# THE NEW ENGLAND COASTAL BASINS
## *A PROPOSAL FOR A LONG-TERM HYDROLOGIC OBSERVATORY*

## Introduction

The New England Coastal Basins have a long history of industrialization. The first textile mill in the United States was constructed in Rhode Island on the Blackstone River in the late 1700s, heralding a new era in American industrialization. From the 18$^{th}$ century to the present day, water resources in the New England Coastal Basins have continued to be used for power generation, as well as other uses such as sources of drinking water, and recreation. A legacy of more than two centuries of industrialization and urbanization has had a profound impact on the landscape, hydrology, and water quality of the New England Coastal Basins.

## Site Characteristics

The New England Coastal Basins (see Figure 1) drain 23,000 square miles of western and central Maine, central and eastern New Hampshire, eastern Massachusetts, and most of Rhode Island (Flanagan *et al*., 1999). The largest rivers are the Kennebec (5,893 mi$^2$), Androscoggin (3,524 mi$^2$), Saco (1,700 mi$^2$), and Merrimack (5,010 mi$^2$) that drain the northern two-thirds of the region. Rivers draining the southern one-third of the region include the Charles (321 mi$^2$) and the Blackstone (480 mi$^2$). The Kennebec, Androscoggin, Saco, and Merrimack Rivers originate in the mountainous and forested Northeastern Highlands ecoregion, and drain southeasterly to the hilly plains of the Northeastern Coastal Zone or the Laurentian Plains and Hills ecoregions. The southern watersheds of the Blackstone and Charles Rivers are within the Northeastern Coastal Zone ecoregion (Omernik, 1987).

The New England Coastal Basins are mainly underlain with near-surface bedrock creating strong connections with overlying surficial sediments. . Bedrock lithology consists of mostly igneous and metamorphic rocks with varying degrees of fracturing and mineralogy. Glacial deposits of clay, silt, sand, gravel are found along stream valleys and coastal plains and serve as sole-source aquifers in many parts of the basin. In the upland areas, the dominant glacial deposit is till (Flanagan *et al*., 1999). High arsenic levels (>10 µg/L) have been found in groundwater supplies, and a geologic source has been suggested (Ayotte *et al*., 2003).

The climate of the basins consists of cold winters, and cool summers. Peak streamflows occur during the spring as a result of snowmelt and precipitation. The average annual precipitation ranges from 42 inches in low-lying coastal regions to greater than 60 inches in mountainous regions (Flanagan *et al*., 1999).

Water quality and aquatic ecosystem health is closely related to human activity - both past and present. Residential, commercial, and industrial land uses have been associated with rapid degradation of stream ecosystems during the process of urbanization. From the early to mid-1990s, the basins were predominantly forested (72 percent), with 8 percent of the land classified as urban, and 6 percent as agricultural. Figure 2 provides a map of land use in the New England Coastal Basins. The population of the New England Coastal Basins increased 6.8 percent from

1990 to 2000 from 7.78 million to 8.31 million people. In 2000, the majority of the population lived along the coast (Robinson *et al*., 2004).

The National Water Quality Assessment Program found that water quality impairments, such as arsenic, chromium, copper, cadmium, lead, mercury, and zinc in streambed sediments, and VOCs such as the gasoline additive methyl tert-butyl ether (MTBE) were associated with urban sources. The occurrence of VOCs was more common in waters of the New England Coastal Basins than in waters in other urban areas of the Nation, and was explained by the widespread use of MTBE in gasoline, in addition to a long history of industrial activity in New England (Robinson *et al*., 2004).

Withdrawals for water supply total 1.43 billion gallons per day, nearly 70 percent of which is taken from rivers and reservoirs. Major cities such as Boston, Providence, and Portland obtain their water supply from reservoirs. Interbasin transfer of water to meet water supply needs is common in the New England Coastal Basins. The Quabbin Reservoir, located outside of the New England Coastal Basins study unit, supplies the City of Boston with 149 million gallons of water per day (Robinson *et al*., 2004). Within the New England Coastal Basins, another example of interbasin transfer is the Ipswich River Basin in northeastern Massachusetts from which water is withdrawn for water supply outside of the Ipswich basin, and not returned (Zariello, 2004).

The cumulative effects of interbasin transfers of water, both from within the New England Coastal Basins, in addition to external transfers, are of major scientific interest with respect to the creation of a Hydrologic Observatory for this region.

