THE EFFECTS OF THE 2001-2002 DROUGHT

ON MAINE SURFACE WATER SUPPLIES

By

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B.S. University of Massachusetts, 1998

A THESIS

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

(in Ecology and Environmental Sciences)

The Graduate School

The University of Maine

December, 2003

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An Abstract of the Thesis Presented
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Maine lakes and streams serve as significant sources of public water supply, serving 40 % of the population. Drought affects surface water resources by reducing water quantity and altering water quality, for example by reducing inputs of materials from the watershed and increasing water residence times. The 2001-2002 drought was the worst in Maine in over thirty years, and it exposed deficiencies in current water resources planning and management. In this study, I evaluated the effects of the 2001-2002 drought on Maine public water systems in order to identify characteristics of systems vulnerable to drought and determine appropriate indicators of drought sensitivity. I also evaluated the future of Maine's water supply industry in a potentially changing climate.

In addition to reviewing drought problems reported to the Drinking Water Program and Public Utilities Commission, I surveyed all public surface water systems to identify systems affected by the drought. Historical hydrological and chemical data from a subset of seven public water supply lakes provided a more intensive analysis of the effects of drought on water quantity and quality. Monthly hydrologic conditions

antecedent to the drought were assessed to determine the most robust triggers for future use in public water system drought planning and management. Data on lake morphometry, geology, landscape position, land use, and demographics from a second subset of 28 public water supply lakes were assessed to identify the best indicators of drought sensitivity. Manager responses to the drought were documented to establish a record of institutional knowledge for dealing with drought.

Forty-five of approximately 400 community groundwater systems and eight of 68 surface water systems were affected by the drought, although most systems experienced below-average water levels. No consistent changes in water quality variables related to water clarity were noted, although comparisons were limited by a lack of consistent source water monitoring data. Environmental factors such as morphometry or geology were not useful predictors of the sensitivity of a particular system to drought. A key finding was that affected systems were withdrawing volumes of water in excess of their safe yield. These stressed systems are located in the populated coastal region and in areas where an increase in water demand is caused by seasonal tourism and development.

An essential management conclusion was that drought conditions or low lake levels alone were not enough to drive a system to implement water conservation; increased demand had to occur simultaneously. The best management tool is monthly monitoring of water withdrawals and demand in addition to local climatic parameters. While the scope and direction of future climate change is uncertain, the effects of the 2001-2002 drought indicate that public surface water systems that already operate close to capacity and that experience seasonal increases in demand are most likely to encounter difficulties in a variable and uncertain climate.

ACKNOWLEDGEMENTS

The author would like to thank the following organizations and individuals for financial and professional support during the research and writing of the thesis: the Senator George J. Mitchell Center for Environmental and Watershed Research, the Maine Drinking Water Program, the University of Maine Department of Biological Sciences, and Jeff McNelly and the Water Resources Committee of Maine Water Utilities Association.

This work could not have been completed without the time, data, and resources of public water systems, most especially: Bangor Water District, Bar Harbor Water Company, Bath Water District, Boothbay Region Water District, Consumers Maine Water Company Camden-Rockland Division, Winthrop Utilities District, and York Water District. Special thanks also to Auburn Water District, Kennebunk, Kennebunkport, and Wells Water District, Bethel Water District, Stonington Water Company, and Portland Water District.

Several individuals, agencies, and organizations made significant data contributions, including Scott Williams of the Volunteer Lake Monitoring Program, Greg Stewart and Pam Lombard of the U.S. Geological Survey, Tom Allen and Greg Zielinski at the University of Maine, Robin Frost of the Drinking Water Program, and the National Park Service. Thanks to Sarah Nelson for help with GIS data and figures.

A most gracious thank you to the Maine Drinking Water Program for funding this research.

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AN INTRODUCTION TO DROUGHT AND DRINKING WATER IN MAINE

The importance of secure freshwater supplies is often underrated in North America (Schindler, 1997). This is especially true in Maine, where a history of glaciation and a humid climate have supplied the state with thousands of natural lakes, large river systems, thousands of miles of coastline and wetlands that occupy one-quarter of the state's land area.

Maine's abundant freshwater supplies serve as important sources of drinking water (Figure 1.1). Although there are more groundwater systems than surface water systems, surface water supplies 75 % of the volume of domestic public water withdrawals, providing drinking water to half a million people (Solley et al., 1998; Figure 1.2). Most of these surface water supplies are moderately- or well-protected and have exceptional water quality, and a number of systems have waivers from filtration requirements.

Despite these plentiful resources, dry conditions in 2001-2002 brought on a 'new frontier' in water conflicts in Maine and the entire northeastern U.S. (Jehl, 2003). Maine experienced the worst drought conditions in over 30 years. Hundreds of groundwater wells went dry, and many water systems imposed conservation measures. The drought revealed inadequacies in public water supply, highlighting the need for planning and management beyond current levels.

Figure 1.1 Maine public water supplies (PWS). PWS Intakes are surface water supplies, PWS Wells are groundwater supplies. Data from ME Drinking Water Program (2002; 2003).

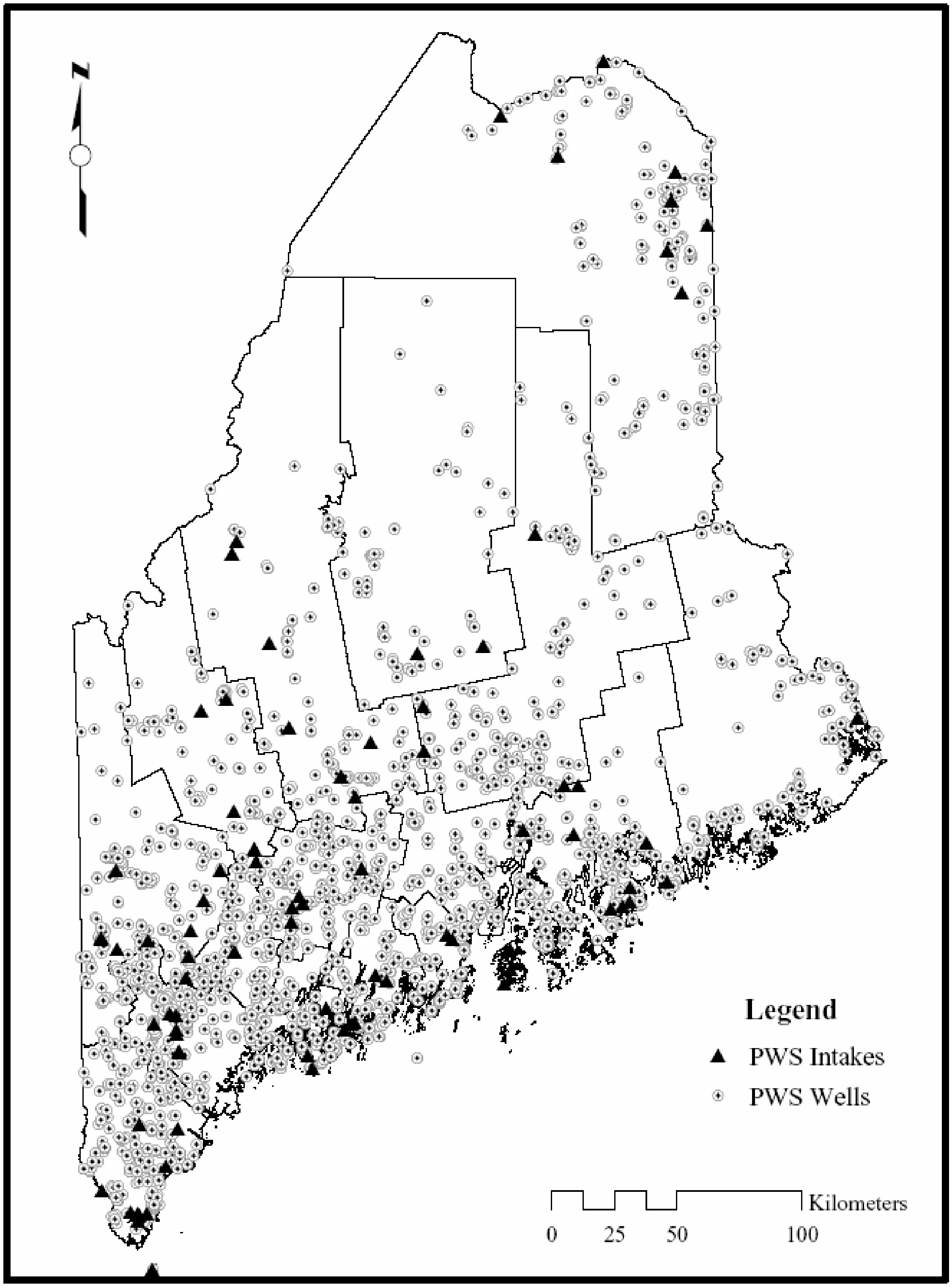
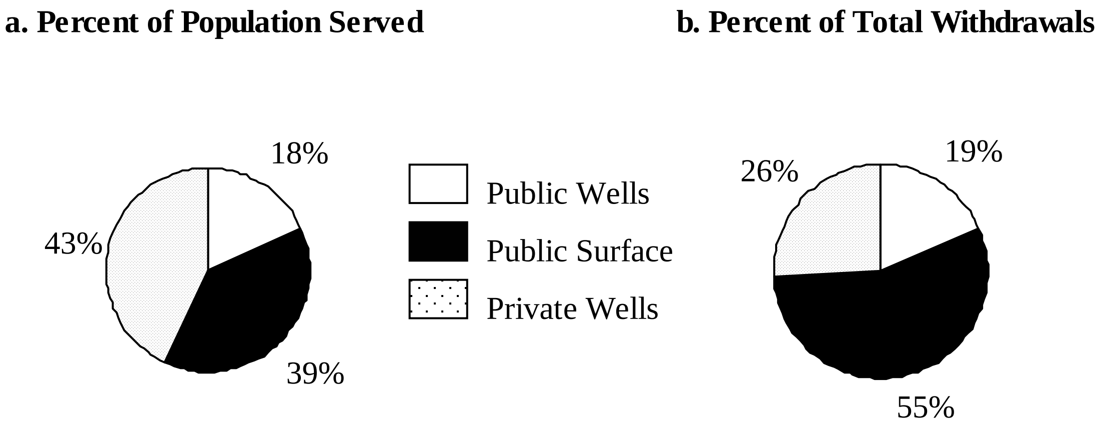


Figure 1.2 Water supply distribution in Maine. The percentages of population served (a) and total withdrawals (b) for the three types of domestic water supplies (public wells, public surface water and private wells) in Maine (Solley et al., 1998; Lombard, 2003).



Defining Drought

There are three definitions of drought: meteorological drought, agricultural drought, and hydrologic drought. The National Weather Service defines meteorological drought as a twelve-month period during which precipitation is less than 85 % of the annual average of the preceding 20 years. Agricultural drought is defined as a shortage of precipitation and below normal soil moisture conditions sufficient to adversely affect crop production or range production (Rosenberg, 1979). Hydrologic drought is a period of below average water content in streams, reservoirs, groundwater aquifers, lakes, and soils (Yevjevich et al., 1977). Much of the difficulty in defining drought is due to its nature. Among natural hazards or disasters, drought is unique: it arrives slowly, with no clear beginning or end. Drought may develop, decay for a while, and then redevelop, as in the case of the 1987-89 drought in the upper midwestern U.S. (Riebsame et al., 1991).

All types of drought originate from a deficiency of precipitation that causes a water shortage for some activity or group. Because of this human aspect, the significance of drought should not be separated from its societal context (Wilhite and Glantz, 1987). Indeed, drought is defined by the people who experience it (Miewald, 1978). Put another way, if there's plenty of water to go around for human needs, is it still a drought? Ecologists would argue yes, because plant and animal communities are affected. Those who deal with human-managed systems such as public water supplies might disagree.

A public water supplier is concerned with two aspects of drought. The first is the hydrological effect on water quantity and water quality. The second is how the drought affects consumers, a function of supply and demand. A drinking water system will be affected by drought when decreasing supply intersects increasing demand. For the purposes of this assessment, I define drought as *a deficit of precipitation sufficient to create stress on and competition for otherwise adequate drinking water supplies.*

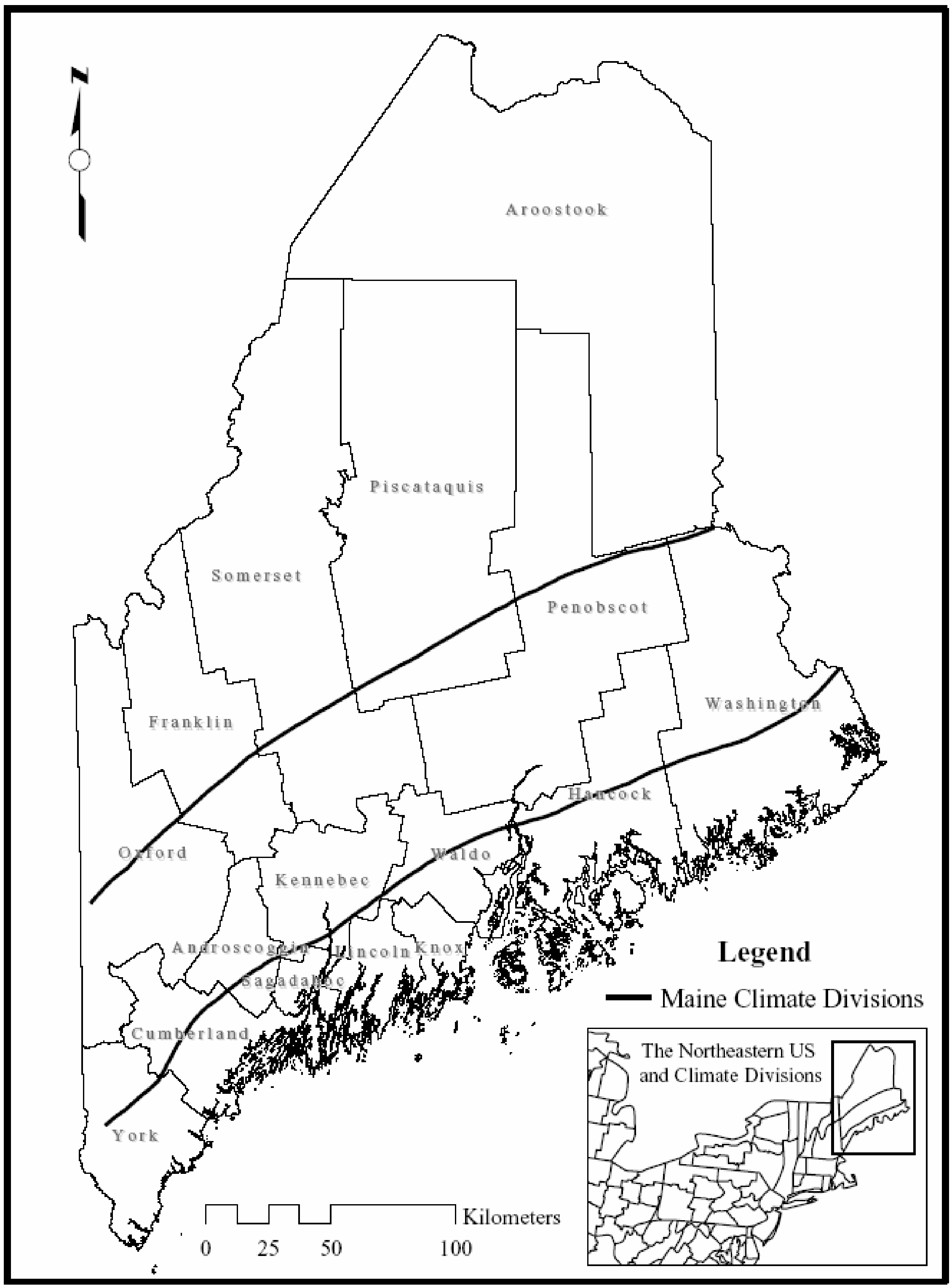
Drought in Maine

New England is not known as a drought-prone region, but droughts do happen here. The last widespread severe drought occurred in the 1960s (Leathers et al., 2000). The 1960s drought may have been less severe in Maine when compared to the other New England states, although precipitation in 1965 was the second lowest annual total in Maine history (Zielinski and Keim, 2003).

The weather in Maine varies spatially and temporally. Large daily and annual ranges in temperature, substantial differences among seasons, and variability across years contribute to considerable heterogeneity across the state. Maine is divided into three climate divisions based on distance from the ocean, elevation, and landscape form (Lautzenheiser, 1959). The Northern Division encompasses the northern and northwestern 54 % of the state. The Southern Interior Division contains 31 % of the land area in a band from southwest to northeast through the middle of the state. The Coastal Division comprises the remaining 15 % along the Gulf of Maine (Figure 1.3).

In New England, drought usually occurs when a strong stationary high-pressure system prevents storms from entering the region. Coastal areas generally experience much shorter-duration droughts because of frequent storms (Johnson and Kohne, 1993). The nearly equal distribution of precipitation in Maine throughout the year means that a short-term drought can occur in any season (Zielinski and Keim, 2003). A winter drought may not have an immediate effect on surface water supplies, but lack of late fall recharge and spring runoff can contribute to water shortages during the spring and summer.

Figure 1.3 Maine climate divisions (NCDC, 1991).

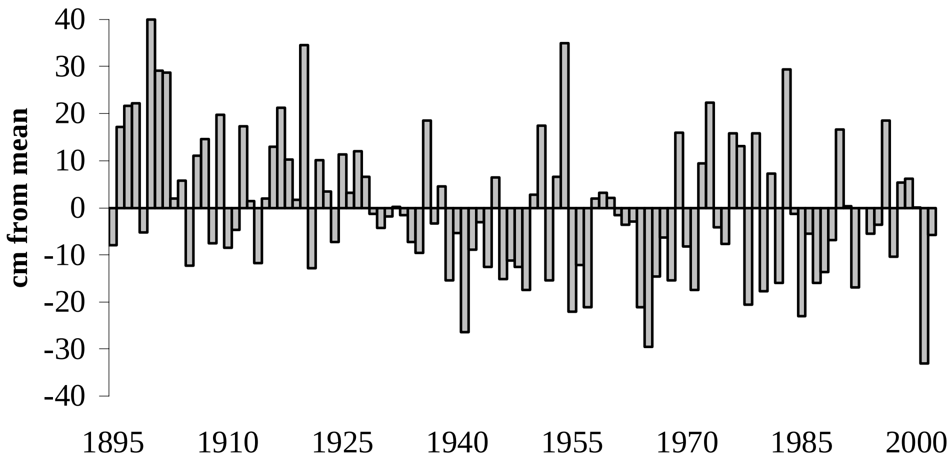


The 2001-2002 Drought in Perspective

Nationally, 2001 was the seventh warmest year on record, and precipitation was slightly below average for the conterminous U.S. (Waple et al., 2002). Severe to extreme drought gradually expanded from about 15 % of the country in January to 20 % in October. Along the eastern seaboard, drought intensified during the last three months of the year (Waple et al., 2002). The drought was part of a widespread drying across the middle latitudes of the globe controlled by tropical ocean conditions (Hoerling and Kumar, 2003). North American atmospheric circulations have been associated with a dry northeastern U.S. (Barlow et. al., 2001) and are linked to lower streamflows in parts of New England (Bradbury et al., 2002).

In Maine, 2001 was the driest year since records began in 1895. Statewide annual precipitation totaled 75.2 centimeters (cm) in 2001, 33.1 cm below the annual average of 108.3 cm and 3.5 cm below the total of the last record drought year, 1965 (Figure 1.4). Streamflow declines were greatest in August and September of 2001; dry conditions persisted into the 2002 winter when groundwater levels across the state reached record lows (Stewart et al., 2003). By late spring, rains had replenished surface water levels; however, groundwater levels remained low (Drought Task Force, 2002a and 2002b).

Figure 1.4 Maine annual precipitation, 1895-2002, expressed as the deviation from the long-term mean (108.3 cm) (NCDC, 2003a).



One important question that remains is whether the drought was an isolated event or part of a larger wax-wane episode (Riebsame et al., 1991). In Figure 1.4, the period from 1895 to 1930 was wetter than average and the precipitation in the years since then was more often below average. During the 1940s, 50s, 60s, and mid-80s, dry conditions persisted for several years at a time. The record is not long enough to discern if there is a decadal pattern to precipitation. It may take several years before the significance of the 2001-2002 drought is completely understood.

The most widely used measure of drought is the Palmer Drought Severity Index (PDSI). The method, developed by Palmer (1965), takes into account precipitation, evapotranspiration and soil moisture conditions. The Palmer Index is calculated weekly, with positive values indicating wetter than normal conditions and negative values indicating drier than normal conditions. The PDSI is one of the few general indices of drought readily available and standardized to regional climates (Alley, 1984), and remains the best index for analyzing drought processes (Lohani and Loganathan, 1997).

The Palmer Hydrological Drought Index (PDHI) uses the same principles and equations of moisture supply and demand as the PDSI, and during the maximum severity of a drought or wet spell the two are identical (Johnson and Kohne, 1993). The principal difference is that at the beginning and ending of droughts or wet periods the PHDI responds more slowly to changes in weather. The advantage of this delayed response is that while the precipitation and temperature may return to normal, there may still be a deficiency in soil moisture, streamflow, and lake levels (Johnson and Kohne, 1993).

