New England Public Policy Center
at the Federal Reserve Bank of Boston

Research Report

05-1

Water, Water Everywhere: Dare I Drink a Drop?

(with apologies to Samuel Taylor Coleridge)

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Abstract:

Given New England's ample rainfall, green forests, and extensive wetlands, many of the region's inhabitants might question the notion that it faces potentially severe water shortages. Yet, parts of the region already confront such shortages. These shortages are likely to spread, absent corrective action. This paper describes the characteristics of New England responsible for its looming water problems, identifies areas within the region most vulnerable to such problems, and analyzes alternative strategies for alleviating them. Small, shallow, porous aquifers are the region's primary geological impediment to trapping and tapping adequate water supplies. Urbanization and a spatial mismatch between economic growth and water availability are contributing factors. Areas within the region most vulnerable to water shortages include, but are not limited to, southern Maine, southern New Hampshire, northern Vermont, and Massachusetts' North Shore and Route 495 corridor. While no single solution to potential water shortages is clearly superior, the authors conclude that conservation is a promising, effective tactic that should be an important component of any water strategy.

Keywords: natural resource (water) economics, regional resource/land use, publicly provided water supplies, natural resource (water) policy

JEL Classifications: H40, Q25, Q28, R14

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The authors wish to thank Kathy Bradbury and Mark Aguiar for their helpful suggestions on an earlier draft and Charles Light for his able research assistance. In addition, thanks are extended to Marilee Horn and Jonathan Yeo for their help with the technical and scientific aspects of this paper as well as their helpful suggestions. Any errors, of course, are the authors' responsibility.

This version: May 2005

Federal Reserve Bank of Boston

"I believe water is the biggest environmental issue that we face in the 21st century, in terms of both quantity and quality."-Christie Todd Whitman, former Administrator, U.S. Environmental Protection Agency (Delta Farm Press 2002)

A city has so little water that it taps an alternate source that it has avoided because of its iron taste and brownish color. Another city, estimating that it has enough water to supply its citizens for only 78 days, is forced to purchase emergency supplies from nearby towns. A third city drains an abutting river to the point where salt water creeps upstream, nearly flooding the city's supply intake. In the countryside, families without water for four months store it in jugs and pray for rain.

Where and when have these water shortages occurred? Not in the deserts of Africa, the Middle East, or the American Southwest, but in the northeastern United States during the past five years.

Several areas within New England have experienced such episodes. However, given the region's ample rainfall, green forests, lush meadows, and extensive wetlands, many of its inhabitants may have difficulty accepting the possibility that their region faces a potentially serious long-term water shortage. Nevertheless, absent corrective action, water shortages are likely to worsen and spread within the region over the next 10 to 25 years. One USDA report predicts that water use will increase in New England by as much as 15 percent between 1995 and 2040; despite the fact that few, if any, "new" sources of water are available within the region (Brown 1999). Since the problem of water scarcity cannot be fixed quickly or cheaply, the region should start thinking about it now. This article is a wake-up call to New Englanders, urging them to confront a problem that, if allowed to escalate, could impose serious long-run economic costs on the region. It contributes to the public policy discussion by introducing a new indicator, based on community expansion, that may identify water-stressed within the region.

Section I analyzes the properties of water that complicate the task of supplying it in adequate amounts in a form fit for human consumption. Section II identifies, in light of these properties, the geological, hydrological, topographical, geographic, and economic characteristics of New England that help and hinder our efforts to secure adequate supplies. Section III identifies the areas of New England most at risk for water supply problems and discusses how that risk is measured. Section IV evaluates alternative strategies for addressing the region's looming water problems. Section V summarizes and draws policy conclusions.

The paper identifies New England's small, shallow, porous aquifers (underground stores of water) as the region's major geological impediment to long-term water adequacy. To complicate the problem, many of the most rapidly developing areas within the region are those with the most meager water supplies. Furthermore, in New England, as well as throughout the nation, economic development is assuming a form ("sprawl") that significantly reduces the earth's capacity to absorb and retain fresh water. While no single solution to potential water shortages is clearly superior, the article concludes that conservation is a promising, effective tactic that should be an important component of any water strategy.

I. The Properties of Water Responsible for Its Scarcity

Water possesses several properties that complicate the task of supplying it in usable form.

Just over 97 percent of the earth's water is salty. About 70 percent of water that is fresh is frozen in the icecaps of Greenland and Antarctica. Consequently, less than 1 percent of the earth's water is fresh and available (Sadeq 1999). Fortunately, some ocean water evaporates, forms clouds, and falls on land in the form of precipitation. Otherwise, to obtain enough fresh water, we would have to rely solely on desalination, a costly, energy-intensive technology.

Gravity acts upon water. Rivers and streams eventually empty into an ocean, completing the hydrological cycle. Some water soaks through the earth's surface and is temporarily captured underground in aquifers. Most groundwater (water that is underground) flows into bodies of water, although some is trapped in rock fissures (this trapped water supplies wells). Therefore, in order to obtain ample supplies of fresh water, people must tap it or trap it as it flows downhill or underground.

The higher the temperature of a body of water at its surface, the faster it evaporates. While evaporation of ocean water is an important step in the hydrological process, where average air temperatures are high, evaporation of fresh water reduces its availability.

Water is an excellent solvent for pollutants. Water is "polar," meaning that it has an unequal distribution of electrical charge. As a result, water can dissolve many polar contaminants. Moreover, animals in general, and humans in particular, have a penchant for depositing their poisonous wastes into large bodies of water. As a result, many lakes, rivers, and wells are polluted.

Water is expensive to transport. If one jurisdiction suffers from a low water supply, its inhabitants cannot easily obtain large quantities of water from other locations. Transport can be expensive because water is very dense—meaning that it has a high mass per unit volume. In fact, water is one of the few compounds that is actually denser in the liquid form than in solid form (this is why ice floats).

Water has competing uses. While human beings may need fresh water primarily for drinking, washing, waste removal, and industrial processing, they also value it for other purposes. Water is a vital component of the habitat of other species, which are a source of food (for example, fish) or are valuable in maintaining ecological balances. Furthermore, biodiversity is important to long-run human survival. Finally, water is indispensable to certain forms of recreation, which, in turn, create jobs and generate income. When people attempt to preserve water for one purpose, they often must do so at the expense of other purposes. For example, draining wetlands to make way for a new reservoir could destroy the habitats of a valuable endangered species of bird.

The supply of water is often erroneously perceived to be infinitely abundant. Because water appears to be so plentiful, providers tend to think that they can continue indefinitely to augment its supply to some without reducing its availability to others. As a result, water is often priced below its true cost and, therefore, consumed to the point where its sources are threatened—a classic case of the "tragedy of the commons" (Mankiw 2001).

II. New England's Relative Advantages and Disadvantages in Supplying Water

Given water's properties, a region's susceptibility to water shortages depends on, among other things: 1) its average precipitation; 2) the depth, porosity, and interconnectedness of its aquifers; 3) the permeability of its land surface; 4) the size and number of its lakes, rivers, streams, and ponds; 5) the degree to which its geological structure naturally traps and retains water runoff; 6) its average air temperature; 7) its degree of water pollution; 8) the percentage of its fresh water supply congealed in the form of snow and ice; and 9) the spatial match between its areas of most rapid development and water availability.

New England's high rate of precipitation—44 inches per year compared with 32 inches per year for the continental United States—is its most important natural advantage in securing ample water (Keim and Rock 2001, National Climatic Data Center). Moreover, a relatively high percentage of its precipitation is in the form of snow—23 percent in 2000[1] compared with a nationwide historic average of just over 10 percent[2]—and much of this falls on the region's mountains. Since water flows downhill only in liquid form, a region that can preserve its water at high elevations for long periods of time in a solid state can slow untapped water runoff. Yet another advantage enjoyed by New England is low average air temperature and, therefore, a low evaporation rate. Over the past ten years, the average air temperature within the region has been 47 degrees Fahrenheit. The comparable average in the continental United States has been 53 degrees (Keim and Rock 2001, National Climatic Data Center).

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1 This is down from 30 percent in 1949. See Huntington et al. 2004.

2 This is based on data from 277 U.S. cities. The 10.41 percent estimate represents an upper limit on snowfall, assuming that all "trace amounts" are the maximum value of 0.009 inches. Data obtained from the National Climatic Data Center at the National Oceanic and Atmospheric Administration.

However, subterranean water supplies and storage capacity in New England are inferior to those in other parts of the country in several respects. Our aquifers are relatively shallow, segmented, and small in both size and number. The shallower an aquifer, the faster its water can flow to the ocean and the more susceptible it is to pollution. Map 1 shows the location of the nation's largest and deepest aquifers. With the exception of a relatively small one that cuts across Connecticut and ends in western Massachusetts, no deep aquifer is located in New England. Furthermore, with the exception of this single aquifer, the region's aquifers are lined with a mixture of gravel and sand, whereas some aquifers located in other regions are lined almost exclusively with sand. Finely grained sand is much more tightly packed and therefore much less porous than large grains of irregularly shaped gravel. (When one wants to keep floodwaters back, one uses sandbags, not "gravel" bags.) Consequently, the few aquifers that we have are relatively "leaky." Largely for this reason, Horn and Weiskel of the United States Geologic Study (USGS) suggest that "the region [New England] should not be considered 'water-rich'" (USGS 2003).