## Uniqueness of the New England Coastal Basins for a Hydrologic Observatory

Many characteristics of the New England Coastal Basins are unique, and include:

- Urban and industrial developments that are among the oldest in the United States - long-term impacts from human activities and related changes of land use and land cover can be studied
- Numerous examples of consumptive water use and interbasin transfers exist, affecting both water quantity and water quality
- Climate and hydrologic records of greater length than most regions of the United States due to the age of settlements
- Densely populated and heavily urbanized regions
- The use of de-icing agents during winter months that can serve as tracers for flux estimation
- Short groundwater residence times ideal for tritium dating for flux estimation
- Shallow water tables highlight direct interaction of groundwater, surface water, and atmospheric control volumes
- Humid climate ensures moist, oxygenated unsaturated zones that support aerobic biomass and natural near surface bioremediation potential
- Watershed length scales are ideal for airborne mapping by radar, infrared, and digital photography
- Well established GIS infrastructure across the region

- Former agricultural areas were widely abandoned in the mid 19th century, reverting back to forest. Reforestation continued through to the mid 20th century after which time urbanization became the primary land use change
- Large-scale atmospheric deposition of nitrogen and mercury, with levels among the highest in the United States

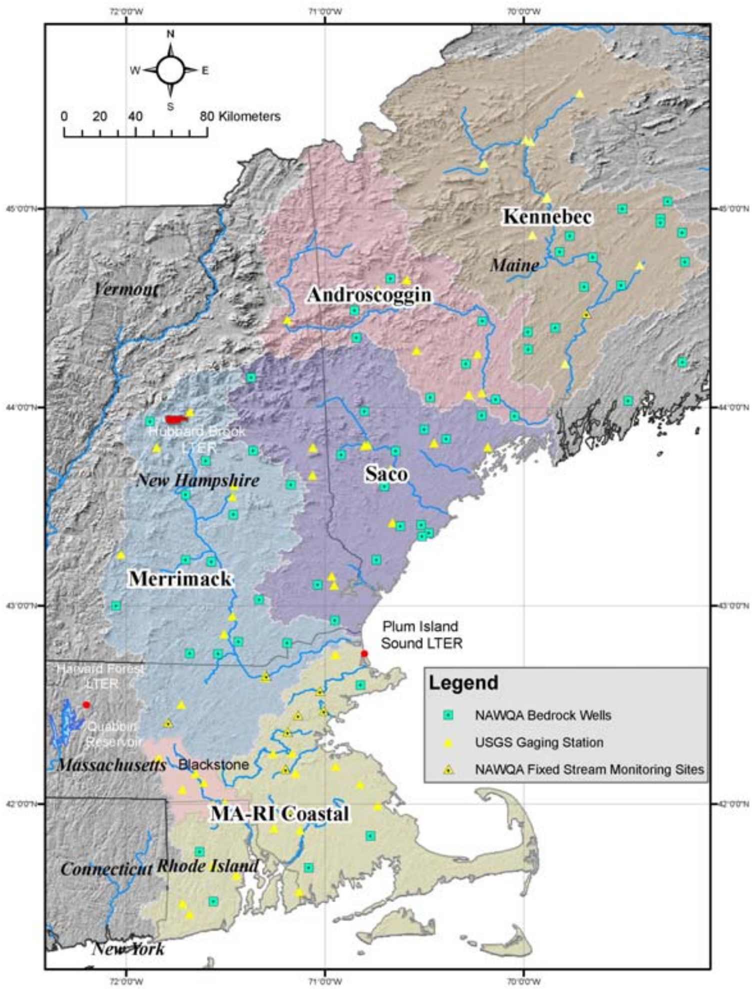


Figure 1. Map and gaging stations of the New England Coastal Basins.

## Scientific Questions

*How are interbasin transfers of water affecting the water budget, and water quality?*

- Are water transfers sustainable for basins involved?
- Are consumptive industrial uses of water (for example in the Upper Charles River) sustainable?
- Are receiving basins being impacted by increased levels of pathogens, endocrine disrupters from wastewater treatment plant effluents?