A comparison to historic drought periods using monthly PHDI values shows that 2001 was the most severe drought in all climate divisions of Maine in over thirty years (Figure 1.5). The severity varied by division, with the Southern Interior Division experiencing the lowest PHDI values. The 2001-2002 PHDI values were higher in the Coastal Division (Figure 1.6).

<u>Drought and Drinking Water: A Background</u>

<u>The Effects of Drought on Water Quantity</u>

Reduced water levels in lakes and rivers are one of the most obvious signs of drought. The response of a particular water supply will depend on the relative contributions of precipitation, surface drainage, and groundwater. In Maine, approximately 30-40 % of annual precipitation is lost via evapotranspiration and half ends up in streamflow. The remaining 10 % to 20 % of precipitation recharges groundwater, depending on soil type (Caswell, 1987).

Figure 1.5 Maine drought periods by climate division (three or more months of severe to extreme drought with Palmer Hydrologic Drought Index < -3). Numbers indicate record low monthly mean PHDI for each division (NCDC, 2003b).

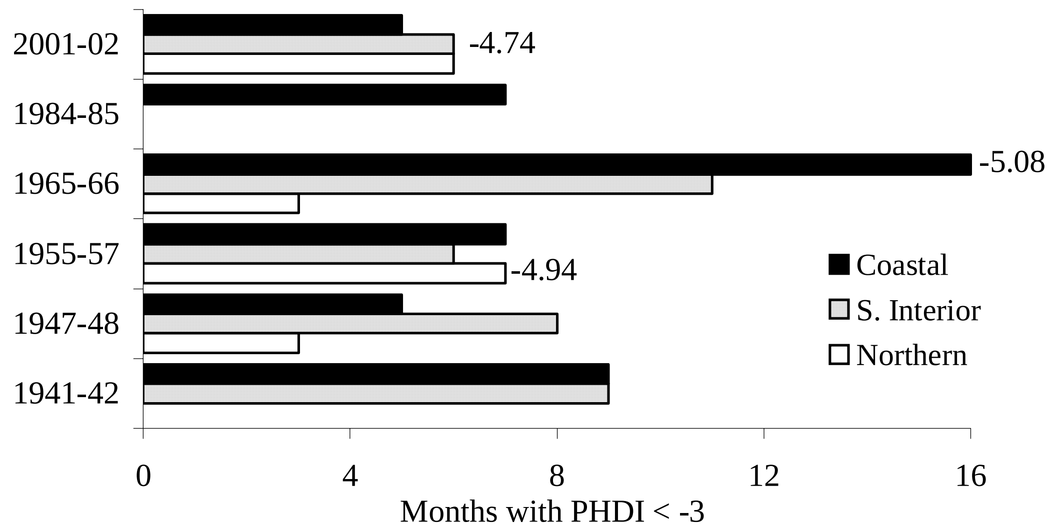
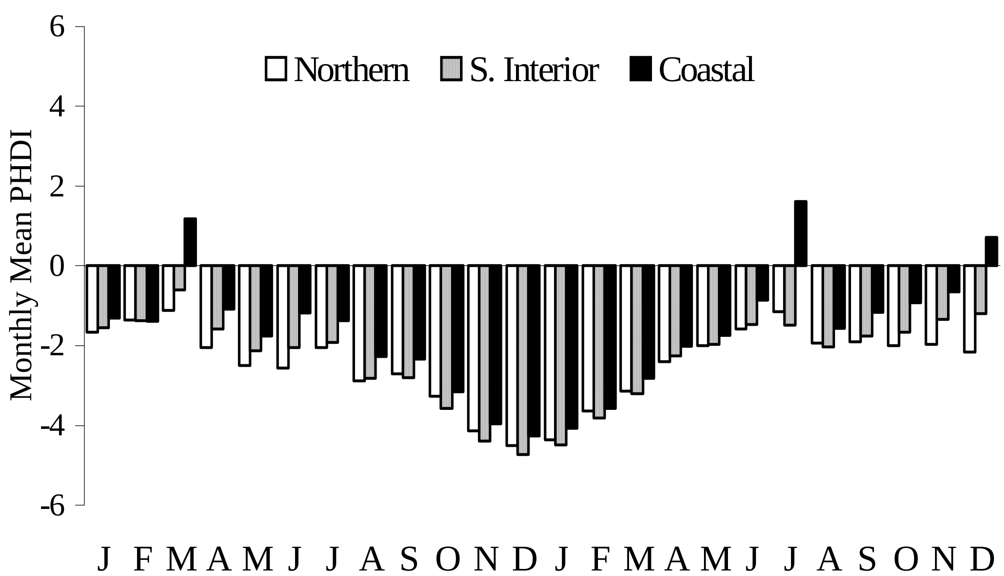


Figure 1.6 Monthly mean Palmer Hydrological Drought Index by climate division, 2001-2002 (NCDC, 2003b).



Surface water sources that are most dependent on direct precipitation would be expected to be the first to experience water level declines. For example, during the 1987-1990 drought in Wisconsin, water levels of some lakes at the North Temperate Lakes Long-Term Ecological Research site declined by up to one meter (Webster et al., 1996). Seepage lakes that received most of their water inputs from direct precipitation experienced the largest declines in lake levels; water losses were driven by evaporation. Drainage lakes (with inlets and outlets) located hydrologically lower in the landscape which received inputs of both surface and groundwater experienced only slight water level declines (Webster et al., 1996).

The response of lakes and streams to drought may depend on the seasonal and temporal patterns of precipitation. In Maine, the timing of snowmelt and the ratio of rain to snow in late winter influence spring and summer streamflows. Peak streamflow generally occurs in early spring when rain falls on melting snowpack or on saturated soils (Dudley and Hodgkins, 2002) and is dependent on the amount of snow and the intensity of precipitation. Prolonged drought lowers groundwater levels and will reduce baseflow in perennial streams, since groundwater provides baseflow in perennial streams during periods without precipitation (Allan, 1995). Depending on the season, ephemeral streams may not flow at all; perennial streams and lake outlets may become intermittent (Lake, 2000). The effects of drought on groundwater levels are less obvious. While streamflow responds relatively quickly to precipitation, changes in groundwater levels often lag in response time (USGS, 2003a).

The Effects of Drought on Water Quality

By affecting water quantity, drought has an indirect effect on water quality. Managers of public water supplies are charged with providing adequate quantity and quality of clean drinking water. The Safe Drinking Water Act mandates that public water systems comply with national health-based standards for drinking water to protect against both naturally occurring and human-made contaminants (U.S. EPA, 1999a). Anything that affects water quality is a serious concern because public health may be affected.

Moderate climate fluctuations that alter hydrologic regimes can have substantial effects on lake chemistry (Webster et al., 1990; Webster et al., 1996). Sediment, organic matter, and nutrients are transported to surface waters by runoff, a pathway that is interrupted during drought. Surface water quality is also influenced by materials derived from groundwater, soil exchange, and in-lake and in-stream processes. A decline in material transport from the watershed during drought is countered by an increase in retention of some materials as water residence time increases and evaporation increases relative to precipitation (Meyer and Pulliam, 1992).

As precipitation decreases, a lake will generally have less interaction with the surrounding terrestrial environment. Water level declines expose littoral zones and adjacent wetlands, altering vegetation patterns and chemical cycling pathways (LaBaugh et al., 1996; Yan et al., 1996; Burkett and Kusler, 2000). For example, the majority of dissolved organic carbon (DOC) export is derived from the near-surface layers in wetlands and riparian areas in the watershed (Dillon and Molot, 1997; Schiff et al., 1998; Gergel et al., 1999), which are the first to dry out during severe drought. As water levels within wetlands recede and flushing and runoff decline, the pathway of DOC export to lakes and streams is severed (Schindler et al., 1996). Both DOC and color have been shown to decrease in lakes during dry periods (Watts et al., 2001; Pace and Cole, 2002; Seger, 2004). Ultraviolet radiation also contributes to DOC degradation in lakes (Allard et al., 1994; Lindell et al., 1995).

Water supply managers are concerned about carbon because it reacts with added chlorine to form disinfection by-products. These compounds include trihalomethanes and haloacetic acids, which are regulated by the Safe Drinking Water Act due their carcinogenic potential (U.S. EPA, 2002). Color is considered a nuisance or aesthetic problem for drinking water. Color serves as an indicator of DOC (Cuthbert and del Georgio, 1992) since humic fractions of DOC derived from the watershed account for most of the color observed in lakes (McKnight et al., 1994).

Microorganisms are one of the most common and longest-regulated drinking water contaminants (U.S. EPA, 1999b). Drinking water was a major source of disease until the widespread introduction of chlorination in the early 1900s (Frederick, 1991). *Cryptosporidium*, *Giardia*, and *Legionella,* pathogens that can cause gastrointestinal illness and disease, are transported to drinking water sources via surface runoff and infiltration to surficial aquifers. Waterborne disease outbreaks in water supplies are usually associated with periods of extreme precipitation, because contaminated stormwater can infiltrate drinking water systems during flooding (Rose et al., 2000). Outbreaks also have been linked to drought, when wastewater effluent makes up a greater portion of surface water flows (Leland et al., 1993). Caruso (2002) found higher fecal coliform counts and higher dissolved solids in New Zealand streams during a summer drought, reflecting decreased dilution, increased evaporation and increased subsurface water residence time in soils discharging to streams under low flow conditions (Schindler, 1997; Murdoch et al., 2000).

Excess nutrients, specifically phosphorus and nitrogen, can stimulate algae blooms in surface water supplies. Excess algae are responsible for numerous drinking water quality problems, including clogged filters, color, turbidity, taste and odor, altered pH, oxygen depletion, and elevated organic carbon. Phosphorus is bound to soil particles that are suspended in runoff and transported to surface waters; therefore phosphorus loadings are lower during drought as a result of lower flux from the watershed (Schindler et al., 1996; Magnuson et al., 1997).

Water quality responses are site-specific, however. Nutrient concentrations can increase despite reduced runoff as retention and in-lake processing increase. With sufficient nutrient concentrations, drought-induced decreases in DOC, increased transparency, and increased light transmission would have two expected effects on phytoplankton: algal populations that are light-limited would grow faster, and annual phytoplankton production would increase (Magnuson et al., 1997).

Algal biomass and total number of species increased in western Ontario lakes during drought years, although nutrients decreased (Findlay et al., 2001), possibly due to increased temperatures and deeper light penetration. Algal species composition shifted toward a greater percentage of mixotrophic species (dinoflagellates and chrysophytes; Findlay et al., 2001), which may have a competitive advantage under reduced nutrient conditions because they can consume bacteria as a carbon source (Isaksson et al., 1999). Soranno et al. (1997) found less blue-green algal biomass in a normal runoff year compared to a year of higher than average runoff in Lake Mendota, WI, as internal phosphorus loading increased relative to external loading. Noges and Noges (1999) found reduced water quality in the Baltic's Lake Vortsjarv during drought because low water levels had a concentrating effect on lake composition. Nutrient loading may also vary depending on watershed land use, as contributing areas change with interannual variability in runoff (Soranno et al., 1996).

These potential water quality changes during drought may affect drinking water supplies by lowering overall water quality for human consumption. For example, the need to withdraw water closer to the stream bottom led to musty, earthy smells, a brown color, and subsequent complaints from water customers in Maryland in 2002 (Brenner, 2002). Changes in water quality require adjustments in water treatment that can be costly for water suppliers, and these costs are passed on to consumers.

Sensitivity of Surface Water Supplies to Drought

Numerous factors, including natural characteristics, influence whether or not a water supply is affected by drought. Lakes located in areas with similar topography, geology, and climate can have different hydrologic regimes. A lake's position in the landscape relative to the local hydrologic flow system is determined by the proportion of water inflow supplied by groundwater, from lakes that receive all of their water from direct precipitation to lakes that receive substantial inputs of groundwater (Webster et al., 1996). This "hydrologic landscape" setting (Winter, 2001) may serve as a predictor of drought sensitivity (Kratz et al., 1997). Water quality changes during drought are similarly related to hydrologic landscape position (Wentz et al., 1995; Webster et al., 1996; Webster et al., 2000).

Geology is a factor governing the hydrology of surface water bodies. Groundwater inputs to lakes range from negligible amounts in small basins underlain by unfractured rock, to about 50 % in some drainage lakes. The groundwater contribution can be higher in seepage lakes in porous sandy basins (Kalff, 2002). In general in Maine, sand and gravel aquifers yield 40-50 % of annual precipitation to groundwater baseflow, till yields 5-35 %, and bedrock yields 2-5 % (Caswell, 1987; A. Tolman, ME Drinking Water Program, pers. comm., 2003).

Higher yield formations, because they have more water in storage, tend to respond more slowly to drought. Because water-bearing fractures in bedrock are only a very small portion of the entire rock mass, reductions in recharge lead to rapid water level declines. Sand and gravel aquifers, with 10 % to 20 % of the total volume available for water storage and transmission, respond more slowly to reductions in recharge (A. Tolman, ME Drinking Water Program, pers. comm., 2003).

Land cover also influences water and solute inputs to lakes and streams. Of all land uses, intact forests yield the most reliable and highest quality water (Dissmeyer, 2000). In contrast, the effects of drought may be exacerbated in highly or even moderately developed watersheds (Otto et al., 2002), because large amounts of impervious surfaces associated with development redirect and reduce groundwater recharge and increase surface runoff (Simmons and Reynolds, 1982). Land use change is generally considered to be the major factor affecting ecosystem health (Hunsaker and Levine, 1995). In Maine, the water quality of rivers begins to degrade when impervious surface cover in urbanizing watersheds exceeds 6-10% (Morse, 2001). Surface water supplies in highly developed watersheds may be expected to experience both reduced water quantity and degraded water quality during drought.

Land development is correlated with population. Increases in population and development drive increases in water demand. Any situation in which demand exceeds supply mimics the effects of drought, and a deficiency of water for any use can occur regardless of weather conditions. The manner in which managers respond to changes in supply and demand can be as important as the environmental effects of drought. An assessment of drought impacts cannot ignore the consumers, since they comprise the demand-side of the equation.

Even natural lakes and streams that serve as drinking water supplies are human-managed ecosystems. Although drought *sensitivity* may depend on natural attributes, such as landscape position, watershed geology, land use, and morphometry, drought *vulnerability* has as much to do with human factors as with natural ones.

Study Objectives

Identifying the vulnerability of public water supplies is critical for future drought planning and preparedness (Wilhite, 1997). The dry conditions experienced by the entire state in 2001-2002 provided an opportunity to study the effects of drought on Maine’s drinking water infrastructure and supply, and to update current understanding of potential effects of drought in Maine. In a broader sense, the drought may serve as a “surrogate” for climate change or other global or regional environmental changes, providing insight into the vulnerability of public water systems to future climate conditions.

Here I assess the effects of drought on public surface water supplies in Maine, and the implications for future research and management needs. My objectives are:

- to identify systems that may be vulnerable to drought and how they are likely to be affected (Chapter 2);
- to evaluate drought preparedness for vulnerable systems and examine the status of drought planning among water managers in the state (Chapter 3); and
- to apply the lessons learned from the 2001 drought to Maine's public water supply future under a changing climate (Chapter 4).

The results will contribute both to scientific knowledge on how drought affects surface water resources in the state, and to water supply management planning efforts. Assessing climate effects on water use and availability will help to ensure that Maine continues to be a water-rich state.

Chapter 2

VULNERABILITY OF MAINE SURFACE WATER SUPPLIES TO DROUGHT

Introduction

Maine's abundant freshwater resources serve as significant sources of drinking water. But as natural systems, these supplies are subject to the weather. Weather patterns that result in decreased precipitation, and increased temperature, can stress water systems by both reducing supply and increasing demand. In Maine, the 2001-2002 drought that was experienced by the entire eastern seaboard of the United States (Waple et al., 2002) was the most significant in over thirty years. The drought focused attention on emerging conflicts over water for drinking, irrigation, and in-stream uses in a state usually perceived as water-rich.

Drought affects both quantity and quality of drinking water resources. Adequate quantities are necessary to satisfy customer demand and maintain viability of public water systems. Water quality often improves during a drought, because surface waters receive nutrients, sediments, and organic matter in runoff from the surrounding watershed (Schindler et al., 1996). Water quality parameters of particular concern for drinking water supplies are color and organic matter, turbidity, and nutrient concentrations, because of their associated regulation and treatment costs.

Identifying the systems most sensitive to past droughts can provide an indication of future drought sensitivity. Not all systems will respond similarly to climate fluctuations, for both natural and anthropogenic reasons. Lakes and streams will vary in their response to drought depending on environmental factors such as their position along a landscape gradient (Webster et al, 1996); watershed land use and geology, and morphometry. Surface waters that provide drinking water are human-managed ecosystems, and there may be infrastructural or operational aspects of drinking water systems that make them more or less vulnerable to drought.

Prior to the recent drought, the response of Maine drinking water supplies to severe drought was relatively unknown. The last extreme drought in New England occurred in the 1960s, when Maine's population and economy were much smaller than today. In their assessment of the effects of the 1960s drought on Massachusetts water supplies, Russell et al. (1970) found that the amount of precipitation shortfall at which each system was unable to meet demand was different because each system had different levels of demand relative to available water yield.

A number of recent assessments exist of the potential impacts of drought and climate on water supply (e.g., Riebsame et al., 1991; Johnson and Kohne, 1993; Kirshen and Fennessy, 1995; Kirshen, 2002), but none address the vulnerability of smaller, rural surface water supplies common to Maine. Short-term droughts of a few months, which may be climatologically less significant but can still create water shortages, have received less attention (Illston and Basara, 2003).

Both surface water flows and groundwater levels reached record lows during the 2001-2002 drought (Stewart et al., 2002). While groundwater suffered more than surface water, I focused on surface water systems in this study because a significant portion of Maine's population is served by surface sources, a fact that is mostly the result of the state's unique abundance of clean freshwater supplies.

In this chapter, I evaluate the effects of the 2001-2002 drought on public surface water supplies to determine which systems were most affected. From this assessment, I infer which systems will be most vulnerable to future droughts and climate variability. Historical hydrological and chemical data from a subset of small public water supply lakes allowed an analysis of the effects of drought on water quantity and quality. Environmental and demographic attributes of surface water systems were evaluated to discern any similarities among those systems affected by the drought using existing data.

The results suggest that for individual surface water systems in Maine, the available volume of water relative to peak demand is more important than environmental factors in determining drought vulnerability. Most of the systems that were stressed by the drought and had to implement water conservation measures were located in the coastal region where demand driven by summer population increases and development patterns exceeded available water supply. The affected systems had existing imbalances in supply and demand that were magnified, not created, by the drought.

Methods

Individual public water systems and state regulatory agencies were surveyed via telephone interviews and paper surveys in order to inventory which systems were affected by the drought. The survey of managers was also used to select a representative group of surface water systems using small lakes for more intensive study of drought effects on water quantity and quality. I used existing data from state and federal environmental agencies and databases to compare affected and unaffected public water supply lakes.

Affected Public Surface Water Systems

Public water systems are governed by the Maine Drinking Water Program (DWP), which enforces the Safe Drinking Water Act, and the Maine Public Utilities Commission (PUC), which regulates community, non-transient public water systems. These systems are defined as having 15 connections or serving 25 or more people year-round. During the 2001-2002 drought, the DWP kept an inventory of public water systems that reported drought-related problems; also, a subset of public water systems submitted status reports to the PUC during droughts.

To verify and supplement information on drought problems provided by the DWP and PUC, I surveyed public surface water systems via telephone in August and September of 2002. Of a total 68 surface water systems, 59 responded (87 %). A copy of the survey and summarized responses are provided in Appendix A. I defined a system as affected by the drought if: 1) water quantity was enough for the system to impose voluntary or mandatory conservation; 2) water quantity was reduced enough to require the system manager to utilize or explore additional or alternative supplies; and/or 3) the manager expressed concern about the drought's effects on water quantity or quality. I did not consider systems that had adequate quantities of water to supply demand but implemented voluntary conservation as a precautionary measure to be affected.