While the region has a fair amount of natural surface water, the region's geological configuration facilitates runoff. Its hills and mountains are not arranged in long parallel ridges, which trap lake and pond water. Moreover, many of New England's ponds, rivers, and streams are either polluted (see Table 1) or ecologically sensitive. Water pollution is especially severe in Vermont, where 90 percent of lake water is polluted (U.S. Environmental Protection Agency [henceforth, EPA] 2002). Many parts of Lake Champlain—the sixth largest lake in the nation at 435 square miles (Lake Champlain Basin Program) — currently has unsafe concentrations of phosphorous, much of which originates in the city of Burlington, Vermont, and its environs.[3] Water

3 Lake Champlain supplies water to approximately 200,000 residents of Vermont and New York. However, rising pollution levels threaten this important source of fresh water (Lake Champlain Basin Program). The metropolitan area of Burlington, VT, is apparently responsible for most of the problem. Storm-water runoff from the area's roads, parking lots, and strip malls has carried pollutants into the lake and, in turn, has caused excessive (and sometimes highly toxic) algae growth. Point-source pollution from the discharge of hazardous industrial waste and household waste, as well as the discharge of municipal sewage, has also contributed. Non-point-source

pollution is not limited to surface bodies of water; toxic chemicals and organisms also seep into aquifers and, therefore, contaminate wells.

While no indicator currently compares regions in terms of the permeability of their land surface, urbanization has reduced the capacity of the earth to absorb water throughout the nation. Since pavement is much less porous than soil, proliferation of buildings, roads, and parking areas accelerates the runoff of surface water. Moreover, since all kinds of toxic chemicals (primarily from automobiles) tend to be deposited on such "improved" surfaces, urbanization also exacerbates non-point-source pollution.[4] The rising incidence of large suburban houses, another feature of sprawl in many metropolitan areas, further worsens runoff and pollution. In constructing these homes, developers remove topsoil, level the plot, and compact the remaining soil with heavy construction equipment. As a result, the ground under many suburban lawns is nearly as impermeable as roads or sidewalks.

In addition, a recent study of the Seattle metropolitan area found that larger suburban properties consume nearly 16 times more water than a traditional urban house with a smaller lawn (EPA 1995). The EPA estimates that almost one-third of all water used by households occupying such large homes is devoted to outdoor activities, including lawn and garden watering (Otto et al. 2002). The average lawn in the United States receives the equivalent of 145 days of indoor water use by a single person per year and is sprayed with 10 times more pesticides per acre than farms that grow food (Vickers 2002). Pesticides and fertilizers are major sources of non-point-source pollution, contributing phosphorous and other chemicals.

One should not assume, just because the population of New England as a whole has not grown very rapidly in recent decades, that the problems associated with urbanization are less severe here than in other regions. In every region, the area of land

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pollution from the runoff of dairy farm waste, which initially seeps into groundwater and then eventually flows into the lake, is another source of contamination (Lake Champlain Land Trust). According to the Conservation Law Foundation, lack of planning and regulation and lax enforcement of existing laws and regulations have all contributed to the lake's pollution.

that is urbanized has grown much more rapidly than the population. This phenomenon, sometimes referred to as "urban sprawl," has been relatively pronounced in New England. According to Fulton et al. in a study published in 2001 by the Brookings Institution, the amount of urbanized land in the United States grew by 47 percent between 1982 and 1997, while the population in those areas grew by only 17 percent. Thus, a rough indicator of the severity of a region's urban sprawl is the absolute difference between the rate of growth of its urbanized land and the rate of growth of its population: 30 percentage points nationwide. Fulton et al. estimated this difference for 282 metropolitan areas in the United States, 15 of which are in New England (Table 2). In 10 of these areas, the degree of urban sprawl exceeded the national average. In the greater Boston metropolitan area, by far the region's largest, the population grew by only 6.7 percent, while the area of urbanized land grew by 46.9 percent—over a 40 percentage point differential.[5] In Portland, ME, the differential was 91 percentage points. The metropolitan areas within New England exhibiting the lowest differentials were in Connecticut—ironically the state with the best aquifers in the region.

Highlighting the Region's Disadvantages: Southern Nevada vs. New England

Clark County, Nevada, most of whose population is concentrated in the Las Vegas metropolitan area, receives an average of 4.2 inches of precipitation annually, about one-tenth of New England's precipitation (Nevada Division of Water Planning). With its high temperatures, dry climate, and concomitant high evaporation rate, the county effectively receives the equivalent of a mere one inch of precipitation per year (Nevada Department of Conservation and Natural Resources 2002). Yet, between 1950 and 2000, its population increased 30-fold (Clark County Comprehensive Planning). The state's Division of Water Planning predicts that between 2000 and 2020, the county's

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[4] Non-point-source pollution is defined as water pollution that cannot be traced to a specific spot (National Water Quality Monitoring Council).

[5] A report issued by three environmental groups estimated that groundwater losses due to sprawl in Boston could be as high as 102.5 billion gallons per year (Otto et al. 2002). This is enough to meet the needs of nearly 67 percent of all publicly supplied households in New England.

population will grow by another 61 percent; the Nevada state demographer thinks that this projection is low (Nevada Division of Water Planning). In addition, the county hosts a continuous influx of millions of water-consuming tourists. With such meager precipitation, how has Clark County obtained sufficient water to support such explosive population growth and such a robust tourist industry? Where will the county obtain enough water in the future?

The answer is buried underground. The county, as well as Nevada as a whole, has deep, extensive, interconnected, impermeable aquifers (see Map 1). Consequently, in 2000, Nevada met 27 percent of its water withdrawal needs with groundwater, more than the U.S. average of 21 percent and well above New England's level of only 6 percent (USGS 2004). There is a vast, yet-to-be-tapped aquifer under Utah and eastern Nevada. According to Nevada State Engineer Hugh Ricci, there are "millions of acre feet"[6] hidden in the underground reservoir, an estimate shared by the U.S. Geological Survey (Ritter 2004).

While Nevada, and areas surrounding it, may not get a lot of precipitation, what little they do get falls as snow at high elevations, especially on the Sierras to the West and on the Rockies to the East. Snow-melt from these mountains supplies Clark County and the rest of Nevada with much of its ground and surface water. In fact, the National Snow and Ice Data Center estimates that snow pack contributes up to three-quarters of all year-round surface water for some Western states (National Snow and Ice Data Center). Furthermore, Nevada's mountains are arranged in long, narrow ranges, a configuration that slows runoff, and there are only two large rivers running through the state—the Colorado and Snake Rivers—that drain directly into the ocean. In total, just over 84 percent of the state lies in this "great basin," a geological area that facilitates the retention of both surface and ground water (Nevada Division of Water Planning). Nevada also has the ability to "bank" water in wet years and "withdraw" it later in drier ones. In an innovative interstate program, Nevada deposits some of its Colorado River

[6] An acre-foot is defined as the volume of water that would cover one acre to a depth of one foot, that is, 43,560 cubic feet or 325,851 gallons of water.

water allotment in Arizona in exchange for the right to draw on it at a later date and/or take some of Arizona's annual allotment in the future (Nevada Colorado River Commission). By comparison, as noted above, since five of the New England states border the ocean, and the region as a whole has many rivers and streams, its extensive river and tributary system efficiently collects runoff and transports it into the ocean. Likewise, New England does not have an efficient natural storage system, effectively eliminating the practice of water banking.

To a significant extent, Las Vegas's water problems are ameliorated both by the proximity of the Colorado River, a 1,400-mile river much larger than any flowing through New England, and by the water management capabilities enabled by the massive Hoover Dam. Lake Mead, an artificial lake created by the dam that is about 60 percent the size of Lake Champlain, supplies approximately 30 million acre-feet of water per year (U.S. Bureau of Reclamation). The availability of this and other bodies of water enabled Nevada to obtain an impressive 73 percent of its water from surface sources in 2000, although this amount was lower than the U.S. average of 79 percent and much lower than New England's 94 percent for the year (USGS 2004). Nevertheless, Nevada must fight with many other southwestern states for rights to Colorado River water. Without its ample underground water supplies and storage areas, the state could not meet its water demand, and Las Vegas could not have grown as fast as it has or contemplate such rapid growth in the future.

Largely because Nevada, although urbanizing rapidly, is still much less extensively urbanized than New England, its potential sources of fresh water are much less polluted than those of the New England states or the nation as a whole. Despite the fact that 59 percent of Nevada's monitored rivers are considered "impaired," exceeding the 39 percent national average and the 20 percent average for New England, Nevada recorded no impaired lakes in the EPA's report for the year 2000. In contrast, New England (28 percent) and the U.S. as a whole (45 percent) had much higher percentages of impaired lakes (EPA 2002). Furthermore, the Las Vegas metropolitan area has relatively little urban sprawl. According to the Brookings Institution study, the area's population grew by 130.8 percent between 1982 and 1997, but its urbanized area grew by only 53.1 percent. Consequently, the density of its urbanized areas has increased sharply, just the opposite of the nationwide trend.

III. Areas of New England Most at Risk for Water Shortages

New England's actual and potential water problems are most acute in cities and towns that are both growing and "sprawling" rapidly but have access to the most meager supplies of water. Many of these "problem" areas, especially in the northern three New England states, rely on well and spring water. For instance, the percentage of the population in these states that uses "self-supplied" water sources (often springs and wells) far exceeds the national average. In 2000, only 15 percent of the nation's population used self-supplied sources. By contrast, four New England states, Connecticut (22 percent), Maine (43 percent), New Hampshire (39 percent), and Vermont (41 percent), all had much higher percentages.[7] Since wells and springs in these states are supplied by relatively shallow, porous aquifers, they often suffer water shortages during droughts. Other stressed municipalities have access to public water supplies, but these supplies are fed by lakes or rivers whose water volume is also drought-sensitive. Since New England's droughts are by and large short-lived (no more than one or two seasons), affected areas generally respond with stringent short-term conservation measures, the purchase of emergency water supplies, and other temporary measures. Because these areas used to be sparsely populated, the percentage of the region's total population affected by these short-term emergencies was small. Consequently, public officials were reluctant to adopt more extensive measures designed to alleviate the problem permanently.

For reasons too numerous to discuss in this paper, the population of many of these vulnerable areas has grown rapidly in recent years, causing demand for water to soar. Public officials have strained to meet surges in water demand, even in times when

[7] The other two New England states—Rhode Island (12) and Massachusetts (7)—had percentages lower than the U.S. average in 2000 (USGS 2004).

precipitation has been plentiful. Franklin, Massachusetts, is a case in point. Over the last two decades, the town's population has skyrocketed from 18,000 to 30,000. Many of its new residents have moved into large homes with multiple bathrooms and underground sprinkler systems, causing the town's water consumption to exceed five million gallons a day. Recently, William Fitzgerald, Director of Public Works for Franklin, lamented to a *Boston Globe* reporter, "I can't keep up with five million gallons per day" (Blanton 2002).