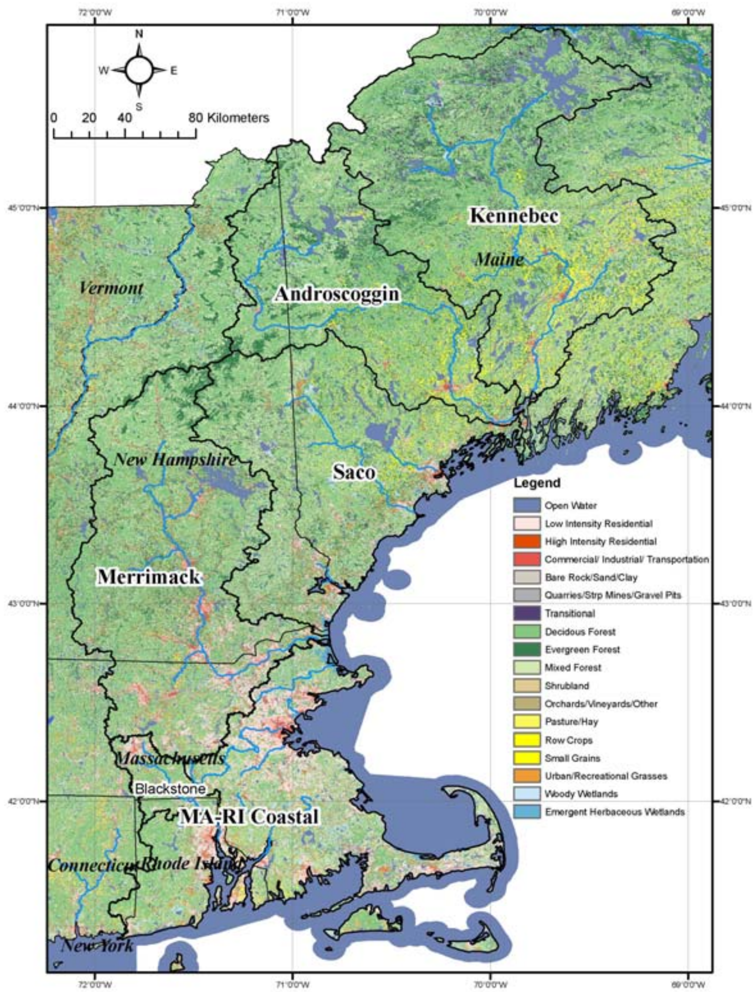


Figure 2. Land use in the New England Coastal Basins.

*How important are groundwater/ surface water interactions?*

- How well are groundwater and surface waters connected?
- With shorter travel times in the New England Coastal Basins as compared to semi-arid regions, what are the effects on groundwater recharge and discharge to surface waters?
- Can we use conservative and isotopic groundwater tracers to hindcast present aquifer pollution from historically contaminated surface water sources? Can we use these tracers to predict marine contamination where coastal aquifers discharge into the ocean?

*What are the effects of atmospheric deposition of nitrogen and mercury?*

- With a consumption advisory for all of Massachusetts, what are the sources of high mercury levels in fish in New England?
- How are rivers and lake ecosystems responding to acidification?

*Rivers such as the Blackstone, have approximately 1 dam for every mile. What are the cumulative effects of channel modification?*

- How does channel modification affect base flow?
- What are the effects of habitat fragmentation?
- As many dams are slated for removal, what are the impacts of dam removal (resuspension of heavy metal laden sediments, etc.)?

*What are the cumulative effects of increasing urbanization on ground and surface water hydrology, water quality, and the health of the coastal bays?*

- As forested land becomes impervious, what are the effects on groundwater recharge, and surface water hydrology?
- How are densely populated areas contributing to higher levels of contaminants, such as pathogens, nutrients, and metals?
- How do hydraulic residence times, chemical reaction times, and microbial kinetics govern the response of surface and groundwater to stormwater runoff?

*How are riverine and groundwater fluxes affecting the coastal bays?*

- How are "red tides" and the presence of algal neurotoxins in coastal bays connected to $H_20$ and biogeochemical fluxes from coastal watersheds?
- How are wastewater effluents from large coastal cities impacting the coastal bays?
- How are groundwater plumes from wastewater infiltration basins impacting coastal sediments and benthos?

*How will climate change affect $H_20$ fluxes in the New England Coastal Basins?*

- What will be the impact of climate change on water resources?
- What will be the biological response to changing watershed hydrology?
- Will the management of water resources be sustainable for human uses and ecosystem functions?
- What will be the effects on $H_20$ fluxes with a predicted rise in sea level?
- What is the decadal scale response of surface moisture, water table elevation, and recharge to long term changes in temperature and insolation?