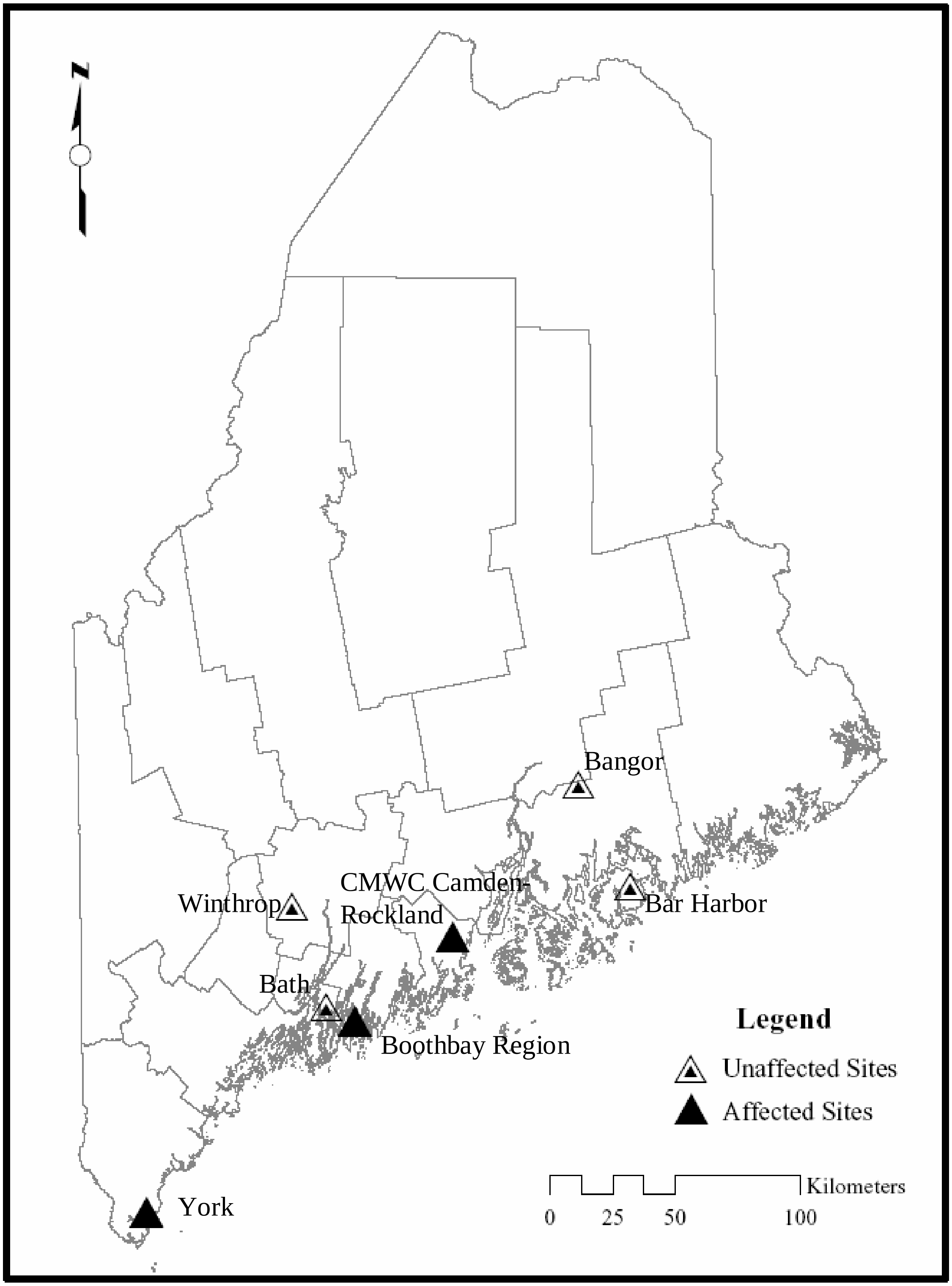
Selection of Surface Water Systems for Intensive Study

To illustrate the effects of the drought on drinking water quantity and quality, a subset of small (<300 ha) surface water systems were selected from the survey for more detailed data analysis. Neither large lakes nor large rivers were selected—large lakes due to their complex hydrology and adjustment of water levels for hydropower, and rivers due to a lack of streamflow and volume data for smaller stream sources, management via dams, and the size and complexity of stream watersheds. Smaller lakes are more characteristic of Maine surface water supplies and management and water treatment is a greater challenge for smaller systems due to the lack of financial and human resources (GAO, 1994; Phoenix, 2002).

No sites in northern Maine were included because most of those systems use streams, rivers, or managed lakes as a source of supply. Comparison between affected and unaffected systems is necessary in order to measure the true drought signal in the affected system (Easterling and Riebsame, 1987). The final seven study systems included sites that were not affected by the drought but otherwise met the selection criteria.

The seven systems chosen for intensive study (Figure 2.1) represent a range of lake and watershed size. As a group, the seven Intensive-Study lakes have low turbidity and relatively moderate biological productivity (see Appendix B for Intensive-Study System characteristics). Three of the systems (Bangor, Bar Harbor, Camden-Rockland) have waivers for filtration because of the high water quality of the supply.

Figure 2.1 Intensive-Study systems.



The operators provided unpublished data on water levels, water usage, transparency, turbidity, color, and other available water quality parameters measured as part of utility monitoring. In the case of Bar Harbor, monitoring data were available from the National Park Service since the source is located within Acadia National Park. Transparency (Secchi disk) data were also obtained from the Maine Volunteer Lake Monitoring Program (VLMP) for participating lakes. Data records generally extended back to the 1990s; several lakes have longer records for some parameters. The lakes were sampled at different times by different people with a variety of instruments. Many water utilities monitor raw water for adjusting treatment, but these data are not necessarily subjected to the same rigorous quality review of finished water analyses. Some data were transcribed from paper records and other data were available in electronic format. With the exception of data from Acadia National Park and the VLMP, there is little if any quality assurance or quality control on the data used.

Once data were compiled, I compared information from all systems to determine which water quality parameters to evaluate. Comparable datasets must contain the same types of measurements for the same time periods. Some systems had data for iron, manganese, silica, pH, alkalinity, and conductivity. However, these parameters were not available for all systems, were not analyzed with the same laboratory methods, and were not considered the best indicators of water quality changes during drought for the selected intensive study systems (e.g., Seger, 2004). Similarly, total organic carbon, bacterial counts, algal counts, and dissolved oxygen/temperature profile data were inconsistent among the systems. The parameters with the most complete and comparable information were turbidity, color, and transparency. These parameters would also be expected to respond to short-term changes in climatic conditions.

Most systems experience the greatest demand in mid- to late-summer. This period is also when biological activity peaks, and in 2001-2002 happened to be when drought conditions were most severe for surface water. To determine affects on water quality, color, turbidity, and Secchi disk values for July and August of 2001 were compared to all July and August values prior to and after 2001 for lakes where data were available. Turbidity data are reported monthly to the DWP, however utilities only have to report their maximum turbidity value for the month. Not all systems record daily values; some systems only recorded the daily maximum. Therefore monthly maximum turbidities for July and August were used for all lakes (except Nequasset Lake, where raw water turbidity is not measured because the source is filtered).

Some systems monitor lake transparency as part of their own water quality monitoring programs; other supplies are monitored as part of the VLMP. Some measurements are monthly, some weekly or biweekly. All available transparency measurements for July and August were compared to 2001 values. Complete data sets for the seven Intensive-Study systems are located in Appendix D.

<u>Indicators of Drought Sensitivity</u>

I examined another set of surface water systems to determine the best indicator(s) of drought sensitivity. This set is referred to in this paper as the Indicator-Study systems, and includes the seven Intensive-Study systems and 21 other public water supply lakes where data were available from the state's Source Water Assessment Program reports

(Drumlin Environmental, 2003; Appendix C). I compared natural attributes of systems affected by the drought to unaffected systems to determine if there were any similarities among affected surface water systems.

Natural Attributes. Consistent water quality data for public water supply lakes is lacking. However, quantitative measurements are available that are representative of chemical and biological processes. For example, mean depth is correlated with probability of stratification, water flushing rate, and nutrient loading (Kalff, 2002). Other data for these systems, such as landscape and watershed information, are available from state-level data sets. Because the results of this study are intended to apply to all surface water systems in the region, I chose indicators that are commonly measured and easily obtainable for any source. Morphometric attributes (maximum depth, mean depth, lake area, and watershed area) were obtained from the Maine DEP morphometric data set (PEARL Group, 2003) and Source Water Assessment Program reports (Drumlin Environmental, 2003).

Since attributes of lakes can be related to their position in the groundwater flow system (Kratz et al., 1997), landscape position was defined as lake order. Lake order was determined following Riera et al. (2000) and stream order as in Strahler (1964) using 1:24,000 scale digitized USGS topographic maps.

Direct watershed boundaries were obtained as GIS layers from the DWP (ME Drinking Water Program, 2003). Watershed geology was evaluated using digital 1:250,000 scale surficial geology map units developed from the Maine Geological Survey regional data set (Maine Geological Survey, 2003). Land use in the direct watersheds of affected systems was evaluated using the 1992 Maine Land Cover Dataset of the Multi-

Resolution Land Characterization Consortium (U.S. EPA and USGS, 1992). Derived from the early to mid-1990s Landsat Thematic Mapper satellite data, the National Land Cover Data (NLCD) is a 21-class land cover classification scheme applied consistently over the United States. The NLCD are provided on a state-by-state basis. The Maine state data set, revised in 2000, was clipped from the larger data sets that are mosaics of Landsat scenes.

System Infrastructure and Demand. The ratio of water use to water availability (or safe yield) serves as an indicator of water supply vulnerability (Russell et al., 1970; Lins and Stakhiv, 1998; Hurd et al., 1999). Safe yield is the maximum quantity of water that can be withdrawn during an extended dry period or drought. The safe yield is usually defined from multi-year hydrological data. As the ratio approaches or exceeds the value of 1, the susceptibility to drought increases (Russell et al., 1970). Use:yield ratios were calculated for each study system where yield estimates were available.

Seasonal changes in demand were estimated using seasonal housing unit and retail sales data for the major town served by each of the Intensive-Study systems. Seasonal housing data from the U.S. Census (2000) were calculated as percent of total housing. Retail sales data are published quarterly by Maine Revenue Services (1998). Summer retail sales were calculated as third quarter sales as a percent of total yearly retail sales. See Appendix C for complete data sets.

Results

Affected Public Surface Water Systems

A total of 53 public water supplies were affected by the drought, based on the survey of 58 surface water systems and reports to the Maine Drinking Water Program and Public Utilities Commission (Figures 2.2 and 2.3). Eight of the affected systems use surface water, two use streams as a source of supply, and the remaining six use lakes or ponds. Eleven systems, four utilizing surface water (indicated by * below), implemented voluntary conservation (Bethel*, Calais, Camden-Rockland*, East Millinocket, Island Falls, Kennebunk-Kennebunkport-Wells*, Monson, Mt. Desert*, New Portland, Port Clyde, Winter Harbor). Four systems implemented mandatory conservation (Alfred, Castine, Boothbay*, South Freeport). Seventy percent of the surveyed surface water systems reported below normal water levels in the summer of 2001.

Figure 2.2 Public groundwater supplies affected by the 2001-2002 drought.

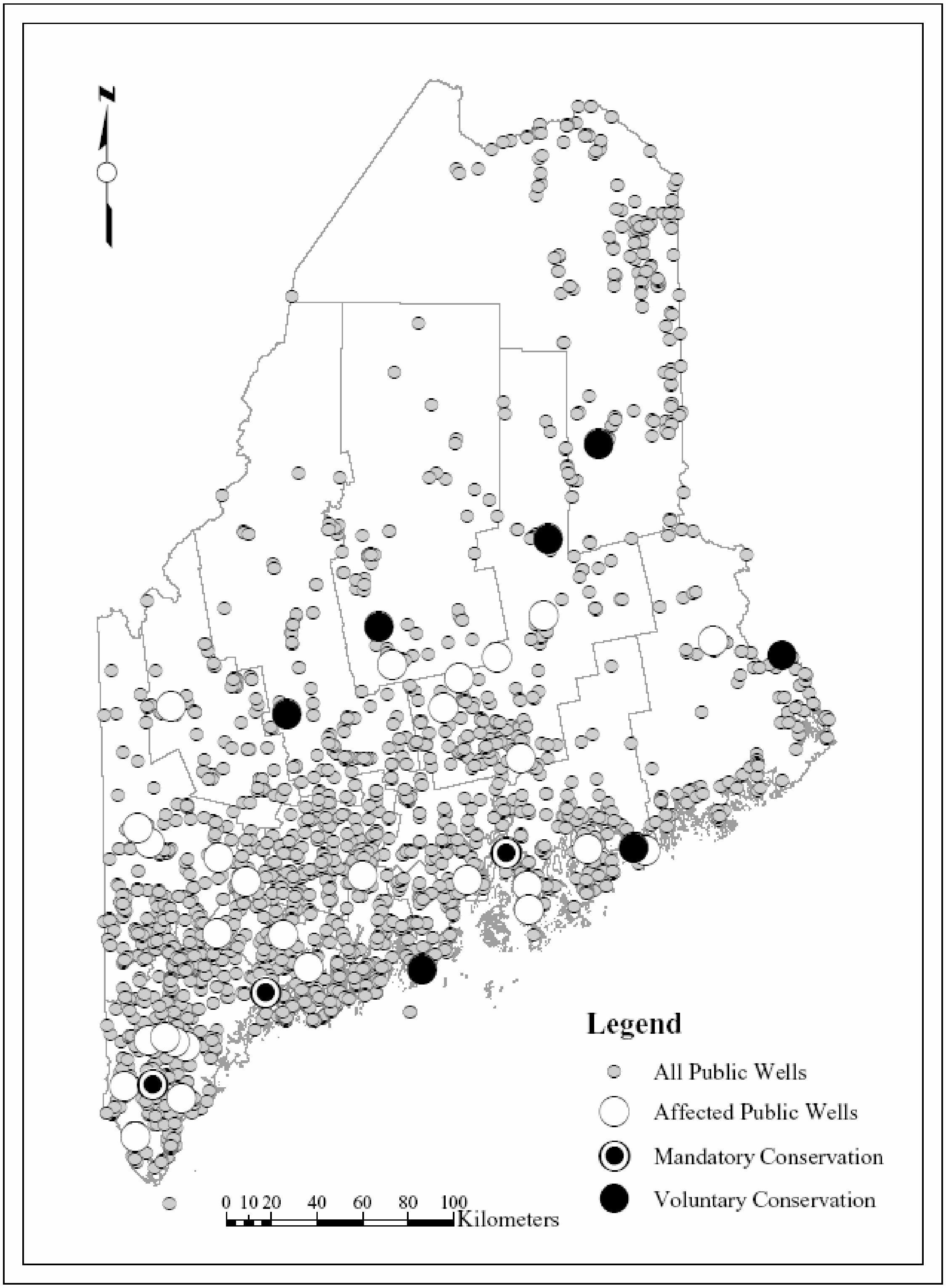
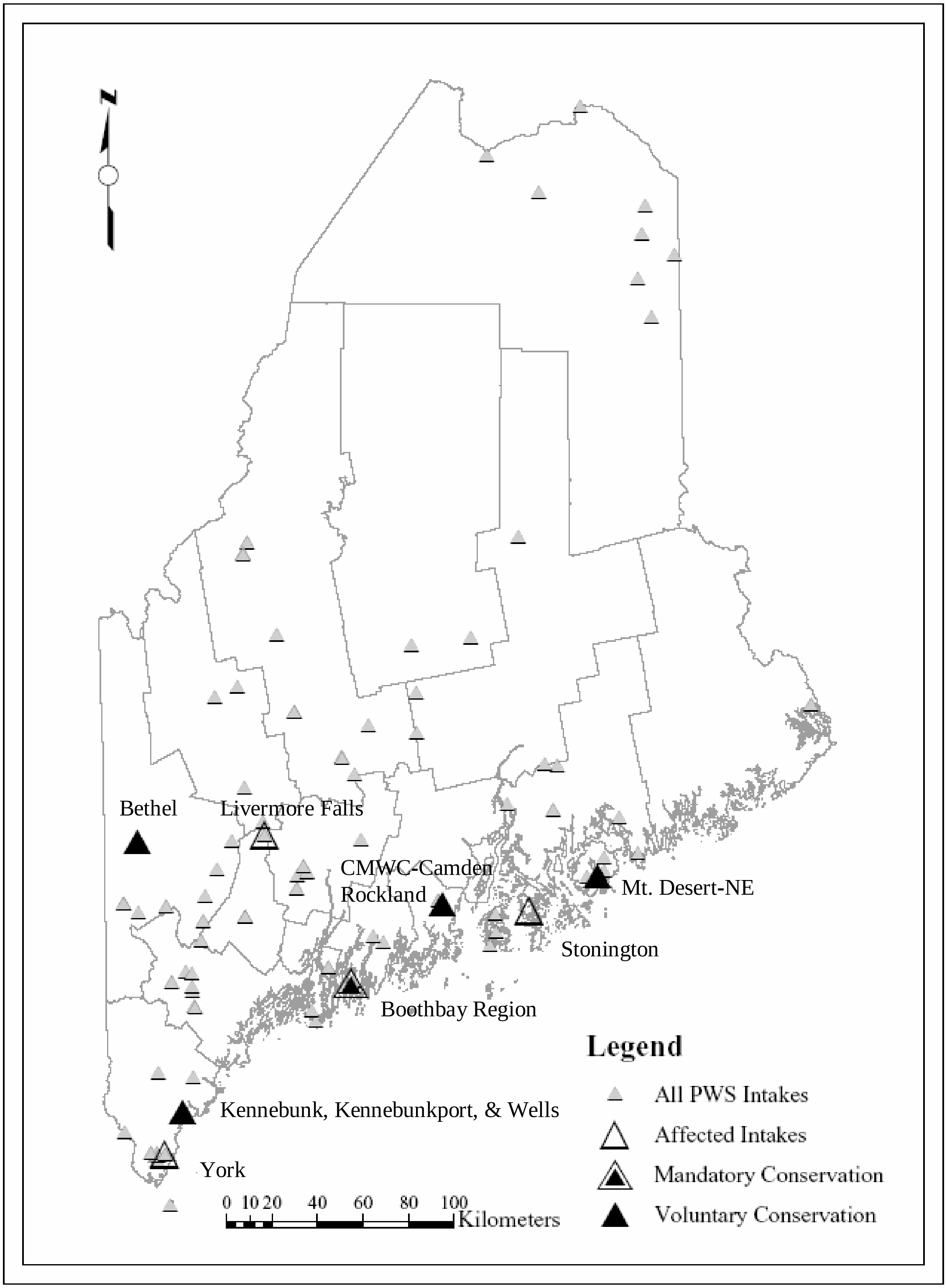


Figure 2.3 Public surface water supplies affected by the 2001-2002 drought.



Intensive-Study Systems: Effects on Water Quantity and Quality

Most of the Intensive-Study systems experienced record low lake levels in the fall of 2001 (Figure 2.4). Three lakes remained low through the winter of 2002, and the rest returned to normal by the end of the year. All of the lakes with the exception of Eagle Lake experienced greater than normal water level fluctuations in 2001. Water level changes ranged from 0.2 to 1.5 meters during a normal precipitation year and from 0.5 to over 2.0 meters during the 2001-2002 drought.

Comparison of water quality parameters from 2001 versus non-drought years revealed no consistent response to the drought (Figure 2.5). Values for 2001 were within normal ranges for most systems.

Figure 2.4 Water levels of Intensive-Study systems, 2001-2002. n = years of data. Levels calculated as meters from reference point (dam spillway, staff gauge, or estimated elevation of "full" lake). Data are from individual utility records, except Eagle Lake data from the National Park Service. Dashed lines represent maximum and minimum values.

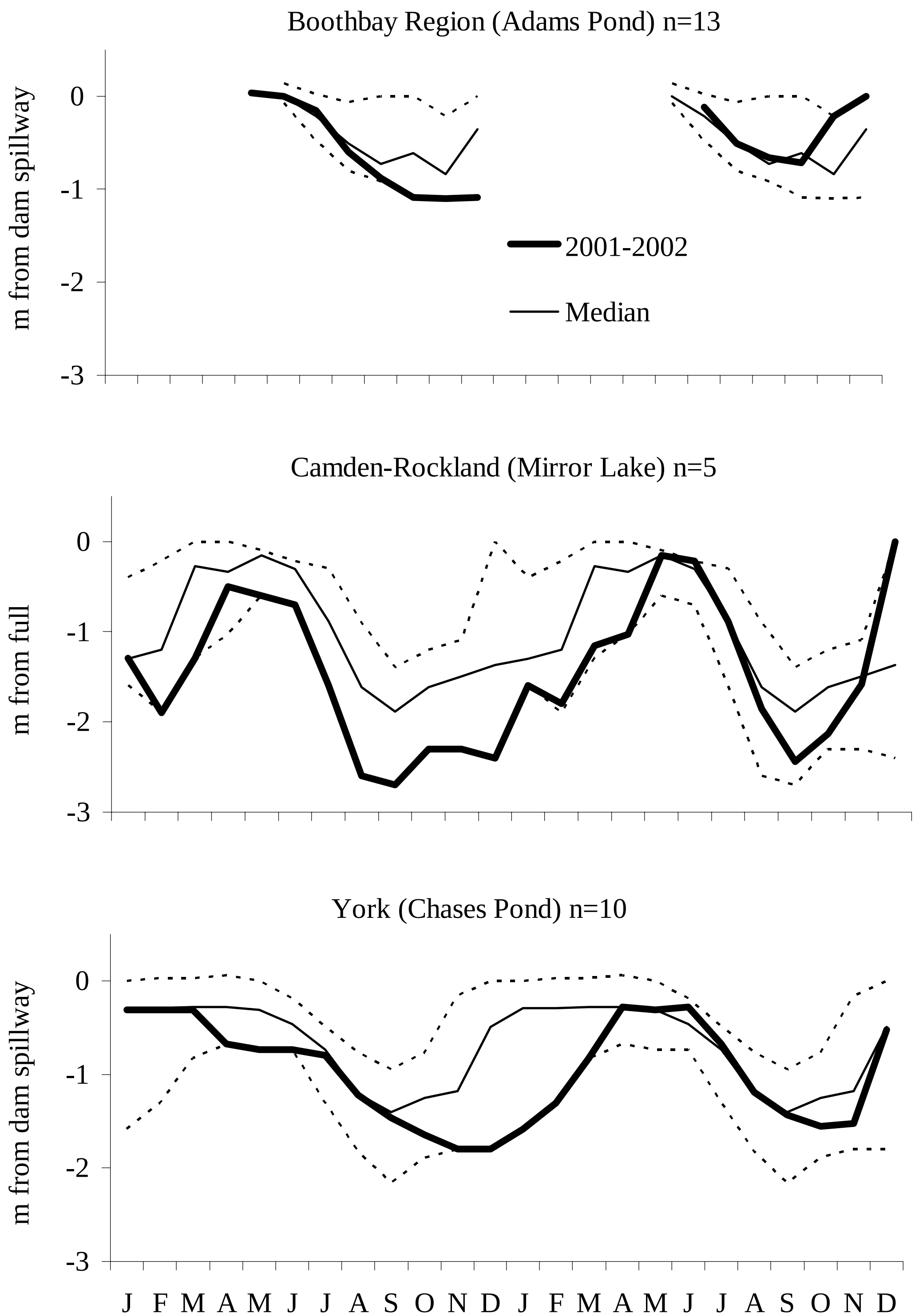


Figure 2.4 continued.