In some water-stressed areas within New England, conflict over limited water supplies has emerged, reminiscent of long-standing water battles common in the West. Competition for water among communities along the Ipswich River, on Boston's North Shore, is a dramatic example. This conflict originated in the late 1800s, when the towns of Beverly, Salem, Lynn, and Peabody were given legislative authority to pump water out of the river. By the early 1900s, Salem and Beverly created a water board and began withdrawing 25 million gallons a day from the Ipswich, diverting it to a reservoir. The town of Lynn quickly followed suit. In 1972, Peabody also erected a pumping station, taking water from the river and placing it in reservoirs for town water consumption. While this was occurring, other towns, among them rapidly developing Hamilton, Wenham, Ipswich, Reading, North Reading, Wilmington, Topsfield, and Lynnfield, all dug wells along the river. In addition, two other towns, Danvers and Middleton, have reservoirs that capture water from the Ipswich naturally (Kirk 1998). As a result of these sharp increases in water withdrawal, the river has run dry in several upstream locations over 300 times in the last few years (Cole 2001). Consequently, the river ranked third on American Rivers' [8] list of "America's Most Endangered Rivers of 2003." The organization attributes the river's endangered status to "excessive groundwater pumping and municipal water consumption." Lou Wagner, a water resources specialist with the Massachusetts Audubon Society, notes that if water conservation is not enacted, "…in twenty years [communities along the Ipswich] will be looking for new sources of water" (Kirk 1998).

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[8] American Rivers is a nonprofit conservation organization dedicated to the restoration and protection of America's rivers.

Defining an Indicator of Water Stress

Data limitations preclude precise identification of those New England cities and towns most vulnerable to water shortages.[9] However, the authors of this paper reasoned that such municipalities would include those larger than some threshold minimum size and those experiencing the most rapid growth. Constructing the indicator in this way allows areas that may be water stressed due to housing and population growth to be identified, though it does not directly measure water stress. Rather the indicator measures the growth in the community, which in turn the authors believed to be correlated with water stress.

The minimal size level is defined as a population of at least 500 in 1990. This was done for two reasons. First, towns with a population of fewer than 500 persons likely have relatively small aggregate water demand and are therefore unlikely to confront physical limitations in water supplies even if they experience very rapid growth. Second, many states define "major" public water suppliers as those that serve at least 500 persons year round. As a result, it seemed sensible to choose the town size threshold to match this definition.

Rapid growth is defined as equaling or exceeding 20 percent in the average rate of growth of housing units plus population between 1990 and 2000.[10] In addition, a

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[9] This is a fact realized by some New England states. In a recently released report from the Massachusetts Executive Office of Environmental Affairs entitled "Massachusetts Water Policy," the number one recommendation of the report was to create a thorough and meaningful "stress framework" to help identify communities under the greatest water stress (Massachusetts Executive Office of Environmental Affairs 2004).

[10] Two additional indicators were used for the Massachusetts; unfortunately, similar indicators were unavailable for the remaining New England states. The first indicator is "basin stress" as identified in a 2001 Water Resources Commission Report [MWRC], "Stressed Water Basins in Massachusetts" http://www.mass.gov/envir/mwrc/pdf/Massachusetts_Stressed_Basins. (shown shaded red on Map #2, Massachusetts). The report examines relative water stress for inland towns in the Commonwealth by using various river and stream-flow data. The second indicator is enrollment in the Massachusetts Water Resources Authority (MWRA) water supply system. If a community was included in the MWRA system, it was not highlighted on the map because of the relatively deep supplies enjoyed by the MWRA. One should not confuse the MWRC, the

distinction was made between those towns with a major public water supplier (defined as serving 500 or more end-users year round) and those lacking a major public water supplier.

It should be noted that this is a rather crude method of identifying water-stress levels in the region. At best this new indicator reveals areas that may be experiencing water stress due to their rapid expansion. It is not without its drawbacks. For instance, it ignores towns that have experienced such sever water shortages that their growth rate between 1990 and 2000 was held below the imposed "rapid" threshold. However, absent better data, the new indicator can serve as a valuable first-stage filter to identify areas potentially vulnerable to water stress due to their rapid growth.

Identified in Maps 2 through 4, stressed communities generally appear in clusters and are found in each of the New England states. Maine's water-stressed towns are in the southwest portion of the state. Interestingly, nearly all of the rapid growth occurred in towns with no major public water supply. Vermont's most vulnerable communities are in the northern part of the state, with a few bordering the city of Burlington. In contrast, the at-risk communities in New Hampshire are in the southern portion of the state, primarily along the transportation corridor with its southern neighbor, Massachusetts. Water-stressed towns in Massachusetts are scattered throughout the state, although there are clusters along route 495 and along the north shore. Connecticut has relatively few water-stressed towns. Slower growth and the region's major aquifer help keep many of Connecticut's towns flush. Southern Rhode Island has a small cluster of water-stressed towns, none of which has a major public water supply.

IV. Solutions to New England's Water Problems

state commission in charge of Massachusetts water policy and planning, with the MWRA, the Massachusetts public authority that provides water to much of metro Boston.

Potential solutions to the region's water problems generally fall into one of four categories: supply augmentation, infrastructure improvement, geographic reallocation, and demand management.

Supply Augmentation

Historically, supply augmentation has been the favored strategy (Gleick 2000). As the demand for water has grown, municipalities have increased rates of withdrawal from existing sources; turned to previously untapped rivers, ponds, and lakes; dug new wells and deepened existing ones; or constructed dams and reservoirs to trap water runoff more effectively. When necessary, they have invested in the necessary transmission structures and equipment (pumps, filtration and purification plants, pipelines) to access these new water sources.

There are few new water sources left for New England to tap. Since dams and reservoirs are extremely expensive investments, they are economically feasible only for large public water systems encompassing a large metropolitan area. Even where economically feasible in theory, however, such large-scale projects would face serious obstacles, impediments that were not so severe half a century ago. A comparison of the experience of two such areas, greater Boston and greater Providence, illustrates the dilemma.

New reservoirs for the Boston and Providence metropolitan areas. Throughout most of its history, Boston has managed to augment its water supplies to satisfy growing demand. Prior to 1795, local wells, rain barrels, and a spring on what is now the Boston Common supplied the city with its water. After 1795, private water companies employed a system of wooden pipes to supply water from Jamaica Pond. This source of water was adequate until the mid-1800s, when Boston and its estimated 50,000 residents needed both a cleaner and larger source of water. In 1845, the Cochituate Water Board, the governing water supply authority, impounded a tributary of the Sudbury River to create Lake Cochituate. In 1870, Boston added another source of water, the Mystic Lakes system. Combined, these sources had the potential to supply the city with nearly 40 million gallons of water per day (Massachusetts Water Resources Authority).

The combined effect of technical advances, such as indoor plumbing and continued population growth, again rendered Boston's water supplies inadequate. In response, the Commonwealth used its power of eminent domain to create the Wachusett Reservoir in 1908. Water from the 6.5 square mile reservoir was conveyed just over 50 miles across the state into storage facilities before finally being disbursed in the city of Boston and 29 surrounding municipalities. When completed, the Wachusett Reservoir was the largest public water supply reservoir in the world, with a daily safe yield—the maximum withdrawal rate that does not jeopardize the long-term health of the reservoir—of 118 million gallons per day (Massachusetts Water Resources Authority).

After a few decades, the Wachusett Reservoir had to be supplemented by a second massive reservoir—the Quabbin. Construction of the Quabbin required seizing four towns—Dana, Enfield, Greenwich, and Prescott—and impounding the Swift River. When it was completed in 1946, the 412 billion gallon reservoir was the largest man-made supply reservoir in the world, with a daily safe yield over 30 percent larger than the yield of the Wachusett Reservoir. Once again, the city of Boston and its surrounding communities had met their seemingly insatiable thirst by erecting the largest public water reservoir ever built. However, like the Wachusett Reservoir before it, the Quabbin soon became inadequate. By the early 1970s, water demand far exceeded the safe average yield of the reservoir system of 320 million gallons per day (see Figure 1). The situation was exacerbated when the Sudbury Reservoir was taken offline in the early 1970s, reducing the system safe yield to 300 million gallons per day.[11] By this time, the central part of the Commonwealth had become populated and developed to an extent that made the construction of yet another reservoir too costly, both financially and politically. The strategy of supply augmentation was no longer a viable option; as discussed below, the Commonwealth subsequently turned primarily to demand

[11] Fortunately, during the periods of excess withdrawals, from 1969-1988, the system avoided a major supply crisis because of ample precipitation (Yeo 2004).

management to address the Boston metropolitan area's water problems (Massachusetts Water Resources Authority).

The currently limited opportunities for supply augmentation were evident in the failure of Providence to build a new reservoir on wetlands near the Big River Management Area (BRMA). State officials believed that the reservoir was needed; as Timothy Brown, the Kent County Water Authority general manager noted, "We're concerned about securing additional water supplies because the Scituate and almost all the states' aquifers have met their capacity" (Wims 2002). This concern was exacerbated by continued growth in neighboring counties and a projected increase in demand of 1.5 million gallons per day attributable to a new Amgen Pharmaceutical plant in nearby West Greenwich. Seeking to expand its supply, the Providence Water Supply Board (PWSB) by 1967 had acquired 8,600 acres near what is now I-95 in southwest Rhode Island under the power of eminent domain. The state removed 200 single-family homes and compensated their owners a total of $7.5 million (Wims 2002). The proposed reservoir would have flooded a region of 3,700 acres to a depth of sixty feet. Although the price tag was estimated to be $350 million in 1964, the potential for an additional 27 billion gallons per day made it highly desirable from the perspective of the Providence Water Supply Board (Providence Water Supply Board).