## Existing Data Infrastructure

*Long-Term Ecological Research (LTER) Sites*

Two LTER sites are located within the proposed study area, each with a unique set of goals. The first, Hubbard Brook that flows into a tributary of the Merrimack River, has been in existence since 1956. It has been continuously measured for streamflow and precipitation (Schenck Bailey *et al*., 2003). Data on air and soil temperature, snow cover, soil frost, solar radiation, windspeed and direction, and humidity have been collected as part of the ongoing Hubbard Brook Ecosystem Study (HBES). The Hubbard Brook LTER has examined the cycling of water, nutrients, and energy in forests and related aquatic ecosystems. The second LTER, Plum Island Ecosystem was established in 1998 with the goal of developing an understanding of the long-term dynamics of watershed and estuarine ecosystems at the land-sea interface. The Plum Island Ecosystem is made up of the Plum Island Sound estuary, its coupled Parker and Ipswich River basins and the coastal ocean.

In addition to the LTER sites located within the New England Coastal Basins, another LTER site, Harvard Forest, is located nearby within the Connecticut River Watershed. A portion of the Harvard Forest is within the Quabbin Reservoir Watershed, which supplies water to the Massachusetts Water Resources Authority. Water is transferred out of the Connecticut River Basin to the New England Coastal Basins Region to provide Boston, and other communities with drinking water.

*Microwave Remote Sensing Laboratory*

To this end, the Microwave Remote Sensing Laboratory in the Electrical and Computer Engineering Department of the University of Massachusetts at Amherst has developed more than a score of advanced instruments to study hydrological phenomena from remote (aircraft) sensors over a 25 year period (Swift et al. 1991). One project, which lasted for more than a decade, concerned the development (under NASA funding) of a very long wavelength (21 cm) passive microwave instrument which can remotely sense changes in soil moisture through corresponding changes in microwave thermal emission caused by changes in the soil water content. The microwave device, when coupled with airborne temperature probes and land based short and long wave radiation arrays, quantifies fluxes of water vapor at the watershed scale.

*Salt Remediation Program*

The University of Massachusetts at Amherst and US Geological Survey have conducted field research associated with highway deicing agent applications in the Massachusetts-Rhode Island Coastal Basin for over 20 years, with primary funding provided by the Massachusetts Highway Department. The USGS efforts include surface and groundwater monitoring stations (Church et al. 1996) and a calibrated model of the Plymouth-Carver Aquifer (Hansen and Lapham 1992). The UMass program includes extensive surface and groundwater monitoring arrays at three sites within the Basin that support recharge (Ostendorf et al. 2004a), groundwater flow (Ostendorf et al. 2004b) and contaminated runoff (Ostendorf et al. 2001) at diurnal, seasonal, and decadal scales in drumlins and glacial outwash deposits.

Microbiology has been characterized at the sites at field transport and bacterial length scales as well, through cooperative efforts with the Departments of Microbiology and Civil and Environmental Engineering of the University of Massachusetts at Amherst. In this regard, calcium magnesium acetate is used as a highway deicing agent at one of the study sites. The resulting acetate exerts an oxygen demand on subsurface moisture, at rates quantified by soil gas oxygen and carbon dioxide profiles (Ostendorf et al. 1997). The anoxic plume and iron coating of the glacial outwash soil grains sustain a robust *Geobacter* population, acclimated to episodic acetate substrate availability in cold groundwater. DNA arrays have been used to characterize *Geobacter* species from other sites with acetate as the electron donor at a bacterial scale (Methe et al. 2005). We will expand these efforts at the Salt Remediation Program study site across bacterial and field transport limiting length scales.

*Blackstone River Initiative*

The Blackstone River Watershed covers approximately 475 $mi^2$ in central Massachusetts and northern Rhode Island (Mangarillo et al. 2005). Its headwaters are composed largely of the *urban* and *industrialized* areas of Worcester, Massachusetts, the third largest city in New England. The river played a key role in the industrialization of the northeast, at one point having one dam for every one mile of river. The impact of these impoundments on contaminant fate and transport, in particular their affect on propagation of improvements in upstream water quality to downstream reaches, is not well understood. The Blackstone thus represents a key case study for understanding watersheds with a history of industrialization and heavy suburban development. While already a stressed environment, the Blackstone faces additional degradation due to development pressures.