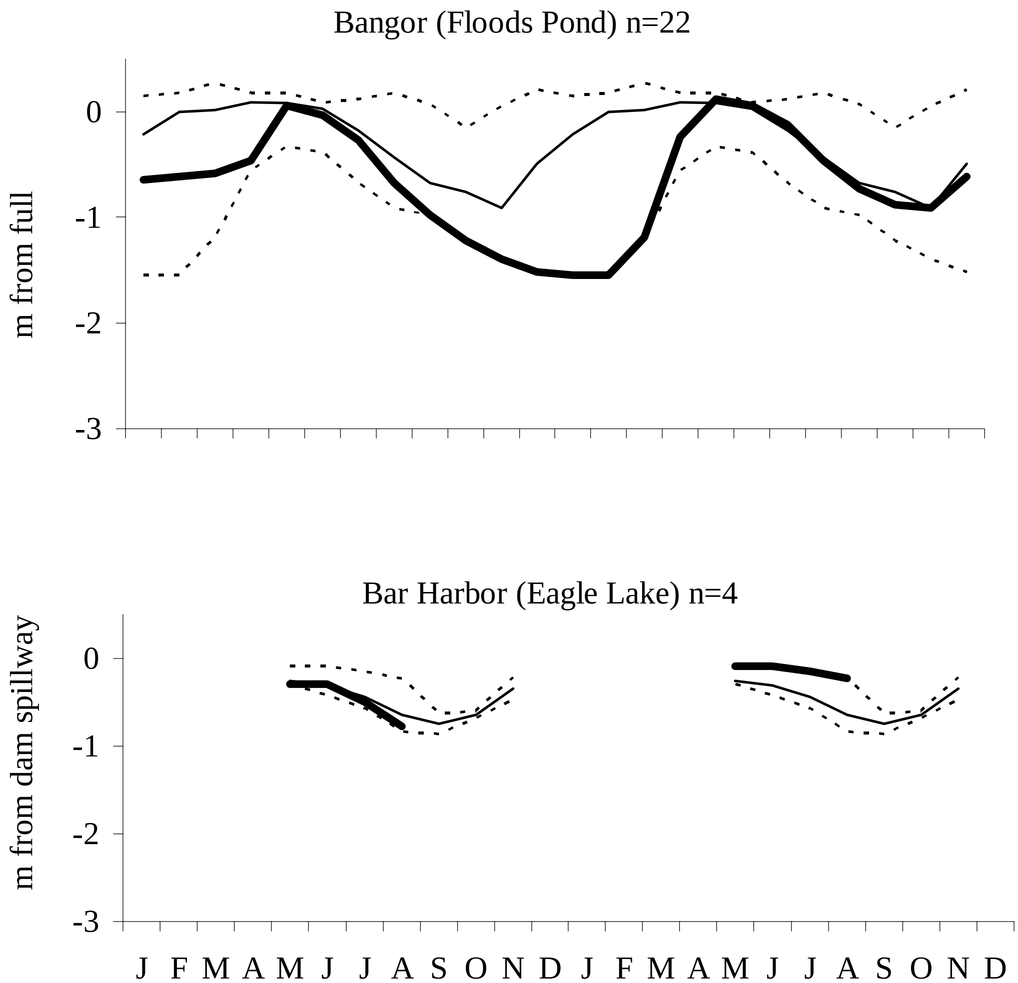


Figure 2.4 continued.

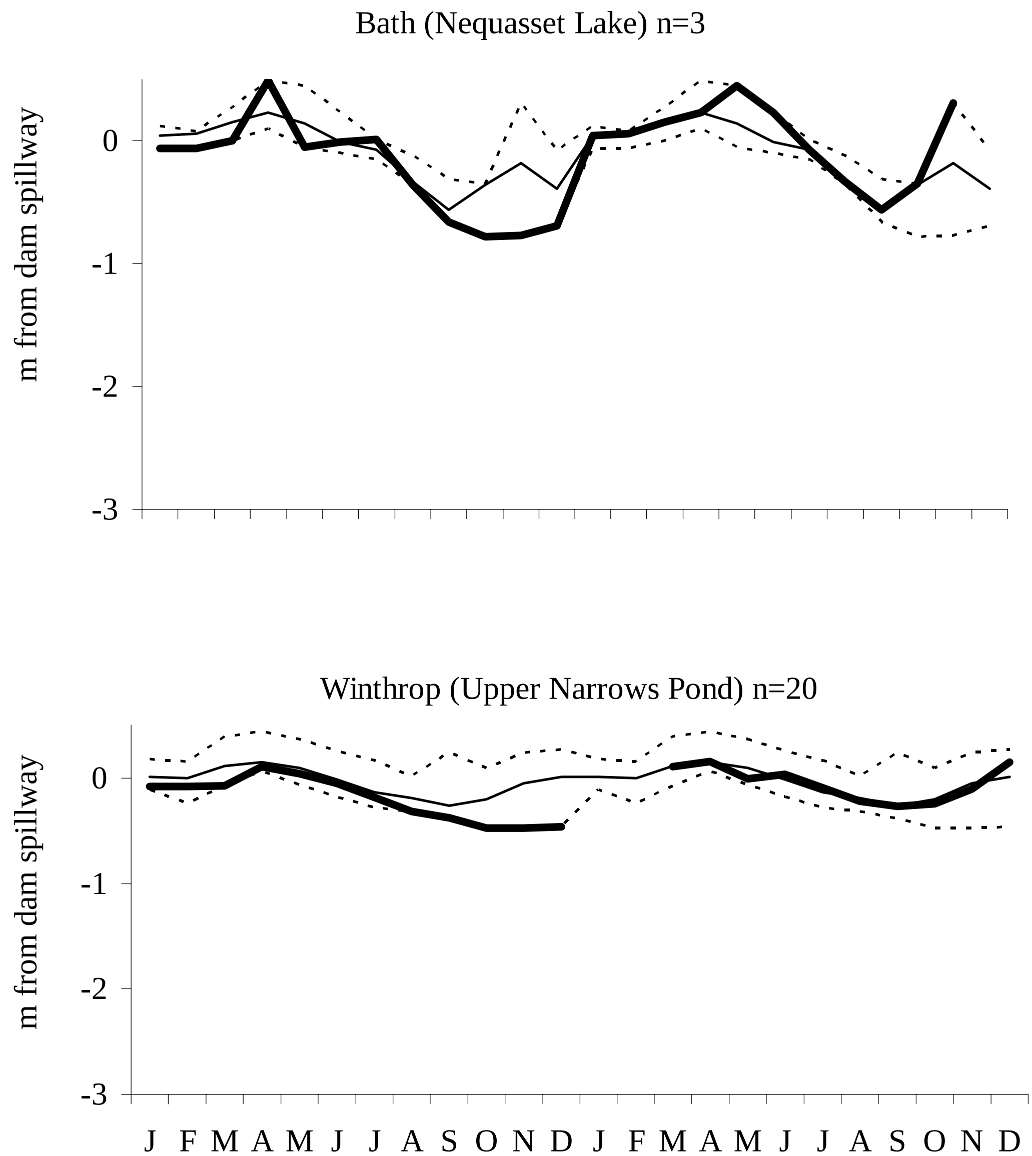
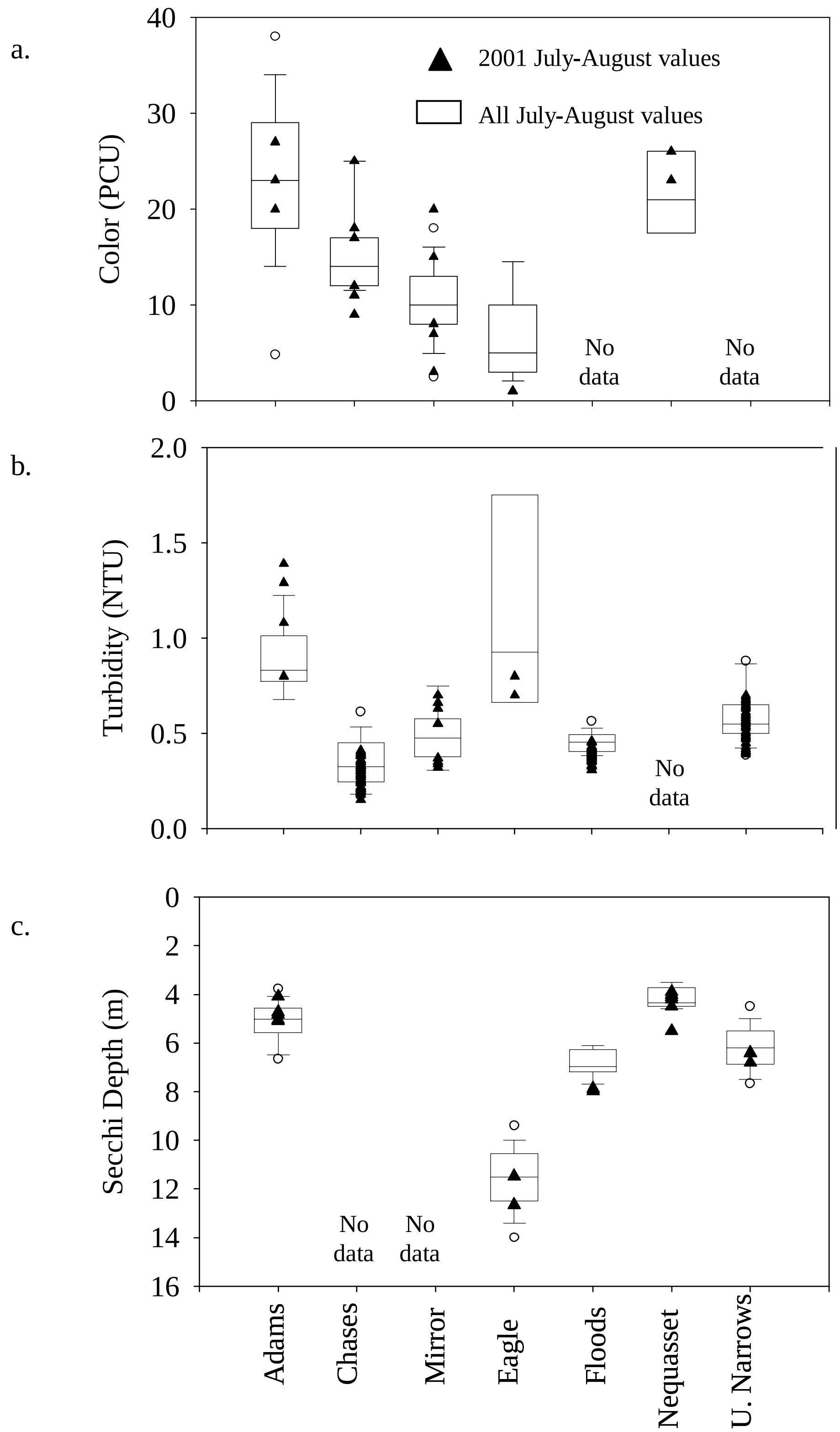


Figure 2.5 Water quality of Intensive-Study systems: July-August color (a), turbidity (b), and transparency (c). Boxes are all July and August values for the period of record (2000 and 2002 only for turbidity); points are 2001 July-August values.



Indicators of Drought Sensitivity

Natural Attributes. Affected lakes tended to have lower elevation, maximum depth, mean depth, lake area and watershed area compared to unaffected lakes (Table 2.1). These variables all relate to water volume, suggesting that affected lakes were smaller. Landscape position, estimated as lake order, ranged from 0 to 3. Affected systems tended to be higher in the flow system (headwater-type lakes and first- or second-order streams). No trend for geology or land cover was apparent from the data. The dominant surficial geology in the watersheds of 77 % of all systems analyzed is till, not surprising since two-thirds of Maine is classified as till (Appendix C). Urban and suburban development percentages of land cover in the source watersheds ranged from <5 % to 10 %. Most systems had less than 5 % of their watershed developed (Appendix C).

Table 2.1 Attributes of Indicator-Study systems. Elevation, maximum and mean depth, lake and watershed areas from PEARL Group (2003), lake order calculated as in Riera et al. (2000); summer retail sales data from Maine Revenue Services (1998); seasonal housing unit data from U.S. Census (2000).

ATTRIBUTE	AFFECTED (N=6)		UNAFFECTED (N=22)	
	median	range	median	range
Elevation (m)	52	(11-142)	87	(5-353)
Maximum depth (m)	12	(2-20)	21	(4-45)
Mean depth (m)	5	(2-9)	8	(2-26)
Lake Order	1	(-1-2)	2	(-2-4)
Lake Area (ha)	34	(8-54)	99	(2-1092)
Watershed Area (ha)	325	(80-998)	874	(3-7796)
Summer Retail Sales (%)	48	(29-55)	28	(26-59)
Seasonal Housing Units (%)	34	(1-46)	13	(1-64)

System Infrastructure and Demand. With the exception of Bangor and Winthrop, all of the Intensive-Study systems experienced above-normal water usage in August 2001 (Figure 2.6). For the affected systems, the timing of high demand coincided with low surface water flows. Affected systems have increased seasonal population, as suggested by summer retail sales and seasonal housing data (Table 2.1).

Discussion

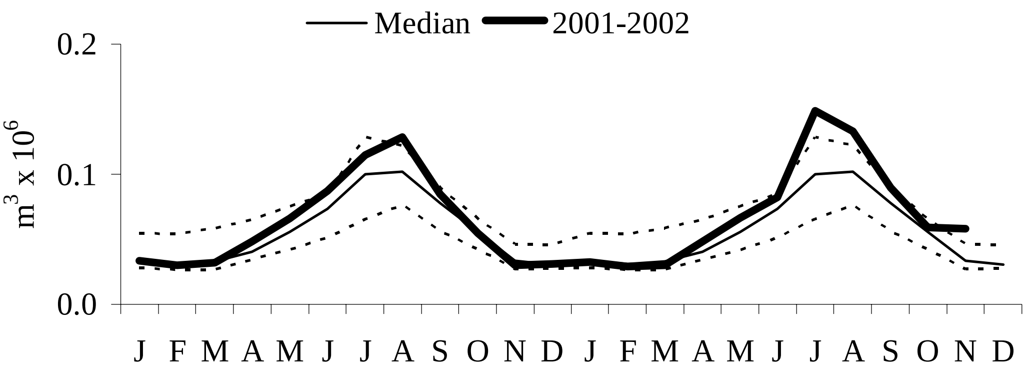
Intensive-Study Systems: Effects of Drought on Water Quantity and Quality

Of the water supplies selected for intensive study, four were unaffected by the drought and three were affected. All of the lakes experienced low water levels in the summer of 2001 (Figure 2.4). In general water quality results were in the range observed over the previous years. There were no clear differences in water quality responses to drought between affected and unaffected lakes (Figure 2.5).

Transparency data suggest improved water quality in 2001, a phenomenon also observed by the Volunteer Lake Monitoring Program (VLMP). In 2001, a majority of VLMP lakes were as clear as or clearer than their historical Secchi disk transparency annual average, and 14 lakes were the clearest ever recorded (Williams, 2002). However some lakes experienced negative water quality events during the same period. Increases in water clarity were possibly the result of reduced watershed runoff, which is the largest source of sediment and phosphorus to Maine lakes (ME DEP, 1998). In central Ontario lakes, water quality improvements during dry periods were mostly due to less runoff from the watershed (Schindler et al., 1996).

Figure 2.6 Intensive-Study system monthly water withdrawals, 2001-2002, in millions of cubic meters. Dashed lines represent maximum and minimum values. n = years of data.

Boothbay Region (Adams Pond) n = 13



Camden-Rockland (Mirror Lake) n = 5

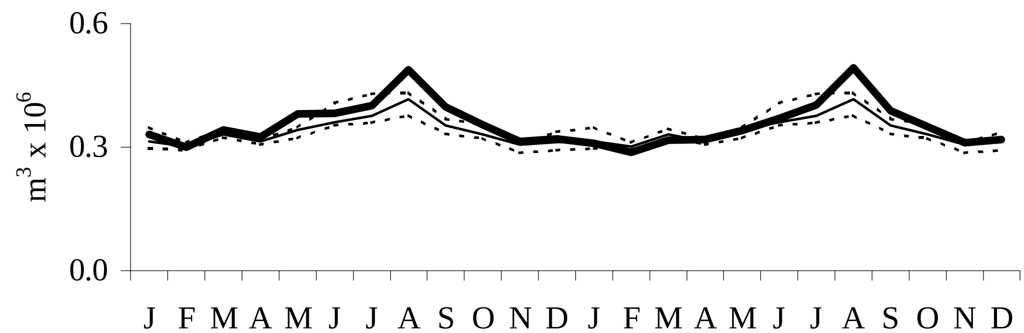
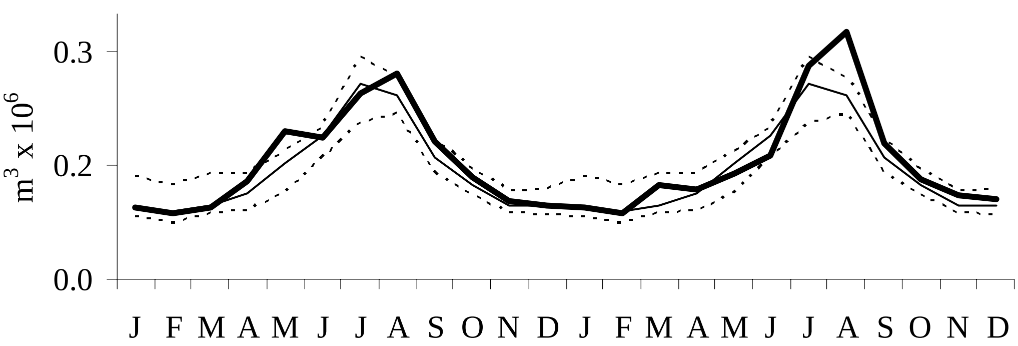
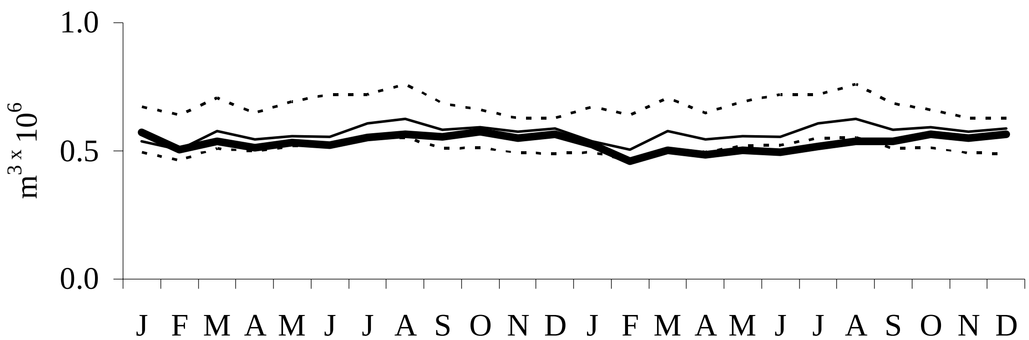


Figure 2.6 continued.