However, the project met with constant opposition and has yet to materialize. Groups opposed to the reservoir's creation expressed concern that, by building it on wetlands, the city of Providence would be cutting off its nose to spite its face. Wetland areas have the ability to store groundwater runoff, acting as "natural tubs or sponges" that can retain water during wet periods and contribute to water recharge in drier ones. One acre of wetland can store up to 1.5 million gallons of floodwater (EPA web site). Given that New England's geological structure precludes the efficient storage of groundwater, this attribute of wetlands is very important. Wetlands also help to filter out dissolved impurities or chemicals. Some wetland areas are so effective at removing impurities that environmental managers construct artificial wetlands to drain storm water or wastewater.

Beyond the environmental objections to damaging a pristine wetland environment, the EPA and several environmental groups cited inaccuracies in the methodology of the study used to justify the creation of a reservoir in the BRMA. Questions were raised surrounding the study's population-growth assumptions and its characterization of industry water needs. Some of the opposition to these embedded assumptions seems warranted. For instance, the study predicted a 17.7 million gallon per day increase in water demand between 1975 and 1987; this increase never materialized. Based on this and other evidence, in 1990 the EPA ruled against the creation of the reservoir since it would, "destroy 575 acres of wetlands, including 10 ponds, 17 miles of streams and 2,500 acres of upland forest" (Conservation Law Foundation 1993). Following this ruling, the project was put on "indefinite hold" (Rhode Island Water Resources Board 1997). The land is now classified as an "open space—to be utilized and enjoyed by the residents and the State of Rhode Island." (Rhode Island Water Resources Board). However, the PWSB is exploring the possibility of drilling deep wells, which would have a less drastic environmental impact on the region than a reservoir but would still produce as much as 16 million gallons of water per day (Wims 2002).

Manmade, covered water-storage systems. The construction of manmade, covered water-storage systems is a method of compensating for New England's poor natural underground water storage capacity. In May 2004, the MWRA opened a $100 million covered reservoir in Weston with 115 million gallons of storage. This unit covers 17 acres of land along the turnpike and will eventually become a green space (Yeo 2004). The MWRA is also designing two storage facilities, one in Quincy and one in Spot Pond, each holding 20 million gallons (Massachusetts Water Resource Authority). Such capital-intensive solutions may not be practical for more rural or even newly urbanizing areas. Large man-made storage facilities need certain economies of scale to be feasible. Water suppliers need significant financial resources to fund such a construction project, requiring either annual revenues that exceed expenditures or substantial borrowing, neither of which is easily obtained by smaller water suppliers. Beyond these economic issues there are physical considerations as well. Man-made water storage requires towns to have excess water. There are not many water districts in New England with large enough annual surpluses to make the construction of large-scale storage tanks a cost-effective solution. Capturing the region's bountiful rainfall would require an extensive well system, which, like the man-made storage facilities, would carry a hefty price tag.

Desalination. A few New England municipalities are considering investing in this process to solve their water problems. The two primary alternative methods of desalination, (1) boiling water and redistilling it or (2) forcing it through membranes, require significant amounts of electricity (Conaughton 2001). One desalination plant in Tampa, Florida, has been able to provide water at a price 20 percent above that charged by traditional water suppliers; however, it has been plagued by technical problems and its service has been unreliable (Conaughton 2001). In New England, only one desalination plant is currently in operation, on MacMahan Island, Maine. Still, some towns in New England hope that desalination will be their water panacea. Construction of a $40 million facility near Brockton began in September 2004. The plant would help ease the water crunch in Brockton, Norton, and any other town willing to purchase its fresh water, albeit at a markup. In contrast, after considering desalination, other Massachusetts towns, such as Stoughton, Provincetown, and Swansea, have rejected this approach (Daley 2004).

Infrastructure Improvement

Old water pipes leak. A Congressional Budget Office (CBO) study found that the majority of the water transmission pipes in the United States were installed shortly after World War II and are now reaching the end of their useful lives. According to the Conservation Law Foundation, the most antiquated water transmission systems lose as much as 30 percent of the water they transmit (1993). Fixing the problem would not be cheap. The CBO report estimates that capital investments in the range of $230 billion to just over $400 billion (2001 dollars) would be required between 2000 and 2019 to stop the leakage (Congressional Budget Office 2002).

While such repairs may be costly, they also yield valuable benefits. Shortly after its establishment in 1985, the MWRA launched a vigorous leak detection and pipe replacement program, inspecting over 5,000 miles of pipes. Fixing the leaks found on this examination saved an estimated 30 million gallons of water each day (Massachusetts Water Resources Authority). Currently, the MWRA mandates that communities do a full system check on their own every two years. Following these inspections, the MWRA replaces six to seven miles of pipe each year. To help communities fund the needed capital expenditures, it offers interest-free loans totaling $25 million each year to communities in its water district (Massachusetts Water Resources Authority). These funds have helped several communities in the MWRA to replace some pipes that were over 100 years old. Arlington, Massachusetts, was one of the first towns to implement a rigorous leak detection program; this program led to investment that stopped leaks from claiming 250 million gallons per year (Conservation Law Foundation 1993). Unfortunately, a majority of water suppliers do not follow a similar path. A report by the General Accounting Office (GAO)[12] (2002) found that fewer than 38 percent of water suppliers surveyed had plans that included assessing the physical capital of their system.

The Providence Water Supply Board last implemented a major upgrade of its water system during the late 1960s. With no upgrading since then, nearly 30 percent of the system's water mains currently in operation were installed between 1874 and 1899 (Providence Water Supply Board). Pipes of this vintage are sometimes made of brick or even wood, materials far more porous and leak-prone than modern plumbing materials (Environmental Protection Agency 2002a).

Improvements to water supply systems are also mandated by increasingly tighter federal regulation. The number of regulated contaminants has increased, while their acceptable levels in "safe" water have decreased (Association of State Drinking Water Administrators 2003). Exacerbating the situation, the costs of water treatment and

[12] In July 2004, the General Accounting Office changed its name to the Government Accountability Office.

purification have increased in recent years, making it extremely hard for smaller water systems and older treatment plants to meet the requirements (Yeo 2004).

Geographic Reallocation

Some municipalities thirsting for water are near others that have plenty of it. Prime examples include cities and towns near the boundaries of the MWRA's district (towns served by the MWRA appear in Table 3 and Map 5). In theory, the MWRA could alleviate water shortages in abutting towns by expanding its jurisdiction to include them, thereby granting them access to the Quabbin and Wachusett Reservoirs. In fact, since 1993, two such towns, Bedford and Stoughton, have been admitted to the MWRA system, while Reading, Wilmington, and Dedham/Westwood have applied for membership (Yeo 2004).

However, as noted in Section I, transporting water is difficult and expensive. In addition, communities already in the system are reluctant to share their excess water, since they might need it if a drought develops or their pace of economic development accelerates. Consequently, gaining admission to the MWRA is no easy task. Applicants must demonstrate that they have exhausted all alternative potential supplies, have implemented severe conservation measures, and have met strict state environmental guidelines contained in such laws as the Inter-Basin Transfer Act and the Massachusetts Environmental Policy Act (Yeo 2004). Applicants must also prove that their inclusion in the water system will not have negative consequences for the existing MWRA system. In order to reduce pipe corrosion, the water from the applicants' existing sources must have a pH level compatible with MWRA water (Yeo 2004). Finally, applicants must pay an entrance fee and all connection expenses, including the costs of any necessary pipes and accompanying land. All these obstacles have prevented many water-poor communities in Massachusetts from tapping into the excess supplies of their relatively water-rich MWRA-supplied neighbors.

Demand Management

Water problems throughout New England and, for that matter, the nation as a whole, have been alleviated somewhat by the evolution of the industrial base of the economy toward services from manufacturing. Manufacturing industries are much more water-intensive than services in their production processes. In 1980, 27.3 percent of New England's gross regional product originated in manufacturing. Falling steadily since then, this percentage reached 14.5 percent in 2000 (Bureau of Economic Analysis http://www.bea.gov). This fact, combined with more water-efficient manufacturing processes, has led to decreased industrial consumption within the region. In 2000, water used in New England for industrial purposes was only about one-quarter of the amount used for such purposes in 1980 (USGS 2004). This decline in industrial demand has been offset by increases in demand for other purposes, such as household consumption (up 54 percent) and agriculture (up nearly 300 percent). As a result, total water usage in the region has been roughly flat during the 20-year period (USGS 1983, 1988, 1993, 1998, 2004).

In addition, the efforts of public authorities to curtail water demand have helped to mitigate water shortages. Officials have employed three basic demand management tactics: the limitation and regulation of water withdrawal, the encouragement of voluntary conservation, and the reconfiguration of water price schedules.

Regulation of water usage. Attempts to regulate water usage on a long-term basis (as opposed to short-term measures dealing with water emergencies) have not been entirely successful. The water-sharing agreement for communities drawing water from the Ipswich River is a case in point. In an attempt to reduce water withdrawals from the river to a sustainable rate, the Commonwealth's legislature enacted a law (the 1985 Water Management Act) designed to ration water by community for a 20-year period. However, in order to get the law enacted, the legislature set limits that were not particularly stringent. For the 14 affected communities combined, the law permitted growth in withdrawals of 24 percent, while population growth in the 14 communities was projected to grow by only 7 percent (Kirk 1998). Given evidence that the Ipswich River has been drying up, the limits on withdrawals were apparently too lax. Moreover, considerable disparity in water adequacy exists across these 14 communities. Danvers, Middleton, Hamilton, Ipswich, Lynnfield, Reading, and Wenham have all imposed restrictions on such uses as lawn watering and swimming pools. North Reading has been forced to buy water from its neighbor, Andover. By contrast, several other communities, such as Salem, Beverly, Lynn, and Peabody, do not currently have restrictions on water use, since the combination of their Ipswich allocation and access to other surface water sources is sufficient to meet demand (Kirk 1998).