In the early 1990's, detailed wet and dry weather data were collected as part of the landmark EPA funded, interagency and interstate Blackstone River Initiative (BRI) study (Wright et al., 2001). A new monitoring effort led by UMass is underway to collect additional wet and dry weather data along the river, building upon the data available through the BRI. These data will be used to assess changes in loadings to the river over the past fifteen years, the effects of impoundments on the river, and the relative contributions of point and nonpoint sources of contamination. The monitoring effort will include deployment of state-of-the-art in-situ analyzers for nitrate and phosphate. These analyzers will provide continuous (~ 3hr) data on concentrations in the river below the heavily urbanized headwaters in Worcester and downstream of the main impoundments, at the MA-RI border.

Historic and newly collected water quality data will be used by UMass to develop an HSPF *water quality* model for nutrient and DO dynamics in the watershed; metals may be modeled at a future date. Through cooperation with the USGS, this model will be built upon an HSPF water quantity model under development (by the USGS) for the RI Water Resources Board to study the effects of transfers and withdrawals on the river.

Table 1. Examples of Existing Data for the New England Coastal Basins

| **Source of Data** | **Data Collected** | **Length of Record** | **Sites** |
|---|---|---|---|
| USGS | Streamflow<br>Groundwater head | Varies with location, Androscoggin: 1900 - | NECB Study Area |
| NOAA Climate Monitoring Stations | Temperature<br>Precipitation<br>Winds | 1895 - | NECB Study Area |
| USGS (NAWQA) | Atmospheric Deposition, Hg | 2002 | Eastern Massachusetts, New Hampshire |
| USGS Study | Effects of Withdrawals on Streamflow | 1989-1997 | Ipswich |
| Rhode Island Department of | Water Quality | ~1991 - | Rivers in Rhode Island, Narragansett |

| | | | |
|---|---|---|---|
| Environmental Management | | | Bay |
| Hubbard Brook, NH Long-term Ecological Research Sites | Streamflow<br>Chemistry<br>Paleoecology<br>Atmospheric inputs | 1956 - | Hubbard Brook Watershed |
| Plum Island Ecosystem Long-term Ecological Research Site | Streamflow<br>Water quality<br>Atmospheric inputs | 2000- | Ipswich River, Parker River, Plum Island Sound |
| USGS (NAWQA) | Surface and Ground<br>Water Quality | 1998 - 2001 | NECB Study Area |

## Proposed Core Data for the Hydrologic Observatory

Initially, the Hydrologic Observatory will centrally compile existing data sources for data mining purposes, and critical data gaps will be identified. The objective of data collection is to identify at each interface (land-surface-atmosphere, land-surface-groundwater, groundwater-surface-water, and land-surface-surface water), each with their own time scales, the dominant processes and how they regulate fluxes of $H_2O$, biogeochemical cycling, and the transport of contaminants.

The temporal scales to be examined begin at the hourly scale for streamflow, moving to the decadal scale for groundwater flow processes, and finally up to the century scale for understanding the long term impacts of land use changes. Data will be collected for the recreation of the hydrologic cycle over relatively short time periods. In addition, paleoclimate data will be collected for understanding long term changes in $H_20$ and biogeochemical fluxes. The spatial scales to be monitored begin at the hillslope scale, going to the reach scale and finally up to the scale of the length of the basin.

The development of the monitoring program will involve the selection of reaches to measure and estimate base flow to streams, and the creation of a network of wells with optimal use of existing wells. A network of mini sensors (battery powered) for microscale monitoring will be set up for $H_2O$ fluxes and nitrates). Climate data will also be collected.

Fluxes within the New England Coastal Basins will be monitored by detailed and focused studies of specific areas, which may include:

- Plymouth Carver Aquifer for measuring groundwater/stream fluxes (with coast as boundary condition)
- Massachusetts Bay for surface water/ atmosphere fluxes
- Ipswich River for the effects of interbasin transfer
- Rivers with dams slated for removal to study the effects of channel modification

Data to be collected will use both remote sensing (e.g. from aircraft and satellites) and groundtruthing for all time scales and length scales. It includes:

- Soil moisture and heat signatures for estimating evaporation rates
- Land use/ land cover
- Water vapor pressure and precipitation
- Temperature, all media
- storage
- evaporation fluxes
- Wind speed
- Currents (streamflow, velocity)
- Groundwater elevations
- Radiation, long and short wave
- Contaminants (fluxes)
- Soil gas $CO_2$, $O_2$
- Dissolved oxygen and inorganic carbon
- Organic carbon
- Nutrients (Nitrogen, Phosphorus)
- Bacteria
- Heavy metals
- pH
- Conductivity
- Sediments (turbidity, total suspended solids)

## Participants

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Hubbard Brook LTER has also expressed an interest in participating in this effort in the near future.