York (Chases Pond) n = 10



Bangor (Floods Pond) n = 22



Bar Harbor (Eagle Lake) n = 4

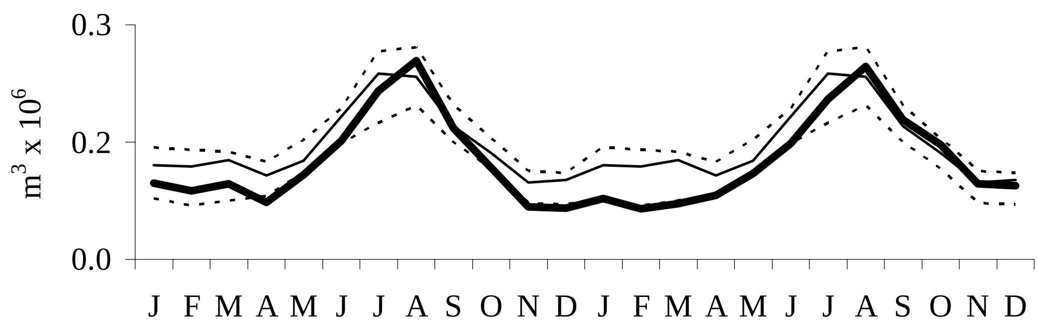
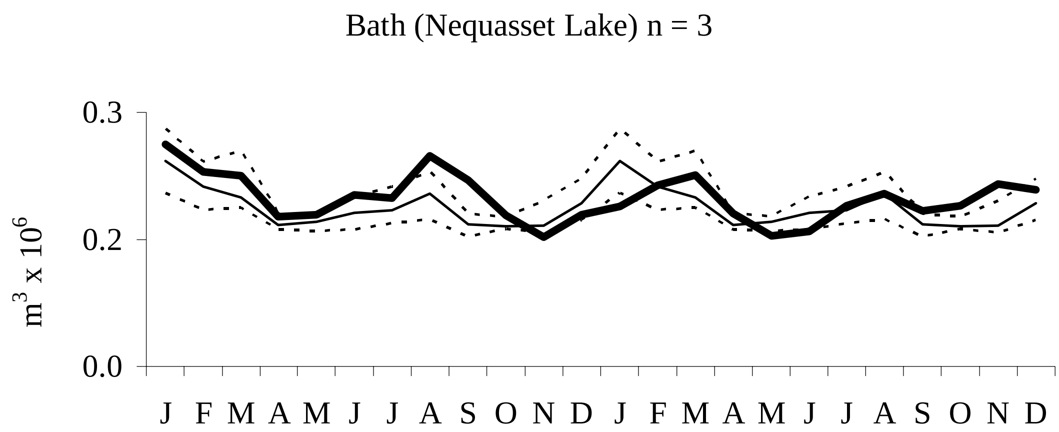
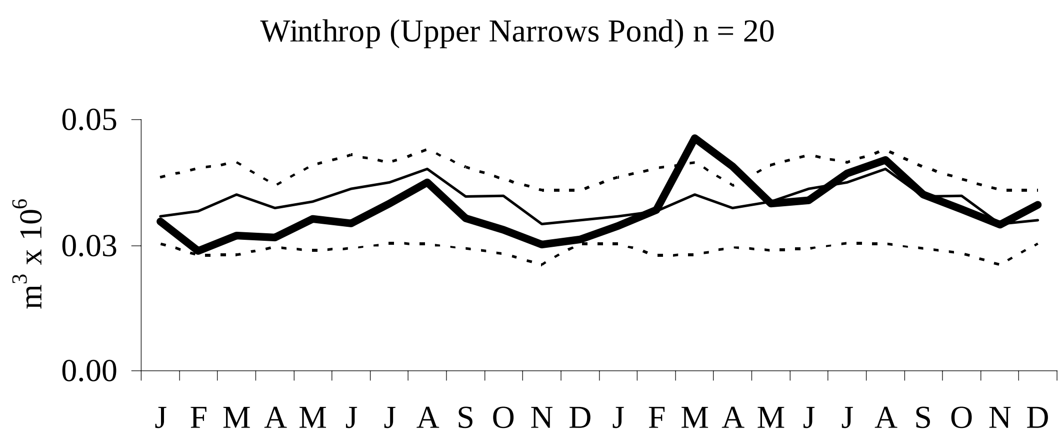


Figure 2.6 continued.





Water quality in 2001 did not diverge from reference years in the seven Intensive-Study systems (Figure 2.5). It is probable that there were simply not enough water quality data to make a sound analysis. The frequency of measurement and analytes varies among utilities and this lack of consistency makes inter-lake comparisons and regional conclusions difficult. The Safe Drinking Water Act requires that water suppliers monitor the finished (treated) water for a variety of parameters of human health concern. Source water monitoring is recommended but not required for surface water supplies, and most systems in Maine do not have the financial or staff resources to conduct extensive monitoring programs. As a result, it is difficult for managers to predict and prepare for an individual system's response to changing weather patterns. A coordinated monitoring program, accompanied by financial and technical resources, would enable public water systems to secure adequate water quantity and quality during drought periods.

Indicators of Drought Sensitivity

What makes a drought affect one system but not another? In the Indicator-Study systems evaluated here, affected lakes tended to be smaller, shallower, and higher in the flow system. However, the results are inconclusive with respect to the effects of natural attributes on drought sensitivity of surface water supplies (Table 2.1).

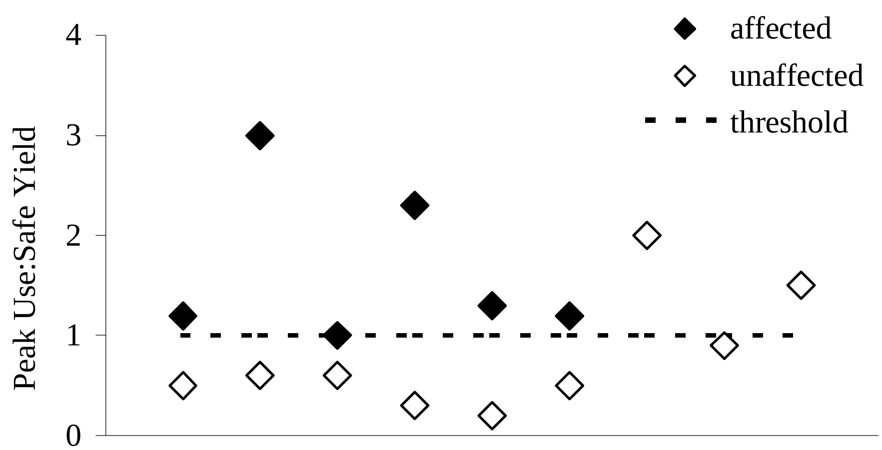
Environmental factors alone were not enough to cause a system to be adversely affected by the drought; other factors that override natural variation influence surface water supply vulnerability. In the 1930s dustbowl, most public water supply shortages were experienced by small communities of fewer than 5,000 people where there was inadequate capacity or extreme aridity that made supply difficult even in non-drought times (Frederick, 1991). Russell et al. (1970) found that in the 1962-66 drought in Massachusetts, there were systems that did not have difficulty in meeting demand. Relatively common periods of rainfall shortage were enough to drive other systems to apply restrictions or utilize emergency supplies.

Five of the eight surface water systems in Maine that were affected by the 2001-2002 drought (based on the survey, PUC and DWP reports) implemented conservation measures. Imposing voluntary or mandatory conservation implies that there is not enough water to satisfy customer demand: the available water is not enough to meet expectations. Yet above-normal or even record-high demand does not appear to be a good indicator of drought stress on the water system. For example, Bath and Camden-Rockland both experienced record water demand in August 2001 (Figure 2.6). Camden-Rockland imposed conservation; Bath did not.

When demand is viewed in conjunction with supply, however, the interpretation becomes clearer. All of the affected systems experienced higher than normal demand in the summer of 2001, and were pumping volumes equal to or greater than the safe yield of the supply (Figure 2.7). Safe yield is the maximum quantity of water that can be withdrawn during an extended dry period, usually calculated for a six-month time frame. The more often a system pumps over the safe yield, the greater the risk of a water shortage. When use is below the safe yield, for example during the winter season, the usable storage volume is recharged and risk decreases.

All but two of the unaffected systems in the Indicator-Study group used less than their safe yield even during periods of maximum demand. One of the unaffected systems above safe yield, Augusta Water District (Carlton Pond), used alternative sources to augment supply during times of high use. Use:yield ratios appear to be a good indicator of drought vulnerability.

Figure 2.7 Ratios of peak use to safe yield of Indicator-Study systems (data from Drumlin Environmental, 2003, and individual utility records).



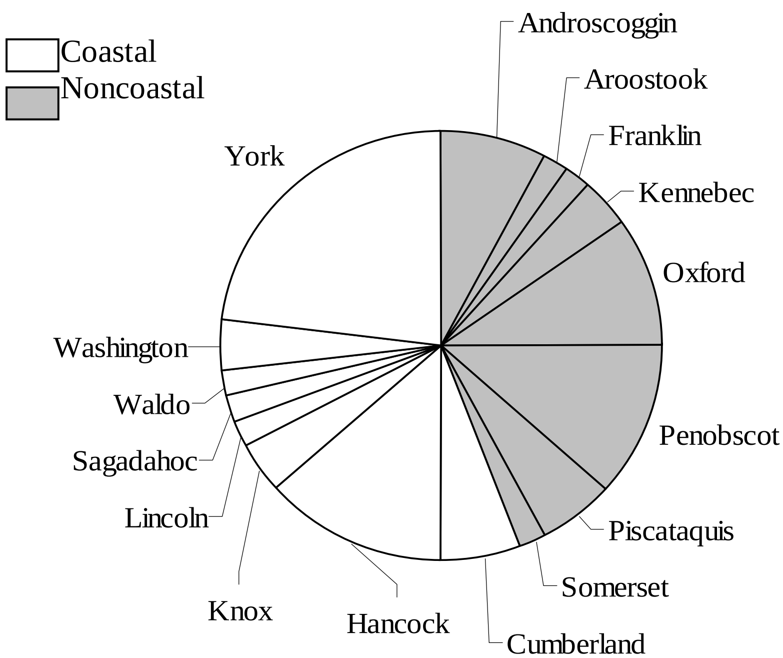
Development in the watersheds of the supply was not a factor contributing to drought stress. This result was expected because the connection between population, development, and drought lies outside of the source watershed, in the areas actually served by the public water system. In fact, most of the watersheds were over 80 % forested and several were well protected through land ownership and conservation. Because demand originates mostly outside of the supply watershed, land use and population within the service area may be a better predictor of drought sensitivity than land cover in the source watershed.

The majority of public water systems, both groundwater and surface water, affected by the drought were located in coastal counties (Figure 2.8). While coastal areas in Maine may have less water content in snowpack available for spring recharge (Loiselle and Hodgkins, 2002), the 2001-2002 drought was the mildest in Maine's coastal zone and many other systems along the coast were not affected by the drought. Coastal water supplies that were affected by the drought had greater demand increases due to seasonal changes in population, as evidenced by seasonal housing unit and retail sales data (Table 2.1).

The affected surface water systems have a greater percentage of seasonal housing units, and the towns served by these systems also conducted 26 % to 59 % of their yearly retail sales in the summer (Table 2.1). Two-thirds of the estimated 92,000 seasonal housing units in Maine are located in coastal counties (U.S. Census, 2000). While not all of these seasonal housing units are connected to the public water system, the data are an indicator of seasonal commercial activity.

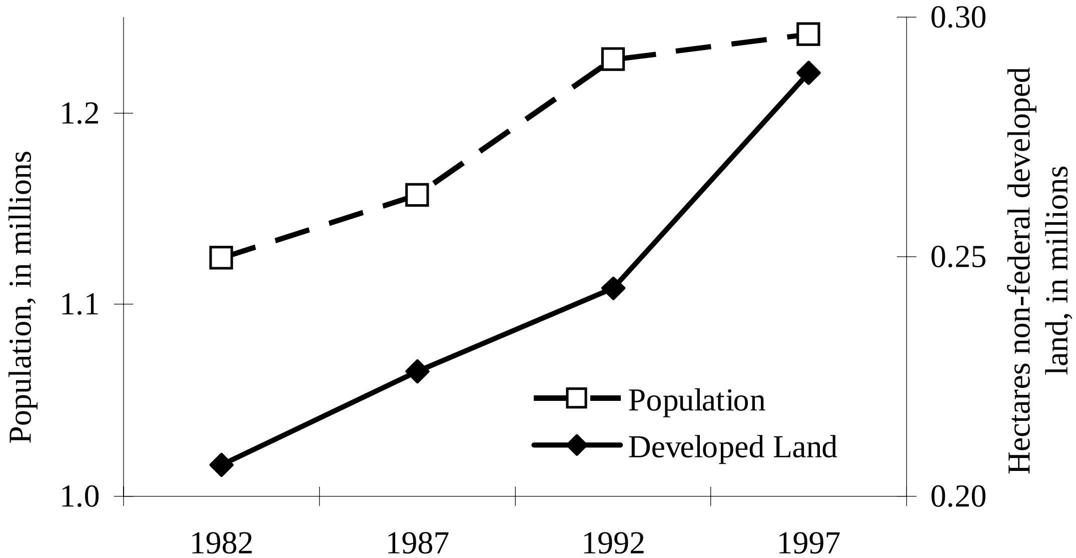
Boothbay Region provides a good example of seasonal demand increases. The population served by Boothbay Region Water District (BRWD) increases from 6,000 to 25,000 in the summer months. Water withdrawals mirror this increase, from 300,000 gallons per day in January to over one million gallons per day in August. The region's shift from a natural resource-based economy to tourism encourages this growth (J. Ziegra, BRWD, pers. comm., 2002). In the summer of 2001, greater than normal consumption coincided with rapidly decreasing water levels in Adams Pond. BRWD was the only surface water system to implement mandatory conservation.

Figure 2.8 Public water systems (surface and groundwater) affected by the drought by county.



Development in Maine has increased at a greater rate than population in the last decade (Figure 2.9), and most population increases have been in coastal areas. Future population increases are predicted to be greater for coastal counties compared to non-coastal counties (Maine State Planning Office, 2001). These same areas experience increased seasonal populations and commercial activity, which create stress on water supplies that are already operating close to their maximum capacity.

Figure 2.9 Maine population and development, 1980-1997. Developed land data from the 1997 Natural Resources Inventory (USDA, 2000). Population data from USGS water use reports (Solley et al., 1998) and U.S. Census (2000).



Implications

The major effect of the 2001-2002 drought on water supplies in Maine was reduced water quantity. The drought resulted in water level declines in streams, lakes and ponds; many sources were at record-low levels. These reduced quantities affected systems where demand was also high. When water demand was high, small, shallow systems that were already pumping close to their safe yield were vulnerable to drought. In Maine, these systems are located along the populated coastal region and in areas where seasonal tourism and residential development increases water demand.

Coastal counties contain 54 % of Maine’s population, a figure consistent with patterns in the rest of the U.S. (Culliton, 1998). With increasing affluence and market incentives, suburban development is increasing at a faster rate than population in Maine’s coastal towns (Richert, 2002). For public water supplies, this development lies outside of the source watershed, requiring that water resource managers also look outside of the existing source watershed to predict and prevent drought impacts, and to find new water supplies.

Small surface water systems in the coastal zone that operate close to maximum capacity or safe yield due to seasonal increases in demand were most vulnerable to drought. A more refined spatial and demographic analysis of Maine's coastal water supplies would broaden understanding of drought stress. Future research efforts aimed at assessing the effects of climate changes on drinking water supplies would benefit from comprehensive information on water use and availability. Rather than being viewed as one constituent, customer demand should be evaluated by sector in order to target conservation and education efforts.

The 2001-2002 drought revealed water shortages in a water-rich state. The drought affected public water systems that had insufficient supplies to satisfy demand created by suburban and tourism population pressure. Drought conditions varied across the state of Maine; these conditions are not likely to be the same for future droughts. It is possible that drought may become more frequent as a result of global climate change (IPCC, 2001a). Areas that are currently experiencing stress due to increasing population and demand should expect those stresses to continue or worsen under future climate change. The results of this study agree with other studies (Moore et al., 1997; Rapport and Whitford, 1999; Murdoch et al., 2000; IPCC, 2001b) that suggest ecosystems already stressed by human activity are more vulnerable to climate variability.

Chapter 3

ENHANCING PUBLIC WATER SUPPLY DROUGHT PREPAREDNESS

Introduction

Drought affects water supplies in two ways, by increasing seasonal demand and reducing supply. With potentially serious consequences for water quantity and quality, drought should be a concern for water resource managers. Yet planning at the local level is largely reactive, treating drought in an emergency response mode (Wilhite, 1997). The uncertainty and randomness of droughts (and thus uncertainty and randomness in drought-related costs and losses) provides no incentive for society to prepare for them (Walker et al., 1991; Wilhite, 1993).

In Maine, preparedness has not been a priority because the state is perceived and portrayed as a place where drought is infrequent (Lautzenheiser, 1959). The interannual variability of wet and dry conditions hinders drought preparedness. Human nature assumes that next year will be a good year (Wilhite, 1993). This tendency is especially true in New England, where variable weather is the norm, not the exception (Zielinski and Keim, 2003).

In their assessment of drought planning by states, Hrezo et al. (1986) conclude that in Maine, "the balance among climate, population pressures, and water use seems to justify a decision not to develop a drought management framework. Supply and demand remain relatively balanced, at least in some areas. Drought problems exist, but they are not sufficiently severe to warrant development of a comprehensive management program."

The drought of 2001-2002 revealed that climate, population pressures, and water use have the potential to be out of balance. Forty-five public groundwater systems and eight public surface water systems were affected by the drought (Figure 2.2 and 2.3). Twenty-seven public water systems drilled new wells, 15 of which were approved under Emergency Conditions (A. Tolman, Drinking Water Program, pers. comm., 2003). More than 1,500 private wells went dry (Drought Task Force, 2002b).

Managers of systems that have already been affected by drought are more willing to prepare and respond to future droughts—they know it *can* happen to them (Tierney et al., 2001). This knowledge can contribute to a post-drought review of response actions (Riebsame et al., 1991; Wilhite, 1993). Such a review is important because drought management improves when evaluations of past droughts are available (Riebsame et al., 1991). In Maine, little institutional knowledge exists because the last severe drought occurred in the 1960s (Figure 1.5). Few, if any, managers working today experienced the droughts of the 1950s or 1960s. The 2001-2002 drought provides an opportunity to establish a foundation of institutional knowledge for dealing with future drought.

It is important to identify vulnerable water systems in advance so that adequate mitigation measures can be adopted (Wilhite, 1997). Because of the difficulty of deciding when droughts start and end, specific drought indicators must be used to decide when to implement a management plan. For example, the point when stressed water systems implemented conservation measures in 2001 might coincide with parameters which could act as threshold or action levels for water managers. When monitored regularly, parameters such as temperature, precipitation, streamflow, lake and groundwater levels, snowpack, soil moisture, and changes in system yield and demand can serve as early warning signals for drought (Walker et al., 1991).

In designing a water supply sensitivity study, both hydrological responses and manager adaptations are important (Easterling and Riebsame, 1987: Lins and Stakhiv, 1998). The first sign of drought is often below normal water levels and exposed shorelines, yet drought conditions can build for months before hydrological responses become obvious. Manager adaptations might include implementing conservation, utilizing secondary supplies, increasing plant capacity, or educating customers.

The National Study of Water Management during Drought (Joyce et al., 1994) identified indicators that might trigger a system to approach a critical point. These indicators include: (1) local water availability, use, and demand; (2) new construction projects or events that might alter the demand for water; (3) laws, regulations, or agreements that might affect the ways water or related land resources are used; (4) system-specific watershed conditions and operational procedures; (5) climatic and hydrologic conditions; and (6) public views on water resources management, conservation, and use.

As seen in Chapter 2, public water systems in Maine that were affected by the drought had some environmental attributes in common, but system infrastructure and demand were the most promising indicators of drought stress for managers. Here I assess several measures of drought in order to identify triggers marking the critical point of stress or conservation implementation during the drought. I also document manager responses to the drought to establish a record of institutional knowledge.

Local water availability, use, and demand combined with climatic conditions are the best indicators for drought vulnerability of Maine surface water systems. Knowledge of both the environmental characteristics of the supply and trends in water use will help managers prepare for the next major drought.

Methods

Triggers of Drought Stress

I used the Intensive-Study systems described in Chapter 2 (Figure 2.1) to identify triggers of drought stress. The following parameters were assessed as potential indicators: water levels, water usage, regional precipitation, Palmer Hydrological Drought Index (PHDI), streamflows and groundwater levels. These indicators are easily obtainable by water managers and are applicable to all systems. Water levels and usage are regularly monitored by water systems. Climate and hydrological data are available on the World Wide Web.

The National Climatic Data Center monthly divisional precipitation and PHDI data (NCDC, 2003b) were compiled for the three climate divisions of Maine from 1895 to 2002. The division boundaries are based on variation in distance from the ocean, elevation, and landscape form (Lautzenheiser, 1959).

Monthly streamflow and groundwater level data for stations in each division were obtained from the USGS National Water Information System accessed on the World Wide Web (http://waterdata.usgs.gov/me/nwis). Stations were selected based on hydrologic unit code. The stream stations have periods of record ranging from 53 to 81 years; the groundwater stations from 15 to 22 years (Table 3.1).

Table 3.1 USGS monitoring wells and stream gauges used for monthly conditions. (n)= years of data.

System	Climate Division	USGS Groundwater Well	USGS Surface Water
Bangor	2	OW1214 Oxford (21)	Little Androscoggin (81)
Bar Harbor	1	WW797 Hadley Lakes (16)	Narraguagus (53)
Bath	1	WW797 Hadley Lakes (16)	Narraguagus (53)
Boothbay Region	1	WW797 Hadley Lakes (16)	Narraguagus (53)
Camden-Rockland	1	WW797 Hadley Lakes (16)	Narraguagus (53)
Winthrop	2	OW1214 Oxford (21)	Little Androscoggin (81)
York	1	YW807 Sanford (14)	Salmon Falls (35)

Manager Responses

Systems affected by the drought were identified by the survey of all surface water systems and reports to the Maine Drinking Water Program (DWP) and Public Utilities Commission (PUC) as described in Chapter 2. Managers of systems that experienced problems during the drought were interviewed. Managers were asked to discuss adaptive strategies used during the drought, perceptions of drought severity, production and treatment adjustment, and patterns in customer demand.