Encouragement of water conservation. Once again, the MWRA has set an example for other public water authorities to follow. The MWRA was created in 1985 after a 16-year period during which water was withdrawn from its reservoirs at a rate exceeding 320 million gallons per day. Officials estimated that withdrawal rates above this amount would jeopardize the long-run stability of the water supply within the MWRA's system. The Authority was able to reduce the average daily withdrawal rate below this ceiling within four years of its creation (Figure 1), primarily by implementing and encouraging conservation measures. MWRA employees went door-to-door fixing leaky faucets and retrofitting 370,000 homes with low-flow plumbing devices, low-volume showerheads, and low-volume aerator faucet heads (Massachusetts Water Resources Authority).[13]

The Authority also upgraded meters in ways that enhanced municipalities' capacity to track and analyze their water use. Previously, water use in some communities was either untracked or tracked only annually, and so communities saw little relation between their water use activities and their water consumption. Monitoring water use by category helps communities understand their allocation of water and rein in water use for non-essential categories (Beecher et al. 2001).

Education was, and still is, another important component of the MWRA's demand management strategy. School programs emphasizing water conservation and the use of water-efficient appliances are carried out in MWRA communities; such

[13] Other New England water districts also make use of these technologies. A law in Connecticut requires water suppliers to provide consumers with conservation kits that include educational materials and low-flow water devices (Conservation Law Foundation 1993).

programs include writing and poster contests as well as interactive web features for students. In addition, the MWRA introduced "water efficiency studies" for businesses in the late 1980s. These studies were designed to "provide a twofold service: to present facility managers with solutions for efficient water use and to demonstrate a cost/savings analysis of the measures outlined in the report…" (Massachusetts Water Resources Authority). Under a test program, the Authority audited 34 companies, achieving an average water reduction of 25 percent with an investment of $40,000 and an average payback period of only 16 months. Following this success, the MWRA decided to audit its 600 largest non-household customers. Examples of successful audits include those conducted for many prominent businesses, including Gillette, Digital Equipment, MicroSemi USPD, Inc., and Robins Company. Water use was cut by as much as 95 percent and payback periods were as short as just over a year. (Conservation Law Foundation 1993).

Modification of water pricing. Water pricing is another demand management tool being used with increasing frequency. Water is frequently "underpriced," that is, its price is insufficient to permit water departments to recover costs, let alone to deter socially undesirable "excess" consumption. For example, the PWSB boasts that its water prices have risen by less than the rate of overall consumer price inflation over the last 20 years, even though its transmission system is antiquated (Providence Water Supply Board). In real terms, the average monthly water bill for a one-family home in California was actually less in 1984 than in 1965 (Schwartz 1988). Nationwide, a study carried out by the GAO in 2002 found that more than 25 percent of the nation's water utilities lacked sufficient revenues, largely as a result of being unable to charge sufficiently high rates, to cover their operating costs in fiscal year 2001.

Because water is a necessity, some elected officials are understandably reluctant to charge a sufficiently high price to cover production costs, let alone to internalize the external costs imposed by excessive water consumption. Some would rather subsidize water production and distribution than make water departments financially self-sufficient (Bromley 1997).

Econometric studies suggest that water consumption is moderately responsive to changes in rates. After surveying over 100 such studies, economists at the National Regulatory Research Institute concluded that a 10 percent increase in the price of water decreases residential water use by 2 to 4 percent, and industrial water use by 5 to 8 percent (Beecher et al. 1994). Since water use is only moderately "elastic" with respect to price, the potential for conservation via rate hikes is limited. Moreover, since water is essential to life, arguably some limits should be placed on its price, especially for low-income households (Berk 1980). "Life-line" pricing, which offers a minimum ration of water to low-income households at a reduced price, would address this concern (Beecher et al. 2001).

According to neoclassical economic theory, a universally applied rate structure equating the price of water to the total marginal cost of producing it would maximize economic efficiency. A cash transfer to low-income households would insure that everyone would have the capacity to obtain a ration of water necessary to preserve health.[14] However, this solution, while theoretically appealing, may be politically unpalatable.

Simply increasing the frequency of water billing could decrease water usage. If customers received water bills on a monthly basis, they could see more clearly the relationship between their usage and water bills (American Water Works Association 2000). Typically, water use is billed on a quarterly or even semi-annual basis. According to a survey of Massachusetts water suppliers in 2002, 47 percent used quarterly billing, and an additional 45 percent billed only twice a year[15] (Tighe and Bond 2002). According to proponents of more frequent billing, water users fail to see the link between usage and cost when billing is so infrequent.

Changing the structure of water rates is another widely touted method of inducing greater water conservation. Specifically, conservation advocates have endorsed

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[14] Economists term this the compensating variation, defined as the monetary subsidy sufficient to make the consumer just as well off as before the price increase. See Mas-Collel et al. (1995).
[15] This refers to the survey respondents. Complete details appear on Tighe and Bond web page: http://rates.tighebond.com/.

"increasing block rates," a scheme which requires rates to rise with the volume of water consumed (American Water Works Association 2000).[16] A large number of water suppliers charge a flat fee, which is invariant with respect to usage, or a constant rate per unit of consumption. According to the Tighe and Bond survey of water rates in Massachusetts, 4 percent of suppliers charge a flat fee, 49 percent charge a uniform per unit rate, and 45 percent use an increasing block rate structure.[17]

Imposing "seasonal" rates can also curb demand (American Water Works Association 2000). These rates impose a surcharge during times when water markets are tight. Pricing water higher in the summer months could help encourage conservation during a time when water demand is high and water recharge is relatively low (EPA 2003). Enacting a surcharge during water shortages is another way to diminish water demand. Many water suppliers add a "drought" surcharge, or alter base water prices in times of drought. In 2002, only 11 percent of water suppliers in Massachusetts used seasonal rates (Tighe and Bond 2002).

Many of the rate and price policies mentioned above are most effective when they are carried out in tandem. For instance, instituting an increasing block rate structure and changing to a monthly billing cycle may have a synergistic effect and result in more water savings. Timmins (2003) notes this effect in a study on California's water use and finds that the conservation effects of low-flow appliances "…are most successful when adopted in conjunction with a program of pricing austerity."

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[16] Several cities and towns have had success with increasing block rates. Tucson, Arizona, implemented an increasing block rate in 1977; this led to a 20 percent reduction in water demand (Conservation Law Foundation 1993). Town officials in Clinton, Massachusetts, recently proposed switching from their flat rate to an increasing block rate for this reason, and because they needed to fund a new $10 million filtration plant (Blanton 2002).

[17]However, not all block structures encourage prudent water use. Use of "volume discounts" or "decreasing block rates," in which water price declines as consumption increases, would not encourage water conservation. This particular variant of pricing is actually illegal in some places, such as Massachusetts, since it fails to promote water conservation (Nugent 2002). A report entitled "Top 21 Recommendations" put out by the State of Rhode Island Water Resources Board (RIWRB) proposes that the state eliminate flat or fixed rates and instead, "…tie rates to volume of water used" (RIWRB). Currently, two water suppliers in Rhode Island use declining block rates (Terebus 2002).

There is some evidence that water rates in New England are increasing or will increase in the future, as a result of tighter federal rules on disinfection (Association of State Drinking Water Administrators 2003). The previously preferred technique of water treatment, chlorine, has some environmental downsides; as a result, water providers are switching to "greener," though more expensive, alternatives (Yeo 2004). The MWRA has started using ozone gas for treatment, and other regional providers are exploring UV light disinfection and other techniques (Yeo 2004). If these additional costs are passed on to water consumers, their higher water bills may have a conservation effect.

IV. Conclusions

New England faces an uncertain water future. Vulnerable to transient changes in precipitation and confronting a longer-term demand and supply mismatch, water will become a more important issue in future policy debates. Former New Hampshire Governor Jeanne Shaheen reiterated the importance of water for the region, stating, "It has been said that water is the oil of the 21st century. In communities around the country, as populations and businesses grow, we've seen intense battles break out over water supplies…It should be abundantly clear that water is a precious resource, a resource we must protect" (Kittredge 2002).

While there is no single clear-cut solution to the region's water problems, there are several pragmatic policy actions that could ameliorate them. Demand management is perhaps the most promising tactic. Aggressive leak detection, greater use of water-saving technologies, and more conservation-friendly rate structures may ease the supply crunch felt throughout New England. In addition, better long-term land- and water-use planning could curb water pollution and ensure greater water recharge.

Addressing the region's short-term water supply concerns is more problematic. As long as current patterns persist and New England receives its annual three-and-a-half feet of precipitation, the region's short-term prospects are good. If global climate patterns change, then the region may be in a more precarious position. According to experts, global warming may eventually create harsher seasons—warmer summers and more bitter winters. The impact that such a development would have on New England is uncertain. Warmer and drier summers may require greater water, yet harsh winters may be accompanied by greater snowfall. Even without these fundamental climatic changes, the region's short-term water supplies will be closely tied to annual precipitation. Options for storing and trapping runoff will continue to be limited.

In the chorus of his lyric, "You Never Miss the Water," Rowland Howard wrote:

> Waste not, want not is a maxim I would teach,
> Let your watch word be dispatch and practice what you preach;
> Do not let your chances like sunbeams pass you by,
> For you never miss the water 'till the well runs dry" (Bartlett 1955).

New Englanders should heed Howard's advice. By fathoming the potential depths of their water problems now, they may avoid the fate of the Ancient Mariner, as chronicled by Samuel Taylor Coleridge: "Water, water everywhere, nor any drop to drink" ("Rime of the Ancient Mariner," quoted in Bartlett 1955).