## References

Ayotte, J.D., Montgomery, D.L., Flanagan, S.M., Robinson, K.W. 2003. Arsenic in Groundwater in Eastern New England: Occurrence, Controls, and Human Health Implications. Environmental Science & Technology. 37: 2075-2083.

Church, P.E., Armstrong, D.S., Granato, G.E., Stone, V.J., Smith, K.P., and Provencher, P.L., 1996, Effectiveness of highway drainage systems in preventing contamination of groundwater by road salt: US Geological Survey Open File Report 96-317, 72 pp.

Flanagan, S.M., Nielsen, M.G., Robinson, K.W., and Coles, J.F., 1999, Water-quality assessment of the New England Coastal Basins in Maine, Massachusetts, New Hampshire, and Rhode Island—Environmental settings and implications for water quality and aquatic biota: U.S. Geological Survey Water-Resources Investigations Report 98–4249, 62 p.

Hansen, B.P. and Lapham, W.W., 1992, Geohydrology and simulated groundwater flow, Plymouth-Carver Aquifer, US Geological Survey Water Resources Investigations Report 90-4204, 69 pp.

Mangarillo, J.T., Rees, P.L.S., Westphal, K., and Walsh, T., 2005, Basin scale methodology for evaluating relative impacts of pollution source abatement, Proceedings EWRI Conference, ASCE, in press.

Methe, B.A., Webster, J., Nevin, K., Butler, J., and Lovley, D.R., 2005, DNA microarray analysis of nitrogen fixation and Fe(III) reduction in *Geobacter sulfurreducens*, Applied and Environmental Microbiology, v. 71, pp. 2530-2538.

Omernik, James, 1987, Ecoregions of the conterminous United States: Annals of the Association of American Geographers, v. 77, no. 1, p. 118–125.

Ostendorf, D.W., DeGroot, D.J., Pollock, S.J., and Long, L.J., 1997, Aerobic degradation potential assessment from oxygen and carbon dioxide soil gas concentrations in roadside soil, Journal of Environmental Quality, v. 26, pp. 445-453.

Ostendorf, D.W., Peeling, D.C., Mitchell, T.J., and Pollock, S.J., 2001, Chloride persistence in a deiced access road drainage system, Journal of Environmental Quality, v. 30, pp. 1756-1770.

Ostendorf, D.W., Rees, P.L.S., Kelley, S.P., and Lutenegger, A.J., 2004a, Steady, annual, and monthly recharge implied by deep unconfined aquifer flow, Journal of Hydrology, v. 290, pp. 259-274.

Ostendorf, D.W., DeGroot, D.J., Shelburne, W.M., and Mitchell, T.J., 2004b, Hydraulic head in a clayey sand till over multiple time scales," Canadian Geotechnical Journal, v. 41, pp. 89-105.

Robinson, K. W., Flanagan, S. M., Ayotte, J. D., Chalmers, A., Coles, J. F., Cuffney, T.F. 2004. Water Quality in the New England Coastal Basins, Maine, New Hampshire,Massachusetts, and Rhode Island, 1999–2001.USGS Circular 1226. 38 p.

Schenck Bailey, A., Hornbeck, J. W., Campbell, J. L., Eagar, C. 2003. Hydrometeorological Database for Hubbard Brook Experimental Forest: 1955 – 2000. USDA Forest Service. General Technical Report NE-305.

Swift, C.T., Le Vine, D.M., and Ruf, C.S., 1991, Aperture Synthesis concepts in microwave remote sensing of the earth. IEEE Trans. Microwave Theory Tech., v. 39, pp. 1931-1935.

Wright, R.M. et al (2001). "Blackstone River Initiative: Water Quality Analysis of the Blackstone River Under Wet and Dry Conditions", USEPA.

Zariello, P.J. 2004. Simulated Effects of the 2003 Permitted Withdrawals and Water-Management Alternatives on Reservoir Storage and Firm Yields of Three Surface-Water Supplies, Ipswich River Basin, Massachusetts. USGS Scientific Investigations Report 2004-5122, 53 p.