Results

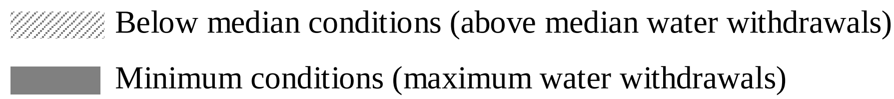
Triggers of Drought Stress

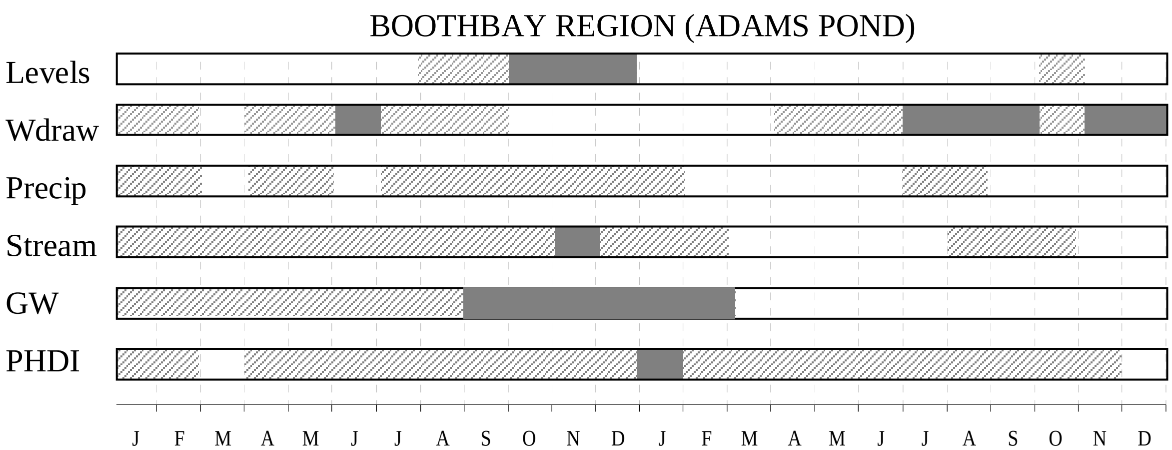
Eight surface water systems were affected by the drought (Figure 2.3), according to the definition of affected as 1) water quantity was enough for the system to impose voluntary or mandatory conservation; 2) water quantity was reduced enough to require the system manager to utilize or explore additional or alternative supplies; and/or 3) the manager expressed concern about the drought's effects on water quantity or quality. I did not consider systems that had adequate quantities of water to supply demand but implemented voluntary conservation as a precautionary measure to be affected.

From a manager's perspective, the peak of the drought was August of 2001, when two of the Intensive-Study systems (Boothbay, Camden-Rockland) implemented conservation measures. PHDI values were below normal in the months before August 2001 for all systems (Figure 3.1). Divisional groundwater and surface water levels and precipitation were also low. Severe hydrologic drought conditions did not occur until after the summer months in 2001, however, evidenced by record low streamflows and groundwater levels in the late autumn and winter of 2001-2002.

Water levels were below normal for all of the systems, but not all systems experienced high demand for water. Affected systems experienced five or more months of above-normal water usage prior to August 2001 (Figure 3.1). With the exception of one (Bath), the unaffected systems (Bangor, Bar Harbor, and Winthrop) did not experience above-normal demand despite similar climatic and hydrologic conditions. Drought conditions or low lake levels were not enough to cause problems; increased demand had to occur simultaneously for systems to be affected enough to begin restricting water use.

Figure 3.1 Monthly hydrologic conditions for Intensive-Study systems, 2001-2002. Levels = water levels; Wdraw = water withdrawals; Precip = precipitation by climate division (NCDC, 2003b); Stream = surface water flow by climate division. GW = monthly groundwater levels for USGS monitoring wells in each climate division. Monthly streamflow and groundwater level data from USGS National Water Information System (2003). PHDI = monthly divisional PHDI values (NCDC, 2003b).





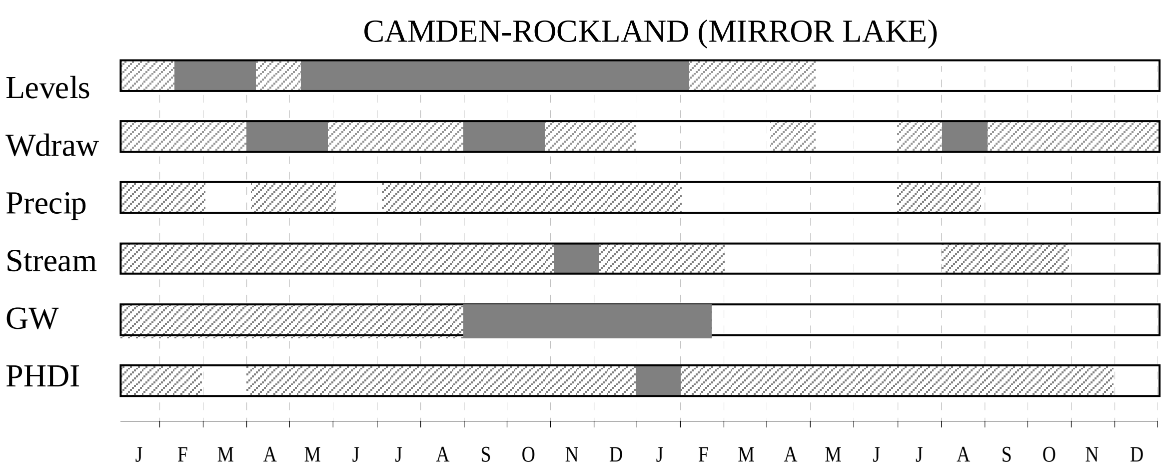
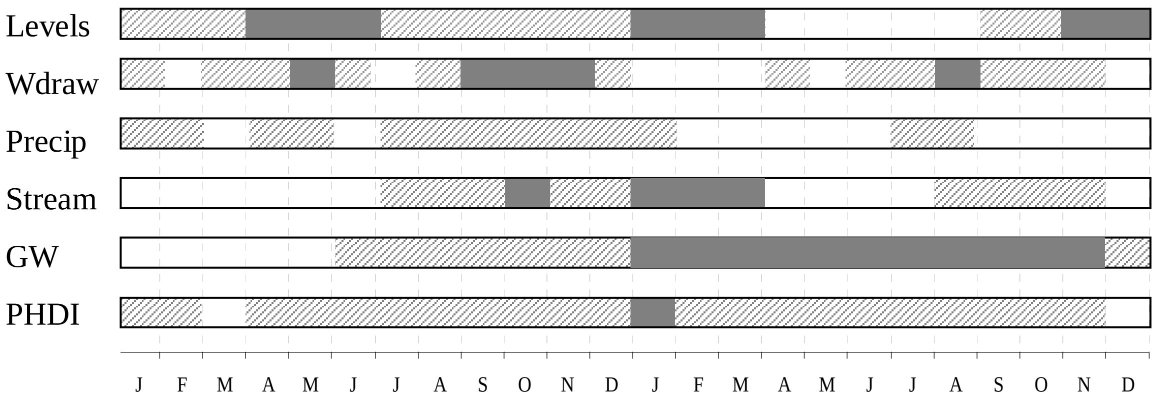
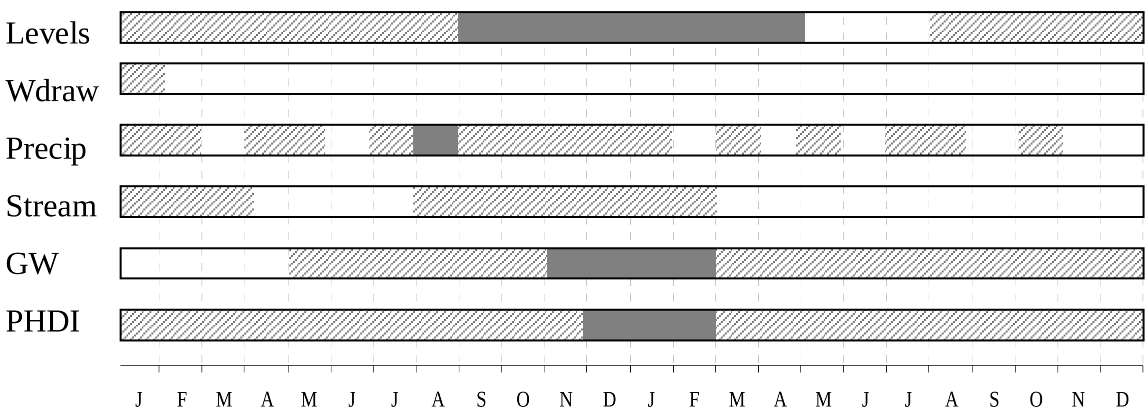


Figure 3.1 continued.

YORK (CHASES POND)



BANGOR (FLOODS POND)



BAR HARBOR (EAGLE LAKE)

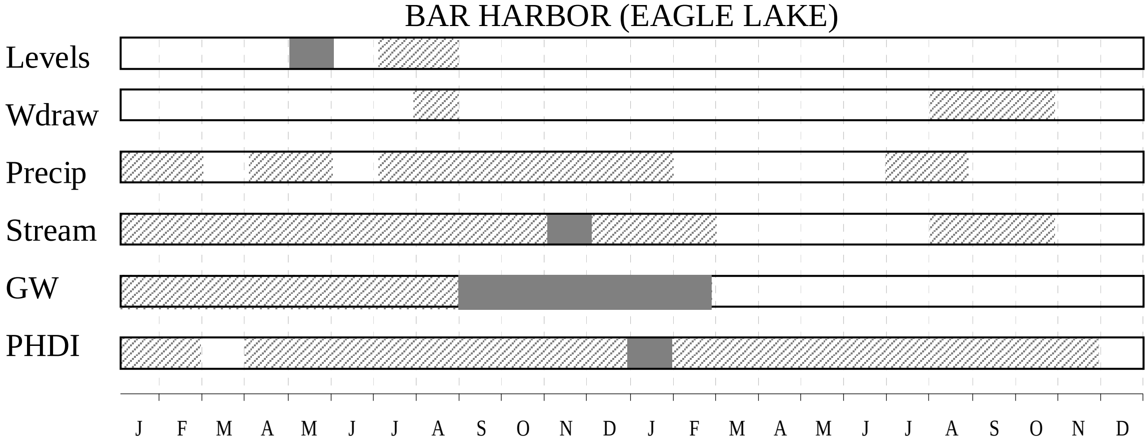
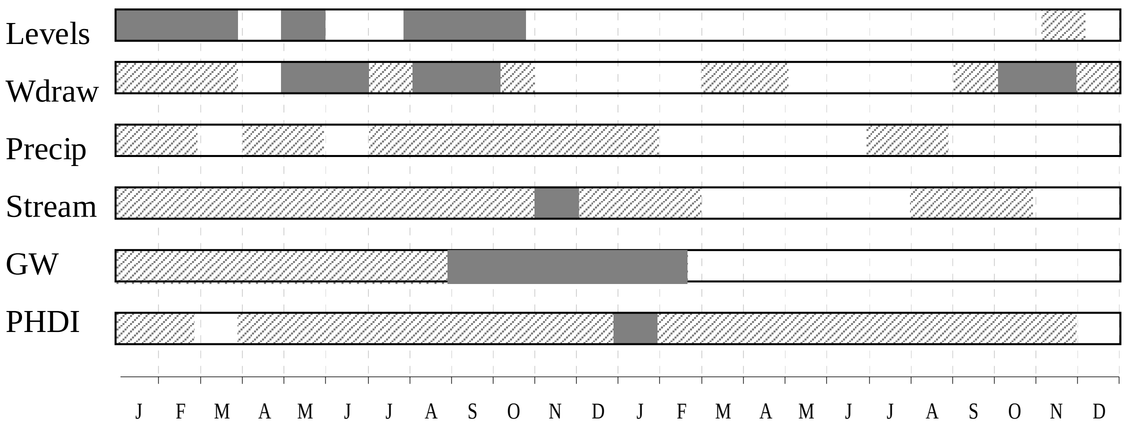
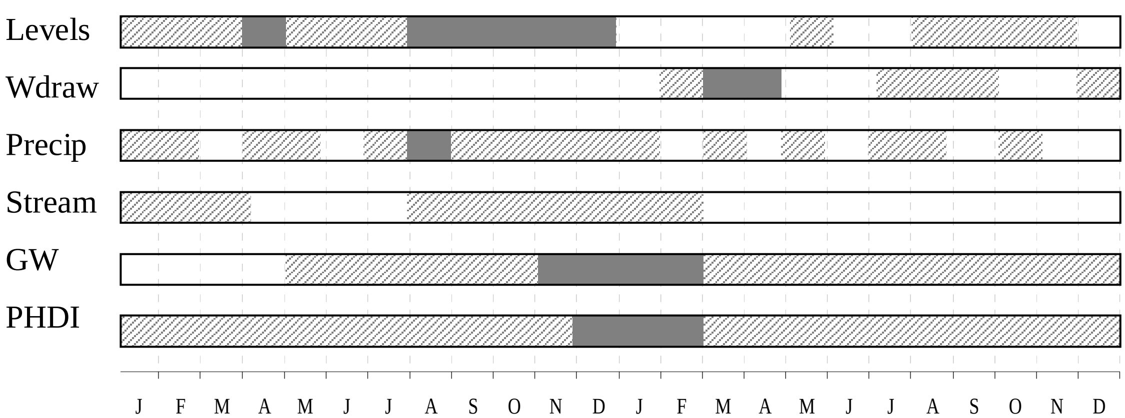


Figure 3.1 continued.

BATH (NEQUASSET LAKE)



WINTHROP (UPPER NARROWS POND)



Manager Responses

Four surface water systems implemented voluntary conservation measures and one system imposed mandatory restrictions. The most common conservation strategy was to target the largest users of water while asking customers for voluntary conservation via newspapers or direct mailings (Table 3.2). This approach was successful for all of the systems except for Boothbay Region, which imposed mandatory restrictions in September 2001. Most systems reported that they would have moved to mandatory restrictions if voluntary efforts were unsuccessful.

Table 3.2 Conservation strategies of drought-affected surface water supplies.

System	Direct visit, mail or phone	Mass Media	Success
Kennebunk, Kennebunkport, Wells (KKW)	Hand delivered drought alert to large customers, large sprinkler systems ("sprinkler police").	Notified local papers and TV stations, cable access channel.	Demand dropped; large users were cooperative.
Bethel	Went to large customers (inns, golf courses). Directly spoke to people if watering was observed. Letters to customers.	Newspaper request for voluntary.	Helped educate community about the drought. Provided water to those with dry wells, good publicity for the water district.
Boothbay	Asked for voluntary conservation.	Newspaper articles, cable access.	Mandatory restrictions coincided with end of summer season.
Camden-Rockland	Only contacted large users.	---	Good cooperation coincided with end of summer season.
Mt. Desert-Northeast	Issued notices, looked for obvious excessive use.	---	Good cooperation from town.

Discussion

Triggers of Drought Stress

The number of months antecedent to conservation implementation may provide a guide for future drought plan triggers (Figure 3.1). Most systems imposed voluntary conservation in August 2001. For all of the systems, five or more months of below normal water levels, precipitation, and PHDI preceded August 2001 (Figure 3.1). Streamflow and groundwater levels, however, did not reach their lowest points until after August 2001. While levels were below normal in some areas, record lows did not occur until the winter of 2001-2002, indicating the lag in response in groundwater and soil water levels (Johnson and Kohne, 1993). The lowest groundwater levels, streamflows, and PHDI values occurred later than the time of peak demand and conservation implementation. For all the systems, water levels of the source were below normal prior to August 2001. The difference between the affected and unaffected systems is that in the affected systems, below normal lake levels decreased concomitantly with an increase in demand.

For systems that regularly experience high seasonal demand, monthly monitoring of PHDI values in the months prior to peak demand coupled with tracking of source water levels and withdrawals appears to be the best indicator of drought stress. The number of months of low hydrologic conditions preceding conservation is not consistent. Instead, the effect on water supplies is strongly influenced by the timing of drought relative to the seasonal demand patterns of a specific system. Had the worst hydrological conditions occurred during July and August of 2001, it is likely that more systems would have had problems.

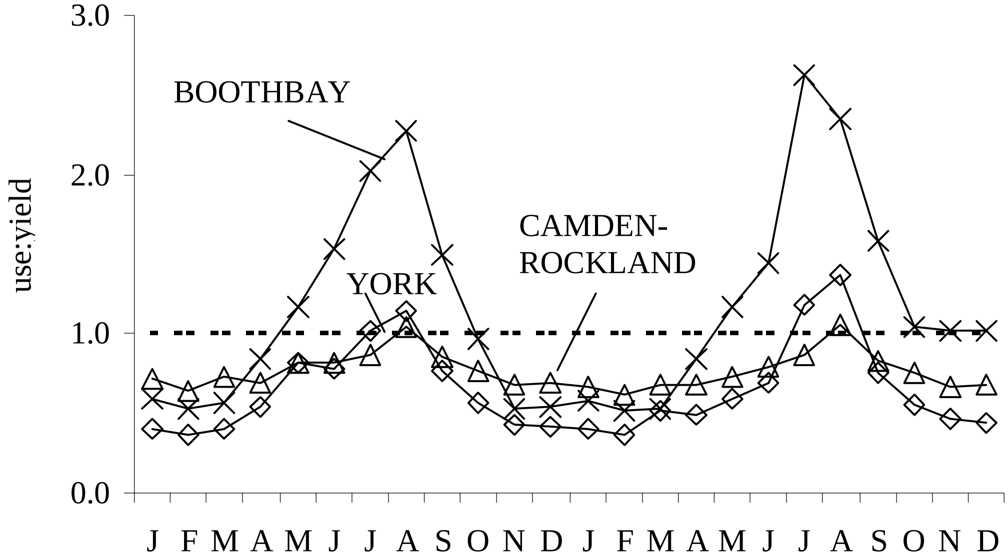
A public water system will be affected by drought when decreasing supply intersects increasing demand. Ratios of water use to safe yield, or the percent of maximum capacity being withdrawn, indicate whether or not a system has reached a point of intersecting supply and demand. Monthly water usage as a percentage of safe yield (Figure 3.2) can be used to predict when systems will begin to experience drought stress. In Maine, affected systems implemented conservation when water production approached or reached the estimated safe yield, which for most systems was in August 2001. Boothbay experienced three months over the threshold of 100 percent prior to implementing conservation; Camden did not implement conservation until the month over the threshold. Based on this result, closely monitoring use:yield ratios in the months prior to peak demand would help managers prepare for seasonal stress on the supply.

While Bath, an unaffected system, had high demand, water use was well below safe yield; in fact most systems I evaluated operate well below the available supply. In general, systems that were affected by the drought had ratios of maximum use to safe yield close to or greater than one prior to the drought (Figure 2.7).

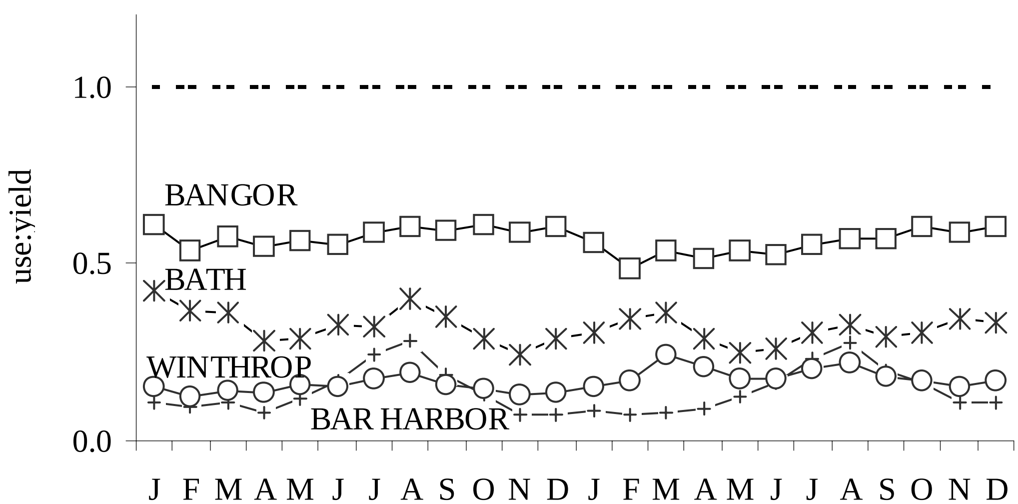
Demand is influenced by the severity and timing of the drought. Six months of dry conditions, based on divisional precipitation and PHDI data, preceded the summer of 2001. If demand on Camden-Rockland's supply had been normal, the drought may not have triggered stress because the system would have remained below the safe yield. For York and Boothbay, even normal usage is above safe yield during the summer, so they would be expected to have problems during a summer drought despite demand.