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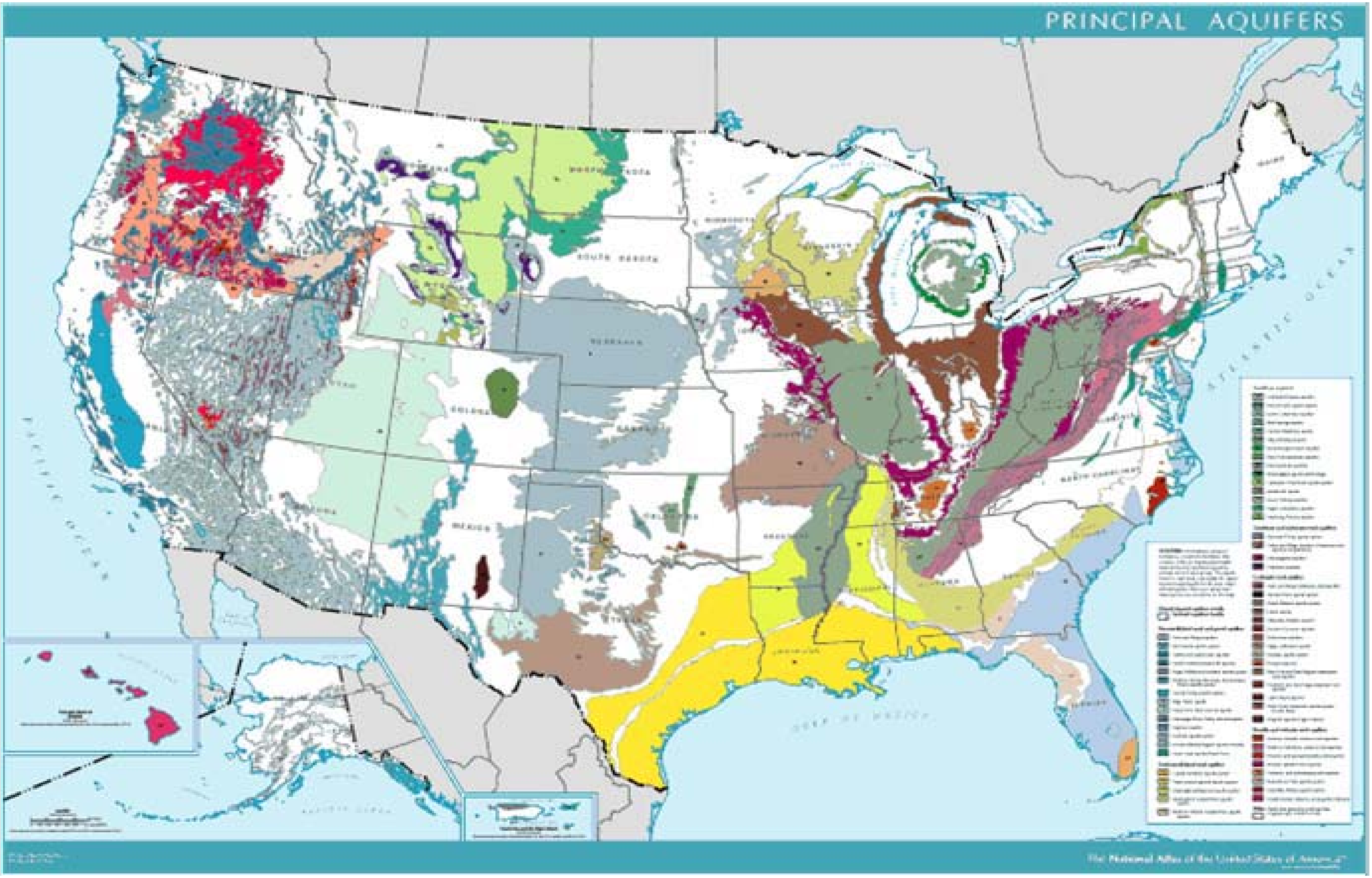
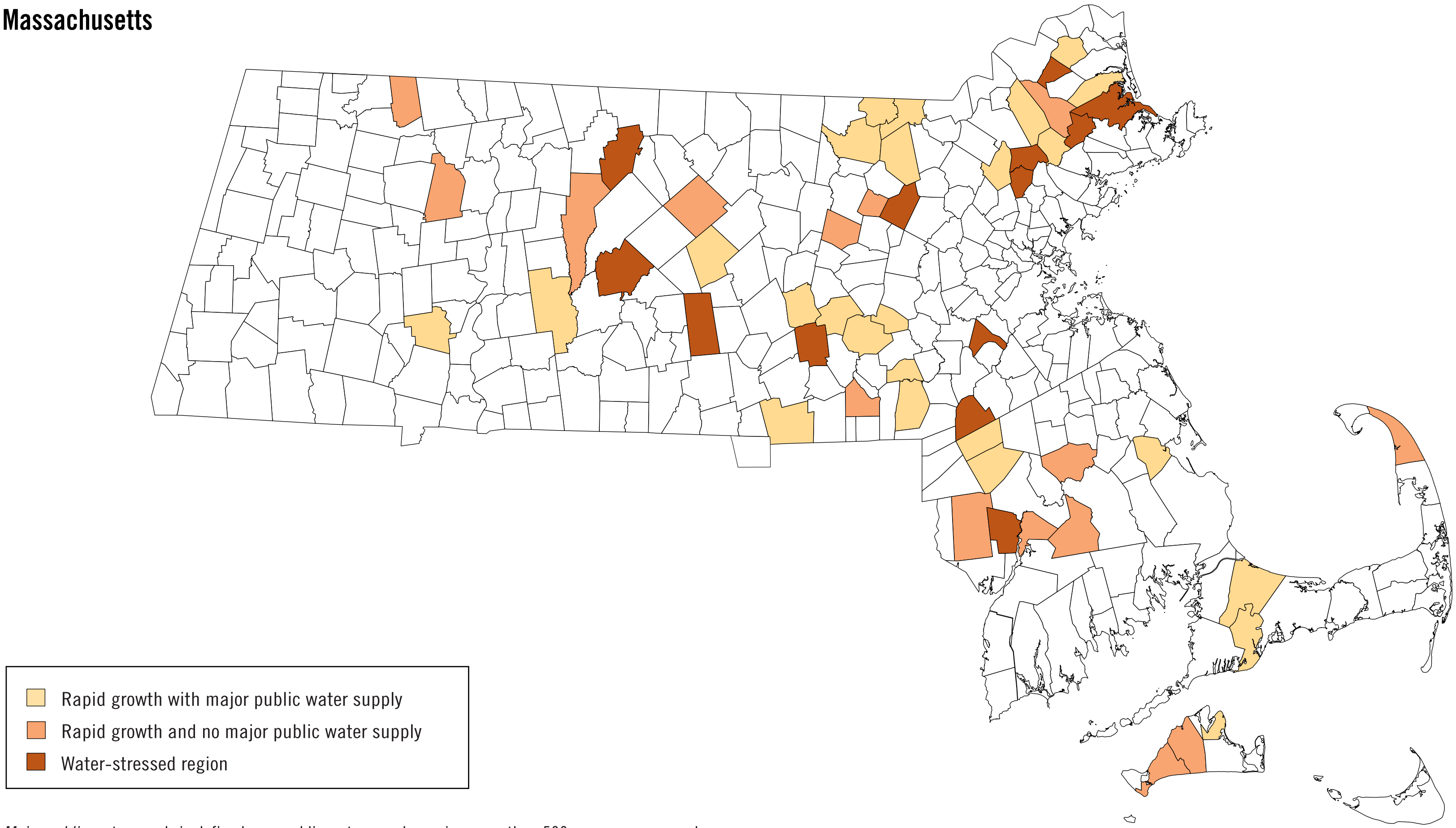
Map 1:
Principal Aquifers in the United States



Source: United States Geological Survey, 1998.

Map 2: Areas of Rapid Growth and Major Public Water Supply Availability* in New England States

Massachusetts



Major public water supply is defined as a public water supply serving more than 500 persons year round.

Rapid growth is defined as growth greater than 20 percent in the average of housing units and population.

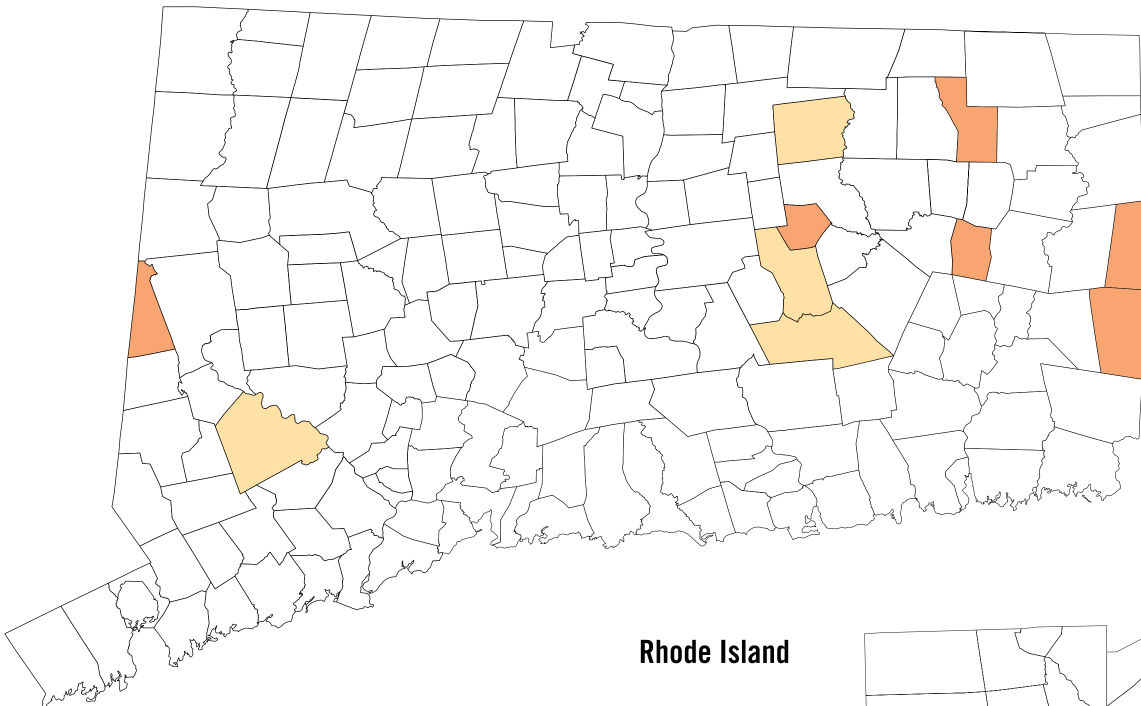
**Water-stressed region* is defined as a region of "basin stress" as identified in "Stressed Basins in Massachusetts," published in 2001 by the Water Resources Commission, a Massachusetts executive agency under the Executive Office of Environmental Affairs. http://www.mass.gov/envir/mwrc/pdf/Massachusetts_Stressed_Basins.pdf.

