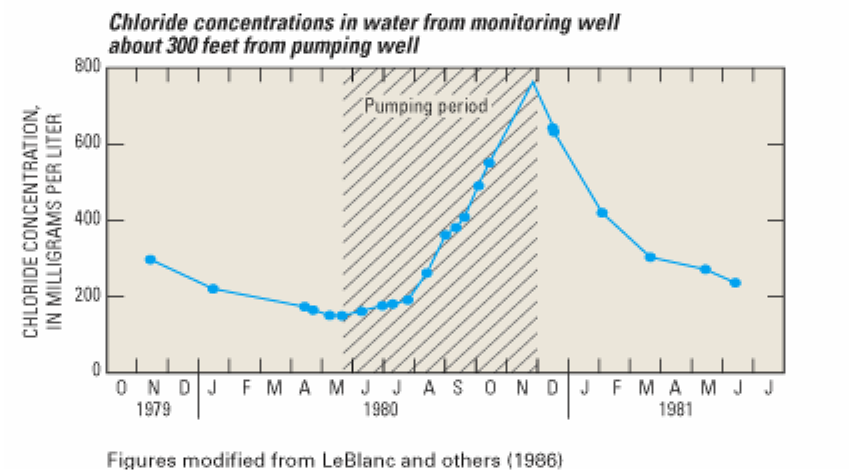
- Case 1: Water table rises with sea level
  - Freshwater/salt water interface moves slightly landward
  - Higher levels in ponds, same storage in aquifer

Impact of Sea Level Rise on Aquifer Storage



- Case 2: Water table rise limited by surface hydrologic features
  - More flow in streams, less storage in aquifer
  - Freshwater/salt water interface moves upward



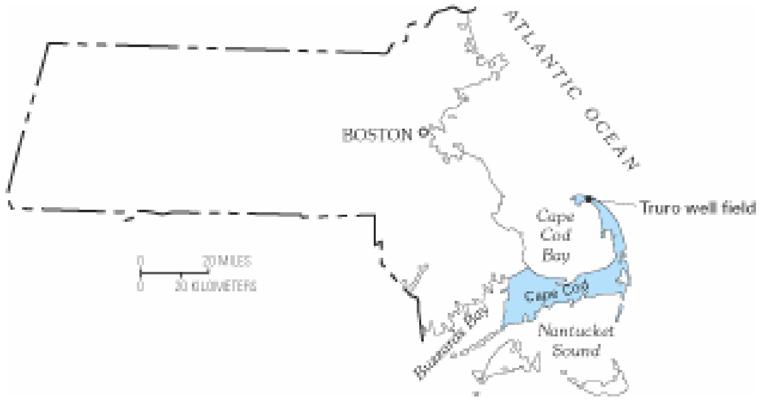


Truro experience with salt water intrusion

- Pumping caused upconing of saltwater
- Cessation of pumping reversed chloride trend

Conclusions

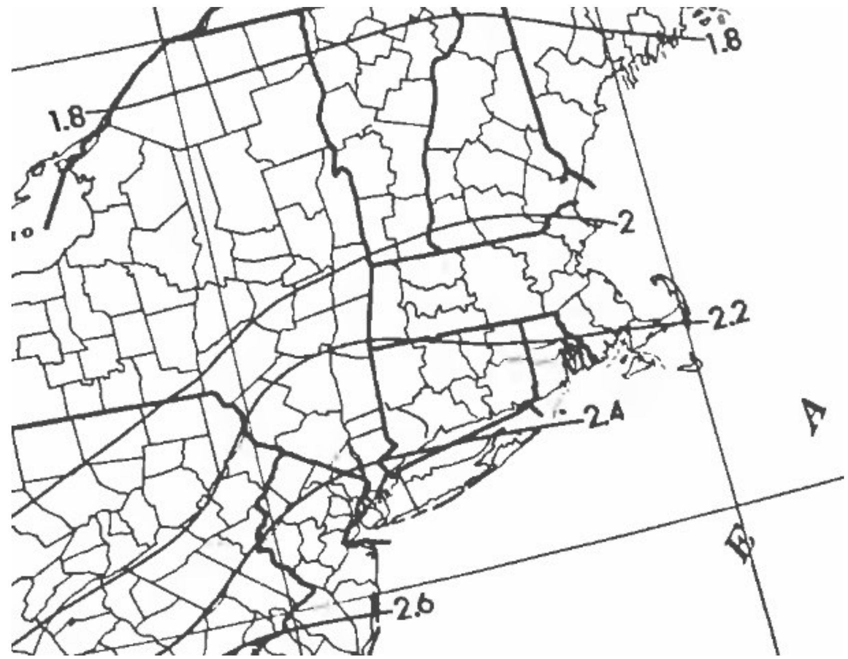
- Cape Cod aquifer is a valuable water resource
- Future periods of extended drought may produce saltwater intrusion
- Maximizing groundwater recharge is beneficial
- Sea level rise may cause reduction in thickness of freshwater lens increasing risk of upconing of saltwater.
- Detailed local studies needed for careful pumping of groundwater



Ongoing USGS monitoring at Truro

More Extreme Events

- Storm Drainage design based on frequency of storm event
  - 25 year storm has a certain intensity (in/hr)
  - Storm intensity determined from historical records of past storms
  - “Stationarity is dead”: Changing climate means past patterns poor predictor of future patterns
- Assume that current design standards underpredict stormflow needs



25-Year 1-hour Rainfall (inches)

References:

USGS Circular 1262,Ground Water in Freshwater-Saltwater Environments of the Atlantic Coast, by Paul M. Barlow, 2003.

Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions: A report of the Northeast Climate Impacts Assessment (NECIA), July 2007, Union of Concerned Scientists.

Thanks to

– USGS for slides
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