Figure 3.2 Ratios of water use to safe yield for (a) affected and (b) unaffected Intensive-Study systems, 2001-2002. Dashed line represents threshold value.

a.



b.



Combining monthly conditions with the capacity of the supply, three or more months of reduced precipitation prior to the period of peak demand could be enough to trigger drought stress in systems already operating close to their maximum capacity. For these systems, monitoring water levels and demand with local precipitation and PHDI values would serve as an early warning system. An effective monitoring plan would calculate inflow, precipitation, demand, and unaccounted-for water relative to normal average conditions.

One way to increase capacity or safe yield of a water supply is to add new, supplemental sources of supply. All of the systems affected by the drought regularly supplement the main supply source (Table 3.3), because the primary supply is not adequate to satisfy customer demand. In their study of the 1960s drought in Massachusetts, Russell et al. (1970) found that water systems affected by the drought emphasized new source development as the most common solution to inadequate supply. The increasing number of back-up supplies and applications for increased capacity illustrate that there are real water shortages in some parts of Maine.

Table 3.3 System components of affected surface water supplies.

System	Main Source	Supplement	Future source
Kennebunk, Kennebunkport, Wells	Branch Brook	Biddeford and Saco Water Co.	Interconnection with York Water District
Bethel	Chapman Brook	Groundwater wells	Groundwater well development
Boothbay Region	Adams Pond	Knickerbocker Lake, Groundwater wells	Knickerbocker Lake as primary source
Stonington	Groundwater wells	Burntland Pond	Increase use of Burntland
Livermore Falls	Moose Hill Pond	Parkhurst Pond	Increase use of Parkhurst
Mt. Desert-Northeast	Lower Hadlock Pond	Upper Hadlock Pond	Upper Hadlock Pond
Camden-Rockland	Mirror Lake	Grassy Pond Thorndike Brook	Increased storage of Grassy
York	Chases Pond	---	Interconnect with KKW

Manager Responses to Drought

Ten percent of surface water systems reported having problems during the drought, but most were unconcerned. “We’re surface water, so we’re okay,” said one manager, illustrating the perception that the 2001-2002 drought was mostly a groundwater problem. The disparate effects of the drought on groundwater versus surface water resources led to confusion about severity and duration of the drought. This confusion could have been minimized had there been a point of contact for comprehensive information on drought for the drinking water community.

Interconnections and Supplemental Sources

Some systems that use a combination of surface and groundwater relied more heavily on surface water sources during the drought. Several systems were in the process of developing alternative supplies, and the drought expedited the process by highlighting the need for capacity development. Kennebunk, Kennebunkport and Wells (KKW) and York Water Districts are located in southern coastal Maine. The population served by KKW has increased 40 % over the last 20 years (N. Labbe, KKW Superintendent, pers. comm., 2002), and the population continues to grow a few percent each year. Large estates and conversions from seasonal to permanent homes have made up a large proportion of the increase.

KKW must supplement Branch Brook, the main source of supply, during the summer months when demand is highest and flow in the brook is lowest. During peak demand periods, KKW has an agreement with Biddeford and Saco Water Company to purchase up to one million gallons of water per day.

Small water systems in Maine have tried several strategies to increase water supplies. In a proposed interconnection with nearby York Water District, KKW would supply York with water during the winter months. York had a proposal with another water district, which was moving forward during the drought, but was dropped in part because the drought ended, according to one manager. For Boothbay Region Water District, the drought contributed to the system gaining approval to use Knickerbocker Lake as a permanent source of supply.

Voluntary and Mandatory Conservation

One of the greatest challenges facing water suppliers is the ability to meet peak seasonal demands (NEWWA, 2003). Five surface water systems implemented conservation measures due to reduced capacity. If the drought had continued, other systems reported that they would have asked customers for conservation. Fortunately, precipitation deficits peaked in the fall and winter of 2001, coinciding with decreasing demand.

Even in times of impending crisis, managers are reluctant to impose water-conservation measures if there is any hope that rain will fall in time to save officials from having to do so (Walker et al., 1991). Tourism is important to Maine's economy, and several managers felt an unspoken pressure not to impose mandatory conservation during the summer tourist season. This concern was echoed by whitewater rafting companies, who blamed media reports of drought for a decline in business (Fleming, 2002).

Most systems were able to avoid restrictions by targeting large users, asking for voluntary conservation from all users, and/or maximizing existing sources. Managers cited good cooperation with towns and customers in reducing water demand. Cooperation coupled with the end of the summer tourist season—not the end of the drought—eased the pressure on systems so they could avoid mandatory restrictions. However, Boothbay Region's efforts at voluntary conservation did not change demand, and the system switched to mandatory restrictions in October 2001. Restrictions were lifted in April 2002. The switch came after peak demand, in part because of the uncertainty of future conditions.

Managers participating in the survey cited excessive water use by summer resorts, golf courses, large estates, hotels, and lawn and landscape watering as contributors to drawdown. These large water users were the first to be targeted in conservation efforts, particularly those who used lawn sprinklers. The emphasis on sprinklers may have been because lawn and landscape watering is a visible, obvious display of water use. Such displays may support the perception that water conservation is not necessary.

Drought Reporting Framework

A state drought plan focuses on monitoring and early warning, preparedness, and response (Wilhite, 1997). The Maine Drought Emergency Plan, developed in 1993, uses the Palmer Drought Severity Index as a trigger. The plan is activated at a PHDI of –2.00 (moderate drought), and at –3.00 an Emergency Proclamation is issued by the Governor. The plan was not followed in 1993 because it contained outdated information and discrepancies (E. Maxim, Maine Emergency Management Agency, 2003, pers. comm.).

The state drought plan contains no specific policies or comprehensive drought reporting framework for public water supplies. The DWP documented 39 public water systems that were affected by the drought. The PUC, which requests that regulated utilities submit status reports during drought, documented six additional affected systems that did not report problems to the DWP. The survey I conducted identified another eight systems that did not report to either agency. Some systems simply ignored the drought status forms sent by the PUC. Some systems never reported implementation of voluntary conservation. There was no single, central point of contact for reporting problems; therefore, the true effects of the drought did not emerge until afterwards.

Recommendations for the Future

The majority of systems interviewed recommended identification of back-up supplies and maximizing capacity as the best insurance against drought problems. Other recommendations included minimizing leakage, developing watershed management plans, coordinating with large water users, and installing point-of-use water meters to create incentives for conservation.

Managers viewed developing a relationship with the community as important for ensuring cooperation with voluntary conservation efforts. "You have to worry about more than your own customers," said one manager, referring to education and outreach efforts beyond the service area. Successful conservation efforts involve everyone in a community, from seasonal visitors to summer homeowners to local businesses. The water supplier acting as "policeman" of water use is not always as effective (NEWWA, 2003), and it should not be the sole responsibility of the public water system to promote water conservation. The potential threat of future droughts and water supply problems must be re-emphasized continually through interaction between regulatory agencies, the water supplier, and the public (Tierney et al., 2001).

Drought preparedness requires that public water suppliers have increased flexibility in developing supplemental sources and interconnections with neighboring systems. Some managers found that existing regulations and government structure prevented the kind of flexibility needed to cope with drought-induced increases in demand. The Water Resources Committee of the New England Water Works Association (NEWWA, 2003) recently recognized the need for readily allowable alternative supplies as well as the prioritization of public water supply public health issues.

Implications

Systems with small, shallow supplies located in areas that experience permanent and seasonal population increases were more likely to be affected by drought (Chapter 2). All of these systems were pumping above the safe yield of the supply. The drought magnified existing problems for those systems, pushing them into conservation mode. Most of the public water suppliers who experienced difficulties due to the drought in 2001-2002 had pre-existing problems that were not adequately addressed (Drought Task Force, 2001).

My results suggest that monitoring the supply and demand along with local precipitation and PHDI values prior to the time of peak demand comprises the best drought early warning system for small surface water supplies. Evaluation of monitoring data will improve routine management of the source as well as provide a drought warning system.

Water is a crisis-driven business. The public's memory of past problems is short, and political attention shifts quickly to new political problems (Walker et al., 1991). The balance among climate and water use in Maine, together with resistance to water use restrictions and belief in local control, might have prevented development of a comprehensive drought management framework prior to the recent drought. The significant impact of the drought and widespread media coverage may help the state overcome the resistance that often hinders implementation of new plans (Hrezo et al., 1986). Drought can happen in Maine, and the state's water infrastructure is not immune to climatic conditions that create conflicts in water use.

Conflicts over water use are likely to be greatest in areas served by small surface water systems in the coastal zone. These areas are experiencing both year-round and seasonal increases in demand related to development and tourism (Chapter 2). Even moderate drought conditions and related increases in demand drive some of these systems to pump over capacity. At the same time, PUC reporting frameworks and regulations on capacity development prevent these vulnerable systems from effectively managing their supply. Public water systems must obtain special permission from the PUC to impose mandatory conservation on a short-term basis. This procedure does not allow systems to proactively respond to drought conditions based on weather and water availability triggers. A state water supply drought plan will help public water systems prepare for drought only if it makes drinking water the priority water use for the protection of public health.

Chapter 4

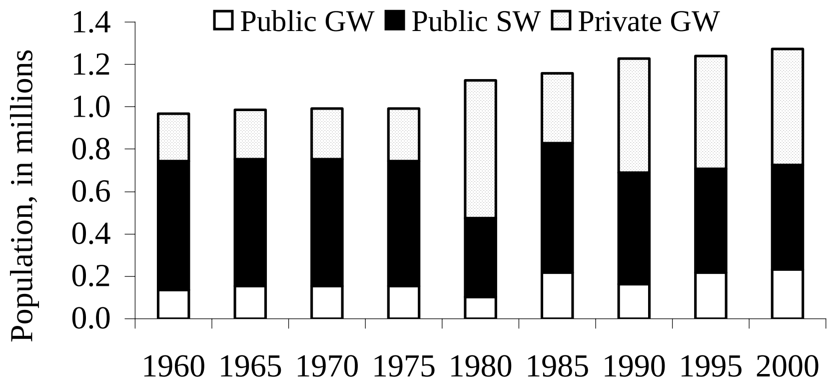
MAINE'S FRESHWATER SUPPLIES IN AN UNCERTAIN FUTURE

Finding ways to satisfy human demands for water while protecting the integrity of freshwater systems will be one of the most difficult challenges of this century (Postel, 2000). Superimposed on this challenge is the potential for global climate change, which will alter water resources in unpredictable ways (IPCC, 2001a). The drought of 2001-2002 in Maine and increasing human demands for water highlight the need to understand local hydrologic and climatic variability to protect future water supplies.

What We Know: 1. Changing Water Demands

Demands on freshwater supplies in the United States are increasing, and water shortages are likely in the near future (GAO, 2003). In the New England region, freshwater withdrawals are projected to increase by 550 million gallons per day, or 15 %, over the next 40 years (Brown, 1999). The region has also seen a shift toward greater use of groundwater. Over the past 35 years, withdrawal from groundwater rose from 9 % to 15 % in the eastern U.S. (Brown, 1999). Maine population has increased 24 % since 1960, but the number of people served by public water has decreased slightly. The numbers suggest that new population and development are being served by private groundwater wells (Figure 4.1).

Figure 4.1 Population served by public water supplies, 1960-2000. (Data from U.S. Geological Survey water use reports: MacKichan and Kammerer, 1961; Murray, 1968; Murray and Reeves, 1972; Murray and Reeves, 1977; Solley et al., 1983, Solley et al., 1998; Lombard, 2003; USGS, 2003).



The drought of 2001-2002 revealed imbalances of supply and demand in some parts of the state, with surface water systems in developed coastal areas experiencing the greatest stress (Chapter 2). Local conditions that reduce water supplies might drive communities that are not on a public water system to connect or purchase water from a neighboring utility. According to a report commissioned by the Maine Emergency Management Agency on the impacts of the drought, 7 % of private wells in Maine went dry at some point between June 2001 and April 2002 (Galubickaite, 2002). Some of these homes obtained water from public utilities, either temporarily or through permanent connections to the public water system. Twenty-seven public water systems drilled new wells during the drought, and many others relied on supplemental supplies.

New drinking water regulations, which decrease allowable contaminant levels, may also change the distribution of public versus private water supplies. Small water systems in particular may lack the resources and technical expertise needed to comply with drinking water regulations (GAO, 1994). Treatment for individual private wells may become too costly for homeowners and small systems, leading to increased connections with public water systems and/or abandonment of sources.

Surface water systems affected by the drought are more reliant on supplemental or alternative water supplies (Chapter 3). Other systems increased efforts to develop interconnections with neighboring systems during drought. Regulators do not readily permit emergency or redundant supplies, and system managers are often restricted to use of existing supplies (NEWWA, 2003). As peaks in seasonal demand increase, surface water systems will look farther afield for additional supplies at the same time that environmental or health regulations limit the availability of suitable water sources.

What We Know: 2. A Changing Climate

Reconstructions of past climate suggest that changes have been widespread and sometimes abrupt (NRC, 2002). Alternating glacial and interglacial periods have been accompanied by rapid and large temperature changes. During the current interglacial period (the Holocene), initial warming was followed by a return to colder conditions before the most recent warming. Since the late 19th century, global surface temperatures have increased between 0.4 and 0.8 °C (IPCC, 2001a).

Locally, climate changes during the last 10,000 years have been inferred from pollen and lake level records (Jacobson et al., 1987; Overpeck et al., 1991). Spruce and fir forests appeared in Maine 1,000 to 1,500 years ago as temperatures cooled about 0.5 °C (Jacobson et al., 1987; Schauffler and Jacobson, 2002). While overall the New England region has warmed over the last century, Maine's average temperature has decreased by -.2° C between 1895 and 2002 (NERAG, 2001). Changes in weather patterns observed elsewhere in North America have not been as intense in Maine (Bloomer, 2000).

Analysis of 150-year long-term records from lakes and rivers in the northern hemisphere shows a measurable warming trend in winter and spring based on earlier ice-out dates and later ice-on, with statistical significance in some individual records (Magnuson et al., 2000; NERAG, 2001). New England lakes with records from 64 to 163 years show statistically significant trends for earlier ice-out dates (Hodgkins et al., 2002). Duration of ice cover has also decreased on rivers in coastal Maine (Dudley and Hodgkins, 2003). Ice thickness has decreased on the Piscataquis River since 1912 (Huntington et al., 2003).

Although precipitation has increased in the U.S. and New England as a whole (Karl and Knight, 1998) in Maine the 100-year trend is toward decreasing precipitation (Figure 1.3). A greater portion of precipitation in the U.S. may be coming from heavy and extreme events (Karl and Knight, 1998), though it is still unclear whether this is due to global climate change (Karl and Easterling, 1999).

Hydrological conditions in the northeastern US are linked to global-scale atmospheric circulations (Bradbury et al., 2002; Hoerling and Kumar, 2003). As temperature and precipitation change, lakes, rivers, and groundwater respond accordingly. For example, lake levels in Maine were at their lowest—2-6 meters lower than today—around 6,000 years ago after the late glacial period (Harrison, 1989; Maine Geological Survey, 2000). Lake water approached current levels around 2,000 years ago.

Studies of hydrologic trends during the 20th century have revealed changes in the volume and timing of surface runoff, suggesting earlier onset of spring conditions. Mean stream discharge in the autumn and winter months have increased in most of the U.S. (Lettenmaier et al., 1994; Lins and Michaels, 1994; Lins and Slack, 1999) and spring peak flows occur earlier (Burn, 1994; Lins and Slack, 1999; Dudley and Hodgkins, 2002). Changes in snow cover influence the timing and volume of surface runoff. Both April snow water equivalent in North America and snow cover extent in March and April over the northern hemisphere have decreased during the 20th century (Brown, 2000). However, in Maine coastal river basin late winter snow density and streamflows in winter and early spring are increasing, contrary to larger-scale trends (Dudley and Hodgkins, 2002).

What We Don't Know: Predicted Regional Climate Changes

Applying predicted global climate model results to Maine is difficult because of a lack of consensus on the magnitude, direction, or timing of climate changes. This uncertainty combined with the natural variation in weather limits projections of water use and availability (Kahl, 1999). At the geologic timescale, ice ages rather than warm interglacial periods have dominated earth's climate. The current interglacial period has persisted for 12,000 years, and geologic data indicate the planet is overdue for rapid cooling, not global warming. Indeed, the Holocene appears to have the longest stable period of warm temperatures of the last 400,000 years (Petit et al., 1999).

One objective of my thesis was to evaluate whether the 2001-2002 drought could serve as a surrogate for expected effects of climate change on public water systems. Recognizing that nine possible scenarios exist for climate change: warmer and drier, warmer and wetter, cooler and drier, cooler and wetter, wetter or drier with no change in temperature, and cooler or warmer with no change in precipitation, to be consistent with the drought responses tracked in Chapters 2 and 3 I focus on examining effects of a scenario of continued drier climate on water supplies.

The vulnerability of water resources to climate change in New England appears relatively low compared to other parts of the U.S. due to the region's plentiful freshwater supplies (Hurd et al., 1999). Still, predicted increases in temperature and precipitation foretell a different New England environment from what we know today (NERAG, 2001). Some global circulation models used to model climate change predict more frequent or extreme droughts, while other models predict the opposite. Large-scale atmospheric circulation patterns that create a negative North Atlantic Oscillation trend could contribute to the persistence of regional hydrologic drought (Bradbury et al., 2002). Drought may occur more often, persist longer, increase in severity, or decrease.

Any significant change in temperature or precipitation can alter the hydrology of freshwater supplies. While annual streamflow may decrease (Moore et al., 1997), winter runoff could increase if rainfall replaces snow. Groundwater levels and annual recharge could decrease under severe drought conditions (Kirshen, 2002). Lake levels would similarly drop, with the newly exposed shorelines colonized by vegetation or converting to wetlands (e.g., Tyree, 2003).

Hydrologic changes have implications for drinking water quality and treatment. Water quality is the result of hydrologic interactions with the terrestrial environment, therefore hydrologic responses to climate change cannot be viewed independently of other potential watershed responses (Poff, 1992). A changing climate could change terrestrial plant communities, which would alter the inputs of elements and organic matter to lakes and streams. For example changes in DOC transport are expected to be substantially greater than changes in runoff (Meyer and Pulliam, 1992). As streamflows decrease, anthropogenic inputs could make up a greater proportion of nutrient load. In Maine coastal communities, salt-water intrusion into freshwater supplies may increase due to sea level rise and increased groundwater withdrawals (U.S. EPA, 1998).

Aquatic ecosystems do have a buffering capacity that provides some resistance to the stresses associated with climate change. The major vulnerability to the effects of climate change occurs at the intersection of human societies and ecosystems (IPCC, 2001b; NRC, 2002). Climate effects are likely to interact with human land and water uses (Moore et al., 1997), and so will be first observed in surface waters where and when the added stress is sufficient to overcome the system's resistance to change (Murdoch et al., 2000). Water supplies located in highly urbanized watersheds with large amounts of impervious surface and high loadings of non-point source pollution may be more stressed than supplies in less developed rural areas (DeWalle et al., 2000; Otto et al., 2002). Demand on water supplies in urban areas may increase more rapidly than in rural areas (H.J. Heinz Center, 2002).

Chapter 2 illustrated that small water systems in coastal regions that are already stressed by peak seasonal demands and inadequate capacity are more vulnerable to drought. These same areas are projected to experience increasing population and development. Under a climate scenario with decreased precipitation, surface runoff, and groundwater recharge, the most vulnerable public water systems would be those that have high seasonal demands for water relative to available supply.

What's a Manager to Do?

For managers of individual water systems, trying to sort through the volume of literature on global climate change and apply it to his or her system is overwhelming. A manager should not be expected to translate large-scale climate change forecasts to a region of smaller scale, or figure out how to prepare for the most likely changes with achievable management strategies. Global climate information is not very useful for managers of small water supplies, who normally function on time scales more influenced by monthly and yearly weather patterns.

Water and climate are issues that cut across institutional lines, and therefore tend to be neglected or poorly managed simply because they are not the sole purview of one agency (Riebsame et al., 1991). Most climate research has focused on the environmental effects of climate change. Less effort has gone into modeling or even speculating on what the implications might be for human economic and social systems that are affected by water (Chalecki and Gleick, 1999).

Large-scale patterns predicted by global circulation models may not provide good guidelines for how climate changes might be distributed locally (Root and Schneider, 1995). Most of climate change impact assessments (e.g., Kirshen and Fennessy, 1995; Wood et al., 1997; Risbey, 1998; Blake et al., 2000; Frei et al., 2002; Fowler et al, 2003) conclude that predicted effects on public water systems depend on the climate change scenarios used, the scale of the climate models, and the flexibility of the system to adapt to changes. In fact, this adaptive ability is a greater factor in the severity of climate change effects than the nature of the change.

The primary purpose of water resources management is to ameliorate hydrologic extremes to ensure public health and safety and to reallocate and redistribute available water for a variety of uses (Stakhiv, 1998). Risk and uncertainty are inherent in water resources management. Until water managers see credible and more certain evidence of climate change, their existing methods are sufficient to deal with any emerging near term trends (Schilling and Stakhiv, 1998). Even when presented with climate change impact scenarios, water managers correctly do not feel the need to make major policy decisions based on these predictions, mostly because of the uncertainty about potential effects (Kirshen and Fennessy, 1995).