Sources: Population and housing data – U.S. Census Bureau. 1990 and 2000 decennial Census files.
Availability of major public water supplies – Massachusetts Department of Environmental Protection, Drinking Water Program. Email correspondence with Mark Bolivar.

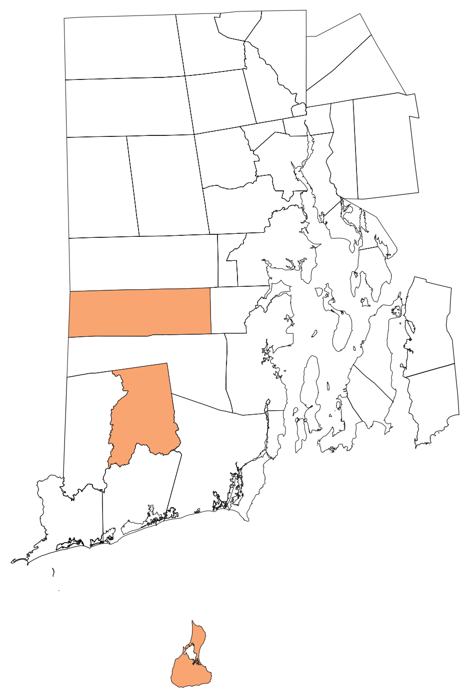
Note: Each state is drawn to its own scale.

Map 3: Areas of Rapid Growth and MajorPublic Water Supply Availability in New England States

Connecticut



Rhode Island



Rapid growth with major public water supply

Rapid growth and no major public water supply

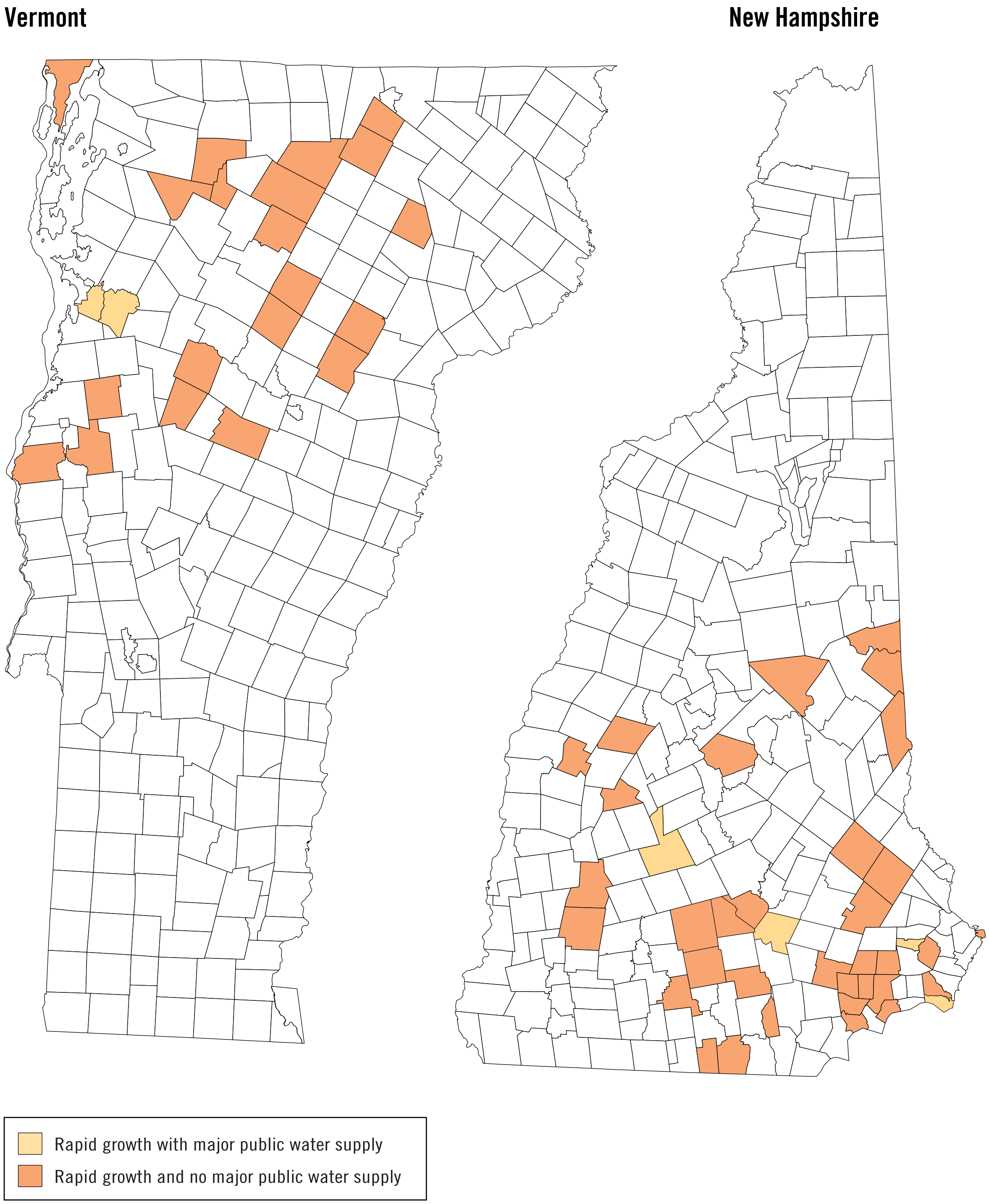
Major public water supply is defined as a public water supply serving more than 500 persons year round.

Rapid growth is defined as growth greater than 20 percent in the average of housing units and population.

Sources: Population and housing data – U.S. Census Bureau. 1990 and 2000 decennial Census files. Availability of major public water supplies – Connecticut Department of Public Health, Drinking Water Division. Email correspondence with Christopher Roy, Sanitary Engineer 2. Rhode Island Water Resources Board, Rhode Island Drought Management Plan.

Note: Each state is drawn to its own scale.

Map 4: Areas of Rapid Growth and Major Public Water Supply Availability in New England States



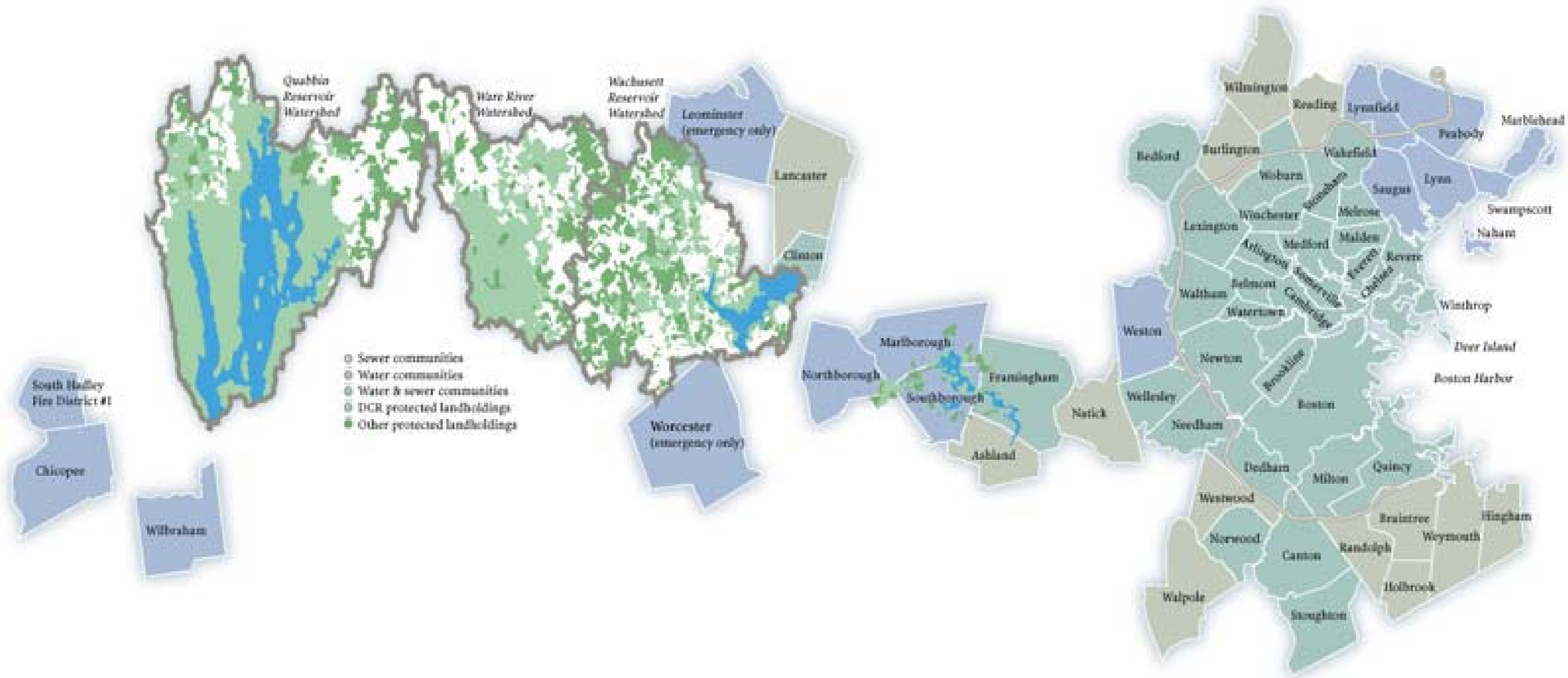
Major public water supply is defined as a public water supply serving more than 500 persons year round.

Rapid growth is defined as growth greater than 20 percent in the average of housing units and population.

Sources: Population and housing data – U.S. Census Bureau. 1990 and 2000 decennial Census files.
Availability of major public water supplies – Vermont Water Supply Division. Email correspondence with Laura LaFleur, Environmental Technician.
New Hampshire Department of Environmental Services, Water Supply Engineering. http://www.des.state.nh.us. Accessed 12/17/04.

Note: Each state is drawn to its own scale.

Map 5:
Communities Served by the Massachusetts Water Authority



Source: MWRA webpage: http://www.mwra.state.ma.us/02org/html/whatis.htm#comlist. Date accessed 12/17/04.

Table 1:
Summary of Surfacewater and Groundwater Pollution in Selected Areas

	US	*NE*	*CT*	*ME*	*MA*	*NH*	*RI*	*VT*	*NV*
river and stream assessment size (miles)* percent imparied	3,692,830 39%	65,174 20%	5,830 **53%**	31,752 3%	8,229 **65%**	10,881 16%	1,383 33%	7,099 22%	143,578 **59%**
lake assessment size (acres)* percent impaired	40,603,893 45%	1,621,997 28%	64,793 8%	987,283 15%	151,173 **58%**	168,017 4%	21,796 17%	228,915 **90%**	553,279 0%

*numbers represent the water that is monitored in the EPA report cited below.
bold indicates exceeds national average

Source:
Environmental Protection Agency. "2000 National Water Quality Inventory."
http://www.epa.gov/305b/2000report/

Table 2: Measures of Urban Development (Sprawl) in New England

Metropolitan Statistical Area	*Change in Population 1982-1997 (percent)*	*Change in Urbanized Land 1982-1997 (percent)*	*Difference (column 3-column 2)*
(1)	(2)	(3)	(4)
Bangor, ME	5	**47**	**42**
Boston, MA*	7	**47**	**40**
Burlington, VT	**21**	**50**	**30**
Hartford, CT*	8	20	13
Lewiston, ME*	5	43	**38**
Manchester, NH*	**28**	**70**	**42**
New Bedford, MA*	10	**45**	**35**
New Haven, CT*	7	19	12
New London, CT*	6	21	15
Pittsfield, MA	-4	32	**36**
Portland, ME	**17**	**108**	**91**
Portsmouth, NH*	**32**	**77**	**45**
Providence, RI*	9	22	13
Springfield, MA	5	42	**37**
Worcester, MA*	14	**53**	**39**
US Average**	17	47	30

bold indicates equal to or greater than U.S. average

*Metro areas abbreviated--full names appear below
Boston-Lawrence-Salem-Lowell-Brockton, MA
Hartford-New Britain-Middletown-Bistol, CT
Lewiston-Auburn, ME
Manchester-Nashua, NH
New Bedford-Fall River_attleboro, MA
New Haven-Waterbury-Meriden, CT
New London-Norwich, CT
Portsmouth-Dover-Rochester, NH
Providence-Pawtucket-Woonsocket, RI
Worcester-Fitchburg-Leominster, MA

**U.S. Average of 282 metro areas

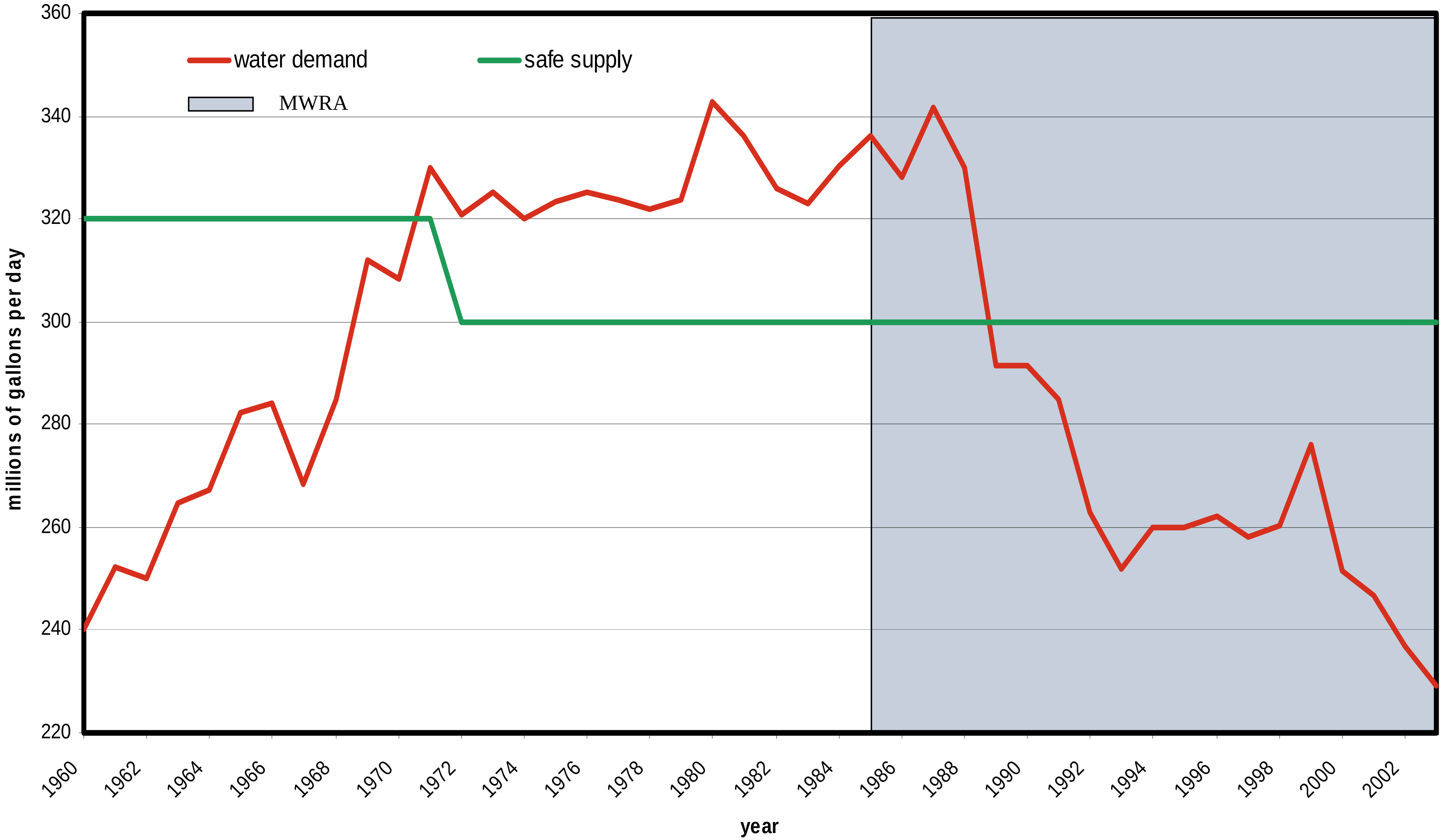
Source: "Who Sprawls Most? How Growth Patterns Differ Across the US"
Fulton, William et al. Brookings Institution. 2001

Table 3: Communities Served by the Massachusetts Water Resources Authority

Town	*Service*	*Town*	*Service*
Braintree	Sewer	**Arlington**	Water and Sewer
Burlington	Sewer	**Belmont**	Water and Sewer
Ashland	Sewer	**Boston**	Water and Sewer
Dedham	Sewer	**Brookline**	Water and Sewer
Hingham	Sewer	**Chelsea**	Water and Sewer
Holbrook	Sewer	**Clinton**	Water and Sewer
Lancaster	Sewer	**Everett**	Water and Sewer
Natick	Sewer	**Framingham**	Water and Sewer
Randolph	Sewer	**Lexington**	Water and sewer
Reading	Sewer	**Malden**	Water and Sewer
Walpole	Sewer	**Medford**	Water and Sewer
Westwood	Sewer	**Melrose**	Water and Sewer
Weymouth	Sewer	**Milton**	Water and Sewer
Wilmington	Sewer	**Newton**	Water and Sewer
Chicopee	Water	**Norwood**	Water and Sewer
Lynnfield Water District	Water	**Quincy**	Water and Sewer
Marblehead	Water	**Revere**	Water and Sewer
Nahant	Water	**Somerville**	Water and Sewer
Saugus	Water	**Stoneham**	Water and Sewer
South Hadley Fire District #1	Water	**Waltham**	Water and Sewer
Southborough	Water	**Watertown**	Water and Sewer
Swampscott	Water	**Winthrop**	Water and Sewer
Weston	Water		
Wilbraham	Water		
Leominster	Water (emergency back-up only)		
Worcester	Water (emergency back-up only)		
Cambridge	Water (emergency backup only), Sewer		
Lynn (GE only)	Water (partially supplied)		
Marlborough	Water (partially supplied)		
Northborough	Water (partially supplied)		
Peabody	Water (partially supplied)		
Bedford	Water (partially supplied), Sewer		
Canton	Water (partially supplied), Sewer		
Needham	Water (partially supplied), Sewer		
Stoughton	Water (partially supplied), Sewer		
Wakefield	Water (partially supplied), Sewer		
Wellesley	Water (partially supplied), Sewer		
Winchester	Water (partially supplied), sewer		
Woburn	Water (partially supplied), Sewer		

Source: MWRA webpage:http://www.mwra.state.ma.us/02org/html/whatis.htm#comlist

Figure 1:
Water Demand in Massachusetts Water Resources Authority



Source: Data obtained from Massachusetts Water Resources Authority Communications Director Jonathan Yeo, 2004.