Climate change effects are less important than continued implementation of water conservation measures, pricing and other regulatory controls on development (Stakhiv, 1998). Based on the survey of surface water systems described in Chapter 2, I found that most managers were more concerned with day-to-day operational issues than with climate conditions several months away. Those operating at full capacity during the summer season do not have the resources to plan ahead for new treatment and water quality requirements, let alone the prospect of extended drought.

In Maine, the 2001-2002 drought revealed that conflicts over freshwater are real and not uncommon. Actions taken now to ensure continued supplies of high quality freshwater may ameliorate the effects of climate change. The uncertainty of Maine’s future climate requires monitoring, planning, and preparedness that traditionally have not been a concern of most public water suppliers. Extrapolating climate change effects requires a working understanding of the local factors that control water quality and volume in a particular source (Murdoch et al. 2000). Current efforts in source water protection, such as acquiring and protecting undeveloped land in the watershed, improving security, and enhancing flexibility may also improve a system’s ability to withstand the damaging effects of climate change. Preserving the natural integrity of ecosystems that supply drinking water will help to protect systems against effects of local climate variability and change.

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APPENDICES

Appendix A

SURVEY OF SURFACE WATER SYSTEMS

SURFACE WATER SYSTEM DROUGHT SURVEY FORM, August 2002

DATE:
SYSTEM NAME:
MANAGER NAME:

1. Were you affected by last year's drought? If yes, how?

2. Were water levels below normal?

3. Do you measure water levels? How? How long have you been keeping records? Are levels managed?

4. Do you measure precipitation?

5. Do you monitor the raw water ? Do you monitor organic carbon, color, dissolved oxygen profiles, tranparency, nutrients, turbidity, etc.?

6. Do you have a drought management plan?

Table A.1 Survey of surface water systems.

System Name	Source	Surveyed	Affected	Levels
AGASSIZ VILLAGE #3	THOMPSON LAKE	Y	N	normal
ANSON WATER DISTRICT	HANCOCK POND	Y	N	low
AUBURN WATER DISTRICT	LAKE AUBURN	Y	N	low
AUGUSTA WATER DISTRICT	CARLETON POND	Y	N	low
BALD MOUNTAIN CAMPS	MOOSELOOKMEGUNTIC LAKE	N		
BANGOR WATER DISTRICT	FLOODS POND	Y	N	normal
BAR HARBOR WATER CO.	EAGLE LAKE	Y	N	low
BATH WATER DISTRICT	NEQUASSET LAKE	Y	N	low
BERWICK WATER DEPARTMENT	SALMON FALLS RIVER	Y	N	low
BETHEL WATER DISTRICT	CHAPMAN BROOK	Y	Y	low
BIDDEFORD & SACO WATER CO.	SACO RIVER	Y	N	low
BOOTHBAY REGION WATER DIST.	ADAMS POND	Y	Y	low
BREWER WATER DISTRICT	HATCASE POND	Y	N	normal
BUCKFIELD WATER DISTRICT	NORTH POND	Y	N	
CAMP CHERITH	BUNGANUT POND	Y	N	low
CAMP FERNWOOD	THOMPSON LAKE	Y	N	low
CAMP TAPAWINGO	KEYES POND	Y	N	normal
CAMP WAWENOCK	SEBAGO LAKE	Y	N	
CANTON WATER DISTRICT	LAKE ANASAGUNTICOOK	Y	N	low
CARIBOU UTILITIES DISTRICT	AROOSTOOK RIVER	Y	N	low
CMWC, BUCKSPORT	SILVER LAKE	N		
CMWC, CAMDEN & ROCKLAND	GRASSY POND, MIRROR LAKE	Y	Y	low
CMWC, HARTLAND	STARBIRD POND	N		
CMWC, MILLINOCKET	FERGUSON POND	Y	N	normal
CMWC, SKOWHEGAN	KENNEBEC RIVER	N		

Table A.1 continued.

COBBS PIERCE POND CAMPS	PIERCE POND	Y	N	low
DEXTER UTILITIES DISTRICT	LAKE WASSOOKEAG	Y		
DOVER-FOXCROFT WATER DIST.	SALMON POND	Y	N	low
EAGLE LAKE WATER DIST.	FISH RIVER	Y	N	low
ELLSWORTH WATER DEPT.	BRANCH LAKE	Y	N	low
FORT FAIRFIELD UTIL. DIST.	PATTEE BROOK	Y	N	low
FRYE ISLAND MSC - EAST	SEBAGO LAKE-EAST	N		
GREAT SALT BAY SANITARY DIST.	LITTLE POND	Y	N	low
HEBRON WATER COMPANY	HALLS POND	Y	N	low
HURRICANE ISLAND OBS	SURFACE-QUARRY	Y	N	low
JACKMAN UTILITY DISTRICT	BIG WOOD POND	Y	N	
KENNEBEC WATER DISTRICT	CHINA LAKE	Y	N	low
KENNEBUNK,KENNEBUNKPORT,WELLS	BRANCH BROOK	Y	Y	low
KIPPEWA FOR GIRLS	LAKE COBBOSSEECONTEE	Y	N	low
KITTERY WATER DISTRICT	BELL MARSH RESERVOIR	Y	N	low
LEWISTON WATER DEPARTMENT	LAKE AUBURN	Y	N	low
LIVERMORE FALLS WATER DISTRICT	MOOSE HILL, PARKHURST PONDS	Y	Y	low
LONG POND WATER DISTRICT	LONG POND	Y	N	low
LORING UTILITIES	LITTLE MADAWASKA RIVER	Y	N	normal
MADAWASKA WATER DISTRICT	ST JOHN RIVER	Y	N	low
MADISON WATER DISTRICT	HANCOCK POND	Y	N	
MARS HILL & BLAINE WATER CO.	YOUNG LAKE	Y	N	
MIGIS LODGE	SEBAGO LAKE	Y	N	
MILO WATER DISTRICT	SEBEC RIVER	Y	N	low
MOUNT DESERT WATER DIST.-NE	LOWER HADLOCK	Y	Y	low

Table A.1 continued.

MOUNT DESERT WATER DIST.-SEAL	JORDAN POND	Y	N	low
NEWPORT WATER DISTRICT	NOKOMIS POND	Y	N	low
NORTH HAVEN WATER DEPARTMENT	FRESH POND	Y	N	normal
PASSAMAQUODDY WATER DISTRICT	BOYDEN LAKE	Y	N	normal
PORTLAND WATER DISTRICT	SEBAGO LAKE	Y	N	low
PRESQUE ISLE WATER DISTRICT	PRESQUE ISLE STREAM	Y	N	low
SAPPI FINE PAPER, N.A.	KENNEBEC RIVER	Y	N	normal
SEBASCO HARBOR RESORT	WAH-TUH LAKE	N		
SOUTHWEST HARBOR WATER DEPT.	LONG POND	Y	N	low
ST. FRANCIS WATER DISTRICT	PETITE BROOK	Y	N	normal
STONINGTON WATER COMPANY	BURNTLAND POND	Y	Y	low
SUGARLOAF WATER ASSOCIATION	CARRABASSETT RIVER	Y	N	low
TWO LAKES CAMPING AREA #2	HOGAN LAKE	N		
US NAVY SERE SCHOOL C/O BNAS	FIRE POND	N		
VINALHAVEN WATER DIST	ROUND POND	N		
WILTON WATER DEPARTMENT	VARNUM	Y	N	normal
WINTHROP UTILITIES DISTRICT	UPPER NARROWS	Y	N	low
YORK WATER DISTRICT	CHASES POND	Y	Y	low
TOTALS	68	59	8	41

List of surface water systems provided by the Maine Drinking Water Program. Systems that were not surveyed did not respond to telephone or mail inquiries. “Affected” systems as defined in Chapter 2. Levels are manager perceptions that water levels were normal or below normal. Survey conducted in August and September 2002.

Appendix B

INTENSIVE-STUDY SYSTEM CHARACTERISTICS

Table B.1 Intensive-Study system characteristics.

Parameter	Bangor*	Bar Harbor*	Bath	**Boothbay**	**Camden***	Winthrop	**York**
Elevation[1]	91	84	5	**11**	**114**	52	**47**
Maximum depth (m) [2]	45	34	19	**7**	**20**	16	**11**
Mean depth (m) [2]	12	13	9	**4**	**9**	8	**4**
Lake Order [3]	2	2	4	**1**	**1**	2	**2**
Lake Area (ha) [2]	264	176	158	**29**	**44**	113	**54**
Watershed Area (ha) [2]	2124	971	5309	**383**	**267**	1748	**998**
Volume (m^3 x 10^6) [2]	32.0	22.4	13.3	**0.9**	**3.8**	6.1	**1.7**
Average yearly water usage (m^3 x 10^6) [4]	6.9	1.7	2.3	**0.67**	**4.1**	0.4	**1.7**
Median maximum raw water turbity (NTU)[4]	0.37	0.60	---	**1.10**	**0.51**	0.55	**0.44**
Average pH [4]	6.4	6.5	7.1	**6.9**	**6.5**	7	**5.8**
Average secchi transparency (m) [4,5]	7.3	11.2	3.9	**4**	**---**	5.9	**---**
Average total organic carbon (ppm)[4]	3.5	---	5.1	**4.2**	**2.1**	4.6	
Average apparent color (color units) [4]	16.5	7.9	22.9	**28**	**12.7**	13	**12.8**
Color range	8-25	0-20	16-28	**14-45**	**0-37**	7-30	**6-22**
Average chlorophyll-a (ppb)[4,5]	2.2	1.5	3.4	**6.2**	**---**	4.2	**---**

Systems in bold were affected by the drought

* Waiver from filtration

[1] USGS Digitized 7.5 minute topographic map

[2] Drumlin Environmental, 2003; PEARL Group, 2003

[3] Riera et al., 2000

[4] Utility records

[5] Volunteer Lake Monitoring Program

Appendix C

INDICATOR-STUDY SYSTEM DATA

Table C.1 Indicator-Study system data.

System Name	Source Name	MIDAS[1]	Elevation (m)[2]	Max depth (m)[2]	Mean depth (m)[2]	Order[3]
AUBURN	LAKE AUBURN	3748	78	36	11	2
AUGUSTA	CARLTON POND	5310	101	17	7	1
BANGOR	FLOODS POND	4370	90	45	12	2
BAR HARBOR	EAGLE LAKE	4606	83	34	13	2
BATH	NEQUASSET LAKE	5222	4	19	9	4
BOOTHBAY	ADAMS POND	5366	11	7	4	1
BREWER	HATCASE POND	4290	134	29	12	2
BUCKFIELD	NORTH POND	3616	154	15	5	1
CAMDEN-R.	MIRROR LAKE	4814	114	20	9	1
DAMARISCOTTA	LITTLE POND	5706	33	15	6	0
DEXTER	LAKE WASSOOKEAG	227	132	26	8	3
DOVER-FOXCROFT	SALMON POND	768	190	4		1
ELLSWORTH	BRANCH LAKE	4328	72	38	12	3
HEBRON (PARIS)	HALLS POND	3780	255	8	3	0
JACKMAN	BIG WOOD POND	2698	353	22	9	4
LIVERMORE	MOOSE HILL POND	5790	142	13	5	0
LONG POND	LONG POND	4390	72	17	6	0
MADISON	HANCOCK POND	82	163	32	7	1
MT DESERT-SEAL	JORDAN POND	4608	84	46	26	2
MT DESERT - NE	L. HADLOCK POND	4610	57	12	5	1
NEWPORT	NOKOMIS POND	5480	95	7	3	1
NORTH HAVEN	FRESH POND	5504	3	4	2	1
SOUTHWEST HBR	LONG POND	4622	18	34	11	2

Table C.1 continued.

System Name	Source Name	MIDAS[1]	Elevation (m)[2]	Max depth (m)[2]	Mean depth (m)[2]	Order[3]
STONINGTON	BURNTLAND POND	5556	19	2	2	-1
VINALHAVEN	ROUND POND	5508	5	6	4	-2
WILTON	VARNUM POND	3680	230	23	12	1
WINTHROP	U. NARROWS POND	98	52	16	8	2
YORK	CHASES POND	5598	46	11	4	2

[1] Maine Lake Identification Number (PEARL Group, 2003).
[2] Maine Department of Environmental Protection and Inland Fisheries & Wildlife Morphometry Dataset (PEARL Group, 2003).
[3] Lake order calculated following Riera et al., 2000.

Table C.1 continued.

Source Name	Geology[4]	Climate Zone[5]	Lake Area (ha)[2]	Watershed Area (ha)[2]	Urban Land (%)[6]
LAKE AUBURN	15	2	913	4740	10
CARLTON POND	15	2	84	604	5
FLOODS POND	15	2	264	2124	1
EAGLE LAKE	7	3	176	971	5
NEQUASSET LAKE	15	3	158	5309	5
ADAMS POND	15	3	29	383	10
HATCASE POND	15	2	68	777	5
NORTH POND	15	2	66	417	5
MIRROR LAKE	15	3	44	267	5
LITTLE POND	15	3	32	181	5
LAKE WASSOOKEAG	15	2	429	3030	15
SALMON POND	15	2	30	331	1
BRANCH LAKE	15	3	1092	7796	5
HALLS POND	15	2	21	70	1
BIG WOOD POND	15	1	869	7051	5
MOOSE HILL POND	15	2	38	181	5
LONG POND	15	3	23	98	5
HANCOCK POND	15	1	129	1254	5
JORDAN POND	18	3	76	497	1
L. HADLOCK POND	18	3	16	466	5
NOKOMIS POND	15	2	80	502	5
FRESH POND	7	3	34	433	5
LONG POND	18	3	362	1821	5

Table C.1 continued.

Source Name	Geology[4]	Climate Zone[5]	Lake Area (ha) [2]	Watershed Area (ha) [2]	Urban Land (%)[6]
BURNTLAND POND	17	3	8	30	10
ROUND POND	17	3	2	3	1
VARNUM POND	15	2	134	1070	5
U. NARROWS POND	15	2	113	1748	5
CHASES POND	15	3	54	998	5

[4] Maine Geological Survey, 2003. 15 = Till, 7= Glaciomarine, 17 = Drift, 18 = Bedrock.
[5] Climate Zone GIS digital data set. 1 = Northern, 2 = Southern Interior, 3 = Coastal.
[6] EPA and USGS, 1992.

Table C.1 continued.

Source Name	Peak Use (mgd)[7]	Safe Yield (mgd)[7]	Use:Yield	Summer Retail (%)[8]	Seasonal Housing (%)[9]
LAKE AUBURN	8.5	16.0	0.5	26	2
CARLTON POND	3.0	2.0	1.5	26	2
FLOODS POND	5.0	8.3	0.6	26	1
EAGLE LAKE	2.9	N/A	N/A	59	19
NEQUASSET LAKE	3.2	5.5	0.6	28	2
ADAMS POND	1.5	0.5	3	53	40
HATCASE POND	1.0	3.0	0.3	26	1
NORTH POND	0.1	N/A	N/A	N/A	3
MIRROR LAKE	4.3	4.1	1	39	13
LITTLE POND	0.2	N/A	N/A	32	14
LAKE WASSOOKEAG	0.5	N/A	N/A	28	12
SALMON POND	0.4	N/A	N/A	28	17
BRANCH LAKE	0.8	N/A	N/A	30	16
HALLS POND	0.1	N/A	N/A	27	2
BIG WOOD POND	N/A	N/A	N/A	40	33
MOOSE HILL POND	0.8	0.6	1.3	N/A	1
LONG POND	0.1	N/A	N/A	N/A	52
HANCOCK POND	1.0	0.5	2	41	13
JORDAN POND	0.8	N/A	N/A	55	N/A
L. HADLOCK POND	1.5	N/A	N/A	55	46
NOKOMIS POND	0.5	1.0	0.5	26	13
FRESH POND	0.1	N/A	N/A	N/A	64
LONG POND	0.6	N/A	N/A	N/A	25

Table C.1 continued.

Source Name	Peak Use (mgd)[7]	Safe Yield (mgd)[7]	Use:Yield	Summer Retail (%)[8]	Seasonal Housing (%)[9]
BURNTLAND POND	0.4	N/A	N/A	N/A	37
ROUND POND	0.1	0.1	0.9	N/A	52
VARNUM POND	0.6	N/A	N/A	27	6
U. NARROWS POND	0.3	1.7	0.2	31	15
CHASES POND	2.5	2.1	1.2	43	33

[7] Source Water Assessment Program Reports (Drumlin Environmental, 2003) or utility records.
[8] Maine Revenue Services, 1998. Courtesy T. Allen, Dept. Resource Economics and Policy, University of Maine.
[9] U.S. Census, 2000.

Table C.2 U.S. Census population and housing data (U.S. Census, 2000).

Town	**Population**	**Housing Units**	**Seasonal Units**	**% Seasonal**
Auburn	23203	10608	231	2%
Augusta	18560	9480	155	2%
Bangor	31473	14587	144	1%
Bar Harbor	4820	2805	524	19%
Bath	9266	4383	68	2%
Boothbay Harbor	2334	1993	802	40%
Brewer	8987	4064	38	1%
Buckfield	1723	715	22	3%
Camden	5254	2883	363	13%
Damariscotta	2041	1151	158	14%
Dexter	3890	2054	244	12%
Dover-Foxcroft	4211	2200	372	17%
Ellsworth	6456	3442	543	16%
Hebron	1053	410	7	2%
Jackman	718	585	193	33%
Livermore Falls	3227	1502	21	1%
Madison	4523	2308	300	13%
Mount Desert	2109	1900	883	46%
Newport	3017	1574	205	13%
North Haven	381	488	313	64%
Sorrento	290	282	146	52%
SW Harbor	1966	1288	326	25%
Stonington	1152	909	338	37%
Vinalhaven	1235	1228	637	52%
Wilton	4123	1882	113	6%
Winthrop	6232	3053	451	15%
York	12854	8053	2666	33%
MAINE	**1,274,923**	**651,901**	**101,470**	**16%**

Table C.3 Quarterly retail sales data (Maine Revenue Services, 1998).

Town Name	Q1-1998	Q2-1998	Q3-1998	Q4-1998	Q3/total
Auburn	$89,067	$106,526	$110,478	$121,156	0.26
Augusta	$107,859	$129,127	$131,610	$135,021	0.26
Bangor	$179,391	$219,715	$227,829	$251,263	0.26
Bar Harbor	$5,911	$22,926	$67,884	$17,690	0.59
Bath	$16,218	$17,966	$20,601	$19,205	0.28
Boothbay Harbor	$3,672	$11,880	$27,253	$8,373	0.53
Brewer	$29,033	$37,050	$36,064	$34,322	0.26
Buckfield	N/A	N/A	N/A	N/A	N/A
Camden	$9,415	$14,972	$26,488	$16,710	0.39
Damariscotta	$7,941	$12,221	$15,256	$11,805	0.32
Dexter	$6,971	$8,125	$9,063	$8,475	0.28
Dover-Foxcroft	$6,820	$8,987	$10,000	$9,384	0.28
Ellsworth	$38,949	$57,325	$66,098	$58,351	0.30
Hebron*	$9,093	$12,358	$12,299	$12,124	0.27
Jackman**	$3,591	$4,902	$8,799	$4,788	0.40
Livermore Falls	N/A	N/A	N/A	N/A	N/A
Long Pond	N/A	N/A	N/A	N/A	N/A
Madison	$4,540	$5,679	$11,378	$6,274	0.41
Mount Desert	$1,932	$4,535	$11,809	$3,069	0.55
Newport	$10,466	$13,251	$13,699	$14,483	0.26
North Haven	N/A	N/A	N/A	N/A	N/A
Southwest Harbor	$2,562	$7,708	$16,686	$4,319	0.53
Stonington	N/A	N/A	N/A	N/A	N/A
Vinalhaven	N/A	N/A	N/A	N/A	N/A
Wilton	$2,551	$2,788	$3,168	$3,243	0.27
Winthrop	$8,011	$9,006	$11,311	$8,753	0.31
York	$10,614	20702.3	$36,965	$17,707	0.43

* used Paris

** used Greenville

BIOGRAPHY OF THE AUTHOR

Catherine Schmitt was born in Glen Rock, NJ. She graduated from Glen Rock High School in 1994. She graduated from the University of Massachusetts in Amherst, MA, in 1998 with a Bachelor of Science degree in Environmental Sciences.

Her professional work experience includes several summers as an environmental education specialist with the Bergen County (NJ) Utilities Authority, coastal waterbird monitor with the Massachusetts Audubon Society, and student research assistant at the Marine Biological Laboratory's Ecosystems Center in Woods Hole, MA. She worked for two years as an Environmental Analyst for Pioneer Environmental, Inc., in East Longmeadow, MA. Prior to beginning graduate study at the University of Maine, Ms. Schmitt worked on scientific publications for the University of Maryland Center for Environmental Science in Cambridge, MD.

Catherine Schmitt is a freelance writer with essays and articles appearing in numerous publications. She is a member of the Society of Environmental Journalists and the National Association of Science Writers.

She is a candidate for the Master of Science degree in Ecology and Environmental Sciences from The University of Maine in December, 2003.